NUREG/CP-0153
CONF-960715

Proceedings of the 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference

Held in Portland, Oregon
July 15-18, 1996

Edited by M. W. First

Sponsored by
U.S. Department of Energy
U.S. Nuclear Regulatory Commission
International Society of Nuclear Air
Treatment Technologies, Inc.
Harvard School of Public Health

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Sponsored by
Office of Environmental Guidance
U.S. Department of Energy
Washington, DC 20585

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

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Treatment Technologies, Inc.
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**Proceedings prepared by The Harvard Air Cleaning Laboratory
NRC Job Code G6543**

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ABSTRACT

This report contains the papers presented at the 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference and the associated discussions. Major topics are: (1) nuclear air cleaning issues, (2) waste management, (3) instrumentation and measurement, (4) testing air and gas cleaning systems, (5) progress and challenges in cleaning up Hanford, (6) international nuclear programs, (7) standardized test methods, (8) HVAC, (9) decommissioning, (10) computer modeling applications, (11) adsorption, (12) iodine treatment, (13) filters, and (14) codes and standards for filters and adsorbers.

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FOREWORD

The 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference was held July 14 - 18, 1996 in Portland, Oregon The Conference was sponsored by the International Society of Nuclear Air Treatment Technologies, the Harvard Air Cleaning Laboratory, and by the US Department of Energy and US Nuclear Regulatory Commission. International interest and participation remained high, with 30% of the papers being presented by scientists and engineers from nine foreign countries A panel session was held to discuss international programs and research in nuclear air cleaning technology. Other major topics covered were· standards for manufacturing, operation and testing of air cleaning elements and systems; decontamination and decommissioning processes, waste management; instrumentation and measurement systems, gas adsorption, chemical operations, reactor accident scenarios, filters and filtration Panel sessions were held to discuss the testing of air and gas cleaning systems and codes and standards for the construction and installation of filters and absorbers

A highlight of the conference was a detailed review of DOE's operations at the Hanford Reservation, Richland, WA, where a ten-year multi-billion dollar decontamination and decommissioning project is underway. Some conference attendees toured the Hanford site after the Conference The special emphasis on air cleaning for process gas treatment in the waste management area, featured at the 23rd Conference in July 1994, continued as a common theme throughout this conference Air cleaning requirements for reactor decontamination and decommissioning has also come to the forefront.

I would like to express thanks to the representatives of the Conference's sponsors and financial supporters: Dr. Richard Lee, US Nuclear Regulatory Commission, Mr James Slawski, US Department of Energy, and Mr. Richard Porco, Chairman of the International Society of Nuclear Air Treatment Technologies. Each of these individuals provided unstinting support and assistance during the planning and conduct of the Conference

The Chairman would also like to extend his sincere thanks to all members of the Program Committee who worked diligently over the past couple of years to put together the program of the 24th Conference and who helped conduct it in an orderly manner He is very grateful to each of them for their devotion to the Air Cleaning Conferences and for their willing assistance to the Chairman.

The thanks of all the attendees, as well as the Chairman, are due Mary Kovach for her kind management of each morning's hospitality gathering of family members

The Chairman extends his special thanks to Suzanne Doyle Shaffner for her able handling of all the business affairs of the Conference and for her careful and timely assembly of the camera-ready master copy of the Proceedings.

Melvin W First
28 February, 1997

SESSION 1

OPENING OF THE CONFERENCE

Monday July 15, 1996
Chairman: M.W. First

OPENING COMMENTS OF CHAIRMAN AND GREETINGS FROM SPONSORS
M. W. First, Conference Chairman

KEYNOTE ADDRESS: NUCLEAR AEROSOLS: UNFINISHED BUSINESS
Thomas Kress
Chairman, Advisory Committee on Reactor Safeguards

AIR CLEANING ISSUES WITH CONTAMINATED SITES
R.R. Bellamy

NEW CHALLENGES TO AIR/GAS CLEANING SYSTEMS
J.L. Kovach

APPLICATION OF INNOVATIVE POLICIES FOR CONTROLLING RADIONUCLIDE RELEASES: THE "OPEN-MARKET TRADING RULE"
D.W. Moeller

24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

OPENING OF THE CONFERENCE & GREETINGS FROM SPONSORS

FIRST: It is my special privilege to call the Conference to order, and to bid you all welcome on behalf of the program committee and the several sponsors of this conference. One of the conference sponsors is the Harvard Air Cleaning Laboratory. I am Melvin First, I bring you Harvard's greetings and a hearty welcome. The other sponsors will greet you shortly. I would like to extend a special greeting to the many friends who have joined us from other countries. I know I speak for all of the US attendees as well as myself when I say how much we appreciate your active participation in these conferences over the many years that they have been held. The delegates from other countries continue to be a major factor in these conferences. Were it not for the fact that two of US government agencies are financial sponsors, I would think of this Conference as being a world conference because truly it does represent the world community in the technical areas covered by the conference. So once again, we welcome you and hope that you find your trip useful and pleasurable.

It's obvious that these conferences require a lot of hard work on the part of the entire Program Committee. Their duties don't cease at the beginning of the conference, because they all have been given assignments as session chairmen, and you will interact with them throughout the Conference. The Conference Committee members are listed in the Conference Program. Let me identify by name: Wendell Anderson, consultant Ronald Bellamy, Region One, Nuclear Regulatory Commission. Werner Bergman, Lawrence Livermore National Laboratory, California. Richard Dorman, formerly with the Porton Downs military establishment in England, and currently a consultant. Ken Duvall, Department of Energy. Tetsuo Fukasawa, Hitachi in Japan Jack Hayes, Nuclear Regulatory Commission, Headquarters in Maryland. Robert Jubin, Oak Ridge National Laboratory. J Louis Kovach, NUCON International. Richard Lee, the Nuclear Regulatory Commission. Joseph Paul, Westinghouse Savannah River Company. Richard Porco, Ellis & Watts. Richard is the president of the International Society for Nuclear Air Treatment Technologies. Paul Sigli, consultant France. James Slawski, Department of Energy. Ray Weidler, Duke Power Company. Ray is the Chairman of the Committee on Nuclear Air and Gas Standards. Jeurgen Wilhelm, Germany, many years associated with KLK, and currently a consultant. And Roger Savadowski, Defense Nuclear Facilities Safety Board. One additional member of the program committee that I have not yet named is Humphrey Gilbert. Humphrey, because of physical disability, has been unable to be with us today. I'm sure this is the first Air Cleaning Conference he has missed since they started forty-five years ago. I know we all miss him as much as he misses not being here We extend all our best wishes to him.

Now, for the other sponsors of the conference, I'm going to call on a representative from each of the organizations to send their own greetings and welcome to you. The first of these, from the US Department of Energy, is James Slawski, who is in DOE's Industrial Hygiene Office of Defense Programs. He is a certified industrial hygienist, with twenty-five years experience in occupational safety and health. He has been at the DOE for six years.

SLAWSKI: This is the first conference, that Humphrey Gilbert has missed, and the first conference I have attended. On behalf of DOE I welcome all of you. I look at this as an opportunity for all of us to figure out where we are and figure out what we have to do to try to do our jobs a little bit better and smarter in the future. We are working with CONAGT on standards for filters on the FC section in particular. We are trying to work our way to adopting for the Department that consensus standard. We are not sure we are there yet. We are working in that direction and we have discussions ongoing here at this Conference to help us go in that direction. Whatever we can do to get us to a state that satisfies DOE's needs for a consensus standard will be very beneficial. Again, welcome and thank you for attending

FIRST: I will next call on Dr Richard Lee representing the US Nuclear Regulatory Commission

LEE: On behalf of the Nuclear Regulatory Commission, I welcome you to this Conference We are very pleased that we have supported this Conference with the DOE and since its inception, and we hope we will do so in the future Tomorrow Ronald Bellamy and I will give you a briefing on what is happening at the Commission with respect to domestic activities and international activities I am from the Office of Research Most of our research now focuses on the national arena, but I hope to give you a very brief report on what other programs we are tracking in the European and in the Pacific regions I wish that you have a successful Conference and a pleasant stay at this city

FIRST: The fourth sponsor is the International Society of Nuclear Air Treatment Technologies To represent that organization we have Richard Porco, who is the president of ISNATT

PORCO: Welcome you to the 24th Nuclear Air Cleaning and Treatment Conference on behalf of ISNATT I also welcome you to the ISNATT Expo I hope you will all take time to visit by the exhibits They will be held in the foyer I think you will find a lot of equipment on display there that will be topics of discussion at some of the technical sessions I also want to thank all you who participated in the ISNATT short courses Those interested in future short courses should stop by the booth for the ISNATT and ASME booths I think it is very important to point out the work that ISNATT is doing to support the Nuclear Air Cleaning and Treatment Conferences To in this endeavor I would encourage all to join ISNATT and get involved in promoting the Expo as well as the international exchange of technologies This is the way to make this Conference a success and to make sure that we continue to have the type of support and the type of exchange that we have enjoyed during the course of the meetings

FIRST: In addition to the many technical papers that are a hallmark of these Conferences, there are numerous highlights that I would like to call to your attention Shortly, our keynote speaker will address a topic of special interest to specialists in nuclear air and gas cleaning technology This will be followed by three very seminal papers concerning new directions for the nuclear industry, in general, and air and gas cleaning specialists in particular Each will leave you with many new and important things to think about I look forward to hearing the presentations On Tuesday, we will have a working lunch with John Wagoner, Manager of the DOE's Richland Operations Office He will talk about progress and challenges in cleaning up Hanford Those intending to go on the Hanford tour starting Thursday afternoon will, I know, find this address a very special preparation for your visit There will be an International Panel after the working lunch, and then our traditional Open-end Session Those who have things you would like to present or questions you would like to ask the assembled group, please keep this session in mind There will two panel sessions one on testing of nuclear air cleaning systems that will include a newly-proposed AG1 code section on acceptance testing, plus a new standard tentatively referred to as N-511 on in-service testing Both of these documents are nearing their final phase, and I am sure you will be interested in learning what they propose as well as having some input into the final document The second panel session is concerned with the new AG1 code section on HEPA filters This code section basically replaces the military specifications that we have been using for this purpose for many decades Here also, I think you will want to hear about projected changes to the codes and how they will be brought about I can promise you that these will be very interesting sessions

KEYNOTE ADDRESS

Introduction of Thomas Kress, Keynote Speaker

FIRST: Dr. Kress has recently been appointed to the very important post of Chairman of the Nuclear Regulatory Commission's Advisory Committee for Reactor Safeguards. This committee, as many of you know, was created by a congressional statute at the very beginning of the government's nuclear program after World War II It has continued, uninterrupted as a very important committee that assists the NRC with technical advice on all aspects of nuclear safety. One of the topics, of course, is air and gas cleaning technology. Dr. Kress has been involved in this technical area for many years. Before his appointment to the Advisory Committee for Reactor Safeguards he worked for thirty-five years at Oak Ridge National Laboratory in various posts concerned with areas of nuclear safety. He managed the NRC's research program at Oak Ridge in the area of source terms and nuclear aerosol behavior. His education included a number of different schools, but he received his doctorate in engineering sciences at the University of Tennessee. I've known Tom for many years, served on advisory panels with him, and it has been a sheer delight for me to have had him respond positively to the program committee's invitation to give this keynote address. The title of his talk is "Nuclear Aerosols Unfinished Business".

NUCLEAR AEROSOLS: UNFINISHED BUSINESS

T. S. Kress
Talk presented to the 24th Nuclear Air Cleaning Conference*
July 15, 1996
Portland, Oregon

I am delighted to be here to give the keynote address to this the 24th meeting of the Nuclear Air Cleaning Conference - a conference that I well respect. I have attended several of these in the past but I haven't been active recently. That is because the extent of my technical involvement in nuclear air cleaning over the past 5 years has been to argue with fellow ACRS members as to which is most important to reactor safety - thermal hydraulics or aerosol behavior. I am not sure who is winning the ongoing argument.

I think you can even correlate being asked to be a keynote speaker as being a pretty good sign that you may be near the end of your useful technical life. When asked if I would make this presentation, my first thought was why, couldn't the 1st, 2nd, 3rd, 4th, and 5th choices make it?

I understand the focus of this conference is on "nuclear air and waste treatment technology and its relationship to nuclear safety" If I interpret that in a broad sense to include aerosol behavior in general, I can say a few words about that.

I would like, first, to make the observation that over the years that I have dealt with source terms, severe accidents, and levels 1 and 2 PRAs, I have come to realize that assessing these important aspects of nuclear safety is largely an exercise in thermal hydraulics, chemistry, and aerosol physics. In the past, this series of conferences has made very substantial contributions to the field of aerosol physics and how to effectively clean aerosols and gases from air spaces and streams.

If you look at todays NRC's research effort on aerosol behavior, it is mostly limited to evaluating a few of the source magnitudes. NRC has proclaimed that they no longer need do research on the subsequent transport behavior of aerosols Why have they reached this conclusion? They say because, in the overall assessment of risk of nuclear power plants, the uncertainties are very large and thecontribution that is due to uncertainties in the aerosol transport behavior is very small compared to the other sources of uncertainty. If this is indeed true, then I take it as a tribute to the fine work that has been done in this area by you and others. But, will this remain the situation for much longer?

One of the very strong trends on the international nuclear scene for "new generation" nuclear power plants is that the containment <u>must</u> be designed to cope with severe accidents - meaning that they <u>will not fail</u> under even the lowest probability severe accident sequences.

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* I am required by the by-laws of ACRS to announce that I do not represent the committee and that the views I express are my own and are not necessarily those of the committee

Along with this requirement for the containment to maintain its integrity under severe accident conditions, is a requirement that the release from the containment must be kept low enough that there will be no need for an emergency response.

These are, indeed, very stringent requirements. I just returned from a week-long meeting in Vienna for the IAEA in which the subject was....how should the source term be specified for such new generation plant requirements for use in containment and ESF design and for assessing compliance with the possible regulatory requirement of no evacuation.

One question we wrestled with a great deal in Vienna was...just how do you specify a fission-product/aerosol source term for a future plant of unknown design and give freedom (and even incentive) to the designer to choose such design parameters as reactor type, power, power density, fuel and cladding design, burnup, quantity of water available to the reactor cooling circuit, and strategies for coping with ex-vessel phenomena? If you have any thoughts or suggestions on this, I would like to hear about them before the follow-on meeting to be held in November which is supposed to come to grips with this issue.

Let me tell you now though that if these are to be new requirements, then the complete spectrum of aerosol considerations and their uncertainties jumps back to front and center. We may have to reconsider the need for additional research in this area.

Of course, nuclear aerosol research is still needed for decontamination, fuel reprocessing, waste treatment, and waste storage. If, also, it does re-emerge for nuclear reactor safety, then what are some of the areas that may need additional research or sharpening up?

Well - back in 19 ought..?????, when I was actively developing and conducting research programs on nuclear aerosols, times were very good. *How good were they?????* They were so good that my group had more research then they could actually handle. Therefore, I always made it a habit to keep in my left hand desk drawer a list of potential future aerosol research areas to follow-on with when we completed the ones that we were currently working on. In today's times of limited research money, I don't think this would be a successful strategy, but it worked well back then.

So, in preparation for this talk, I went back to my files to see if I could find my old list. Sure enough, it was still there. This is a list, mind you, that I made back in 1986 (before Chernobyl) which was essentially the time I quit being a researcher to become a Department Head -- a fate I would not wish on any of you.

[Slide number 1]

Ten years later, I do not really know the status of these, but I would bet that this would still be a pretty good list to start from. I meant to do as many of these as I could, but I didn't get the chance. That is why I have subtitled this talk "unfinished business." I no longer have a use for this list so you are welcome to it.

Before I leave this list, there is one more research area I nearly forgot. The British think more research is needed on the effects of smoke. They have concluded that smoke is an essential ingredient in making electronic and electrical equipment function properly. They reached this conclusion because of an astute observation that every time a piece of such equipment failed or malfunctioned it was because the internal smoke had escaped - they could see it leaving the piece of equipment. They conclude that better means to keep it from escaping are needed...an imminently reasonable conclusion don't you think.

In parting then, I don't think I could do better than to quote from Mel First

[Slide number 2]

> "These conferences have been a force for advancement as well as a forum for refinement of current technology "
>
> "The conference will continue to be highly involved in the important task of maintaining and improving engineered safety features for existing power reactors and with meeting the air cleaning and treatment needs of advanced reactors "

I can only add ..keep up the good work and I trust this Conference will be as highly successful as have been past ones.

POTENTIAL NUCLEAR AEROSOL RESEARCH PROJECTS

THE FOLLOWING WERE COPIED FROM A 1986 LIST

1. THEORETICAL VALIDATION OF THE GRAVITATIONAL SETTLING ASSUMPTION/MODEL
2. A BETTER MODEL FOR SHAPE FACTORS AS FUNCTIONS OF AEROSOL SIZE
3. DIRECT EXPERIMENTAL MEASUREMENT OF   AND   (AS FUNCTIONS OF AEROSOL SIZE AND TYPE)
4. EFFECTS OF HYDROGEN BURNING/DETONATION ON AEROSOL SIZE (DE-AGGLOMERATION AND EVAPORATION OF ABSORBED WATER)
5. CHEMICAL EFFECTS ON AEROSOLS (MOISTURE, H_2 BURNING, ATMOSPHERIC OXYGEN).
6. LIFT-OFF/RESUSPENSION
7. BETTER CODE TREATMENT OF MULTICOMPONENT AEROSOLS.
8. EXPERIMENTAL DETERMINATION OF THE NUCLEATION SIZES OF AEROSOLS . RELATE NUCLEATION SIZE TO MACROSCOPIC PROPERTIES.
9. AEROSOL SOURCES FROM STEAM EXPLOSIONS.
10. EFFECTS OF AEROSOLS ON RECOMBINERS.
11. BETTER IMPACTION DEPOSITION MODELING.
12. EXPERIMENTAL VALIDATION OF DIFFUSIOPHORESIS MODELS IN PRESENCE OF NON-CONDENSABLE.
13. BETTER MODELS FOR AEROSOL TRANSPORT THROUGH CRACKS IN CONCRETE CONTAINMENTS.
14. EFFECTS OF RADIATION-INDUCED CHARGES ON AEROSOL BEHAVIOR IN CONTAINMENTS.
15. EFFECTS OF AEROSOLS ON ELECTRONIC EQUIPMENT.

QUOTES FROM MEL FIRST

THESE CONFERENCES HAVE BEEN A FORCE FOR ADVANCEMENT AS WELL AS A FORUM FOR REFINEMENT OF CURRENT TECHNOLOGY."

THE CONFERENCE WILL CONTINUE TO BE HIGHLY INVOLVED IN THE IMPORTANT TASK OF MAINTAINING AND IMPROVING ENGINEERED SAFETY FEATURES FOR EXISTING POWER REACTORS AND WITH MEETING THE AIR CLEANING AND TREATMENT NEEDS OF ADVANCED REACTORS."

DISCUSSION

FIRST: The talk is open for questions and comments. I would like to ask Tom to comment further on the long list of projects you wrote down approximately a decade ago. I gather that they have not yet been accomplished.

KRESS: I meant to do all of them, but I got out of the business about then, and that is the reason I listed them as unfinished business. At least they are unfinished for me.

FIRST: What do you think is the most important area that we should be concentrating on now, assuming that somebody will come up with adequate funds, which I realize is somewhat uncertain these days.

KRESS: That is a tough question, but I will try to give you a quick answer. I think that better, higher capacity HEPA-type filters that do not fail under loads that are relatively large, would go a long way toward solving many problems, I think that would be my choice.

INTRODUCTION

FIRST: As I mentioned earlier, we have three seminal papers that will occupy the rest of the morning, and I do call your attention to these papers because I think they are opening new ground. They are of extreme interest at present and will continue to be into the future. The first of these papers will be presented by Dr. Ronald Bellamy. Many of you know Ron, he's been a constant attender and contributes at these Conferences since he left Ohio State University and joined the Nuclear Regulatory Commission. Because his doctoral thesis work was in activated carbon, he came to AEC headquarters at an opportune time with all the knowledge and assurance of a newly minted Ph.D. A nice thing about Ron is his consistency, he is still very positive and he has maintained his enthusiasm and elan through the years. He is my very valued colleague. He is presently Chief of the Decommissioning and Laboratory Branch in Region One of the Nuclear Regulatory Commission. He is on the ASME and ASTM committees on standards and on the Program Committee for this Conference. He's a visiting lecturer at Harvard University and lectures in the course that I am associated with, the In-place Filter Testing Workshop, as well as Dade Moeller's course on Nuclear Emergency Preparedness issues.

AIR CLEANING ISSUES WITH CONTAMINATED SITES

Dr. Ronald R. Bellamy
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Abstract

The US Nuclear Regulatory Commission has developed a list of contaminated sites that warrant special USNRC attention because they pose unique or complex decommissioning issues. This list of radiologically contaminated sites is termed the Site Decommissioning Management Plan (SDMP), and was first issued in 1990. A site is placed on the SDMP list if it has;

1. Problems with the viability of the responsible organization (e.g., the licensee for the site is unable or unwilling to pay for the decommissioning;
2. Large amounts of soil contamination or unused settling ponds or burial grounds that may make the waste difficult to dispose of;
3. The long-term presence of contaminated, unused buildings;
4. A previously terminated license; or
5. Contaminated or potential contamination of the ground water from on-site wastes.

In deciding whether to add a site to the SDMP list, the NRC also considers the projected length of time for decommissioning and the willingness of the responsible organization to complete the decommissioning in a timely manner. Since the list was established, 9 sites have been removed from the list, and the current SDMP list contains 47 sites in 11 states. The USNRC annually publishes NUREG-1444, "Site Decommissioning Management Plan", which updates the status of each site.

This paper will discuss the philosophical goals of the SDMP, then will concentrate on the regulatory requirements associated with air cleaning issues at the SDMP sites during characterization and remediation. Both effluent and worker protection issues will be discussed. For effluents, the source terms at sites will be characterized, and measurement techniques will be presented. Off-site dose impacts will be included. For worker protection issues, air sampling analyses will be presented in order to show how the workers are adequately protected and their doses measured to satisfy regulatory criteria during decontamination operations.

Introduction

The cleanup of radiological contamination, both within the property of a licensee, and in the general environs as a result of licensee operation, is a major challenge facing the nuclear industry. In recognition of this focus of activity, the NRC formally acknowledged several contaminated sites to promote timely and safe cleanup of these sites and provide special NRC attention because they pose unique or complex decommissioning issues. This list is presently composed of 47 sites in 11 states. In addition, numerous other sites are undergoing or have completed decontamination efforts and have been decommissioned. Some of these are active licensees, while others are formerly-licensed sites from as long as 40 years ago. The methods used to review the decontamination activities, and the acceptance criteria, should be well-defined and understood so that achievable goals are acknowledged and used in the activities. The specified end-points for the cleanup activities used to release areas for unrestricted use should be readily available to the technical experts, and the public alike, open to public scrutiny, and, as generic as possible.

The Site Decommissioning Management Program

NRC developed the Site Decommissioning Management Plan (SDMP) in 1990 to identify a list of contaminated sites that warrant special NRC attention because they pose unique or complex decommissioning issues. While none of these sites represent an immediate threat to the public health and safety, they have contamination that exceeds criteria for release for unrestricted use. All of these sites require some degree of remediation, and several involve regulatory issues that will need to be addressed by the NRC Commissioners. These problematic sites have buildings, former waste disposal areas, large piles of tailings, groundwater, and soil contaminated with low levels of uranium or thorium (source material) or other radionuclides. Consequently, they present varying degrees of radiological hazard, remediation complexity, and cost. Some of the sites are still under the control of active NRC licenses, whereas, licenses for other sites already may have been terminated or never may have been issued. At some sites, licensees are financially and technically capable of completing decommissioning in a reasonable timeframe, whereas, at other sites, the licensee or responsible party may be unable or unwilling to perform decommissioning. In addition, the sites are currently in various stages of decommissioning. At some sites, licensees have initiated decommissioning, whereas, at other sites, decommissioning has not yet been planned or initiated. Sites are placed on the SDMP if there are:

(1) Problems with the viability of the responsible organization (e.g., the licensee for the site is unable or unwilling to pay for the decommissioning;
(2) Large amounts of soil contamination or unused settling ponds or burial grounds that may make the water difficult to dispose of;
(3) The long-term presence of contaminated, unused buildings;
(4) A previously terminated license; or
(5) Contamination or potential contamination of the groundwater from on-site wastes.

In deciding whether to add a site to the SDMP list, the NRC also considers the projected length of time for decommissioning and the willingness of the responsible organization to complete the decommissioning in a timely manner. Since the list was established, 9 sites have been removed from the list, and the current SDMP list contains 47 sites in 11 states. The USNRC annually publishes NUREG-1444, "Site Decommissioning Management Plan", which updates the status of each site. The list was established in 1990, and 9 sites have been removed after successful completion of cleanup to meet requirements, or transferred to another regulatory authority. There are eight major activities associated with any major decommissioning activity. Progress can be measured against these milestones.

(1) A characterization of the site, which would identify the amount and location of radioactive material. A characterization plan is part of this activity, the performance of the characterization, and preparing the characterization report;
(2) Regulatory review and approval of the site characterization plan and the site characterization report;
(3) Development and submission of a decommissioning plan, outlining the steps to be taken to perform the decontamination activities;

(4) Regulatory review and approval of the decommissioning plan;
(5) Performance of the decontamination and decommissioning activities outlined in the plan;
(6) Performance of a final status survey to verify releasability of the site and submittal of a final status survey report;
(7) Regulatory review of the termination survey report, and performance of a confirmatory survey;
(8) Termination of the license.

Radiological Criteria for Decommissioning

Generally, licensees decommission their facilities with the intent of terminating the license and using the facility for activities that do not involve licensed material. The ultimate goal of decommissioning is to reduce residual radioactivity to levels that are indistinguishable from background levels. These facilities must be decommissioned such that they do not contain residual radioactive material levels in excess of criteria for unrestricted use. The radiological criteria for unrestricted use are identified in the "Action Plan to Ensure Timely Remediation of Sites Listed in the Site Decommissioning Management Plan", 57 FR 13389, April 16, 1992. These criteria include the following:

- USNRC Policy and Guidance Directive FC 83-23, "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Byproduct, Source and Special Nuclear Material Licenses", November 14, 1983;
- Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors", June 1974;
- Options 1 and 2 of the Branch Technical Position, "Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations" 46 FR 52601, October 23, 1981;
- 40 CFR Part 141, Interim National Primary Drinking Water Regulations;
- EPA's "Radiation Dose Guidelines for Protection Against Transuranium Elements Present in the Environment as a Result of Unplanned Contamination".

These criteria are applied on a site-specific basis with emphasis on remediating residual radioactive material to levels that are as low as reasonably achievable. In addition, these criteria will be considered in establishing site-specific ALARA levels for SDMP sites in license amendments and orders. Further, implementation of residual contamination criteria is dependent on the establishment of acceptable dose or risk criteria for unrestricted use of nuclear facilities.

The Policy and Guidance Directive and the Regulatory Guide provide criteria in terms of fixed and removable contamination and acceptable radiation exposures associated with beta-and gamma-emitting surface contamination. The guidance also provide acceptable volumetric concentrations of uranium, thorium, americium and plutonium in soil. The Branch Technical Position, published in the Federal Register on October 23, 1981, 46 FR 52061, provides acceptable activity concentrations of uranium and thorium (with and without decay products) in soil under a variety of conditions.

The Environmental Protection Agency's (EPA's) Interim National Primary Drinking Water Regulations, 40 CFR Part 141, July 9, 1976, 41 FR 38404, provides maximum contaminant limits for radionuclides in public drinking water, which can be extended to apply as acceptable activity concentration in groundwater and surface water. These documents provide guidelines for acceptable average and maximum surface contamination levels for a wide variety of radionuclides. Also provided are average and maximum radiation levels of 0.2 and 1.0 millirad per hour at 1 centimeter for beta and gamma-emitters. In addition, an acceptable external radiation exposure rate for soil contamination of 10 microroentgen above background per hour at one meter is specified.

Regulatory Guide 1.86

When these acceptable surface contamination levels are combined with an exposure rate limit of 5 μR/hr above background at 1 meter, this guide has been used in decommissioning and terminating licenses for a number of research reactors. The 5 μR/hr criterion for indoor contamination corresponds to an annual whole body dose of about 10 millirem for an assumed indoor occupancy period of 2000 hours per year. The 5 μR/hr criterion has been applied to ^{60}Co, ^{137}Cs, and ^{152}Eu that may exist in concrete, components, and structures at nuclear reactor research facilities, with an overall dose objective of 10 millirem/year.

The Branch Technical Position (BTP) on Disposal or Storage of Thorium and Uranium Wastes, 46 FR 52061 provides guidance on decommissioning and cleanup of fuel cycle and other facilities contaminated with relatively large volumes of waste with low activity concentrations of uranium and thorium. In combination with the disposal provisions in 10 CFR 20.302, the technical position provides four "options" for disposal of uranium and thorium wastes, which vary in activity concentration and corresponding potential radiological dose. Only the lower-activity concentration limits and disposal methods provided in Options 1 and 2 of the technical position can be applied as criteria for the release of a site for unrestricted use. Options 3 and 4 require deed restrictions, in effect releasing a site for restricted use.

Under Option 1 of the Branch Technical Position, licensees may dispose of wastes containing natural thorium, depleted or enriched uranium, and natural uranium without restrictions for burial method or post-termination land use. The activity concentrations for this option are consistent with the levels identified in Table I. The maximum activity concentration for natural uranium is based on EPA standards for cleanup and stabilization of uranium mill tailings for ^{226}Ra (5 pCi/g) including its decay products (42 FR 2556-2563). The activity concentrations for natural thorium and depleted or enriched uranium are based on internal radiation dose guidelines recommended by the EPA for protection against transuranium elements present in the environment as a result of unplanned contamination (42 FR 60956-60959). As shown in Table 1, committed doses are expected to be on the order of one millirad per year to the lung or three millirad per year to the bone from inhalation and ingestion. The resulting concentrations would also limit external exposures to less than 10 μR/hr above background.

Under Option 2 of the 1981 BTP, concentrations of natural thorium and depleted or enriched uranium are required to be buried under prescribed conditions without requiring land use restrictions after license termination. Disposals performed under Option 2 guidelines must be covered by four feet or more of clean soil. Acceptable activity concentrations for burial were calculated based on the criteria that (1) radiation doses to members of the public should not exceed Option 1 levels when the waste is buried in an approved manner under routine exposure conditions, and (2) radiation doses to an inadvertent intruder should not exceed 170 millirems to a critical organ or whole body.

When applying Option 2 of the technical position, the human intruder pathway is evaluated. In addition, consistent with the technical position, groundwater considerations are also evaluated, when necessary, because of site specific hydrogeologic features and groundwater use. Dose from the groundwater pathway should not exceed 3 mrad/yr to the bone (approximately 1.8 mrem/yr effective-dose-equivalent) consistent with the stated dose basis for the Option 1 concentration values. Dose from the human intruder pathway should not exceed 170 mrem/yr to the critical organ. For soluble uranium, the critical organ is the bone. For insoluble uranium, the critical organ is the lung. For thorium, both soluble and insoluble, the critical organ is the whole body.

The dose of 170 mrem/yr to the whole body, from Option 2 concentrations of thorium, via the human intruder pathway, may be unacceptably high. Further, this 170 mrem/yr whole body dose assumes 0.8 occupancy factor and a 0.5 shielding factor. If the occupancy and shielding factors are set to 1, the dose from thorium may be as high as 420 mrem/yr to the whole body. Therefore, for thorium concentrations above the Option 1 limit, the 10 CFR 20 limit of 100 mrem/yr total effective dose equivalent may be the appropriate unrestricted-use release limit. The intruder exposure pathway could possibly be ignored when the disposal method makes the chance of future human access very remote, such as via deep disposal, or disposal by mine backfill. Disposals under Option 2 that involve depleted or enriched uranium are evaluated for buildup of decay products for a period of 1000 years. The original dose assessments to determine the Option 2 limits for depleted and enriched uranium did not include decay products because the decay products are removed in processing the uranium. Significant ingrowth of the decay products requires more than 1000 years and has not been routinely considered in assessing the acceptability of the disposal under Option 2 even though potential doses may increase considerably with time (i.e., beyond 10,000 years).

TABLE I

Contamination	Criteria	Dose Basis
Average, fixed U-nat, ^{235}U, ^{238}U,	5000 dpm/100 cm^2	13 mrem/yr
Average, fixed ^{226}Ra, ^{228}Ra, transuranics, etc.	100 dpm/100 cm^2	0.2 mrem/yr
Average, fixed Th-nat, ^{232}Th, Sr, etc.	1000 dpm/100 cm^2	28 mrem/yr
Avg. and max. external beta-gamma dose	0.2-1 mrad/hr at 1 cm	20 mrem/yr
U-nat with decay products in soil	10 pCi/gm	2.4 mrem/yr
Depleted Uranium in soil	35 pCi/gm	1.8 mrem/yr
Th-nat with decay products in soil	10 pCi/gm	35 mrem/yr
Enriched Uranium in soil	30 pCi/gm	1 mrad/yr to lung 3 mrad/yr to bone
^{239}Pu in soil	25 pCi/gm	15 mrem/yr
^{241}Am in soil	30 pCi/gm	19 mrem/yr
External radiation	10 μR/hr at 1 meter above background	24 mrem/yr

Listing of Sites

The sites currently on the Site Decommissioning Management Plan include the following:

Advanced Medical Systems, Inc., Cleveland, OH
Aluminum Company of America, Cleveland, OH
Anne Arundel County/Curtis Bay, Anne Arundel County, MD
Army, Department of, Aberdeen Proving Ground, Aberdeen, MD
Army, Department of, Jefferson Proving Ground, Jefferson, IN
Babcock & Wilcox, Apollo, PA
Babcock & Wilcox, Parks Township, PA
BP Chemicals America, Inc., Lima, OH
Brooks & Perkins, Detroit, MI
Brooks & Perkins, Livonia, MI
Cabot Corporation, Boyerton, PA
Cabot Corporation, Reading, PA
Cabot Corporation, Revere, PA
Chemetron Corporation, Bert Avenue, Cleveland, OH
Chemetron Corporation, Harvard Avenue, Cleveland, OH
Clevite, Cleveland, OH
Dow Chemical Company, Bay City and Midland, MI
Elkem Metals, Inc., Marietta, OH
Englehard Corporation, Plainville, MA
Fansteel, Inc., Muskogee, OK
Hartley and Hartley (Kawkawlin) Landfill, Bay County, MI
Heritage Minerals, Lakehurst, NJ
Horizons, Inc., Cleveland, OH
Kaiser Aluminum, Tulsa, OK
Kerr-McGee, Cimarron, OK
Kerr-McGee, Cushing, OK
Lake City Army Ammunition Plant (formerly Remington Arms Co., Independence, MO)
Minnesota Mining and Manufacturing Co., (3M), Pine County, MN
Molycorp, Inc., Washington, PA
Molycorp, Inc., York, PA
Northeast Ohio Regional Sewer District/Southerly Plant, Cleveland, OH
Nuclear Metals, Inc., Concord, MA
Permagrain Products, Media, PA
Pesses Company, METCOA Site, Pulaski, PA
RMI Titanium Company, Ashtabula, OH
RTI, Inc., (formerly Process Technology of North Jersey, Inc.), Rockaway, NJ
Safety Light Corporation, Bloomsburg, PA
Schott Glass Technologies, Duryea, PA
Sequoyah Fuels Corporation, Gore, OK
Shieldalloy Metallurgical Corporation, Cambridge, OH
Shieldalloy Metallurgical Corporation, Newfield, NJ
Texas Instruments, Inc., Attleboro, MA
Watertown Arsenal/Mall, Watertown, MA

Watertown GSA, Watertown, MA
Westinghouse Electric Corporation, Waltz Mill, PA
Whittaker Corporation, Greenville, PA
Wyman-Gordon Company, North Grafton, MA

The nine sites that were formerly on the list, but have been removed are:

Allied Signal, Teterboro, NJ
AMAX, Inc., Washington Bottom, WV
Budd Co., Philadelphia, PA
Chevron Corp, Pauling, NY
Magnesium Electron, Flemmington, NJ
Old Vic, Inc., Cleveland, OH
United Nuclear Corp., Wood River Junction, RI
Pratt & Whitney, Middletown, CT
West Lake Landfill, Bridgeton, MD

Formerly-Licensed Sites Identified As Potentially Contaminated

In 1976, the General Accounting Office (GAO) raised concerns about the decommissioning of sites formerly licensed by the Atomic Energy Commission's (AEC's) regulatory body, which is now the Nuclear Regulatory Commission (NRC). In its response, NRC agreed to reexamine the files of the terminated licenses. Between 1977 and 1982, Oak Ridge National Laboratory (ORNL) reviewed the docket files for all fuel cycle and materials licenses terminated before 1965 to verify that all sites had been properly decommissioned. This was done under an interagency agreement with the NRC. The files of 16,230 former licensees were reviewed and a total of 12 contaminated sites were identified. All of the 12 sites had been licensed pursuant to 10 CFR Part 40 and none represented a significant risk to public health and safety. NRC took action to have former licensees decontaminate seven of the sites. The Department of Energy (DOE) accepted responsibility for the other five sites under its Formerly Utilized Site Remedial Action Program (FUSRAP).

In 1989, GAO issued a report on NRC decommissioning procedures and criteria. This report raised additional concerns about the decommissioning of formerly-licensed sites. Before testimony presented to the House Subcommittee on Environment, Energy, and Natural Resources, a commitment was made to review the records of all sites terminated since 1965. ORNL was contracted again to review all docket files retired between 1965 and 1985. This second study required the creation of a computerized inventory of the docket files in addition to screening the files to determine whether all licensed sites had been properly decommissioned. If documentation were inadequate to verify that a formerly-licensed site had been properly decommissioned, the status of the site was to be verified by inspection. It was subsequently decided to review the files of all terminated licenses (Pre-1965 and Post-1985) using the same screening criteria and to document their status in one computer inventory. This would improve information retrieval and permit comparison of the review findings for all terminated license files.

The objective of the review was to evaluate the likelihood and possible magnitude of contamination at formerly licensed materials sites. In its review, ORNL used license files and related files (e.g., inspection and correspondence files) to obtain information relevant to the possibility of site contamination. The information was entered into a database and evaluated by an expert system that prompts the reviewer to enter additional data and judgements. For the sake of efficiency, the system first determined whether the license could be eliminated for administrative reasons, e.g., it was superseded by another license or it was transferred to an Agreement State. There is a provision to override this determination if the site had the potential for serious contamination based on materials possessed.

The system next assigned a score based on the nuclides and quantities the licensee was authorized to possess. This score considered the form of the material, inhalation and ingestion dose factors, and decrements for half-life. Some licenses were eliminated from consideration on the basis that they had small quantities of materials, only low-hazard materials, or materials that would have decayed to below levels of concern. The score was modified by information disposition, and by indications of possible contamination of equipment, structures, or the environment (releases, burials, incineration, operational incidents).

Using this system, ORNL has reviewed the files of over 31, 000 materials licenses. Scores from zero to as high as almost 500,000 were assigned. For 622 sites (or 2%), there was sufficient question about the documentation in the files to warrant further examination of the license. Scores greater than 300 were given first priority, then, scores less than 300 and then, sealed source files. Requests to the former licensee, current site owner or occupant, Agreement Sates, and NRC staff were made regarding concerns about the sites. Site visits have been required to resolve some concerns, including radiological surveys. If contamination above release limits is found, remedial actions are decided on, and responsible parties identified.

Approximately 10% of the 600 sites are being found to contain contamination above release limits for unrestricted use. Some of these sites have been cleaned up, others added to the SDMP (and in the case of Pratt-Whitney, since removed), and others are awaiting further action. This process is ongoing and is not expected to be complete until at least 1997.

Timeliness of Actions

Throughout the United States, there are approximately 7,000 licensees authorized to use nuclear materials. Each specific license expires at the end of the day listed on the license, unless a renewal is requested. If a license expires, or is terminated, it is the licensee's responsibility to initiate any necessary decontamination and decommissioning efforts, at their expense, to return the property to such a condition that it can be released for unrestricted use. Financial responsibilities are discussed in the following section.

Decommissioning begins (license status is changed from active to decommissioning) if any of the following occur:

(1) The license expires or is revoked;
(2) The licensee decides to permanently cease operations with licensed material at the entire site, or in any separate building or outdoor area that contains residual radioactivity, such that the area is not releasable in accordance with NRC requirements;

(3) Twenty-four months have elapsed since principle activities have been conducted under the license; or
(4) No principle activities have been conducted in a separate building, or outdoor area, for a period of 24 months and residual activity is present that would preclude release of the area in accordance with requirements.

Once any of the above occur, the licensee is required to notify NRC in writing, and begin decommissioning the facility, or within 12 months submit a decommissioning plan and begin decommissioning according to the plan once approved.

Regulations discussing these timeliness actions are contained in 10 CFR 30.36(d) (1-4), 40.42(d) (1-4), 70.38(d) (1-4) and 72.54(d) (1-4). The effective date of the rule was August 15, 1994, (59 FR 36026, July 15, 1994).

For licensees with unused facilities on August 15, 1994, the following submittals are required by August 15, 1996:

(1) Within 12 months of submitting the required notification of decommissioning, they are to submit a decommissioning plan (if required) and begin decommissioning upon approval of the plan;
(2) Unless otherwise approved, they are to complete decommissioning within 24 months of initiating decommissioning;
(3) If notification was made prior to August 15, 1994, no further notification is required; and
(4) Those licensees that made prior notification were required to submit a decommissioning plan, or request an alternative decommissioning schedule by August 15, 1995.

Extensions may be granted to these time periods in accordance with 10 CFR 30.36(e), 40.42(e), 70.38(e), and 72.54(s) (1). The extension must not be detrimental to the public health and safety and otherwise, in the public interest, considering:

(1) Whether it is technically feasible to complete the decommissioning in the 24-month period;
(2) Whether sufficient waste capacity is available to complete the decommissioning in the 24-month period;
(3) Whether a significant volume reduction in waste requiring disposal and radiation exposures to workers will be achieved by allowing short-lived isotopes to decay, and
(4) Other site-specific factors, such as the requirements of their regulatory agencies, lawsuits, groundwater issues, actions resulting in more environment harm than deferred cleanup, and other factors beyond the control of the licensee.

These actions are all designed to ensure that sites are decommissioned and released for unrestricted use in a timely manner, and that the responsible parties and the regulatory authorities ensure these actions occur.

Timeliness Rule for Former Radioactive Waste Burials

Prior to 1981, general licensees were allowed to bring radioactive waste on their property in accordance with 10 CFR 20.304 and 20.302. No regulatory approval was required for this action. The decommissioning timeliness rule discussed above applies to these sites, and current property owners need to assess these burials and possibly remediate them based on current regulatory release criteria for unrestricted use. However, this position was not clearly explained in 1989 with the promulgation of the Timeliness Rule, as mentioned in previous 10 CFR 20 regulations. Sites will need to be reviewed to ascertain existing information about the radionuclide content, concentration and total activity, the location and design of the burial, and applicable environmental characteristics important to waste isolation. Radionuclide concentrations and quantities below the threshold values of Table I do not warrant additional investigation, and these former burial areas are suitable for release without land use restrictions. Additional characterization may be needed to:

(1) Assess the type, concentration, and total activity of radionuclides in the waste;
(2) Determine environmental characteristics to estimate long-term fate and transport of radionuclides; and
(3) Evaluate the potential for human intrusion into the waste and associated exposure characteristics.

The goal is to ensure that doses to members of the public will be a small fraction (e.g., 10-20 mrem/year) of the 100 mrem/year public dose limit in 10 CFR 20.1301. Stabilization or exhumation and disposal may be necessary if projected doses exceed a small fraction of the public dose limit.

Compliance with these decommissioning timeliness requirements may be difficult since universities and research institutions may not be aware of the requirements. There may be considerable cost to comply. The safety significance associated with the burial sites may not be high. It may not be possible to identify and notify the large number of property owners who own sites where former licensees may have conducted authorized burials. And finally, the Decommissioning Timeliness Rule only applies to present licensees. Non-licensed, responsible parties will be encouraged to meet the decommissioning schedules discussed in the timeliness Rule.

Financial Assurance

In addition to identifying a responsible party for decontamination and decommissioning activities, and criteria for release for unrestricted use, an assurance of adequate financial resources is a key component is an overall decommissioning process. In recognition of this, regulations have been promulgated at 10 CFR 30.35, 40.36, and 70.25, with the purpose of assuring that decommissioning for licensed facilities will be accomplished in a safe and timely manner and that adequate licensee funds will be available for this purpose, such that, the financial burden and responsibility does not rest with the taxpayer.

Financial assurance is based on the radioisotopes allowed to be possessed by the licensee, and the possession limits. Financial Assurance is not required for licenses involving radionuclides with half-lives less than 120 days. Possession limits for financial assurance requirements for materials licenses are based on Appendix B to 10 CFR Part 30. For a licensee that only possesses sealed sources, and in amounts greater than 10^{10} times the quantities in Appendix B, financial assurance in the amount of $75,000 is required. For licensees with materials in unsealed form and greater than 10^3 but less than 10^4 times the quantities in Appendix B, financial assurance in the amount of $150,000 is required. For licensees with materials in unsealed form greater than 10^4 but less than 10^5 times the quantities in Appendix B, financial assurance in the amount of $750,000 is required. If the quantity in unsealed form exceeds 10^5 times the Appendix B quantities, a decommissioning funding plan is required.

A decommissioning funding plan outlines the work required to decommission a facility, provides a site-specific cost estimate for the decommissioning, and states that funds necessary to complete the decommissioning have been obtained. In general, the cost estimate should provide for decommissioning the facility to allow unrestricted release. The estimate should assume that the work will be performed by an independent, third party contractor and not take credit for salvage value or reduced taxes. However, for certain sites where the licensee provides a viable alternative approach, or alternative basis for the cost estimate, the plan may be approved if the approach provides sufficient assurance of funding for decommissioning. Licensees may demonstrate financial assurance for decommissioning by one or more of the following mechanisms:

(1) Prepayment - a deposit at the start of operation in a segregated account outside of the licensee's control. Prepayment mechanisms include trust funds, escrow accounts, certificates of deposits and government securities;

(2) Surety, Insurance, or Parent Company Guarantee Method - assurance that the cost of decommissioning will be paid by another party should the licensee default on the responsibility to complete the decommissioning. In addition to insurance, surety methods may include payment surety bonds, letters of credit, lines of credit and parent company guarantees;

(3) External Sinking Fund - a sinking fund account plus insurance or surety mechanism, such that the total of both at least equals the cost of decommissioning. A sinking fund is a segregated account outside of the licensee's control and any of the prepayment mechanisms may be used to hold the assets for the sinking fund account.

In addition, Federal, State or Local Government licensees may provide financial assurance for decommissioning with a statement of intent. A statement of intent is a statement from the appropriate government entity indicating that decommissioning funds will be obtained when necessary. Such statements need to state the estimated cost of decommissioning, as well as a demonstration that the party signing the statement has the authority to make such a statement on behalf of the government. In limited cases, a private licensee may rely on a government statement of intent if it is part of a binding contract between the government and the licensee.

The objective of NRC's financial assurance requirements are to ensure that a suitable mechanism for completing the decommissioning of licensed facilities is in place in the event that a licensee is unwilling or unable to complete the decommissioning.

Enhanced Participating Rulemaking or Radiological Criteria for Decommissioning

Commencing in May 1993, a significant effort has been expended to establish radiological criteria for decommissioning. After a series of seven public workshops to elicit informed discussions of the options and approaches for developing criteria, a proposed rule was published August 22, 1994 (FR 43200). The proposed criteria would apply to the decommissioning of all licensed facilities. The intent is to provide a clear and consistent regulatory basis for determining the extent to which lands and structures must be remediated before a site can be considered decommissioned. It is anticipated that having specific criteria in the regulations would result in more efficient and consistent actions related to the numerous and frequently complex site remediation and decommissioning activities anticipated in the future.

Decommissioning is presently allowed on a site-specific basis using the existing guidance as discussed above. Codifying the radiological criteria for decommissioning in the regulations should allow a more effective implementation of policies to protect public health and safety and the environment at decommissioned sites, by more efficient use of regulatory and license resources, consistent application for all types of contamination, and a predictable basis for decommissioning planning. In addition, delays in decommissioning could be eliminated since licensees could proceed with decommissioning without waiting for specific regulatory approval.

The overall conceptual basis for decommissioning, as proposed in this rulemaking, consists of an objective to reduce the residual radioactivity at the site so that it is indistinguishable from the background, a limit on the dose considered acceptable for release of a site with a stipulation that dose be as far below this limit as reasonably achievable (i.e., ALARA), provisions in regulatory guidance for administrative relief from performing sophisticated ALARA analyses for licensees who have little or no site contamination, provisions for restricted termination of a license when physical remediation activities cannot achieve the limit, and enhanced provisions for public participation. The limit for release of a site is 15 mrem/year total effective dose equivalent (TEDE) for residual radioactivity distinguishable from background. If doses from residual radioactivity are less than the TEDE, the license will be terminated and release for unrestricted use following the licensee's demonstration that the residual radioactivity at the site is ALARA.

The goal is to reduce residual radioactivity to levels that will allow unrestricted release of the site. However, in recognition that this may not always be feasible, licenses may be considered for termination where restrictions may be imposed on the use of the site to ensure that public doses are maintained below the 15 mrem/year TEDE limit, provided the licensee:

(1) Can demonstrate that further reductions in residual radioactivity necessary to comply with the 15 mrem/year TEDE limit for unrestricted use are not technically achievable, would be prohibitively expensive, or would result in net public or environmental harm;

(2) Has made adequate provisions for institutional controls to reduce annual TEDE from residual radioactivity distinguishable from background to the average member of the appropriate critical group to 15 mrem/year TEDE;

(3) Has provided sufficient financial assurance to enable an independent third party to assume and carry out responsibilities for any necessary control and maintenance of the site; and

(4) Has reduced the residual radioactivity at the site so that the TEDE from residual radioactivity would not exceed 100 mrem/per year even if the restrictions applied in the termination were no longer effective in limiting the possible scenarios or pathways of exposure.

It is important for the public to not only be fully-informed of the decommissioning actions at a particular site but also to be able to effectively participate in site decommissioning decisions. The proposed rule will provide for public participation in the decommissioning process through three mechanisms in addition to the relevant requirements regarding hearing opportunities for a particular site. Upon the receipt of a decommissioning plan from the licensee or a proposal for restricted release of a site, the following actions will occur:

(1) Notify and solicit comments from local and state governments in the vicinity of the site and Indian Nation or other indigenous people that have treaty or statutory rights that could be affected by the decommissioning;
(2) Publish a notice in the Federal Register as well as in other media, such as local newspapers which are readily accessible to individual in the vicinity of the site; and
(3) Solicit public comment on the proposed decommissioning action. These provisions are designed to provide affected individuals and organizations with both information about the proposed decommissioning and an opportunity to provide comments on the licensee's proposal. The Commission believes it is particularly important to provide notice in a forum that is accessible to local individuals. This forum may vary from site to site but would usually include providing notice to local media for publication.

With publication of the proposed rulemaking in August 1994, significant public comments were received. Comments argued for both higher and lower dose limits, more and less sophisticated ALARA analysis, and more and less guidance on surveys, surveying techniques and mathematical data analysis. Consideration of the comments and resolution continues.

Pennsylvania Contaminated Site I

Schott Glass Technologies in Duryea, PA, is a site on the SDMP due to an onsite landfill containing relatively small, discrete volumes of thoriated glass chips and refractory material. Waste glass and materials from manufacturing of glass, including the thoriated glass, were placed in a landfill on the licensee's property from 1969 until 1980. Schott Glass proposes to keep the thoriated glass in the landfill, undisturbed. This will reduce exposure of radiation workers to radiation and lead, a hazardous material in the refractory and minimize air cleaning issues with disturbing a land area. The landfill contains 15,000 cubic feet of scrap, with 8000 lbs. of thoriated glass at a concentration of 17%. This translates into 1400 lbs of source material, or 30 cubic feet.

Since the property will remain under the control of Schott Glass, release for restricted use is appropriate. Schott Glass will cap the existing landfill with a multi-layered cap and erosion control plan consisting of a high density polyethylene (HDPE) textured synthetic liner, HDPE composite drainage net, granular drainage layer, and either a vegetative soil layer or asphalt layer.

These added layers will eliminate any airborne contamination, reduce the external dose to levels indistinguishable from background, provide long-term erosion control, and reduce the likelihood of future excavation in the area of the landfill.

Nonetheless, an ALARA analysis was done. This analysis assumed that an individual would excavate the landfill, select a piece of thoriated glass over refractory or other scrap, fashions a 50 carat pendant by grinding, wears the pendant, and displays the thoriated glass in a display jar at home. The resulting dose for this scenario is approximately 100 mrem/year.

Pennsylvania Contaminated Site II

At the Babcock & Wilcox facility in Leechburg, PA, operations continue to decontaminate several buildings used by the reactor test staff. Procedures have been generated to assure appropriate air sampling. Air contaminant sampling is necessary in order to determine the extent of worker exposure, to determine the effectiveness of air contaminant controls, and to determine regulatory compliance.

Prior to performing air monitoring, a survey of the operation to be monitored should be made. This survey should include:

(1) A review of specific operational activities;
(2) A review of the materials used in the operation;
(3) Identification of employee tasks associated with the operation; and
(4) Review of the results of all previous monitoring for the operation.

In certain instances, it may be desirable to obtain and analyze grab samples by use of direct reading meters or instantaneous reading methods. The resulting information will be used to determine the duration of each sampling period and the number of samples required to obtain results that are representative of the normal work conditions for the operation. The sampling methodology should identify the sampling equipment, sample media, flow rate, and the total sample volume needed for proper sample collection. It is recommended that, prior to any sampling, the analytical laboratory be contacted in order to discuss any special requirements or limitations which may affect sampling methodology.

Prior to performing air sampling, all air sampling pumps must be charged and checked for proper operation prior to use. All air sampling pumps must be calibrated against a primary standard to the specific flow rate identified in the sampling methodology. As an alternate, the pumps may be calibrated against calibration equipment which is periodically checked against a primary standard.

If direct reading meters or instantaneous colorimetric detector tubes are used, follow the manufacturer's directions for equipment preparation and calibration.

Once sample pumps have been adequately charged and properly calibrated, proceed to the selected sample location and perform the following:

(1) Record employee identification and job description;
(2) Place the sampling pump on the employee's belt and attach the sampling media to the employee's shirt collar (or similar position) so that it is within the employee's breathing zone (within a 6 to 9 inch radius of the nose). If measuring welders, place the media under the welder's helmet;
(3) If sampling cassettes are used, ensure that they are in a vertical position with the inlet port of the cassette facing toward the employee's feet. Remove the cap from the inlet port of the cassette;
(4) Turn on the sample pump and note the start time;
(5) Instruct the employee to perform his duties in a normal fashion;
(6) Observe employee activities and operation periodically, (at least every 2 hours) and record any significant observations.

It may also be advisable to record weather conditions and, if possible, obtain photographs of typical sample pump locations.

Procedures such as these have proven to be adequate for obtaining representative samples and assessing the hazard under which decontamination operations are performed.

Massachusetts Contaminated Site

Nuclear Metals, Inc. has manufactured products from depleted uranium for various purposes since 1988. Located in Concord, MA, the major source of uranium contamination at the site was the discharge of neutralized pickling liquor containing copper and depleted uranium to an on-site holding basin between 1958 and 1985. Discharges to the holding basin ceased in 1985, and the basin has been covered with a synthetic cover to minimize evaporation, prevent additional water (rain and snow) from adding to the basin, and to eliminate the potential for any airborne concerns. A decommissioning plan has been prepared that includes removal of the basin sludge and shipment offsite in "superpoly" bags for disposal. Airborne sampling similar to that described above will be conducted during operation for worker's protection and environmental impact.

Two recent incidents have occurred that involved air cleaning issues. The first was a fire in a ventilation system, and the second was a broken buried pipe.

In February 1996, an unplanned/unexpected vent fire occurred within a torrit filter plenum housing and downstream prefilters assembly servicing a pulsed - combustion wastewater evaporation system. The thermocouple systems for the ventilation, installed to detect temperature inconsistencies, was reading low. After replacement of lead wires, troubleshooting, and startup testing, the system was approved for restart. Nonetheless, less than two hours after restart, a fire was observed coming out of the filter cartridges, and a maximum temperature of 750°F observed. Both water and carbon dioxide were used to extinguish the fire. The root cause of the fire was determined to be a thermocouple with reversed wires (polarity).

Damage was obvious. The cardboard framed pipefilters had been completely burned. The high temperature HEPA filters were substantially intact. Upon removal, they were physically dropped to the floor below, resulting in handling damage. Further analysis indicated three of the four HEPA filters were in good condition, with the fourth having suffered some heat damage, blinding the media rather than opening voids. The media had physically pulled away from one side of the frame, believed to be the result of dropping the filters on the floor.

A total of eight individuals were identified as potentially exposed; five were Emergency Response Team members involved in control and extinguishing of the vent fire; the remaining three acted in support positions, and were never very close to (or actively fighting) the fire itself. All personnel responding to the fire wore SCBA respiratory protective equipment, but were not monitored with any kind of breathing zone air sampler. Because the building was evacuated during response activities, and the HEPA exhaust filtration systems(s) were not compromised, there was no potential for outside/offsite exposures. Urine bioassay samples have been collected from all personnel identified as potentially exposed to any airborne activity, or involved in immediate response to the incident. No indication of uptake to any individual was noted. All potentially affected personnel were equipped with routine external dosimetry devices (film badges).

Air samples of four general types were collected and counted:

(1) In-plant portable "hi-vol" samples (high flow rate, short duration 'grab' samples); taken during the incident, and preparatory to return to service;
(2) In-plant stationary (fixed, continuous, low flow rate); routine workplace air monitoring samples;
(3) Effluent (continuous, low volume); and three exhaust ventilation stacks servicing other areas;
(4) Ambient/environmental (continuous, high volume); a total of eight samplers, two of which can be used as "backgrounds" for evaluation of local/closer stations.

Results of these analyses show no significant or unusual potential for exposure to any individuals (on or off-site) other than those eight persons already identified. Analyses (in-house counting using an automated gas-flow proportional counter) of samples from the eight environmental air stations yielded effective average ambient air alpha activity concentrations ranging from 4.9×10^{-15} to 3.1×10^{-15} μCi/ml; this value is well within the analytical uncertainty of the measurement process, and the normal distribution of values observed in past datasets. It is apparent from these data that any potential exposure to the environment, public, or outside personnel arising from this incident is not significant with respect to routine facility operating emissions, and all applicable effluent regulatory statutes and standards.

During excavation to improve building drainage in May 1996, a wastewater transfer line was broken. This resulted in a leak of approximately 1800 gallons of water containing 380 grams of depleted uranium, a concentration of 20 picocuries/milliliter. The spill was contained onsite, and there were no offsite releases or effects. Contaminated soil was removed. The workers did not use respiratory protection equipment, but breathing zone air samples were employed. Workers with samplers included the maintenance staff who removed the soil, repaired the broken pipe, transferred the soil to bulk bags, provided shoring for the hole, and the backhoe operator. Results indicated minimal worker exposure; the highest DAC-hr (derived air concentration-hour) was less than 0.75.

In addition, two hi-vol grab samples were taken. For ten-minute intervals, the count was equivalent to the minimum detectable activity (MDA) of 4.5×10^{-13} microcuries/milliliters. Similar results were obtained with 30-second counts and an MDA of 2×10^{-13} μCi/ml.

Conclusion

A significant challenge for the nuclear community lies ahead in being able to successfully decontaminate and decommission contaminated structures and environment. Criteria must be clear, concise, fully-understood and achievable. A successful program for decommissioning has the following objectives:

(1) Safety and Timeliness - Ensure timely and safe decommissioning of licensed and unlicensed sites that are contaminated with radioactive materials associated with the possession and use of source, special nuclear, and byproduct materials;
(2) Documentation - Ensure that decommissioning decisions are thoroughly documented to develop a record that will withstand the test of time and avoid transferring a burden to future generations to redevelop information on the radiological status of formerly licensed sites;
(3) Coordination - Coordinate decommissioning actions with regulatory agencies at the federal, state and local levels, with interested parties, and with members of the public to promote efficiency and finality for decommissioning actions;
(4) Minimal Burden - Minimize the burden imposed on licensees and other responsible parties consistent with accomplishing the other objectives; and
(5) Review Capabilities - Develop and maintain review capabilities, as required, to fulfill the objectives of the decommissioning program.

It is expected and anticipated to be able to release sites so that members of the public will have unrestricted access to areas where radioactive materials were once used.

DISCUSSION

FIRST: The acceptable numbers that you gave us with regard to residual contamination, would the NRC consider them to be de minimus exposures? I know the word de minimus gets a lot of peoples' hackles up, but still, you are proposing what I would interpret in that context. Would you comment on that?

BELLAMY: I am glad to. The Nuclear Regulatory Commission tried, about four or five years ago, to define a term which we called, and I have to say this very quietly, "below regulatory concern". That is not a term that we are allowed to use anymore. But to answer your question very specifically, the answer is, yes. This was our attempt to try to define a de minimus-type level, to define a below regulatory concern value without using it as a number.

PORCO: A couple of general questions on the fire, were the prefilters, the Torrit prefilters, cellulose or glass?

BELLAMY: They were glass.

PORCO: Were the HEPA filters commercial grade or were they in accordance with the accepted nuclear standard?

PORCO: Did anyone check on the type of binder that was used? It seems to me that they burned more vigorously than you would expect. Was this an issue?

BELLAMY: It was not an issue. You asked whether anybody checked and the answer is I don't know. I did not check, and I can't answer your question, I believe it may be in the Licensee Event Report that they submitted and I can get you and anybody else a copy if it is of interest.

WEIDLER: You talked about some small scale projects, are there any large-scale projects going on in Region 1 right now? And if so, do the same criteria apply to power plants.

BELLAMY: The answer is, yes. Region 1, in the northeast part of the country, seems to have more than its share of these activities. Of the forty-seven STMP sites that are presently on the list, twenty are in my region, and I have project management responsibility for eleven of them. Nine are managed out of headquarters, but it is still my responsibility to inspect them and make sure that the criteria are met. I believe you are referring to the decommissioning of nuclear power plants and I can assure you that the Shoreham facility did use the criteria. Shoreham has been officially decommissioned and is basically done. The activities at Yankee Rowe are still ongoing and the criteria we are trying to use for decommissioning tend to resist coming up with definitive criteria in the beginning. They would prefer to negotiate the process as it goes along. We have had a challenging time working with them and trying to agree on what would be the objective endpoints. The answer to your question is, yes, there are a number in Region 1.

DAUBER: Were the criteria for determining what would be the worst case determined by the facility owner, by NRC, or by whom?

BELLAMY: The criteria were generated by the Nuclear Regulatory Commission staff in Region 1. The responsible project manager and I, plus our headquarters staff (who give us the project and the program management guidelines) said, what is the worst-case scenario we can come up with that is somewhat realistic? I know that is a contradiction in terms, but that is what we headed for. So it was a Nuclear

Regulatory Commission, an agency-generated scenario I am not sure what area of the Aberdeen Proving Grounds you are from, but I should mention that Aberdeen is one of the sites on the decommissioning management plan that will be successfully removed from the list in the near future and we expect to renew their license after a public meeting that we will have to have down there Please attend and be my supporter in the audience So, congratulations to Aberdeen.

ANON: You talked about Shoreham as one of the utilities that was scheduled for decommissioning, did they meet your original time line? Second, are you aware of a user group, or any issues group, that has been established to effect the decommissioning of public utilities?

BELLAMY: The answer to your first question is, no There was no success whatsoever in meeting the time lines for any of these activities by nuclear power stations I am not aware of any utility user group. I know that there is an inter-agency task force that Ken Duvall is a member of, that is generating many decommissioning criteria, but I don't believe there are any utility activities in this area.

FIRST: Last Conference we went out to West Valley, do you have any comments on the clean-up of that facility?

BELLAMY: We are looking at West Valley as a fuel facility, it is in our fuel facility category I would say we are not so much concerned about the clean-up of that facility as using it for the manufacture of the waste that will be generated from the clean-up of other facilities. I am not involved in West Valley day-to-day, but I understand that we are getting closer and closer to commercial operation at that facility, although we are not there yet

ENGELMANN: Can you tell us something about the relative authority, the interrelationship of communications between EPA, NRC, and other federal agencies with regard to release criteria?

BELLAMY: As I indicated, there is an interagency task force that is looking on these activities as we speak. If you look at the preprint of my paper, you will note that there is a very long discussion on rule making. We have an enhanced participatory rule-making process which states that members of the public are welcome and expected to participate as we go along in the process, i e., the term is "enhanced". The proposal is to take the numerical criteria that I have just gone over, and replace them with a criterion that simply says "fifteen millirem per year to any member of the public", period. The Environmental Protection Agency has separate criteria that are in the same ballpark but they are not exactly the same. There are some high level discussions going on at the cabinet level and at the Commission level to try to work out these differences with the Environmental Protection Agency At the staff level, we work very closely with the Environmental Protection Agency and the Department of Energy on these sites. We will review any EPA documents that are generated They take our comments very seriously, they welcome our comments, and we are working hand-in-glove with them at the staff level on a number of sites The particular one that I can think of is the Metcoa-Pesses site near Pittsburgh, Pennsylvania.

INTRODUCTION

FIRST: Our next speaker is Dr. J Louis Kovach, President of NUCON International, Incorporated. Dr. Kovach is a chemical engineer who graduated from the Technical University in Hungary, his native country. This is Lou's seventeenth consecutive Air Cleaning Conference that he has attended. He tells me when he wants to remember how long he's been in the field of air and gas cleaning, he deducts seven from the current Air Cleaning Conference number, and multiplies by two, and that's how he knows how long he's been in the field. Those of you who have attended previous Conferences know that he has made a major contribution to the volumes of the Proceedings and we trust he will continue to do so. He has over a hundred papers in the field up to the present time. Currently he is on the High Level Waste Technical Advisory Panel for the Department of Energy. He is senior technical advisor of the Department of Energy's Hanford privatization initiative. And he is chairman of the Hanford Tank Waste Remediation Environmental Impact Statement preparation panel. He is a consultant for the US Department of Energy, US Environmental Protection Agency, and the US Nuclear Regulatory Commission. It seems like everybody wants a piece of Lou Kovach. We are delighted he is giving us one of the pieces this morning. The title of his paper is, “Challenges to Air and Gas Cleaning Systems”.

NEW CHALLENGES TO AIR/GAS CLEANING SYSTEMS

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The construction of new nuclear power reactors in the U.S has stopped now for over a decade Thus, the currently generated conventional air cleaning system technical information is generally restricted to evaluation of operational problems with the existing systems However, extensive nuclear waste management related needs have developed in the U S during this same period—mainly at DOE sites The waste management and site remediation related air and gas cleaning needs are much broader in scope than the control of radioiodine and low concentration aerosols, and the systems in current design or in application also have different processing conditions

The major difference is that many of the new air and gas cleaning needs are required to treat effluents continuously and under widely different processing conditions than those applied in the past for the nuclear power industry Even the systems which are postulated for handling gases under potential upset conditions have different design envelopes than the conventional nuclear power plant (NPP) air cleaning or air handling units.

The new, greatly varied processing conditions of waste management activities make it difficult to use the standardized designs developed by ANSI and ASME for the NPPs, and most of the current design specifications and codes are not directly applicable for the new applications The current conditions in the waste management and remediation activity are similar to the early days of the development of the NPP air cleaning systems in that their designs are highly individual and varied both by the specifiers, the designers and the manufacturers The result is a greatly varied quality non-standard equipment specification and supply At the same time, many of the application needs, but not all, are one of a kind systems, making the development and application of standard specifications and codes difficult and uneconomical

There is a change needed in the design and manufacturing philosophy from the relatively large number of identical purpose units to the highly individualized special purpose design and manufacturing philosophy For the new needs it is difficult to use the "cookbook" concept of such standards as ANSI/ASME N-509, ASME AG-1 or to follow the test requirements of ANSI/ASME N-510 or the currently developing Section TA of the ASME AG-1 code This does not mean that the old NPP related standards are useless, but that their usefulness is only partial and inadequate to solve the waste management needs

Examples of New Waste Management Related Problems

Radon control from uranium wastes

Uranium processing solids containing silos need to be degassed prior to further processing by vitrification or during the initial steps of vitrification While extensive information was developed for noble gas control (krypton and xenon isotopes) of the BWR off gas system or PWR gaseous radwaste system design and operation, there is very limited data available for the commensurate radon control design and operating conditions. The recent literature and data relating to home radon control or uranium mining purge control has not been extended to satisfy the design and operating requirements of the waste management type radon processing field.

Effluent treatment from thermal processing of various radioactive wastes at greatly varying temperatures and gas compositions

Most waste management related activity is initially from dilute solutions which require concentration as a first step. As an example, evaporator effluents need to be treated under high humidity, corrosive or, in some cases, flammable gas presence conditions. Another process effluent is from drying radioisotope loaded spent liquid phase adsorbents which require both high efficiency solid particulate and vapor phase removal of hazardous constituents from humid and potentially corrosive streams.

Off gas treatment for vitrification facilities which need product recycle, and in some cases, product recovery at very high concentration of volatiles and semivolatiles and particulates

The radioactive waste vitrification technology always includes the capture and treatment of volatile and semivolatile radioactive and other hazardous constituents. In some cases, the operating temperatures are high enough to vaporize large amounts of alkali metals and other waste constituents which need to be quenched, converted to filterable components and result in an off gas stream which can be above the lower flammability limits without additional dilution. There are special selective constituent removal needs for elements such as mercury, selenium, cadmium, ruthenium, etc.

Filtration from potentially flammable gas streams

In several waste storage complexes, the original complexant organic material used to separate specific isotopes in the past is thermoradiolytically decomposing with a commensurate generation of hydrogen. This thermoradiolysis of organic compounds in the stored waste creates concerns of flammable or explosive environment generation even under normal storage temperature conditions. The various wastes have different gas retention capability and intrusive activity or transfer of the waste can release sufficient volumes of flammable gas mixtures which can result in structural damage in waste storage tanks if ignited.

Filtration from highly corrosive gases

The waste processing technology generally includes dissolution steps involving concentrated acids or alkalis. The currently used glass fiber based filtration elements do not have sufficient corrosion resistance and the typical adsorbents used (e.g. carbon based) are unsafe in highly oxidizing environments. At the present time there is inadequate corrosion resistant filter or adsorbent material development and application data available to select material of construction or estimate filter/adsorbent life and performance information.

Filtration from gas streams which may have significant pressure challenges

As an example, at the Hanford site of the U S DOE, many of the potential consequences of off design conditions can result in unacceptable radioactivity release estimates, if the sudden pressure rise causes failure of the conventional HEPA filters Currently, a large percentage of the "unsafe" conditions could be eliminated from the safety analysis if the pressure resistance of the HEPA filters can be increased to prevent pressure spike related failure. There is also inadequate information available on the aging of conventional HEPA filter components, particularly under high humidity conditions, for which deterioration is not measurable by conventional in-place aerosol testing.

Back washable filter elements

The continuous processing of high particulate load streams does not permit the use of high efficiency filters which cannot be "regenerated" in place. The life of a conventional HEPA filter under many of the operating conditions is too short to permit economical and waste minimization satisfying requirements While there is some development of metal filter media, currently there is very limited information on the efficiency, life, regenerability etc., of these media and often fibrous metal and sintered metal filters are considered as equals in performance

Continuously operating demister elements

While in the NPP application area, demisters only have a very limited expected operating life In the continuous waste processing applications there is a requirement for droplet elimination as a continuous unit operation Even in the NPP field, one of the least understood components is the "moisture eliminator" element However, for waste processing application, the mist elimination component design and continuous operating technical data is not available

Adsorptive removal of varied constituents from air and gas streams

In the NPP applications, only radioiodine and noble gases are considered for gaseous phase treatment The waste management area is much broader, and specific adsorbents need to be developed, optimized and applied for other elements or compounds under more adverse environmental conditions than that of the NPP field Examples are mercury, ruthenium, iodine-129, etc

In-place testing highly contaminated systems

One of the major shortcomings of even the NPP related air and gas cleaning activity is the proof testing of highly contaminated components or systems (It is generally assumed that the event for the amelioration of which the "safety" train is installed will never occur, thus testing under those conditions would not be needed This misconception, as an example, created some interesting problems even after the TMI accident when highly contaminated air cleaning systems needed to be tested or serviced) However, in waste processing gaseous or particulate treatment systems, the air and gas cleaning components can be highly contaminated by either alpha, beta or gamma radiating components Many of these systems do not permit man entry into the air/gas treatment units on the contaminated side and, at times, not even on the "clean" side due to the radiation fields or other hazards present Most of the current in-place testing steps as described in the existing test procedures cannot be performed on highly contaminated or, as an example, flammable gas containing systems.

Maintainability under contaminated conditions

This is another area where even the NPP related currently available standards and codes fail to adequately address the design requirements. The consideration of replacement of most components of a contaminated air cleaning system are not included in the existing codes and standards. In the waste management field, the contamination of most air and gas processing systems, other than possibly the final building filtration units, is a forgone conclusion.

Waste minimization challenges for consumable components

In most cases, the disposal cost of contaminated air and gas cleaning components is higher than their initial new cost. At the same time, the least specified (if at all) of the properties of the filters or adsorbents used is their operating life or disposal cost. This is also true in the NPP field, where, as an example, radioiodine adsorbent is purchased solely on initial efficiency cost without any regard for adsorbent life.

It is intended that by describing examples of these new challenges that the standard preparers, designers and manufacturers will be better informed of the special needs of these new air cleaning/gas processing applications.

The major challenge is that all parties involved in the specification, design and operation of these systems will have to be better trained in the broader filtration, and other contaminant removal basic principles and less dependent on the set design and operation practice of the NPP related applications. There will be no time available to develop detailed consensus specifications or codes for components and systems for the waste management field, but there is time to assure that all those involved with the program have available additional training opportunities to satisfy the qualification needs, i.e. the chemical, physical and engineering principles required to comprehend the air and gas purification specification, design, construction and operation expertise.

Regulatory Concerns

The NPP related activity in the U.S. is regulated by the NRC, while the U.S. DOE sites are "self-regulated" with some oversight provided by the Defense Nuclear Facilities Safety Board (DNFSB). However, the impending privatization of some of the U.S. DOE activities postulates the integration of the NRC into the regulation of the waste management operations. The post-TMI new source term development in the U.S. has resulted in a lowered technical concern of air and gas cleaning activity by the NRC, while the administrative legalistic enforcement of Technical Specification or FSAR cited standards and codes has increased. Some of the "enforce the words," even if they are technically undefensible, has converted the regulation of the design, performance and testing of the NPP air cleaning systems into a "cargo cult" basis. This type of regulation will not suffice for the existing or the upcoming waste management area. There will be limited directly applicable standards and codes for the upcoming applications of air and gas cleaning systems and blind citing of standards and codes originally developed for other applications or of those which are outdated and, in many cases, withdrawn, that will not create a better or safer environment for the workers or the public Both the DOE and the NRC has to establish a pool of competent technical personnel who clearly understand the technical basis for the specification, design control and operation of the existing, or to be developed, components and systems which are needed for the safe operation of waste management facilities.

The technical qualifications and the basic engineering expertise of all personnel involved in air and gas processing research, specification preparation, design, construction, operation and regulation for the waste management field needs to be far better than that which existed for the relatively narrow NPP type applications, which itself lately suffered from inadequate technical expertise As John W Crawford, one of the DNFSB members, explicitly pointed out in one of his recent reports "An Assessment Concerning Safety at Defense Nuclear Facilities, The DOE Technical Personnel Problem,"(1) the root cause of all currently identified safety and operational problems is lack of adequate technical expertise of design, operation and regulatory personnel. While the Crawford report concerned itself mainly with the DOE, its conclusions are valid for the entire U S. nuclear industry whether public or private

Conclusions

The great variety of type and purpose of air and gas cleaning needs for radioactive waste management industry will require individual, special designs rather than many identical air/gas treatment systems. It would be very difficult to apply the existing codes and standards developed for the nuclear power plant environmental protection, as they exist, for this new application The design, construction and safe operation of the new systems will be strongly dependent on the good understanding of the commensurate filtration, adsorption and absorption science and the special needs of engineering knowhow relating to both the nuclear and the chemical processes involved. The very large and expensive, but mostly one or two of a kind systems, are not amenable to long duration consensus standardization. The challenge of still meeting the required protection factors or separation efficiencies of the air and gas cleaning systems, often with greatly different components than the conventional systems, will be dependent on the technical understanding of all of the relevant criteria by a limited pool of personnel involved from the design of the process to the regulation of the quality and performance of these systems

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(1) Crawford, Jr., J.W , "An assessment concerning safety at defense nuclear facilities, the DOE technical personnel problem," DNFSB/TECH-X, Vol iii, March 1996

DISCUSSION

FIRST: I appreciate your comments, warnings, and peering into the crystal ball. As you were talking about many of the technologies that you say we need, I was reminded of the fact that back in the 1950's and some part of the 60's, we were very much involved with the kinds of equipment that you cited. The particular application at that time was incineration. All of the problems that you enumerated, corrosion, heavy dust loadings, and so on, were all encountered in these situations. And you know we never solved the problems in 1960, therefore, we still have them with us today.

BERGMAN: A lot of comments you made ring true to many of the technical people who are familiar with the problems. For example, for the last three years, maybe even five, I have been going up and down the halls of the bureaucrats in the Department of Energy with a shopping list at least as long as yours with issues and problems, some of which are very severe. Almost invariably the response is, "we have not had a major accident". By an accident, they mean an entire city having to be evacuated, things of that nature. The philosophy is that if you don't have a major accident, you don't have to put money in. And it is a local issue. For example, it is like a stop sign, usually local communities do not install a stop sign or a street light until somebody is killed. After someone is killed they start to think, "we'd better do something about it". For example, in the HEPA filter area after the '69 Rocky Flats fire, there was a lot of money. The attitude right now from all of the bureaucrats I've encountered is that we are not going to spend any money on HEPA filters. In fact we're going to downsize. ES&H activities are slated for at least a thirty percent decrease. So, not only are we not keeping up, DOE in particular is going dramatically down. If there is no money, there are no opportunities to do any of the activities you suggest. I would appreciate your comments.

KOVACH: In some of these areas we are not doing anything either. So it is no wonder we do not have accidents. As long as we are only studying the problems rather than processing the wastes we are reasonably safe. Once we start waste processing, I am not sure we can do it without accidents.

WEBER: Dr. Bergman's comment and your response remind me of these issues every time I step on an airplane. I mean, the airplane hasn't fallen down, so why should we spend money maintaining it? That is a comment, not a question. As a comment, you mentioned a problem which was encountered with backwashing a metallic filter. I am totally unfamiliar with that particular installation. Over my involvement with backwash filters I've learned that for all manner of industries, including electric power generation, chemicals, liquids, gases, there are many, many parameters to bear in mind when installing a backwash-cleanable filter, including, but not limited to, the backwash-technique. This is because there are a myriad of backwash techniques. They include the cleaning fluid itself as you pointed out. There may be chemical interactions with the contaminant, and there are important waste disposal issues, i.e. you don't want to create more backwash waste than you started out with. I recommend that when someone is thinking of procuring such a system, that they make the vendor responsible to educate them and in those areas where they do not feel knowledgeable, that they seek out vendors who have the expertise to work with them to solve all the problems. Education can be acquired that way. So, seek out a vendor who is qualified, because if the vendor doesn't know the answer, you must question whether their system will work.

KOVACH: I agree that we all have the duty, not only the vendors, to learn at each step about the entire life cycle of the components that we are designing. When we deal with a back-washable filter, it is not enough just to say, "okay", we will just put water on it or spray a solution on it and it will be back-washed. Instead, we have to understand clearly the consequences of operating such a system.

INTRODUCTION

FIRST: Our next speaker is Dr. Dade Moeller, also a long-time attender at the Air Cleaning Conferences, and for many years a member of the Program Committee. He has taken a very active role in the conduct of the Conferences, and has made major contributions with his technical papers He is currently President of Dade Moeller and Associates, located at New Bern, North Carolina. He worked for the US Public Health Service as a commissioned officer from 1948 to 1966, with assignments that included Oak Ridge National Laboratory, Los Alamos National Laboratory, and the headquarters offices of the US Public Health Service in Washington, DC. From 1968 to 1983 he was Professor of Engineering and Environmental Health, and Chairman of the Department of Environmental Health Sciences at the Harvard School of Public Health. During those years, Dade and I worked very closely together, and it was a delightful experience for me. He is a first-class scientist and a wonderful person to work with. From 1983 to 1993 he became Associate Dean for Continuing Education at Harvard School of Public Health. It is interesting that Dade was a member of the Advisory Committee on Reactor Safeguards from 1973 to 1988, and for a number of those years was Chairman. I invited him to introduce our current chairman but he said their tenures did not overlap and he thought perhaps he didn't know quite enough about the speaker to undertake that assignment Dade is a certified health physicist and a diplomate of the American Academy of Environmental Engineers. He has received the distinguished achievement award of the Health Physics Society, and a meritorious achievement award from the US Nuclear Regulatory Commission in 1988. He is a member of the National Academy of Engineering, dating from 1978. He is author of a textbook, now going into its second edition, entitled Environmental Health. Dade has many more honors, but I'm taking up too much of his time, so I will stop at this point. It is a delight to have you here, Dade. The topic of his talk is, "Application of Innovative Policies for Controlling Radionuclide Releases: The 'Open-market Trading Rule'". I think you will find this a very interesting concept.

APPLICATION OF INNOVATIVE POLICIES FOR CONTROLLNG RADIONUCLIDE RELEASES: THE "OPEN-MARKET TRADING RULE"

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Abstract

In the past, most efforts for reducing airborne radionuclide releases and controlling radioactive wastes have been directed to the development of new and improved technologies. Little attention has been paid to the possible application to these problems of new, innovative policies. Yet, experience in other fields shows that such applications could be beneficial. A prime example is the "open-market trading rule," now being widely used in the U.S. for the control of a range of environmental problems. Through this rule, nuclear facility operators would be permitted to control airborne emissions in a more cost-effective manner, and those responsible for decommissioning and decontaminating nuclear facilities no longer in operation could do so at far lower costs while generating significantly smaller volumes of radioactive wastes. Application of such a policy would also significantly reduce the demands on existing, and the need for research to develop new, improved, control technologies.

I. Introduction

Most efforts for reducing airborne radionuclide releases from operating nuclear facilities have been directed to the development and application of new and improved technologies. This is also true in the case of the decommissioning and decontamination of commercial nuclear power plants and the cleanup of nuclear installations under the control of the U.S. Department of Energy (DOE), as well as in the management and disposal of the associated radioactive wastes. Little attention has been paid to the possible application of new, innovative policies. Yet, experience in other fields of environmental protection shows that the application of such policies might be beneficial. The purpose of this paper is to review one such policy that may prove useful, namely, the "open-market trading rule."

II. The "Open-Market Trading Rule"

Through the "open-market trading rule," the U.S. Environmental Protection Agency (EPA) permits an industry that is having a problem with excessive releases of a given toxic chemical either: (a) to spend whatever is required to reduce the releases; or (b) to "make room" for the releases either by purchasing and shutting down other industries discharging the same toxic chemical within the same geographic area, or by assisting other dischargers of the same pollutant in reducing the quantities of their releases.

One of the major benefits of this approach, sometimes called "emissions trading," is that it enables industrial and governmental organizations to control pollutants in the most cost-effective manner.(1) That is to say, if one company can control their releases of a given toxic agent at a lower cost than another, it is wiser for the second company to assist the first in its cleanup efforts than to spend more money in trying to reduce its own releases.

Initially, the "open-market trading rule" was applied solely to the control of a single toxic chemical within a single environmental medium. Under the Clean Air Act, for example, U.S. industries are permitted to optimize releases to the atmosphere based on mitigative technologies, thereby "trading" exposure rights.(2) In effect, this Act permits industries to buy and sell pollution rights and encourages one industry to assist another in reducing its airborne releases, if this can be accomplished at lesser costs. The same type of optimization is permitted under the Clean Water Act to control discharges to lakes and rivers. With the increasing success of this approach, however, its applications have been extended to broader arenas. For example, through an emission allowance program, the rule is being used to control airborne emissions that cause acid rain, thus providing opportunities for additional low-cost reductions of sulfur dioxide emissions. In fact, an allowance market for such emissions has been established by the Chicago Board of Trade.(3) The rule is also being applied to trade-offs in which industrial and community organizations have been given permission to create artificial wetlands to replace those that have been (or will be) destroyed by industrial and commercial development.

But the broadening of the applications of this rule has not stopped here. In recent months, still wider applications have been explored and implemented. EPA, for example, is now exploring trade-offs among different pollutants within the same medium (for example, trade-offs between releases of oxides of sulfur and oxides of nitrogen to the atmosphere), as well as trade-offs among several media, so called "cross-media" trading whereby releases of one or more pollutants to the atmosphere can be balanced against releases of other pollutants to the water environment.(4)

To exploit the benefits of this rule, EPA is proposing that it be applied on a generic basis and they are encouraging State and local agencies to create new, innovative programs for its application.(5) In fact, the EPA Assistant Administrator for Air and Radiation has stated that "EPA's experience with these trading programs, and with our own successful acid rain program, (has) led us to conclude that properly structured programs can reduce emissions earlier and cheaper than would otherwise be possible."(6) Dan W. Reicher, J.D., Chief of Staff, U.S. DOE, has also expressed interest and support for the concept. Concurrently, application of the "open-market trading rule" has received widespread endorsement from various independent "watchdog" agencies, such as the U.S. General Accounting Office.(7,8) In addition, the concept has been endorsed by a variety of other groups,(9,10) and it is being applied internationally as part of the worldwide efforts to reduce airborne emissions that could lead to global warming. One of the major benefits of this concept is that it requires that an integrated or systems approach be applied to the control of environmental releases of various pollutants.

III. Applications of the Concept to Nuclear Facilities

Although the applications cited above have proven extremely successful, it appears that the "open-market trading rule" would have even greater benefits in the control of airborne releases from operating nuclear facilities, in the cleanup of contaminated nuclear facilities, and in the control of associated wastes. These benefits, which are unique due to the origin of the radiation sources affecting typical population groups, include those of a technical and economic nature as well as public education and goodwill. Perhaps surpassing all of these benefits, however, is the fact that applications of the "open-market trading rule" to the control of environmental radiation exposures may prove to be exactly the vehicle needed to expedite the cleanup of decommissioned commercial nuclear power plants and various DOE facilities. It may also enable State and local regulatory groups and nuclear facility operators to ensure that financial resources for the control of radiation exposures are being directed to those sources that contribute the highest dose and can be controlled at least cost.

As an example, consider the operation of an existing nuclear facility or the cleanup of a facility that is no longer in operation. As in most such cases, the goal will be to assure that offsite population groups will not be exposed to radiation doses in excess of the applicable limits. The basic steps required in applying the rule to such a situation, and the benefits that would be accrued, are outlined below. As will be noted, in certain cases, application of the concept requires changing the ways in which exposures from such sources have been viewed in the past.

Basic Steps

1. As an initial step, there would be a need to assess the full range of radiation sources that affect nearby population groups. Such sources include natural background radiation, medical and dental uses, and consumer products, as well as contributions from the nuclear facility.

   The benefits of this exercise would be several. First of all, it would require all concerned parties, both within and outside the facility, to apply an holistic approach to the assessment and evaluation of the various radiation sources affecting nearby members of the public and stakeholders. Other benefits would be gained in terms of public education since it would reveal to nearby groups the major sources of their exposures. In essentially all cases, the nuclear facility would prove to be a minor contributor.

2. The next step would be to rank the various sources according to their relative contributions to the doses to offsite population groups. Once this had been done, the dose rates from each source would be compared to the relevant mandatory limits, where such limits exist. This would lead to the identification of those sources to which controls must be applied and the quantification of the degree of reduction that is necessary. It is only after these basic reductions in dose rates have been achieved that the "open-market trading rule" would be applied.

   For facilities being decommissioned and/or decontaminated, such an assessment would need to include the decision on whether the site on which the facility is located is to be released for unrestricted or restricted use -- with appropriate consideration of the degree to which this affects the amount by which the associated dose rates must be reduced. As a minimum, restoration efforts would probably need to be applied to the nuclear facility to reduce the accompanying dose rates to neighboring population groups to the long-term standard dose rate limit of 1 mSv (100 mrem) per year, as recommended by the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements,(11) and as required by the regulations of the U.S. Nuclear Regulatory Commission.(12) Under terms of the "open-market trading rule," additional cleanup of the facility would be required only if it were more cost-effective as compared to other sources affecting local population groups.

3. Subsequent to this step, each individual contributor (from both onsite and offsite sources) to the radiation dose rates to offsite population groups would need to be evaluated in terms of its feasibility for control, including a review of the applicable control technologies, associated costs, and potential societal impacts. On the basis of this evaluation, each source would then be ranked in terms of its priority for reduction and/or control.

   Following this approach, public health and regulatory agencies, as well as members of the public, would soon learn that, in many cases, it would be far more effective and less expensive to reduce exposures to offsite groups from indoor radon or medical sources, than to continue to pursue additional controls on airborne releases from operating facilities or to proceed with additional cleanup of a nuclear facility that is no longer operating. Studies have shown, for example, that reductions in exposures to indoor radon (and its decay products) can be accomplished at relatively low cost.(13,14) Other steps that could be taken include the installation of a more modern (reduced dose) mammography x-ray unit or an improved fluoroscopy screen in the local hospital, as well as encouraging wider scale application of newer techniques, such as endoscopy and colonoscopy, in place of x-ray fluoroscopy, as a primary means for conducting gastrointestinal examinations. Additional steps that might be considered include developing better controls for handling the excreta from medical patients to whom radiopharmaceuticals have been administered.

4. Once doses due to releases from the nuclear facility had been reduced to the basic mandatory standard, attention would be directed to the control of other sources for the required additional dose reductions, for example, down to perhaps 0.1 to 0.25 mSv (10 to 25 mrem) per year. As explained above, this would be accomplished by reducing those sources that can be reduced most effectively and at least cost.

Based on this information, a definitive plan of action for remediating the dose rates to the offsite population living in the neighborhood of the given facility would be proposed, taking into account the input of the facility operators, regulatory authorities, the local populace, and related stakeholders.

IV. Benefits of the "Open-Market Trading Rule"

There is a multitude of benefits that would be generated as a result of the application of the "open-market trading rule" to the cleanup of nuclear facilities.

Benefits

1. First and foremost, this rule would require the use of an integrated or systems approach in assessing and controlling radionuclide releases and associated radiation exposures. One of the immediate outcomes would be to provide significant latitude to State and local regulatory officials, as well as facility operators, in selecting which sources should be addressed to accomplish the required dose rate reductions.

    a. Having been provided this latitude, such officials and facility operators could direct their attention to sources, such as natural radiation background and medical radiation applications, which currently contribute over 95% of the total dose to the average member of the U.S. public.(15)

b. This would also permit regulatory officials and facility operators to direct their attention to those sources that can be most effectively controlled at least cost.

2. Another benefit would be significant reductions in the associated costs of nuclear facility operation and/or cleanup and the volumes of radioactive wastes being generated.

   a. Because of the reduced controls and cleanup required, there would be ancillary reductions in the demands on associated technologies.

   b. There would be similar reductions in the expenditures required for research on the development of new, improved technologies.

3. This approach would serve as an outstanding tool for educating the public on the relative importance of various radiation sources. In this regard:

   a. The procedures involved would offer unusual opportunities for involving and gaining the approval of offsite populations and stakeholders for programs proposed for the operation and cleanup of nuclear facilities.

   b. This approach would enable nuclear facility operators to demonstrate on a one-on-one basis their interest and concern for controlling dose rates to local population groups. In many cases, application of this approach would enable facility operators to reduce the dose rates to neighboring populations to levels less than they were prior to the original construction and operation of the facilities. This becomes possible, as noted above, because of the relatively high dose rates currently coming from medical and natural background sources, such as indoor radon, and the fact that many of these sources can be readily controlled.

4. Application of this rule would enable nuclear facility operators to begin now to reduce the dose rates to offsite population groups, not having to wait until all the environmental and associated administrative and regulatory requirements had been met.

5. It would provide a cushion in case the engineered barriers installed to control environmental releases did not perform as designed, or unanticipated failures occurred in various natural and engineered control systems. In such cases, facility operators could immediately apply additional controls to other radiation sources while awaiting corrections to be made in the controls being applied to the nuclear facility.

6. Application of this policy would enable State and local regulators to apply a risk-based approach to the cleanup of nuclear facilities. This has long been a major goal of the EPA, the U.S. Congress, and many State and local regulators.

7. A program such as this would provide a stimulus to the efforts of the EPA and various State and local environmental and public health groups to encourage the monitoring and control of exposures to members of the public from indoor radon. It would also provide a stimulus for increased assessment and evaluation of the radiation doses associated with medical procedures.

8. In the case of U.S. Federal nuclear facilities, such a program would provide a new and challenging mission for the DOE National Laboratories. These Laboratories represent a rich resource of scientists and engineers whose expertise would be extremely beneficial in evaluating, analyzing, and applying the concepts associated with such a program. Participation in such activities would bring them into the mainstream of DOE's environmental restoration program.

9. This approach would provide an initial step in the ultimate development of a system for making similar tradeoffs among the various human and environmental impacts of toxic chemicals and radiation sources. Here, again, the DOE National Laboratories could play a major role.

V. Commentary

As noted above, application of the "open-market trading rule" would offer a range of benefits to State and local officials and industrial organizations in their efforts to improve the control of airborne releases and the cleanup of nuclear facilities as well as to apply a risk-based approach to associated decision-making.

In addition, it appears that application of such a rule would be entirely consistent with directives issued by the President. Under Executive Order 12866, all Federal agencies, including DOE, are required, in setting regulatory priorities, to "consider, to the extent reasonable, the degree and nature of the risks posed by various substances or activities within its jurisdiction," and to "design their regulations in the most cost-effective manner to achieve the regulatory objectives.(16) In doing so, each agency shall consider incentives for innovation, consistency, predictability, the costs of enforcement and compliance (to the government, regulated entities, and the public), flexibility, distributive impacts, and equity," and "each agency shall indentify and assess alternative forms of regulation and shall, to the extent feasible, specify performance objectives, rather than specifying the behavior or manner of compliance that regulated entities must adopt."

What is needed is the conduct of several pilot studies to demonstrate the feasibility of the concept through its application to one or more nuclear facilities. In terms of the commercial nuclear utilities, such studies might be directed to several of the plants for which decommissioning operations are underway or contemplated. In terms of DOE, such studies might be directed to the control of radionuclide releases from one or more operating faciities or to the cleanup of sites such as Hanford, Idaho Falls, and West Valley. Although application of this approach might not prove viable for the control of facilities in which the principal radionuclide contaminants (for example, ^{239}Pu) are extremely long-lived, it would be directly applicable to the control of doses from facilities in which shorter-lived radionuclides, such as ^{3}H, ^{60}Co, ^{90}Sr, and ^{137}Cs, play dominant roles. For many facilities, this is the case.

Once these studies have been completed, the resulting reports and analyses could be submitted to the National Academy of Sciences/National Research Council for review and evaluation. Assuming that such a review would result in their endorsement, Federal, State and local regulatory agencies and plant operators would be armed with a powerful tool for the more effective control of radiation doses to offsite population groups. They would also be provided with a vehicle that would enable them to move ahead with the cleanup of the vast array of Federal nuclear facilities now awaiting action. Proving success in the radiation arena could well lead to more widespread applications of the concept. Such applications might ultimately include trade offs in exposures derived from combinations of radioactive materials and toxic chemicals.

Application of the "open-market trading rule" to the control of doses to offsite populations from nuclear facilities would represent professional environmental and public health practices at their best. This approach would also serve as a superb tool for educating the U.S. public in gaining a better understanding of the relative significance of various radiation sources in their everyday lives.

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DISCUSSION

FIRST: I was wondering about the aspect of not requiring reductions by nuclear facilities as an offset How do you reconcile that with the ALARA principle?

MOELLER: I have no problem whatsoever reconciling it, because I am practicing ALARA at the highest level. This is more ALARA than any nuclear facility ever thought of, because I am looking at all sources. I am saving money, that's ALARA.

FIRST: But the reality is that the regulation applies only to nuclear facilities.

MOELLER: Correct. And that is where we obviously need to make some changes. But I think we would have very little difficulty making these changes because of the support of the concept by the congress, by all of the federal agencies, and so forth I don't mean to be flippant, but I really think that once people understand it, we will have no problems. Obviously it is going to take education of the public, the technical community, and our politicians.

FIRST: Do you think it is possible to educate the public? Look what has happened over the past fifty years with regard to trying to educate the public, not only with nuclear power, but also sanitary landfills, incinerators, and Olestra, the latest on the hit list. What gives you hope?

MOELLER: What gives me hope is the following example. At a public meeting around the XYZ Nuclear Facility, I would say all of you are taxpayers. For fifty dollars per person, (or five hundred or whatever the number is), I can reduce your dose fifty millirems a year. Would you rather have me do that by controlling something in your personal environment, radon, medical x-rays, consumer products that you use or would you rather control the same amount of dose within this nuclear facility at a cost of a million dollars per person. I think if that approach is used often enough, we will prevail, I am an optimist. I know it is going to be difficult, but if there is ever to be any hope of educating the public about the risk associated with various sources of ionizing radiation, this policy may provide a vehicle. And at the moment it seems to me to be one of our best vehicles.

DAUBER: Do you think we will have to have a congressional or a bureaucratic implementation of this principle to make it work, or can simply education do the job?

MOELLER: I believe we already have much of what we need. As I mentioned, the Chief of Staff of DOE is for it, the top people in EPA are for it. In fact they've spoken out, and have written on it. Congress is for it. I am not a lawyer or even a legislative authority, but I can see no obstacles to it if we can get the right people to get going What is needed, immediately, is to conduct a pilot study at Hanford, at Idaho Falls, West Valley, at Oak Ridge. We need a few pilot studies. Once they have been completed the results should be submitted to the National Research Council for an independent review.

SESSION 2

WASTE MANAGEMENT

Monday July 15, 1996
Co-Chairmen: R.R. Bellamy
J.G. Wilhelm

RADIOACTIVE WASTE TANK VENTILATION SYSTEM INCORPORATING TRITIUM CONTROL
P.D. Rice

DEVELOPMENT OF A COMPUTER CODE TO PREDICT A VENTILATION REQUIREMENT FOR AN UNDERGROUND RADIOACTIVE WASTE STORAGE TANK
Y.J. Lee and E.L. Dalpiaz

TESTING CLEANABLE/REUSABLE HEPA PREFILTERS FOR MIXED WASTE INCINERATOR AIR POLLUTION CONTROL SYSTEMS
D. B. Burns, A. Wong, B.W. Walker, and J.D. Paul

DEVELOPMENT OF AN AIR CLEANING SYSTEM FOR DISSOLVING HIGH EXPLOSIVES FROM NUCLEAR WAR HEADS
W. Bergman, K. Wilson, K. Stagges, D. Beason, S. Doughty, R. Arganbright, D. Wapman, and G. Nelson

A THICK HOMOGENEOUS VEGETATED COVER DESIGN PROVES COST- AND SCHEDULE-EFFECTIVE FOR THE RECLAMATION OF URANIUM MILL SITES NEAR SPOKANE, WASHINGTON
J. Blacklaw, G. Robertson, D. Stoffel, J. Ahmad, E. Fordham, S. Pachernegg, L. Wainhouse, and J. Riley

RADIOACTIVE WASTE TANK VENTILATION SYSTEM INCORPORATING TRITIUM CONTROL

Paul D. Rice, P.E.
ICF Kaiser Hanford Company
Richland, Washington 99352

Abstract

This paper describes the development of a ventilation system for radioactive waste tanks at the U.S. Department of Energy's (DOE) Hanford Site in Richland, Washington. The unique design of the system is aimed at cost-effective control of tritiated water vapor.

The system includes recirculation ventilation and cooling for each tank in the facility and a central exhaust air clean-up train that includes a low-temperature vapor condenser and high-efficiency mist eliminator (HEME). A one-seventh scale pilot plant was built and tested to verify predicted performance of the low-temperature tritium removal system. Tests were conducted to determine the effectiveness of the removal of condensible vapor and soluble and insoluble aerosols and to estimate the operating life of the mist eliminator. Definitive design of the ventilation system relied heavily on the test data.

The unique design features of the ventilation system will result in far less release of tritium to the atmosphere than from conventional high-volume dilution systems and will greatly reduce operating costs. NESHAPs and TAPs NOC applications have been approved, and field construction is nearly complete. Start-up is scheduled for late 1996.

Introduction

Safe storage of radioactive waste resulting from reprocessing nuclear reactor spent fuel can be a special challenge when large amounts of tritium are present. High tritium concentrations have been a concern at the Aging Waste Tank Farm (AWTF) at the Hanford Site in Richland, Washington. The AWTF is a complex of four 3800-m^3 (1,000,000-gallon) underground double-shell tanks (DST) identified as 241-AY-101 and -102, and 241-AZ -101 and -102. Although the aging waste volume is small compared to the total waste in the 177 underground tanks at Hanford, its activity level is high. The AWTF tanks have the potential to operate at significantly higher temperatures and can generate large quantities of tritiated water vapor at the waste surface as a natural consequence of heat and mass transfer to the ventilation flow through the tank head space. The ventilation system design for heat removal alone presents no great challenge. The fact that tritium is present changes the entire direction of the design.

Background

In 1986 a conceptual design was begun by Kaiser Engineers Hanford (KEH; renamed ICF Kaiser Hanford Company in 1994) to upgrade the AWTF facility (then operated by Rockwell Hanford Operations) to current codes and standards, to achieve compliance with new environmental release criteria, and to handle unusually high heat from future fuel reprocessing campaigns.

The design criteria imposed on the project greatly restricted allowable radionuclide concentrations in the ventilation system exhaust stack and also identified deficiencies in the existing system. In particular, the HEPA filters had lifetimes that varied from two days to two years, depending on waste processing operations.

The initial conceptual design of the new system included two stages of HEPA filters to control (primarily) strontium, cesium, and plutonium particulate, and a refrigerated wet scrubber to control tritium, ruthenium, and other condensible vapors and to protect the HEPA filters from various soluble compounds such as ammonium salts.

The search for an effective wet scrubber that was practical to maintain in a radioactive mixed waste environment led to a rather novel device, patterned after a submerged gravel scrubber (SGS). The SGS had been developed by Westinghouse Hanford Company (WHC) as a passive venting system for nuclear reactor containment during accident conditions. The device designed by KEH incorporated ceramic balls, rather than gravel, and added a cooling system and a high-efficiency pad-type mist eliminator. See Figure 1.

Two stages of cooling with a total capacity of 4.4 MW (15 million Btu/h) were incorporated in the ventilation system design. The first stage incorporated shell-and-tube heat exchangers with evaporative cooling towers to take efficient advantage of the high-temperature process-ventilation air stream. The second stage of cooling was accomplished with a refrigerated heat exchanger in connection with the scrubber spray system.

Kaiser Engineers recommended that funds be allocated for construction and testing of a prototype scrubber to verify the calculated performance of the proposed system. The services of Pacific Northwest Laboratories (PNL) at Hanford were requested to construct and test the prototype.

By chance, PNL had recently completed a series of tests of a scale SGS in combination with a high-efficiency mist eliminator (HEME) as part of a development program for a waste vitrification melter off-gas ventilation system. PNL's tests revealed that operation of the SGS resulted in a large mist carryover fraction, which drove the use of the HEME in the design. Since the HEME also collected submicron particulate, PNL recommended incorporation of the HEME into KEH's scrubber system to extend the life of the HEPA filters. PNL also suggested that a shell-and-tube heat exchanger be substituted for the SGS and still accomplish the desired end results, using off-the-shelf equipment. The goal was to remove a high percentage of condensible vapors and to enhance HEPA filter protection by removing a wide range of soluble and insoluble particulate.

The "new" scrubber design proposed for testing is shown in Figure 2. It was agreed that a pilot plant based on this configuration should be built and tested. Appropriate program and test plans were prepared by PNL, while KEH procured the needed refrigeration equipment for the pilot plant. The completed pilot plant was ready for testing in 1988.

Off-Gas Characterization

In support of the PNL test program, the Hanford operations contractor, WHC, performed characterization tests of the AWTF off gas. These tests (Powell 1989) determined particle size, mass concentration, and chemical composition of the off-gas aerosol. The sample data was intended for PNL's use in selecting test aerosols for the pilot plant experiments.

The sample port in the AWTF existing ventilation system was located to approximate the conditions expected just upstream of the proposed scrubber system. The point selected was downstream of existing raw-water-cooled condensers, similar to a location between the two stages of cooling proposed in the new system. An off-gas temperature of approximately 38°C (100°F) was typical at this point.

Test results showed that the temperature of the saturated off gas leaving the condensers affected mass and beta emission concentration (principally Cs 137) in the gas stream. As the vapor outlet temperature of the condensers increased, the mass concentration in the off gas increased. Mass concentration varied from 0.9 to 64.8 $\mu g/m^3$, averaging 16.5 $\mu g/m^3$. Beta concentration increased with increasing condenser outlet temperature, varying between 507 and 2935 pCi/m^3. Gamma concentration in the off gas varied between 408 and 1294 pCi/m^3 Cs137, but had no apparent correlation to condenser off-gas temperature.

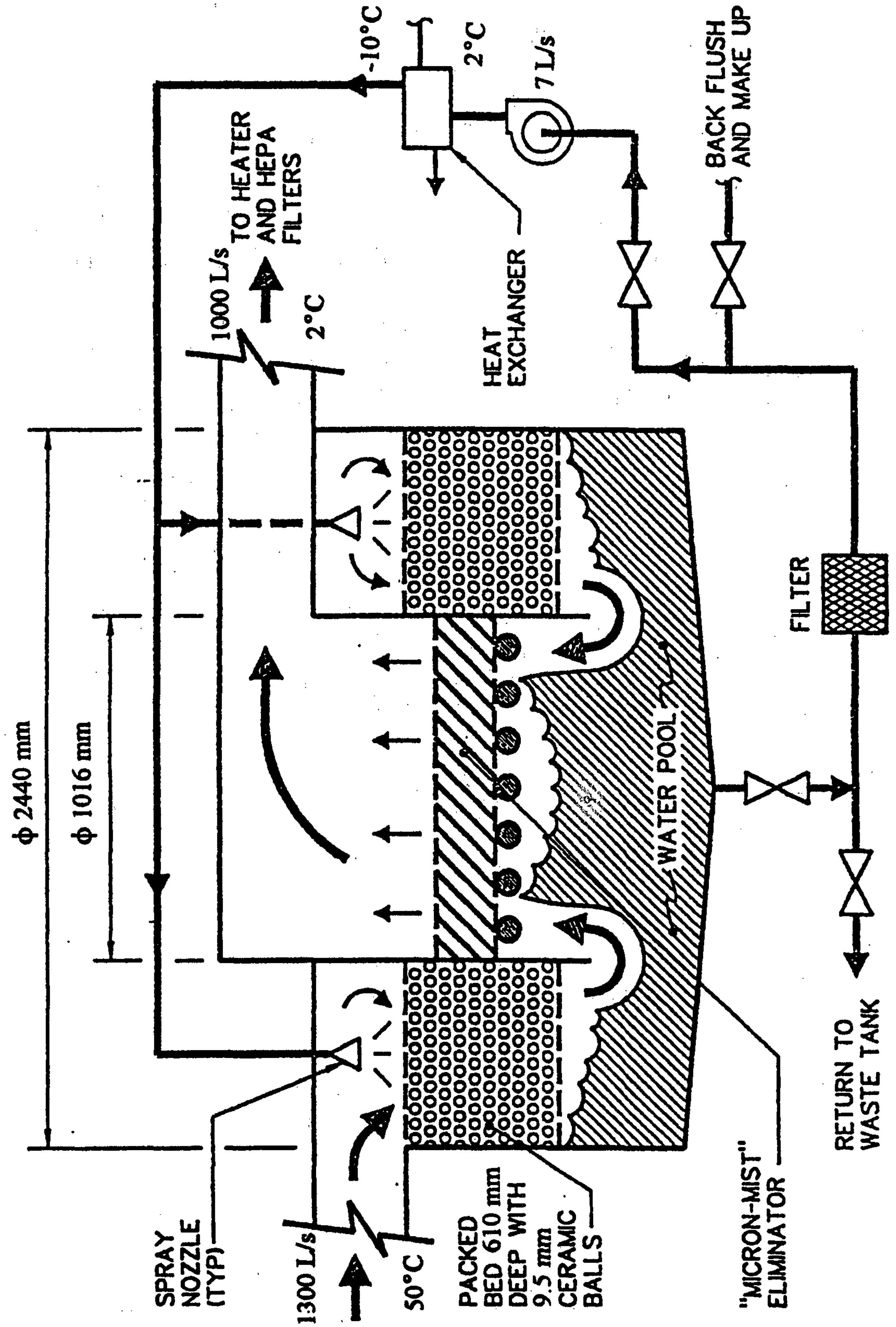

Figure 1 Scrubber/deentrainer/filter.

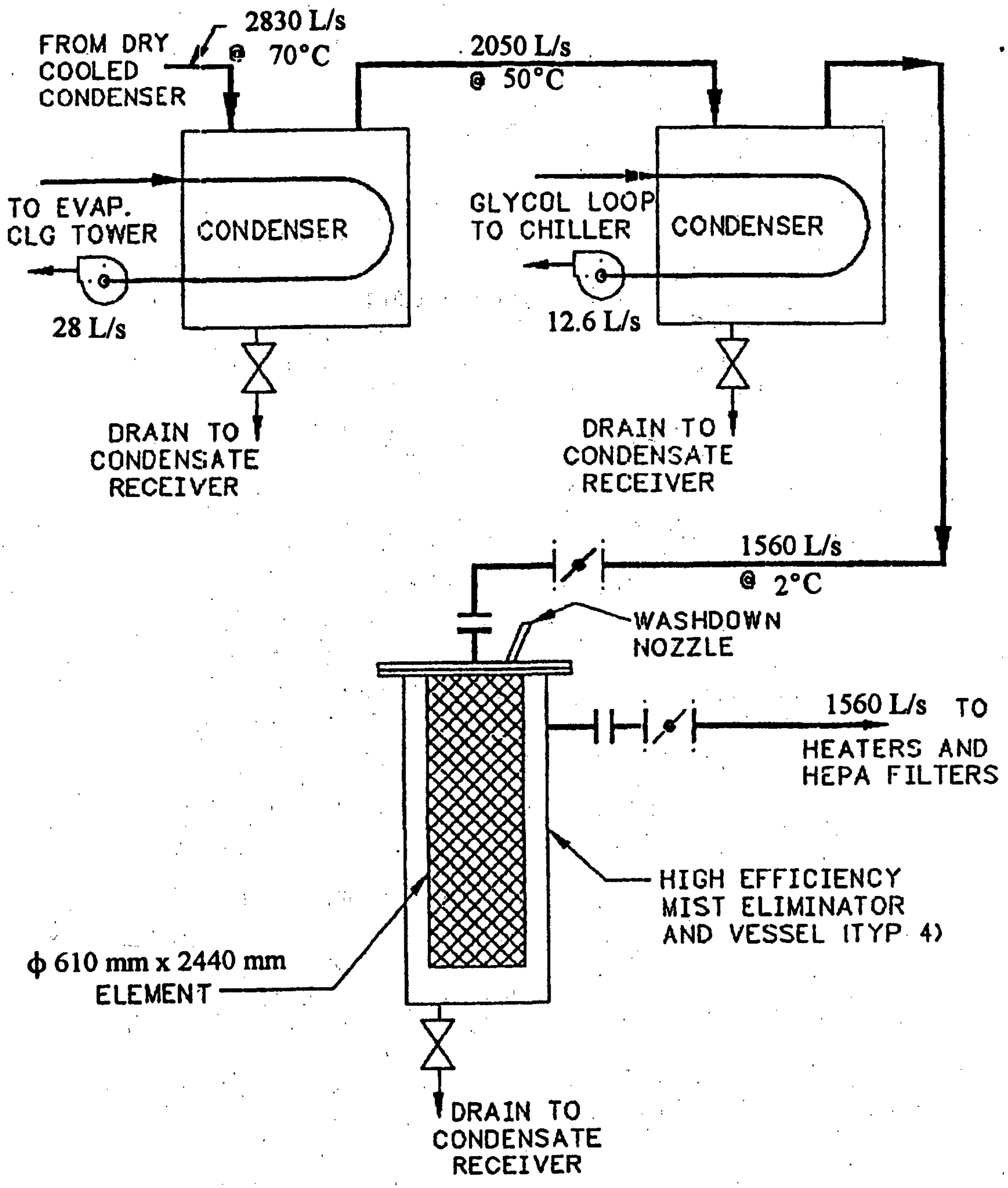

Figure 2 Primary vent scrubber.

The off-gas stream was found to have two separate mass size distributions (bimodal). Both mass and beta activity readings confirmed that the bimodal size distribution existed. Most of the mass loading and beta/gamma activity was concentrated in the smaller aerodynamic diameter size range of 0.4 to 0.05 μm. The average mass mean aerodynamic diameter (MMAD) of the particulate in the gas stream was 0.073μm. The beta mean aerodynamic diameter (BMAD) of particulate containing beta activity was 0.084 μm. The established mean of the larger diameter mass and beta distribution was about 2 μm. Statistical analysis indicated that the mean particle size was a function of the temperature of the off gas and location of the sample point in the duct. The larger particulate size distribution was found in the high velocity center of the off-gas duct at higher off-gas temperatures.

Experimental Apparatus

A pilot-scale scrubber for a DST ventilation system, shown in Figure 3, was fabricated, installed, and tested at PNL (Brouns and Peterson 1989). Table 1 contains the key for the symbols used in Figure 3. Ambient air is pulled into the inlet through a HEPA filter by an off-gas blower. Aerosols are injected into the line to simulate test conditions. Steam can be injected into the aerosol-containing air stream through a metered injection port to adjust the absolute humidity. The stream then passes through a heat exchanger that is used to adjust the relative humidity and temperature. The simulated off gas then passes through the primary components of the pilot-scale system--the refrigerated condenser and the HEME--and then out through the off-gas blower. Temperature, pressure, and flow rate sensors are mounted throughout the test system to monitor, adjust, and record operating parameters. The system was designed to allow for simulation of a variety of conditions expected in a full-scale ventilation system. The individual components in the pilot-scale ventilation system are described in the following sections.

Aerosol Generation

Aerosols were produced by Virtis® SG-40 aerosol generators. This apparatus uses a Laskin-type nozzle that shears a liquid solution with sparged air to create a liquid aerosol. Air at 140 kPa (20 psi) was provided to generate the aerosols. Soluble aerosols were produced from a NaCl or NH_4NO_3 solution. Insoluble aerosols were produced from a suspension of TiO_2 in water. Mixed soluble-insoluble tests were conducted by means of two aerosol generators, one for soluble NH_4NO_3 and the other for insoluble TiO_2. Each generator was adjusted separately to obtain the desired aerosol production rate. Aerosol sizes in the 0.05- to 25-μm size range were measured.

Process Gas Line Heater or Cooler

The incoming process gas stream could be heated above or cooled below the ambient temperature with the heater or cooler. The stainless steel shell and tube heat exchanger used either 200 kPa (30-psig) steam or process water. The process gas temperatures that were used in testing ranged from 16° to 66°C (60° to 150°F).

High-Efficiency Mist Eliminator

The HEME unit, shown in Figure 4, is a mist eliminator designed to eliminate submicron particles from the process gas stream. The process gas enters the top and center of the HEME and then passes through a cylindrical filter (Flexifiber® type BD-PFF) consisting of approximately 80 mm of 8- to 10-μm-diameter glass fibers. The filter captures aerosol particles by impaction and by Brownian diffusion. A water-spray full-cone nozzle positioned above the filter sprays directly at the filter and can be used to wash the filter free of captured particles. Wash solution and mist removed from the off-gas stream are collected and metered via a dip leg connected to the bottom of the HEME. This collection rate is monitored and is necessary for material balance calculations.

Process Gas Chiller

The process gas chiller consists of an air/glycol condenser coupled to a glycol/refrigerant heat removal system. The air/glycol condenser is a four-pass shell-and-tube heat exchanger, with the process gas passing through the shell side of the exchanger and the water-glycol mixture passing through the tube side. A refrigerant evaporator cools the 50 wt% water-glycol mixture, which is maintained at -1°C (30°F) to +2°C (35°F) in a storage tank. A three-way splitter valve (V8) is adjusted to maintain the temperature of the process gas stream leaving the condenser. The three-way valve is manipulated by a pneumatic actuator tied to a set-point temperature controller.

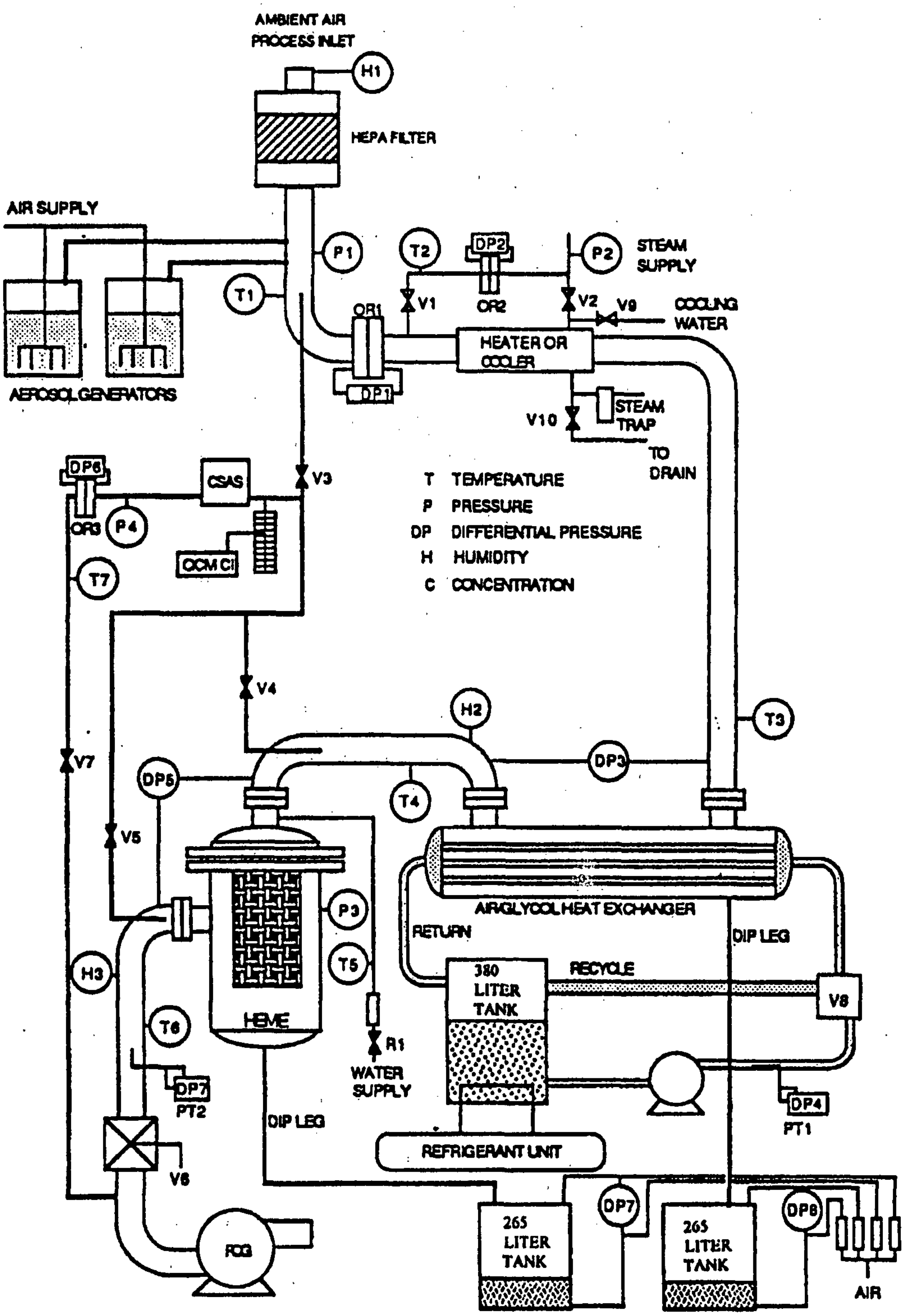

Figure 3 Schematic of the pilot-scale scrubber
(from Brouns and Peterson 1989).

Table 1 Equipment descriptions.

ID Number	Description
CSAS	Classical scattering aerosol spectrometer
QCM CI	Quartz crystal microbalance cascade impactor
TI-T7	Type K thermocouples - temperature
H1	Hygrometer - ambient air dewpoint
P1	Barometer - ambient pressure
P2	Pressure gauge - steam pressure
P3	Differential pressure transducer - HEME operating pressure
P4	Differential pressure transducer - CSAS operating pressure
OR1	Orifice plate (102 mm) - inlet flow rate
OR2	Orifice plate (13 mm) - injection steam flow rate
OR3	Orifice plate (25 mm) - CSAS flow rate
PT1	Pitot tube - water/glycol coolant flow rate
PT2	Pitot tube - HEME outlet flow rate
DP1	Differential pressure transducer - OR1
DP2	Differential pressure transducer - OR2
DP3	Differential pressure transducer - heat exchanger pressure drop
DP4	Differential pressure transducer - PT1
DP5	Differential pressure transducer - HEME pressure drop
DP6	Differential pressure transducer - OR3
DP7	Differential pressure transducer - HEME condensate level
DP8	Differential pressure transducer - HX condensate level
V1	Regulating valve - steam injection control
V2	Regulating valve - steam heater control
V3	Ball valve - inlet aerosol sample manifold
V4	Ball valve - HEME inlet aerosol sample manifold
V5	Ball valve - HEME outlet aerosol sample manifold
V6	Control valve (102 mm) - system air flow control
V7	Regulating valve - CSAS sample flow control
V8	Diverter control valve - process gas temperature control
V9	Regulating valve - water cooler control
V10	Diverter valve - cooling water drain
R1	Flowmeter and control valve - HEME water spray
POG	Primary off-gas system blower

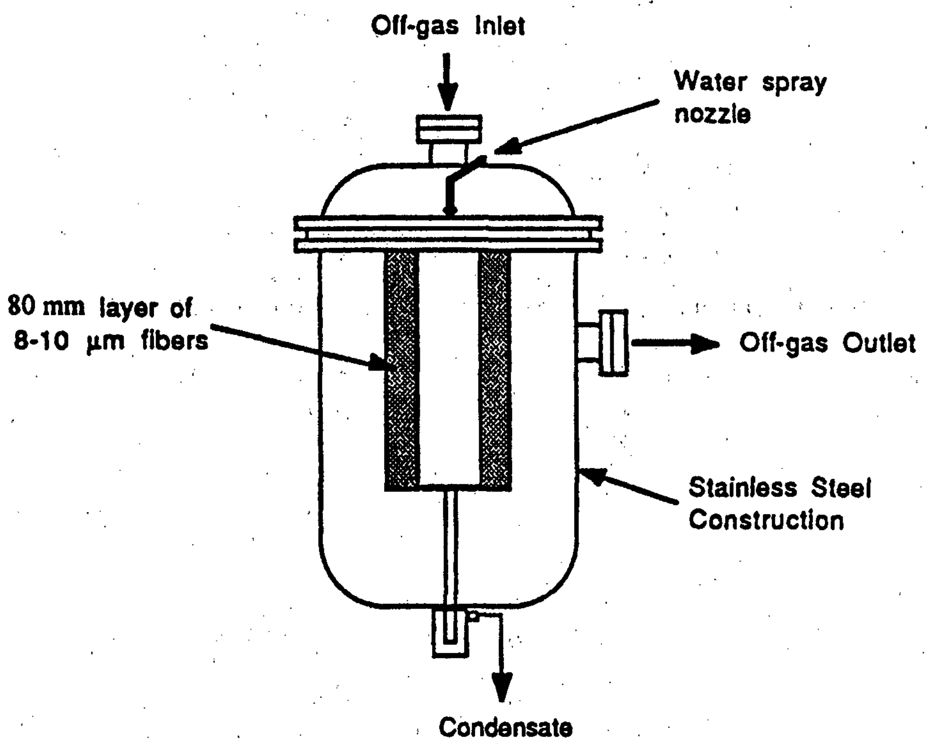

Figure 4 Schematic of the high-efficiency mist eliminator.

With this system, it is possible to cool 70 L/s (150 acfm) of saturated air at 38°C (100°F) to 2°C (35°F), saturated. Condensate from the condenser was collected and monitored by means of a dip leg arrangement similar to that described above for the HEME.

Condensate Collection System

The water collection system consists of two steel tanks to contain condensate from the condenser and HEME. Dip legs from the condenser and HEME terminate several inches above the bottom of each tank. Instrument air is purged through tubing to the top and bottom of each tank. Rotameters are used to set and adjust the purged air flow rate. Differential pressure transducers are connected between the top and bottom air lines to measure the liquid head in each tank.

Classical Scattering Aerosol Spectrometer/Sampling Manifold

The classical scattering aerosol spectrometer (CSAS) system uses light-scattering theory to measure aerosol particle diameters. A classical He-Ne laser tube is used to create a light beam that is passed through windows mounted on the side of the sample tube. The process gas is drawn through the sample tube, and any entrained aerosols will scatter the light beam. The energy of the pulse of scattered light is proportional to the size of the aerosol that scattered the light; thus, the CSAS can count the number of aerosols passing through the beam and determine the aerosol "optical" or equivalent geometric size distribution. The instrument was calibrated for aerosols in the 0.32 to 0.755-µm size range; therefore, aerosols below 0.32 µm or above 0.755 µm were not measured by the CSAS. The sampling manifold allowed for samples to be drawn from three locations in the system. By appropriate valve switching, samples were taken and analyzed from the inlet to the system, from the entrance to the HEME, and from the exit from the HEME. In general, results of aerosol sampling are expected to be quite accurate for particles smaller than 3 µm and inaccurate for larger particles. Aerosol data from each sample port were used to determine the efficiency and the DF for the heat exchanger, the HEME, and the overall system. It was necessary to maintain the temperature of the gas flowing through the sampling chamber above saturation in order to avoid condensation on the optics of the CSAS. Data were not collected when sample lines were at a temperature lower than that of the process gas.

Quartz Crystal Microbalance Cascade Impactor

In addition to the CSAS, a quartz microbalance cascade impactor (QCM CI) was used to measure aerosol particle size distribution and concentration. While the CSAS measures a particle number distribution, the QCM CI measures a mass concentration distribution. Use of the QCM CI in series with the CSAS allowed comparison between the two methods and obtained data that could be compared directly to field data.

The QCM CI pulls process gas from the CSAS sampling manifold through an isokinetic sampling probe into the sensing stack, which comprises 10 impactor stages. Particles of sufficient size and mass strike a piezoelectric crystal microbalance (PCM) present on each stage of the impactor. Smaller particles escape impaction on the first stages but are captured later as the velocity of the process gas is increased through smaller orifices. The sensing stack segregates particles into ten 50%-efficiency cut-off sizes (Dp50) between aerodynamic diameters of 25 and 0.05 μm. With an assumed particle density of 2 g/mL, the Dp50s are shown in Table 2. The impacted particles on each stage result in a change in frequency of the quartz crystal that is proportional to the mass of particles collected. Because the QCM CI measures particle size distribution over a wider size range than the CSAS, it is better suited to broadly distributed aerosols. The CSAS is more precise in a narrower distribution but inaccurate for broadly distributed aerosols.

Table 2 QCM CI 50% cut-off sizes.

Stage	Dp50, μm
1	25.00
2	12.50
3	6.40
4	3.20
5	1.60
6	0.80
7	0.40
8	0.20
9	0.10
10	0.05

Data Acquisition System

The data acquisition system consists of a Hewlett-Packard 9000/200 computer system interfaced to a Fluke 2240B data logger, a Validyne SPM 380 digital scanning panel meter, and the CSAS. All temperature measurements were provided by Type K thermocouples interfaced to the Fluke logger. Flow rates were measured by means of orifice plates and pitot tubes with all pressure drops, and all operating pressure measurements were determined with Validyne pressure transducers interfaced to the Validyne panel meter. Temperatures, pressure drops, flow rates, and aerosol size and count in each of the 15 channels of the CSAS were collected by the HP 9000/200 computer system and stored on its hard disc. QCM CI measurements were printed on thermal paper, referenced in the laboratory record book, and stored for later analysis.

Experimental Test Results

Condensible Vapor Removal

The pilot-scale ventilation system effectively removed 100% of the water that theoretically could be condensed with a saturated stream at the HEME outlet conditions. Condensed water not collected by the condenser was removed by the HEME. When the flow rate was at the high test level (70 L/s or 150 scfm) and the absolute humidity was high, condensate was collected by the condenser. At the low humidity, the condensate was carried to the HEME before collection. At the low test flow rate of 38 L/s (80 scfm), condensate was collected by the condenser at all absolute humidities. The condenser was operated with a coolant temperature of 2° to 3°C (35° to 37°F). Lower temperatures resulted in ice formation and a subsequent decrease in the heat transfer coefficient.

Soluble Aerosol Removal

Removal of sodium chloride (NACl) and ammonium nitrate (NH_4NO_3) soluble aerosols occurred in both the condenser and the HEME. At high absolute humidity (0.07 to 0.08 kg H_2O/kg air), condenser DFs ranged from 3 to 16 with a feed concentration of 30 to 51 $\mu g/m^3$. Condenser DFs generally increased with the off-gas flow rate. At a lower absolute humidity, condenser DFs ranged from 1 to 2, and decontamination was primarily controlled by the HEME. System DFs for soluble NH_4NO_3 aerosols based on total mass concentrations were between 5.8 and 37 with an average of 19. System DFs averaged 18 for NH_4NO_3 aerosols in the 0.05- to 0.1- μm size range and 7.1 for aerosols in the 1.6- to 3.2- μm size range at an inlet concentration of 120 $\mu g/m^3$.

Insoluble Aerosol Removal

Removal of insoluble titanium dioxide (TiO_2) aerosols was controlled primarily by the HEME and appeared to be affected by the aerosol concentration. HEME DFs for insoluble aerosols averaged 5.9 at an inlet concentration of 68 $\mu g/m^3$. At a higher inlet concentration of 188 $\mu g/m^3$, the average HEME DF increased to 25. An average system DF of 13 was obtained during tests with a system inlet concentration of 153 $\mu g/m^3$ and a HEME inlet concentration of 68 $\mu g/m^3$. System DFs averaged 22 for TiO_2 aerosols in the 0.05- to 0.1- μm size range and 12 for aerosols in the 1.6- to 3.2-μm size range at an inlet concentration of 153 $\mu g/m^3$.

HEME Life Expectancy

HEME life expectancy tests with soluble, insoluble, and mixed soluble-insoluble aerosols resulted in an increase in pressure drop of less than 15% over the 30-day test periods. The results of the mixed soluble-insoluble aerosol test indicated that increase in the pressure drop through the HEME of less than 8% was achieved with a system inlet concentration of 537 $\mu g/m^3$. Based on these results, an estimated average full-scale aerosol concentration of 16.5 $\mu g/m^3$, and similar operating conditions (i.e., HEME face velocity of 122 mm/s to 244 mm/s [0.4 to 0.8 ft/sec], and >80% RH), we conclude that the HEME will operate for more than 900 days ((537/16.5)(30 days)) without an appreciable (>15%) increase in the pressure drop. Water spray was effective at washing soluble aerosols from the HEME filter and partially effective at washing insoluble aerosols. Intermittent washing of the HEME filter with a water spray would be beneficial in removing collected aerosol and regenerating the filter, especially during periods of low absolute humidity. A spray flow rate of 10 L/(h·m^2) (0.25 gph/ft^2) filter surface was effective during testing.

The detailed report of the pilot-plant experiment was published by PNL in December 1989, in time for use by KEH in definitive design of the AWTF ventilation system.

Recirculation Ventilation Concept

Definitive design of the new AWTF ventilation system (Project W-030) was approved to start in 1989. However, changes in the project scope had occurred since the original conceptual design, creating growth in the project cost estimate. The scope changes were related to changes in the Hanford mission, closure of the PUREX spent fuel reprocessing facility, interfaces with other projects, and previously hidden problems in the existing AWTF ventilation system.

A Value Engineering team was assigned to investigate methods of cutting costs. One major outcome of the investigation was the recommendation by KEH that a detailed study of a recirculation ventilation and cooling concept be performed. An engineering report (KEH 1992) comparing three alternative recirculation schemes was completed in 1992. All three schemes resulted in cost savings, mainly from the reduction in size of facilities required to house smaller equipment in a recirculation ventilation system. The report recommended a tank farm ventilation system that incorporated a small central ventilation exhaust system with individual air recirculation loops to cool each tank.

The proposed central ventilation exhaust system was sized for a 190- to 480-L/s (400- to 1000-scfm) flow rate and allowed a minimum ventilation flow of 50 L/s (100 scfm) for each of four tanks for gas dilution and pressure control. The additional 280 L/s (600 scfm) capacity provided operational flexibility for existing airlift circulator (waste mixing) operation or additional inleakage if desired. Each tank ventilation system recirculated and cooled an airflow of 240 L/s (500 scfm).

A major environmental benefit will be realized by using recirculation for cooling in lieu of the once-through system. The total discharge to the environment will be reduced from about 1400 L/s (3000 scfm) to 190 to 480 L/s (400 to 1000 scfm). Recirculation not only reduces the total discharge, but also reduces material collected in the air cleanup train which reduces operational and maintenance costs.

A side benefit of the reduced size exhaust system was to effectively change the pilot plant scale factor from 1/20 to 1/7 scale, thus boosting credibility of the test data.

The project cost for the recirculation ventilation concept was estimated at $24.6 million. The project cost for the facility incorporating a once-through system was estimated at $30 million. This considerable cost savings, as well as the environmental advantages, drove the definitive design to incorporate the recirculation ventilation concept.

Environmental Impact

Process flow diagrams were developed by using the pilot plant test results to predict environmental discharge for four different operating scenarios. These operating scenarios resulted from different assumptions about heat generated in the waste tanks and variations in waste composition and from operation with failed cooling systems.

During normal operation (current waste composition, no mechanical waste agitation, and operating cooling systems), the annual radioactive release was calculated to be 18 Ci, of which tritium is more than 99%. By comparison, calculated tritium release from the existing system under the same operating scenario amounts to 840 Ci/yr. This gross reduction in tritium release achieved with the new system depends heavily on reliable operation of the cooling system. It should be noted that failure of the cooling system, or for that matter, continued operation of the existing system, will result in a dose to the public that is less than 1% of the exposure permitted by DOE guidelines.

The TAP and NESHAP applications were approved in 1994, and permission to construct the project was granted by the Washington Department of Health, the Washington Department of Ecology, and the U.S. Environmental Protection Agency.

Conclusion

A unique ventilation system has been developed and constructed at the AWTF at DOE's Hanford Site. The new system includes recirculation ventilation and cooling for each tank in the facility, followed by a central exhaust air clean-up train that includes a low-temperature vapor condenser and an HEME.

The system is capable of reducing the atmospheric release of tritium to only 2% of the existing system capability. The condenser and HEME will reduce loading of the final HEPA filters in the air clean-up train by a factor of 20 for soluble aerosols, and by a factor of 13 for insoluble aerosols. The operating life of the remotely replaceable HEME cartridge is predicted to be approximately three years.

The new ventilation system, along with the support facilities, is scheduled to begin full-time operation in late 1996.

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DISCUSSION

BELLAMY: The comment I would like to make is that it took me a little while to understand exactly what you meant by HEME. I think, as an industry, we are falling into a very poor habit of using acronyms for everything. Some of the things that we discussed last week at our ASME standards committee meeting were HEMA's versus HEPA's, high efficiency metal filters versus high efficiency particulate filters, and what do these terms really mean. I think you were understood, but it took me a couple of minutes to realize exactly what you were talking about. You will notice that in the summary that we prepare for this Conference for publication in Nuclear Safety there is a very detailed list of acronyms in the beginning. I would just caution all of us to pay attention to explaining acronyms.

WILHELM: At one of the earlier Air Cleaning Conferences, we published results identified as a HEME, a metallic filter with a layer of glass fibers; in this case around twenty microns thick. The real decontamination factor measured was around 3,000 for all the aerosols together.

RICE: I might have forgotten to mention the decontamination factors that we achieved. I should have mentioned that the system of the condenser and the HEME together gave us a decontamination factor of about thirteen for insoluble particles, and about twenty for soluble particles. We really did a pretty good job of relieving the load on the HEPA filters.

CONKLIN: I am with the Washington State Department of Health, and I regulate radioactive air emissions from Hanford. Since you are already below 0.1 millirem per year to the maximally exposed individual, what was the reason to put in this system? I am not sure I caught how efficient it is for tritium. The third question is, do you consider this system cost-effective?

RICE: Yes, it was definitely cost-effective compared to other methods that might be used to reduce tritium. Of course, we are taking advantage of the fact that tritium is basically tritiated water vapor, so we are really just handling water vapor. The concentration off-site is, in fact, quite low and you asked, why did we bother to do this in the first place? I tried to point out that we engaged in this upgrading project for several reasons: one was that we were anticipating adding extra heat to the tanks by operating mixer pumps in order to keep the waste mixed. Other methods of mixing, such as the air lift circulators that are now in those tanks have given us problems. The mixer pump demonstration program will greatly impact the heat load in the tanks. That is a reason for the upgrades, plus the fact that spent fuel intended to be processed in the PUREX plant still remains in storage, and there would be a whole new load of hot fuel that we would have to handle. As it turned out, that fuel probably never will be reprocessed because the PUREX plant has been shut down. However, we do have a cooling system in the tanks that is able to handle extra heat loads. The cooling system also had to meet new codes and standards, plus the Derived Concentration Guides, at the point of release. So you see, our criteria were telling us that it did not matter what the off-site projected dose was; design-wise, we had a problem at the point of release and had to face up to it. It was kind of unrealistic in a way because the off-site impact is so terribly small. Nevertheless, it is just one of many release points at Hanford and you always do the best you can. We felt that using the refrigeration system would be very cost-effective, which it turned out to be. So, we did our job.

CONKLIN: What was the efficiency for tritium?

RICE: The existing system, under more or less standard operating conditions, releases to the atmosphere 840 curies per year. That is more than 99% of the total radioactivity released from the entire tank farm. The new system, i.e., the recirculation and refrigeration system together, will release 18 curies, a 50:1 reduction.

WEBER: This apparently is the same HEME which was used in the Zone -1 melter offgas test. As you mentioned, it was also used upstream of a HEPA-grade filter, in fact a metallic filter. If you have not already done so you may be interested in speaking with Greg Whyatt at Battelle who did this study, and who documented the performance of the HEME and the downstream HEPA life in that study.

RICE: Yes, I know Greg Whyatt. The work for this project started back in '89. It's been a long time, and there were three different scientists at Battelle that worked on this project.

WEBER: Apparently there is a completed report by Greg and his co-authors which has now been awaiting DOE approval for issue for something like two years.

RICE: Maybe that is a different report. One of my references is a report that was done by Brouns and Peterson. They were the last two individuals that worked on the development of the HEME for this particular project. The HEME that was in the laboratory was, in fact, used for a melter off-gas experiment.

WEBER: That would put it back to Greg.

DEVELOPMENT OF A COMPUTER CODE TO PREDICT A VENTILATION REQUIREMENT FOR AN UNDERGROUND RADIOACTIVE WASTE STORAGE TANK

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Abstract

Computer code, WTVFE (Waste Tank Ventilation Flow Evaluation), has been developed to evaluate the ventilation requirement for an underground storage tank for radioactive waste. Heat generated by the radioactive waste and mixing pumps in the tank is removed mainly through the ventilation system. The heat removal process by the ventilation system includes the evaporation of water from the waste and the heat transfer by natural convection from the waste surface. Also, a portion of the heat will be removed through the soil and the air circulating through the gap between the primary and secondary tanks. The heat loss caused by evaporation is modeled based on recent evaporation test results by the Westinghouse Hanford Company using a simulated small scale waste tank. Other heat transfer phenomena are evaluated based on well established conduction and convection heat transfer relationships.

I. Introduction

The ventilation system has been used as the main method of removing heat from the underground tank that stores heat-generating radioactive waste materials on the Hanford Site. The ventilation system can remove a large amount of heat from the waste tank by introducing cold and dry air into the tank vapor space and removing hot and humid air. The ventilation air removes a major portion of the heat from the tank by carrying away water vapor evaporated from the waste surface. Also, the heat is removed from the waste surface to the ventilation air by the natural convection in the vapor space. In addition to the ventilation air, a small portion of the heat will be removed by air circulating between the primary and secondary tanks (annulus flow). The tank will lose heat through the soil if the temperature of the tank is higher than the temperature of the surrounding soil. An evaluation of the required ventilation flow to remove the heat from the waste tank is an important design parameter for the design of a new tank.

Waters(1) developed a simple code to predict the ventilation requirement based on the evaporation rate equation developed by Boelter et al(2). In this code, other heat transfer phenomena such as the natural convection have not been evaluated properly. Recently, Crea(3) at Westinghouse Hanford Company has performed an experiment measuring the evaporation rate from a 12-ft (3.66-m) diameter simulated waste tank to improve the Boelter equation. Based on these experimental results, computer code WTVFE has been developed to predict the ventilation flow conditions for a waste tank containing heat-generating elements. Also, other heat transfer phenomena have been properly treated in this new code.

II. Description of Analysis Methods

This section discusses the analysis methods used in code WTVFE for various heat removal modes such as evaporation, natural convection, conduction through the soil, and heat removal by the annulus flow. The analysis methods are based on steady-state conditions with well mixed waste.

1. Evaluation of Evaporation Rate from the Waste

Since water has a large latent heat, a small amount of water evaporation from the waste into the ventilation system will remove a significant amount of the heat from the tank. The water vapor pressure in the ventilation outlet depends on the equilibrium between the amount of water vapor transferred from the waste surface to the bulk air space above the waste and the amount of vapor taken away by the ventilation system. In this evaluation, it is assumed that the bulk air inside the tank is well-mixed and that the outlet condition of the ventilation air is the same as that of the bulk air inside of the tank. Boelter et al(2) have developed the following equation to predict the amount of the water vapor transferred from the pure water surface to the bulk air based on the experimental data.

$$W = 0.00129A(P_i - P_b)^{1.22} \tag{1}$$

where:

W -- amount of water vapor transferred (lb/hr)
A -- surface area (ft^2)
P_i -- waste surface water vapor pressure (mm Hg)
P_b -- bulk phase water vapor pressure (mm Hg)

The validity of applying the Boelter equation to a large tank has been questioned, since Boelter et al developed the empirical equation based on experimental data using a small pan. To confirm the Boelter equation for a large tank like the radioactive storage tanks at Hanford, an experiment was performed by Westinghouse Hanford Company(3) to measure the evaporation rate from a 12-ft (3.66-m) diameter tank. The comparison between the experimental results and the predictions by the Boelter equation shows that the predictions by the Boelter equation are an average of 2.9% lower than the experimental data. In the code, Boelter's equation has been used for the calculation of the evaporation rate with this adjustment. Table 1 summarizes the comparisons between the experimental data and the predictions by the original and improved Boelter's equation.

Table 1 Comparison between Westinghouse Experimental Data and Predictions for Water Loss.

Test Run No	Experimental Data (lb/hr*ft^2)	Prediction Boelter (lb/hr*ft^2)	Error (%)	Prediction Modified (lb/hr*ft^2)	Error (%)
1	1.2	1.19	-0.8	1.23	2.5
2	14.75	15.13	2.6	15.5	5.1
3	29.03	25.38	-12.6	25.9	-10.8
4	12.73	12.47	-2.0	12.79	0.5
5	23.98	22.86	-4.7	23.35	-2.6
7	30.25	27.16	-10.2	27.69	-8.5
6	9.78	8.92	-8.8	9.14	-6.5
8	23.96	21.9	-8.6	22.39	-6.6
11	25.79	22.06	-14.5	22.54	-12.6
12	3.52	2.98	-15.3	3.05	-13.4
10-10R	8.71	8.5	-2.4	8.71	0.0
17	2.58	2.74	6.2	2.81	8.9
20	12.66	13.39	5.8	13.68	8.1
5R	23.43	23.8	1.6	24.3	3.7
6R	8.48	9.02	6.4	9.25	9.1
9	14.57	16.0	9.8	16.37	12.4
21	4.92	4.55	-7.5	4.67	-5.1
13	0.71	0.69	-2.8	0.72	1.4
22	1.53	1.44	-5.9	1.49	-2.6

The inlet flow rate of the ventilation air required to remove the water vapor transferred from the waste surface shown in equation (1) is equal to:

$$V_a = \left(\frac{760}{60\rho(760-P_n)}\right)\left(\frac{1.6W}{\frac{P_b}{(760-P_b)} - \frac{P_n}{(760-P_n)}}\right) \qquad (2)$$

where:

V_a -- inlet ventilation air flow rate (SCFM)
P_n -- inlet air water vapor pressure (mm Hg)
ρ -- air density (lb/ft^3)

Since the waste contains chemicals, the vapor pressure is lower than pure water. The code has an arrangement to input the factor representing the vapor pressure suppression due to chemicals in the waste.

2. Evaluation of Ventilation Exit Air Temperature

The ventilation air removes heat from the waste by increasing the air temperature while the air is passing through the tank. To evaluate this method of heat removal, the temperature of the ventilation exit air has to be evaluated accurately. As stated previously, the exit conditions of the ventilation air is assumed to be the same as that of the bulk air inside of the tank. The temperature of the ventilation exit air is dependent on the heat transfer rate from the waste surface to the bulk air space above the waste and the ventilation air flow rate. The heat is transferred to the bulk air from the waste surface by the natural convection caused by the density difference between the bulk phase and the interface at the waste. This density difference is caused by the temperature and water vapor pressure differences.

The relationships between the Nusselt number (Nu) and the Rayleigh number (Ra) have been established for laminar and turbulent natural convection(4). The heat transfer coefficient from the waste surface to the bulk phase can be calculated from these relationships. The Nu and Ra numbers are defined as

$$Nu = \frac{h}{Lk} \qquad (3)$$

where:

h -- heat transfer coefficient (Btu/hr*F*ft^2)
k -- conductivity (Btu/hr*F*ft)
L -- characteristic length (ft)

$$Ra = \frac{g\Delta\rho L^3 \rho_f Cp_f}{\mu_f k_f} \qquad (4)$$

where:

g -- acceleration of gravity (ft/hr^2)
$\Delta\rho$ -- density gradient ($=(\rho_b-\rho_i)/\rho_i$)
Cp -- specific heat (Btu/lb*F)
μ -- viscosity (lb/ft*hr)
subscript i -- interface
b -- bulk phase
f -- film

The relationship between the Nu and Ra number for the laminar natural convection (Ra < 10^8) is

$$Nu=0.56Ra^{1/4} \qquad (5)$$

and the relationship for the turbulent natural convection (Ra > 10^8) is

$$Nu=0.13Ra^{1/3} \qquad (6)$$

The exit temperature of the ventilation air can be evaluated from the energy balance equation using the heat transfer coefficient obtained by either equation (5) or (6).

$$60V_a\rho Cp_a(T_b-T_n) + Cl = 1.5hA(T_i-T_b) + (Cp_sW+Cp_aW_{1c})(T_i-T_b) \qquad (7)$$

where:

T -- temperature (F)
Cl -- heat loss through soil (Btu/hr)
W_{1c} -- air flow rate trough air lift circulation (lb/hr)
subscript n -- inlet
a -- air
s -- water vapor

The heat transfer surface, A in equation (7), is increased by 50% to account for the side wall of the tank above the waste. This surface increase minimizes the exit temperature differences between predicted values and experimental data.

Also, the code prediction for the exit temperature of ventilation air has been compared to the Westinghouse experimental data[(3)]. The results show that the predicted values are an average 1.2% lower than experimental ones. This difference has been factored into the code. In this comparison, a few experimental data have been disregarded since its values are so obviously erroneous. Table 2 summarizes the

Table 2. Comparison between Westinghouse Experimental Data and Predictions for Exit Air Temperature

Test Run No	Experimental Data(F)	Prediction Theory(F)	Error (%)	Prediction Modified(F)	Error (%)
1	98.8	96.0	-2.8	96.8	-2.0
2	170.1	166.8	-1.9	167.5	-1.5
3	154.4	149.0	-3.5	149.8	-3.0
4	171.7	168.4	-1.9	169.0	-1.6
5	167.2	168.8	1.0	170.4	1.9
7	163.6	159.3	-2.6	160.9	-1.7
6*	167.3	180.6	-	182.3	-
8*	172.2	182.4	-	184.2	-
11	172.2	168.6	-2.1	170.3	-1.1
12	126.2	123.0	-2.5	124.1	-1.7
10-10R	155.3	154.7	-0.4	156.1	0.5
17	141.1	143.5	1.7	144.8	2.6
20	154.2	147.8	-4.2	149.2	-3.2
5R	170.9	169.5	-0.8	171.2	0.2
6R	174.3	182.2	4.5	183.9	5.5
9*	155.3	172.6	-	174.3	-
21	140.1	138.9	-0.9	140.1	0.0
13	95.6	91.8	-4.0	92.6	-3.1
22	127.4	129.0	1.3	130.1	2.1

* These runs are not used for the comparison.

comparisons between the experimental data and the predictions by the original and improved code calculations. If the exit water vapor pressure calculated in the previous section is higher than the saturation vapor pressure at the exit air temperature calculated in this section, the code will evaluate the exit air temperature where the exit vapor pressure matches with the saturation pressure. In this calculation, it is assumed that the heat that increases the exit air temperature to the saturation temperature comes from the condensation of the water vapor.

3. Evaluation of Heat Loss through the Soil

Since the waste tanks on the Hanford Site are underground, heat loss from the tanks to the soil will occur when the waste temperature is higher than that of the surrounding soil. Because the surrounding soil has a large heat capacity and the amount of heat generated by the waste in the tank is relatively small, it will take a long time to reach a steady state during the operation. In the code, it is assumed that there is a water table with a constant temperature of 55°F (12.8°C) below 200-ft (60.96-m) from the tank bottom and the surrounding soil has reached the steady state temperature as suggested in the thermal analyses of the MWTF(Multi-Function Waste Tank Facility) design(5). Also, there is a steady state heat loss through the soil covering the top of the tank to the outside air.

A simplified model developed for a disc heat source stored in the infinite medium(6) was used as the basis for the calculation of heat loss from the tank through the soil to the water table. The tank is assumed to be a disk, since the tank height is small compared with the distance from the tank to the water table and the upper portion of tank will loose heat to the outside air. Furthermore, the pads installed under the tank bottom, such as the concrete and insulating pads with annulus air distribution channels, are ignored since the conduction resistance through 200- ft (60.96-m) of soil is dominant compared with the resistance through these pads.

$$Q_{cb} = \left(\frac{4.45D}{1-\frac{D}{1-5.67z}}\right) k_z (T_t - T_w) \qquad (8)$$

where:

Q_{cb} -- heat loss to water table (Btu/hr)
D -- tank diameter (ft)
z -- distance from tank bottom to water table (ft)
subscript t -- tank
w -- water table
z -- soil

The conductivity of the soil is estimated to be 0.35 Btu/F*hr*ft (0.606 W/m*K) in the code(5).

The heat loss from the top of the tank to the outside air was evaluated assuming that the top surface of the tank is a flat circle and the heat transfer path in the soil is limited to the cylindrical area above the tank. This is an acceptable approach since the depth from the ground surface to the tank is not generally deep. Also, a factor is assigned to adjust possible error due to this simplification as shown in the following equation.

$$Q_{ct} = F\pi D^2 \frac{1}{h_a + \frac{d_s}{k_s} + \frac{d_c}{k_c}} \qquad (9)$$

where:

Q_{ct} -- heat loss to outside air (Btu/lb)
F -- factor to adjust the error
d -- Thickness (ft)
subscript c -- concrete

The heat transfer coefficient from the ground to the air is assigned to be 0.5 Btu/F*hr*ft^2 (2.837 W/m^2*K) and the conductivity of the concrete to be 0.6 Btu/F*hr*ft (1.038 W/m*K) in the code.

If the tank top surface is not flat, it is recommended to use the average depth based on the area. The factor assigned to accommodate any possible error was determined to be 1.12 comparing the code predictions with the calculation results using a sophisticated finite element code(7) for the design of the MWTF tank(5). The comparisons between the finite element code calculations and the predictions with and without a factor by equation (9) are summarized in Table 3. Since the factor in equation (9) was determined based on the comparison to the analysis data for only the MWTF design, a large amount of error is possible in applying this factor to other configurations. However, an error in the conduction loss calculation will not significantly affect the evaluation of the ventilation flow rate in most cases since the conduction loss through the soil is very small compared with the other losses.

Table 3. Comparison between Finite Element Calculations and Predictions for Heat Loss through Soil

Waste Temperature (F)	Out side Air Temperature (F)	Finite Element Prediction (Btu/hr)	The Code Prediction (Btu/hr)	Error (%)
187	77	33000	31166	-5.6
118	77	12000	13539	12.8
109	77	10000	10963	9.6
104	77	9000	9757	8.4
98	77	7000	8136	16.2
93	53	12000	10267	-14.4
88	53	9000	8771	-2.5
69	53	4000	3928	-1.8
64	53	3000	2577	-14.1

4. Evaluation of Heat Loss to Annulus Air Flow

Most of the waste tanks designed to store radioactive nuclear waste have a secondary containment. Air is circulated through the gap between the primary tank and the secondary tank in to detect any radioactive waste leak from the primary tank. This circulating air is called the annulus air flow and removes heat from the tank. The overall heat transfer coefficient from the waste to the annulus air flow consists of the resistance in the waste side, tank wall, and air side heat transfer coefficients. An arbitrarily high heat transfer coefficient of 10 $Btu/F*hr*ft^2$ (56.74 W/m^2*K) has been assigned for the waste side since the waste is assumed to be well mixed.

For the air side, the heat transfer coefficient[8] based on natural convection was used when the air flow was not turbulent (Reynolds number is less than 10^4).

$$h_a = 0.19 \ (\Delta T)^{1/3} \qquad (10)$$

where:

ΔT -- Temperature difference (F)

Since the temperature difference is not uniform (large at the bottom of the tank and small at the top of the tank), the logarithmic mean temperature difference is used for the calculation. When the air flow is turbulent, the heat transfer coefficient is evaluated based on forced convection[9].

$$h_a = 0.023 \ Re^{0.8} Pr^{0.4} \ k_a/Gp \qquad (11)$$

where:

Re -- Reynolds number
Pr -- Prandtl number
Gp -- gap distance (ft)

In this equation, properties of the air are evaluated at 100°F (37.8°C).

For the overall heat transfer calculation, it is assumed that air is uniformly distributed throughout the annulus and that 30% of the tank bottom area is in contact with the annulus air. When the annulus air temperature is higher than waste temperature, it is assumed in the code that there is no heat transfer between the annulus air and the waste.

5. Consideration on Air Lift Circulation Air

Some of the radioactive waste storage tanks on the Hanford Site have an air lift circulation system to mix the waste during storage. In the air lift circulation system, air is introduced into the waste and passes through it as bubbles. Since air from the air lift circulation system is introduced into the waste, it is assumed in the code that the air temperature leaving the waste is the same as the waste temperature and that the water vapor pressure in the air is the same as the saturation vapor pressure for the waste at the surface. When air from the air lift circulation system mixes with the ventilation air, proper material and energy balance equations are solved to account for the high air temperature and vapor pressure from the air lift circulation system.

III. Description of Computer Code

This section presents a brief description of computer code WTVFE. The code is written in Q-Basic language and a detailed description on how to use the code is in the user's manual section of reference 10.

The code requires the ventilation air inlet conditions, the annulus flow rate, tank geometry and the vapor suppression factor for the waste as input data. Also, it requires the waste temperature and the heat generation rate as input data. First, the code calculates the heat removal rate by the conduction through the soil and annulus air flow. Then, it calculates the amount of water to be vaporized in order to remove the rest of the heat, assuming that heat removal due to the ventilation air temperature rise is negligible. The required vaporization rate is converted to the required ventilation flow rate using equation (2). Based on the required ventilation flow rate and the outlet temperature to be calculated later, heat removal by the ventilation air temperature rise will be calculated and the required ventilation flow rate recalculated. This iteration continues until the previous value of the ventilation flow rate matches the recalculated value within 0.5% of error.

After the iteration of the ventilation flow rate, the iteration of the ventilation air exit temperature will be performed. First, the temperature of the exit air is assumed to be 20°F (11°C) lower than the waste temperature. Using this assumed exit temperature, the Ra number and heat transfer coefficient are calculated. Then, the temperature of the exit air is calculated using equation (7). If the difference between the calculated temperature and the assumed temperature of the exit air is larger than 0.05°F (0.03°C), the exit temperature will be reassigned based on the previously assumed and calculated values. This iteration continues until the difference becomes less than 0.05°F (0.03°C).

After the exit air temperature is converged properly, the code will return to the iteration of ventilation air flow rate again with the newly calculated exit air temperature. Iteration of the ventilation air flow rate and exit air temperature will be repeated until the differences between the previous values and the recalculated values of both variables are within the desired limits.

IV. Conclusions

Computer code, WTVFE, has been developed successfully to predict the requirement of the ventilation air flow rate for an underground storage tank for heat-generating radioactive materials.

Acknowledgment

This work was performed under the auspices of the U.S. Department of Energy by ICF Kaiser Hanford Company under contract number DE-AC06-87RL-10900.

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DISCUSSION

BERGMAN: We heard this morning from Louis Kovach about potential accidents in some of the tank farms, e.g., explosions, filter burstings, things like that. Can you tell us something from your experience that you have actually observed; cracks, things of that nature?

DALPIAZ: No, I don't have any actual experiences I could use to answer your question.

PORCO: I will address this to speakers from Hanford. Based on your experience with tank farm ventilation, what do you see as the biggest need for product development? I guess the best way to phrase it is, is there a lack in the industry for a product that would serve your needs or assist you in treatment? Is everything that you need available in the market today?

RICE: The thing that comes to my mind right away as the biggest concern at Hanford, is flammable gas issues. Control of particulates is really not a problem and has never been a problem as far as I know. Sometimes the filters have a rough life and they may need rapid change-out, but they have never really been a big deal. But now the flammable gas issue is the real problem. What we are faced with are tanks that generate flammable gases in the waste that can build a pressure under the crust and then suddenly overturn the contents and make a large release to the environment. There have been occasions of this occurring. There is one tank in particular that has equipment in it, a mixer pump, to prevent gas build up by keeping the contents agitated. This prevents episodic releases of gas, by allowing continuous average releases. In the paper I presented we discussed a cleanable mist eliminator that is taking out particles. We may find out that it loads up quickly or that there is some problem with washing it. That is why we studied the prototype. We hope, based on the prototype test, that it will turn out to be okay.

BERGMAN: I forgot the exact details, but Russia had some tanks out by the Urals that had minor mishaps. And I think they had, as a consequence, several hundred miles of uninhabitable area. I am sure this is well known to your people. I was not quite satisfied with your response to my earlier question as we have an inconsistency between what Louis Kovach said this morning and what you are saying. And I would like to find out who is telling the truth.

BELLAMY: I think Dr. Kovach was indicating a little different opinion this morning . You are welcome to comment further if you want. I don't think it's a question of who is telling the truth and I do not think we should go further with that thought. The way I interpreted Mr. Porco's question was that, as a representative of the industry, if there is some piece of equipment that would help to control radioactive releases from the Hanford facility, please speak up and maybe we can take care of it. The answer I heard was that, there really is nothing that would basically solve all our problems.

RICE: I think there is really a lot to the idea that the codes and standards that we are forced to use in the processing industry are related to the nuclear power plant industry. They really do not line up very well with the real problems that we are trying to solve. We have been getting by, but if there were a set of codes and standards designed for processing and reprocessing, maybe some new equipment would come out to meet those codes. But right now, we have only N-509 and we build HEPA filter systems to that standard.

TESTING CLEANABLE/REUSABLE HEPA PREFILTERS FOR MIXED WASTE INCINERATOR AIR POLLUTION CONTROL SYSTEMS

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Abstract

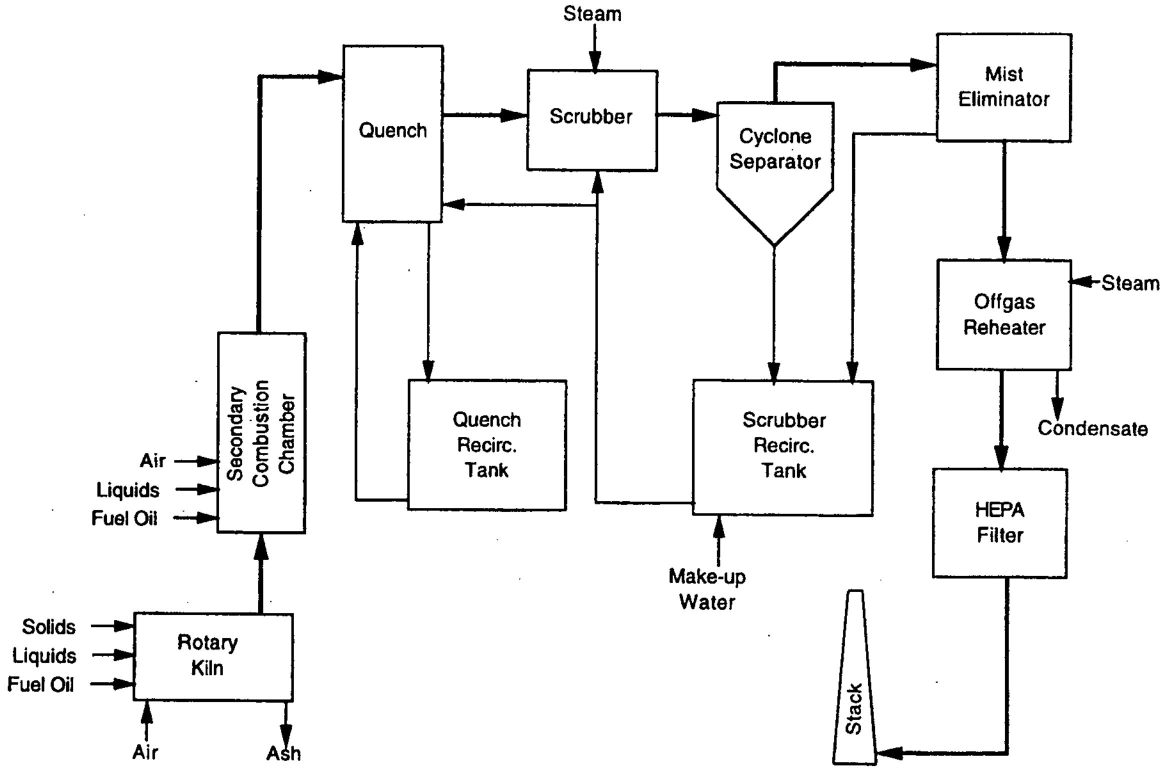
The Consolidated Incineration Facility (CIF) at the US Department of Energy (DOE) Savannah River Site is currently undergoing preoperational testing. The CIF is designed to treat solid and liquid RCRA hazardous and mixed wastes generated by site operations and clean-up activities. The technologies selected for use in the CIF air pollution control system (APCS) were based on reviews of existing commercial and DOE incinerators, on-site air pollution control experience, and recommendations from contracted consultants. This approach resulted in a unique facility design utilizing experience gained from other operating hazardous/radioactive incinerators. In order to study the CIF APCS prior to operation, a 1/10 scale pilot facility, known as the Offgas Components Test Facility (OCTF) was constructed by the Savannah River Technology Center and has been in operation since late 1994. Its current mission is to demonstrate the design integrity of the CIF APCS and optimize equipment/instrument performance of the full scale production facility. Operation of this on-site pilot facility has provided long-term performance data of integrated systems and critical facility components. This effort has reduced facility start-up problems and helped to insure compliance with all facility performance requirements. In today's environment of increased public participation and awareness, technical support programs of this type assist in assuring all stakeholders the CIF can properly treat combustible hazardous, mixed, and low-level radioactive wastes.

Due to the nature of the wastes to be incinerated at the CIF, High Efficiency Particulate Air (HEPA) filters are used to remove hazardous and radioactive particulates from the exhaust gas stream before being released into the atmosphere. The HEPA filter change-out frequency has been a potential issue and was the first technical issue to be studied at the OCTF. Tests were conducted to evaluate the performance of HEPA filters under different operating conditions. These tests included evaluating the impact on HEPA life of scrubber operating parameters and the type of HEPA prefilter used. This pilot-scale testing demonstrated satisfactory HEPA filter life when using cleanable metal prefilters and high flows of steam and water in the offgas scrubber.

I. Introduction

The Consolidated Incineration Facility (CIF), located at the Savannah River Site, is currently undergoing preoperational testing to treat solid and liquid RCRA hazardous and mixed wastes generated by site operations and clean-up activities. In this facility, waste thermal treatment is performed in a 13 million Btu rotary kiln incinerator and 5 million Btu secondary combustion chamber. The facility air pollution control system (APCS) consists of a recirculating liquid quench and steam-atomized scrubber for offgas cooling and cleaning, a cyclone separator and mist eliminator for liquid/gas separation, and final HEPA filtration prior to atmospheric discharge through the facility stack. A process flow diagram for the CIF is shown in Figure 1.

Figure 1
CIF Process Flow Diagram

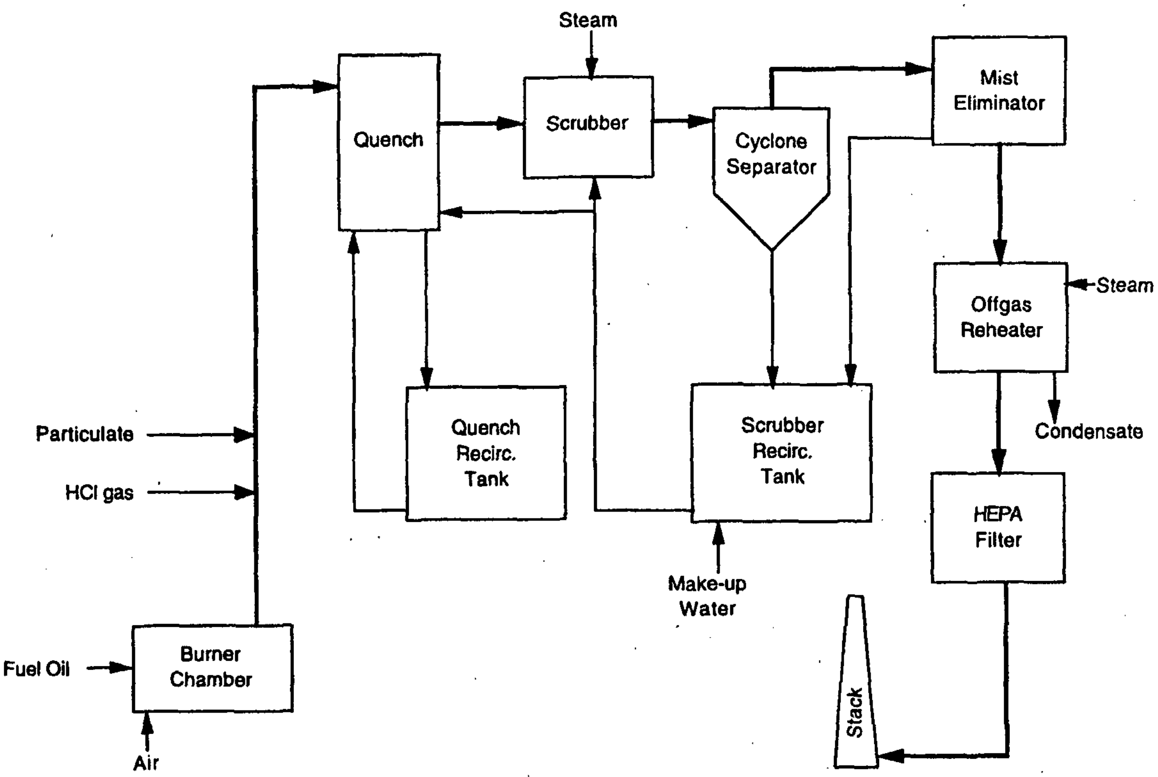


The technologies selected for use in the CIF were based on reviews of existing commercial and DOE incinerators, on-site air pollution control experience, and recommendations from contracted consultants This approach resulted in a unique facility design utilizing experience gained from other operating hazardous/radioactive incinerators. The Savannah River Technology Center (SRTC) designed, installed, and operated a 1/10 scale pilot facility, known as the Offgas Components Test Facility (OCTF), to demonstrate the design integrity of the CIF APCS and optimize the equipment/instrument performance in the full scale waste treatment facility. Operation of this on-site pilot facility has provided long-term performance data of integrated systems and critical facility components. This effort has reduced facility start-up problems and helped to insure compliance with all facility performance requirements.

II. OCTF Design and Capabilities

The OCTF is a pilot-scale air pollution control system, currently configured to test the design of the CIF APCS. A schematic of the OCTF is shown in Figure 2. Hot offgas is produced in a three million Btu burner chamber. Particulate and HCl gas are metered into the gas stream to simulate particulate carry-over and acid gas produced during incineration of typical hazardous wastes. The offgas is cooled in a co-current recirculating water quench before entering a high efficiency steam-atomized scrubber. The scrubber removes particulates and neutralizes acid gases. The scrubbed offgas enters a cyclone separator where liquid and solid particulates are removed from the gas stream. After exiting the cyclone, the offgas enters a mist eliminator to remove any residual liquid droplets. A reheater upstream of the HEPA filters prevents condensation in the filter housing. The filtered offgas is discharged to the atmosphere through the facility stack.

Figure 2
OCTF Process Flow Diagram



The OCTF is designed to evaluate operational parameters of air pollution control system designs. The OCTF utilizes a modular design which allows replacement/addition of existing unit operations with other technologies that could be tested in the future. The current configuration of the OCTF is a 1/10 scale mock-up of the CIF APCS. Individual equipment components and instruments currently installed were designed and fabricated by the same vendors selected for the CIF. The performance of all CIF APCS components were evaluated as a function of system operating parameters at the OCTF. In addition to obtaining valuable performance data, the OCTF is a useful tool for training operators and maintenance personnel.

III. OCTF Filter Testing

The first test series at the OCTF investigated process parameters that impact system HEPA filter and prefilter life. The APCS must be operated in such a manner to provide acceptable HEPA filter and prefilter life (> 30 days). Short filter life significantly increases facility operating costs associated with procuring, replacing (or cleaning), and disposing system filters. The filter housings used both at the CIF and the OCTF contain 24" x 24" x 11.5" disposable fiber HEPA filters. Upstream of the HEPA filters are 24" x 24" x 6" prefilters. The primary objective of these tests was to determine the APCS operating parameters that are required to meet the goal of 30-day HEPA filter and prefilter life.

Test Plan

This test consisted of six runs. The test facility was operated in a mode that simulated the average design operating conditions of the CIF. The gas temperature exiting the burner chamber was held at approximately 1026°C. The gas flow through the HEPA housing was maintained at approximately 2100 ACFM (700 ACFM/HEPA filter). The offgas temperature passing through the HEPA housing was maintained above 115°C to prevent water condensation. The concentration of salt (NaCl) in the quench recirculating stream was held constant during each run. Salt concentrations in the scrubber solution were maintained below 0.1 wt% due to inflow of makeup water. The operating parameters that were investigated in this test included:

- Type of HEPA prefilter
- Mass ratio of scrubber steam to offgas (α)
- Mass ratio of scrubber water to offgas (β)
- Salt concentration in the quench liquid

Two types of HEPA prefilters were tested. The first was a Flanders paper prefilter (model # T-00K-C-04-00-NL-12-00-E0281, 60-65% @ 1000 cfm). The second prefilter was an Otto York 304 stainless steel prefilter sized to remove 99% of all particles greater than 5 µm in diameter. The Flanders prefilter is a disposable filter, while the Otto York prefilter was cleaned with water after each test and reused.

The test matrix for this program is shown in Table 1.

Table 1 Test Matrix

Run #	Steam/Offgas (α)	Water/Offgas (β)	Quench Salt (wt %)	Prefilter Type
1	0.22	0.5	10	Paper
2	0.22	0.5	5	Paper
3	0.43	1.0	10	304 SS
6	0.26	1.0	10	304 SS
7	0.26	1.0	10	Paper
8	0.26	0.5	10	304 SS

Discussion

The results of all HEPA life test runs are summarized in Table 2. New (or cleaned) prefilters and HEPA filters were installed in the test facility prior to beginning each run. The scrubber operating conditions were maintained at the settings given in the Table 2. Each run ended after sufficient filter pressure drop vs. time data was collected. The actual prefilter and HEPA filter pressure drop observations at the conclusion of each run is listed in Table 2.

Table 2 HEPA LIFE TESTS RESULTS SUMMARY

	Run #					
	1	2	3	6	7	8
Steam Alpha	0.22	0.22	0.43	0.26	0.26	0.26
Water Beta	0.5##	0.5	1.0	1.0	1.0	0.5
Prefilter Type	Paper	Paper	304 SS	304 SS	Paper	304 SS
Quench Salt Concentration	10 wt%	5 wt%	10 wt%	10 wt%	10 wt%	10 wt%
Observed Prefilter dP	3.50" after 40 hrs	2.20" after 110 hrs	1.20" after 415 hrs	1.15" after 375 hrs	3.25" after 215 hrs	0.85" after 475 hrs
Observed HEPA dP	0.40" after 40 hrs	0.35" after 110 hrs	0.85" after 415 hrs	3.00" after 375 hrs	0.40" after 215 hrs	2.80" after 475 hrs
Projected Prefilter Life*	2 days	10 days	42 days	30 days	10 days	68 days
Projected HEPA Life**	#	#	37 days	18 days	#	27 days

* Projected Prefilter Life estimates are derived by extrapolating a third order polynomial function fit to observed data. For paper prefilters, the maximum dP permitted is 4". For cleanable metal prefilters, the maximum dP is 10"

** Projected HEPA life estimates are derived by extrapolating a third order polynomial function fit to observed data. The maximum dP for HEPA filters is 4".

\# Insufficient data to fit a valid a third order polynomial model.

\#\# Partial plugging of scrubber water nozzles during this run is expected to have contributed to poor scrubber performance.

A mathematical model was fitted to the prefilter and HEPA filter pressure drop (dP) vs. time data. The model that consistently showed the best data fit (in particular for the data sets showing a filter at the maximum useful dP) was a third order polynomial relating the dependent variable (dP) to the independent variable (time). Using this model, filter life expectancies were extrapolated for runs ending prior to reaching the maximum allowable dP. For the disposable Flanders prefilters and HEPA filters, this value was assumed to be 4" water. If filter dP was allowed to exceed this value, filter breakthrough was often observed. For the cleanable metal prefilters, the maximum dP was assumed to be 10" water. These filter life predictions are included in the last two lines of Table 2.

Acceptable filter performance was obtained only when using the cleanable metal prefilters. The maximum observed disposable prefilter life was 10 days under all conditions tested. Under similar conditions, prefilter life was extended approximately 3X when using the metal prefilters. It should be noted that use of the disposable paper prefilters always resulted in plugging and changing of the prefilter before any significant dP increase occurred on the HEPA filter. This explains the inability to predict HEPA life for these runs (1, 2, 7). Insufficient data was available for the HEPA dP profile because the prefilter would plug too rapidly. Yet, use of the metal cleanable prefilter often resulted in plugging of the HEPA filter before the dP limit for the prefilter was obtained. Thus, the data tends to indicate the cleanable prefilter allows a greater fraction of particulate through to the HEPA filter. Yet, this more even distribution of particulate between the prefilter and HEPA filter permits a significantly longer time interval between filter (either prefilter or HEPA filter) changeout or cleaning.

The runs which utilized cleanable HEPA filters were #3, 6, and 8. During these runs, the steam/offgas flow ratio was varied between 0.43 and 0.26. Also, the scrubber water/offgas flow ratio was varied between 1.0 and 0.5. The theoretical best conditions are at higher steam and water flowrates (Run 3). Figures 3 and 4 contain the graphs of prefilter (Fig 3) and HEPA filter (Fig 4) dP vs. time. Also on the plots are the projected performance curves predicted by the third order polynomial model. For this run, it can be seen that the actual data does not cover a significant fraction of the model, particularly were the slope begins increasing. It is likely that the model being used for these conditions is a "worst case" projection. Thus, there is a relatively high probability that actual filter life would be at least what is predicted for this case (and possibly greater).

Figure 3 Run 3 Prefilter Performance

Model: V6=K+A*V1+B*V1**2+C*V1**3

y=(0.1817287)+(0.003141479)*x+(-8.596414e-006)*x**2+(1.379748e-008)*x**3

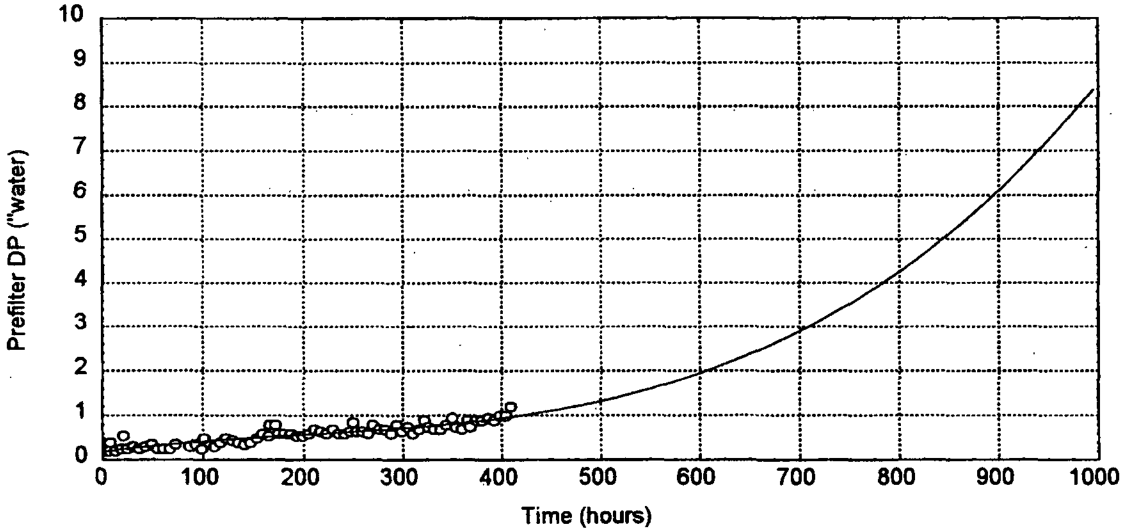
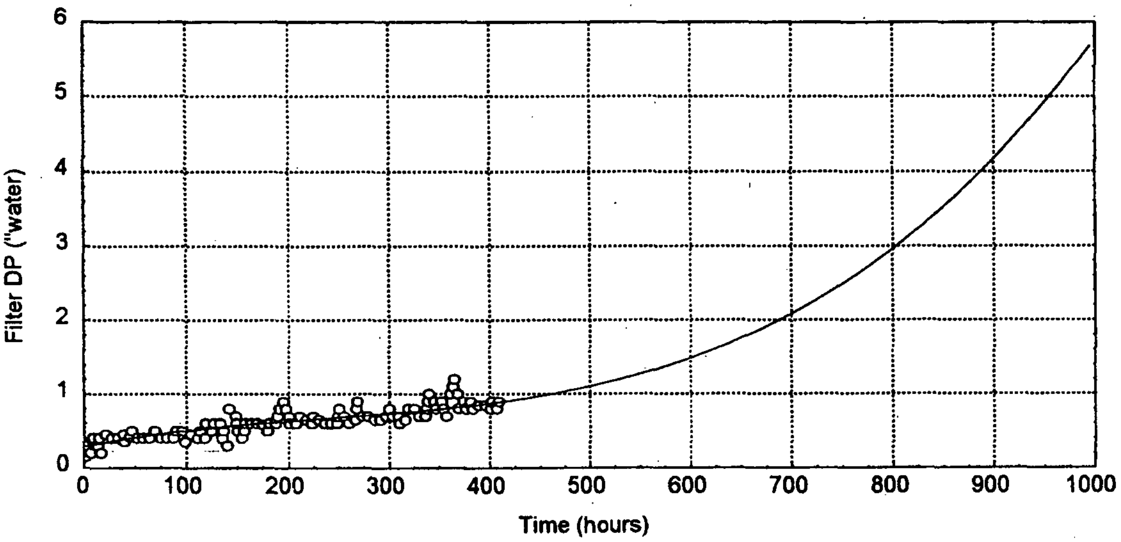


Figure 4 Run 3 HEPA Filter Performance

Model: V7=K+A*V1+B*V1**2+C*V1**3

y=(0.2844875)+(0.002788966)*x+(-7.295733e-006)*x**2+(9.993183e-009)*x**3



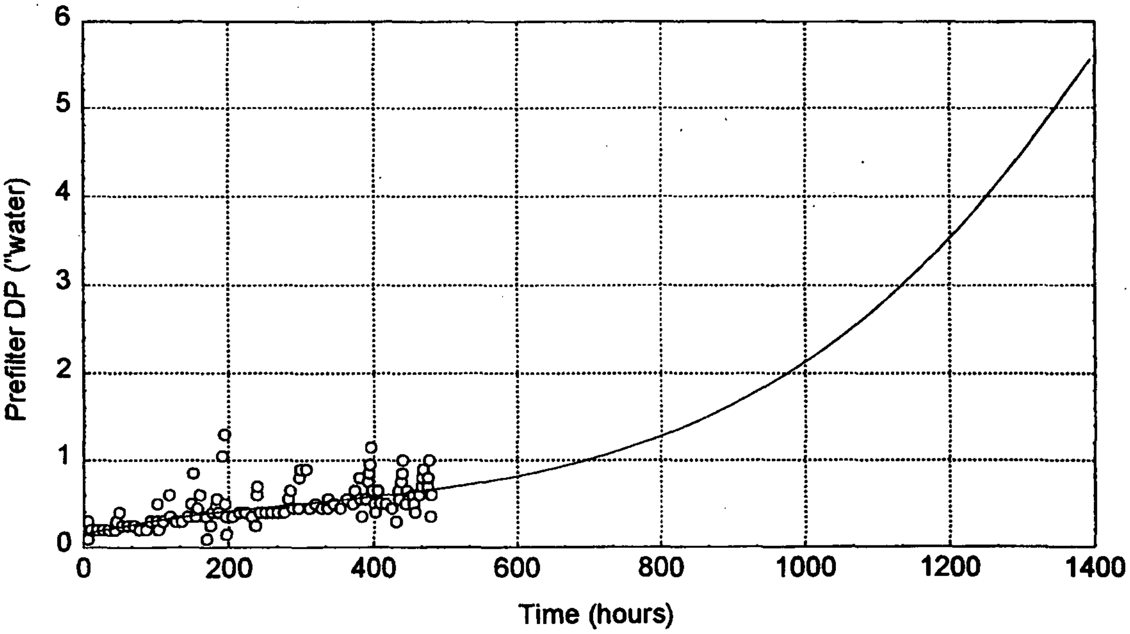
The second best performance was observed in Run 8, when the steam and water flows were both low. This is due to the fact that proper scrubber performance requires the ratio between the scrubber water flow to scrubber steam flow equal two (# water / # steam = 2). If the ratio is too high, the majority of the steam is used to atomize the water and there is insufficient steam for turbulence and pulling offgas through the scrubber. While a low ratio results in insufficient water to properly scrub the offgas. This explains the relatively poor performance in Run 6 (water / steam ratio = 3.8).

Figures 5 and 6 contain the graphs of prefilter (Fig 5) and HEPA filter (Fig 6) dP vs. time for the second best run, Run 8. For this run, it can be seen that the actual data covers enough of the model (especially for the HEPA filter), to consider the projected HEPA filter life a likely estimate. Thus, it is probable that the projected HEPA life of 27 days is an accurate estimate, not a "worst-case" estimate as in Run 3

Figure 5 Run 8 Prefilter Performance

Model: V13=K+A*V1+B*V1**2+C*V1**3

y=(0.1525723)+(0.001824109)*x+(-3.208998e-006)*x**2+(3.36416e-009)*x**3



The particulate size distribution data obtained during these tests indicated that increasing the flow of steam to the scrubber decreased the fraction of large particulates (> 10 µm). This can be seen by comparing the size distribution plot for runs 6 and 3 (Figures 7 and 8). The only difference between these runs is the mass flow of steam. The steam flow was low (0.26 alpha) in Run 6 (Fig 7), and high (0.43 alpha) in Run 3 (Fig 8). This change in the particulate size distribution resulted in increased filter life at the higher steam flow (and a water/steam ratio closer to 2).

Figure 6 Run 8 HEPA Filter Performance

Model: V12=K+A*V1+B*V1**2+C*V1**3

y=(0.5212461)+(0.0009766396)*x+(9.477834e-006)*x**2+(-4.058634e-009)*x**3

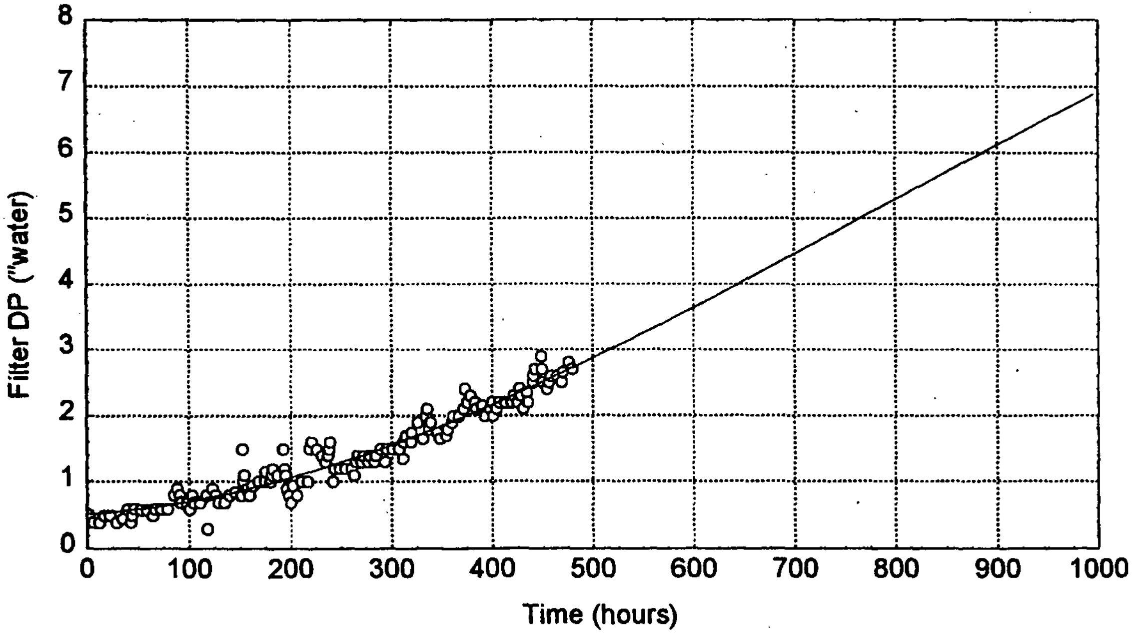


Figure 7 Run 6 Offgas Particulate Size Distribution

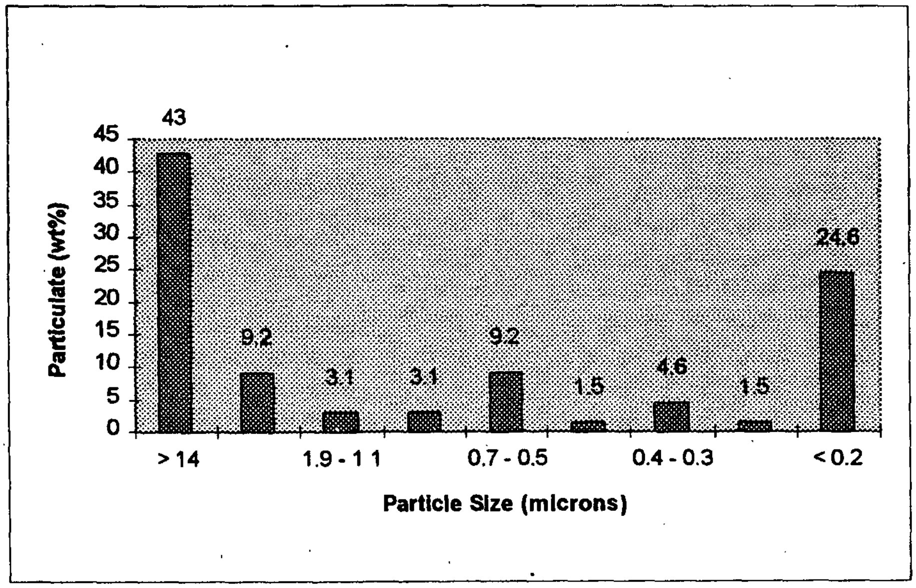
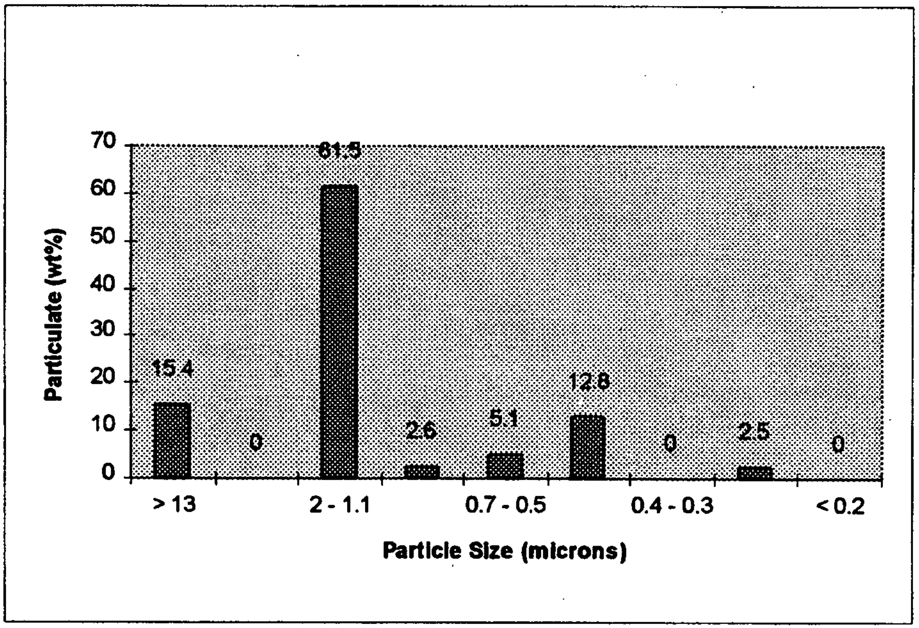


Figure 8 Run 3 Offgas Particulate Size Distribution



Conclusions

The primary conclusion of this test program is that satisfactory prefilter and HEPA filter life is obtainable with the existing CIF APCS. Test results indicate that the life of HEPA prefilters/filters can exceed the operational goal of thirty days under the following conditions: steam ratio, $\alpha = 0.43$, scrubber water ratio, $\beta = 1$, and using 304 SS cleanable prefilters.

IV. Summary

The Consolidated Incineration Facility (CIF) at the US Department of Energy (DOE) Savannah River Site has a unique facility design utilizing experience gained from other operating hazardous/radioactive incinerators. In order to study the CIF APCS prior to operation, a 1/10 scale pilot facility, known as the Off-gas Components Test Facility (OCTF) was constructed by the Savannah River Technology Center and has been in operation since late 1994. This test facility demonstrated the design integrity of the APCS and is currently being used to optimize the equipment/instrument performance of the full scale production facility. Operation of this on-site pilot facility has provided long-term performance data of integrated systems and critical facility components. This effort has reduced facility start-up problems and helped to insure compliance with all facility performance requirements.

Tests were conducted to evaluate the performance of the HEPA filters under different operating conditions. These tests included evaluating the impact on HEPA life of scrubber operating parameters and the type of HEPA prefilter used. This pilot-scale testing demonstrated satisfactory HEPA filter life when using cleanable metal prefilters and high flows of steam and water in the offgas scrubber.

DISCUSSION

BELLAMY: I have two questions I would like to ask. The first is on the slide that showed useful life versus number of runs. For the three runs that were done for the cleanable filters, two of the runs did not get to your acceptable thirty day life. I assume that each run was under different operating conditions?

BURNS: Correct.

BELLAMY: So run three, that was over thirty days, basically defined for you your future operating conditions, rather than the average of those three to be over thirty days?

BURNS: Each run was for a separate operating condition.

BELLAMY: The second question I have is concerned with service life and useful life. For a cleanable pre-filter, how many washable cycles are possible? If I buy one filter am I done forever? If I wash it every thirty days, do I have to replace it every year, two years, three years?

BURNS: That is something we haven't an update on. We are still using the original filter in the test facility. We have at least twenty-five cycles on it. Typically, we just load it up until we have to shut down; usually the HEPA filter is plugged and has to be replaced. The most resistance we have ever gotten on the prefilter has been about 3 in. w.g. When it starts clean, it is less than an inch.

BELLAMY: Not being intimately familiar with manufacturers' names and products, the final conclusion on your final slide used the term Otto-York prefilter. What is the significance of an Otto-York prefilter versus anybody else's prefilter?

BURNS: That just happens to be the one we tested. We consulted our site experts and they had some experience with that particular type of filter, so that was what was recommended. I have no doubt that a similar filter, manufactured by another company, would most likely behave the same.

PORCO: The question I have is, did you check the initial resistance after you cleaned your moisture separator? Did you do a pressure drop test on your moisture separator after you cleaned it?

BURNS: Yes.

PORCO:: How close did it get to the original pressure drop?

BURNS: The same.

PORCO: That answers the question about being reusable. As long as you keep coming down to the initial resistance it means you are getting most of the particles off.

BURNS: The particles we have are salt and iron oxide. When we analyze it we typically see a lot of iron chloride, stuff that washes out fairly easily. It is not sticky or anything like that. It tends to return to the silver clean apperance every time after we have washed it.

PIERCE: You noted on your slide that the glass prefilter you used was rated at 60 - 65% ASHRAE efficiency. What was the ASHRAE efficiency rating of the stainless prefilter?

BURNS: It is a mist eliminator, it has no ASHRAE efficiency rating because it is not really an air filter. The closest figure I have is what the manufacturer says, 95 % removal for water droplets greater than five microns.

PIERCE: The suggestion I am making is that you might not be looking at apples-to- apples if they do not have the same efficiency.

BURNS: It is a totally different item, it is a mist eliminator. It is not an air filter and it is not sold as an air filter.

WEBER: This was an extremely interesting paper. It is not critical to your presentation, but would you say that there was anything done to the knit-mesh of glass and stainless steel to create a fixed pore size?

BURNS: For that filter, to my knowledge, they do not advertise any kind of fixed pore size, it is just a spun fiber. This is really just a totally new application. The gases we are dealing with here contain a lot of water vapor. It is a totally different application than a typical HVAC HEPA filter application. In this case, we found that this particular unit happened to help us out quite a bit.

PORCO:: If you want to find the ASHRAE efficiencies for moisture separators, there is a Mine Safety Appliances Co. report, MSAR-71-45 where you will find efficiencies for a moisture separator. Also in Air Cleaning Conference Proceedings, 14th Conf. p. 694.

FLEMING: Did you say that you were adding HCL to the airstream at some point?

BURNS: Yes, we burn PVC waste, so there is an acid gas. That is the source of the sodium chloride.

FLEMING: That is what I was going to ask, is the sodium coming from a neutralization of the HCL?

BURNS: Exactly.

FLEMING: Do you put it in after the quench or before the quench?

BURNS: It is before. Here is how the system works: from burning PVC or chlorinated waste, HCL or chlorine gas comes out of the incinerator. The scrubber takes it out and the pH in the scrubber solution quickly goes very low, so you have to neutralize it with a caustic. That creates the sodium chloride. The sodium chloride is usually what gets entrained into a fine salt mist that plugs the HEPA filters. Therefore, the concentration of sodium chloride you allow to build up in your loops is a very critical parameter.

FLEMING: What I am really getting to is, what effect does the corrosion have on the filters themselves? Up to this point, have you noticed any corrosive effects, any eating away of the filter as you rinse it off, anything like that?

BURNS: We have seen some. We have not seen any corrosion on that particular unit, but we have seen some signs of corrosion in our HEPA filter housings. Corrosion would be what is going to limit the life of the prefilter. I am surprised we have not seen any corrosion yet.

FLEMING: I am too.

BURNS: It stays pretty dry in there, so that is probably what limits corrosion.

FRANKLIN: From looking at your data, I concluded that you are really using the Otto-York pad as a mist eliminator. The pressure drop does not seem to be rising very much, and I assume all the particles are going through into your HEPA filter. Are you really collecting anything on the pad?

BURNS: Absolutely, yes. The unit is a very dark red when pulled out. The ideal situation for us would be to get a more efficient mist eliminator that would allow more loading. We are not loading the prefilter up as much as we would like to, because our HEPA filter is plugging. To even further optimize the system, we would like to find a more efficient mist eliminator to increase HEPA life.

FRANKLIN: Have you measured the amount of particles on the prefilter?

BURNS: Yes, we did weights before and after. The most we have seen is about three pounds.

DYMENT: I am a little puzzled as to why you decided to use a mist eliminator as a dry filter. Would it not have preformed better as a mist eliminator by using it earlier in the system, before you had heated the solution?

BURNS: We have a mist eliminator earlier in the system. We have a mist eliminator already in the process line.

DYMENT: Is it perhaps not a very good mist eliminator?

BURNS: I would not argue with that.

DEVELOPMENT OF AN AIR CLEANING SYSTEM FOR DISSOLVING HIGH EXPLOSIVES FROM NUCLEAR WARHEADS*

by

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Abstract

The Department of Energy (DOE) has a major effort underway in dismantling nuclear weapons. In support of this effort we have been developing a workstation for removing the high explosive (HE) from nuclear warheads using hot sprays of dimethyl sulfoxide (DMSO) solvent to dissolve the HE. An important component of the workstation is the air cleaning system that is used to contain DMSO aerosols and vapor and radioactive aerosols.

The air cleaning system consists of a condenser to liquefy the hot DMSO vapor, a demister pad to remove most of the DMSO aerosols, a high efficiency particulate air (HEPA) filter to remove the remaining aerosols, an activated carbon filter to remove the DMSO vapor, and a final HEPA filter to meet the redundancy requirement for HEPA filters in radioactive applications. The demister pad is a 4" thick mat of glass and steel fibers and was selected after conducting screening tests on promising candidates. We also conducted screening tests on various activated carbons and found that all had a similar performance. The carbon breakthrough curves were fitted to a modified Wheeler's equation and gave excellent predictions for the effect of different flow rates. After all of the components were assembled, we ran a series of performance tests on the components and system to determine the particle capture efficiency as a function of size for dioctyl sebacate (DOS) and DMSO aerosols using laser particle counters and filter samples. The pad had an efficiency greater than 99% for 0.1 μm DMSO particles. Test results on the prototype carbon filter showed only 70% efficiency, instead of the 99.9% in small scale laboratory tests. Thus further work will be required to develop the prototype carbon filter.

I. Introduction

This study is a continuation of the development previously described of an air cleaning system in support of the DOE nuclear weapons dismantlement program in which hot DMSO sprays are used to dissolve the HE from nuclear warheads.(1) The DMSO spray generates a high concentration of aerosols containing dissolved HE that must be contained and filtered by HEPA filters in the exhaust line to prevent HE or potential radioactive contamination from being released to the

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*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-ENG.45.

atmosphere. In our previous study, the exhaust from the dissolution workstation was exhausted directly into wooden frame HEPA filters.(1) These HEPA filters showed rapid plugging from the DMSO aerosols and developed leak paths through chemical attack by the DMSO. The exhaust system was criticized by reviewers of the previous paper for not using a demister to remove the bulk of the DMSO mist prior to reaching the HEPA filter. This paper presents the results of our recent efforts to develop a more robust exhaust filtration system for the HE dissolution workstations.

II. Air Cleaning System for the HE Dissolution Workstation

The major components of the air cleaning system for the HE Dissolution Workstation are shown in the schematic in Figure 1. The air cleaning system consists of a condenser to chill and condense the hot DMSO vapor, a demister pad to remove most of the DMSO aerosols, a high efficiency particulate air (HEPA) filter to remove the remaining aerosols, an activated carbon filter to remove the DMSO vapor, and a final HEPA filter to meet the redundancy requirement for HEPA filters in radioactive applications. An inlet valve connected to the workstation is used to vent the workstation chamber with HEPA filtered air.

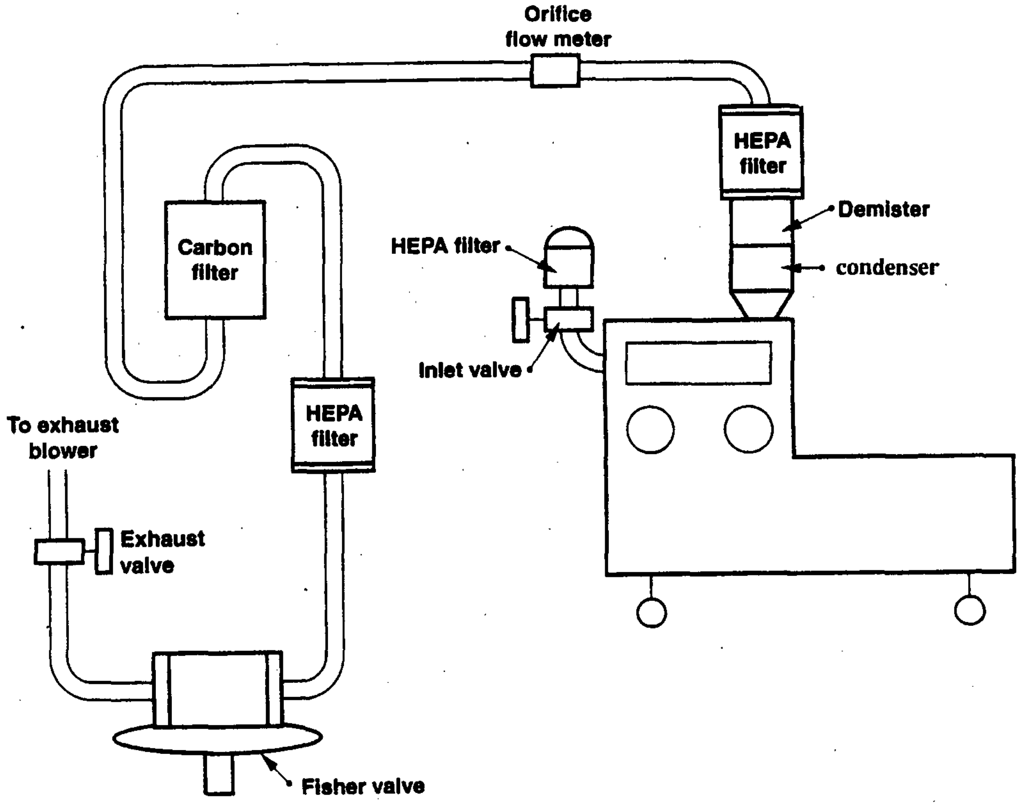

Figure 1 Schematic of exhaust system on the HE dissolution workstation.

One of the most important safety features of the exhaust system is the Fisher regulator valve. The Fisher valve controls the amount of vacuum applied to the workstation by opening or closing the valve as the workstation vacuum drops below or increases beyond a preset vacuum (usually 1 inch of water) respectively. A vacuum control line (not shown in Figure 1) from the workstation to the diaphragm of the Fisher valve controls the opening of the valve. Maintaining a negative pressure within the workstation insures that the contaminants do not leak out into the workplace. When the inlet valve to the workstation is closed, the building exhaust blower pulls an increasing vacuum on the workstation until the Fisher valve is nearly closed. The Fisher valve is still cracked slightly open to draw a small flow through the workstation due to unintentional leaks in the workstation and components of the exhaust system. Generally this flow is about 1 cfm. The leak flow should be minimized to avoid drawing an excessive amount of DMSO aerosol and vapor through the exhaust system.

In addition to controlling the workstation vacuum during normal operations, the Fisher valve also provides a rapid exhaust flow under accident conditions when the workstation barrier is breached. The most likely scenario for a breached barrier is the loss of a glove. Under this condition, the workstation vacuum drops to nearly 0 vacuum (atmospheric pressure), and the Fisher valve opens fully. This pulls the maximum air flow from the workstation into the exhaust. The exhaust system was designed with minimal restriction to this flow.

A photograph of the front side of the HE Dissolution Workstation is shown in Figure 2. The heated DMSO reservoir and the pump for the DMSO spray are located in the lower, covered portion of the workstation. Hot water is used to heat the DMSO liquid to 150-155 °F by means of a heat exchanger also located in the lower part of the workstation. The dissolution is performed in the 18 ft^3 chamber having glove ports and a viewing window. An access door on the right side of glove ports is used to install and remove the HE assembly. The exhaust condenser, demister and first HEPA filter are mounted directly on the roof of the workstation. Condensate from the condenser and the demister can freely drip back into the workstation. The carbon filter, second HEPA filter, Fisher valve, and exhaust valve are mounted on the rack to the left of the workstation.

Figure 3 shows the side view of the workstation as well as the exhaust rack on the right. The cover plate to the side access door is clearly visible. The access door is opened and closed by using a turn screw to slide the access door along tracks. The exhaust train consisting of a condenser, demister, and first HEPA filter are seen directly over the access door. The remainder of the exhaust system is mounted in the rack on the right. Note that the rack has a duplicate set of components to accommodate a second workstation. A detailed view of the exhaust rack is shown in the photograph in Figure 4. This figure also shows the inlet valve and HEPA filter leading to the workstation.

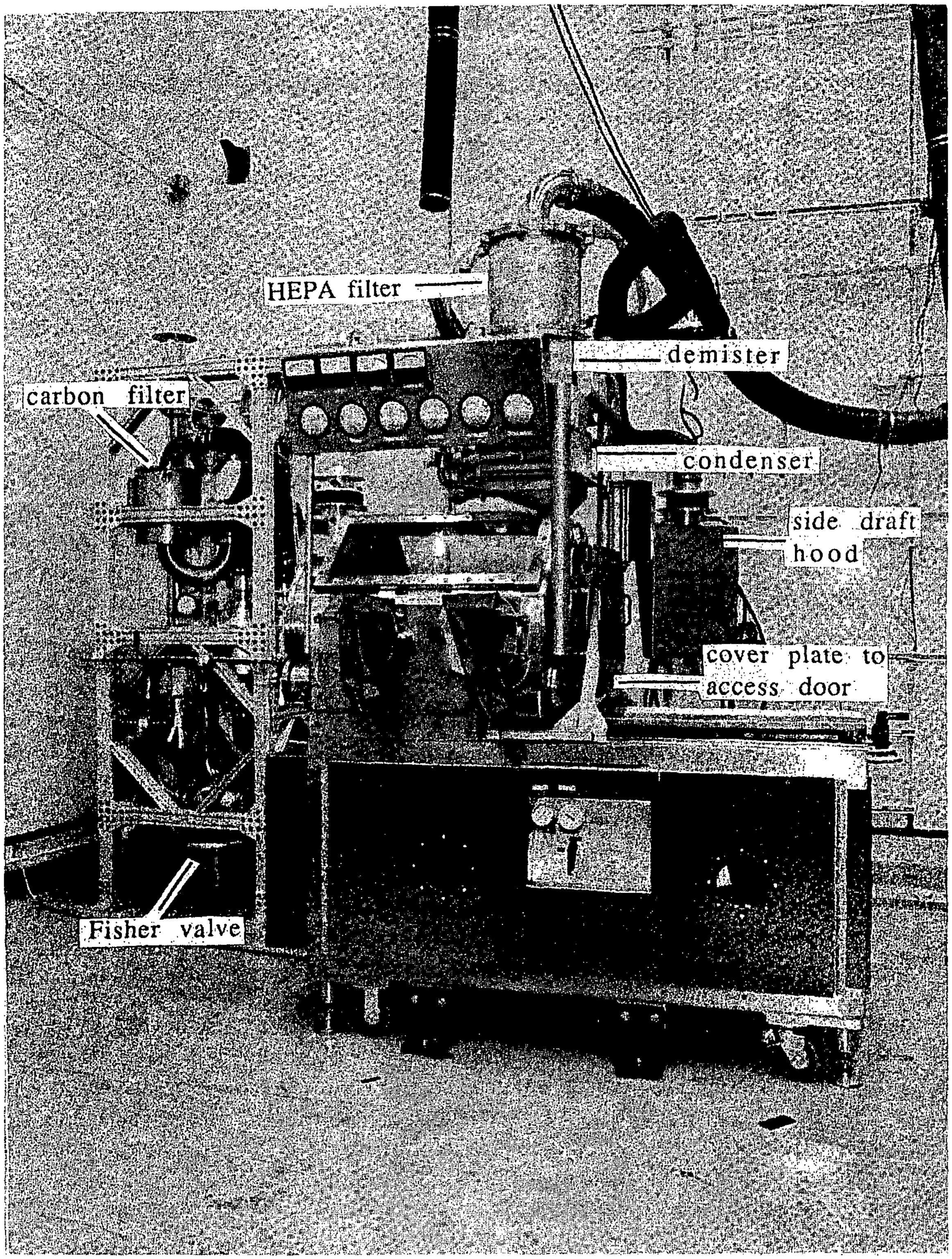

Figure 2. Photograph of the front side of the HE Dissolution Workstation with the exhaust rack on the left side.

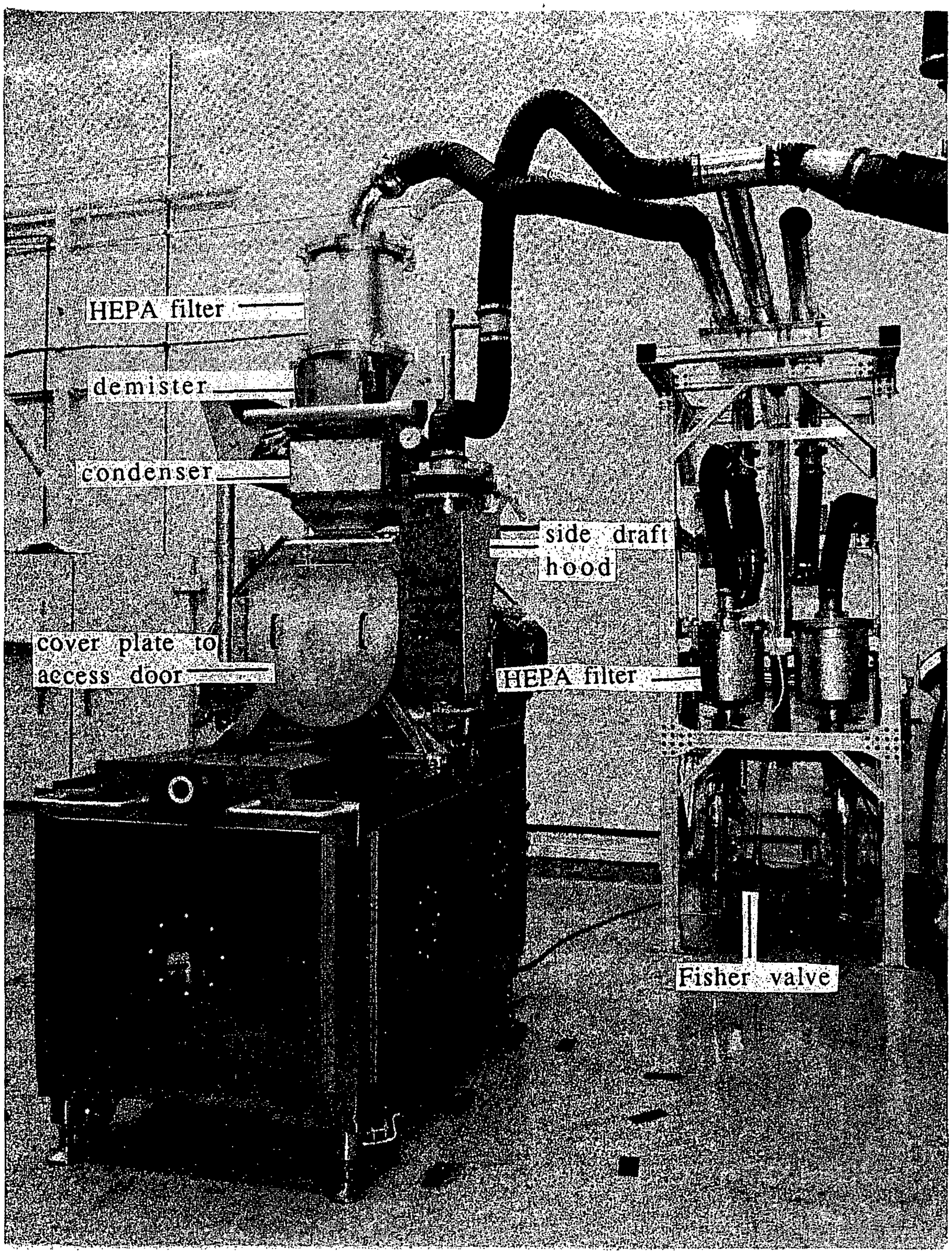

Figure 3. Photograph of the side view of the HE Dissolution Workstation with the exhaust rack shown on the right side. Note that the exhaust rack contains a duplicate set of components for a second workstation.

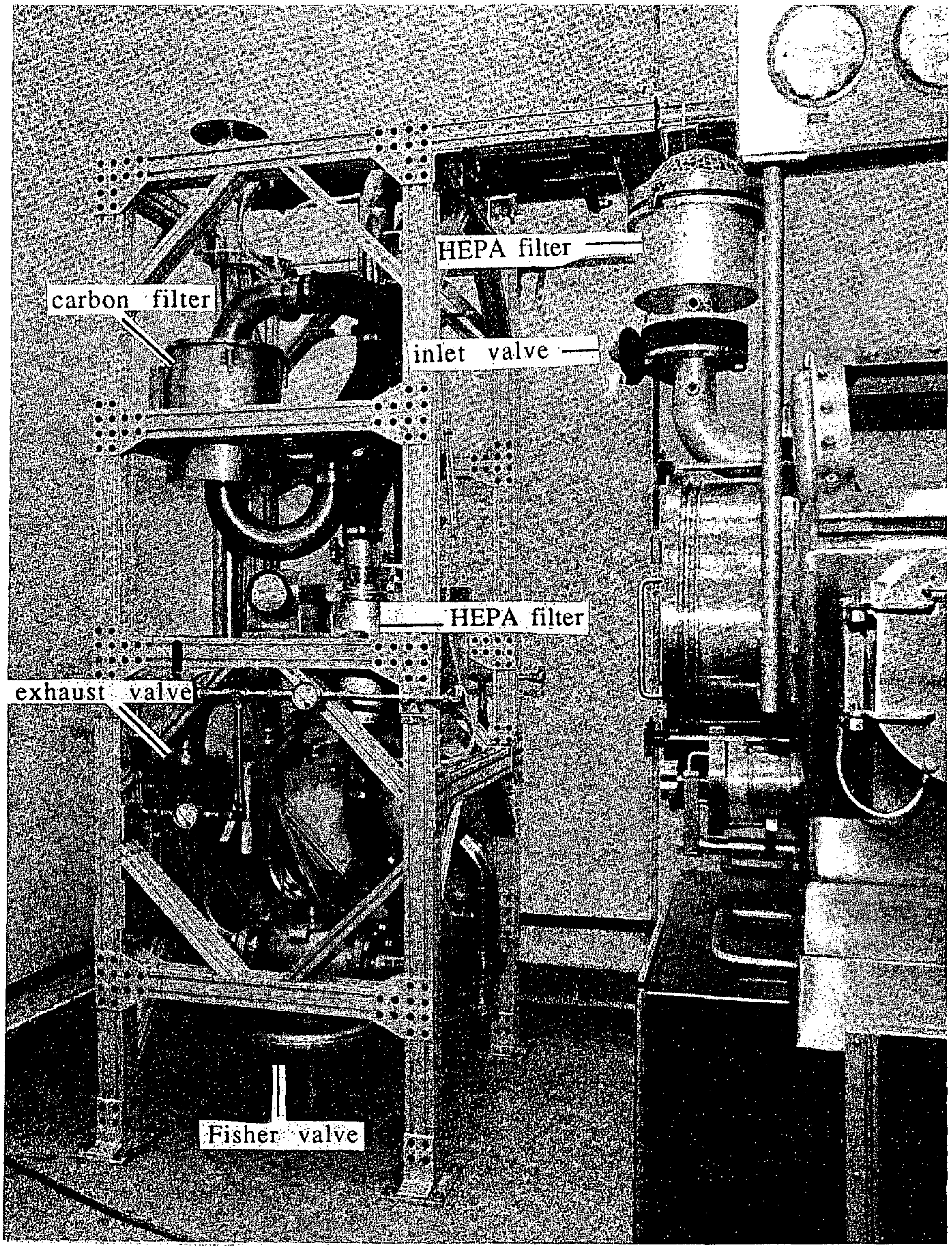

Figure 4. Photograph of the exhaust rack showing the carbon filter, HEPA filter, Fisher valve and exhaust valve. The HEPA filter and inlet valve to the workstation are also seen in this photograph.

From the point of view of the air cleaning system, the HE dissolution operation can be divided into two phases, a dissolution phase and a venting phase. After the HE assembly is mounted on a fixture and placed inside the workstation, the inlet valve is closed and the hot DMSO spray turned on. In this dissolution phase the workstation is filled with DMSO aerosols and vapor. The only flow through the workstation into the exhaust is due to leaks. When operators need to make adjustments or other operations inside the workstation, the spray is first turned off and the inlet valve opened. This pulls HEPA filtered air through the workstation and sweeps out DMSO aerosols and vapor. The workstation is vented, and personnel are electrically bonded to the workstation prior to entry through the glove ports to prevent the unlikely occurrence of a spark from human electrostatic discharge. This phase of the dissolution operation is the vent phase. The operating parameters during the two phases and during an actual operation are shown in Table 1. We also tabulated some of the measurements made during a preliminary test to demonstrate the actual operation. The exhaust flow and temperatures in the air cleaning system are expected to differ slightly during the venting phase in production operations because the exhaust blowers are stronger than that used in our tests.

Table 1. Operating parameters in the HE Dissolution Workstation (WS).

	Steady State Simulation		
Parameter	Dissolution	Venting	Actual Operation*
Exhaust flow	1 cfm	20 cfm	1-20 cfm
DMSO liquid reservoir temp.	150+/-3 °F	150+/-3 °F	145-155 °F
WS interior air temp.	127+/-5 °F	127+/-5 °F	----
WS exterior surface temp.	107+/-3 °F	107+/-3 °F	----
Condenser inlet temp.	65+/-5 °F	105+/-5 °F	58-107 °F
Condenser exit temp.	44+/- 2 °F	52+/-3 °F	50-56 °F
Demister inlet temp.	44+/- 2 °F	52+/-3 °F	50-56 °F
Demister exit temp.	65+/-3 °F	55+/-3 °F	53-67 °F
HEPA 1 exit temp.	72+/- 2 °F	60+/-3 °F	----

*Note that not all of the temperature measurements were taken during the actual operation. The missing data falls between the 1 and 20 cfm steady state data.

The most significant improvement over the previous exhaust system was the addition of a condenser and demister at the exhaust port.(1) The condenser consists of tightly packed stainless steel tubes in which Fluorinert, FC-77, chilled to 40 °F, flows at 3 gallons/min. We used Fluorinert as the heat exchange medium instead of water because of incompatibility issues with water in case the condenser develops a leak. The 130 °F exhaust, which contains DMSO/HE aerosols and saturated DMSO vapor, is cooled to 50-56 °F under typical conditions. The condenser performance was selected to condense as much of the DMSO vapor as possible without causing the DMSO to freeze. Although pure DMSO freezes at 65.4 °F, we did not observe any evidence of freezing, presumably due to the freezing point lowering by the dissolved HE. By condensing out the DMSO vapor into the liquid state, most of the DMSO is removed by the condenser tubes or by the demister. Locating the condenser and demister directly above the workstation allows condensate to drop back into the workstation.

We evaluated how quickly the workstation is vented after the DMSO spray is turned off and the inlet valve opened to establish a time limit before the side access door can be opened to prevent DMSO aerosols from contaminating the workplace. Figure 5 shows the concentration of DMSO aerosols measured in the exhaust of the workstation before the condenser while the inlet vent is open and a constant 20 cfm of air passes through the workstation. Separate measurements were made with the waist and the polar spray manifolds operating normally except for the inlet valve being open. These spray manifolds are two of several different types that are used in the dissolution operation. Figure 5 shows that when the spray is turned off, the aerosol concentration decreases very quickly. After 1 minute, the concentration decreased by about 70%, and after 3 minutes, by 99%. These aerosols have an average diameter of 0.1 μm and behave like gas. Figure 6 shows the same data on a logarithmic scale. The aerosol venting will be much faster in the production operations since the venting flow will be about 30 cfm instead of 20 cfm in our tests.

The release of DMSO vapor from films of hot DMSO on the interior workstation walls, the spray manifold fixture, and the cleaned assembly is expected to be the primary source of DMSO release into the workplace. Allowing the workstation to vent until most of the liquid film is drained and the temperature reduced before the side door is opened will mitigate the release of DMSO vapor. No tests were conducted to establish these time limits. A side draft hood shown in Figures 2 and 3 is intended to mitigate the vapor release when the cleaned assembly is removed from the workstation chamber.

Since we have demonstrated in our previous study that the DMSO sprays are flammable, we set a 1 minute waiting period before workers can work inside the workstation using the butyl rubber gloves after turning off the spray. This time limit was based on computations to establish how quickly the spray droplets would settle out in the workstation. The typical size of the droplets ranged from 107 to 120 μm, based on data from the spray nozzle manufacturer, Bete Fog Nozzle Company (Greenfield, MA). Willeke and Baron showed that the fraction of particles, N, remaining after time, t, is given by (2) .

$$N = \exp(-V_g t / H) \qquad (1)$$

$$V_g = 0.003 \rho_p d_p^2 \qquad (2)$$

where N = fraction of particles of diameter d_p remaining

V_g = settling velocity, cm/s

t = time, s

H = height at the start of settling, cm

ρ_p = particle density, g/cc

d_p = particle diameter, μm

We used Equations 1 and 2 to compute the settling times for different size DMSO droplets and plotted the results in Figure 7. To be conservative, we assumed that all the droplets were located at the ceiling of the workstation chamber, 3 feet. We see that the spray droplets greater than 50 μm will be gone in less than one minute. Since we have shown in a separate study that it is only possible to ignite the DMSO spray droplets and not the small aerosols, waiting for one minute after the spray is turned off will eliminate any potential fire hazard from human electrostatic discharge.[3]

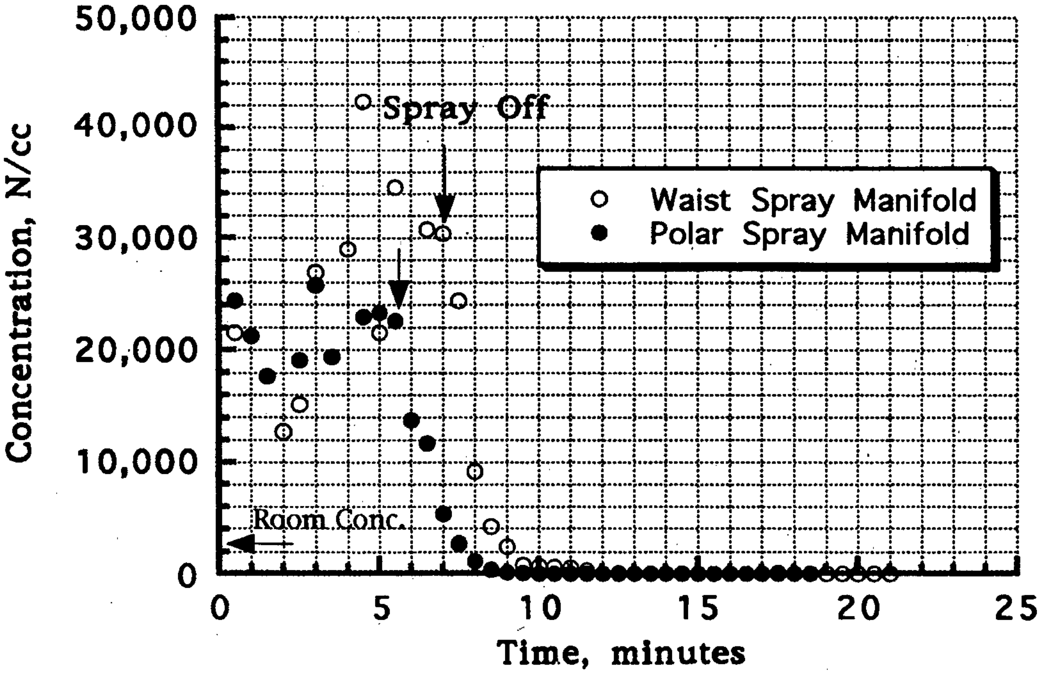

Figure 5. Concentration decay measurements using the polar and waist spray manifolds.

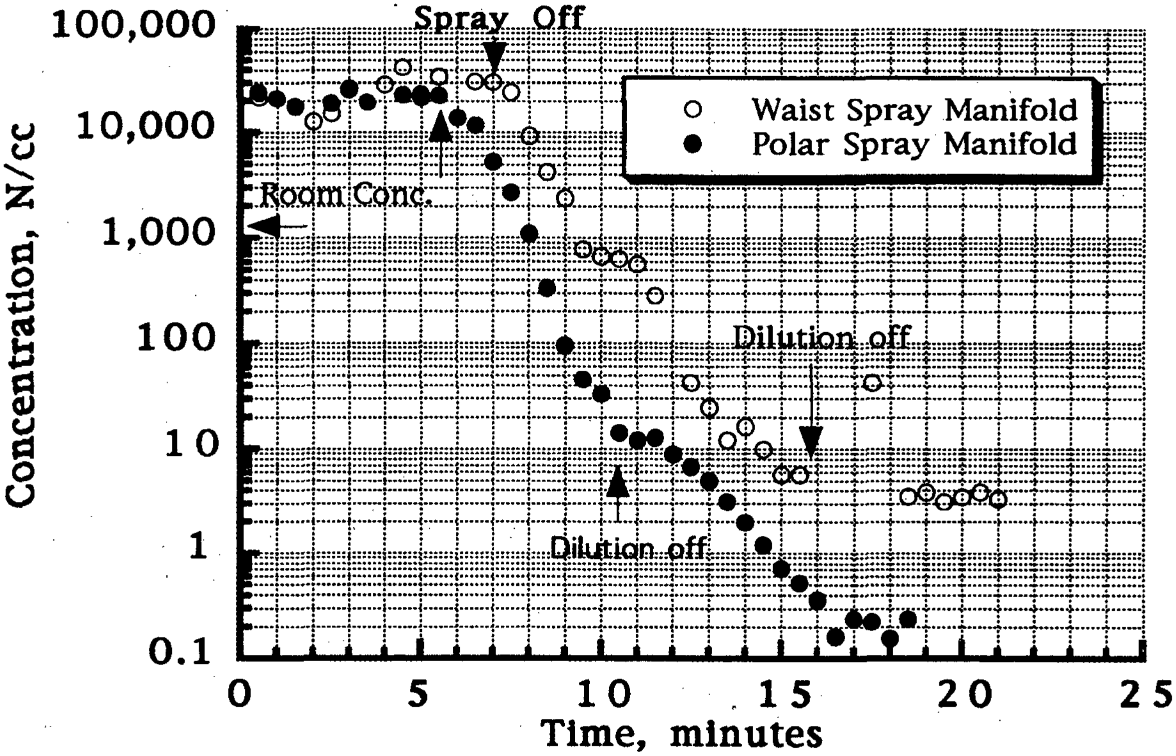

Figure 6. Concentration decay measurements using the polar and waist spray manifolds

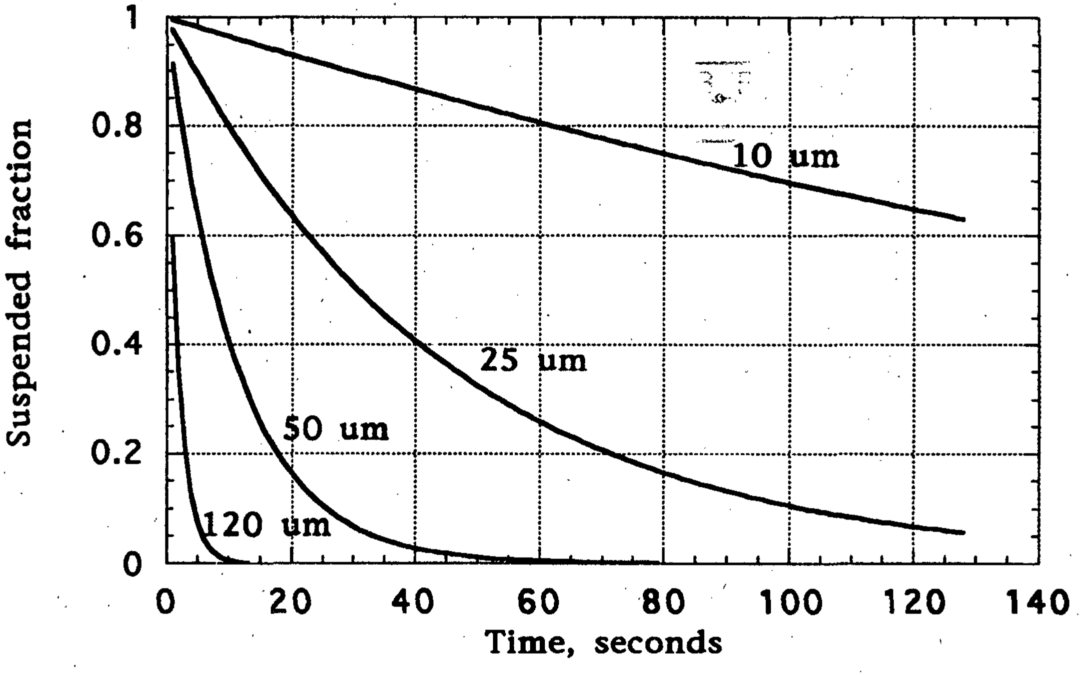

Figure 7. Sedimentation loses as a function of time for different size DMSO droplets.

III. Demister Evaluation

We conducted a series of screening tests to select the most promising demister for use in the air cleaning system. The candidate demisters were chosen based on the performance data provided by the different manufacturers. Most of the standard demisters used in nuclear exhaust systems were not available in smaller sizes and were therefore not evaluated. The most promising demisters were purchased from Amistco (Alvin, TX 77511) and from Coastal Technologies, Inc. (Hampton, SC 29924) and are designated Am and CT respectively. Each of the test samples were 12" x 12" x 4". A description of the different demisters is given in Table 2.

Table 2. Description of selected demisters evaluated in our study.

Demister	Bulk density, lb/cu. ft	Composition	Fiber volume fraction	Fiber Dia. inches
Am GLEC	15	90% 304 ss fiber 10% glass fiber by weight	0.027 ss 0.010 glass 0.037 total	0.011 ss 0.00045 glass
Am 1112	12	304 ss fiber	0.024	0.011
Am 1105	5	304 ss fiber	0.010	0.011
Am 0607	7	304 ss fiber	0.014	0.006
CT 1111	10.8	316 ss fiber	0.022	0.011
CT 911	9	316 ss fiber	0.019	0.011
CT 806	8	316 ss fiber	0.016	0.006

Our screening tests consisted of mounting each demister in a frame and measuring the penetration of DOS aerosols through the demister at 1 and 20 cfm flow rate. Since the demister has a 1 ft^2 cross-sectional area, the flow velocity through the filter is either 1 or 20 ft/min.. DOS aerosols were generated using the Laskin nozzle generator from the Virtis Co. (Gardiner, NY). We used the Aerodynamic Particle Sizer from TSI (Minneapolis, MN) to measure the DOS particles before and after the demister. The ratio of the downstream to the upstream concentration at each particle size gave the demister penetration at that size. Tables 3 and 4 show the test results for the demister penetration measurements at 1 and 20 cfm respectively.

Table 3. DOS penetration measurements on candidate demisters at 1 cfm.

		DOS Penetration at Indicated Diameter			
Demister	DP, in. H2O	0.5 µm	1.0 µm	2.0 µm	3.0 µm
Am GLEC	0.004	0.33	0.34	0.12	0.05
Am 1112	<0.001	0.95	0.86	0.67	0.38
Am 1105	<0.001	0.91	0.83	0.70	0.45
Am 0607	<0.001	1.00	1.00	0.80	0.60
CT 1111	<0.001	0.88	0.83	0.65	0.48
CT 911	<0.001	0.90	0.85	0.72	0.56
CT 806	<0.001	1.00	0.95	0.88	0.70

Table 4. DOS penetration measurements on candidate demisters at 20 cfm.

		DOS Penetration at Indicated Diameter			
Demister	DP, in. H2O	0.5 µm	1.0 µm	2.0 µm	3.0 µm
Am GLEC	0.165	0.80	0.65	0.38	0.15
Am 1112	<0.001	0.86	0.85	0.80	0.68
Am 1105	<0.001	1.00	0.98	1.00	0.83
Am 0607	<0.001	0.92	0.92	0.92	0.90
CT 1111	0.002	0.90	0.90	0.90	0.80
CT 911	0.003	0.98	0.94	0.95	0.90
CT 806	0.002	0.95	0.95	0.83	0.60

Based on these screening tests, the best demister for our application was the Amistco GLEC demister. Note that this demister also had significantly higher pressure drop than the other demisters because of the glass fiber blend. We did not evaluate the ease of liquid drainage as part of our screening test because we were primarily concerned with high removal efficiency. In effect, we viewed the demister as a disposable prefilter.

Figure 8 shows a photograph of the GLEC demister pad selected for our study. The demister pad consists of multiple layers of glass fiber cloth with steel fibers interwoven to provide rigidity and some space between the layers. The high collection efficiency and pressure drop for the GLEC demister is due to the small diameter glass fibers (12 µm) that make up the yarn in the cloth layers.

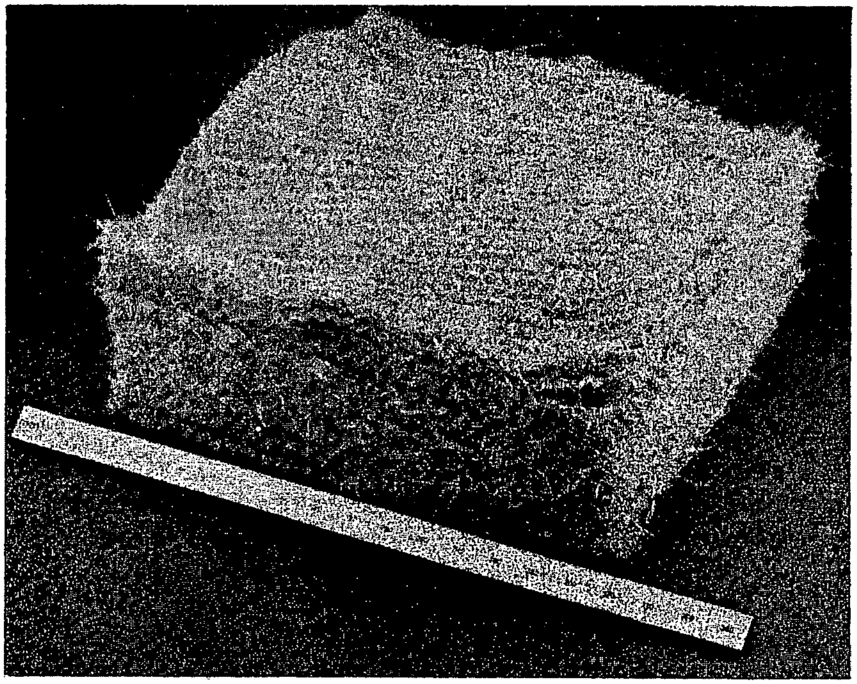

Figure 8. Photograph of the Amistco GLEC glass/steel fiber demister next to 410 mm ruler.

We then evaluated the performance of the GLEC demister using DOS aerosols at room temperature and DMSO aerosols under actual operating conditions in the HE dissolution workstation. The DOS aerosols were generated using a Laskin nozzle generator and were injected into the workstation. We determined the penetration of DOS aerosols through the demister from the ratio of the downstream to the upstream concentration measurements. We used a LASAIR laser particle counter from Particle Measuring Systems (Boulder, CO) to measure the aerosols.

Figures 9 and 10 show the results of our DOS penetration measurements on two different GLEC demisters at 1 and 20 cfm. Note that the maximum DOS penetration at 1 cfm and 20 cfm occur at about 1.4 µm and 0.5µm diameter respectively. The aerosol penetration at 20 cfm is also much higher than at 1 cfm. These observations are consistent with filtration theory and demonstrate that diffusional deposition is the primary mechanism responsible for capturing the submicron particles.

We obtained separate measurements with the demister at 70 °F and at 40 °F to determine what effect the temperature would have on the demister performance. The data collected at 40 °F are shown as dark points, whereas the data collected at 70 °F are shown as open points. From Figures 9 and 10, we see that at 20 cfm, the tests at 40 °F showed a higher penetration at the smaller particle sizes than the corresponding tests at 70 °F. This is consistent with the diffusional capture mechanism whereby particles have lower Brownian motion at lower temperatures and consequently are not captured as well as at the higher temperatures. The temperature effect on the aerosol penetration is less noticeable at 1 cfm than at 20 cfm because Brownian capture is already dominant at the low flow rate, and increasing the temperature would not make a large change.

The higher penetration at the 1 cfm flow in Figure 10 compared to the 1 cfm flow in Figure 9 is most likely due to greater leak paths through the demister. It is well established that filters having leaks have much higher penetrations at low flow rates than filters without leaks because of the preferential flow through leaks. The preferential flow through leak paths does not occur at higher flow rates as shown by the same penetration in Figures 9 and 10.

We also measured the penetration of DMSO aerosols through the demister at 1 and 20 cfm under steady state conditions with constant DMSO spraying. Although the DMSO spray normally would be turned off before the inlet valve is opened, we conducted the tests to see if there were any differences in performance between the DMSO and the DOS tests. We also measured the DMSO concentration before the condenser to characterize the challenge DMSO aerosols. Figure 11 shows the results of the DMSO concentration measurements at 1 cfm. An important finding in this figure is that the DMSO challenge aerosols have an average diameter of 0.1 µm. These are extremely small aerosols and generally require high efficiency filters to remove them. Figure 11 also shows the condenser is removing about 50% of the aerosols. This is not surprising considering the thermal gradient that is driving the DMSO aerosols to the cold condensing tubes. A portion of this removal efficiency also may be an artifact of the aerosol measurement. The DMSO

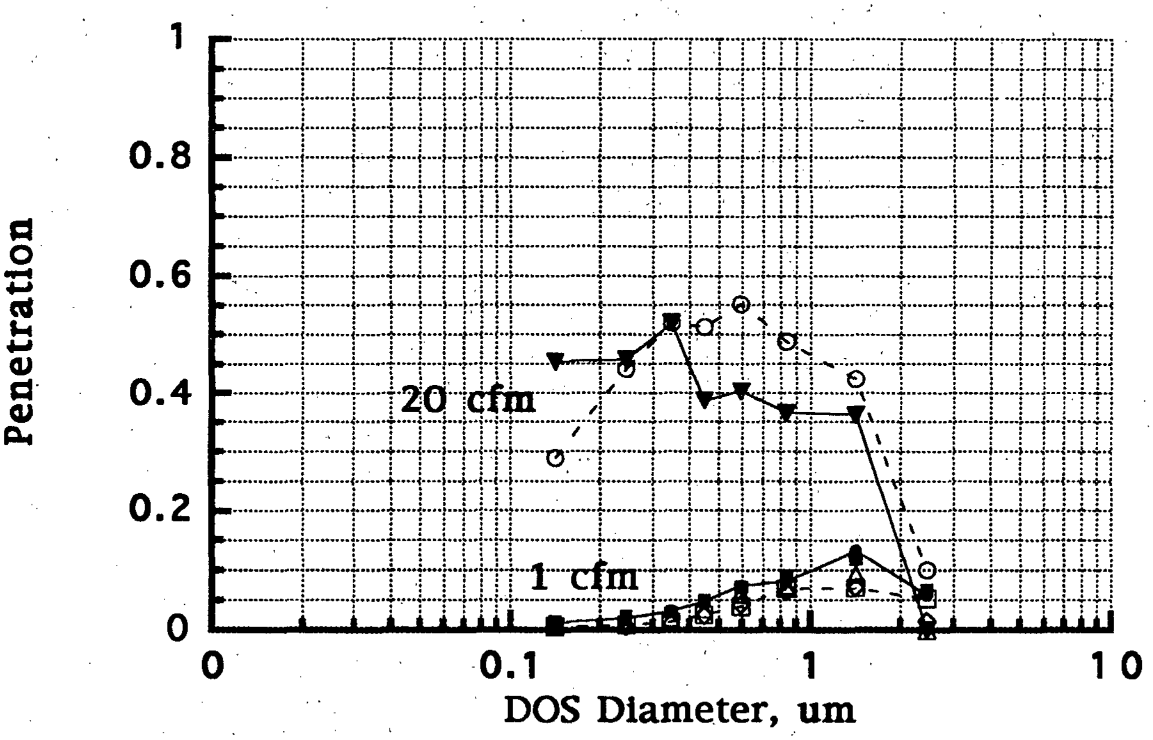

Figure 9. Penetration of DOS aerosols through a demister at 1 and 20 cfm exhaust flow. The open data points were taken at 70 °F. The solid data points were taken at 40 °F.

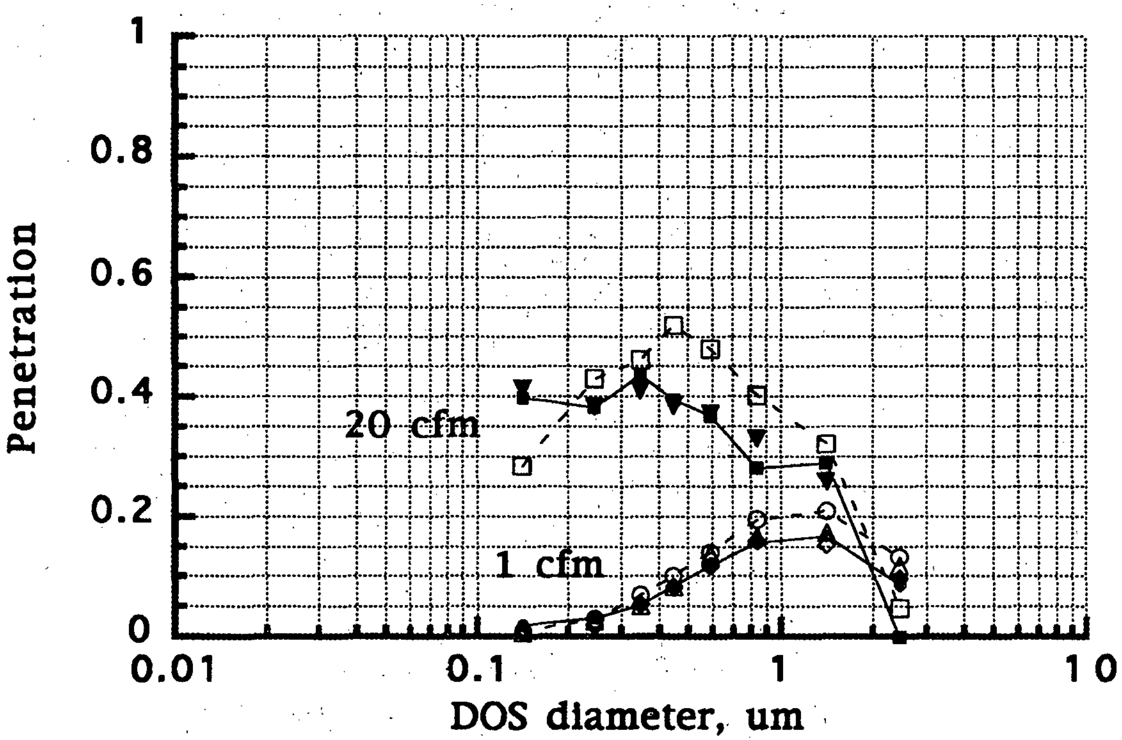

Figure 10. Penetration of DOS aerosols through another demister at 1 and 20 cfm exhaust flow. Open data points were taken at 70 F. Closed data points were taken at 40 F.

aerosol concentration may have decreased due to evaporation in the diluter prior to the laser counter as the temperature increased from 44 °F at the condenser exit port to 70 °F at the diluter.

However, an unexpected finding in the 1 cfm test is that the aerosol penetration increases with increasing particle diameter until 65% of the particles at 0.3 µm penetrate the demister as shown in Figure 12. We did not have data beyond 0.3 µm because we did not have measurable counts with the 100:1 dilution prior to the laser counter. The DMSO penetration in Figure 12 is in sharp contrast to the DOS penetration in Figures 9 and 10, where the demisters have very low penetration in this size range. We have carefully reviewed the data in Figures 11 and 12 and verified that the results are not due to coincidence counting, a common measurement error. The unexpected results are also not due to Brownian motion effects as previously discussed with the DOS tests. In addition, we were able to repeat the results several times.

We believe that the high penetration with DMSO aerosols is an artifact resulting from a decrease in the pre-demister aerosol concentration due to evaporation as the 44 °F sample is heated to 70 °F in the sampling lines and diluter. The aerosol sample after the demister is only heated from 65 °F to 70 °F in the sampling lines and diluter and therefore would not suffer much evaporation. The disproportionate sample heating before and after the demister is the most probable cause of the unusually high demister penetration in Figure 12.

Anomalies were also found in the DMSO aerosol measurements at 20 cfm. Figure 13 shows the DMSO aerosol concentration measurements taken at 20 cfm before the condenser, before the demister, and after the demister. We see that the concentration of DMSO aerosols has increased significantly after passing through the condenser. This is opposite to what was seen in Figure 11 at 1 cfm. The only explanation is that the saturated DMSO vapor condensed into particles at a faster rate than the DMSO particles were deposited on the cooling tubes. Note in Table 1 that the temperature across the heat exchanger drops 53 °F at 20 cfm and only 21 °F at 1 cfm. The greater temperature drop coupled with the rapid transport through the condenser are the likely reasons for the increase in particle concentration across the condenser. Sampling artifacts due to heating and cooling of the aerosols and the subsequent evaporation and condensation are probably also reflected in Figure 13. Accounting for these effects would increase the difference in aerosol concentration before and after the condenser.

However, the most striking anomaly in the DMSO measurements at 20 cfm is the rapid increase in aerosol penetration with decreasing particle size as shown in Figure 14. Based on the DOS measurements shown in Figures 9 and 10, the aerosol penetration in Figure 14 should decrease with decreasing particle size, not increase. Filtration theory also supports the contention that the Brownian motion will increase with decreasing particle size and therefore result in decreased penetration. We were able to repeat the anomalous results and also verified that the laser counter was not in error due to coincidence counting. As previously

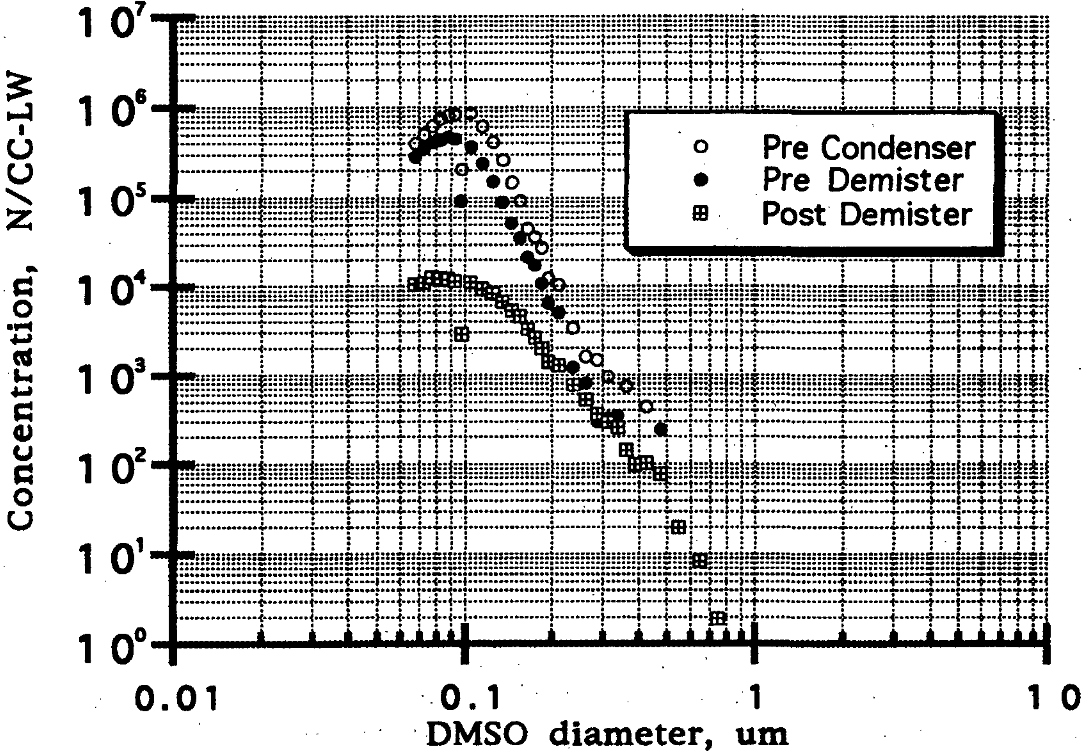

Figure 11. DMSO concentration before the condenser and before and after the demister at 1 cfm exhaust flow.

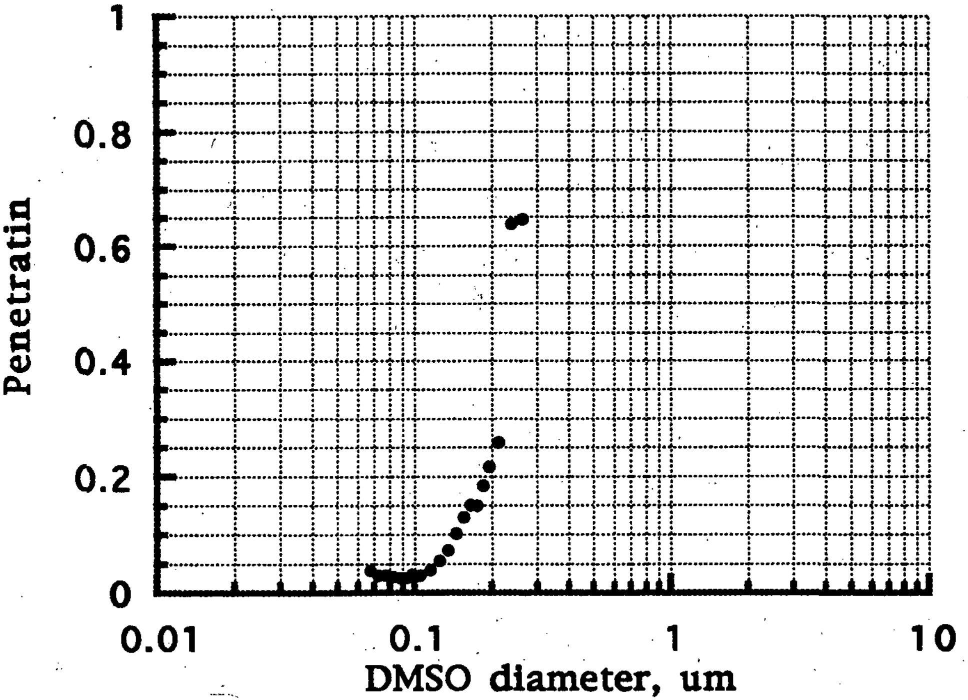

Figure 12. Penetration of DMSO aerosol through the demister at 1 cfm exhaust flow.

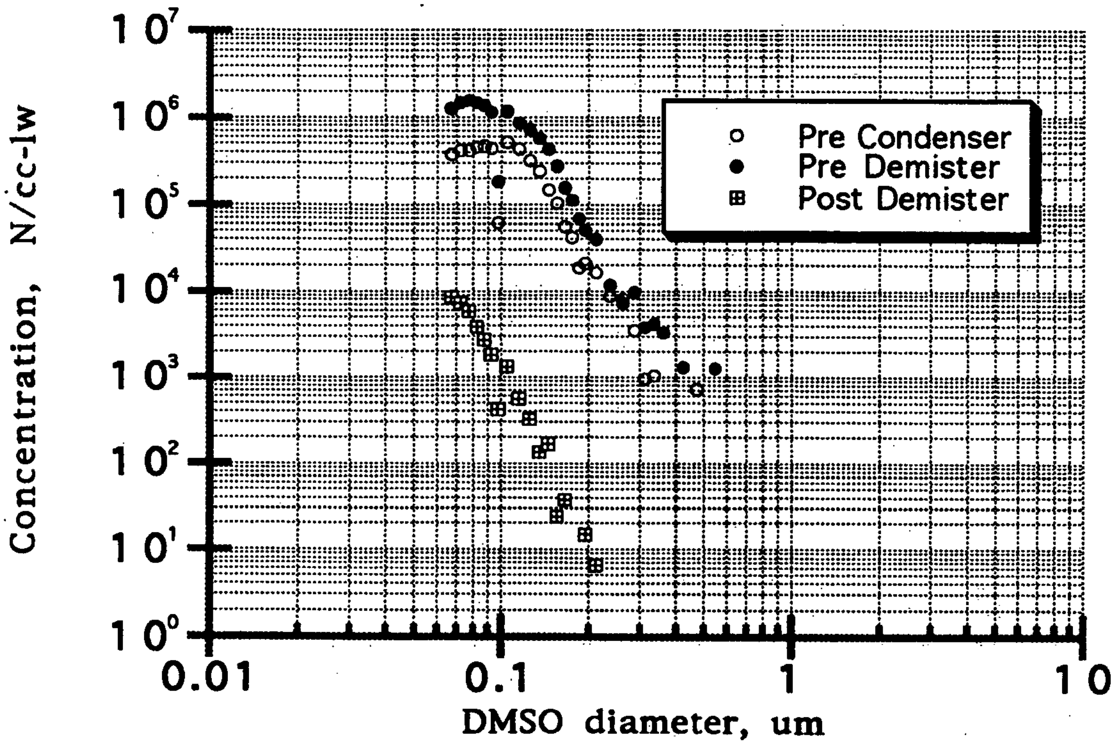

Figure 13. Concentration of DMSO aerosol before the condenser and before and after the demister at 20 cfm exhaust flow.

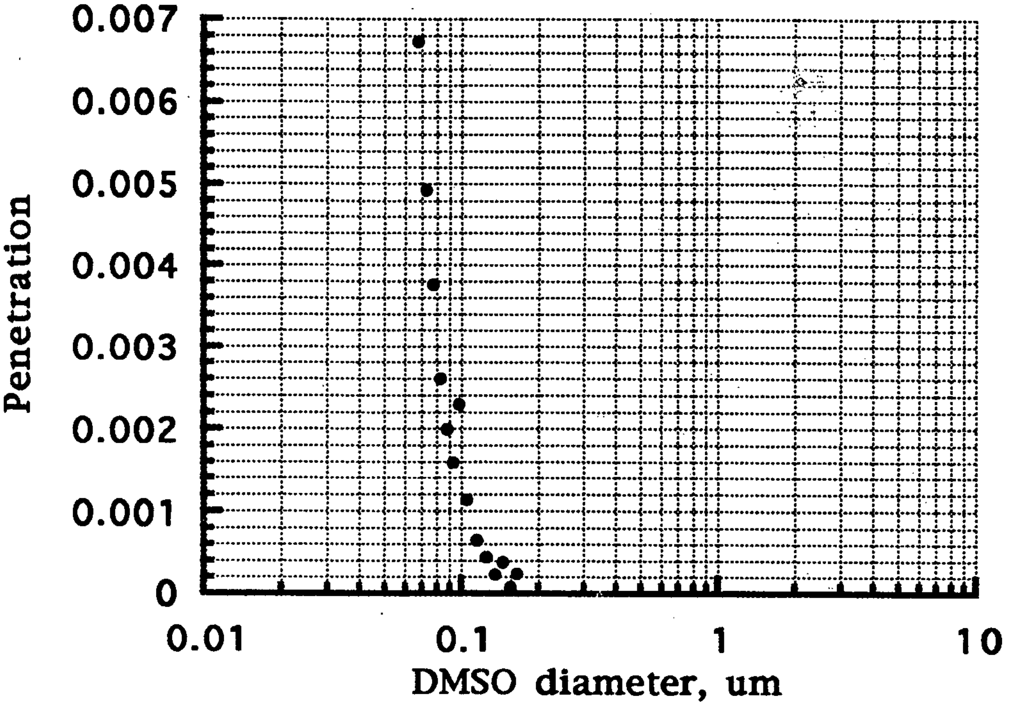

Figure 14. Penetration of DMSO aerosol through the demister at 20 cfm exhaust flow.

discussed with the 1 cfm data, we believe that the observed penetration curve in Figure 14 is an artifact resulting from changes in concentration due to condensation/evaporation due to temperature changes.

Another observation when comparing the DMSO aerosol penetration in Figure 14 with the DOS aerosol penetration in Figures 9 and 10 is that the demister removes about 100 times more DMSO than DOS. This large difference can only be explained in terms of other processes that are occurring in the demister than classical particle filtration. We can only speculate that DMSO condensation plays a major role in these observations.

In addition to the aerosol measurements with the LASAIR and HSLAS laser counters, we also measured the aerosol concentration using filter samples. Most of our filter measurements were made using MSA HEPA filter cartridges typically used in respirators. In some cases, we also used flat filter media samples. A major problem in all of these measurements was the hygroscopic nature of the DMSO. In our initial filter measurements, we observed a weight loss despite the accumulation of significant DMSO mass. We attributed this loss to the removal of adsorbed water on the filter when filtering DMSO aerosols and vapor. To mitigate this weight loss problem, we preconditioned all filter samples by taking baseline filter samples prior to the actual sample. Another problem with the filter samples was the rapid increase in weight after the filter was removed from the filter holder. To mitigate this problem, we measured the filter weight at periodic intervals (typically 60 seconds) and extrapolated to the time the filter was removed. In some cases, we obtained negative mass measurements as seen in Tables 5 and 7 despite our precautions. For the mass measurements before and after the condenser, the DMSO liquid would condense and accumulate in the filter holder and in the upstream sample line. This weight was measured separately.

Table 5. Concentration measurements of liquid DMSO in the exhaust of the Workstation at 1 cfm.

		Concentration, g/m3		
Location	test	Total	Aerosol	Condensate
pre-condenser	1	12.78	2.07	10.71
	2	9.16	2.45	6.71
pre-demister	1	2.64	0.54*	2.10
	2	----	0.12,0.11,0.067	----
post-demister	1	----	0.005*, 0.012*	----
	2	----	-0.011,-0.007	----

* Test conducted on a new demister. All other tests conducted on a used demister.

Using the procedures described, we measured the DMSO mass concentration before the condenser, before the demister and after the demister when the workstation was operated at 1 and 20 cfm under the conditions shown in Table 1. The test results for the 1 and 20 cfm measurements are shown in Tables 5 and 7 respectively. By taking the ratio of the mass measurements before and after the condenser and before and after the demister, we were able to determine the DMSO removal efficiency for the condenser and the demister. The mass removal efficiencies for the 1 and 20 cfm operations are shown in Tables 6 and 8 respectively. We did not compute efficiency values for negative values of the mass concentration.

Table 6. Removal efficiency for liquid DMSO in the exhaust of the Workstation at 1 cfm.

		Efficiency, %		
Component	test	Total	Aerosol	Condensate
condenser	1	79	74	80
	2	----	95,96,97	----
demister	1	----	99, 98	----
	2	----	----	----

Table 7. Concentration measurements of liquid DMSO in the exhaust of the Workstation at 20 cfm.

		Concentration, g/m3		
Location	test	Total	Aerosol	Condensate
pre-condenser	1	11.77	1.81	9.96
	2	----	----	----
pre-demister	1	5.72	1.09	4.63
	2	----	3.62*	----
post-demister	1	----	-0.013	----
	2	----	0.0053*	----

* Test conducted on flat filter sample and may include condensate.

Table 8. Removal efficiency for liquid DMSO in the exhaust of the Workstation at 20 cfm.

		Efficiency, %		
Component	test	Total	Aerosol	Condensate
condenser	1	51	40	54
	2	----	----	----
demister	1	----	-----	----
	2	----	99.9	----

Our measurements based on laser counts and filter weights show the demister has an efficiency greater than 99% for removing 0.1 µm DMSO aerosols. This data is shown in Figures 12 and 14 for the laser counts and in Tables 6 and 8 for the filter weight measurements. The demister also has a relatively high pressure drop due to the higher fiber volume fraction and small diameter glass fibers.

However, we have not demonstrated the ability of the GLEC demister to drain the DMSO liquid. Data collected on the weight gain of the demisters used in our efficiency studies and demonstration tests showed the demister could collect about 1 kg of DMSO when the pressure drop reached our limit of one inch of water at 20 cfm. The weight gains and corresponding pressure drops for 4 GLEC demisters were 1.57 kg at 0.8 inches, 1.17 kg at 1.1 inches, 0.92 kg at 1.1 inches, and 0.55 kg at 0.7 inches. We could not determine the number of dissolution operations per demister because separate tests were not conducted. However, we estimate each demister can be used for about three dissolutions before changing the demister. No further studies were conducted because we decided to replace the demister after each dissolution operation to avoid the possibility of HE accumulation in the demister. Thus, the demister in our air cleaning system is used as a disposable prefilter.

III. Carbon Filter

We developed a carbon filter to remove the DMSO vapor from the Workstation exhaust because commercially available units were either designed for much larger ventilation systems or had excessive pressure drops. The typical ventilation filter had a 2' x 2' cross sectional area and was designed for flow rates of 1,000 cfm or greater. Smaller annular cartridge filters were developed for military vehicle applications but had pressure drops that greatly exceeded the requirement of less than one inch of water at 50 cfm. In addition to the lack of suitable carbon filter units, there also was no information on the performance of carbon filters for removing DMSO vapors. Thus, we had to establish the basic adsorption characteristics in addition to the design parameters to develop the DMSO carbon filter. The initial step was to demonstrate that activated carbon was effective in removing DMSO vapors.

We conducted a survey test of eight different activated carbons to establish that activated carbon is effective in removing DMSO vapors and to identify the best carbon. The test carbons were packed into empty respirator cartridges having a total carbon volume of 112 cc, a diameter of 7.9 cm and a bed depth of 2.3 cm. The cartridges were filled with carbon poured through a tube having multiple screens and a 2 foot free fall to insure tight packing. Each of the cartridges were weighed before and after the test to establish the weight of the carbon and the weight gain due to adsorbed DMSO vapor. The test consisted of passing 29.4 l/min air containing 500 ppm (1.59×10^{-3} g/l) of DMSO vapor with less than 10% relative humidity at 25 °C through each cartridge. This flow rate corresponded to a flow velocity of 6 m/min since the area was 49 cm^2 (4.9 l/m). The efficiency of DMSO removal was determined by measuring the concentration of DMSO vapor before and after the cartridge using a Miran infrared analyzer (Foxborough Inc.). Since each of the tests were conducted until the carbon was saturated and had 0% efficiency, the increase in carbon weight represented the dynamic adsorption capacity of the carbon for DMSO.

Figure 15 shows the DMSO removal efficiency for each of the eight carbon canisters as a function of exposure time. All of the carbons have similar DMSO adsorption properties. However, sample G215 from PICA USA Inc. (Columbus, OH) had a slightly better performance than the other samples and was therefore selected for the carbon filter in our project. The carbon weight, adsorbed DMSO weight, and the pressure drop for each of the canisters is shown in Table 9.

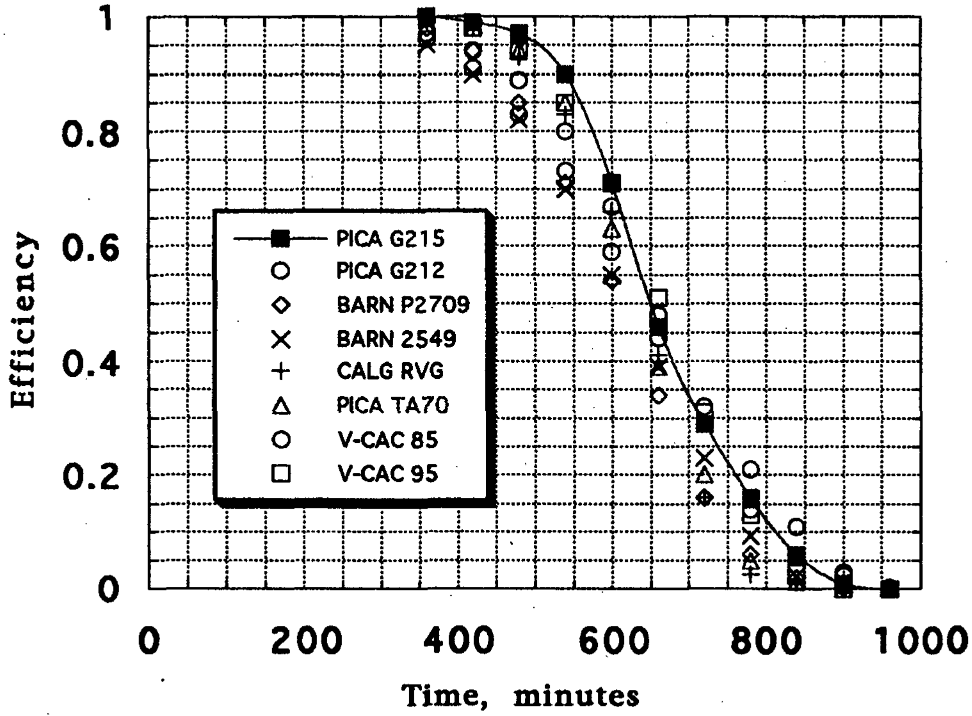

Figure 15 . Survey of carbon capacities plotted as efficiency versus exposure time at 6m/min flow velocity.

Table 9. Experimental measurements of carbon cartridge samples in screening tests at 6 m/min.

Sample	Carbon Weight, g	DMSO Adsorbed, g	Pressure Drop, in. H2O
PICA G215	45.9	31.6	0.31
PICA G212	42.6	31.3	0.21
BARN P2709	55.2	29.7	0.27
BARN 2549	47.7	30.4	0.20
CALG RVG	51.7	30.9	9.31
PICA TA70	51.1	30.6	0.30
V-CAC 85	44.3	31.9	0.29
V-CAC 95	45.8	32.5	0.31

We then conducted additional tests on new cartridges of PICA G215 at 14.7 and 43.9 l/min flow rates, which correspond to flow velocities of 3 and 12 m/min. These tests were needed to establish the adsorption parameters for the design of the carbon filter. Figure 16 shows the results of the three carbon canisters of PICA G215 tested at 3, 6 and 12 m/min flow velocity. We see that the faster flows results in shorter saturation times. The experimental measurements of the PICA G215 carbon samples are shown in Table 10.

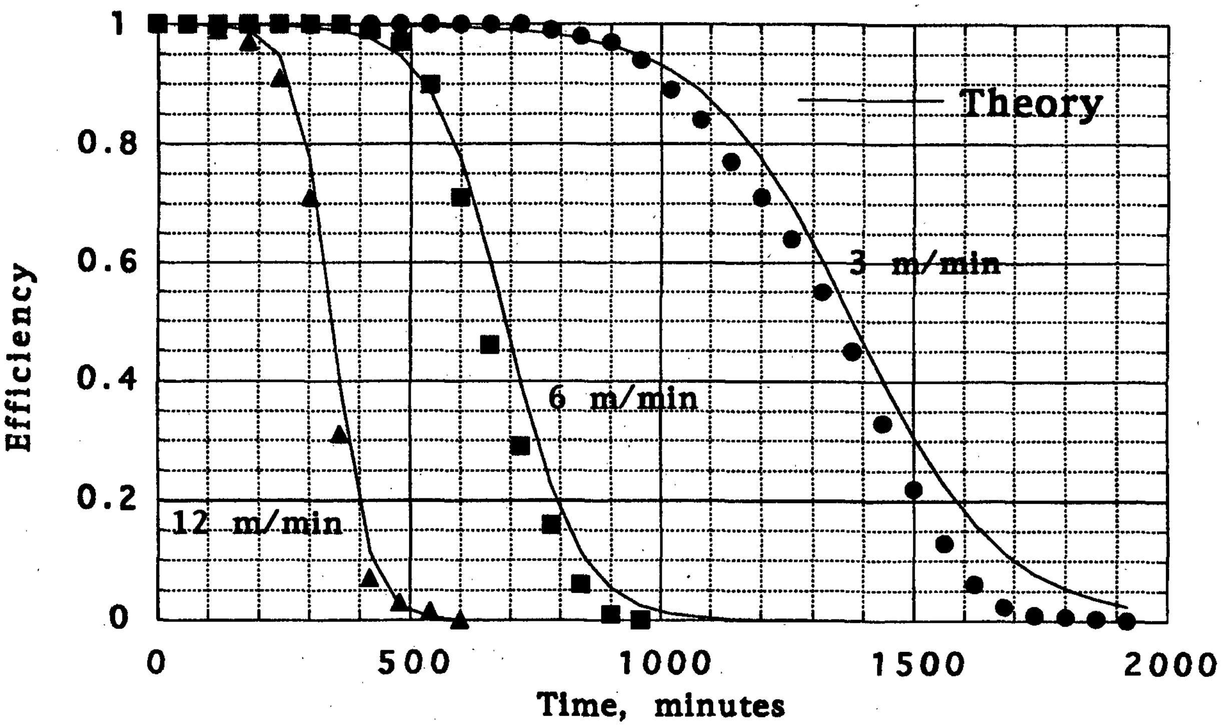

Figure 16. Efficiency of PICA G215 canisters at 3, 6 and 12 m/min flow velocity. Points are experimental data; solid lines represent theory.

Table 10. Experimental measurements of PICA G215 carbon samples in tests at 3, 6 and 12 m/min.

Velocity V m/min	Flow rate, l/min	Pressure drop in. H_2O	Carbon Wt W_c, g	DMSO Wt W_a, g	Saturated Capacity $W_s = W_a/W_c$	Carbon bulk density, ρ_c g/l
3	14.7	0.13	44.0	32.8	0.745	393
6	29.4	0.31	45.9	31.6	0.688	410
12	58.8	0.57	43.9	32.5	0.740	392

In order to design an activated carbon filter for removing DMSO vapor, it was first necessary to determine the adsorption capacity of the selected carbon for DMSO, W_s, and the coefficient, K_v, for the rate of adsorption. Once these two parameters are determined, theoretical equations can be used to determine the key design parameters for the gas filter. The dynamic adsorption capacity, W_s, was experimentally determined and is shown in Table 10. The kinetic coefficient, K_V, characterizing the rate of adsorption is derived from matching experimental data with a theoretical model. We used the modified Wheeler equation, shown in Equation 3 to derive the kinetic coefficient.[(4)]

$$t = W_s W_C/(C A V) + W_s \rho_C/(C K_V) \ln [(1 - E)/ E] \qquad (3)$$

where A = cartridge area, 4.9 l/m (49 cm^2)
C = DMSO concentration, 1.59×10^{-3} g/l (500 ppm)
E = DMSO removal efficiency
K_V = kinetic adsorption coefficient, $min.^{-1}$
ρ_C = carbon bulk density, g/l
t = time, minutes
V = flow velocity, m/min.
W_C = carbon weight in cartridge, g
W_a = DMSO weight adsorbed, g
W_S = DMSO saturated capacity = W_a/W_C, dimensionless

Values of K_v were determined by substituting the parameter values from Table 10 into Equation 3 and fitting each of the three equations to the corresponding efficiency curves in Figure 16. The least squares fits produced K_V values of 1369, 2750 and 4801 min^{-1} at 3, 6 and 12 m/min flow velocities respectively. To establish the velocity dependence of K_V, we plotted the values of K_V versus the flow velocity in Figure 17.

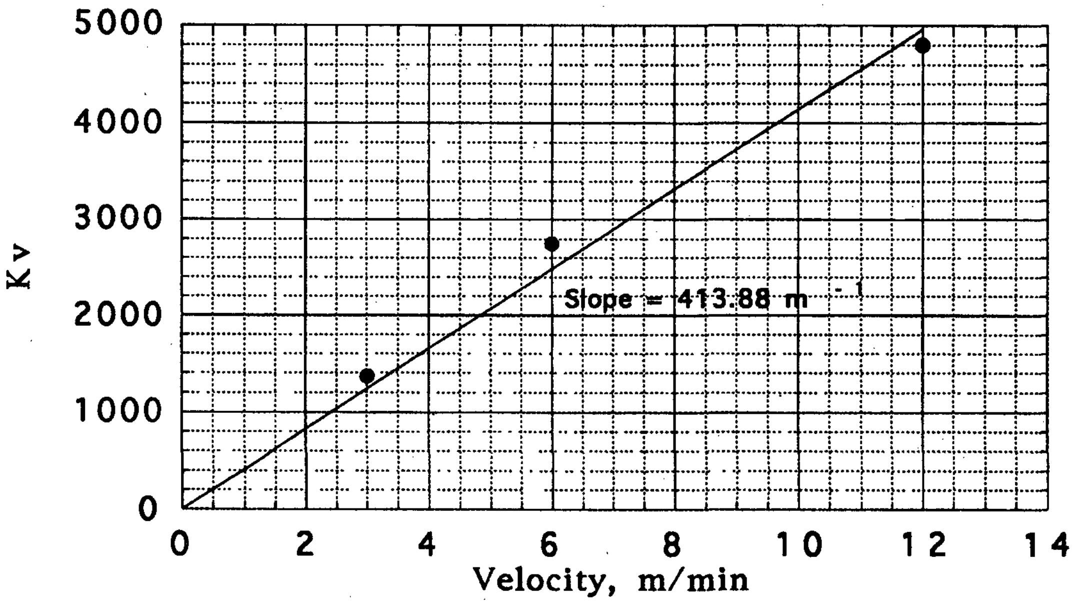

Figure 17 Determination of K_V dependence on velocity.

From Figure 17, we have

$$K_v = k_v V = 413.88\ V\ \text{min.}^{-1}\quad (R=0.99035) \tag{4}$$

where the slope, kv, equals 413.88 m^{-1}. Substituting this expression into Equation 3 yields,

$$t = W_s W_c/(C\,A\,V) + W_s\,\rho_c/(C\,k_v V)\ \ln[(1 - E)/E] \tag{5}$$

All of the constants in Equation 5 can be lumped together into constants c_1 and c_2 to yield.

$$t = c_1/V + (c_2/V)\ \ln[(1 - E)/E] \tag{6}$$

Replacing the constants in Equation 6 with the values in Table 10 yields c_1 = 4207.4, 4053 and 4169.7 and c_2 = 444.6, 427.7 and 439.7 for V = 3, 6 and 12 m/min respectively. Averaging these constant values yields

$$t = 4143.4/V + (437.3/V)\ \ln[(1 - E)/E] \tag{7}$$

Equation 7 was used to generate the theoretical curves in Figure 16.

The increasing deviation in Figure 16 between the experimental data and theory at slower velocities is most likely due to the assumption of irreversible adsorption. In practice, the adsorbed DMSO will not be adsorbed irreversibly and will be released, which is more pronounced at longer times and at higher carbon saturation values.

We used Equation 5 and the parameter values determined in the cartridge studies to design the carbon filter for use in the HE Dissolution Workstation. A major constraint on the filter design is the thickness of the carbon bed. Although we used a bed depth of 2.3 cm (0.91 inch) in our screening tests, existing standards on carbon filters require a minimum of 2 inches.(5,6) This minimum bed depth was established to avoid channeling effects in the ventilation filters. However, since the pressure drop across the filter is directly proportional to the bed depth, it is desirable to minimize the bed depth. Thus, the optimum bed depth that satisfies the current standards and minimizes the pressure drop is 2 inches. To include the effect of carbon bed depth in Equation 5, we made the following two substitutions:

$$Q = A\,V \tag{8}$$

$$\rho_c = W_c/A\,T \tag{9}$$

where, Q = flow rate, l/min.
T = carbon bed thickness, m

Substituting Equations 8 and 9 into Equation 5 and rearranging yields,

$$t = W_s W_c/(C Q) [1 + (1/k_v T) \ln [(1 - E)/E] \qquad (10)$$

Equation 10 can be used to establish how much carbon, W_c , should be used for a given set of operating conditions and for a desired filter life, t.

The primary operating conditions are exhaust flow rate, Q, and concentration of DMSO, C. The exhaust flow to be used in Equation 10 is primarily the leak flow in the Workstation during the dissolution operation. We have estimated the leak at 1 cfm based on previous measurements. The only critical leaks are those that allow air into the Workstation during the spraying operation. Leaks occurring in the exhaust system do not increase the DMSO loading on the carbon although they obviously increase the exhaust flow. The increased flow during the venting cycle can be ignored because the box is purged in less than three minutes as shown in Figures 5 and 6.

The DMSO concentration is determined by the air temperature to which the exhaust is cooled. We can assume the DMSO concentration equals the saturated concentration at the demister temperature because the demister removes nearly all of the suspended aerosols, thereby leaving only the saturated vapor to reach the carbon filter. In our application, the typical air temperature within the demister is less then 65 °F, which corresponds to a concentration of 1.6 g/m^3.(7)

In our design, we wanted the carbon filter to have a useful life of at least one month of continuous operation. The number of operating minutes in a typical month is 5,160 minutes, assuming 4 hours of dissolution per day and 21.5 days per month. We also assumed the life of the carbon filter was over when the efficiency decreased below 95%.

Substituting these and the other parameter values into Equation 10 yields

$$5{,}160 \text{ min.} = \{(0.724)\, W_c /[(1.6 \text{ X } 10\text{-}3 \text{ g/l})(28.3 \text{ l/min})]\} \text{ x}$$
$$\{ 1 + [1/(413.9 \text{ m}^{-1})(0.0508 \text{ m})] \ln [(1- 0.95)/(0.95)] \}$$

Solving this equation yields W_c = 375 g . Since the average bulk density of the carbon from Table is 398g/l, the minimum volume of carbon for one month operation is 0.95 l or 58 in.^{3}. Dividing this volume by the required 2 inches for the bed thickness yields an area of 29 in.^{2}. How this area will be configured into a filter is now a matter of construction considerations. We have selected the cylindrical cartridge design because it is easy to fabricate and to service.

The cylindrical cartridge filter that we designed is shown in Figure 18, where the cartridge is shown mounted inside a cylindrical housing. The exhaust flows from the bottom port into the interior of the carbon filter, passes through the 2 inch bed and exits around the exterior of the cartridge and finally through the top port. The carbon bed is a 2 inch thick concentric cylinder contained between concentric cylinders made of perforated metal screens that are 12 inches long and have 10 and 6 inch diameters. The net carbon volume of this filter is 9.82 l, which is much larger than the minimum 0.95 l required for one month operation. If the operating assumptions for the HE Dissolution Workstation are correct, then the carbon filter will last for 10.4 months of daily operation before it must be recharged with fresh carbon. Even if the Workstation developed leaks up to 2 cfm, the carbon filter will last for 5.2 months of daily operation.

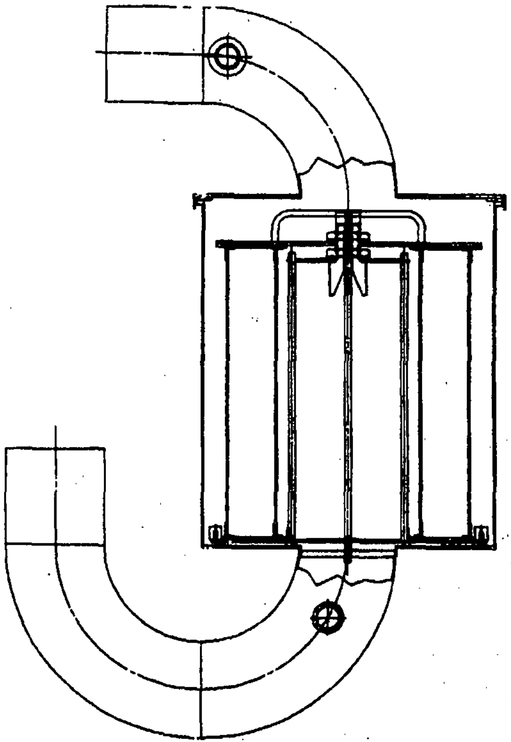

Figure 18. Schematic of cylindrical carbon filter cartridge mounted in a housing.

To prevent the remote possibility of DMSO condensing and collecting inside the carbon filter, we directed the exhaust through a U-tube section before entering the carbon filter. Any DMSO condensate would collect at the low point of the U-tube and can be drained through a plug. It is possible to form DMSO condensate in the lines if the ambient laboratory temperature is lower than the exit temperature of the demister. This can happen if the room heater or if the exhaust condenser do not work properly.

We have not yet completed developing and testing the carbon filter, but will do so in the near future. A preliminary test during a practice dissolution operation showed the carbon filter was only about 70% efficient. Since the predicted efficiency should be in excess of 99%, additional development is required before the carbon filter is acceptable for use in the HE Dissolution Workstation. One of the leading possibilities for the poor performance is the carbon loading procedure that we used. We filled the annular space with carbon by pouring the carbon granules directly from a container and then shaking the filter unit to insure tight packing. Although we designed a fixture to fill the annular space using gravitational settling, the unit was not available at the time of this report. We plan to complete the loading fixture and correct the low removal efficiency. We also plan to conduct accelerated loading tests on the filter in a similar fashion as seen in Figure 16 for the small test cartridges.

IV. Conclusions

We have developed an air cleaning system for workstations that will be used to remove HE from nuclear warheads using hot sprays of DMSO. The air cleaning system consists of a condenser to cool and condense the hot DMSO vapor, a demister pad to remove most of the DMSO aerosols, a HEPA filter to remove the remaining aerosols, an activated carbon filter to remove the DMSO vapor, and a final HEPA filter to meet the redundancy requirement for HEPA filters in radioactive applications. The demister pad is a 4" thick mat of glass and steel fibers and has an efficiency greater than 99% for 0.1 µm DMSO particles. However, the demister pad is disposed after each dissolution operation to prevent the accumulation of HE. Test results on the prototype carbon filter showed only 70% efficiency instead of the 99.9% in small scale laboratory tests. Thus further work will be required to develop the prototype carbon filter.

V. Acknowledgment

We gratefully acknowledge the help of Messrs. Donald Beason, Scott Doughty, and Ron Arganbright in performing tests on the HE Dissolution Workstation and of Mr. Jeff Oh for designing the exhaust system components. We also thank Mr. Gary Nelson of Miller-Nelson Inc. (Monterey, CA) for performing the carbon canister tests.

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DISCUSSION

BELLAMY: It is interesting to hear about the destruction effort that is underway. There are people worried about nuclear war heads, but it is now more in decontamination and decommissioning activities than in their use.

FLEMING: I was going to suggest that when conducting the filling procedure for the cartridge that perhaps you could take a lesson from the people who fill carbon filters, Fred Leckie will tell you that you need to "triculate" the carbon in to get it to pack efficiently. Perhaps you should talk to a few of the manufacturers to get a good method, because I think that will improve your efficiency dramatically.

BERGMAN: Thank you for your suggestion.

RICKETTS: I was wondering how you actually measured the DMSO concentration up and downstream of your carbon filter?

BERGMAN: We measured DMSO as a relative measurement, based on a Moran analyzer, it was not an absolute measurement. We calibrated the instrument in the laboratory with a known concentration, by injecting it with a syringe, and called that the 100% upstream concentration. Then, for zero percent, we used air filtered through a carbon bed. Although we could do this fairly nicely in the laboratory when we went into the field we did not have the luxury of all these things, and whatever the instrument read at the time, we used. So, it was a relative measurement. We had an upstream zero, and that was the extent of our calibration.

RICKETTS: I understand DMSO is very hygroscopic. Do you have to worry about the concentration of the water vapor in the air stream coming into the system?

BERGMAN: Yes, DMSO is extremely hygroscopic, to the point where we had tremendous experimental problems with things like measuring filter weights. We would load a lot of particles on to a filter, but the filter would lose weight because of losing the previously absorbed water. We had to effectively precondition the filter, i.e., dry it, by passing DMSO vapor through it. It is a tremendously effective water scrubber. For most applications we would have to use an inlet filter to remove water vapor, otherwise we would have a real horrendous problem. Fortunately, the place where these operations will be conducted is in Pantex, which typically has 10% RH, so they do not foresee it as a problem. If there is a problem, you immediately start seeing a lot of high explosives on the bottom of all your trays, not the most optimum condition. When that becomes apparent, you do not proceed very far under those conditions.

A THICK HOMOGENEOUS VEGETATED COVER DESIGN PROVES COST- AND SCHEDULE-EFFECTIVE FOR THE RECLAMATION OF URANIUM MILL SITES NEAR SPOKANE, WASHINGTON

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Abstract

The Washington State Department of Health (WDOH) has licensed two medium sized uranium mills with tailings impoundments covering 28 and 40 hectares (70 and 100 acres), respectively. The uranium mill licensees have submitted closure and reclamation plans to the state, and site-specific conditions have determined the closure design features.

Conventional uranium mill cover designs usually incorporate an overall cap of one to three meters, which includes a low-permeability clay barrier layer. A technical evaluation of several uranium mill facilities that used this design was published in the fall of 1994 and reported that unexpected vegetation root damage had occurred in the low-permeability clay (or bentonite amended) barrier layers. The technical report suggested that the low-permeability design feature at some sites could be compromised within a very short time and the regulatory goal of 1,000 years performance might not be achieved. In October 1994, WDOH sponsored a technical forum meeting to consider design alternatives to address these reliability concerns. Representatives from the federal government, nuclear industry, licensees, engineering firms, and state regulatory agencies attended the workshop.

Risk factors considered in the evaluation of the uranium mill reclamation plans include: (1) radon gas emanation through the cover (the air pathway), and (2) migration of hazardous and/or radioactive constituents (the groundwater pathway). Additional design considerations include site structural stability, longevity of 1,000 years, and no active (ongoing) maintenance.

Both closure plan designs originally presented to the department incorporated conventional low-permeability clay or bentonite amended cover layer designs. The department determined that the low-permeability layers at the Washington sites would be prone to failure due to biointrusion and freeze-thaw at these sites. A thick homogeneous vegetated cover design was then evaluated. Consequently, both closure plan designs were revised. All outstanding design and construction regulatory requirements were addressed prior to final approval by the state. The revised plan meets regulatory requirements, allows for construction efficiency (cost and schedule), and meets QA/QC goals.

I. Introduction

The Waste Management Section of the Division of Radiation Protection in the state's Department of Health manages the Uranium Mill program through rules and regulations. These rules are the result of professional rule development based on legislative authority and evaluation of risk. The NRC(1) and EPA(2) each produced environmental impact statements as the basis for their uranium mill regulations. The state of Washington, as an NRC Agreement State, enforces the federal regulations under state legislative mandate(3) and agency rule.(4) The resulting rule language is presented in the form of performance-based, non-prescriptive "Criteria." The NRC has developed several guidance documents, with the most applicable being a Staff Technical Position for Design of Erosion Protection Covers for Uranium Mill Tailings Sites.(5) This paper describes the state's involvement in the evolution of the thick homogeneous vegetated cover design.

II. Conventional Cover Design

When the state's uranium mill licensees decided to terminate their radioactive materials licenses and begin closure and reclamation of their sites, the department required that final closure plans be submitted for approval. This review was a technical evaluation to ensure compliance with regulatory criteria. WDOH regulations allow licensees to propose any cover designs that can demonstrate compliance with performance-based requirements in the regulatory "Criteria". In 1994, both uranium mill licensees submitted closure plans(6) & (7) to the department for review and approval.

During the same period of time, a technical report(8) was published by the Uranium Mill Tailings Remedial Action (UMTRA) Project. The report described how biointrusion on rock-covered disposal cells had impacted the stability of covers at completed U.S. Department of Energy (DOE) sites. The study suggested that "continued plant growth on the rock-covered cells will alter the characteristics of the cover system. As roots advance through the cover, they introduce organic matter into the cover, and upon their death leave conduits through which liquids and gasses may pass readily. These roots and associated processes will eventually transform the radon barrier into a biological soil, which could degrade the performance of the engineered layer relative to its intended function." In response to this report and staff concerns, the Waste Management Section sponsored a technical meeting(9) to discuss and identify potential impacts to the low-permeability barriers from biointrusion, freeze-thaw, no active maintenance, and other factors.

III. Long-Term Reliability Concerns

One of the major concern with uranium mill cover designs is that they should be stable for 1,000 years. Studies show that conventional cover designs may not meet this longevity requirement. Since department regulations do not allow the inclusion of active maintenance into closure plans, cover designs must be evaluated to account for this. The following paragraphs describe typical problems faced by uranium mill sites, which conventional cover designs may not be adequate to meet:

III.1 Background

Uranium production in this nation supports the uranium fuel cycle for the nuclear power industry, and the nation's nuclear weapons program. Uranium mill tailings are the byproduct (waste stream) resulting from the production of uranium oxide from uranium ores. Tailings are produced as a result of chemical separations and typically produce an acidic liquid slurry waste stream. The high volume liquid waste is pumped to large impoundments where pH balance is accomplished and solids precipitate and settle out. Larger particles settle near the discharge, with fine particles settling further away. This results in a concentrating effect in the distribution of fine particles, sometimes called "slimes." These slimes are difficult to stabilize because they do not readily de-water and lack structural strength.

The radioactive constituents of potential environmental concern include radium-226 and radon-222 gas produced by radioactive decay. Radon gas has a half-life of 3.8 days and diffuses from the tailings through the cover to the atmosphere. Uranium mill covers are designed to slow the rate of radon gas diffusion/emanation to acceptable regulatory standards. Many of the radioactive and hazardous constituents present in the tailings may affect the groundwater. Their mobility and potential impacts are dependent on many factors. For example, the site-specific geology and hydrogeology can strongly influence how well the uranium mill tailings are isolated. Design features of the impoundment include the liner (or lack thereof), methods used to control pH during waste disposal, ore and process variables, and cover design. Environmental site features of major importance include weather, upstream watershed characteristics, soil characteristics, earthquake potential, and natural vegetation succession.

Since radium-226 has a half life of 1620 years, the regulatory requirement for the isolation of uranium mill tailings is "1,000 years to the extent reasonably achievable, and, in any case, for at least two hundred years." From a regulatory point of view, it is impractical to expect that active, ongoing maintenance could be assured by administrative and institutional controls for more than 100 years. Therefore, the regulatory requirement states that "final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation."

III.2 UMTRA Project Experience

Burt and Cox reported on experiences at UMTRA Project sites in a technical report published in 1994(8). The six sites discussed included five in relatively dry locations, some at higher elevations, and one in much wetter Pennsylvania. In each case, site-specific environmental and design features affected the impact and rate of sand and vegetation intrusion. The contaminated materials at these disposal cells were covered by a three-part system consisting of a radon barrier, a bedding layer, and a rock erosion layer. The radon barrier consists of a highly compacted soil/clay layer designed to limit radon emanation and water infiltration. The bedding layer is designed to support the rock erosion layer, prevent the rock from penetrating the radon barrier, and reduce or prevent the erosion of the radon barrier. The rock cover is designed to prevent water and wind erosion from affecting the stability of the disposal cell. In the relatively short time-span of one to three years after construction completion, the characteristics of vegetation coverage had exceeded design expectations. Deep-rooted species had invaded cover areas and had begun to grow into the radon barrier. Maintenance of the sites now includes cutting of vegetation and use of herbicides. Report recommendations include design modifications for new sites to either increase cover rock thickness to prevent vegetation, or increase thickness of cover to minimize detrimental effects of deep-rooted vegetation.

Conventional cover designs are typically based on a design infiltration rate of 2.5×10^{-7} cm/sec (1.0×10^{-7} in/sec), and there are concerns that vegetation or animal intrusion could increase the infiltration rate.

III.3 Biointrusion

In 1994, the department began its technical review of the submitted closure plans, with both plans incorporating relatively thin (about two meters) cover designs with low-permeability clay or bentonite amended soil layers. The amended layers were 0.5 to 1.0 meter (1.5 to 3 feet) thick and were placed below native soil and a top soil cover. A rock mulch and synthetic layer were included in one of the designs. After extensive study, the department determined that biointrusion could cause failure of the low-permeability clay barrier. Factors which influenced this determination included the inability of clay-type soils to self-heal following root intrusion, and the ability of burrowing animals to move through supportive soils to depths of two meters, thus creating holes (voids) or channels which then could fill with less permeable materials. The net effect of such biointrusion is possible failure of the low-permeability clay barriers during the 1,000 year period at these sites.

III.4 Freeze-Thaw

For many sites at higher elevations or in northern latitudes, the soil column will freeze to an appreciable depth during periods of prolonged cold weather. This is true for each of Washington's sites, which are located in the northeastern section of the state. Soil columns in these areas are known to freeze to a depth of one meter or more. When considering a design that must retain performance for such a long time period, even rare occurrences that affect performance must be considered. It has been demonstrated that highly compacted clay barriers lose their low-permeability performance after repeated cycles of freeze-thaw conditions. Therefore, any clay barrier designed in a soil horizon susceptible to freeze-thaw action will not likely retain its long-term low-permeability performance.

III.5 Maintenance

Any design that must last 1,000 years must not be based on administrative/institutional controls to assure performance. Man's historical record does not justify such an allowance, even in the best of assumptions of political and economic stability. If maintenance is required over short time periods, then such a design cannot be considered, unless there is no other practical approach. When the department considered this factor, it became obvious that plant and animal intrusion would occur at Washington's sites because there is sufficient moisture and the soil and weather conditions are favorable for plant and animal life. The department had to assume that biointrusion would occur; not only that, but biointrusion could potentially be very beneficial to the cover design. Therefore, the cover must be designed to either prevent biointrusion, or to incorporate it; either way, ongoing active maintenance would not be required.

IV. Thick Homogeneous Vegetated Cover Design

The concept of a thick homogeneous vegetated cover design is certainly not new and novel in the sense that it has been considered in the past. Such a design is simple and is not considered high-technology. It is simply a brute force method that uses a larger mass of material (greater thickness) to provide isolation of tailings. The larger mass is more stable, considering structural impacts from the environment (erosion, earthquakes, root penetration, etc.). The larger mass is also less sensitive to construction methods and techniques, material properties for available borrow soils, and requires less exported materials (bentonite, clay, rock, synthetics, etc.).

IV.1 Vegetation

The thick cover design must account for vegetation and animal intrusion. Since the presence of vegetation is almost guaranteed, one should consider its effects on the design. A thick cover that contains homogeneous, free-flowing material will be self-healing and the presence of plant root successional effects will not provide preferential pathways, since a low-permeability barrier layer is not present. Performance will not be degraded by the presence of plants and plant roots. If the cover is thick enough, a very large portion of root mass will be found in the upper portion, and root effects will be diminished. A cover depth of four to five meters is considered sufficient to mitigate biointrusion impacts.

There is a very significant benefit from vegetation in that plants transpire large volumes of water from the ground into the air in the process of producing plant mass. The ratio of water volume transpired to plant mass produced is species-dependent, and ranges from 100 to 1,000. Evapotranspiration is greater during higher temperature summer conditions and generally exceeds natural rainfall precipitation, on average. Since most precipitation occurs during winter and most evapotranspiration occurs during summer, the soil column (cover) must be thick enough to contain the water without allowing deep percolation during the winter and spring, and release it in the summer and fall through evapotranspiration. If the cover is thick enough, the seasonal cycles will not impact deeper than the upper layer of the cover, and the tailings will remain well protected. In fact, if vegetation is deep rooted enough to access available moisture, essentially all of the year's accumulated precipitation will be removed by the end of the dry season. This process achieves the same general result as a low-permeability clay layer design.

IV.2 Radon Gas Emanation

Radon gas emanation is a process of vapor diffusion through the soil and release to the atmosphere at the surface, where it could be inhaled. The radon gas inhaled could decay and produce a negative health effect to the exposed person. In practice, a relatively thin (about one meter) low-permeability clay barrier layer incorporated into a conventional design (total cover thickness of about two meters) has almost the same theoretical radon emanation rate as a thick (about four meters) homogeneous uncompacted soil cover. With conservative assumptions of soil characteristics, soil moisture, and soil compaction, it becomes quite unlikely that any external variable can cause the thick soil cover design to exceed the design limit. This is not the case with thin barriers placed near the surface. For instance, gas diffusion is highly dependent upon soil moisture content. A thick cover design is much more likely to maintain generally average soil moisture properties during the course of seasons and years than will a thin clay layer.

IV.3 Infiltration of Radioactive or Hazardous Constituents

Infiltration of moisture through the cover, and subsequent percolation through tailings and the underlying vadose zone to the groundwater, will determine the groundwater impact. This impact is generally in the form of a concentration (e.g., ppm) or a rate of contaminant flux, (e.g., gm/yr). For radioactivity, the usual units are pCi/l for concentration and pCi/yr for flux rate, and each radionuclide is considered individually because of the inherent difference in potential health effects. Reducing infiltration rates to zero theoretically eliminates the groundwater impact, since a potential waste stream that does not flow is not evident (impacting) to a potential recipient. Low-permeability barrier layers that are likely to fail their design permeability rates will likely produce greater infiltration rates on average over the design life of 1,000 years, than thick homogeneous vegetated cover designs that are optimized for vegetative production and high rates of evapotranspiration. Specific site conditions are important to this general statement and must be fully evaluated to achieve the benefit expressed.

IV.4 Structural Stability

The structural stability design parameters for uranium mills provide guidance to assess performance over the long term. This includes resistance to the detrimental effects of wind and water erosion, earthquakes, post-construction settlement, rock durability limitations, and others. The design analysis that justifies the design compliance with structural requirements includes long-term wind and water erosion and deposition estimates, and flooding from a probable maximum precipitation (PMP) event and its resulting probable maximum flood (PMF). In all cases, the thickness of the cover enhances compliance and long-term reliability performance. The effects of settlement can produce changes in slope that could affect erosion or deposition. Closure plans reviewed by the department used very shallow slopes (less than 2%) and did not require rock mulch on the surface to attain erosional stability. This enhances the natural vegetative production needed by other performance parameters. It was determined that even if settlement occurred and changed the slope, it would not be significant to erosional performance; vegetation would eliminate any ponding of water that might result, so there would be no increase in infiltration. The detrimental settlement effects of compacted clay barriers (infiltration breaks) are absent in thick homogeneous cover designs. Therefore, an uncompacted cover design would not be compromised by settlement. The department also found that the thick homogeneous cover is easy to build and readily meets design specifications.

IV.5 Longevity

The thick homogeneous cover was determined to be the most suitable for assuring compliance with the 1,000 year design criteria at Washington State sites.

IV.6 Administrative Requirements

The regulations impose several administrative requirements that take effect after construction is completed, and after the radioactive materials license is terminated. By regulation, the following requirements are imposed: (1) surety is provided, based on a 1% real rate of return, to perpetually fund a surveillance program; (2) the state or federal government will own the land and/or provide responsibility for long-term performance; and (3) the facility will be annually surveyed.

V. Conclusions

The performance-based regulations relative to the development of closure and reclamation plans at Washington's two uranium mill sites have allowed for a potential improvement in their closure designs. There is now another method of isolating waste using a thick cover approach that has potential long-term reliability benefits, when compared with the low-permeability, relatively thin barrier designs. It is likely that these benefits can also be achieved at other sites with similar environmental characteristics. In the following sections are examples of department experience at the two uranium mill sites, both of which are located in northeastern Washington:

V.1 Cost Impacts

The closure design for one of the mills was approved conceptually, on condition that detailed construction designs and specifications be submitted for review when the site is ready for final closure. It is estimated that by using the thick cover design instead of the conventional design, approximately $1 million will be saved on closure costs.

Closure of the other uranium mill is being performed in phases and contains a Tailings Reclamation Plan that includes the design basis and construction of the tailings cover and surrounding diversion channel. The mill building and process equipment were disposed of previously. Contaminated site soils were cleaned up in a separate plan that is essentially complete. Construction is well underway and is expected to be essentially complete by autumn 1996. The cover will be installed, the diversion channel cut, rock erosion protection placed, and exposed disturbed ground re-vegetated (seeded). Again, it is estimated that by using the thick cover design instead of the conventional design, approximately $1 million will be saved on closure costs.

V.2 Schedule Impacts

Schedule impacts at one uranium mill facility have not been identified, as the design is approved only conceptually and details of construction scheduling have not been developed. Nevertheless, it will certainly be a positive schedule benefit when bentonite imported from Wyoming and mixed and placed to tight specifications is replaced by native borrow material from the site or from other local sources.

It is readily apparent that the closure project at the other uranium mill facility would be greatly impacted by the schedule implications of a conventional cover design. The normal weather conditions in northeast Washington would make it quite difficult to produce a highly compacted clay barrier in any case. The normal requirement to monitor for settlement of the cover would, in itself, cause an additional year of construction. The design, as approved is approximately 25% complete at this time and is expected to be greater than 95% complete this fall. When time is money, this schedule benefit will surely result in additional unaccounted cost savings.

V.3 Quality Assurance

Although not mandated, it is important for a regulatory agency to be cost or schedule conscious; it is a public service to be considerate of such things, so long as the environment and the public are adequately protected by compliance with regulatory requirements. Quality assurance can therefore provide the check that all regulatory requirements have been, or will be, met. Compliance has been assured by considerable technical review by a multi-disciplinary review team of engineers, hydrogeologists, health physicists, licensing specialists, and others. The licensees, their engineering and technical consultants and their contractors have been most cooperative. Quality control will be provided by department field inspection.

V.4 Long-Term Reliability

One of the best ways to achieve long-term reliability is to develop something that is in harmony with its environment and also resistant to the erosional and depositional forces that may come to bear. Such stability must be assured for both the relentless forces of everyday environmental impacts and for the intensity of the unusual event (floods, earthquakes, droughts, and others).

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5. "Final Staff Technical Position, Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites," U.S. Nuclear Regulatory Commission, August 1990.
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8. Burt, Charles J., and Cox, Steven W., "An Assessment of Plant Biointrusion on Six UMTRA Project Disposal Cells," UMTRA Project, Albuquerque, NM, 1994.
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DISCUSSION

BELLAMY: Do you know any basis for the thousand-year criterion that you mentioned, because I don't?

BLACKLAW: The first basis is that it is in the regulations as a criterion, and is specifically noted there. I believe it comes from the development of regulations by NRC, which also came from a generic environmental impact statement where risks were evaluated. I am sure that it comes from the half-life of radium-226, 1600 years.

CHAIRMAN'S CONCLUSION

BELLAMY: It is clear that decontamination and decommissioning in the waste management area is an up and coming concern and that we are going to have to tackle it in the years to come. Additional discussion of Hanford will be presented tomorrow at the working luncheon. I encourage everybody to have further thoughts on the topic.

SESSION 3

INSTRUMENTATION AND MEASUREMENT

Monday July 15, 1996
Co-Chairmen: W.L. Anderson
R. Zavadoski

PRACTICAL EXPERIENCE APPLIED TO THE DESIGN OF INJECTION AND SAMPLE MANIFOLDS TO PERFORM IN-PLACE SURVEILLANCE TESTS ACCORDING TO ANSI/ASME N-510
E.M. Banks, W.O. Wikoff, and L.L. Shaffer

UNIT VENT AIRFLOW MEASUREMENTS USING A TRACER GAS TECHNIQUE
D.G. Adams, P.L. Lagus, and K.M. Fleming

DEVELOPMENT OF REAL TIME DETECTOR FOR FLUORESCENT PARTICLES
C. Prevost, J. Vendel, and A. Seigneur

ACCURACY IMPROVEMENT IN LEAK DETECTION OF CHARCOAL ADSORBERS BY HALIDE PULSE INTEGRATION METHOD
B.J. Kovach and E.M. Banks

TESTING THE SAMPLING EFFICIENCY OF A NUCLEAR POWER STATION STACK MONITOR
L.H. Ström

THE INFLUENCE OF SALT AEROSOL ON ALPHA RADIATION DETECTION BY WIPP CONTINUOUS AIR MONITORS
W.T. Bartlett and B.A. Walker

PRACTICAL EXPERIENCE APPLIED TO THE DESIGN OF INJECTION AND SAMPLE MANIFOLDS TO PERFORM IN-PLACE SURVEILLANCE TESTS ACCORDING TO ANSI/ASME N-510

Eric M. Banks, Walter O. Wikoff, Larry L. Shaffer
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Abstract

At the current level of maturity and experience in the nuclear industry, regarding testing of air treatment systems, it is now possible to design and qualify injection and sample manifolds for most applications. While the qualification of sample manifolds is still in its infancy, injection manifolds have reached a mature stage that helps to eliminate the "hit or miss" type of design.

During the design phase, manifolds can be adjusted to compensate for poor airflow distribution, laminar flow conditions, and to take advantage of any system attributes. Experience has shown that knowing the system attributes before the design phase begins is an essential element to a successful manifold design. The use of a spreadsheet type program commonly found on most personal computers can afford a greater flexibility and a reduction in time spent in the design phase.

The experience gained from several generations of manifold design has culminated in a set of general design guidelines. Use of these guidelines, along with a good understanding of the type of testing (theoretical and practical), can result in a good manifold design requiring little or no field modification. The requirements for manifolds came about because of the use of multiple banks of components and unconventional housing inlet configurations. Multiple banks of adsorbers and pre and post HEPA's required that each bank be tested to insure that each one does not exceed a specific allowable leakage criterion.

Introduction

The often critical application of nuclear air treatment systems (NATS) installed at various nuclear, chemical, and biological facilities has necessitated the testing of the individual components to ensure their leak tightness. As the various facilities have grown and matured over the years, so have the NATS. The design of NATS has gone from simple single bank, sheet metal, and silicone sealed units to multiple bank, stainless or coated steel, all welded construction. Since the industry needs to ensure with a high degree of confidence that the individual banks of components inside the NATS will perform as required, refined injection and sampling techniques had to be developed. The use of injection and sample manifolds has been introduced to meet this need.

While this paper will introduce some basic design guidelines for manifolds, it can in no way envelop all of the variables associated with system, component, and application design and installation. The major emphasis will be placed on injection manifolds required on post installation NATS. Although the major emphasis is on injection manifolds, most of these guidelines can be applied to the design of sample manifolds as well.

Discussion

One of the most important steps in the design of an injection manifold is deciding where to place the manifold in the NATS. The primary placement of the manifold is determined by the function of the manifold and the component layout of the filter bank. The best location takes advantage of system or component attributes that create increased velocity and flow turbulence in the housing (for example, at the outlet air slots of type II adsorber trays or at the inlet or outlet slots of a type III deep bed adsorber bank). Other locations could be at the air flow traverse station or just upstream of the system inlet plenum. All these options must be examined and the best location chosen before the design phase.

These steps are given in order of importance for determining the best location of the injection manifold:

- Function of the injection manifold.
    - Is it an injection or sample manifold only or is to be used as a combination injection / sample manifold?
- Airflow velocity.
    - What are the maximum and minimum velocities expected at the manifold location?
- Airflow distribution.
    - What is the velocity profile of the airstream at the manifold location?
- Ease of installation and use.
    - Is the manifold to be temporary or permanent?
    - Is the manifold to be installed in the ductwork or inside the NATS housing?
    - From what material should the manifold be constructed?

During the design process it is important to understand how the system and its components work For example:

- The air velocity through a NATS housing is usually less than 200 feet per minute (fpm) which is considered to be in the laminar flow region. By being laminar, very little mixing will occur inside the housing.
- The air velocity at the face of a 24 x 24 x 11.5 inch standard size 1000 cfm HEPA filter is approximately 300 fpm.
- The air velocity at the face of the outlet air slot for a standard type II adsorber tray is approximately 1300 fpm.
- The airflow velocity at the inlet and outlet air slots of a type III adsorber bed is generally lower than that exiting a type II tray, and higher than at the face of a standard size HEPA.
- On most Type III adsorber beds the outermost air slots are, by design, operating at an assumed 50% of the airflow of the inner air slots due to the bed geometry.

Another factor that will affect the manifold design is the airflow distribution (velocity profile) at the proposed manifold location. When designing an injection manifold for use downstream of the upstream HEPA bank, an airflow distribution test must be performed. If the airflow distribution meets the acceptance criteria of no one reading exceeding ± 20% of the average velocity, then no special design adjustments are required. However, if this ± 20% is exceeded then design adjustments of the manifold may be required.

Generally in most NATS there are other factors that enhance challenge agent mixing (e g., distance) to eliminate a concern over a $\leq$ 20% difference in airflow distribution. If the manifold is to be located where the airflow distribution exceeds ± 20%, then the manifold should be designed proportionately. The need for proportionate design usually occurs when the manifold is to be installed in ductwork where short distance mixing is required.

A typical manifold consists of a header and risers (See Figure 1). Each riser has a series of holes through which the challenge agent is introduced to, or withdrawn from, the air stream. See Figure 2 for more details.

Figure 1 Simplified layout of an injection/sample manifold.

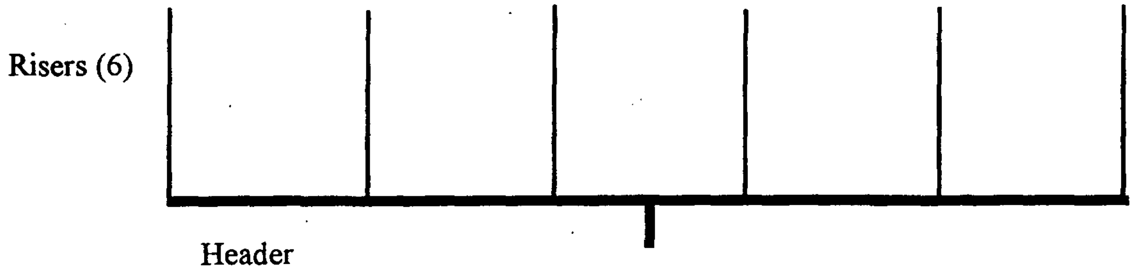
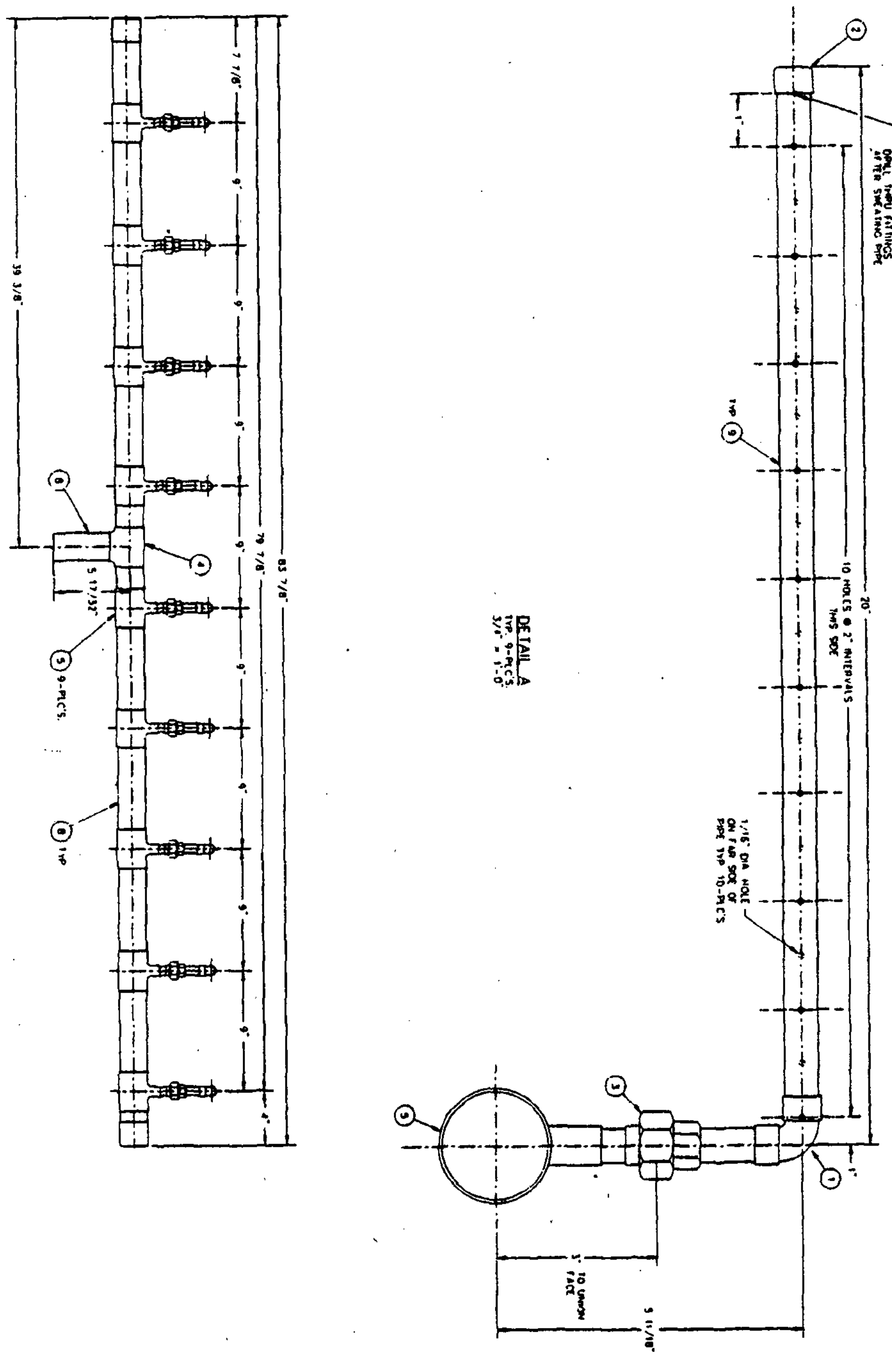


Figure 2
Typical combination manifold (injection & sample) designed to be installed in the air channels of a type II adsorber bank.



Once the location of the manifold is identified, the next step is determining the location of each riser. The risers should be placed to take advantage of system or component designs that increase velocity. For example, risers placed directly in the air channel of a type II or type III adsorber bed will take advantage of the increased velocity associated with those air channels.

If the manifold is to be placed in rectangular ductwork suppling the NATS, then divide one axis of the ductwork into equal areas using the same methodology for determining the traverse points for a rectangular duct airflow traverse. Each manifold riser should be positioned in the center of these equal areas. The distance between these equal areas should generally not exceed six inches. Depending on the velocity of the airflow, duct layout and the distance to the bank being tested, the distance between these equal areas could exceed or be less than six inches. This methodology can also be applied to a round duct.

Another possible location is at the downstream face of the prefilter bank or upstream HEPA bank. The latter would be necessary if the NATS contained a downstream HEPA bank that was required to be tested. While this location is usually less desirable due to the low exit airflow velocity of these components, designing a suitable manifold is possible. Two items to keep in mind are; first, if the filters do not load evenly (dirt loading) this will affect the performance of the manifold and second, when the filter bank is replaced it should be a full replacement rather than a partial replacement. The location of the risers is determined using the same method as for ductwork. The risers need to be positioned to cover only the face of each filter. No holes should be drilled in an area of no airflow (i.e., between filters).

An ideal location for a manifold in a NATS housing will take advantage of the high airflow velocities associated with type II or Type III adsorber banks. The risers for these manifolds need to be located at each air channel. The best position for each riser is just inside each air channel (approximately 50% should be inside the air channel) to take full advantage of the higher velocities.

Design Method

After the location of the manifold and positioning of the risers has been established, the next step is designing the manifold. The basic steps in designing a manifold require determining:

1) Riser hole layouts (spacing and angular position with respect to airflow).

2) Quantity of holes per riser.

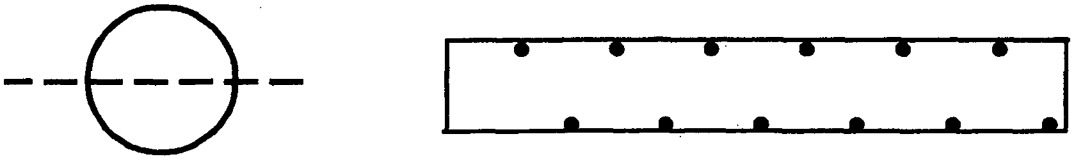
3) Diameter and area of the riser holes.

4) Riser pipe diameter and area.

5) Header pipe diameter and area.

The hole layout on each riser should cover the effective airflow area. From applied experience a hole spacing of approximately two inches apart per side and staggered on each side is desirable. Hole location should be 180° degrees apart and perpendicular to the direction of airflow.

Figure 3 Typical hole layout of a riser.



The riser pipe diameter depends on the quantity of holes per riser and the sum of their areas. Depending on the positioning of the individual risers and the adjacent components (if any), the riser diameter can also be used to increase the velocity and turbulent flow of the air stream. Experience has shown that the decrease in air channel area will add approximately 0.5 to 1.0 inches of pressure drop across the bank. This does not apply when the risers are to be positioned in the ductwork or on the downstream side of a prefilter or HEPA bank.

Two rules apply to the sizing of riser holes:

- The cross-sectional area of the riser should be greater than or equal to (±10%) the sum of the areas of the holes per riser.
- The cross-sectional area of the header should be greater than or equal to (±10%) the sum of the areas of the holes in all the risers.

When designing a manifold to be placed where the airflow distribution (velocity profile) exceeds ± 20% of the average and short distance mixing is required, the hole sizing on the risers must be proportional to the airflow. The use of any spreadsheet program with plotting capabilities is very useful when performing the following steps:

1) Perform an airflow distribution test by measuring the airflow velocities at equal areas for each riser region position.

2) Calculate the velocity total for all readings.

3) Calculate the % of average for each velocity reading.

4) Determine the % of total velocity for each riser region.

5) Determine the total riser area.

6) Calculate the required total hole area for each riser region.

7) Determine the quantity of holes corresponding to each riser region from the location of the velocity readings and the desired hole layout.

8) Determine the hole diameter for each riser region.

The sizing of the holes, riser, and header may allow several variations from which to decide. From these options, several items should be evaluated:

- Difficulty in drilling the holes.
  - Very small holes are difficult and time consuming to drill.
- Ease of use if it is only installed temporarily for testing.
- Complexity of assembling temporary manifolds.

Once the design is finished, the material from which to construct the manifold needs to be chosen. Things to consider when deciding on construction materials are:

- Composition of the airstream (e.g., acid or alkaline gases, particulate types and concentration, moisture, etc.).
- Temperature of the air stream.
- Velocity of the air stream at the manifold location.
- Decontamination requirements, especially if it is a temporary manifold.

While PVC, stainless steel, and mild steel have all been used in the past, copper tends to be the best overall choice. It is easy to work with, relatively light, and cost effective. After the manifold has been constructed it is important that all burrs be ground smooth and provisions made to clean the internals of the manifold. This is especially important when the manifold is to be used as a combination injection and sample manifold.

Once the manifold has been constructed, it still must be qualified by performing an air-aerosol mixing test. If the design guidelines have been properly followed then this test should be uneventful. However, if the design guidelines were not followed or some unforeseen problems occur, then field modifications of the manifold may be required. This field modification may range from minor changes, such as hole plugging or enlarging holes, to major redesign work.

The following is an illustration of a 30,000 CFM NATS. Although it contained only a single HEPA and adsorber, bank an injection manifold was required. The only available injection point was located at the pitot traverse location. This location was approximately four feet from the inlet to the housing (See Figure 4). First, a velocity traverse was performed and this profile was graphically plotted out (See Charts 1 & 2). After analyzing the velocity profile and determining the riser hole layout a spreadsheet was designed to simplify the process of calculating the required velocity percentages and hole areas (See Table 1). The manifold was designed using this information and a successful air-aerosol mixing test was performed with no field modifications required of the manifold (See Figure 5).

Figure 4 Physical layout of the 30,000 CFM NATS.

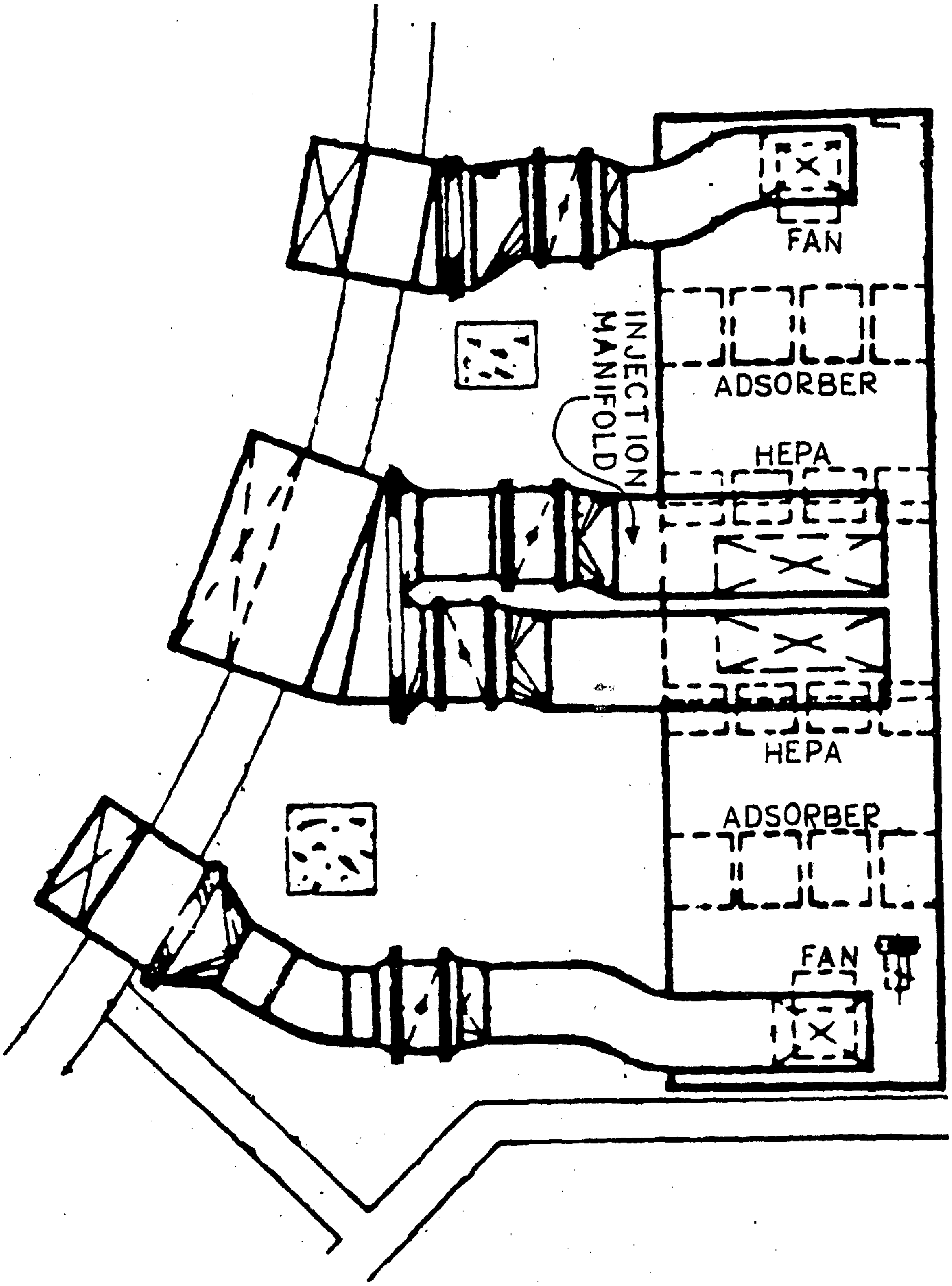


Chart 1 Bar graph plot of the individual velocity points inside the duct.

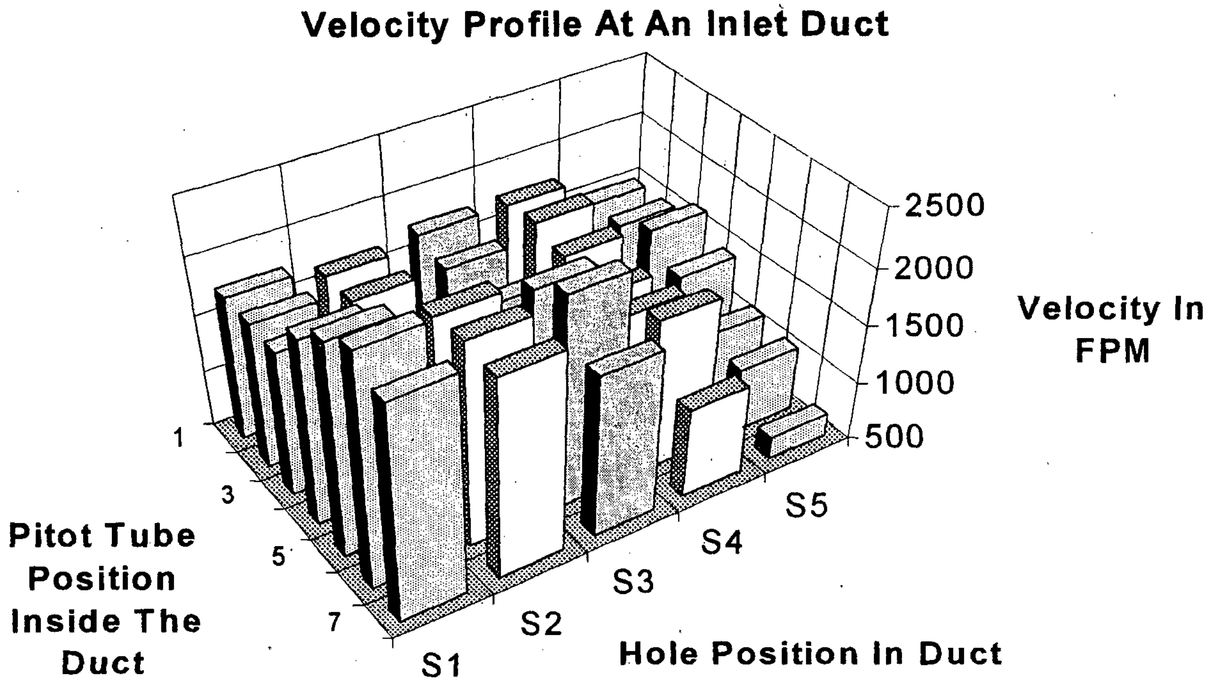


Chart 2 Surface plot of the velocity profile inside the duct.

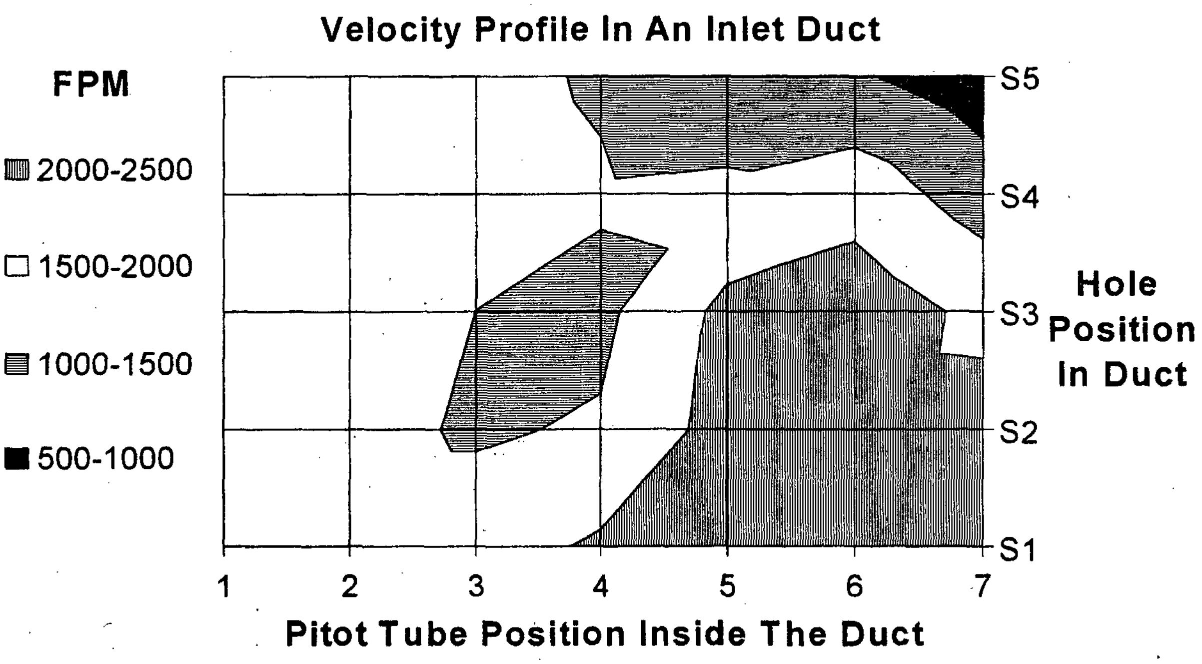


Table 1 Worksheet used to plot velocity graphs and calculate hole size.

	DATA VELOCITY							TOTAL BY TUBE	% BY TUBE
	1499	1499	1651	1444	1133	1060	694	8980	15%
	1746	1791	1699	1551	1602	1791	1266	11446	19%
	1746	1651	1499	1387	2119	2301	1879	12582	21%
	1651	1651	1444	1551	2194	2230	2194	12915	21%
	1746	1746	1746	2081	2301	2469	2335	14424	24%
TOTAL	8388	8338	8039	8014	9349	9851	8368	60347	100%

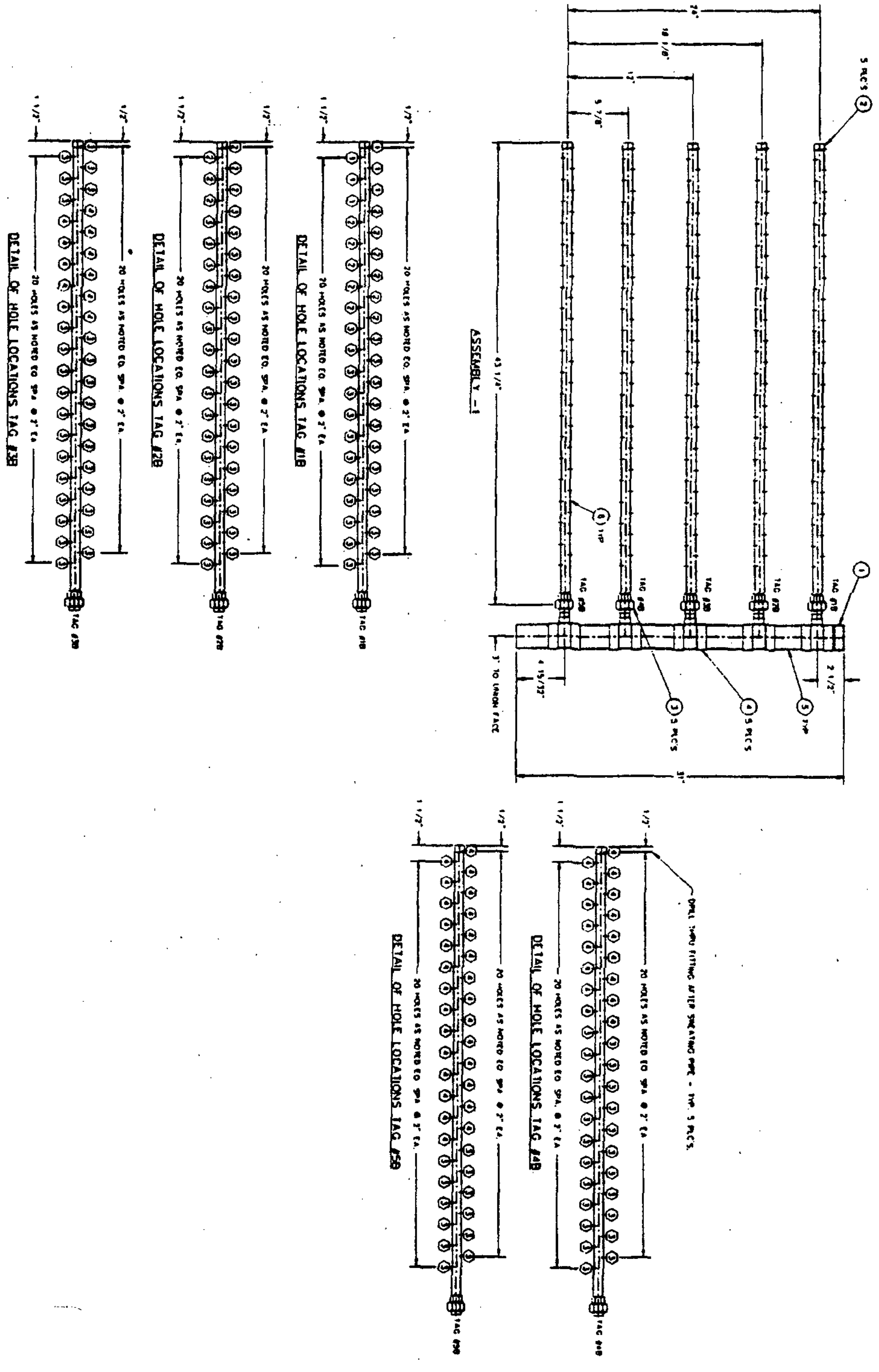
PERCENT OF AVERAGE FLOW						
87%	87%	96%	84%	66%	61%	40%
101%	104%	99%	90%	93%	104%	73%
101%	96%	87%	80%	123%	133%	109%
96%	96%	84%	90%	127%	129%	127%
101%	101%	101%	121%	133%	143%	135%

PERCENT OF FLOW BY RISER							
16.7%	16.7%	18.4%	16.1%	12.6%	11.8%	7.7%	100%
15.3%	15.6%	14.8%	13.6%	14.0%	15.6%	11.1%	100%
13.9%	13.1%	11.9%	11.0%	16.8%	18.3%	14.9%	100%
12.8%	12.8%	11.2%	12.0%	17.0%	17.3%	17.0%	100%
12.1%	12.1%	12.1%	14.4%	16.0%	17.1%	16.2%	100%

AREAS OF OPENINGS BY REGION							TOTAL	AREA OF HOLES 2
0.050	0.050	0.055	0.048	0.038	0.035	0.023	0.298	0.30
0.058	0.059	0.056	0.051	0.053	0.059	0.042	0.379	0.38
0.058	0.055	0.050	0.046	0.070	0.076	0.062	0.417	0.42
0.055	0.055	0.048	0.051	0.073	0.074	0.073	0.428	0.43
0.058	0.058	0.058	0.069	0.076	0.082	0.077	0.478	0.48

	HOLE SIZE BY REGION						
QTY	6	6	5	6	5	6	6
	0.103	0.103	0.118	0.101	0.098	0.086	0.070
	0.111	0.112	0.120	0.104	0.116	0.112	0.094
	0.111	0.108	0.112	0.099	0.134	0.127	0.115
	0.108	0.108	0.110	0.104	0.136	0.125	0.124
	0.111	0.111	0.121	0.121	0.139	0.132	0.128

Figure 5 Injection manifold designed for the inlet duct of a 30,000 CFM NATS.



While this paper does not address manifolds dedicated to sampling only, the general design guidelines for an injection manifold may be applied to the design of sample manifolds. When a manifold is to be used as both an injection and sample manifold, the design guidelines that apply to the injection manifold take precedence.

Summary

The need to test multiple banks of components in a single NATS required that a method be developed to introduce a test agent uniformly for each bank in the NATS. For a single bank of components, this requirement for uniform distribution of the test agent is still required. To meet the acceptance requirements of the various testing documents and Regulatory Guides, a qualified method of test agent distribution had to be developed. Injection and sample manifolds have made it possible to test entire NATS without having to disturb a single bank of components or by placing test personnel inside the NATS to perform a multi-point sample or shroud test method.

The authors would like to thank Mr. Robert R. Sommer II and Mr. Jonathan E. Otermat for their editorial reviews and technical contributions in the writing of this paper.

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DISCUSSION

SCRIPSICK: Has size dependent particle loss been considered when testing HEPA filter systems? Photometry can introduce you to uncertainties. Are you evaluating injection sample manifolds for size-dependent effects? I do not think that has been addressed in this work. For the kinds of testing being conducted the type generator being used, and the amount of aerosol generated, there should be no such effects. I do not think there is a problem in that regard because they are using 0.3 μm particles according to the procedure in N510. When using a light scattering photometer the response is strongly dependent on particle size. Therefore, if you introduce a size bias either to your sampling technique or your injection device, the size distribution upstream will be different from the size distribution downstream. Alternatively, if you have losses in the sampling system that are not balanced, you will not have the same losses as a function of size upstream as you do downstream. The error propagates into your photometer measurement, and ultimately will affect the error in your test results.

GRAVES: I am not sure I follow you, but we can always make the case that our sampling lines will affect the results. I do not believe the aerosol was degenerated. We were using NUCON equipment, we were not using laser light for particle light scattering. I don't think that is a problem with this technique.

KOVACH, B: I know you are talking about large particles becoming lost in different places. This means that you are going to smaller and smaller particles when you use a manifold. Let me tell you that the aerosol generator being used has no particles above 2μm. There is a baffle plate that collects the larger particles. Therefore the manifold is contributing little to change the particle size. Using the particle size spectrometer we have at NUCON, we could not see much difference. Therefore size change if any, has been neglected. If we used a laser spectrometer we might find size differences, but they would not make much change in the results.

ENGELMANN: As a quality control-quality assurance matter, did you, by any chance, sample without any intervening filtration? Did you look at the release characteristics to see if your sampler showed the same thing as is present in the air stream?

GRAVES: After installation you have to qualify manifolds. You do this with an aerosol mixing test; in this particular case, at 30,000 CFM maximum flow rate as shown on the view graphs. You must make the usual scan to see if you have good aerosol mixing. Between the injection point and the measurement point all you have is duct length so there is no filtration involved.

ENGELMANN: The reason for looking at particle size might be to see to what extent the particle size distribution may become biased between the release point and the sampling point in the interpretation of the results. They should show the same sizes.

GRAVES: I would expect them to be the same sizes.

ENGELMANN: What about concentration?

GRAVES: You inject aerosol upstream through a manifold to solve a maldistribution problem. You are using a device that generates an aerosol of the appropriate particle size distribution. You use one that is know to do that. You are simply directing it in such a way as to cover the cross section of the airstream and to get the required distribution. You are solving a problem with a single point injection into the manifold.

and to get the required distribution. You are solving a problem with a single point injection into the manifold.

ENGELMANN: I wonder if you determined the need for an injection manifold based on a mixing test, or just on the geometry of the housing?

GRAVES: In this particular case a single injection point without aa manifold was deemed to be unsuitable because mixing was not very good. A manifold was needed to solve that problem.

HOLTORP: Did you perform some air-aerosol mixing uniformity tests before installing the manifold? What was the improvement you saw on the mixing test results?

GRAVES: This was used as an example because of the quality of the solution. In this particular case, there was no good place designated for this particular system, it just didn't work. After installation it went from failure to easy pass. We are very happy with this particular installation.

UNIT VENT AIRFLOW MEASUREMENTS
USING A TRACER GAS TECHNIQUE

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ABSTRACT

An alternative method for assessing flowrates that does not depend on point measurements of air flow velocity is the constant tracer injection technique. In this method one injects a tracer gas at a constant rate into a duct and measures the resulting concentration downstream of the injection point. A simple equation derived from the conservation of mass allows calculation of the flowrate at the point of injection.

Flowrate data obtained using both a pitot tube and a flow measuring station were compared with tracer gas flowrate measurements in the unit vent duct at the Callaway Nuclear Station during late 1995 and early 1996. These data are presented and discussed with an eye toward obtaining precise flowrate data for release rate calculations. The advantages and disadvantages of the technique are also described.

In those test situations for which many flowrate combinations are required, or in large area ducts, a tracer flowrate determination requires fewer man-hours than does a conventional traverse-based technique and does not require knowledge of the duct area.

I. INTRODUCTION

Air balance and ventilation performance testing requires precise flowrate measurement. Conventionally, flowrates are calculated from duct area and air velocity data. Velocity data are usually obtained by performing a multi-point traverse at the duct using a pitot tube or hot wire anemometer. In order to minimize non quantifiable errors in the velocity measurement certain conditions must be satisfied:

(1) The flow streamlines are parallel to the axis of the duct.

(2) No significant flow change occurs upstream for 8 to 10 diameters and downstream for 2 to 4 diameters from the flow measurement point.

Often in the field, these conditions cannot be satisfied and significant non-quantifiable errors may exist in the measurement. For example, due to access conditions or ductwork design, velocity measurements may have to be performed near a duct transition, elbow or damper. In these cases, the flow profile is perturbed and the previously stated conditions for precise measurement cannot be achieved.

Other field situations exist which resist precise measurement by conventional techniques, e.g. the measurement of air flowrates in plant chiller equipment where duct runs are minimal and velocity traverse based measurements are severely compromised.

II. TECHNICAL BACKGROUND

For most ventilation type measurements, duct flow is completely turbulent resulting in differences in flow velocities measured across the diameter of a duct even in the absence of flow perturbing elements such as the above mentioned transitions, elbows or dampers. ANSI/ASHRAE Standard 111(1) requires that for any flow traverse measurement to be valid more than 75% of the traverse readings must be greater than 10% of the maximum velocity pressure. Yet sometimes a flow rate is required from a point where this condition is NOT satisfied. Any flow rate calculated from a traverse under these conditions is in error by an unknown amount. This standard also requires a minimum of 25 measurement points even in moderately sized ducts.(2) For rectangular ducts larger than 4.5 feet on any side a maximum measurement spacing of eight inches is recommended. This can require that a very large number of data points be obtained. Hence to perform a traverse measurement correctly can require a substantial investment of time to obtain the necessary individual data points in addition to requiring that the flow be well behaved.

For at least twenty years it has been known that an alternative method to measure duct flowrates exists. It entails the use of a tracer gas dilution method. This method is a *volumetric* as opposed to a point measurement. To undertake such a measurement, a tracer gas is continuously metered into a flowing duct at a known rate. After allowing for mixing, air samples are collected at a point downstream and the concentration of tracer gas is measured. The rate of flow is readily calculated from the ratio of the tracer injection flowrate to the diluted concentration--in symbols:

$$Q = S / C$$

where Q = volumetric flowrate

S = tracer injection flow rate

C = duct tracer concentration

Note that for this equation to be valid the tracer must be *well mixed* within the duct. Since mixing is enhanced by the existence of flow direction changes within a duct, unsatisfied conditions (1) and (2) above which serve to complicate a traverse-type flow measurement actually enhance a tracer dilution flow measurement.

The tracer dilution technique has been used in the mine engineering, industrial hygiene, and energy conservation communities, but has been largely ignored in the ventilation engineering community.(3,4,5) This is unfortunate since many difficult flow characterization problems can be easily accommodated using the technique.

The tracer gas of choice for tracer dilution flowrate testing is sulfur hexafluoride, SF_6. This gas is inert, non-toxic, non-reactive, and is easily measured by means of electron capture gas chromatography to concentrations approaching one part per trillion.(10^{-12}) although this sensitivity level is only required for the largest of flows. The gas is monitored on-site using specially designed monitors that have been optimized for the detection of SF_6 used as a tracer gas. These monitors are not affected by the presence of other gases in the plant background such as freons and halogenated solvents. In addition since SF_6 possesses a zero ozone depletion factor it will not harm the ozone layer.

Tracer gas is injected into a duct using a mass flow controller or calibrated orifice. If the duct is large or the sampling point is fairly close to the injection point without adequate flow disturbances to promote mixing, tracer gas may be injected using a distributed manifold inserted into the duct. Tracer gas samples are drawn from the duct using a recirculating pump to take samples for analysis using a gas chromatograph.

III. SYSTEM DESCRIPTION

Ventilation System Lineups

A combination of charcoal filtration units and fans discharge to the unit vent based upon the operational requirements of the plant. The components with their design flow rates for each applicable system are given in Table 1. Which fan or filtration unit is running depends on the ventilation system lineup required by the plant.

Table 1 Unit vent exhaust plenum

Fan/Filtration Unit	Design Flow	
Condenser Air Removal Filtration Unit (GE)	1000	cfm
Main Steam Enclosure Fan Exhaust (GF)	16500	cfm
Aux/Fuel Building Emergency Exhaust Filtration Unit-Train A(GG)	9000	cfm
Aux/Fuel Building Emergency Exhaust Filtration Unit-Train B(GG)	9000	cfm
Auxiliary Building Access Control Exhaust Filtration Unit(GK)	6000	cfm
Auxiliary/Fuel Building Normal Exhaust Filtration Unit(GL)	32000	cfm (Fast)
	13000	cfm (Slow)
Containment Mini-Purge Exhaust Filtration Unit(GT)	4000	cfm

There are five major ventilation system lineups that occur during normal plant operations. Each is given in Table 2 with the fan status as shown. These lineups are designated for testing purposes as Normal, Normal/Mini-Purge, FBIS (Fuel Building Ventilation Isolation Signal)/Mini-Purge, FBIS/CRVIS (Control Room Ventilation Isolation Signal)/Mini-Purge and FBIS/CRVIS. Each lineup is fully explained below.

Table 2 Ventilation lineups/fan status

(X) indicates running

VENTILATION LINEUP	GE	GK	GF	GL (SLOW)	GL (FAST)	GG	GT
NORMAL	X	X	X		X		
NORMAL/MINI PURGE	X	X	X		X		X
FBIS/MINI PURGE	X	X	X	X		X	X
FBIS/CRVIS/ MINI PURGE	X		X	X		X	X
FBIS/CRVIS	X		X	X		X	

Normal Ventilation Lineup-The normal ventilation lineup is a combination of charcoal filtration units GL(Fast), GE,GK and the GF exhaust fan. This ventilation lineup exhausts the Auxiliary Building, the Fuel Building, Access Control Area and the Condenser Air Removal System. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 1.

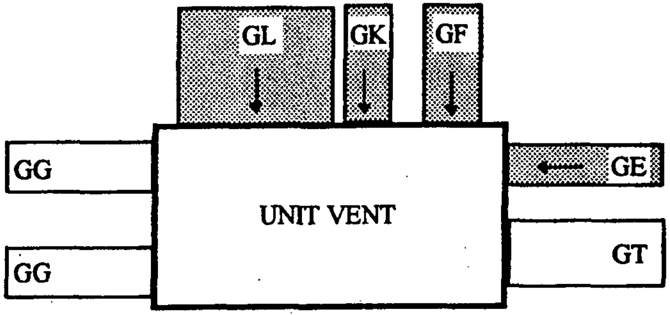

Figure 1 Normal ventilation lineup

Normal/Mini-Purge Ventilation Lineup-The Normal/Mini-Purge Ventilation Lineup is a combination of charcoal filtration units GL(Fast), GE,GK, GT and the GF exhaust fan. The Containment Mini-Purge Charcoal Filtration Unit, GT, controls the containment atmosphere during normal plant operations. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 2.

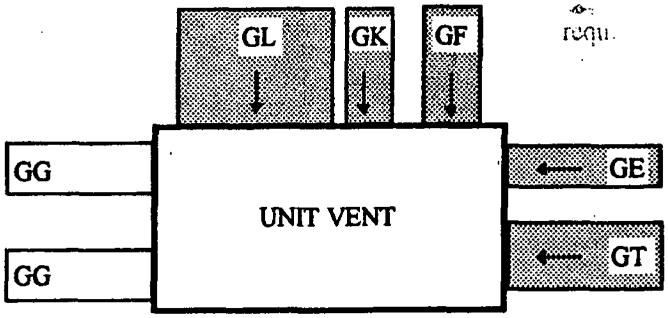

Figure 2 Normal/Mini-Purge ventilation lineup

FBIS/Mini-Purge Ventilation Lineup-The FBIS/Mini-Purge Ventilation Lineup is a combination of charcoal filtration units GL(Slow), GE,GK, GT, GG and the GF exhaust fan. This ventilation lineup supports special fuel handling operations for the Fuel Building. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 3.

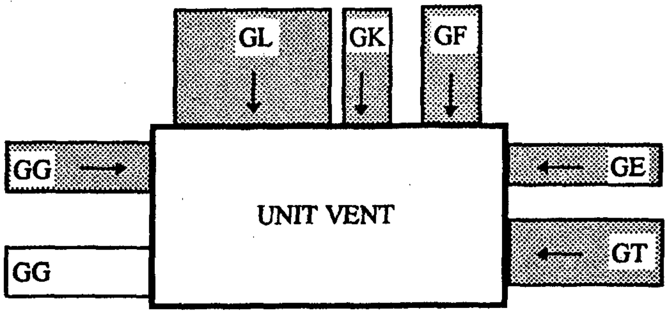

Figure 3 FBIS/Mini-Purge ventilation lineup

FBIS/CRVIS/Mini-Purge Ventilation Lineup-The FBIS/CRVIS/Mini-Purge Ventilation Lineup is a combination of charcoal filtration units GL(Slow), GE, GT, GG and the GF exhaust fan. The ventilation lineup supports special control room and fuel building ventilation requirements. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in the Figure 4.

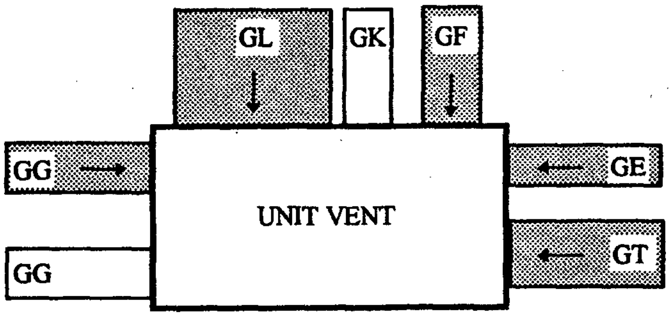

Figure 4 FBIS/CRVIS/Mini-Purge ventilation lineup

FBIS/CRVIS Ventilation Lineup-The FBIS/CRVIS Ventilation Lineup is a combination of charcoal filtration units GL(Slow), GE, GG and the GF exhaust fan. The ventilation lineup supports special control room and fuel building ventilation requirements. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 5.

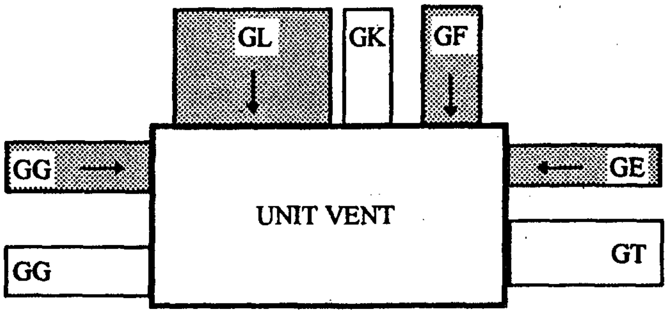

Figure 5 FBIS/CRVIS ventilation lineup

Unit Vent Configuration

The unit vent exhaust plenum exits the Auxiliary Building through the roof as shown by Figure 6 only to make two short coupled 90 degree turns before continuing along the Reactor Building containment structure.

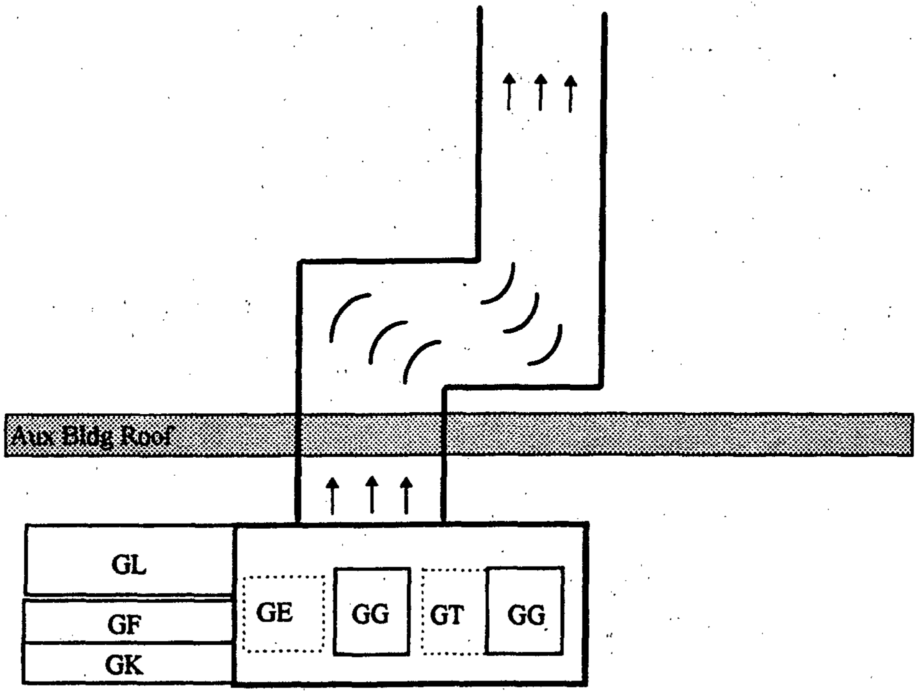

Figure 6 Unit vent exhaust plenum

Figure 7 below shows the physical location of the unit along the Reactor Building containment structure.

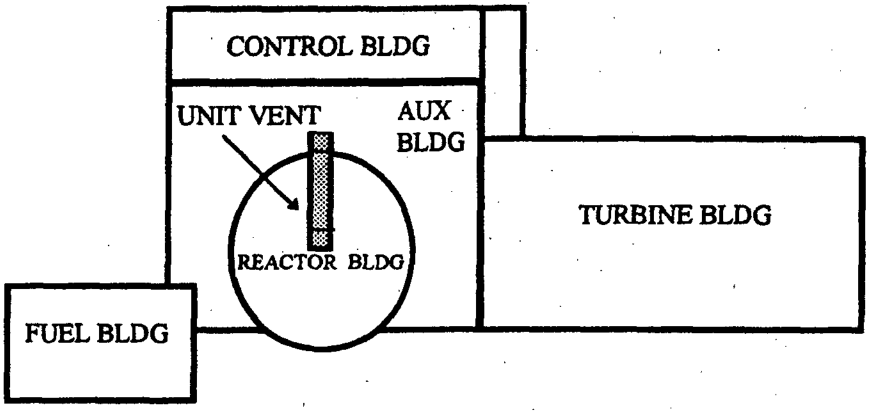

Figure 7 Unit vent location

Figure 8 below shows a side view of the unit vent ducting along the containment structure.

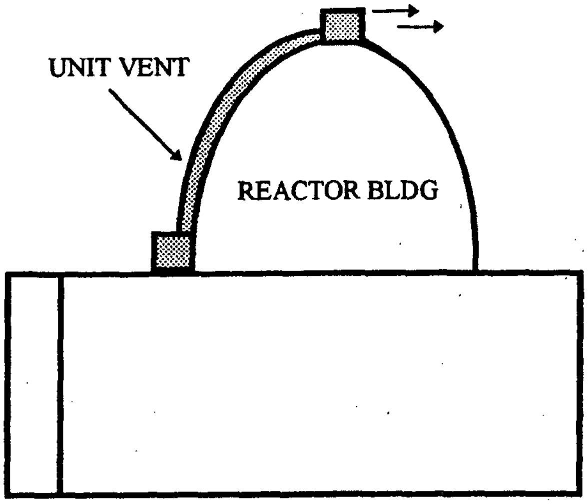

Figure 8 Unit vent physical layout

IV. HISTORICAL SYSTEM PERFORMANCE

The function of the flow measurement station is to provide a 0-5 VDC signal to the Wide Range Gas Monitor (WRGM) RM-80 microprocessor which in turn displays this flow value (cfm) on the RM-11 control panel. The 0-5 VDC output signal is used by the WRGM to maintain isokinetic flow control, isokinetic nozzle selection and perform effluent calculations. The RM-80 microprocessor data base file determines which set of sampling nozzles, *normal or accident*, to use based upon the flow signal developed by the flow measuring station. If the flow signal is above the isokinetic range (46,930 cfm), the *normal* nozzles will be on-line and conversely for the *accident* nozzles should the flowrate become non-isokinetic. An alarm will sound on the RM-11 panel should this condition exist. Nearly all normal operation flow lineups result in isokinetic flow conditions in the unit vent. Should the unit vent flow measuring equipment become inoperable, installation of conservative substituted flows will be initiated. Precise flow measurement to preclude premature switching of the sampling nozzles or the initiation of manual sampling due to inoperable sampling nozzles has proven to be labor intensive and a *work-around* for the unit operators.

October 1994 Testing

Corrective action measures were initiated as early as October 1994 to ensure the unit vent instrumentation components were properly calibrated. Each specific ventilation lineup imparts a different air flow signal for the instrumentation to acquire and condition. Not only did it take several days to affect a complete calibration but the instrumentation exhibited evidence of drift over a period of time.

A pitot tube traverse of the unit vent ducting was performed just upstream of the installed air flow measuring station for each ventilation lineup previously discussed in this paper. This required the erection of a thirty foot scaffolding adjacent to the unit vent ducting. In conjunction with the pitot tube traverse data, RM-11 readings were obtained for comparison. The results of this testing are documented in Table 3. Based upon the data obtained, a single correction factor was applied to the RM-11 readings using linear regression analysis to achieve an RM-11 flow more in line with the pitot tube traverse. This method proved to be precise on only certain areas of the curve.

Table 3 Unit vent measurements without Tracer-Oct 94

VENTILATION LINEUP	PITOT cfm	RM-11 cfm	Difference cfm
NORMAL	50194	63616	13422
NORMAL/MINI PURGE	50394	69014	18620
FBIS/MINI PURGE	44556	55545	10989
FBIS/CRVIS	36813	41639	4826

As can be seen from Table 3, a large difference existed between the RM-11 reading and the pitot tube traverse results for most lineups. Since the unit vent instrumentation was calibrated just prior to the test, the difference between the RM-11 and the pitot tube traverse results was due to the inability to precisely measure the effective duct area or achieve optimum pitot tube orientation in the duct. Figure 9 shows the basic internal construction of the ducting in the area of the flow measuring station. One inch diameter cross-members extend diagonally across the duct every two feet. Additionally, a two inch internal angle iron web is added for strength every two feet as well. The cross-members and the internal web serve to decrease the effective flow area of the duct by approximately 16% as well as set up turbulence throughout the flowstream. These turbulence coupled with an unknown flow area imposes non quantifiable errors for calculating the air flow rate in the duct.

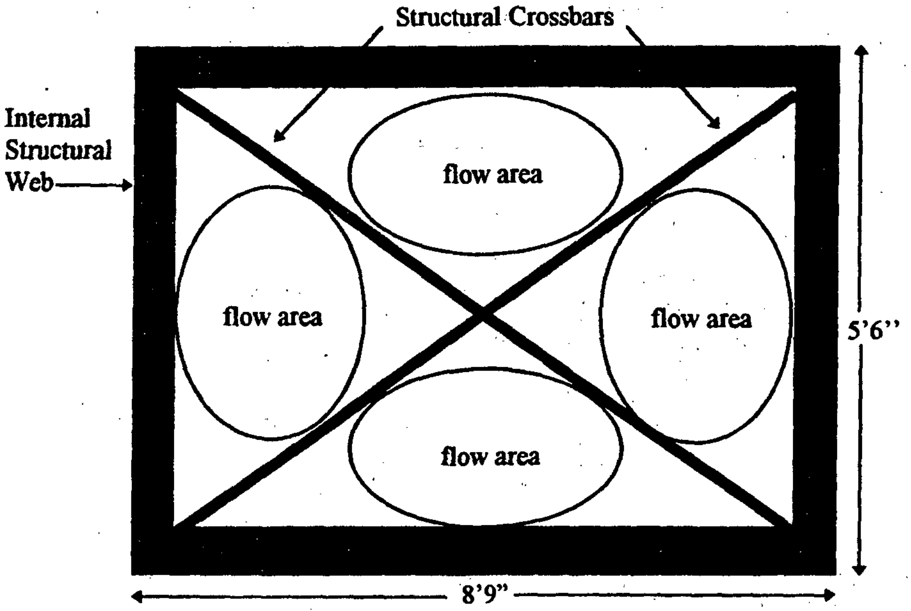

Figure 9 Internal duct construction

V. TRACER GAS TECHNIQUE

Tracer Gas Test Setup

Figure 10 shows the equipment setup to perform the tracer gas test. A 150 ft^3 cylinder of 0.1 % SF_6 injection gas was connected to a flow control valve. The mass flow controller served to finely control the flow of SF_6 injection gas to the injection tube manifold. The injection point for the gas was selected upstream of a fan inlet approximately 50 feet from the unit vent plenum and a total of 90 feet from the sampling point. The injection gas was introduced at three different points across the traverse of the duct with insignificant changes in the results. This established the fact that the gas was sufficiently mixed prior to pulling a sample. The downstream sample was obtained by inserting a sample tube at specific locations in the flowstream and using a pump to retrieve the sample. A list of specific equipment and test precautions is provided in the appendix attached to this paper.

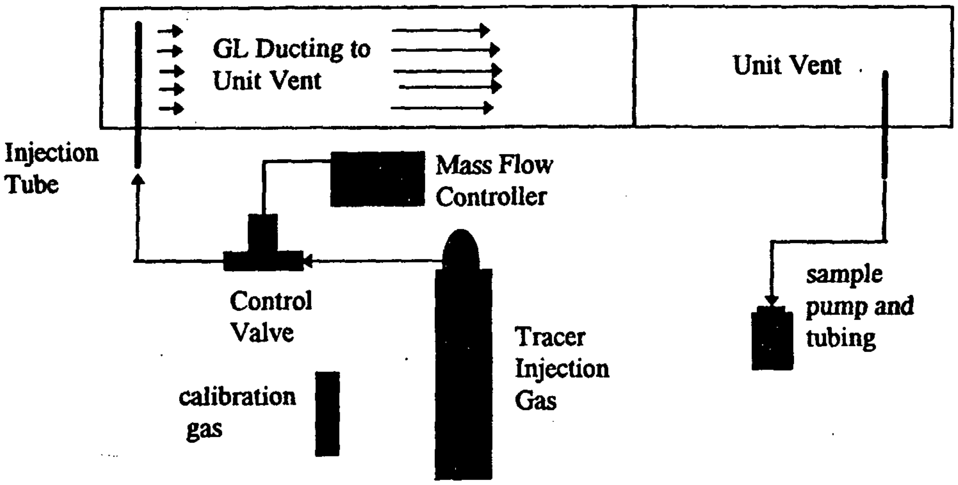

Figure 10 Tracer gas injection setup

Preliminary tracer gas testing-October 1995

Tracer gas technology was tested as to the applicability to Callaway Nuclear for potential incorporation not only in unit vent flow measurement but in the routine checks of all systems and components capacities. The technology had been used for other applications within the nuclear industry to check the migration of noble gases. (6) Basic test verification was conducted to demonstrate the desired results could be achieved on the unit vent.

By October 1995, procedures were in place and equipment had been obtained to perform a trial test of the Tracer Gas Technique in the Normal Ventilation Lineup. A total of 15 samples were taken in the unit vent as shown on Figure 11. There are seventeen access plugs available for testing. Plug #4, #9 and #14 were selected since they were evenly spaced across the duct area and were representative of the total flow within the unit vent. Five samples were taken in each plug location and the samples were labeled accordingly. The results of the test are given in Table 4.

Table 4 Preliminary single test-October 1995

VENTILATION LINEUP	PITOT cfm	TRACER cfm	Difference cfm (pitot - tracer)	RM-11 cfm	Difference cfm (RM 11-tracer)
NORMAL	51037	50812	225	54960	4148

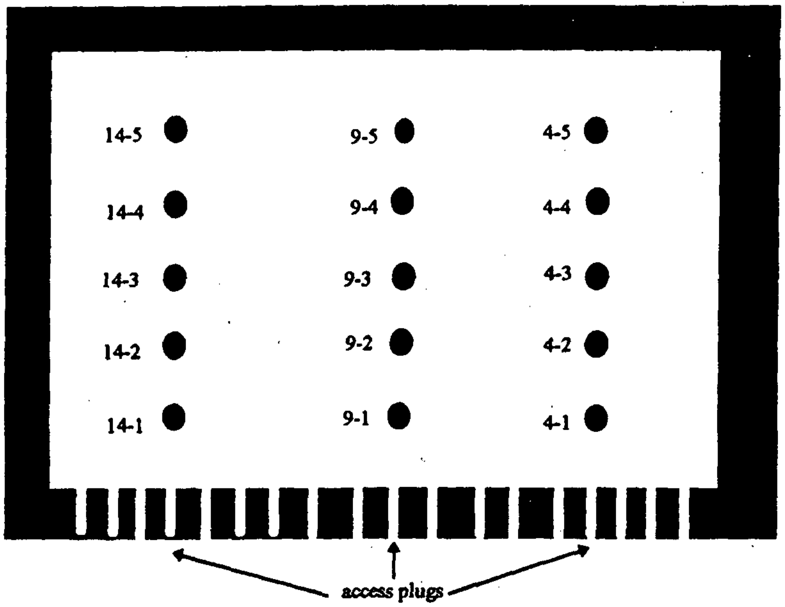

Figure 11 Unit vent sample locations-top view

Tracer gas test-January 1996

January 1996 marked to first unit vent test to be performed at Callaway Nuclear with the Tracer Gas Technique. Ventilation systems were placed in standard lineups that would occur during normal plant operation. A pitot tube traverse was performed on the unit vent ducting just upstream of the flow measuring station at 170 points. The ducting area was estimated based upon the outside diameter of the duct minus the area of the internal web and the cross-members. There would still be non quantifiable errors due to the estimation of area as well as effects from turbulence set up by the design. Nevertheless, attempts were made to meticulously measure the velocity pressures in the duct without encountering the effects of any cross-member. Table 5 below shows the results of this test for the standard ventilation lineups.

Based on the data shown in Table 5, it was apparent that the RM-11 instrumentation was out of calibration. Additionally, the observed difference between the pitot traverse and the tracer gas measurement under these same conditions also indicated a greater difference than projected. The test was rescheduled and the instrumentation was to be calibrated just prior to the next test.

Table 5 Tracer gas test-January 1996

VENTILATION LINEUP	PITOT cfm	TRACER cfm	Difference cfm (pitot-tracer)	RM-11 cfm	Difference cfm (RM-11-tracer)
NORMAL	55881	52027	3854	78200	26173
NORMAL/MINI PURGE	55254	58674	3420	79600	20926
FBIS/MINI PURGE	51480	52614	1134	71800	19186
FBIS/CRVIS/MINI PURGE	48752	43151	5598	66700	23549
FBIS/CRVIS	45186	47247	2061	63000	15753

Tracer gas test- February 1996

The unit vent instrumentation was calibrated and verified to be operating correctly. The same ventilation lineups used in January 1996 were repeated. Table 6 shows fairly good alignment between the pitot traverse and the tracer measurement for most ventilation lineups. Where differences were greater, this would be attributed to the error in determining the effective flow area. Some disparity existed between the RM-11 and the tracer gas test but to a lesser degree after calibration. This can be attributed to several factors in addition to the calibration of instrumentation. The use of a recorder with much better resolution than that used in any previous test improved the precision of this testing. Another impact was the experience level of the individuals performing the testing and refining the test methodology.

Table 6 Tracer gas test-February 1996

VENTILATION LINEUP	PITOT cfm	TRACER cfm	Difference cfm (pitot-tracer)	RM-11 cfm	Difference (RM 11-tracer)
NORMAL	56984	49187	7797	52400	3213
NORMAL/MINI PURGE	56588	53245	3343	56000	2755
FBIS/MINI PURGE	53547	44409	9138	49600	5191
FBIS/CRVIS/MINI PURGE	46167	44187	1980	45400	1213
FBIS/CRVIS	45978	42748	3230	42600	148

Test preparation

Several preliminary items were required prior to the actual performance of the test such as determining the injection rate for the SF_6 gas. This is calculated based upon the estimated flow rate of the system based upon the design flow for the ventilation lineup described given in Table 1 and 2 above. Injection rate is a function of the volumetric flowrate of the system and concentration of tracer gas as discussed in Section II, Technical Background , of this paper. The selection of the concentration value is based upon testing experience to render acceptable results when using a mixture of 0.1% or 0.01% SF_6 in nitrogen or air as the tracer gas. Other parameters such as airstream temperature and barometric pressure are required for conversion assistance.

The equipment was configured as described in Figure 10. Sample retrieval was obtained using heavy duty syringes and needles. Each syringe was clearly marked prior to the test so as not to delay sampling. The syringe with needle attached was exercised prior to sampling to ensure no clogging of the tip occurred.

Tracer gas injection and sampling

Radio communications were established between the injection gas operator and the sampling station at the unit vent. The injection gas was introduced into the airstream and the sampling station was notified. Injection rate was monitored every 30 seconds. A delay of 1-2 minutes was required prior to taking the first sample to ensure the injection gas mixing had time to stabilize. A sample was taken every 30 seconds until all samples for a given access hole were taken. The sampling tube was moved from access hole #4 to #9 and finally to #14 until all samples were obtained. The samples were transported to the counting station taking care not to depress the syringe prematurely.

Sample analysis

Before any sample was analyzed, the atmospheric level of SF_6 (if any) in the vicinity of the gas chromatograph was determined. In addition, two calibration gas standards were read to provide the standard response level for calculating the gas concentration in each sample. Each sample was successively injected into the gas chromatograph after the proper stripchart response was achieved.

Data reduction

The response of each sample is determined by measuring the peak height of each sample. From this value and the standard response level of the calibration gas samples, the concentration of the downstream sample can be determined. From this concentration level and a known tracer gas injection rate, the flowrate of the airstream can be precisely determined.

VI. CONCLUSIONS

By performing flow tests using the tracer dilution method, *volumetric* flowrate data can be easily obtained in the worst duct configurations. Errors introduced by probe orientation, manometer orientation, state of the thermoanemometer batteries, marginal duct velocities, physical configuration, operator fatigue, vents, grilles, and the condition of the flow are eliminated. Another benefit is that expensive flow probes do not have to be inserted into potentially contaminated ducts. The only equipment that actually goes into the airstream is cheap, disposable tubing. Other benefits include minimizing the number of penetrations that must be made in a duct thereby reducing the amount of inleakage or outleakage induced by these holes as well as creating less structural weakening. Flow measurements by the tracer dilution method are more rapid than those by conventional techniques thereby decreasing the time required in high radiation areas in keeping with ALARA considerations of the Health Physics staff.

Since the flow data are not dependent on operator skill and the other physical problems associated with the flow measurement process, more reliable, precise and defensible test data can be generated. These flow rate data can be directly compared to one another to assess the effect of various operational configurations. In-place flow measurement instruments can be directly and wholly calibrated with real volumetric flows using real time data. This provides Health Physics personnel with reliable flowrates to calculate precise radioactive release data. The technique can also provide operations personnel with precise air flow monitoring information, and systems engineering personnel with flow balancing data that are more reliable than those obtained by conventional techniques.

VII. REFERENCES

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Appendix A. Equipment list and test precautions

Equipment list

- Electron capture gas chromatograph with SF_6 oven installed
- Mass flow meter
- Mass flow meter, extension transducer
- 30 ft^3 cylinder SF_6, 1 ppb calibration gas with regulator
- 30 ft^3 cylinder SF_6, 10 ppb calibration gas with regulator
- 150 ft^3 cylinder .1% SF_6 injection gas with regulator
- 150 ft^3 cylinder .01% SF_6 injection gas with regulator
- Sample pump with tubing and septa
- Tracer gas injection manifold and tubing
- Tracer gas sample retrieval tube and tubing
- Needles-(23 X 1")
- Syringes-(12-20 cc)
- Spare septum
- External recorder

Test precautions

- An electron capture gas chromatograph was used to measure the samples obtained. This same instrument was used to perform bypass leakage test on charcoal filter beds however, the oven column was replaced with one compatible with SF_6 gas. Approximately 24 hours is required for the unit to properly warm-up.
- Cross contamination of the SF_6 gas within hoses and regulators is a constant prevention requirement.
- Background samples of the surrounding atmosphere where the samples are being analyzed is required for pre and post test validation.
- Calibration gas samples are analyzed prior to sample counting.
- Septum on the Calibration Gas tank and sample pump should be periodically changed out.
- New syringes should be used for each sample series/location to preclude any cross contamination.
- A high resolution printer with an integrator is best for a more precise reading.
- Care should be taken to use needles on the syringes that do not clog when the septum is penetrated.
- This test is currently limited to areas where the exhaust from the airstream does not communicate with the compartment where injection is taking place.
- If air flow is < 5,000 cfm, the .01% injection gas should be used.
- Samples should be pulled from the downstream at least every 30 seconds during the injection phase.
- Purging of calibration gas through the regulator prior to taking a calibration sample is essential.
- Samples should not be injected into the gas chromatograph more frequently than 3 minutes apart.
- If replacement of the sample oven is performed on site, ensure the oven snaps fully in place to prevent contamination of the system.
- The holes in the injection tube should point into the direction of flow.
- Only polyethelene or nylon tubing is recommended for use with SF_6.
- All SF_6 containing cylinders and tubing should be stored in a separate cabinet, to prevent cross contamination.

DISCUSSION

RICKETTS: I am wondering if you addressed the compatibility of your choice for a test gas with the proper operation of iodine adsorption filters?

ADAMS: I am not sure I am qualified to answer that. Seeing that the trace gas was inert and non-toxic and that the same tracer gas has been used in other industries, we felt comfortable in doing likewise. Especially because it was not ozone depleting. In fact, I made some calls to some of the charcoal vendors prior to doing the test, and it was their determination that it did not affect the carbon or the HEPA filter tests. The other thing we did to make sure it would have less effect on the filters, was to inject it downstream of the charcoal filtration units. The real answer to your question, I think, is that we injected downstream of the adsorber units and upstream of a fan to get proper mixing.

24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE
PORTLAND, OREGON, JULY 15-18, 1996

DEVELOPMENT OF REAL TIME DETECTOR FOR FLUORESCENT PARTICLES

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ABSTRACT

Aerosols tagged by a fluorescent dye are a worthwhile tool within the framework of ventilation and filtration studies. The detection in real time of a specific particulate tracer allows characterization of ventilation behaviour such as air change rate, the determination of a good or bad mixing zone and transfer coefficient, or the determination of the decontamination factor for High Efficiency Particulate Air (HEPA) filters.

Generally, these tests require specific aerosols in order to get rid of the atmospheric aerosol background.

Until now the principle of fluorescent aerosol concentration measuring has only allowed an integral response with a time lag by means of sampling on filters and a fluorimetric analysis after specific conditioning of these filters.

To make it possible to detect a specific tracer in real time, a new monitor has been developed to count these particles on the following basis :

⇨ fluorescent particles pass through a sampling nozzle to a specially designed measurement chamber ; ducting flow rate is used to contain the test aerosol in the sample flow rate at the nozzle outlet ;

⇨ interception of this stream with a laser beam allows aerosol detection and characterization, particle by particle ;

⇨ optical signals are produced by fluorescence emission of glycerol particles tagged with fluorescein sodium when they are excited by a laser beam emitting on a suitable wavelength (ionized argon laser) ; these signals are transmitted to a photodetector by a patented optical arrangement.

The paper presents the detection concept and the experimental device. The main results achieved in this study show the feasibility of such a technique providing aerosol tracer detection in real time.

I. INTRODUCTION

Aerosols artificially tagged with a fluorescent substance are a powerful tool for the specific follow-up of a polluting agent in an atmosphere naturally free from such particles. Most tests carried out within the framework of research into air contamination, confinement or else purification act on these aerosols both in some industrial fields and in specialist laboratories.

The detection of such particles can thus help in understanding the various complex phenomena produced inside premises and thus enable them to be controlled. In fact, the combination of ventilation and pollutant is a major concern when designing ventilation plant and making it comply with the relevant standards.

Therefore, the follow-up in real time of the transfer of contamination from a harmless polluting agent injected instead of a source of contamination enables the location of detection markers to be optimized and the rate of homogenization of the pollutant in the premises determined. Optimization of the rate of renewal is then conceivable when making a "map" of the concentration of the pollutant inside the premises. This reveals the presence of a "dead zone", the site of pollutant accumulation, and thus enables it to be eliminated.

This particle tracing technique can also be used in designwork concerning in particular dynamic confinement, the validation of aeraulic design calculation codes, the modelling of flows of air loaded with particles or even the qualification of the filtering equipment.
The principle of measuring such specific aerosols previously only allowed for integral measurement of their concentration with a time lag through taking samples on filters, and then preparing the samples for analysis by fluorimetry.

As has previously been explained, the need for following up the concentration of a tracer in the air in real time has led us to show the feasibility of a new technique for detecting fluorescent aerosols.

In this paper, we explain the principle of detection which we apply, the experimental device made, and the main results achieved during our research.

II. PRINCIPLE OF MEASUREMENT

The main objective of our research lies in designing a technique for characterizing and counting aerosols, based on detection of their fluorescence, in real time [4].

When a fluorescent fluid aerosol intercepts a beam of monochromatic light of a wavelength included within its spectrum of absorption, it sends back a light of a higher wavelength due to the fluorescence.
With constant lighting, its intensity is in proportion to the amount of fluorescent substance contained in the particle.

It's a question of collecting this fluorescent light using a suitable optical system on a photosensitive detector in order to quantify the fluorophore content [5].

$$Q_f = k.P_L.\lambda_a.\Phi.\varepsilon.N_f.t$$

where Q_f = amount of fluorescence (number of photons)
k = proportionality factor
P_L = power of the laser beam (Watt)
λ_a = absorption wavelength (nm)
Φ = quantum yield of fluorescence
ε = molar absorption coefficient (L/mol.cm)
t = time during particle remains in the light beam (s)

An aerodynamic focusing device aligns the particles behind each other. Fine focusing of the excitation light enables lighting as a particle moves.

Using a laser source of light facilitates concentration of the excitation power of the beam on a narrow spot of light.

The volume of measurement can be estimated at about 3.10^{-6} cm^3 ; the maximum concentration which can be detected with a rate of coincidence below 5% must not exceed 10^4 particles/cm^3.

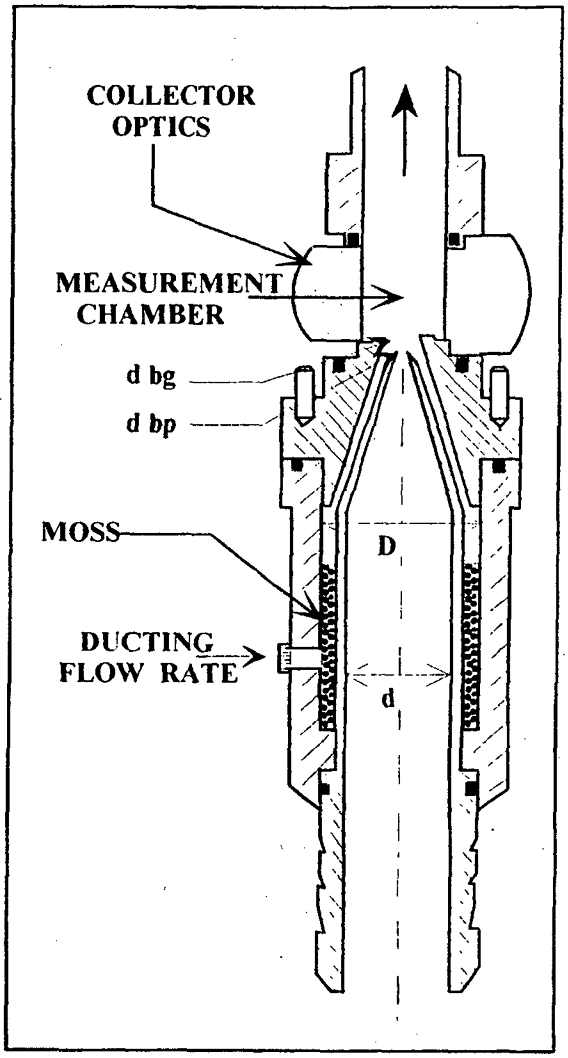
III. MEASUREMENT CELL AND ASSOCIATED OPTICS

The measurement cell essentially comprises :

⇨ a sampling system (Figure 1) in brass with a low surface finish index for the inner surface, ending in a small diameter nozzle (d_{bp} = 0.6 mm) which allows the aerosols to be routed into the measurement chamber within a centered jet.

A ducting air system improves the aerodynamic centering of the output jet in the same time as it prevents any droplets being deposited on the walls of the collector optics.

⇨ a measurement chamber (Figure 2), the special geometry of which enables the maximum fluorescent light emitted to be collected. The fluorescence collection performance is in the region of 15 %. This collector optics is covered by a patent [1]. Its rear face, centered on the jet, is metallized which allows the light emitted to the rear to be returned to the place of emission where it's added to the flow emitted forward.



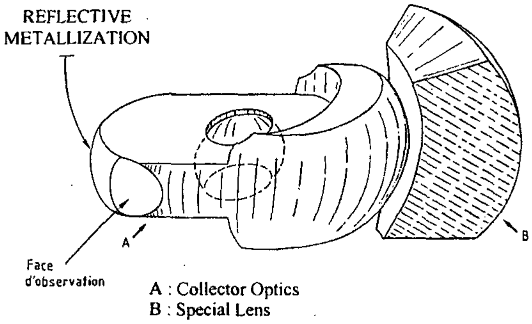


Figure 2 : Measurement chamber

Lens B catches the flow of light and sends it all back to the rest of the optic arrangement.

Figure 1 : Sampling system

Specification of the nozzle : D $= 10.6$ mm
d $= 6.0$ mm
$d_{bp} = 0.6$ mm
$d_{bg} = 2.6$ mm

IV. CHOICE OF FLUOROPHORE

The fluorophore selected for carrying out our tests is soda fluorescein ($C_{20} H_{10} O_5 Na_2$) ; it is an excellent product to use in tracing work, essentially because it's non toxic in the usual concentrations and also because it is soluble in water and in glycerol, often used when producing calibrated droplets.

Further, it's used in a standardized measurement method (NF Standard X 44.011) for the test of HEPA filters efficiency.

This tracer has very good fluorescence properties in solution in glycerol (quantum performance evaluated at 92% under the best conditions) and can easily be detected by any fluorimetric technique.

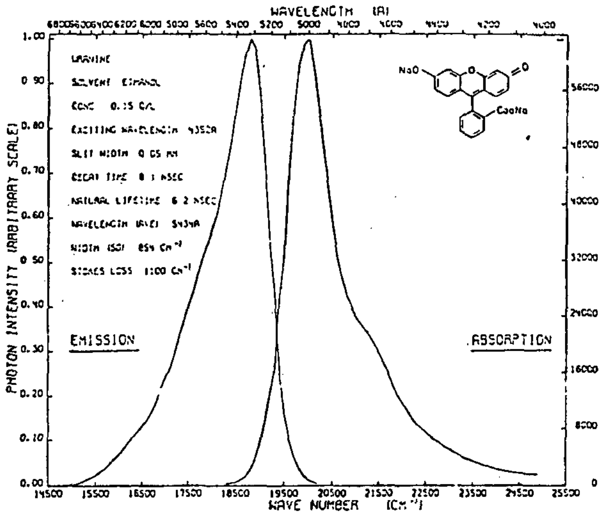


Figure 3 : Spectrum of soda fluorescein absorption and emission [3].

V. SETUP OF THE EXPERIMENT

Two main sections can illustrate the principle of operation of our arrangement (Figure 4) :

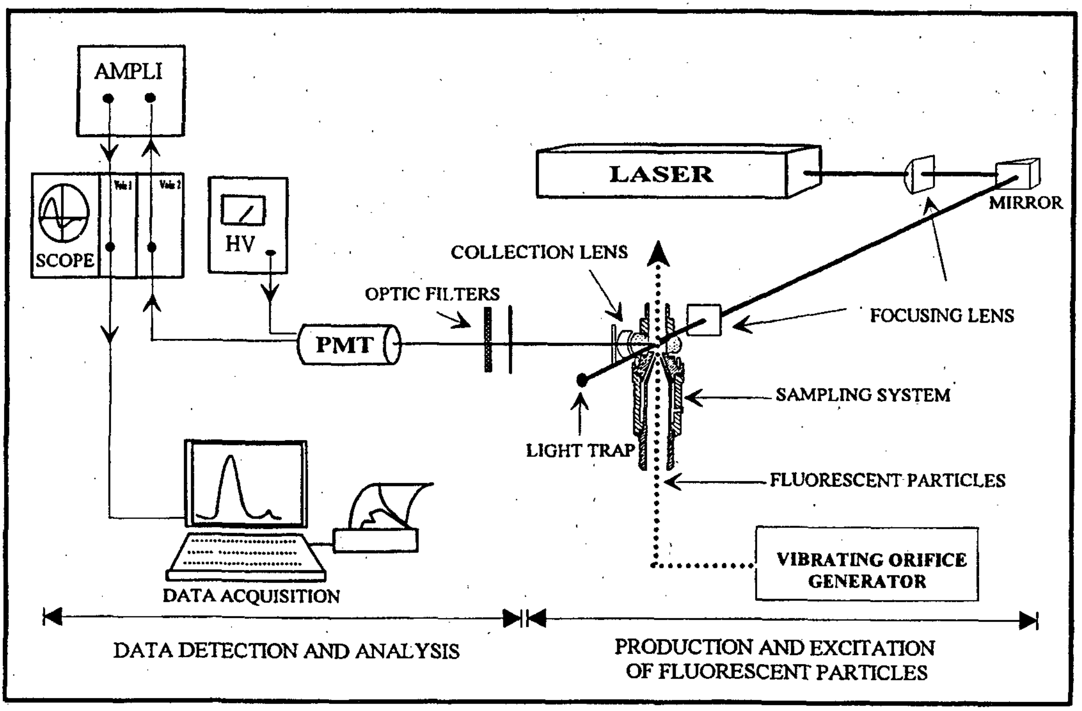


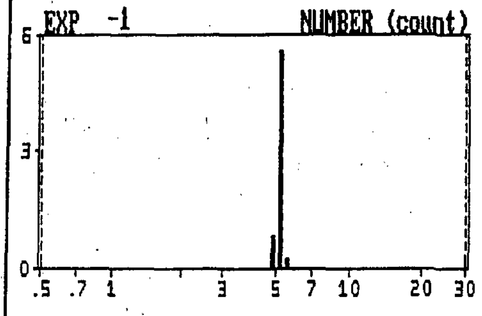
Figure 4 : Overall view of the experimental device

V.1. Production of droplets

A vibrating orifice generator (TSI Inc., Model 3050) provides for producing monodispersed droplets of glycerol tagged with soda fluorescein at concentrations of 1 and 10 g/L.

The range of diameters of aerosols produced extends from 1 to 10 µm (aerodynamic diameter), i.e. quantities of fluorophore contained per particle between 3.10^{-16} and 3.10^{-12} g/particle inclusive i.e. 6.10^{5} to 6.10^{9} molecules/particle.

It has been possible to check the particle size features of the test aerosols by means of an APS (Aerodynamic Particle Sizer, Model 3310, TSI Inc.). The spectrum illustrated in Figure 5 is found when producing droplets with a diameter of 5 µm.



Particles counted : 6583

Number median diameter : 5 033 µm
Surface median diameter : 5 039 µm
Mass median diameter : 5 041 µm
Standard Deviation : 0.391 µm

Figure 5 : Results from APS System

V.2. Dilution and sampling

The reference sample is delivered by an ejector with the flow rate controlled by a calibrated sonic orifice (SAPELEM) at the required rate (5 L/min.).
The total sample (sum of ducting and sampling flow rates) is delivered by two vane pumps mounted in series (RIETSCHLE).

The ducting deliveries and total sampling are checked by calibrated mass flowmeters (BROOKS, Models 5851) in the range of outputs used ; the difference corresponds to the delivery of particles taken.

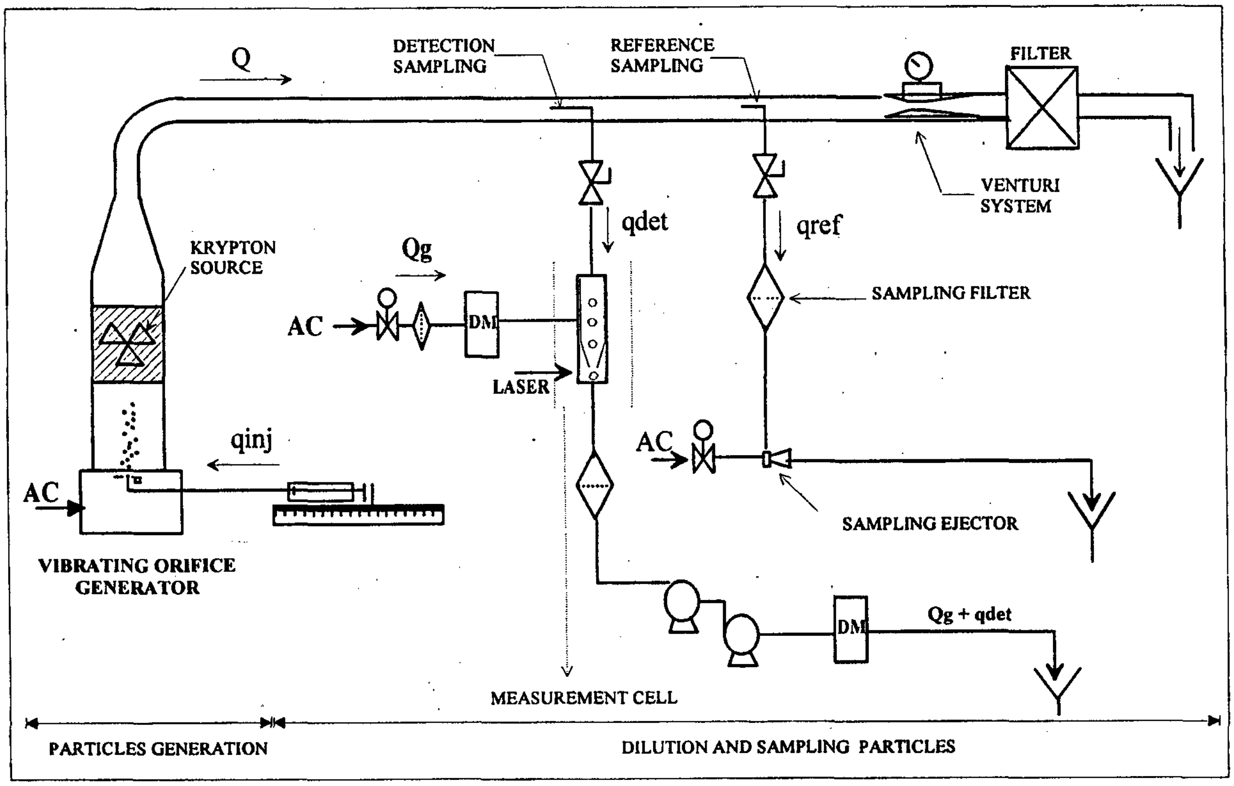


Figure 6 : Aeraulic diagram for the counter qualification

KEYS:
Q = dilution output of aerosols in the main line (m^3/h)
Qg = delivery of ducting air in the measuring cell (L/min)
qdet = sample flow rate in the detection cell (L/min)
qref = sample flow rate on the reference filter (L/min)
qinj = injection delivery of fluorescent solution into the generator (mL/min)
DM = mass flowmeter
AC = compressed air

VI. DETECTION OF AEROSOLS

VI.1. Laser source

The intention to make a device for measuring high sensitivity has led us to adopt a laser as the source of very bright light, monochromatic, easy to focus and, moreover, stable.

So we use an ionized argon laser (SPECTRA PHYSICS, Series 2000) which emits on wavelength 488 nm in accordance with the absorption wavelength of fluorescein sodium.
The power is intentionally limited from 10 to 300 mW. It supplies a beam on TEMoo mode, i.e. its profile of intensity is Gaussian.

VI.2. Focusing the beam

Figure 7 shows the distribution of the intensity of the laser beam at the level of the particles loaded air jet.

The focusing device is large in front of the diameter of the sample stream ; the intensity of the particle excitation is thus uniform, even for particle positions which fluctuate slightly in the lighted area.
The combination of special lenses enables the beam to take on the appearance of a sheet of light at the level of the flow of particles, the focusing thickness of which is fine so as only to illuminate a single particle going through (see Principle of Measurement).

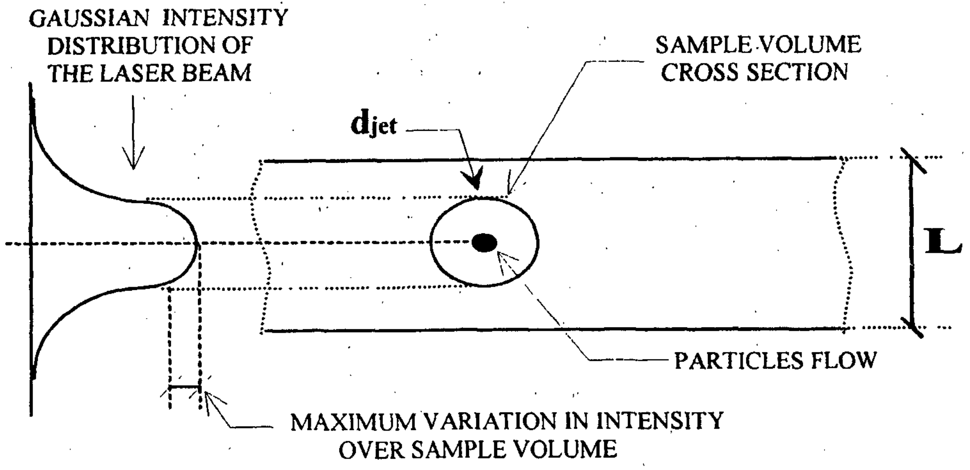


Figure 7 : Distribution of the laser intensity at the level of the jet as it leaves the nozzle.

VI.3. Chromatic filtering on the fluorescence light analysis channel

The association in series of an interference filter (CORION, LL500) and a colored filter (OG515) discriminates well between the wavelengths transmitted in comparison with the excitation light ; only fluorescence signals coming from the particles reach the detector.

Therefore, we clear the parasite light reflected mainly by the walls of the cell and the diffusion light also produced by the particles.

VI.4. Detection and collection of data

A photomultiplier (HAMAMATSU, Type R928) collects the fluorescence photons and converts them, depending on the performance of the photocathode and its gain, into electric current ; the signal leaving this detector can be observed directly on one of the two channels of an oscilloscope before it is transmitted to the amplifier (SCHLUMBERGER, Type 7129) where it is formed and amplified.
The outlet from the amplifier is connected to the second channel of the oscilloscope mounted in parallel with the data collection line.

The data collection line consists of a computer (PC 386) completed with an interface card, type Accuspec NaI (CANBERRA) ; the coding is done on 2048 channels.
We thus have a high performance pulse analyzer which reconstitutes the spectrum of quantities of fluorescent photons detected ; it delivers histograms worked out by adding up the number of events filed according to their amplitude.

This arrangement allows us to follow in real time the detection of fluorescence signals emitted by the particles, simultaneously on the dial of the oscilloscope and on the computer. It is then easy correctly to adjust the focusing of the laser beam on the jet of particles by adjusting the micrometric settings of the cell (XY movement). The interaction between the laser beam and the particle flow is thus optimized by finding the maximum amplitude signal which offers the best resolution.

VII. MAIN RESULTS

VII.1. Estimating the rate of retention in the measurement cell

One of the main stages in the qualification of our device is to validate that laser detection is representative in relation to a reference sampling made in parallel. To do this, we have estimated the rate of retention "T" of the droplets right inside the device.

Three series of ten tests with simultaneous sampling reference and downstream of the laser detection device (Figure 6) carried out for each particle diameter between 1 and 10 µm inclusive, enable us to draw a retention curve characteristic of the device (Figure 8) after conventional fluorimetric analysis of the sampling filters.

The bars associated with the results correspond to uncertainty over the results, given with 95% probability.

$$T = \frac{Cref - Cdet}{Cref}$$

where Cref = reference concentration (g/L)
Cdet = concentration (sampling) measured downstream of the device (g/L)

The characteristic spectrum found during the detection of fluorescent particles is illustrated by few results recorded when detecting particles of different diameters (Figure 9).

The scale of the abscissa is in direct proportion to the amount of fluorescein measured per particle counted off, i.e. to the volume of the particle for a constant fluorescein concentration in the solvent (glycerol).

As far as the scale of the ordinates is concerned, it totals the number of particles detected per unit of time.

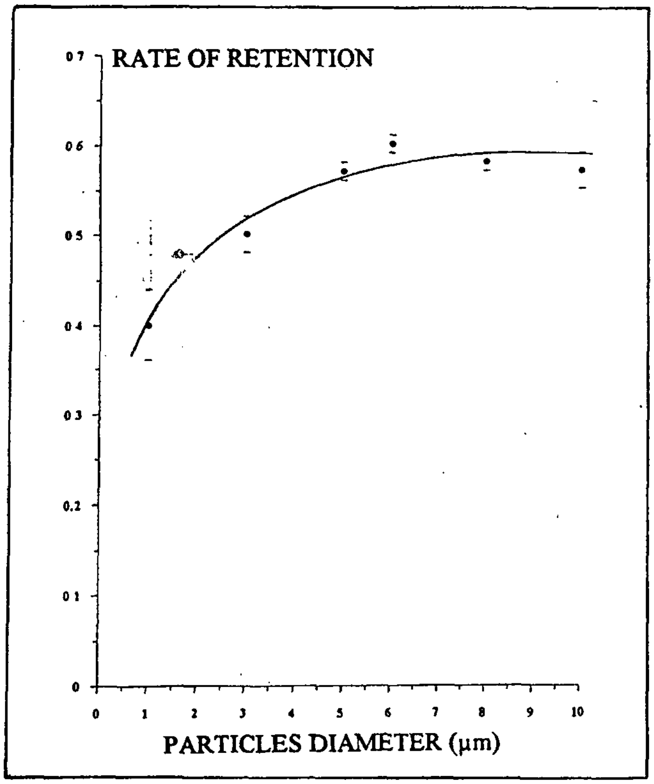
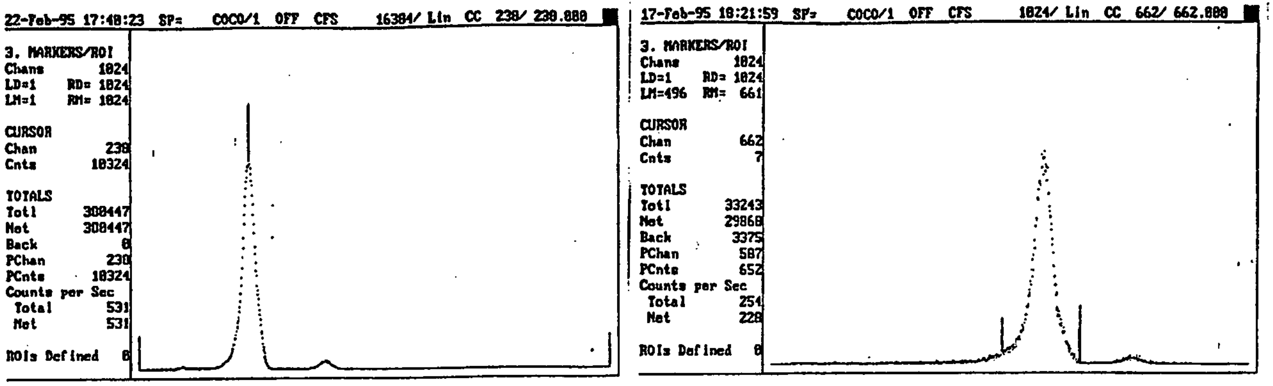


Figure 8 : Rate of retention versus particle diameter.

VII.2. Analysis of the signal given

Under good test conditions, i.e. optimum focusing of the laser beam on the jet of particles and a population of monodispersed droplets, the histogram found takes on a gaussian pace centered on the average value of the intensity of fluorescence measured.

Integration under the peak allows for determining the total number of particles detected during the analysis time.



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Cnts         10324

TOTALS
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Cnts             7

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Net          29868
Back          3375
PChan          587
PCnts          652
Counts per Sec
 Total         254
 Net           228

ROIs Defined     0
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dae = 5 µm

dae = 10 µm

Figure 9 : Examples of spectra recorded

VII.3. Effect of different parameters

Several parameters can change the rate of the spectra recorded for a given diameter of particle with a fixed fluorophore concentration ; they are mainly :

- power of the laser beam (therefore of the excitation lighting) ;
- high voltage applied at the photomultiplier (PMT) ;
- time during particle remains in the laser beam ;

- alignment of the excitation beam on the jet of particles ;
- centering of the flow of particles (action of the ducting air flow rate).

The first three parameters quoted act essentially on the limit of detection of the device ; as for the other two, they can entail the spectrum being wrongly interpreted when they are incorrect.

Figures 10 and 11 show that the figures for the power provided by the laser and for the high voltage applied at the PMT must be optimized to maintain the linearity of the detection signal with the fluorescence of standard particles.

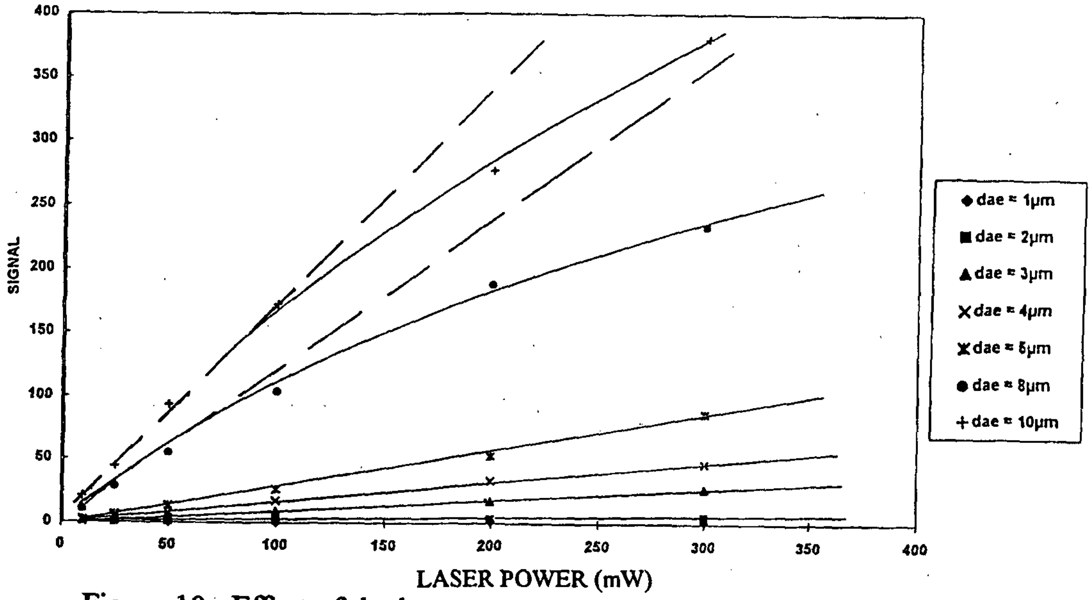

Figure 10 : Effect of the laser power on the fluorescence signal.

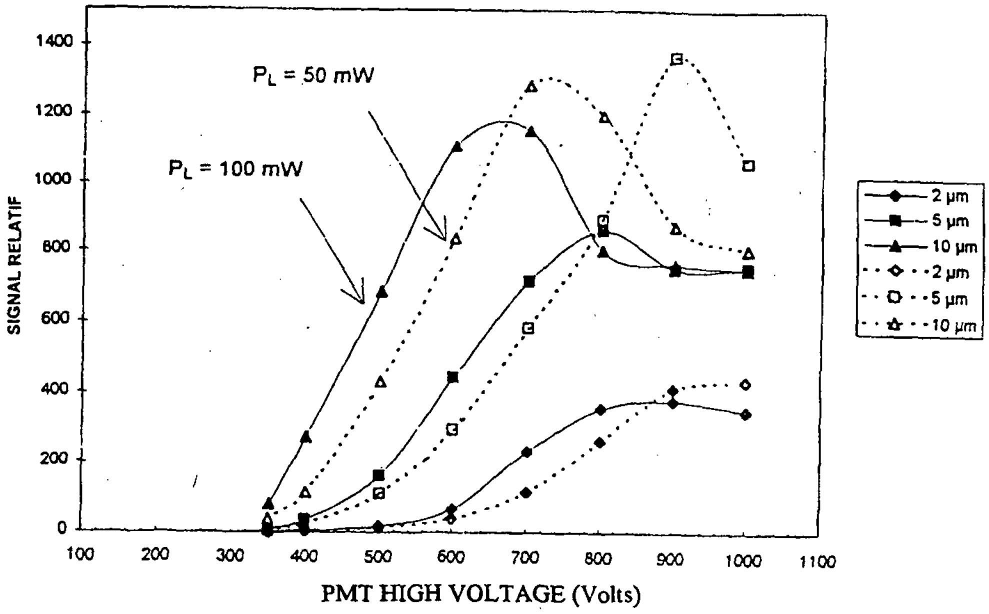

Figure 11 : Effect of the High Voltage of the PMT on the fluorescence signal

VII.4. Calibration test

A calibration curve can be drawn from the time one is working with all different optimized and fixed parameters.

The fluorescence signals emitted depend on the weight of fluorophore contained per particle, this is shown in Figure 12.

However, beyond certain conditions concerning laser power, high voltage of the PMT, size of droplets or else the fluorescein concentration, we encounter problems both with the limit of detection and with electronic saturation of the system.

In fact, when any of these various parameters increase, the linearity of the signal is only maintained in a certain field.

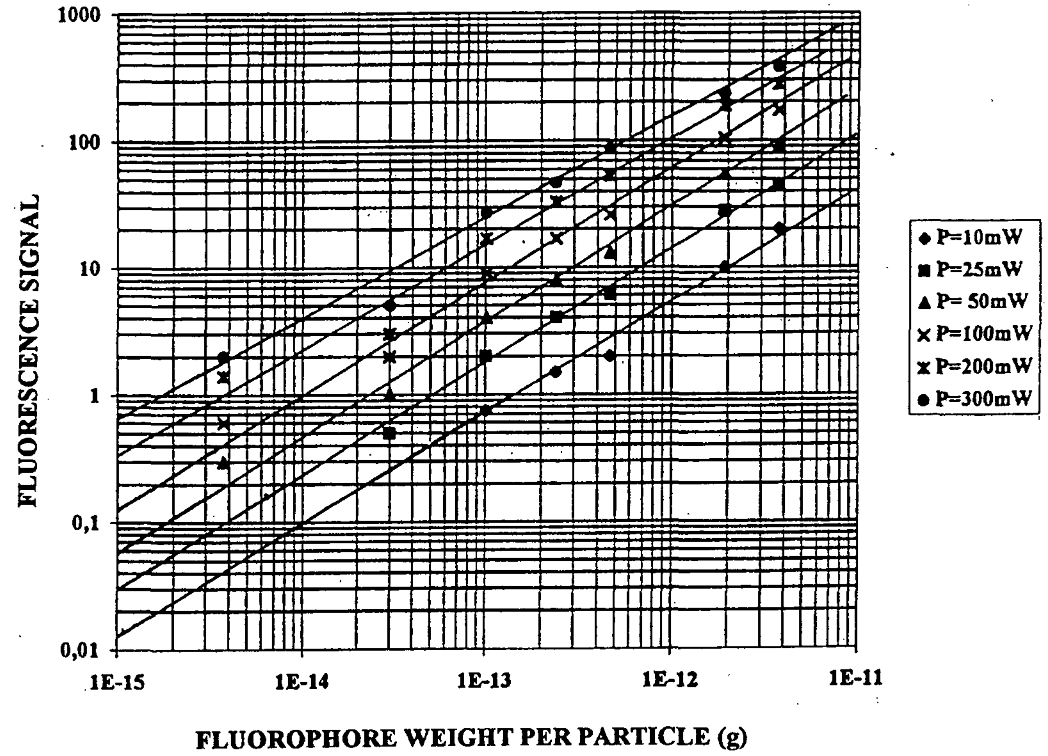

Figure 12 : Fluorescence signal versus weight of fluorophore contained per particle.

VII.5. Threshold of detection

The detection threshold of the device depends on the noise disturbing the signal for a fixed high voltage and laser power.

Thus, the detection threshold characteristic of our device is expressed as the lowest amount of fluorophore which can be detected. It's about 6.10^6 molecules per particle (10^{-15} g of soda fluorescein) detected at a laser power of 50 mW .

This limit value of detection can also be expressed in terms of the minimum particle diameter which can be measured, variable in accordance with the fluorophore concentration used.

VII.6. Comparison of results with conventional fluorimetry

Various tests have enabled us to compare the two differents systems by estimating the mean deviation between the results achieved by laser detection with those achieved with conventional fluorimetry when measuring an identical particulate concentration, for different droplet diameters.

We find results which are quite closed between the two techniques since the difference is below 10% in all instances in which the spectra obtained can be used (separation of the fluorescence signal with that corresponding to the electronic or optic noise).
The parity diagram (Figure 13) illustrates that the laser detection is a reliable method of particles counting versus the conventional fluorimetry method.

The analysis times using the laser counting method are reduced and depend only on the particulate concentration present, for a constant delivery : it is desirable to wait for detection for a minimum of 10^4 events in total in order to reach satisfactory counting statistics (2 % accuracy) which, depending on the concentration measured, can involve counting times of less than one minute.

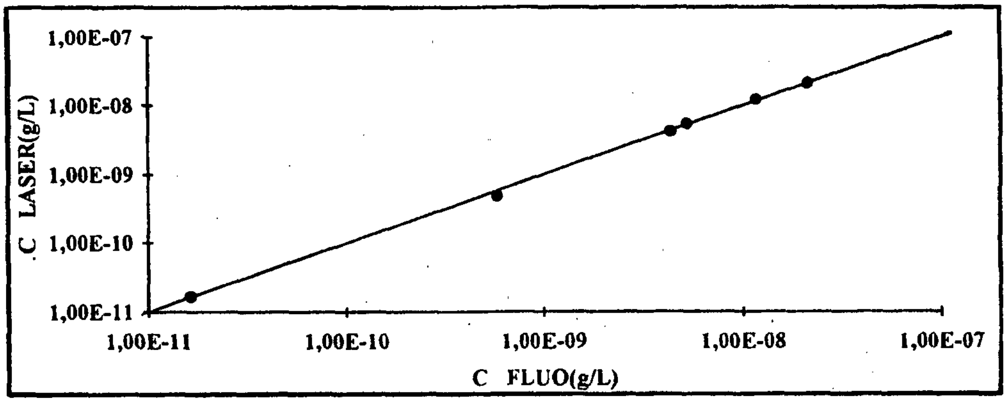

Figure 13 : Parity diagram

where C_{LASER} = results from laser detection (g/L)
C_{FLUO} = results from conventional fluorimetry (g/L)

Our device allows great selectivity of detection since it only counts fluorescent particles. Spectra which have nil counting rates are found when samples are taken direct in the ambient air.

VIII. CONCLUSIONS AND PROSPECTS

Using a suitable laser source associated with high yield collection optics contributes to making a high performance fluorescent aerosol detection device for follow-up in real time and continuously of a test particulate concentration injected into a room or test rig.

Through the data collected the technique allows direct access to particle counting rates while controlling the particle size of the aerosols produced.
Estimating the total weight of fluorophore detected is facilitated for monodispersed particle analysis as soon as the content of each of them is known.

The limitations of this technique are directly connected with the noise level (optics and electronics) produced by the device as well as by the physical and chemical properties of the fluorophore used.

Manufacturing in the course of time a portable unit for taking measurements on site, calls for a technology which is compact and light and that essentially limits the size of the laser source used. In spite of the fact that there are ionized argon lasers on the market producing powers in the region of 20 to 100 mW, it would be wise to consider new excitable dyes in the red to permit the use of laser diodes which are very small and inexpensive. However, the dyes used must be quite harmless to human beings, which considerably limits the choice. In spite of our various researchs, only one dye is appropriate, the allophycocyanin that is a very costly product.

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ACCURACY IMPROVEMENT IN LEAK DETECTION OF CHARCOAL ADSORBERS BY HALIDE PULSE INTEGRATION METHOD.

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Abstract

Due to the phaseout of the supply of R-11, which is used as a charcoal adsorber leak-testing agent, several new substitutes have been suggested and tested. (2) Pulse testing using agents with higher boiling points produced longer response times (due to prolonged evaporation and dispersion times). This longer evaporation time alters the pulse shape and lowers the peak concentration. Since the dispersion and evaporation time under different ambient condition are unpredictable, the peak concentration becomes unpredictable as well. One way to eliminate this unpredictability is to determine the area under the curve (of concentration versus time) after test-agent injection rather than the peak concentration (height). This value should be independent of the injection time and evaporation rate as long as the volume of the test agent injected remains constant.

Thus, tests were performed with a constant volume injection of test agent but with different injection times and evaporation rates. The area under the curve of concentration versus time was then compared with the peak concentration for each injection.

Introduction

Testing with a pulse of challenge agent has an advantage over testing with continuous injection, as described by several authors. (1,3,4) During pulse mode leak testing, the leak is calculated from the ratio of the pulse height detected simultaneously on the downstream and upstream side of the adsorber bed. This calculation is correct as long as the referenced two detectors have identical characteristics and they are working in their linear range. Several institutions have pushed the permissible leak threshold level from 10^{-2} % to 10^{-4} %. This is a new challenge for the detectors, since there is no sensor with linear characteristics over 6-7 orders of magnitude. Therefore, such tests are performed by comparison of a calculated upstream concentration with the detected highest peak concentration detected downstream of the adsorber. The comparison of a calculated concentration value on the upstream side of the adsorber to a detected peak height on the downstream side can be a significant source of error, varying with ambient conditions.

However, if the area under the curve of concentration versus time is used rather than the peak concentration (with constant volume injection of test agent), then this source of error can be reduced Tests were performed to confirm this hypothesis.

Test and Equipment Description

A test was performed on a full size air cleaning unit at the NUCON® facilities to check the validity of the concept. The purpose was to show that no matter what the geometric shape of the pulse, the integrated value would provide an accurate measurement of the quantity of challenge agent.

The challenge agent was injected at the inlet of a 6,000 scfm. air cleaning unit in which the air flow is provided by a downstream fan. A long length of duct (approximately 30 ft) and three stages of filtration (mist eliminator, pre-filter and HEPA filter) provided enough time for complete evaporation and dispersion. A syringe was used to dispense 0.1 cc of 1-Bromobutane liquid onto a hot plate. Injection time varied from 2 seconds to 155 seconds.

A NUCON® F-1000 BBD detector was used to measure the concentration continuously. This instrument has a threshold sensitivity of 1 VPPB and the response is linear over the range of 1 - 450 VPPB. A single point sample was taken and pulled through the instrument by the internally mounted pump. A YOKOGAWA analog recorder recorded the concentration curves and a Hewlett-Packard integrator was used to analyze the output signal from the detector. The points on PPB curve represent the maximum concentrations recorded while the points on the integral curve are proportional to the mass of injected 1-Bromobutane.

Results and Interpretation

The test results shown on Figure 1 proved that if a constant volume of 1-Bromobutane is injected in the air stream, an open diode continuous halide detector will detect a constant integral value with less than ± 10% error although the injection and dispersion time is varied between 2 second and 155 seconds. With pulses shorter than 2 second, larger error is expected, since the open diode response time is in the 1 second range.

Conclusion

1. When using a single downstream continuous Halide detector with calculated upstream injection, the integral value under the detected curve should be used for leak calculation rather than the highest peak concentration.

2. If the mass (or volume) of injected halide is proportional to the air flow rate, a single downstream continuous detector using pulse integration will display the leakage as ratio of masses, even if the pulse height and shape are varied by the injection time. Using this method, the detector can be calibrated to display the leak rate, for fast, easy and accurate operation.

Acknowledgment

The authors wish to thank Miss Luanne Armstrong as well as Mr. Gyorgy Kovacs, Mr. Joseph C Enneking and W. Peter Freeman for technical support during the experiments and interpretation of the results

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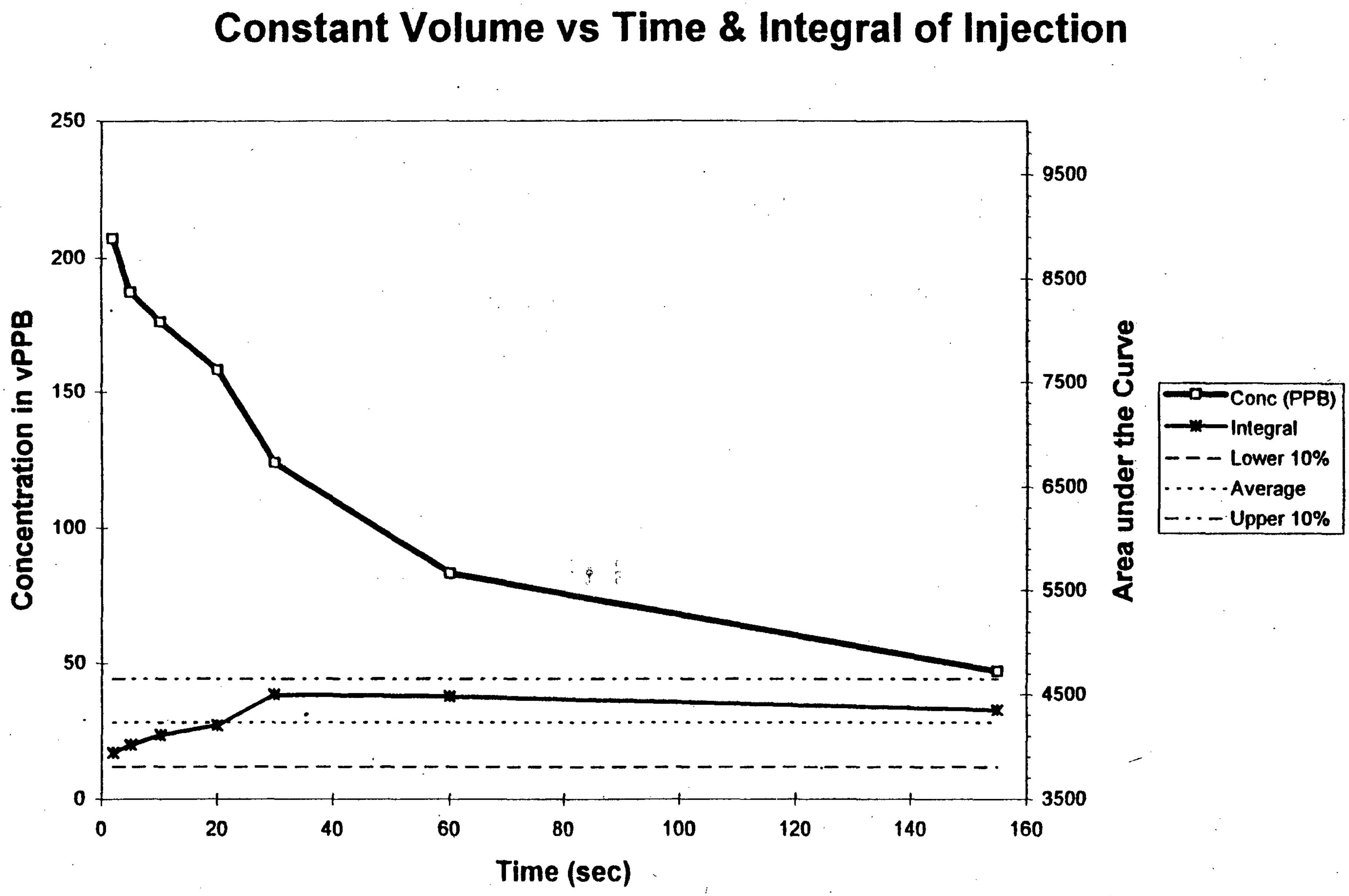
Proceedings of a European Conference, Luxembourg 14—18 October, 1985, on Gaseous Effluent Treatment in Nuclear Installations


Constant Volume vs Time & Integral of Injection
Concentration in vPPB
250
200
150
100
50
0
Area under the Curve
9500
8500
7500
6500
5500
4500
3500
0
20
40
60
80
100
120
140
160
Time (sec)
Conc (PPB)
Integral
Lower 10%
Average
Upper 10%

DISCUSSION

ANON: Is this replacement for R-11 a problem?

B. KOVACH: This is a R-11 replacement solution rather than a problem.

TESTING THE SAMPLING EFFICIENCY OF A NUCLEAR POWER STATION STACK MONITOR*

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Abstract

The test method comprises the injection of known amounts of monodisperse particles in the stack air stream, at a suitable point upstream of the sampling installation. To find a suitable injection point, the gas flow was mapped by means of a tracer gas, released in various points in the stack base. The resulting concentration distributions at the stack sampler level were observed by means of an array of gas detectors. An injection point that produced symmetrical distribution over the stack area, and low concentrations at the stack walls was selected for the particle tests.

Monodisperse particles of 6, 10, and 19 µm aerodynamic diameter, tagged with dysprosium, were dispersed in the selected injection point. Particle concentration at the sampler level was measured. The losses to the stack walls were found to be less than 10 %. The particle concentrations at the four sampler inlets were calculated from the observed gas distribution. The amount calculated to be aspirated into the sampler piping was compared with the quantity collected by the sampling train ordinary filter, to obtain the sampling line transmission efficiency.

Introduction

Installations for the monitoring of ventilation stack releases of radioactive gases and particles should be tested periodically. This report describes experiments with a relatively simple method to investigate the relation between particles passing in the stack and particles collected on a monitoring filter. The stack sampler employed for the experiments was of the normal Swedish design, consisting of four isokinetic probes connected to a 100 mm diameter transport pipe, and filters and radiation detectors, sampling from the transport pipe. Figure 1 shows the stack and the room below the stack where the ventilation air flows come together, the stack base chamber. At the stack sampler level, four isokinetic probes sample the stack air, and a 100 mm pipe conducts the combined air flows (64 l/s) to the monitor room. Assuming equal flows in the probes, the inlet concentration is

$$C_{in} = \left(\sum_{i=1}^{4} C_i \right) / 4$$

The mean concentration of particles in the stack over the time can be expressed as

$$C_{mean} = M / Q\, t$$

where M is the quantity of particles passing the stack in the time interval t. Q is the air flow in the stack, 164 m^3/s. If the particle concentration varies over the stack area, C_{in} and C_{mean} will generally differ by a factor f

$$C_{in} = f\, C_{mean}$$

f is called the "form factor" to indicate that it depends on the shape of the concentration profile and the disposition of the sampler probes.

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*Funding was provided by the Swedish Radiation Protection Institute, Project SSI P 870.95.

In the monitor room several secondary samples are drawn isokinetically from the transport pipe into filters and other monitoring devices (0.5 - 0.7 l/s each). Particle concentration in the air reaching the filters is generally lower than in the stack air, due to losses in the pipes etc. This is expressed by the transmission efficiency η

$$C_{out} = \eta\, C_{in}$$

The purpose of the work reported here was to test a method to determine the sampling efficiency, which includes the form factor as well as the transmission efficiency. By means of these factors the stack release is calculated as

$$M = C_{mean}\, Q\, t = \frac{C_{in}}{f} Q\, t = \frac{C_{out}}{\eta\, f} Q\, t$$

Due to the strong dependence on particle size the investigation could also be called determination of upper size limit of the sampling installation.

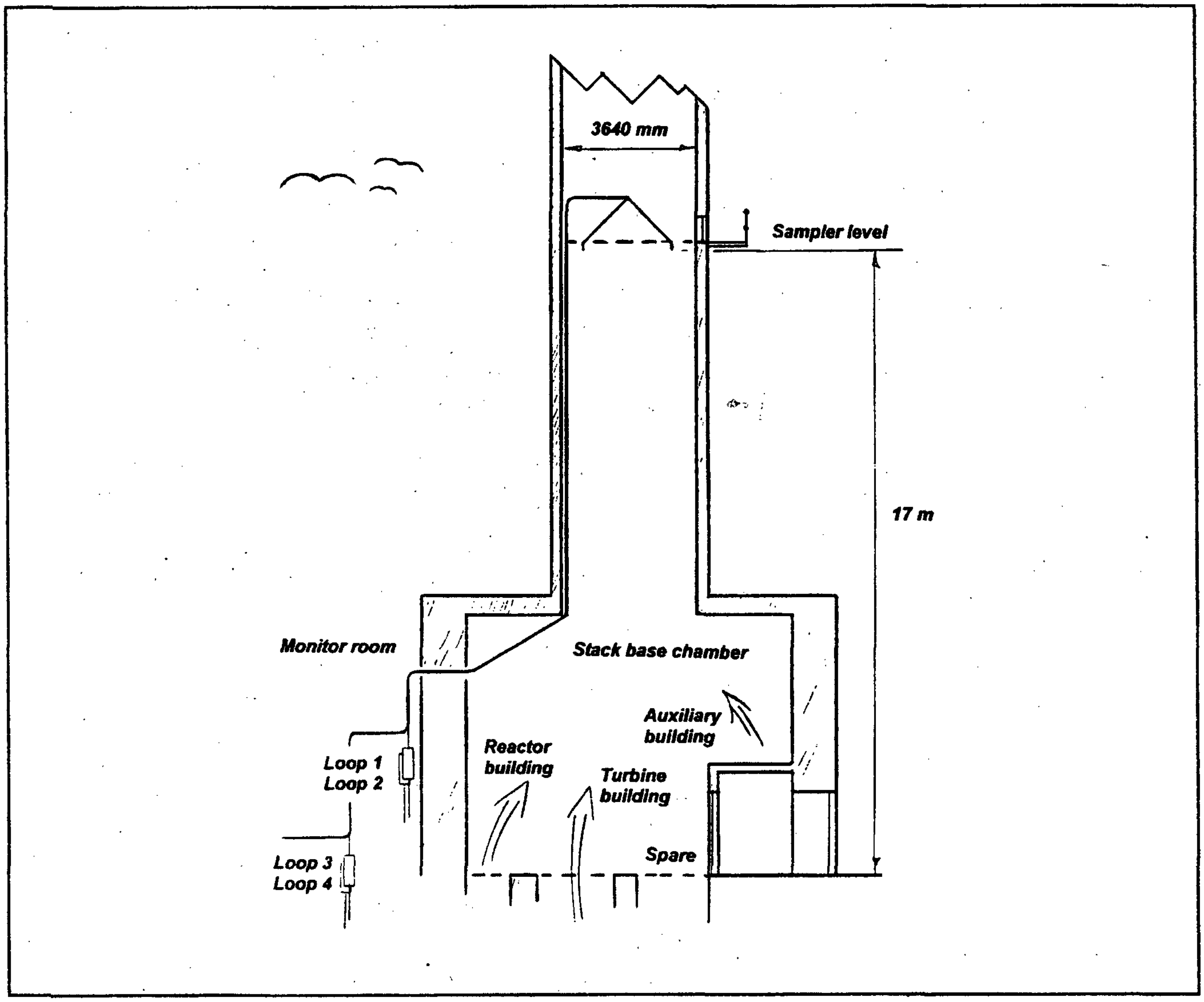

Figure 1. The stack base chamber, the stack, and the installation for air sampling.

The flow pattern

To find the form factor the air flow in the stack was mapped by means of a tracer gas. It was equally important to find a suitable injection point for the subsequent tests with particles. Suitable means in this context that at most a small fraction of the test aerosol is lost on the way from the injection point to the sampler section in the stack, but at the same time it is reasonably well distributed over the sampling section.

Ethanol was chosen as the tracer gas, for which simple solid state sensors are available, sensitive down to the ppm level (Scimarec AF 63, Japan). These sensors are no precision devices, but they are small, rugged, easy to apply, and cheap. 9 sensors were mounted on a cross-shaped frame, connected to a data logger, and hoisted to the sampler level. Ethanol was then injected by means of a compressed air atomizer in a number of points in the stack base chamber. Each injection consumed 1 litre of ethanol and took 10 minutes. Figure 2 shows some of the concentration patterns observed at the sampler level. The three ventilation air streams are evidently not well mixed when they reach the sampler. The arithmetic mean of the observed concentrations was calculated, to be used as a substitue for C_{mean}, and by interpolation also the concentrations at the four sampler inlets, and C_{in} (C_{mean} should not be taken from the injection rate, because of drift in sensor calibration). From this the form factor for the different injection points is obtained. These are provided in the key to Figure 2. In spite of the uneven distributions, the form factor is confined to the range 0.74 - 1.24.

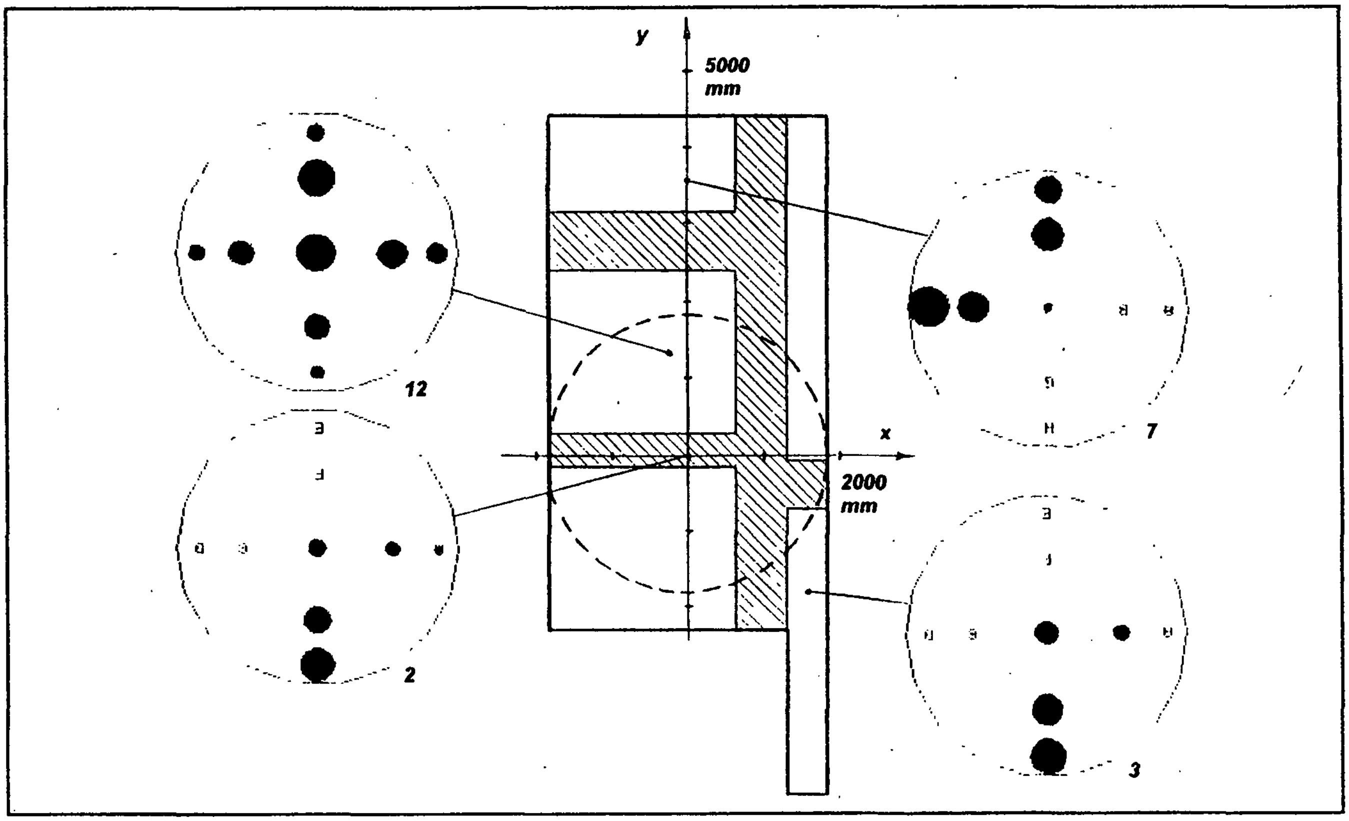

Figure 2. Observed tracer gas concentrations in the 9 measurement points at the sampler level, and the calculated form factors f for the sampler istallation. The dot areas are proportional to concentration.

		x, mm	y,mm	f
Injection 2:	*On the centerline of the stack*	0	0	0.74
Inlection 3:	*In ventilation channel Auxiliary Building*	1575	-1800	0.82
Injection 7:	*In ventilation channel Reactor Building*	0	3500	1.00
Injection 12:	*In ventilation channel Turbine Building*	-250	1300	1.24

The particle tests

Monodisperse styrene - divinylbenzene particles were obtained from DYNO Particles, Norway. The particles were sulfonated and tagged with dysprosium, as a preparation for activation analysis. Three different sizes were employed, with the following properties:

Particle properties

Manufacturer's designation	Q-673	Q-501	Q-851
As received:			
Diameter, µm	4.6	8.6	15.3
Standard deviation, %	1.1	0.9	1.8
After sulfonation:			
Diameter, µm	4.9	9.1	16.3
Density, kg/m^3	1595	1316	1300
Dysprosium, g/kg of particles	109	39.5	35.6
Aerodynamic diameter, µm	6.2	10.4	18.6

The dysprosium was very strongly connected to the particles, with less than 1 % in the liquid phase of the particle suspension.

The particles were to be dispersed from a methanol suspension, and it was feared that the particles would acquire an electrical charge in the process. The charge of the smallest particles after dispersion in a test chamber was therefore measured. With pure methanol (conductivity 0.15×10^{-3} 1/Ωm) a mean charge of about 300 electrons was observed. By adding a small amount of potassium chloride solution to the suspension the conductivity was increased about 10 times, which decreased the particle charge by a similar factor. Such a low charge is not expected to influence particle deposition.

From the droplet spectrum of the atomizer it was calculated that if the particle concentration in the dispersion was 10^{14} particles/m^3 then only about 1 % of the particles generated would be duplets or higher combinations. This was confirmed by measurements. The atomizer was a Lechler 156.330.30.16, the dispersion gas carbon dioxide, the gas pressure 300 kPa, and the methanol flow 8 g/s.

One of the objectives of these tests was to demonstrate that it is possible to conduct the test aerosol to the sampler level without significant losses. With the tracer gas tests it had been observed that injection at the coordinates x=-250 mm, y=1300 mm (Figure 2) gave a symmetrical pattern at the sampler level, with lower concentration at the walls. These conditions would favour low particle losses to the stack walls, and the above coordinates were used for the particle injections.

Particles were dispersed in the stack base chamber, and the particle flow at the sampler level measured by means of eight filter samplers. The form factor for these extra samplers and the chosen injection point was estimated at 0.92. An "injection efficiency" can be calculated as

$$\mathrm{H}=\frac{\textit{Concentration at sampler level}}{\textit{Injected concentration}}=\frac{C_{A..H}\,/\,0.92}{M_{inj}\,/\,t\,Q}$$

where

$C_{A.H}$	Mean concentration measured by the eight samplers
M_{inj}	Injected amount
Q	Stack flow
t	Injection time in seconds

The following results were obtained. The (rather uncertain) results from a calculation of the losses by means of turbulent deposition theory are also provided in the table.

Injection efficiency

Injection number	1	2	3	4	5	6
Particle size, µm	6.2	6.2	10.4	10.4	18.6	18.6
Dy injected, mg	27	33	54	53	191	190
Efficiency, measured	1.10	1.13	1.03	1.12	0.85	0.97
Efficiency, calculated	1	1	1	1	0.96	0.96

The measurements indicate that the particles are overrepresented in the filter samples. The reason could be an incorrect form factor, or non-isokinetic sampling. The important conclusion of this test is, that the injection losses are no greater than 10%, even for the largest particles. The calculation of deposition indicated that the reduced deposition velocity, k^+, for the largest particles had its maximum value, 0.2. Still larger particles, currently considered in connection with new monitor installations, might not deposit faster in the stack.

Sampling line transmission efficiency

During the six injections mentioned above particles were also collected with the ordinary filter of the sampling installation. The transmission efficiency is calculated as

$$\eta=\frac{C_{out}}{C_{in}}=\frac{1}{f}\frac{C_{out}}{C_{mean}}=\frac{Q}{q}\frac{1}{f}\frac{1}{\mathrm{H}}\frac{\textit{Collected amount}}{\textit{Injected amount}}$$

where

f	Form factor C_{in}/C_{mean}
Q	Stack flow
q	Filter flow
H	Injection efficiency

The following results were obtained

Transmission efficiency

Injection number	1	2	3	4	5	6
Particle size, µm	6.2	6.2	10.4	10.4	18.6	18.6
Efficiency η, %						
Loop 2	13*	62	7	8	2	4
Loop 3	47		8		3	
Loop 4	45		7		6	
DEPOSIT calculation	65	65	16	16	0.2	0.2

*probably a gross error

In the table above is also cited the particle transmission calculated with the computer program DEPOSIT 2.0, ref 1. The computer program predicts reasonably well the particle size dependence, considering that the sampling system might be rather dirty, and that the adhesion at contact with the pipe surfaces might be incomplete for the largest particles.

Conclusions

It was demonstrated that in a simple but real geometry a test aerosol could be brought to the sampling section of the monitor installation with only small losses. The mean concentration can then be calculated from the injected quantity of particles, and separate sampling in the stack is not necessary. This simplifies testing considerably. Instead flow mapping with a tracer gas must be performed, to determine a suitable injection point for the test aerosol, and to find the form factor. But it is much easier to measure a gas than to measure particles.

Reference

1. Fan, B J et al. Aerosol particle losses in sampling systems. Paper 6-3, 22nd DOE/NRC Nuclear Air Cleaning and Treatment Conference. Denver, Colorado, USA, August 1992.

DISCUSSION

BARLOW: My question is, if you had field conditions where the number of very large particles was very small, would you get any statistical effects which would render that 2-3% penetration (that you observed in your experiments using similar amounts in each particle size) very variable so that on some days you might get, say, 50% through?

STRÖM: One or two large particles may well be responsible for the bulk of the radioactivity in the sample under real conditions. The statistical nature of the sampling process in the stack will produce variations in the sample. Penetration through the sampling line is strongly size dependent, and statistical variation will only be added in the narrow transition range.

DUVALL: In your last slide you showed poor transmission for large particle sizes, i.e., those over 10 μm. I think it is a very important point because it illustrates the limitation of extractive sampling and a need to assure that large particles are not slipping through cracks in HEPA filters that develop between the filter medium and frame and so go undetected by extractive sampling. These large particles carry a large contribution of the radioactivity in the stack effluent to atmosphere. This illustrates a linkage of requirements for emission monitoring with requirements for air cleaning.

STRÖM: Particles from damaged filters are especially difficult to monitor, because such particles can be parts of the dust cake or the filter, and consequently very large. Sampling for filter damage requires special techniques.

THE INFLUENCE OF SALT AEROSOL ON ALPHA RADIATION DETECTION BY WIPP CONTINUOUS AIR MONITORS

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Abstract

Waste Isolation Pilot Plant (WIPP) alpha continuous air monitor (CAM) performance was evaluated to determine if CAMs could detect accidental releases of transuranic radioactivity from the underground repository. Anomalous alpha spectra and poor background subtraction were observed and attributed to salt deposits on the CAM sampling filters. Microscopic examination of salt laden sampling filters revealed that aerosol particles were forming dendritic structures on the surface of the sampling filters. Alpha CAM detection efficiency decreased exponentially as salt deposits increased on the sampling filters, suggesting that sampling-filter salt was performing like a fibrous filter rather than a membrane filter. Aerosol particles appeared to penetrate the sampling-filter salt deposits and alpha particle energy was reduced. These findings indicate that alpha CAMs may not be able to detect acute releases of radioactivity, and consequently CAMs are not used as part of the WIPP dynamic confinement system.

I. Introduction

This paper discusses how aerosol particle collection on alpha continuous air monitor (CAM) sampling filters influences the reliability of CAM measurements. As a consequence of this study, the design of the Waste Isolation Pilot Plant (WIPP) radioactive confinement system was reevaluated, and a number of additional facility safeguards were added to reduce risks to workers and the environment.

Alpha CAMs were installed to monitor for transuranic radionuclides in the WIPP mine exhaust air. Mine exhaust air is normally unfiltered and flows at a rate as high as 425,000 cubic feet per minute (CFM). If radioactive aerosol were detected, then air flow would be diverted to high efficiency particulate (HEPA) filters and lowered to 60,000 CFM. At the lower air flow rate, some underground operations are not allowed; at high air flow, full underground operations are allowed. Thus, effluent CAMs are important in monitoring unfiltered air flow.

The 1990 WIPP Safety Analysis Report (SAR) required CAMs to be operational whenever unfiltered air was vented.(1) If an effluent CAM was non-operational for an hour, then operations were to be curtailed. Because of the importance of effluent CAMs, the Environmental Evaluation Group (EEG) recommended laboratory and in-situ testing to establish the reliability and detection efficiency of alpha CAMs.(2)

The WIPP repository is located in a bedded-salt formation 655 m (2150 ft) below the surface. The exhaust air contains high-salt-aerosol concentrations during mining, backfilling and other underground operations. It was assumed that alpha particle detection efficiency would not be significantly affected by the salt aerosol. Aerosol particles were expected to impact on the surface of the CAM sampling filters, or on the surface of sampling-filter salt deposits. Because radioactivity would be on the surface of the filter or salt deposit, alpha particle energy would not be reduced before interacting with the CAM detector. For chronic radioactive releases, it was suggested that a saturation plutonium count rate would occur when sampling-filter-salt-deposit thickness exceeded the range of the alpha particles.(3)

The EEG reviewed CAM operational data and found that alpha spectra and radon-thoron daughter background subtraction were significantly affected by the magnitude of sampling-filter salt deposits.(2) These problems were persistent, once a salt deposit accumulated on the sampling filter. The Waste Isolation Division (WID) of the Westinghouse Electric Corporation, located at the WIPP site, addressed this problem by modifying the alpha CAM detector-filter chamber design, but spectral anomalies and poor background subtraction were still observed.(4) It became apparent that aerosol was not collecting on the surface of sampling-filter salt deposits.

In the following discussion, the alpha CAM design is reviewed, particle collection mechanisms discussed, and operational data are presented. From this information, it was concluded that CAMs could not perform their intended function, as required in 1990 SAR. Changes in the facility operations and safeguards were instituted.

II. WIPP Alpha CAM Design, Location and Particle Collection Efficiency

The WIPP alpha CAMs are modified Eberline Model Alpha-6 CAMs and are designed to account for the limited range of alpha particles. Sampled air passes through a membrane filter of either 25 mm (1 in) or 47 mm (1.8 in) in diameter, and when present, salt dust collects on the surface of the sampling filter. The sampling filter is juxtaposed approximately 5 mm (0.2 in) from a 25-mm (1 in) diameter alpha detector (Figure 1). The Figure 1 filter-detector geometry allows alpha particle detection efficiency as high as 11% of the particles emitted (4π efficiency).

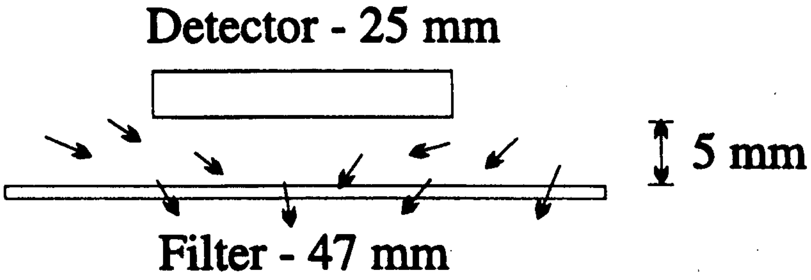

Figure 1 Detector-filter geometry (arrows indicate air-flow path).

The Alpha-6 monitor has a 256-channel spectrometer capable of discriminating ^{239}Pu and ^{238}Pu (5.1 and 5.5 MeV) alpha particles from naturally occurring alpha radiation, particularly alpha peaks from ^{218}Po and ^{212}Bi (6.0 to 6.09 MeV), ^{214}Po (7.69 MeV) and ^{212}Po (8.78 MeV). Net plutonium channel counts are derived by using a fixed region-of-interest (ROI) subtraction method(5) as shown below:

$$\mathbf{Pu_{net}} = \mathbf{(ROI\text{-}1) - [k * \{(ROI\text{-}2) * (ROI\text{-}3)\} / (ROI\text{-}4 + 1)]} \quad (1)$$

where

Pu_{net} = Net counts in plutonium region
ROI-1 = Counts in region 1, plutonium (channels 92-126)
k = k-factor, constant
ROI-2 = Counts in region 2, ^{218}Po, ^{212}Bi (channels 136-143)
ROI-3 = Counts in region 3, ^{214}Po (channels 148-178)
ROI-4 = Counts in region 4, ^{212}Po (channels 179-186)

Figure 2 shows a typical alpha background spectrum, and designated ROIs. If the subtraction method is working properly, the average Pu_{net} count rate will be zero. If the alpha spectrum is anomalous or degraded, ROI-4 may be disproportionately low and cause Pu_{net} to be negative.

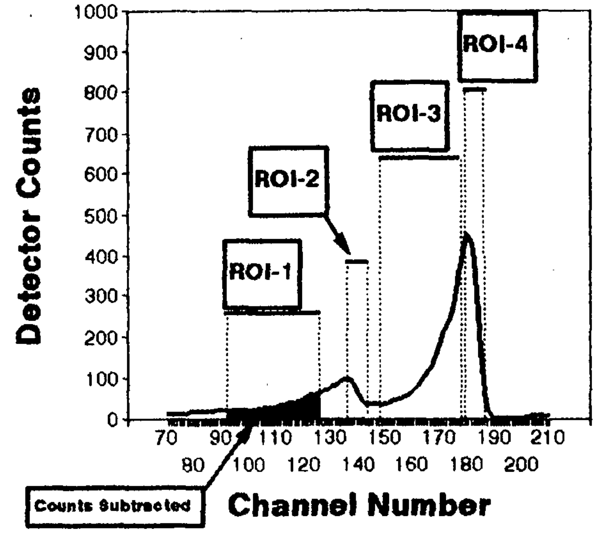

Figure 2 ROIs for alpha background subtraction.

There are four WIPP test CAMs discussed in this report. Three CAMs (153, 157 and an in-line prototype) are located in an above-ground sampling station (Station A) directly above the air exhaust shaft (see Figure 3). All mine air vents through the air exhaust shaft, and consequently, any salt aerosol produced underground can potentially affect the Station-A CAMs. A forth CAM (129) is at the north end of room 1, panel 1 of the underground repository (Figure 3). The repository horizon is approximately 655 m (2150 ft) below the surface. There is usually little salt aerosol in room 1, panel 1 and the performance of CAM 129 in a low aerosol location was compared to the CAMs at Station A where salt aerosol is most likely.

Station-A CAMs are off-line monitors. Sample lines equipped with specially-designed shrouded probes extend from the Station-A sampling room into the exhaust shaft and can continuously sample the underground air effluent at a free stream velocity range of 2 to 14 m s^{-1} (6.5 to 46 ft s^{-1}) and at a rate of 170 L min^{-1} (6 CFM).(6) The sampled air is pulled into three separate collection ports at 56 L min^{-1} (2 CFM). The transmission ratio of particle sizes up to 10 μm AD (aerodynamic diameter) through the shrouded probe is expected to be 0.93 to 1.11.(6)

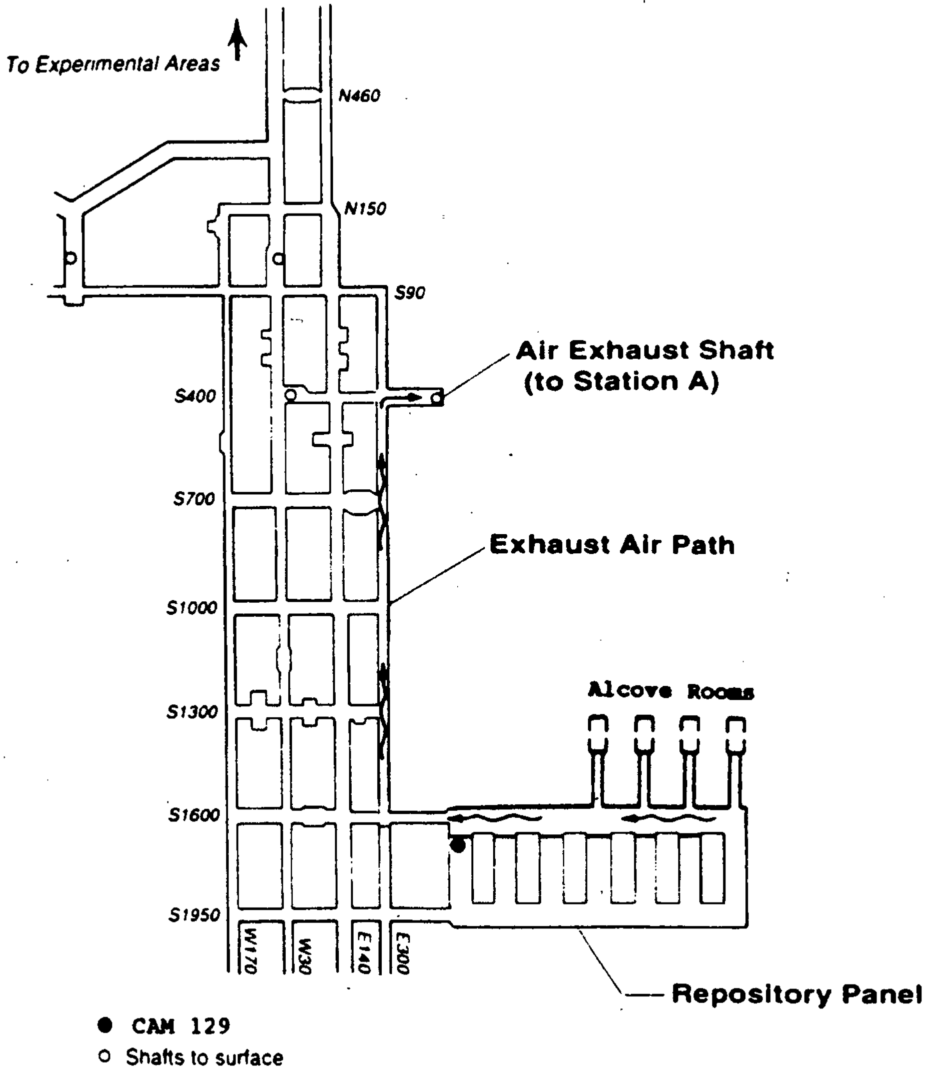

Figure 3 Main areas of underground repository (CAM 129 is located in room 1, panel 1, and station-A CAMs are located at ground level above the air exhaust shaft.)

CAM 129 is equipped with a radial annulus sample head in which aerosol enters the head from any direction around the rim at 28 L min^{-1} (1 CFM). The radial annulus sampler allows essentially 100% collection of particle sizes up to 6 to 8 μm AED (aerodynamic equivalent diameter) at 28.3 L min^{-1} to 85.0 L min^{-1} (1 to 3 CFM) and wind speed of 1 m s^{-1} (3.28 ft s^{-1}).(7)

In diesel-equipped mining operations similar to the WIPP, a bimodal distribution of airborne particles of 0.2 μm and 5 μm average aerodynamic diameter is typical.(8) WIPP measurements indicated a similar distribution and that the aerosol is primarily NaCl.(9)

The ratio of radon-thoron progeny attached to WIPP salt-diesel aerosol is unknown. The NCRP(10) states that mine aerosol concentrations would have to be extremely low to allow unattached fractions to exist. Other investigators suggest that the unattached fraction in diesel-equipped mines is much less than 1%.(11) The WIPP is primarily a day-shift operation, and aerosol concentration may vary widely over a 24-hr period. Alpha spectra shown in this report are primarily from day-shift operations when aerosol concentrations are expected to be high.

III. Potential for Degraded Alpha Spectra

CAM sampling-filter mass loading is as high as 2 to 3 mg cm^{-2} for underground operations, but can be in the range of 15 to 20 mg cm^{-2} during backfilling or some mining operations.(2) Twenty-four hour average air concentrations are as high as 0.3 to 0.5 mg m^{-3}, and up to 2.5 to 3.3 mg m^{-3} in extreme conditions.

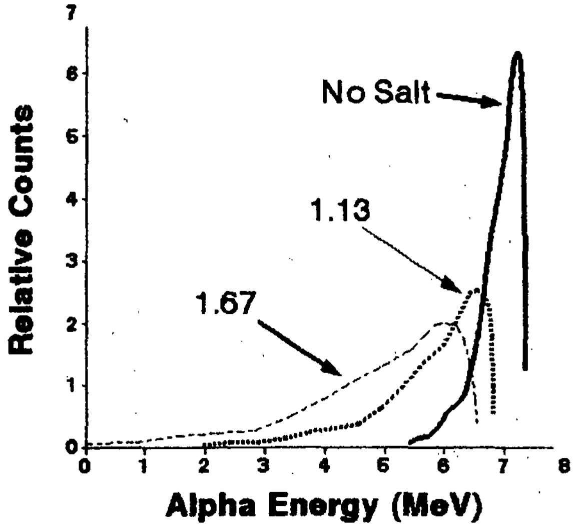

Figure 4 Theoretical reduction a ^{214}Po alpha spectrum with 1.13 and 1.67 mg cm^{-2} salt interposed between the source and detector.

Alpha measurements are dependent on the CAM filter-detector geometry (Figure 1). Radioactivity on the sampling-filter surface will emit alpha particles isotropically. Using the filter surface as the source, alpha particle direction, path length and kinetic energy were predicted and calculated, considering the influence of air and varying salt thicknesses.(4) Figure 4 shows a calculated ^{214}Po (7.69 MeV) alpha spectrum and the effect of interposing as little as 1 mg cm^{-2} of

Table 1 Theoretical ^{238}Pu and ^{239}Pu Alpha Efficiencies*.

Depth in Salt mg cm^{-2}	Efficiency, % (4π)			
	^{239}Pu (5.1 MeV)		^{238}Pu (5.5 MeV)	
	ROI 92-126	ROI 65-126	ROI 92-126	ROI 65-126
0	10	12	11	12
0.56	6	10	5	11
1.13	1	6	2	10

*Efficiencies are relative to a 10% no-load 5.1 MeV efficiency.

salt between the source and detector. The spectral effects of interposed salt are more pronounced when less energetic ^{238}Pu (5.5 MeV) and ^{239}Pu (5.1 MeV) alpha particles are the source. The theoretical efficiency of the Alpha-6 was calculated as shown in Table 1.(4) Changing the lower ROI-1 discriminator setting from 92 to 65 improves theoretical plutonium efficiency, but the overall CAM performance may be affected by other factors such as false alarm rates or background subtraction.

IV. Particle Collection Mechanisms

The EEG collects fixed-air sampling filters each day at the above ground sampling site, Station A. Salt particles ranging in physical size up to 7 μm in diameter were observed using a scanning electron microscope. Microscopic analyses also revealed numerous dendritic structures on the sampling-filter surface. If exposed to high humidity the dendritic structures tend to collapse and form a confluence.(2) Sputtering the sampling-filter surface, as a preparation for electron microscopic analysis, also disrupted the dendritic structures, as did viewing with a scanning electron microscope for long periods. In general, the sampling-filter salt deposits appeared loosely formed and porous. If observed with a light microscope, the dendritic structures remained stable.

The microscopic observations strongly indicated that the aerosol particles are electrostatically bound. The dry, hygroscopic nature of the WIPP salt repository favors electrostatic buildup, and particle-to-particle interactions were evident in our observations. There are no pressure drop measurements across the sampling filter, but air flow is maintained relatively constant by flow control devices. Data from 1993 indicated only 2 days during the year when air-flow rate decreased by more than 10% during a 24-hour sampling period. The lack of filter clogging suggested that the particle packing fraction was low and that air easily passed through the sampling-filter salt deposit.

Because of these observations, it was hypothesized that the sampling-filter salt deposits may behave more like a fibrous filter than a membrane filter. If so, aerosol would penetrate differentially into the salt deposit. As the salt layer becomes thicker, more particles penetrate deeper into the salt deposit. The deeper the aerosol penetrates into the sampling-filter salt deposit, the greater the potential exists for reduced alpha particle energy and poor alpha spectra.

It was suggested that a monodisperse particulate aerosol will collect differentially on a fibrous filter with the fewest particles penetrating to the greatest depth in the filter,(12) and particle penetration was described by a simple differential equation with the following solution:

$$\mathbf{N(x) = N(o)\, e^{-\alpha x}} \tag{2}$$

where
N(x) = particle concentration at depth x
N(o) = particle concentration at surface, x = 0
α = layer efficiency (cm^2 mg^{-1})
x = layer thickness (mg cm^{-2})

and

$$\mathbf{P = N(x) / N(o) = e^{-\alpha x}} \tag{3}$$

where P = penetration fraction

A plot of a hypothetical, monodisperse aerosol penetrating a fibrous matrix appears in Figure 5. A polydisperse aerosol was described as having a more complex penetration pattern and for a bimodal distribution was characterized as follows:(12)

$$P = (1-\beta)\, e^{-\alpha 1\, x} + \beta\, e^{-\alpha 2\, x} \tag{4}$$

where
P = penetration fraction
$\alpha 1$ = layer efficiency of first aerosol fraction ($cm^2\ mg^{-1}$)
$\alpha 2$ = layer efficiency of second aerosol fraction ($cm^2\ mg^{-1}$)
β = fraction of the $\alpha 2$ aerosol particles
x = layer thickness ($mg\ cm^{-2}$)

A plot of a typical monodisperse aerosol penetrating a matrix is represented by either line 1 or 2 in Figure 6. Line 1 shows a highly penetrating fraction while line 2 shows a less penetrating fraction. Line 3 is a combination of two monodisperse aerosol fractions and is characteristic of a bimodal or polydisperse aerosol.

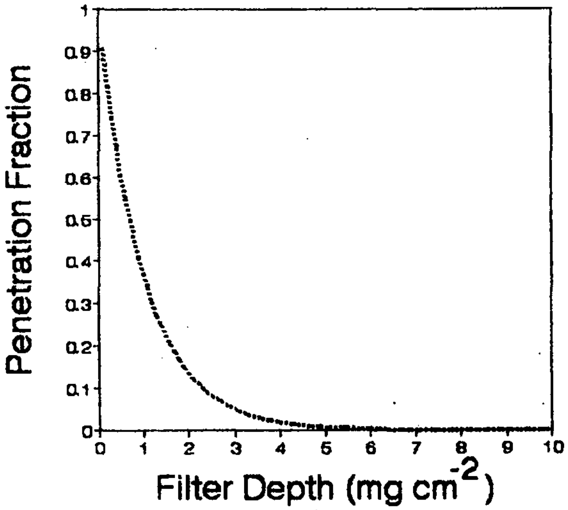

Figure 5 Monodisperse penetration of aerosol into a filter.

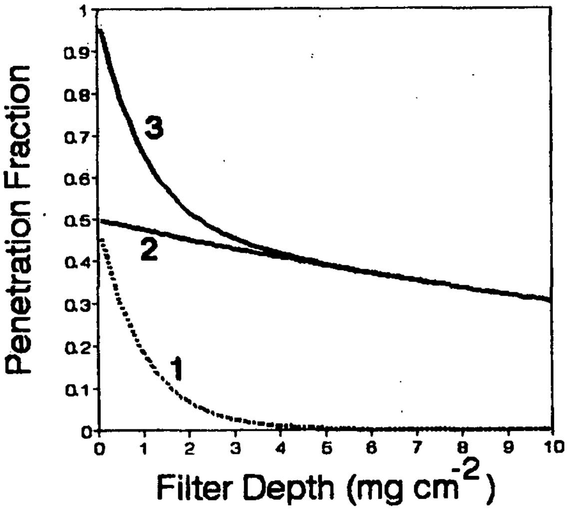

Figure 6 Polydisperse penetration of aerosol into a filter.

IV. Operational Data

Early in 1991, the maximum ^{214}Po peak height at the end of a 12-hour sampling period was evaluated as a function of sampling-filter salt loading, and a declining relationship was found (Figure 7). Following extensive CAM modifications in 1991 and 1992, a similar analysis was performed for a 24-hour sampling period, and a declining relationship was again found (Figure 8). These simple analyses indicated that sampling-filter salt loading was affecting alpha spectra and suggested the need for additional analyses.

CAM sampling filters are changed each morning before underground activities begin, and with a clean filter in place, well resolved spectra begin accumulating. Spectra typically become degraded mid-morning when underground operations begin. The poor spectra persist until filters are changed.

An example of the effects of sampling-filter salt loading occurred on January 25, 1994 when backfill demonstrations were conducted in the alcove rooms (Figure 3). Hourly spectra from 9:00 a.m. to 1:00 p.m. are shown for the underground CAM 129 and Station A CAMs (153, 157, and in-line) in Figure 9. The Station A CAMs accumulated 11 mg cm^{-2} during this sampling period, whereas CAM 129 was out of the salt aerosol air flow and accumulated very little salt deposit. The Station A CAM spectra became severely degraded after 9:00 a.m and continued to be degraded until the sampling filters were changed the next day. CAM 129 spectra remained well resolved.

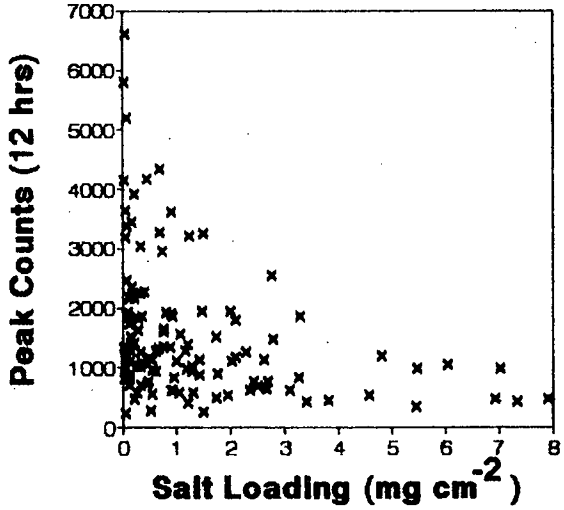

Figure 7 Maximum peak height of ^{214}Po, CAM 153, 1991, 12-hr sampling period.

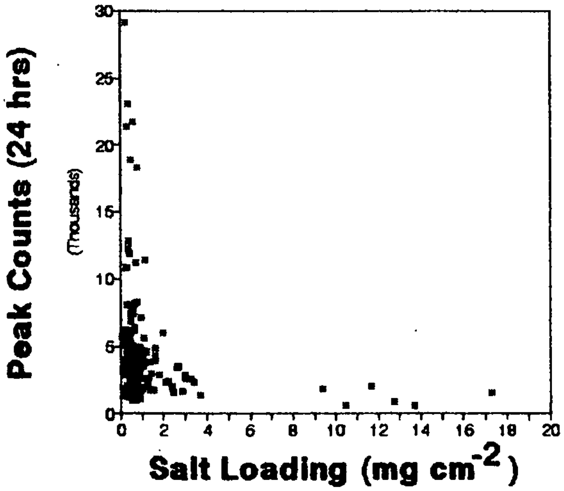

Figure 8 Maximum peak height of ^{214}Po, CAM 157, 1992-3, 24-hr sampling period.

In addition to maximum peak height, the full-width-at-half-maximum (FWHM) of ^{214}Po alpha peaks was used as a performance indicator for alpha spectra. ^{214}Po peak resolutions were calculated for days in January through March 1994 when salt loading varied from near zero to as high as 17 mg cm^{-2}. The average FWHM during a 5-hour afternoon period was calculated and graphed as shown in Figure 10. The FWHM is normally in the range of 14 to 20 channels. The data indicate that as little as 1 to 2 mg cm^{-2} salt loading causes the FWHM to be greater than 20. The increase in FWHM and loss in ^{214}Po resolution at relatively low sampling-filter salt loading (1 to 2 mg cm^{-2}) is consistent with theoretical calculations in Figure 4.

The net counts in the plutonium ROI (Pu_{net} from Equation 1), were also plotted in Figure 10 as a function of filter salt loading. The data indicated periods of very negative Pu_{net} counts (< -100 CPM) for 3 to 5-hour periods. Compared to an effluent alarm setting of 40 CPM, these negative excursions are significant. At relatively low salt loading (0 to 2 mg cm^{-2}), the background subtraction appears reasonably good. At salt loading above 2 mg cm^{-2}, there was consistent oversubtraction of plutonium region counts. At very high salt loading (18 mg cm^{-2}), the oversubtraction was not as pronounced, but alpha peaks were essentially non-existent. Pu_{net} was not a consistent CAM performance indicator, but at times, the oversubtraction of plutonium background counts was so extreme that the monitor could not be considered operational.

The total spectrum counts in each of the Station-A CAMs were compared to total counts from CAM 129 during the same time period. The results were graphed as a ratio shown in Figure 11. When salt loading was low, all CAMs had similar total counts. As salt load increased, efficiency dropped quickly. These data are indicative of the quantitative reduction of CAM efficiency as salt

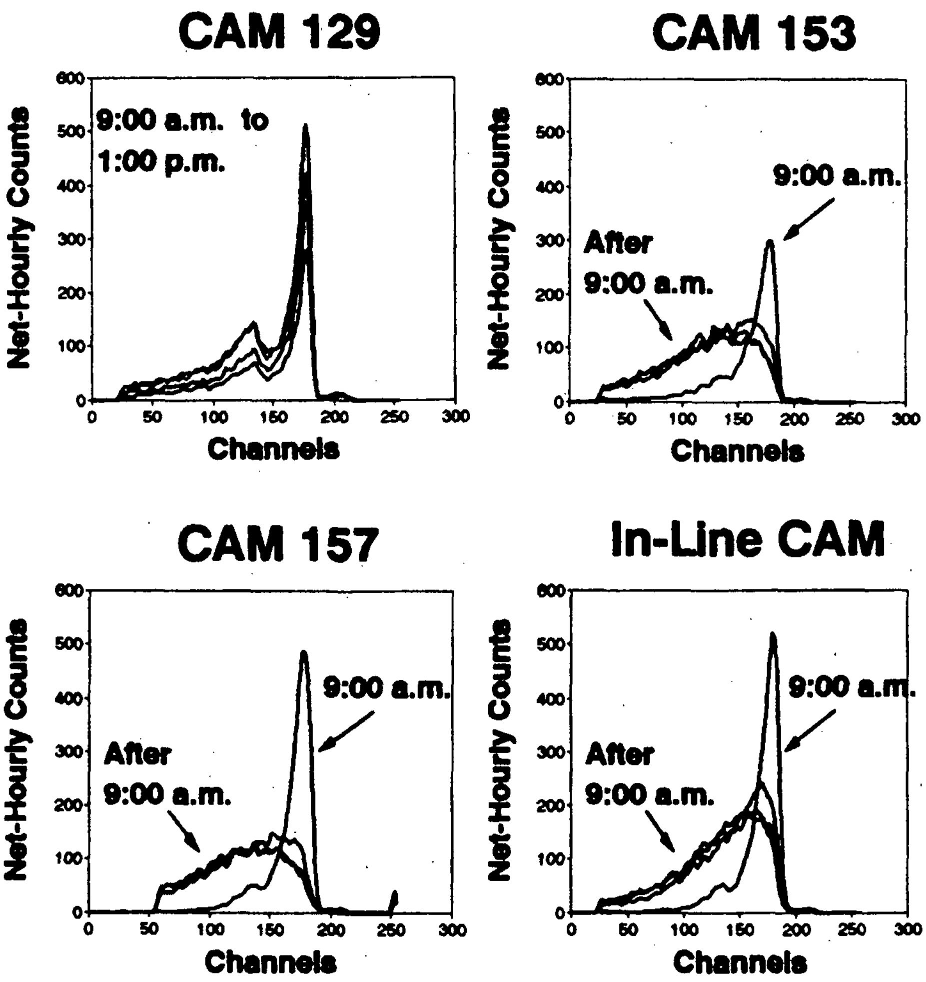

Figure 9 CAM alpha spectra on January 25, 1994.

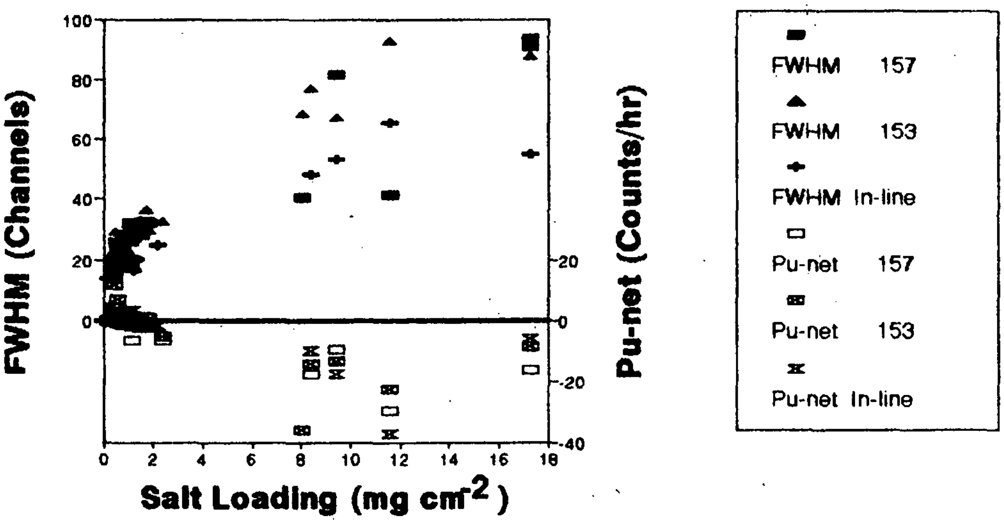

Figure 10 FWHM and Pu_{net} as sampling-filter salt deposits increase.

deposits become greater. The most straightforward explanation is that aerosol particles are penetrating the sampling-filter salt deposit, and alpha particle energy is reduced by interaction with the salt deposits.

If aerosol penetrates a fibrous filter and the sampling-filter salt deposit in a similar manner, then it would be expected that alpha detection efficiency would decrease exponentially as salt deposits increase. The observed relative efficiency data was fit to the exponential equation, e^{-bx} (Figure 12). At the 95% confidence level, data up to 17 mg cm^{-2} yielded a goodness of fit of 0.97. Because previous empirical data(9) and information(8) suggest that the WIPP mine aerosol is a bimodal distribution, data below and above 2 mg cm^{-2} were fit independently with the same exponential equation. The data below 2 mg cm^{-2} yielded a goodness of fit of 0.89, the data above 2 mg cm^{-2} were fit at 0.99. Each of the analyses indicates an exponential loss of counts on CAMs with salt-laden filters. The data suggest that a bimodal distribution is probable, but additional work is needed to confirm this hypothesis.

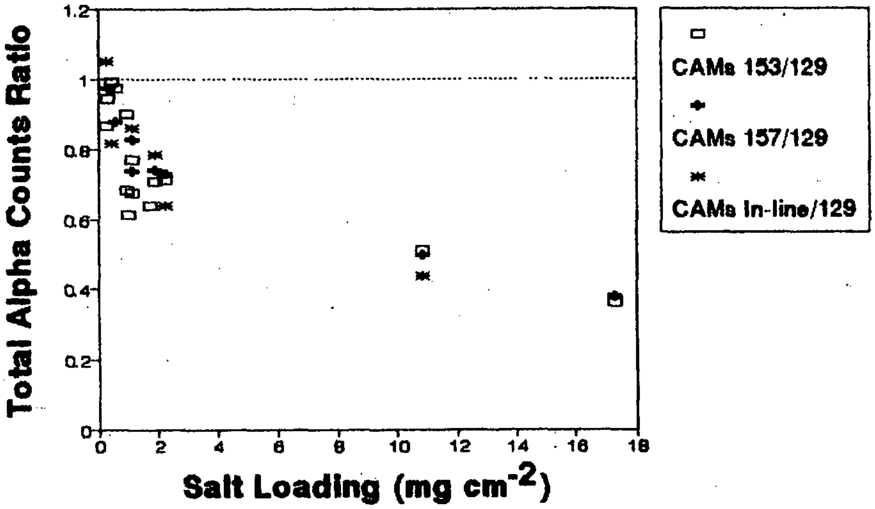

Figure 11 Relative efficiency of station-A CAMs to CAM 129 as a function of salt loading at Station A.

V. Discussion and Conclusions

The operational data and fibrous-filter collection theories suggest that degraded alpha spectra and poor background subtraction are attributed to penetration of aerosol particles into preestablished sampling-filter salt deposits. A number of variables were correlated with sampling-filter salt loading, and each case, there were direct correlations with salt loading. Electron micrographs revealed porous salt deposits and dendritic structures on the surface of the sampling filters. It appeared that once a significant level of salt deposit built up on the surface of a membrane filter, then the filter performed like a fibrous filter, rather than a membrane filter.

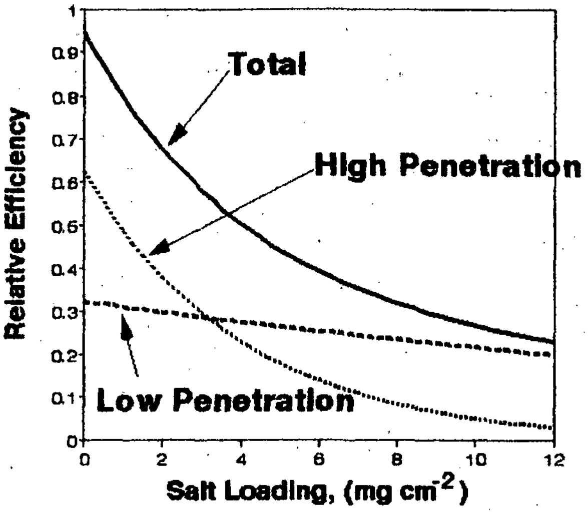

Figure 12 Best fit analysis of relative efficiency data.

If sampled aerosol collected strictly as layers on the surface of the sampling filter, then acutely released radioactive aerosol could be measured, regardless of the sampling-filter salt mass. Neither the reviewed data nor the fibrous-filter collection theories support such a limited mechanism for particle collection. In fact, more questions are raised about the complexity of the aerosol collection mechanism than are resolved. For example, it is generally thought that radon-thoron progeny are attached to ambient salt aerosol, but there are no empirical data to substantiate this assumption. It is not known whether radioactive progeny will preferentially attach to small or large dust particles. If radioactivity were found to attach only to the small particle fraction, then the collection mechanism of small particles would need to be studied. Although it is suspected that aerosol particles are predominantly collected by an electrostatic mechamism, other mechanisms can not be ruled out. And most importantly, it is not known whether transuranic aerosols would behave similarly to those of radon-thoron progeny.

The amount of salt on a sampling filter appears to be a much more important variable than the average-salt-aerosol concentration. Because of this finding, the mass of sampling-filter deposits should be carefully documented, and CAMs ideally should alarm when sampling-filter deposits become significant. Depending on the CAM location and function, the data indicate that sampling filters should be changed when salt deposits are in the range of 0.5 to 2.0 mg-cm^{-2} (Table 1, Figures 11).

Effluent alpha CAMs are no longer a part of the limiting conditions of operations or the dynamic confinement system at the WIPP. Instead, WIPP will reduce potential radioactive uptake risks to workers and the environment by eliminating the operational backfill, restricting radioactive content of waste drums, using underground barriers to control potential releases and fires, modifying ventilation, relocating critical CAM monitors, and changing sampling filters when significant salt buildup is likely.

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DISCUSSION

BRESSON: I thought I heard you say that when you were making measurements and mining operations were being conducted there was a period of enhanced salt concentration in the air. Is that correct?

BARTLETT: That is correct.

BRESSON: Do you have any data that show how the alpha CAM spectrometer system functions when there isn't that kind of activity going on? I would expect such activity would be typical of operations at WIPP. The question is, how do alpha CAMs function when you are not disturbing the environment and creating the particles?

BARTLETT: That's a good question. Figure 2 shows a typical alpha spectrum that you would see at Station A. When there is no salt, the instrument has good resolution, as shown in Figure 2. Your question is interesting because we have been asked this before. Some people think we can not do alpha spectroscopy in a mining environment, but we have five years' worth of electronic data to the contrary. The monitors work well when there is no salt aerosol.

BRESSON: So it is possible to come up with an operational scheme whereby you can rely on the air monitoring system to do its job except during periods when you are deliberately adding contaminants.

BARTLETT: That is very true. In fact, that has been one of our recommendations. The problem is determining when you are going to have salt aerosol collecting on the filter. Rather than manually determining when spectra are poor, it would be advisable to have the monitor automatically recognize poor spectra. Ventilation air could then be diverted to HEPA filters, or other operational options could be considered.

BRESSON: Does the particle size of the salt seem to be several micrometers in diameter?

BARTLETT: Yes, in electron micrographs the largest sized particle we have seen is about 7μm in diameter. There have been other studies by ITRI Research in Albuquerque, NM, in the mid-80's, and they reported particle sizes in the 3-5μm range.

BRESSON: Would a prefilter on the detector system filter out the larger salt particles but allow passage of PuO_2 particles?

BARTLETT: It is not known whether the Pu particles would be attached to the salt.

ENGLEMANN: What is the size distribution of the salt, and of the anticipated plutonium? The geometry you show suggests that salt may deposit around the periphery of the detector, on the filter, and the smaller plutonium makes it hard to get under the detector. Have you considered or tried a cascade impactor?

BARTLETT: There could be a wide range of Pu particle sizes. As mentioned previously, salt particle sizes range up to about 3-5μm.

ENGLEMANN: And larger for the salt?

BARTLETT: That is for the salt.

ENGLEMANN: Now it occurs to me to ask if you have tried the cascade impactor where you would get the activity in the final stage.

BARTLETT: I think that is a good recommendation. That is one of our recommendations, too.

ENGLEMANN: Another question is concerned with the geometry in which the detector is close to the filter. One would expect the salt and the larger particles to be peripheral to the detector. Are they able to make the turn and head toward the center of the filter? I wonder to what extent you are sure that you have a problem, and whether it can be corrected with the geometry.

BARTLETT: Perhaps I have given the wrong impression. Let me go back a bit. The question of geometry and uniform deposition of particles across the filter has been the subject of other studies. As a result of the studies, the collection chamber was redesigned to preclude this problem. I showed you two CAM spectra from station A. One was an older design. Another one was a new design that gives a much more uniform distribution of the particles across the face of the filter. Am I addressing your question?

ENGLEMANN: Perhaps if the fix isn't to correct uneven distribution across the filter, you can collect your large particles around the outside and let the rest go to the center.

BARTLETT: That is difficult.

ENGLEMANN: At any rate, I assume you have studied it?

BARTLETT: Those are questions that have been considered. We have not studied it *per se*, because others have looked at it. I believe these concerns have been addressed by the WIPP project.

SESSION 4

PANEL SESSION: TESTING AIR AND GAS CLEANING SYSTEMS
A) ACCEPTANCE TESTING: PROPOSED AG-1 CODE TA
B) IN-SERVICE TESTING: PROPOSED NUCLEAR STANDARD N511

Tuesday July 16, 1996
Co-Chairmen: S. Banton
M.E. Pest

Panel Members: P. Burwinkel
C. Graves
V. Kluge
L. Leonard

PANEL DISCUSSION

SECTION TA ACCEPTANCE TESTING, DRAFT REVISION 03/06/96

ASME N511-19XX, STANDARD FOR PERIODIC IN-SERVICE TESTING OF NUCLEAR AIR TREATMENT, HEATING, VENTILATING AND AIR CONDITIONING SYSTEMS, DRAFT REVISION 07/09/96

SECTION TA
ACCEPTANCE TESTING

DRAFT

REVISION 03/06/96

Note: This is a draft document. An approved code section may differ in many respects. This draft version is made available for discussion purposes only.

SECTION TA

DRAFT

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ARTICLE TA-1000
INTRODUCTION

TA-1100 SCOPE

This section provides requirements for the field acceptance testing of nuclear safety-related air treatment, heating, ventilating, and air conditioning systems in nuclear facilities.

TA-1110 PURPOSE

The purpose of this section is to provide requirements for field acceptance testing, the results of which are used to verify that nuclear air treatment, heating, ventilating, and air conditioning systems perform their intended function.

TA-1120 APPLICABILITY

This section applies to acceptance testing of nuclear safety-related air treatment, heating, ventilating, and air conditioning systems which are assembled, installed and ready for use. Included are requirements for integrated system performance testing under simulated conditions of operation. It is the Owner's responsibility to meet each of the applicable requirements in this section.

TA-1130 DEFINITIONS AND TERMS

The definitions provided in this section supplement those listed in AA-1000.

Abnormal Incident -- any event or condition which may adversely affect the functionality of the nuclear air treatment, heating, ventilating, and air conditioning system.

Acceptance Test -- a test to verify system or component design function following initial field installation, an abnormal incident, replacement, repair, or modification affecting a test reference value.

Adsorbent -- a solid having the ability to concentrate other substances on its surface.

Adsorber -- a device or vessel containing adsorbent.

Adsorber Bank or Filter Bank -- one or more filters or adsorbers secured in a single mounting frame, or one or more side by side panels containing poured or packed air treatment media, confined within the perimeter of a duct, plenum, or vault cross section, sometimes referred to as a stage.

Aerosol -- a stable suspension of particles, solid or liquid, in air.

Challenge -- to expose a filter, adsorber, or other air treatment device to an aerosol or gas of known characteristics, under specified conditions, for the purpose of testing.

Challenge Gas -- a gas of known characteristics, under specified conditions, used for the purpose of testing. For in-place testing of adsorbers, the challenge gas is to be Refrigerant-11 or an acceptable substitute.

NOTE: For Challenge Gas Substitution Selection Criteria, refer to Non Mandatory Appendix TA-C.

Challenge Aerosol--poly-disperse droplets of dioctyl phthalate, (di(2-ethyl hexyl) phthalate), used as challenge aerosol for testing HEPA filter banks for leaks. The challenge aerosol for in-place leak testing of HEPA filter systems, in accordance with this section, is poly-disperse DOP liquid aerosol having an approximate light scattering droplet size distribution as follows:

99% less than 3.0 micrometer diameter
50% less than 0.7 micrometer diameter
10% less than 0.4 micrometer diameter

NOTE: The poly-disperse aerosol used for in-place leak testing of systems differs from the 0.3 micrometer mono-disperse DOP aerosol used for efficiency testing of individual HEPA filters by manufacturers.

HEPA Filter -- (High Efficiency Particulate Air) a disposable, extended- media, dry type filter enclosed in a rigid casing, that has a minimum efficiency of 99.97% when tested with an essentially mono-disperse 0.3 micrometer test aerosol.

In-Service Test -- A periodic test to verify that a system or component continues to meet its intended design function after being placed into operation.

Pressure, Maximum Operating -- The maximum pressure the system components will be subjected to while performing their function. The allowable pressure during abnormal operating conditions which will not physically damage the system (e.g. sudden closure of dampers or registers), shall be considered maximum operating pressure.

Pressure, Operating -- the pressure that corresponds to the normal design operating mode of the system. This pressure is less than or equal to the maximum operating pressure.

Pressure, Structural Capability -- the pressure to which the designer specifies the component or system can be safely operated without permanent distortion.

Reference Value -- one or more achieved values or test parameters that are measured, observed, or determined when the equipment or system is known to be operating acceptably within its design basis range.

System -- An assembly of components, including associated instruments and controls, required to perform the safety-related function of a nuclear air treatment, heating, ventilating, and air conditioning system.

Test Boundary -- the physical limits of the component, system, or device being subjected to a specified test.

Test Canister -- a specially designed sample holder containing adsorbent for laboratory tests that can be removed from an adsorber bank, without disturbing the remainder of the adsorber, to provide representative samples for laboratory testing.

ARTICLE TA-2000
REFERENCE DOCUMENTS

The reference documents listed below shall supplement those listed in AA-2000.

AMERICAN CONFERENCE OF GOVERNMENT INDUSTRIAL HYGIENISTS (ACGIH) INDUSTRIAL VENTILATION: A Manual of Recommended Practice.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)
ASTM D 3803-1989, Standard Test Method for Nuclear Grade Activated Carbon.

AMERICAN NUCLEAR SOCIETY (ANS)
ANS 3.1 , Selection Qualification and Training of Nuclear Power Plant Personnel. (latest edition)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)
ANSI/ASME NQA-1-1989
Quality Assurance Program Requirements for Nuclear Facilities.

ANSI/ASME NQA-2-1989
Quality Assurance Requirements for Nuclear Facility Applications.

SHEET METAL AND AIR-CONDITIONING CONTRACTORS' NATIONAL ASSOCIATION, INC (SMACNA)
HVAC Systems Testing, Adjusting, and Balancing 1983.

ASSOCIATED AIR BALANCE COUNCIL (AABC)
National Standard of Total System Balance 1989.

DEPARTMENT OF ENERGY, DOE Proceedings
16th DOE Nuclear Air Cleaning Conference, page 125, "Size Distribution of Aerosols Produced from Substitute Materials by the Laskin Cold DOP Aerosol Generator", February 1981, NTIS Springfield, VA. (W. Hinds, J. Macher, M. First).

NATIONAL ENVIRONMENTAL BALANCING BUREAU (NEBB)
Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems 1991.

(**REFERENCES WILL BE UPDATED TO LATEST ADDITION PRIOR TO PUBLICATION**)

ARTICLE TA-3000
GENERAL INSPECTION AND TEST REQUIREMENTS

TA-3010 General

All inspections and tests shall be conducted in accordance with these requirements and the specific requirements of TA-4000.

NOTE: Activities in this section may involve the use of hazardous materials, operations and equipment. This section does not purport to address all of the safety requirements associated with their use. It is the responsibility of the user of this section to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.

TA-3100 TEST INSTRUMENTS

A calibration program shall be established in accordance with the Owner's Quality Assurance Program. All permanent and temporary test instruments used in the conduct of tests required by TA-4000 shall be in calibration. Instrument accuracy shall meet or exceed the requirements of Table TA-3000-1.

TABLE TA-3000-1
INSTRUMENT ACCURACY REQUIREMENTS

MEASUREMENT	RANGE	ACCURACY
Pressure	>1.0 psig (>7.0 kPa(gage))	+/- 2.0 %
Pressure	from 1.0 in wg to 1.0 psig (0.25 to 7.0 kPa(gage))	+/- 0.1 in wg (+/-0.025 kPa)
Pressure	from 0.1 in wg to 1.0 in wg (2.5 to 250 Pa(gage))	+/- 0.01 in wg (+/-2.5 Pa)
Temperature	variable	+/- 2.0 °F (+/- 1.0 °C)
Temperature*	variable	+/- 0.5 °F (+/- 0.25 °C)
Vibration	variable	Per TA-3141
Flow	variable	+/- 5.0 %
Velocity (airflow)	variable	+/- 3.0 %
Speed	variable	+/- 2.0 %
Time	variable	+/- 1.0 sec
Electrical voltage	variable	+/- 1.0 %
Electrical resistance	variable	+/- 1.0 %
Challenge aerosol concentration		Per TA-3142
Challenge gas concentration		Per TA-3143

* Required for pressure testing in mandatory Appendix TA-III.

TA-3110 Range Requirements

The full scale range of instruments shall be limited as necessary to ensure that the readings are within the accuracy requirements of Table TA-3000-1.

TA-3120 Instrument Fluctuation

Symmetrical damping devices or averaging techniques may be used to reduce random signal fluctuations. Hydraulic instruments may be damped by using gauge snubbers or by throttling valves in instrument lines.

TA-3130 Evaluation Following Test Instrument Loss, Damage or Calibration Failure

When a test instrument is lost, damaged, or otherwise fails to meet the requirements of Table TA-3000-1 during calibration, all test results obtained using the instrument shall be evaluated, dating back to the time of the previous calibration. If the evaluation does not confirm that the instrument met the acceptance criteria for the test(s) in question, the test(s) shall be repeated with calibrated instruments.

TA-3140 Specific Instrument Accuracy Requirements

TA-3141 Vibration Instrument

Vibration instrument accuracy shall be at least +/- 10%. The minimum frequency response range of the vibration measuring instrument shall be approximately one third of the minimum shaft speed. For rotating components, the maximum frequency response range shall be at least two times the rotational shaft speed of the component being measured. For reciprocating components, the maximum frequency response range shall be at least two times the speed of the crankshaft, times the number of unique planes occupied by a piston throw.

TA-3142 Challenge Aerosol Measuring Instrument

The Challenge Aerosol Measuring Instrument shall be verified to have a linear range of at least 10^5 times the threshold sensitivity of the instrument with an accuracy in accordance with the Facility Project Specifications and Owner's Quality Assurance Program.

TA-3143 Challenge Gas Measuring Instrument

The Challenge Gas Measuring Instrument shall be verified to be capable of distinguishing challenge gas from background and measuring challenge gas over a linear range of at least 10^5 times the threshold sensitivity of the instrument with an accuracy in accordance with the Facility Project Specifications and Owner's Quality Assurance Program.

TA-3200 REFERENCE VALUES

TA-3210 Establishment of Reference Values

Reference values shall be determined from results achieved during acceptance testing (TA-4000), when a component or system is proven to be operating within the acceptable limits of the Owner's Design Specification. Operating tests and inspections specified in TA-4000 shall be observed, measured, or calculated under conditions readily reproducible during subsequent in-service tests to allow for direct comparison of test results. All test results and associated analyses shall be included in the test procedure documentation (TA-6300).

TA-3300 INSPECTIONS AND TESTS

Acceptance tests shall be conducted following initial component installation but prior to releasing the system for normal operations. Applicable acceptance tests shall also be used to obtain new reference values and verify design function following component replacement, repair, modification, or maintenance. Equipment shall be evaluated as separate components and as functioning parts of an integrated system. The Owner shall define system test boundaries and evaluate system performance with respect to system functional requirements in accordance with the Owners Design Specifications. Field acceptance tests shall be implemented as applicable and in accordance with this section.

Test designations associated with tests required by TA-4000 are listed in Table TA-3000-2. Within the context of TA-4000, when a test is not associated with a Designator it shall be considered a prudent action and not a test requirement.

TABLE TA-3000-2
TEST DESIGNATIONS

TEST	DESIGNATOR
Air-Aerosol mixing test	AA
Airflow distribution test	AD
Differential pressure test	DP
Differential temperature test	DT
Flow rate test	Qf
Functional test*	F
Hydrostatic test	HYD
In-place leak test	IP
Laboratory analysis (adsorbent methyl-iodide penetration)	LAB
Electrical performance test	AMP
Leak test	PL
Structural capability test	PS
Rotational speed test	N
Bearing temperature test	Tb
Vibration test	Vb
Visual inspection	VT

* Functional tests consist of various mechanical actuation and performance verifications and are detailed separately in each test article.

TA-3310 Inspection and Test Parameters

Parameters which need to be observed, calculated and recorded in order to meet the requirements of this section shall be identified for each system based on the functional requirements of the Owner's Design Specification and shall be included in the test procedure documentation (TA-6300).

TA-3320 System Operating Conditions

Operating conditions required for acceptance testing shall be determined for each system. These conditions and acceptance criteria shall be based on the requirements of the Owner's Design Specification and shall be included in the test procedure documentation (TA-6300).

TA-3330 Procedure Requirements

The Owner shall be responsible for the development and implementation of written test procedures that meet the requirements of this section. Each equipment test section consists of generic (TA-3400) and specific (TA-4000) test requirements and acceptance criteria which apply to each of the systems in the facility. The Owner shall document which requirements are applicable in the test procedure documentation (TA-6300).

TA-3340 Test Reports

Test reports shall be prepared in accordance with TA-6300.

TA-3400 GENERIC TESTS

Generic tests as specified in TA-3410 through TA-3433 shall be used in Article TA-4000 where applicable.

TA-3410 Visual Inspection (VT)

Visual inspections shall be conducted in accordance with AA-5000 and the applicable portions of mandatory Appendix TA-I. Field acceptance visual inspections, required in TA-4000, shall include verification of component installation in accordance with the Owner's Design Specification and the applicable sections of this Code. Acceptance inspections shall be conducted prior to releasing the equipment for normal operation.

TA-3420 Pressure Boundary Tests

Pressure boundary tests consist of hydrostatic (or pneumatic) tests for hydronic systems, leak tests for refrigerant systems, and structural capability and leak tests for ducts and housings, including fan and damper housings.

TA-3421 Hydrostatic Tests (HYD)

Hydrostatic tests shall be conducted at the hydrostatic pressure defined by the Owner and shall verify that the component will not rupture, leak or be permanently deformed under design pressure loads. Testing shall be conducted in accordance with the design codes used in the Owner's Design Specification (e.g. ANSI/ASME B31.1). Pneumatic testing may be used in lieu of water where allowed by the applicable codes and in the Owner's Design Specification.

TA-3422 Structural Capability Test (PS)

Structural capability tests shall be conducted at the structural capability pressure defined by the Owner's Design Specification and shall verify that the component will not rupture or be permanently deformed under design pressure loads. Testing shall be conducted in accordance with mandatory Appendix TA-II.

TA-3423 Leak Test, Duct, Housing, and Frames (PL)

Leak tests for duct and housing sections shall be conducted using either the pressure decay method or the constant pressure method to verify that the leak rate for duct or housing does not exceed the allowable limit established for the system. Testing shall be conducted in accordance with mandatory Appendix TA-III. Leak testing performed to satisfy Section SA of this Code may be used to meet these test requirements when the test method is compatible with mandatory Appendix TA-III.

An optional leak test for HEPA filter and adsorber mounting frames is authorized to be conducted in conjunction with the housing leak test by blanking off the frame openings and pressurizing the isolated test boundary. This procedure is useful for detecting small leaks in the mounting frame during acceptance testing. This test is used to verify that there are no defects in a frame that may cause failure of the in-place leak test. Testing should be conducted in accordance with non-mandatory Appendix TA-A.

TA-3424 Leak Test, Refrigerant Piping and Coils (PL)

Leak tests of refrigerant piping and coils shall be conducted in accordance with mandatory Appendix TA-VIII.

TA-3430 Functional Tests (F)

A functional test shall be used to verify mechanical and system performance parameters of equipment. Functional tests include component and system tests as required in Article TA-4000. Component functional tests are used to verify the operational readiness of individual components. Integrated system functional tests are used to verify that all of the system components will operate together under normal operating or simulated conditions and will meet all of the performance requirements of the Owner's Design Specification.

TA-3431 Test Conditions

Equipment shall be tested within the normal operating range specified in the Owner's Design Specification except as otherwise specified in TA-4000.

TA-3432 Restoration of Function Following Testing

Mechanical and electrical equipment status shall be restored as required by plant conditions and according to approved procedures following completion of any test.

TA-3433 Vibration Test (Vb)

Vibration measurements shall be taken on the accessible motor, fan, compressor and pump bearing housings in at least two different orthogonal planes approximately perpendicular to the line of the rotating shaft. When the bearing housing is not accessible, the frame of the component may be used if it will be representative of bearing housing vibration. When portable vibration instruments are used, reference points shall be clearly identified on the component being measured to permit duplication in both location and plane.

TA-3500 ACCEPTANCE CRITERIA

Results of tests described in Article TA-4000 shall be subject to the acceptance criteria in TA-3510 through TA-3530 and to the applicable operating and design criteria specified by the Owner's Design Specification. Test results are considered acceptable if the component or system is not impaired or degraded to the point that it cannot perform its intended function. Acceptance criteria are specified in TA-4000 only when they affect the quality of other tests. When test results do not meet the applicable acceptance criteria, the corrective actions required by TA-5000 shall be initiated.

TA-3510 Visual Inspection

Visual inspections are acceptable when there are no visual indications of improper installation, physical damage, structural distress or degradation that would impair the ability of a component or system to perform its intended function.

TA-3520 Pressure Boundary Tests

Pressure boundary tests are acceptable when there is no permanent structural deformation or leaks in excess of the limits specified in the applicable sections of this Code and the Owner's Design Specification.

TA-3530 Functional Tests

Functional tests are acceptable when they meet the requirements of the applicable sections of this Code and the Owner's Design Specification.

ARTICLE TA-4000
FIELD ACCEPTANCE TESTS

TA-4010 General

Field acceptance tests shall be conducted following initial system installation but prior to releasing the equipment for normal operation. Applicable inspections and tests shall be conducted to verify compliance with the Owner's Design Specifications following equipment replacement, repair, modification, maintenance, or abnormal incident. Within the context of Article TA-4000, a test not associated with a test designator is considered to be a prudent action and not a test requirement.

TA-4100 FAN ACCEPTANCE TESTS

This section provides the field acceptance test requirements for fans, motors, and related accessories. Integrated system testing shall be conducted in accordance with TA-4900.

TA-4101 Acceptance Test Requirements

Acceptance tests shall be conducted with the fan operating at a flow rate within the normal operating range for the system. The tests listed in Table TA-4000-1 shall be conducted and test results verified to be within the acceptance limits of the Owner's Design Specification, the applicable portions of Section BA of this code, and as required in TA-3500 and TA-4150. These test results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison during periodic in-service tests.

TABLE TA-4000-1
FAN ACCEPTANCE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE
Visual inspection	VT		*
Structural capability test	PS	*	
Leak tests	PL	*	
System flow balance test	F	*	
Mechanical run test	F		*
Flow rate test	Qf	*	
Differential Pressure test	DP	*	
Electrical test	AMP	*	
Rotational speed test	N	*	
Vibration test	Vb	*	
Bearing temperature test	Tb	*	
Fan performance test	F	*	

TA-4110 Visual Inspection (VT)

A visual inspection of the fan and associated components shall be conducted in accordance with TA-3410 and mandatory Appendix TA-I (I-1100).

TA-4120 Pressure Boundary Tests

TA-4121 Structural Capability Test (PS)

When a fan housing is part of the system pressure boundary, a structural capability test shall be conducted to verify structural capability of the fan housing and connections in accordance with TA-3422 and mandatory Appendix TA-II. The fan housing may be tested concurrent with the duct and housing structural capability test specified in TA-4321.

TA-4122 Leak Test, Fan Housing (PL)

When a fan housing is part of the system pressure boundary, a pressure boundary leak test shall be conducted to verify the leak tightness of the fan housing and attached interfaces in accordance with TA-3423 and mandatory Appendix TA-III. The fan housing may be tested concurrent with the duct and housing leak test specified in TA-4322.

TA-4123 Leak Test, Fan Shaft Seal (PL)

When a fan shaft seal is part of the system pressure boundary, a pressure boundary leak test shall be conducted to verify the leak tightness of the shaft seal in accordance with TA-3423 and mandatory Appendix TA-III. The shaft seal may be tested concurrent with the duct and housing leak test specified in TA-4322. However, the shaft seal leakage rate shall be evaluated (qualitatively) independent of the overall system leak rate. The qualitative evaluation of the leakage shall be included in the test report.

TA-4130 Component Functional Tests

The following prerequisites shall be conducted on the fan and motor assemblies prior to the system functional tests specified in TA-4140.

TA-4131 Electrical Prerequisites

Prior to the initial energizing of the fan, the electrical power circuits shall be checked for installation, circuit continuity, voltage capacity and protective relay device settings.

TA-4132 Control System Prerequisites

Prior to the initial energizing of the fan, controls shall be calibrated and verified operational.

TA-4133 Startup Prerequisites

Prior to the initial energizing of the fan, the fan and motor shaft shall be manually rotated to verify moving parts are free of interference. The motor shall be momentarily energized to verify correct rotational direction. The fan shall be restarted and stable operation (no surging) verified. Fan and motor vibration, bearing temperature, motor electrical amperage and phase balance, fan speed, differential pressure, and airflow shall be monitored. Following one hour of operation, or immediately after observation of unusual performance (i.e. unstable performance), the fan shall be secured and a detailed visual inspection for signs of damage or degradation shall be conducted.

TA-4140 System Functional Tests

This section provides the system level field acceptance test requirements for fan systems.

TA-4141 System Flow Balance Test (F)

A system flow balance shall be conducted. Recommended procedures include SMACNA, NEBB, ACGIH, OR AABC (reference TA-2000).

System flow balancing may be conducted using artificial resistance in lieu of filters. However, final component reference values shall be obtained with clean system components installed.

TA-4142 through TA-4149 shall be conducted in the same time frame.

TA-4142 Mechanical Run Test (F)

Prior to conducting the tests specified in TA-4143 through TA-4149, the fan shall be operated at the design flow rate for at least 15 minutes and stable system operation (no surging) verified.

TA-4143 Flow Rate Test (Qf)

The fan flow rate shall be measured. Recommended procedures include ACGIH "Industrial Ventilation" or equivalent.

TA-4144 Static Pressure Test (DP)

The fan inlet and outlet static pressure and velocity pressure shall be measured and the overall fan static pressure determined.

TA-4145 Electrical Tests (AMP)

The fan motor supply voltage and amperage shall be measured for each phase.

TA-4146 Rotational Speed Test (N)

The rotational speed of the fan shall be measured.

TA-4147 Vibration Test (Vb)

The vibration of each fan and motor bearing shall be measured in accordance with TA-3433.

TA-4148 Bearing Temperature Test (Tb)

Following bearing temperature stabilization, the fan and motor bearing temperatures shall be measured. Stabilization occurs when temperature changes are less than or equal to +/- 3 °F (1.5 °C) in a 10 minute period.

TA-4149 Fan Performance Test (F)

For systems with filter or adsorber banks, the fan performance shall be measured under maximum design dirty filter conditions. This may be done by increasing the system resistance to the design dirty filter differential pressure, (design basis maximum dirty filter condition), using artificial resistance. The measurement procedures in TA-4142 through TA-4148 shall be used.

TA-4150 Acceptance Criteria

The following acceptance criteria are in addition to the requirements of TA-3500.

TA-4151 Airflow Capacity Test Acceptance Criteria

Airflow capacity shall be within +/- 10% of design when tested in the normal clean and maximum dirty filter conditions.

TA-4152 Fan Performance Acceptance Criteria

Fan performance (flow, static pressure, horsepower) shall meet the specifications of the manufacturer's fan performance curve and the Owner's Design Specification.

TA-4200 DAMPER ACCEPTANCE TESTS

This section provides the field acceptance test requirements for dampers and related accessories. Integrated system testing shall be conducted in accordance with TA-4900.

TA-4201 Acceptance Test Requirements

Acceptance tests shall be conducted with the dampers installed in the system. The tests listed in Table TA-4000-2 shall be conducted and test results verified to be within the acceptance limits of the Owner's Design Specification, the applicable portions of Section DA of this code, and as required in TA-3500. These test results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison to periodic in-service test results.

TA-4210 Visual Inspection (VT)

A visual inspection of the damper and associated components shall be conducted in accordance with TA-3410 and mandatory Appendix TA-I (I-1200).

TABLE TA-4000-2
DAMPER ACCEPTANCE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE
Visual inspection	VT		*
Structural capability tests	PS	*	
Leak tests	PL	*	
Position indication test	F	*	
Exercise test	F		*
Static timing test	F	*	
Flow Control test	F		*
Fire Damper test	F		*
Dynamic time test	F	*	
Interlock Test	F		*

TA-4220 Pressure Boundary Tests.

TA-4221 Structural Capability Test, Damper Housing (PS)

When the damper housing and actuator shaft seal are part of the system pressure boundary, a structural capability test shall be conducted to verify the structural capability of the damper housing, shaft seal, and interfaces in accordance with TA-3422 and mandatory Appendix TA-II. The damper housing may be tested concurrent with the duct and housing structural capability test specified in TA-4321.

TA-4222 Structural Capability Test, Damper Blades (PS)

Isolation dampers shall be tested to verify the structural capability of the damper blade and seat in accordance with TA-3422 and mandatory Appendix TA-II. The damper blades and seat may be tested concurrent with the duct and housing structural capability test specified in TA-4321.

TA-4223 Leak Test, Damper Housing (PL)

When a damper housing is part of the system pressure boundary, a pressure boundary leak test shall be conducted to verify leak tightness of the damper housing and interfaces in accordance with TA-3423 and mandatory Appendix TA-III. The damper housing may be tested concurrent with the duct and housing leak test specified in TA-4322.

TA-4224 Leak Test, Damper Shaft Seal (PL)

When a damper shaft seal is part of the system pressure boundary, a pressure boundary leak test shall be conducted to verify leak tightness of the shaft seal in accordance with TA-3423 and mandatory Appendix TA-III. The shaft seal may be tested concurrent with the duct and housing leak test specified in TA-4322. However, the shaft seal leak rate shall be evaluated (qualitative) independently of the overall system leak rate. The qualitative evaluation of the leakage shall be included in the test report.

TA-4225 Leak Test, Damper Seat (PL)

When dampers have seat leakage limits, a leak test shall be conducted in the direction the damper is expected to function, in accordance with TA-3423 and mandatory Appendix TA-III. The seat leak rate shall be tested by blanking off or otherwise isolating a duct section upstream of the damper. The leak test shall be performed with the damper cycled closed using its normal closing mechanism (without any additional manual assistance).

TA-4230 Component Functional Tests

Component functional tests shall verify that the damper is operational prior to conducting the system functional tests specified in TA-4240.

TA-4231 Electrical Prerequisites

Prior to the initial energizing of the damper operator, the electrical circuits shall be checked for proper installation, circuit continuity, voltage capacity and protective relay device settings.

TA-4232 Pneumatic Prerequisites

Prior to the initial pressurizing of the damper control system, pneumatic systems shall be checked for proper installation and leak tightness.

TA-4233 Control System Prerequisites

Prior to the initial energizing of the damper operator, control instrumentation shall be calibrated and verified to be operational.

TA-4234 Position Indication Test (F)

Dampers having remote position indicators shall be observed during operation to verify that the mechanical damper position corresponds to the remote indication.

TA-4235 Exercise Test (F)

Power operated dampers shall be fully cycled using a control switch or other actuating device to verify operation. Manual dampers, including balancing dampers, shall be fully cycled to verify operation. Fire Dampers shall be tested in accordance with TA-4242.

TA-4236 Static Timing Test (F)

Power operated dampers (electrical or pneumatic), that are required to operate within a specified time limit, shall be tested by measuring time for the damper to fully open or fully close (as required by the Owner's Design Specification).

TA-4240 System Functional Tests

TA-4241 Flow Control Damper Functional Test (F)

Power operated dampers that control air flow shall be observed under throttled (throughout its anticipated operating range) flow conditions to verify free movement and stable operation.

TA-4242 Fire Damper Test (F)

Fire dampers shall be tested, using a normal or simulated actuation signal, to verify activation under design airflow conditions.

TA-4243 Dynamic Timing Test (F)

Isolation dampers having a required actuation response time shall be timed to the fully open or fully closed position (as required by the Owners Design Specification) under design airflow conditions.

TA-4244 Interlock Test (F)

Dampers that have an opening or closing function interlocked with other components (e.g. fans, other dampers) shall be tested to verify interlock action.

TA-4300 DUCT, HOUSING, AND MOUNTING FRAME ACCEPTANCE TESTS

This section provides the field acceptance test requirements for ducts, housings and mounting frames.

TA-4301 Acceptance Test Requirements

Acceptance tests shall be conducted with the ducts, housings and mounting frames installed in the system. The tests listed in Table TA-4000-3 shall be conducted and test results verified to be within the acceptance limits of the Owner's Design Specification, the applicable portions of Section SA of this Code, and as required in TA-3500. These test results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison to periodic in-service test results.

TA-4310 Visual Inspection (VT)

A visual inspection of ducts, housings, and mounting frames, shall be conducted in accordance with TA-3410 and mandatory Appendix TA-I (I-1300).

TABLE TA-4000-3
DUCT, HOUSING AND FRAME ACCEPTANCE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE
Visual inspection	VT		*
Structural capability test	PS	*	
Leak tests	PL	*	

TA-4320 Pressure Boundary Tests

Pressure boundary tests apply to all ducts, housings and interface connections that are parts of the system. Individual components may be tested at separate times provided that all system pressure boundaries are ultimately tested prior to the system being placed into service.

TA-4321 Structural Capability Test, Duct and Housing (PS)

A structural capability test shall be conducted to verify structural capability of ducts and housings in accordance with TA-3422 and mandatory Appendix TA-II.

TA-4322 Leak Test, Duct and Housing (PL)

A pressure boundary leak test shall be conducted to verify leak tightness of the ducts and housings in accordance with TA-3423 and mandatory Appendix TA-III.

TA-4323 Leak Test, Mounting Frame (optional) (PL)

A mounting frame pressure leak test may be used to detect leaks in the HEPA filter and adsorber mounting frames that could affect the results of the in-place leak tests in TA-4600 and TA-4700. This test is optional and may be conducted in accordance with non-mandatory Appendix TA-A.

TA-4400 REFRIGERATION EQUIPMENT ACCEPTANCE TESTS

This section provides the field acceptance test requirements for refrigeration equipment. Integrated system testing shall be conducted in accordance with TA-4900.

TA-4401 Acceptance Test Requirements

Acceptance tests shall be conducted with the refrigeration equipment in service under normal operating conditions. The tests listed in Table TA-4000-4 shall be conducted and test results verified to be within the acceptance limits of the Owner's Design Specification, applicable portions of Section RA of this Code, and as required in TA-3500. These test results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison to periodic in-service test results.

TA-4410 Visual Inspection (VT)

A visual inspection of the refrigeration equipment components shall be conducted in accordance with TA-3410 and mandatory Appendix TA-I (I-1400).

TA-4420 Pressure Boundary Tests

TA-4421 Leak Test, Refrigerant Piping and Coil (PL)

Refrigeration systems, including piping, coils, and pressure vessels, shall have a pressure test conducted to verify structural integrity and leak tightness. Testing shall be conducted in accordance with TA-3424 and mandatory Appendix TA-VIII.

TABLE TA-4000-4
REFRIGERATION EQUIPMENT ACCEPTANCE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE
Visual inspection	VT		*
Leak test	PL		*
Hydrostatic test	HYD		*
Valve position indication test	F		*
Valve exercise test	F		*
Valve timing test	F	*	
Flow Control valve test	F		*
Mechanical run test	F		*
Performance test	F	*	
Electrical test	AMP	*	
Rotational speed test	N	*	
Vibration test	Vb	*	
Bearing temperature test	Tb	*	

TA-4422 Hydrostatic Test, Hydronic Piping and Coils (HYD)

Hydronic piping, coils and pressure vessels, shall have a hydrostatic test conducted to verify structural integrity and leak tightness. Testing shall be conducted in accordance with TA-3421.

TA-4430 Component Functional Tests

The following component functional tests and prerequisites shall be conducted to verify that the refrigeration system equipment is operating acceptably prior to conducting the system functional tests specified in TA-4440. Fans shall be tested in accordance with TA-4100.

TA-4431 Electrical Prerequisites

Prior to the initial energizing of the refrigeration system components, the electrical circuits shall be checked for installation, circuit continuity, voltage capacity, and protective relay device settings.

TA-4432 Control System Prerequisites

Prior to the initial energizing of the refrigeration system components, the system controls shall be calibrated and verified operational.

TA-4433 Valve Position Indication Test (F)

Valves having remote position indicators shall be observed during valve full stroke operation to verify that the valve position corresponds to the remote indication.

TA-4434 Valve Exercise Test (F)

Power operated valves shall be fully cycled using a control switch or other actuating device to verify operation. Manual valves shall be fully cycled to verify operation.

TA-4435 Valve Timing Test (F)

Power operated valves that are required to operate within a specified time limit shall be tested by measuring the time to fully cycle.

TA-4436 Startup Prerequisites

The compressor motor shall be momentarily energized and correct direction of rotation verified. restart the compressor motor,verify stable operation and monitor the compressor motor electrical supply voltage, amperage and phase balance, vibration, bearing temperatures, and rotational speed, as applicable. Following one hour of operation, or immediately after observation of unusual performance (unstable operation), the equipment shall be secured and a detailed visual inspection conducted for signs of damage or degradation.

TA-4440 System Functional Tests

The refrigeration equipment shall be tested to verify mechanical component integrity and design cooling function. TA-4441 through TA-4447 shall be conducted in the same time frame.

TA-4441 Flow Control Valve Test (F)

Power operated valves, controlled by flow instrumentation, shall be observed under throttled (throughout its anticipated operating range) flow conditions to verify freedom of movement, stable operation, and ability to maintain required flow.

TA-4442 Mechanical Run Test (F)

The refrigeration compressor shall be operated with the system in the normal heat load range for at least 15 minutes and stable system operation verified.

TA-4443 Performance Test (F)

The refrigeration compressor inlet and outlet pressure and temperature shall be measured with the equipment operating at achievable load points.

TA-4444 Electrical Test (AMP)

The compressor motor electrical supply voltage and amperage shall be measured for each phase.

TA-4445 Rotational Speed Test (N)

The rotational speed of the compressor shall be measured when accessible.

TA-4446 Vibration Test (Vb)

The vibration of each accessible bearing on the compressor and compressor motor shall be measured in accordance with TA-3433.

TA-4447 Bearing Temperature Test (Tb)

Following compressor and compressor motor bearing temperature stabilization, the accessible bearing temperatures shall be measured. Stabilization occurs when temperature changes are less than or equal to +/- 3 °F (1.5 °C) in a 10 minute period.

TA-4500 CONDITIONING EQUIPMENT ACCEPTANCE TESTS

This section provides the field acceptance test requirements for forced circulation air cooling and heating coils, air washers, evaporative coolers, and electric heating coils. Integrated system testing shall be conducted in accordance with TA-4900.

TA-4501 Acceptance Test Requirements

Acceptance tests shall be conducted with the conditioning equipment in service under normal operating conditions for the system . The tests listed in Table TA-4000-5 shall be conducted and test results verified to be within the acceptance limits of the Owner's Design Specification, the applicable portions of Section CA of this Code, and as required in TA-3500 and TA-4560. These test results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison to periodic in-service test results.

TABLE TA-4000-5
CONDITIONING EQUIPMENT ACCEPTANCE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE
Visual inspection	VT		*
Hydrostatic test	HYD		*
Electric heater step controller test	F		*
Electric heater coil resistance test	F	*	
Electric heater resistance to ground test	F	*	
Valve performance tests	F	*	*
Performance test	F	*	
Electrical test	AMP	*	
Rotational speed test	N	*	
Vibration test	Vb	*	
Bearing temperature test	Tb	*	
Electric heater performance test	F	*	
Hydronic system flow balance	F	*	
Hydronic system heater and coil performance test	F	*	
Air washer, evaporative cooler performance test	F	*	

TA-4510 Visual Inspection (VT)

A visual inspection of the conditioning equipment components shall be conducted in accordance with TA-3410 and mandatory Appendix TA-I (I-1500).

TA-4520 Pressure Boundary Tests

TA-4521 Hydrostatic Test, Hydronic Piping and Coils (HYD)

Hydronic piping, coils and pressure vessels shall have a hydrostatic test conducted to verify structural integrity and leak tightness. Testing shall be conducted in accordance with TA-3421.

TA-4530 Component Functional Tests

The following component functional prerequisites and tests shall be conducted to verify that the conditioning system equipment is operating acceptably prior to conducting the system functional tests specified in TA-4540. Fans shall be tested in accordance with TA-4100. Refrigeration components shall be tested in accordance with TA-4400.

TA-4531 Electrical Prerequisites

Prior to the initial energizing of the conditioning system equipment, the electric circuits shall be checked for proper installation, circuit continuity, voltage capacity, and protective relay device settings.

TA-4532 Control System Prerequisites

Prior to the initial energizing of the conditioning system components, the controls shall be calibrated and verified operational.

TA-4533 Electric Heater Step Controller Test (F)

Electric heater step controllers shall be tested by initiating a simulated demand signal to verify the heater circuit step controller is operational.

TA-4534 Electric Heater Coil Resistance Test (F)

The electrical resistance shall be measured across each heater circuit in accordance with CA-5440.

TA-4535 Electric Heater Resistance To Ground Test (F)

The electrical resistance to ground shall be measured on each heater circuit.

TA-4536 Valve Performance Tests (F)

Conditioning system valves shall be tested in accordance with TA-4433, TA-4434, and TA-4435.

TA-4537 Startup Prerequisites

Prior to starting the conditioning system pumps, the pump shaft shall be manually rotated to verify freedom of movement. The motor shall be momentarily energized and the correct direction of rotation verified. restart the pump motor and verify stable operation and monitor the pump motor electrical supply voltage, amperage and phase balance, bearing vibration, bearing temperatures, rotational speed, pump differential pressure, and fluid system flow rate, as applicable. Following one hour of operation, or immediately after observation of unusual performance (unstable operation), the pump shall be secured and a detailed visual inspection for signs of damage or degradation conducted.

TA-4540 System Functional Tests

The conditioning equipment shall be tested in conjunction with the system to verify mechanical component integrity and design cooling or heating function. TA-4541 through TA-4546 shall be conducted in the same time frame.

TA-4541 Hydronic System Flow Balance Test (F)

A hydronic system flow balance shall be conducted. Recommended procedures include SMACNA, NEBB, or AABC (reference TA-2000).

TA-4542 Flow Control Valve Test (F)

Power operated valves, controlled by flow control instrumentation, shall be observed under throttled (throughout its anticipated operating range) flow conditions to verify freedom of movement, stable operation, and the ability to maintain required flow.

TA-4543 Mechanical Run Test (F)

The conditioning system pumps shall be operated with the system operating in the normal operating range for at least 15 minutes and stable system operation (no surging) verified.

TA-4544 Performance Test (F)

The conditioning system pump differential pressure and flow rate shall be measured with the pump operating at achievable flow rates.

TA-4545 Electrical Tests (AMP)

The conditioning system pump supply voltage and amperage shall be measured for each phase.

TA-4546 Rotational Speed Test (N)

The rotational speed of the pump shaft shall be measured.

TA-4547 Vibration Test (Vb)

The vibration of each bearing on the pump and motor shall be measured in accordance with TA-3433.

TA-4548 Bearing Temperature Test (Tb)

Following pump and motor bearing temperature stabilization, the bearing temperature shall be measured. Stabilization occurs when temperature changes are less than or equal to +/- 3 °F (1.5 °C) in a 10 minute period.

TA-4549 Electric Heater Performance Test (F)

With design airflow (+/- 10%) through the heater bank, the electrical supply voltage, amperage, and phase balance of each heater circuit, and differential temperature and air flow across the heater bank shall be measured. Following one hour of continuous operation, the heater shall be secured and a detailed visual inspection shall be conducted for signs of damage or degradation.

TA-4550 Hydronic System Heating and Cooling Performance Test (F)

With the conditioning system operating at design airflow (+/- 10%) and design hydronic flow (+/- 10%) and at achievable heat load conditions, the air-side flow, differential temperature and differential pressure, and the hydronic side flow, differential temperature and differential pressure shall be measured.

TA-4551 Air Washer, Evaporative Cooler Performance Test (F)

A performance test for the conditioning system air washers and evaporative coolers shall be conducted in accordance with CA-5000, Appendix CA-II.

TA-4560 Acceptance Criteria

The following acceptance criteria are in addition to TA-3500.

TA-4561 Electrical Heater Ground Resistance Acceptance Criteria

Conditioning system electric heater resistance to ground shall be greater than 50,000 Ohms.

TA-4600 MOISTURE SEPARATOR, PRE-FILTER, HEPA FILTER BANK ACCEPTANCE TESTS

This section provides the field acceptance test requirements for installed moisture separator, pre-filter and HEPA filter banks.

TA-4601 Acceptance Test Requirements

Acceptance tests shall be conducted with clean moisture separator, pre-filter and HEPA filter banks installed in the system. The tests in Table TA-4000-6 shall be conducted and test results verified to be within the acceptance limits of the Owner's Design Specification, the applicable portions of Sections FA, FB and FC of this Code and as required in TA-3500 and TA-4630. These test results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison to periodic in-service test results.

TABLE TA-4000-6
MOISTURE SEPARATOR, PREFILTER AND HEPA FILTER
ACCEPTANCE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE
Visual inspection	VT		*
Differential pressure test	DP	*	
Airflow distribution test	AD	*	
Air-aerosol mixing test	AA	*	
In-place leak test @	IP	*	

@ In-place leak tests are not required on systems used for 100% recirculation (e.g. Reactor containment cleanup units) unless the atmospheric cleanup rate is time dependent.

TA-4610 Visual Inspection (VT)

A visual inspection of the installed moisture separator, prefilter and HEPA filter banks shall be conducted in accordance with TA-3410 and mandatory Appendix TA-I (I-1600).

TA-4620 System Functional Tests

TA-4621 Differential Pressure Test (DP)

With the system operating at design flow rate (+/- 10%), the differential pressure across each moisture separator, pre-filter, and HEPA filter bank shall be measured.

TA-4622 Airflow Distribution Test (AD)

With the system operating at design flow rate (+/- 10%), the airflow distribution shall be measured downstream of each moisture separator, prefilter, and HEPA filter bank in accordance with mandatory Appendix TA-IV.

TA-4623 Air-Aerosol Mixing Test (AA)

With the system operating at design flow rate (+/- 10%), the air-aerosol mixing upstream of each HEPA filter bank shall be measured in accordance with mandatory Appendix TA-V.

TA-4624 In-Place Leak Test (IP)

With the system operating at design flow rate (+/- 10%), the challenge aerosol leak rate of each HEPA filter bank shall be measured in accordance with mandatory Appendix TA-VI.

TA-4630 Acceptance Criteria

The following acceptance criteria are in addition to the requirements of TA-3500.

TA-4631 Airflow Distribution Test Acceptance Criteria

With the system operating within +/-10% of design flow rate, the variation in velocity measurements across the HEPA filter banks shall be limited to +/-20% of the average, when measured in accordance with mandatory Appendix TA-IV. Airflow distribution across the moisture separator and prefilter banks shall be in accordance with the Owner's Design Specification.

TA-4632 Air-Aerosol Mixing Test Acceptance Criteria

With the system operating within +/-10% of design flow rate, the variation in concentration of the air-aerosol mixture immediately upstream of the HEPA filter bank shall be limited to +/-20% of the average when measured in accordance with mandatory Appendix TA-V.

TA-4700 TYPE II and TYPE III ADSORBER BANK ACCEPTANCE TESTS

This section provides the field acceptance test requirements for installed type II and III adsorber banks.

TA-4701 Acceptance Test Requirements

Acceptance tests shall be conducted with the adsorbent media installed and in service under normal operating conditions for the system. The tests listed in Table TA-4000-7 shall be conducted and test results verified to be within the acceptance limits of the Owner's Design Specification, the applicable portions of Sections FD and FE of this code, and as required in TA-3500 and TA-4730. These test results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison to periodic in-service test results.

TABLE TA-4000-7
TYPE II AND TYPE III ADSORBER BANK ACCEPTANCE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE
Visual inspection	VT		*
Differential pressure test	DP	*	
Airflow distribution test	AD	*	
Air-aerosol mixing test	AA	*	
In-place leak test @	IP	*	
Test canister flow rate test	Qf	*	
Air heater performance test	F	*	

@ In-place leak tests are not required on systems used for 100% recirculation (e.g. Reactor containment cleanup units) unless the atmospheric cleanup rate is time dependent.

TA-4710 Visual Inspection (VT)

A visual inspection of the type II and type III adsorber banks shall be conducted in accordance with TA-3410 and mandatory Appendix TA-I (I-1700).

TA-4720 Component Functional Tests

TA-4721 Electric Heater Step Controller Test (F)

Electric heater step controllers shall be tested by initiating a simulated demand signal to verify the heater circuit step controller is operational.

TA-4722 Electric Heater Coil Resistance Test (F)

The electrical resistance shall be measured across each heater circuit in accordance with CA-5440.

TA-4723 Electric Heater Resistance To Ground Test (F)

The electrical resistance to ground shall be measured on each heater circuit.

TA-4730 System Functional Tests

TA-4731 Differential Pressure Test (DP)

With the system operating at design flow rate (+/- 10%), the differential pressure across each adsorber bank shall be measured.

TA-4732 Airflow Distribution Test (AD)

With the system operating at design flow rate (+/- 10%), the airflow distribution across each adsorber bank shall be measured in accordance with mandatory Appendix TA-IV.

TA-4733 Air-Aerosol Mixing Test (AA)

With the system operating at design flow rate (+/- 10%), the air-aerosol mixing immediately upstream of each adsorber bank shall be measured in accordance with mandatory Appendix TA-V. This test is not required when it can be determined that the air-aerosol test conducted on a HEPA bank immediately upstream of the adsorber bank also provides equivalent challenge to the adsorber bank.

TA-4734 In-Place Leak Test (IP)

With the system operating at design flow rate (+/- 10%), the challenge gas leak rate of each adsorber bank shall be measured in accordance with mandatory Appendix TA-VII.

TA-4735 Test Canister Flow Rate Test (Qf)

When the system is equipped with test canisters used for obtaining adsorbent samples for laboratory analysis, the velocity through each test canister shall be measured (or calculated from flow measurements) with the system operating at design airflow rate. Alternatively, when access is limited and measurements cannot be performed, the design documentation shall be verified to assure that the installed canisters meet the performance requirements, (differential pressure / flow rate), of canisters used during shop testing of the test canister sampling system.

TA-4736 Electric Heater Performance Test (F)

With design airflow (+/- 10%) through the heater bank, the electrical supply voltage, amperage, and phase balance of each heater circuit, and differential temperature and air flow across the heater bank shall be measured. Following one hour of continuous operation, the heater shall be secured and a detailed visual inspection shall be conducted for signs of damage or degradation.

TA-4740 Acceptance Criteria

The following acceptance criteria are in addition to the requirements of TA-3500.

TA-4741 Airflow Distribution Test Acceptance Criteria

With the system operating within +/- 10% of design flow rate, the variation in velocity measurements across the face of the adsorber banks shall be limited to +/-20% of the average, when measured in accordance with mandatory Appendix TA-IV.

TA-4742 Air-Aerosol Mixing Test Acceptance Criteria

With the system operating within +/-10% of design flow rate, the variation in the challenge gas or aerosol concentration readings immediately upstream of each adsorber bank shall be limited to +/-20% of the average when measured in accordance with mandatory Appendix TA-V.

TA-4743 Test Canister Flow Rate Test Acceptance Criteria

The test canister velocity shall be within +/- 10% of the average adsorber design velocity as specified by the Owner's Design Specification.

TA-4800 ADSORBENT ACCEPTANCE TESTS

This section provides the Laboratory acceptance test requirements for radioactive iodine penetration of the adsorbent used in adsorber systems.

TA-4801 Acceptance Test Requirements

A laboratory acceptance test shall be conducted using representative samples of adsorbent from the adsorber system. This test measures the radioiodine penetration of the adsorbent. Laboratory test results shall be evaluated to the acceptance limits of the Owner's Design Specification. Sample locations shall be documented to ensure they are not reused in periodic in-service testing. Test Results shall be documented in accordance with TA-6300 and shall be retained as reference values for comparison to periodic in-service test results.

TA-4810 Laboratory Analysis of Adsorbent (LAB)

New adsorbent installed in the adsorber banks shall be certified in accordance with the manufacturers test data for radioiodine penetration (ref. FF-5000). Adsorbent stored more than 50 percent of manufacturer's assigned shelf life shall have a laboratory test conducted in accordance with ASTM D-3803-89 prior to installation. The test bed depth, air temperature, humidity, and flow rate, used in the laboratory test, shall be the same as adsorber bank conditions required by the Owner's Design Specification. Adsorbent installed in the adsorber bank shall be sampled and tested in accordance with the procedures in ASTM D-3803-89 prior to system operation.

TA-4900 INTEGRATED SYSTEM TESTS

Each system shall be tested to verify the functional performance at achievable design operating conditions. Integrated system tests shall be conducted to challenge all integrated control functions including interlocks and manual or automatic actuation circuits, (damper position changes, fan starts and stops, compressor and pump starts or stops, valve position changes, heater energization or de-energization). Actuations can be from a number of different sources including radiation sensors, temperature sensors, chlorine sensors, pressure sensors, manual controls and emergency safeguard signals. Sensor operation shall be verified in addition to control circuitry. Integrated testing shall also include an overall system leak test to verify that there are no unacceptable bypasses of the HEPA filter or adsorber banks. Integrated system testing shall verify that the intended design function of the system is achieved in accordance with the Owner's Design Specification. Test results shall be documented in accordance with TA-6300.

TA-4910 Fan Integrated System Test Requirements (F)

Fans designed to respond automatically to a process or emergency actuation signal shall be tested. Sequencing of starts, stops and speed changes shall be conducted utilizing an actual or simulated actuation signal.

TA-4920 Damper Integrated System Test Requirements (F)

Dampers designed to respond automatically to a process or emergency actuation signal shall be tested. Sequencing of damper position changes shall be conducted utilizing an actual or simulated actuation signal.

TA-4930 Refrigeration and Conditioning Integrated System Test Requirements (F)

Refrigeration and Conditioning equipment designed to respond automatically to a process or emergency actuation signal shall be tested. Sequencing of equipment operation (starts, stops, speed changes, valve operations or isolation, heater operation) shall be conducted utilizing an actual or simulated actuation signal.

TA-4940 HEPA and Adsorber Bank Integrated System Test Requirements (F)

All potential HEPA filter and adsorber bank bypass flow paths shall be challenged to verify that leak rates are within the Owner's Design Specification. Bypass flow paths may be challenged during the in-place leak test specified in TA-4624 and TA-4734, by ensuring that the challenge aerosol or gas injection and sample ports encompass all potential bypass flow paths (reference mandatory appendix TA-V, step V-1100). If a potential bypass flow path within the system is not challenged during these in-place tests, a separate test shall be performed using mandatory appendix TA-VI or TA-VII to verify that the HEPA or adsorber banks are not being bypassed in excess of the limits specified in the Owner's Design Specification.

ARTICLE TA-5000
CORRECTIVE ACTION REQUIREMENTS

Corrective action is required when test results do not meet the acceptance criteria specified in the applicable section or in the Owner's Design Specifications. For equipment that is replaced, modified, repaired, or has undergone maintenance, such that reference values may change, a new set of reference values shall be obtained in accordance with the requirements of Article TA-3200. Additional guidance for corrective actions is included in non-mandatory Appendix TA-B.

ARTICLE TA-6000
QUALITY ASSURANCE

TA-6100 General

Field testing of nuclear air treatment, heating, ventilating, and air conditioning systems shall be conducted in accordance with the quality assurance requirements of Article AA-8000, ANSI/ASME NQA-1, and ANSI/ASME NQA-2.

TA-6200 Personnel

Tests shall be conducted by personnel who have demonstrated competence to perform the specific tests, as evidenced by documented experience and training. Personnel shall be certified in accordance with ANSI/ASME NQA-1 or ANS 3.1, and in accordance with the Owner's Requirements.

TA-6300 Documentation

TA-6310 Procedures

Written acceptance test procedures shall document the field acceptance testing performed and test results obtained as specified in Article TA-4000. These records shall be maintained for the life of the facility.

TA-6320 Reports

A written report shall be provided to document the acceptance testing performed in accordance with Article TA-4000. The report shall contain the following as a minimum:

(a) The system name, test/inspection procedure(s) used, date of test results and the test performer's signature;
(b) Identification of instruments, equipment, tools and documents to the extent that they or their equivalents can be identified for future examinations;
(c) Observations and dimensional checks specified by the respective test data and reports developed during inspection and testing;
(d) Conclusions and recommendations by visual examination and testing personnel;
(e) Reference to previous reports if this report is for reinspection and testing.

APPENDIX TA-I
MANDATORY
VISUAL INSPECTION CHECKLIST

I-1000 General

A specific inspection checklist for each component in the system shall be included in the acceptance test procedures. This Appendix lists typical items for each component that need to be inspected visually in Article TA-4000 (Acceptance tests). As a minimum, the lists of items indicated below shall be checked for compliance with the Owner's Specifications. The inspection shall be conducted in accordance with TA-3410. The acceptance criteria for these inspections shall be in accordance with TA-3500 and TA-3510.

I-1100 Fan Inspection Checklist

a. Housing and duct interface
b. Fan belt and shaft guards
c. Interferences with moving parts
d. Fan shaft seal
e. Belt adjustment and condition
f. Lubricant levels
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Control system components
l. Pneumatic connections
m. As built configuration in accordance with design drawings
n. Fan nameplate
o. Access for tests and maintenance

I-1200 Damper Inspection Checklist

a. Housing and duct interface
b. Actuator linkage, motor, controller
c. Interferences with moving parts
d. Damper shaft seal
e. Blade edge seals, damper seat
f. Limit switches
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Pneumatic connections
l. As built configuration in accordance with design drawings
m. Damper nameplate
n. Access for tests and maintenance

I-1300 Duct, Housing and Mounting Frame Inspection Checklist

a. Housing and duct connections (no caulking)
b. Provision for opening access doors from both inside and outside
c. Access door seals, gaskets
d. Access door latches
e. Housing internal access ladders and platforms
f. Sample and injection ports, location and caps
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation, connections
j. Electrical connections
k. Housing/duct penetration seals
l. Loop seals (water level), drain connections
m. Lighting conduits, socket housing seals (flush mounted)
n. HEPA/adsorber mounting frame continuous seal welds
o. Mounting frame penetrations seal welded
p. Mounting frame seating surface (weld splatter, flatness, scratches)
q. Sample canister installation
r. Mounting frame clamping devices
s. As built configuration in accordance with design drawings
t. Access for tests and maintenance
u. Lighting for test and maintenance available

I-1400 Refrigeration Equipment Inspection Checklist

a. Housing or duct interface with refrigeration equipment
b. Fan, pump, compressor belt and coupling guards
c. Interferences with moving parts
d. Belt adjustment and condition
e. Fluid leaks
f. Lubricant levels
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Control system components
l. Pneumatic connections and tubing (No crimping)
m. As built configuration in accordance with design drawings
n. Fan, pump, compressor nameplate
o. Access for tests and maintenance

I-1500 Conditioning Equipment Inspection Checklist

a. Housing or duct interface with conditioning equipment
b. Belt and coupling guards
c. Interferences with moving parts
d. Belt tightness
e. Fluid leaks
f. Lubricant levels
g. Supports and attachments

h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Control system components
l. Pneumatic connections and tubing (No crimping)
m. Drains and spray nozzles not plugged
n. As built configuration in accordance with design drawings
o. Fan, pump, compressor nameplate
p. Access for tests and maintenance

I-1600 Moisture Separator Bank, Prefilter Bank, HEPA Filter Bank Inspection Checklist

a. Moisture separator media, frame, clamps and gaskets
b. Moisture separator water collection system and drains
c. Prefilter media, frame, clamps and gaskets
d. HEPA filter media, frame, clamps and gaskets
e. Sealant or caulking (none allowed)
f. Moisture separator, prefilter, HEPA orientation (vertical)
g. Bolting and fasteners.
h. As built configuration in accordance with design drawings
i. HEPA filter nameplate
j. Access for tests and maintenance

I-1700 Type II, Type III Adsorber Bank Inspection Checklist

a. Type II media, frame, screen, clamps and gaskets
b. Sealant or caulking (none allowed)
c. Type III media, screens, frame
d. Test canisters
e. Bulk loading equipment
f. Fire protection system piping, nozzles, instrumentation
g. Bolting and fasteners
h. As built configuration in accordance with design drawings
i. Adsorber nameplate
j. Access for tests and maintenance

APPENDIX TA-II
MANDATORY
STRUCTURAL CAPABILITY TEST PROCEDURE

II-1000 General

This procedure is used to test the structural capability of ducts and housings.

II-1100 Summary of Method

Ducts, and housings which form the pressure boundary of the system shall be pressure tested, with air, to the structural capability pressure to verify that there is no breach of integrity or unacceptable distortion. Fans, dampers and other components which form parts of the pressure boundary shall be installed and tested with the ducts and housings to verify the interface connection integrity.

NOTE: This test procedure is written as if the operating pressure were positive, but it would be identical for negative pressure systems with appropriate signs used in data collection and calculations.

II-2000 Prerequisites

Construction, modifications or repairs affecting the test boundary shall be complete and inlet and discharge openings of the duct or housing sealed before the test is started. Electrical, piping, and instrument connections shall be complete and all permanent seals installed before the test is started.

II-3000 Test Equipment

a. Pressurization source

b. Covers to seal test boundaries.

c. Pressure indicating device accurate to +/- 0.1 in.w.g. (0.025 kPa(gage)).

II-4000 Procedure

a. Connect the pressurization source to the duct or housing.

b. Install instrumentation to indicate the pressure inside the duct or housing being tested.

c. Start the pressurization source and operate until the structural capability pressure is achieved. Maintain pressure for the duration of the inspection.

d. Inspect the test boundary for breach of integrity or distortion.

e. Release pressure and inspect for permanent distortion.

II-5000 Acceptance Criteria

All distortion shall be measured and compared to the acceptance limits of the Owner's Design Specification.

APPENDIX TA-III
MANDATORY
DUCT AND HOUSING LEAK TEST PROCEDURE

III-1000 General

This procedure is used to test the leak tightness of the ducts and housings including installed fan housings, damper housings and fan and damper shaft seals.

III-1100 Summary of Method

Ducts and housings that form the pressure boundary of the system shall be leak tested, with air, using one of the methods listed in this procedure. Either method may be used and will produce a similar test result. The constant pressure method is useful for testing small volumes and is conducted at the maximum operating pressure for the system. The pressure decay method is useful in testing large volumes and is conducted by pressurizing to 1.25 times the maximum operating pressure, then allowing the pressure to decay for a fixed period of time, or until the pressure decreases to 80% of the maximum operating pressure, whichever occurs first. Fans, dampers, and other components that are part of the pressure boundary shall be installed and tested with the pressure boundary to verify interface connection leak tightness. If the measured leak rate is in excess of the acceptance criteria, the leaks shall be located by one of the methods listed in this procedure. After leaks are repaired, the duct and housing shall be re-tested to verify leak tightness.

NOTE: This test procedure is written as if the operating pressure were positive, but it would be identical for negative pressure systems with appropriate change in signs used in the data collection and calculations.

III-2000 Prerequisites

Construction, modifications and repairs affecting the test boundary shall be complete and the inlet and discharge openings of the duct or housing sealed before the test is started. All electrical, piping, and instrument connections shall be complete and all permanent seals shall be installed before the test is started. For pressure decay testing, the volume of the pressure test boundary must be calculated.

III-3000 Test Equipment

a. Pressurization source

b. Covers to seal test boundaries.

c. Clock or timer accurate to +/- 1.0 second.

d. Pressure indicating device accurate to +/- 0.1 in.w.g. (0.025 kPa(gage)).

e. Flowmeter or Totalizing Gas Volume meter accurate to +/-5% (constant pressure method).

f. Temperature indicating device accurate to +/- 0.5 °F (0.25°C).

g. Bubble solution for detecting air leaks (bubble method).

h. Optional portable electronic sound detection equipment (audible leak method).

i. Barometer

III-4000 Procedure

III-4100 Constant Pressure Test

a. Connect the pressurization source to the duct or housing.

b. Connect the flowmeter or totalizing gas volume meter between the pressurization source and the housing (downstream of the throttling valve, if used).

c. Install temperature and pressure indicating devices so that they will indicate representative temperature and pressure inside the duct or housing being tested.

d. Seal test boundaries and close access doors in the normal manner. Do not use temporary sealants, duct tape, or similar temporary materials except for sealing the temporary blank-off panels.

e. Start the pressurization source and operate it until the maximum operating pressure is achieved. Maintain pressure constant with the flow control device until temperature remains constant within +/- 0.5 °F (0.25 °C) for a minimum of 10 minutes. Record the initial stabilized pressure, temperature, and barometric pressure.

f. Measure the flow rate of the air being added to or removed from the duct or housing while maintaining the maximum operating pressure within +/- 0.1 in. w. g. (0.025 kPa(gage)). When using the flow meter, record flow readings once a minute for a 5 minute continuous period and average the readings to calculate the measured leak rate. When using a totalizing gas volume meter, measure the total volume of air for a 10 minute continuous period and divide the measured volume by time (10 minutes) to calculate the measured leak rate. Record final pressure, temperature and barometric pressure.

g. Convert the final calculated leak rate to standard cubic feet per minute (cubic meters per second) in accordance with the method illustrated in "Industrial Ventilation" (ref. TA-2000).

III-4200 Pressure Decay Test

a. Connect the pressurization source (with a leak tight shutoff valve) to the duct or housing.

b. Install the temperature and pressure indicating devices where they will indicate representative temperature and pressure inside the duct or housing being tested.

c. Seal test boundaries and close access doors in the normal manner. Do not use temporary sealants, duct tape, or similar temporary materials except for sealing the temporary blank-off panels.

d. Start the pressurization source and operate until the pressure is 1.25 times the maximum operating pressure (but not to exceed the structural capability pressure). Maintain this pressure constant with a flow control device until temperature remains constant within +/- 0.5 °F (0.25 °C) for a minimum of 10 minutes. Close shutoff valve.

NOTE(1): If the structural capability pressure for the duct or housing is less than 1.25 times the maximum operating pressure, the final test pressure shall be calculated as follows to achieve an average test pressure equal to the maximum operating pressure:

$$Pf = 0.8(OP_{max}) + (1.25(OP_{max}) - SCP)$$

where: Pf = final test pressure
OP_{max} = maximum operating pressure
SCP = structural capability pressure

e. Record the initial time, pressure, temperature, and barometric pressure.

f. Record pressure readings once a minute until pressure decays to 80% of the maximum operating pressure, or for a minimum of 15 minutes (see NOTE(1) in step d above).

h. Record final time, pressure, temperature, and barometric pressure.

i. Calculate leak rate from the following equation in English Units:

$$Q_{ave} = \left(\frac{Pi}{Ti} - \frac{Pf}{Tf} \right) * \frac{V}{R * \Delta t * 0.075}$$

Metric Units:

$$Q_{ave} = (1.39 * 10^{-5}) * \left(\frac{Pi}{Ti} - \frac{Pf}{Tf} \right) * \frac{V}{R * \Delta t}$$

where:
Q_{ave}= Average leak rate, scfm (sm^3/s). (air density 0.075 lb/ft3)
V = Volume within test boundary, ft^3 (m^3).

P_i = Initial pressure within test boundary, lb/ft^2 ABS (Pa(absolute)).
P_f = Final pressure within test boundary, lb/ft^2 ABS (Pa(absolute).

T_i = Absolute Temperature at start of test, °R (°K).
T_f = Absolute Temperature at end of test, °R (°K).
Δt = $t_i - t_f$ Time difference (minutes).
t_i = Time at start of test (minutes).
t_f = Time at end of test (minutes).
R = Gas Constant for Air; 53.35 $\frac{\text{ft-lb}}{\text{lb-°R}}$, (0.286 $\frac{\text{kJ}}{\text{kg-°K}}$)

III-4300 Acceptance Criteria

If the calculated leak rate exceeds the Owner's acceptance criteria, locate leaks in accordance with one of the techniques outlined in III-4400 or III-4500.

III-4400 Bubble Leak Location Method

a. Pressurize the test boundary to the maximum operating pressure for the system.

b. With the test boundary under continuous pressure, apply bubble solution to areas to be tested. Identify places where bubbles are found and perform corrective actions.

c. Following corrective actions, retest in accordance with III-4100 or III-4200.

III-4500 Audible Leak Location Method

a. Pressurize the test boundary to the maximum operating pressure for the system.

b. With the test boundary continuously pressurized, locate audible leaks (electronic sound detection equipment optional) and perform corrective actions.

c. Following corrective action, retest in accordance with III-4100 or III-4200.

APPENDIX TA-IV
MANDATORY
AIRFLOW DISTRIBUTION TEST PROCEDURE

IV-1000 General

This procedure is used to measure the air flow distribution across the face of moisture separator, prefilter, HEPA filter, and adsorber banks. Uniform air velocity distribution ensures maximum air treatment efficiency and uniform loading of air treatment components.

IV-1100 Summary of Method

The system is operated at design flow rate. Airflow velocity readings are measured downstream of each moisture separator, prefilter, and HEPA filter in the bank. For adsorbers, readings shall be taken in line with the flow slots. Each reading is compared to the average for the bank.

IV-2000 Prerequisites

System operating within +/- 10% design flow rate.

IV-3000 Test Equipment

Rotating vane, heated wire or heated thermocouple anemometer, pitot tube, or other suitable air velocity measuring device as appropriate for the anticipated velocities.

IV-4000 Procedure

a. For each moisture separator, prefilter, and HEPA filter, measure the air velocity at the approximate centers of equal areas with at least one measurement per each moisture separator, prefilter and HEPA filter, and a minimum of 9 measurements per bank. Adsorber velocity measurements shall be made in the approximate center of the flow slots. For flow slots greater than 24 inches long (60 cm), measurements shall be nominally every 12 inches (30 cm) along the length of the slot.

b. Calculate the average velocity (V_{ave}) using the following formula:

$$V_{ave} = \frac{\sum_1^n V_i}{n}$$

where:

$\sum_1^n$ = sum of readings from 1 to n

V_i = individual velocity readings
n = number of readings

c. Identify the highest and lowest velocity readings and calculate the percentage they vary from the average calculated above.

APPENDIX TA-V
MANDATORY
AIR-AEROSOL MIXING TEST PROCEDURE

V-1000 General

This procedure is used to ensure that the challenge aerosol or gas injection ports, used for the in-place leak tests of mandatory Appendix TA-VI and TA-VII, provide a uniform challenge across the entire face of the HEPA filter or adsorber banks. Uniform air-aerosol mixing ensures that all areas of the bank are challenged during these in-place tests. Once an injection port is qualified by this procedure, it shall be used in all subsequent in-place leak tests as outlined in the acceptance tests of TA-4600 and TA-4700.

V-1100 System Test

Injection and sample port location shall be located so that the entire system is challenged for inadvertent bypass flow paths around the HEPA filter or adsorber banks. If this cannot be accomplished, an integrated system test shall be included in addition to the bank tests outlined in appendix TA-VI, TA-VII and TA-4940.

V-1200 Summary of Method

The system is operated at design flow rate. Challenge aerosol or gas is injected through an injection port upstream of the bank. Challenge aerosol or gas concentration readings are obtained at equal cross-sectional areas in front of the HEPA filter or adsorber bank. Each reading is then compared to the average for the bank. DOP aerosol is the preferred challenge agent for this test. However, use of a challenge gas may be useful in some cases.

V-1300 Injection Port Selection Criteria

Injection ports should be located upstream of a flow disturbance to maximize mixing. The challenge gas will pass through the HEPA bank and challenge the adsorber bank. For systems with two or more HEPA filter banks in series, or two or more adsorber banks in series, separate injection ports must be qualified for each bank. Use of injection manifolds may be necessary when there is insufficient room between banks to provide adequate mixing.

V-2000 Prerequisites

The system is operating within +/- 10% of design flow rate. The airflow distribution has been verified in accordance with Appendix TA-IV.

V-3000 Test Equipment

a. Challenge aerosol or gas generator.

b. Challenge aerosol or gas measuring instrument.

V-4000 Procedure

a. Connect challenge aerosol or gas generator to the injection port to be tested.

b. Place the challenge aerosol or gas measuring instrument sample probe upstream of the bank to be tested with adequate hose length to reach all areas of the bank.

c. Start the challenge aerosol or gas injection and establish a constant injection rate.

d. Take a concentration reading upstream of and at the approximate centers of equal areas, with at least one reading per HEPA filter and a minimum of 9 readings per HEPA bank. For type II and type III adsorbers, readings shall be taken upstream of and in the approximate center of each flow slot. For flow slots greater than 24 inches (60 cm) in length, a reading shall be taken nominally every 12 inches (30 cm) along the length of the slot.

e. Calculate the average concentration (C_{ave}) readings using the following formula;

$$C_{ave}=\frac{\sum_1^n C_i}{n}$$

where:

$\sum_1^n$ = sum of readings from 1 to n

C_i = individual readings.
n = number of readings.

f. Identify the highest and lowest concentration readings and calculate the percentage it varies from the average above.

APPENDIX TA-VI
MANDATORY
HEPA FILTER BANK IN-PLACE LEAK TEST PROCEDURE

VI-1000 General

This procedure is used to leak test HEPA banks.

VI-1100 Summary of Method

The system is operated at design flow rate. Challenge aerosol is injected upstream of each bank through injection ports qualified in Appendix TA-V. The concentration of the challenge aerosol is measured upstream and downstream of the HEPA bank. The ratio of the downstream and upstream concentrations represents the HEPA filter bank leak rate.

VI-2000 Prerequisites

Airflow distribution shall be verified in accordance with Appendix TA-IV. The injection port shall be qualified to provide uniform air-aerosol mixing in accordance with Appendix TA-V.

VI-3000 Test Equipment

a. Challenge aerosol generator.

b. Challenge aerosol measuring instrument.

c. Flow measuring device.

VI-4000 Procedure

a. Connect challenge aerosol generator to the qualified injection port.

b. Place the challenge aerosol measuring instrument sample probes upstream and downstream of the bank to be tested. The sample tubing shall be of equal bore and approximately equal lengths and as short as possible to minimize the measuring instrument response time. The upstream sample probe shall be located in approximately the center of the bank. The downstream sample probe shall be located in a downstream sample manifold or downstream of a mixing source such as a turbulent fan discharge.

c. Start the system and verify stable flow rate within +/-10% of design flow rate.

d. Measure the upstream and downstream aerosol background concentration. The pre-injection background levels shall be stable to ensure correct instrument response and shall not interfere with the detector's ability to detect leaks in excess of the maximum allowed by the acceptance criteria.

e. Start the challenge aerosol injection.

f. Record the upstream and downstream concentrations. Repeat until at least three of the readings are stable.

g. Stop the injection.

h. Using the final set of readings meeting the stability and tolerance criteria, calculate the bank leak rate using the formula below:

$$L = (100)\frac{C_d}{C_u}$$

L = % Leak
C_d = Downstream concentration
C_u = Upstream concentration

APPENDIX TA-VII
MANDATORY
ADSORBER BANK IN-PLACE LEAK TEST PROCEDURE

VII-1000 General

This procedure is used to leak test adsorber banks.

VII-1100 Summary of Method

The system is operated at design flow rate. Challenge gas is injected upstream of each bank through the injection port qualified in Appendix TA-V. The concentration of challenge gas is measured upstream and downstream of the bank. The ratio of the downstream and upstream concentrations represents the bank leak rate.

VII-2000 Prerequisites

Airflow distribution shall be verified in accordance with Appendix TA-IV. The injection port shall be qualified to provide uniform air-aerosol mixing in accordance with Appendix TA-V.

VII-3000 Test Equipment

a. Challenge gas generator.

b. Challenge gas measuring instrument.

c. Flow measuring device.

VII-4000 Procedure

a. Connect challenge gas generator to the qualified injection port.

b. Place the challenge gas measuring instrument sample probes upstream and downstream of the bank to be tested. The sample tubing shall be of equal bore and approximately equal lengths and as short as possible to minimize the measuring instrument response time. The upstream sample probe shall be located in approximately the center of the bank. The downstream sample probe shall be located in a downstream sample manifold or downstream of a mixing source such as a turbulent fan discharge.

c. Start the system and verify stable flow rate and within +/-10% of design flow rate.

d. Measure the upstream and downstream challenge gas background concentration. The pre-injection background levels shall be stable to ensure correct instrument response and shall not interfere with the detector's ability to detect challenge gas leaks less than the maximum allowed by the acceptance criteria.

e. Start the challenge gas injection.

f. Record the upstream and downstream concentrations, as rapidly as instrument response time allows, until sufficient data have been recorded to allow calculation of adsorber bank leak rate. Care must be taken to obtain sufficient readings quickly after injection.

g. Terminate challenge gas injection.

h. Using the upstream and downstream concentration data, calculate the adsorber bank leak rate using the formula below.

$$L = (100)\,\frac{C_d}{C_u}$$

L = % Leak
C_d = Downstream concentration
C_u = Upstream concentration

APPENDIX TA-VIII
MANDATORY
REFRIGERANT PIPING AND COIL SYSTEM LEAK TEST PROCEDURE

VIII-1000 General

This procedure is used to test the leak tightness of refrigerant system piping and coils. The system will be pressurized with a test mixture to identify any leaks. After all identified leaks are repaired a vacuum will be drawn on the system to prove that there are no remaining leaks and to remove any contaminants from the system.

VIII-1100 Summary of Method

The pressure method consists of admitting a test gas, which is usually a mixture of refrigerant and inert gas, into the pressure vessel, coils and piping system and checking for leaks. The vacuum method consists of drawing a vacuum in the closed system and watching for a rise in pressure on a pressure indicator.

VIII-2000 Prerequisites

a. All flare, flange, solder, braze, weld or thread fittings mechanically tight.

b. All seals, packing glands and service valve packing nuts mechanically tight.

c. All service, purge and charging valves closed to the atmosphere.

d. Wire brush and wipe flux and oxides from all heated joints.

VIII-3000 Test Equipment

a. Refrigerant gas.

b. Inert gas (Nitrogen or carbon dioxide).

c. Pressure indicating device.

d. Pressure regulating device with relief valve.

e. Electronic refrigerant leak detector.

f. Leak detection bubble solution.

g. Vacuum Pump.

h. Vacuum indicating device (thermocouple vacuum indicator or other suitable vacuum indicating device).

VIII-4000 Procedure

VIII-4100 Leak Test Procedure

a. Open all interconnecting manual system valves, solenoid and expansion valves to ensure access to the complete system volume. CAUTION: Do not exceed the safe test pressure limits established by the unit manufacturer.

NOTE: It is advantageous and less costly to use an inert gas (Nitrogen or carbon dioxide), to back up the refrigerant vapor pressure. Only about 5 to 10% of the total mixture need be refrigerant vapor for this method to work.

b. Pressurize the entire system to the manufacturers recommended test pressure with the test mixture.

NOTE: Allow time for the refrigerant and inert gas to mix before checking for leaks.

c. Leak test the entire system, including factory joints, seals, and insulated lines with an electronic leak detector. Usually a one inch (2.5 cm) per second movement of the detector probe is sufficient to pick up leaks. Soap solution may also be used to locate leaks.

d. Mark or identify any leaks located.

CAUTION: Use appropriate reclaim equipment to prevent release of refrigerant gas to the atmosphere.

e. Leak testing is complete when all leaks have been repaired and the system has been re-pressurized and retested to verify that there are no leaks.

VIII-4200 Evacuation and Dehydration Procedure

Evacuate and dehydrate after leak testing per step VIII-4100. Proper evacuation and dehydration prove system tightness, expel non-condensables, and assure a dry system before charging with refrigerant.

VIII-4210 Deep Vacuum Method

a. Vent all system pressure.

CAUTION: Use appropriate reclaim equipment to prevent release of refrigerant gas to the atmosphere.

b. Connect a temporary connection between the system high and low pressure sides. Connect the vacuum pump, vacuum indicator, and refrigerant cylinder to the system.

c. Open the vacuum pump suction and start the evacuation.

d. When the system reaches less than 500 micrometers (Hg) absolute, it is isolated from the vacuum pump.

e. When the system holds 500 micrometer (Hg) absolute for at least 15 minutes, with the vacuum source isolated, the system is free of moisture and leaks and the vacuum should be released by charging with refrigerant.

APPENDIX TA-A
NON-MANDATORY
MOUNTING FRAME PRESSURE LEAK TEST PROCEDURE

A-1000 General

This optional test is used to identify leaks through seal welds of the HEPA filter or adsorber mounting frames. The presence of these leaks may be evident when conducting the in-place leak tests on the HEPA filter and adsorber banks. A good visual verification per Appendix TA-I, steps I-1600 and I-1700, is usually adequate. This procedure is provided for use when the frame leaks need to be located.

A-1100 Summary of Method

Temporary blanks, with gaskets, are installed in place of the HEPA filters or adsorbers on the mounting frame in the system. The pressure boundary is then secured by blanking off upstream of the mounting frame in the housing or associated ducts. This modified pressure boundary is then pressurized using the techniques outlined in Appendix TA-III and any leaks in the mounting frame welded interface is detected using the techniques in Appendix TA-III, steps III-4400 or III-4500.

A-2000 Prerequisites

Construction, modifications, and repairs affecting the test boundary shall be completed and temporary blanks (with gaskets) installed on the gasket side of the mounting frame. The opening of the duct or housing upstream of the mounting frame shall be blanked off to form a modified pressure boundary.

A-3000 Test Equipment

a. Pressurization source.

b. Covers to seal test boundaries.

c. Pressure indicating device accurate to +/- 0.1 in. w.g. (0.025 kPa(gage)).

A-4000 Procedure

a. Connect the pressurization source to the duct or housing pressure boundary.

b. Install pressure indicating device so that it will indicate the pressure inside the duct or housing being tested.

c. Close access doors.

d. Start the fan and operate until the pressure is greater than or equal to the maximum operating differential pressure for the filter bank (not to exceed the structural capability pressure for the duct and housing assembly). Maintain pressure for the duration of the inspection.

e. Inspect the mounting frame welds and attachments for leaks using the methods outlined in Appendix TA-III, steps III-4400 or III-4500.

APPENDIX TA-B
NON-MANDATORY
CORRECTIVE ACTION GUIDANCE

Corrective action may consist of replacement, repair, modification, maintenance, or analysis to demonstrate that the equipment will fulfill its design function. A revised set of reference values, as described in TA-3200, should be established after the corrective action has been taken.

Results of a failed test should not be resolved simply by a successful repetition of the test. A successful repetition of the test should be preceded by corrective action.

If the cause of the test failure cannot be determined by inspection or analysis, corrective action may consist of re-calibration of test instruments and subsequent re-testing. If it is determined that the test failure is due to an equipment malfunction, instead of difficulties with the test equipment, or test procedure, the equipment should be declared unavailable for service until the specific cause has been determined and the condition corrected.

APPENDIX TA-C
NON-MANDATORY
CHALLENGE GAS SUBSTITUTE SELECTION CRITERIA

Alternative test agents (challenge gas) may be used to perform In-Place Leak Testing of Adsorbers, as required in Mandatory Appendix TA-VII, when their selection is based on meeting the following characteristics:

1. The test agent gives the same In-Place Leak Test results as one of the following: R-11, R-12, R-112 or R-112a.
2. The test agent has similar retention times on activated carbons, at the same concentration levels, as one of the following: R-11, R-12, R-112 or R-112a.
3. The test agent has similar lower detection limit sensitivity and precision in the concentration range of use as one of the following: R-11, R-12, R-112 or R-112a.
4. The test agent exhibits chemical and radiological stability under the test conditions.
5. The test agent causes no degradation of the carbon and its impregnant(s) or of the other Nuclear Air Treatment System components under the test conditions.
6. The test agent is listed in the Environmental Protection Agency "Toxic Substance Control Act" (TSCA) inventory for commercial use.

ASME N511-19XX

Standard for Periodic In-Service Testing of Nuclear Air Treatment, Heating, Ventilating and Air Conditioning Systems

For ASME AG-1 Systems

ASME Committee on Nuclear Air and Gas Treatment
(CONAGT)

Note: This is a draft document. An approved standard may differ in many respects. This draft version is made available for discussion for discussion purposes only.

Draft Revision
07/09/96

DRAFT

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IN-SERVICE TESTING OF NUCLEAR AIR TREATMENT, HEATING, VENTILATING, AND AIR CONDITIONING SYSTEMS

1 SCOPE

This Standard covers the requirements for Periodic In-Service testing of nuclear safety-related air treatment, heating, ventilating, and air conditioning systems in nuclear facilities.

1.1 Purpose

The purpose of this Standard is to provide requirements for periodic in-service testing, the results of which are used to verify that nuclear air treatment, heating, ventilating, and air conditioning systems continue to perform their intended function. Such in-service testing is conducted for the purpose of:

(a) Monitoring the performance of the equipment and system(s) to provide assurance that they continue to function within their specified design basis limits;

b) Providing test results which are compared to Acceptance Test Reference Values and to previous in-service test results to establish system performance trends.

1.2 Applicability

This Standard applies to periodic in-service testing of nuclear safety-related air treatment, heating, ventilating, and air conditioning systems which have been designed, built, and acceptance tested in accordance with ASME AG-1. Sections of this Standard may be used for technical guidance for testing air treatment, heating , ventilating, and air conditioning systems designed to other standards. It is the Owner's responsibility to meet each of the applicable requirements in this Standard.

1.3 Use of This Standard

This Standard provides a basis for the development of test programs and does not include acceptance criteria, except where the results of one test influence the performance of other tests. Acceptance criteria shall be developed by the Owner based on the system design and function(s) in accordance with ASME AG-1.

This Standard is arranged so that users may select those portions (tests) which are relevant to their facility. The users must specify which tests shall be employed in their test programs and the acceptance criteria for those tests. The Non-Mandatory Appendices provide additional information and guidance.

1.4 Terms and Definitions

The definitions provided in this section supplement those listed in ASME AG-1 Section AA-1000.

Abnormal Incident -- any event or condition which may adversely affect the function of the nuclear air treatment, heating, ventilating, and air conditioning system.

Acceptance Test -- a test to verify system or component design function following initial field installation, abnormal incident, replacement, repair, or modification, that may affect a test reference value.

Adsorbent -- a solid having the ability to concentrate other substances on its surface.

Adsorber -- a device or vessel containing adsorbent.

Adsorber Bank or *Filter Bank* -- one or more filters or adsorbers secured in a single mounting frame, or one or more side by side panels containing poured or packed air treatment media, confined within the perimeter of a duct, plenum, or vault cross section, sometimes referred to as a stage.

Aerosol -- a stable suspension of particles, solid or liquid, in air

Challenge -- to expose a filter, adsorber, or other air treatment device to an aerosol or gas of known characteristics, under specified conditions, for the purpose of testing.

Challenge Gas -- a gas of known characteristics, under specified conditions, used for the purpose of testing. For in-place testing of adsorbers, the challenge gas is Refrigerant-11, or an acceptable substitute. (Refer to Non-Mandatory Appendix C for alternate challenge gas selection criteria)

Challenge Aerosol -- poly-disperse droplets of dioctyl phthalate, (di(2-ethyl hexyl) phthalate), used as challenge aerosol for testing HEPA filter banks for leaks. The challenge aerosol used for in-place leak testing of installed HEPA filter systems, in accordance with this section, shall be a poly-disperse liquid aerosol having an approximate light scattering droplet size distribution as follows:

99% less than 3.0 micrometer diameter
50% less than 0.7 micrometer diameter
10% less than 0.4 micrometer diameter

NOTE: The poly-disperse aerosol used for in-place leak testing of systems differs in size from the 0.3 micrometer mono-disperse DOP aerosol used for efficiency testing of individual HEPA filters by manufacturers. For potential substitutes for DOP, reference ASME AG-1 paragraph TA-2000. (reference DOE Nuclear Air Cleaning Conference proceedings "Size Distribution of Aerosols Produced From Substitute Materials by Laskin Cold DOP Aerosol Generator")

HEPA Filter -- (High Efficiency Particulate Air) a disposable, extended media, dry type filter enclosed in a rigid casing, that has a minimum efficiency of 99.97% when tested with an essentially mono-disperse 0.3 micrometer test aerosol.

In-Service Test -- a periodic test to verify that a system or component meets its intended design function.

Pressure, Maximum Operating -- The maximum pressure the system components will be subjected to while performing their function. The allowable pressure during abnormal operating conditions which will not physically damage the system (e.g. sudden closure of dampers or registers), shall be considered maximum operating pressure.

Pressure, Operating -- the pressure that corresponds to the normal design operating mode of the system. This pressure is less than or equal to the maximum operating pressure.

Pressure, Structural Capability -- the pressure to which the designer specifies the component or system can be safely operated, including transient conditions, without permanent distortion.

Reference Value -- one or more achieved values or test parameters that are measured, observed, or determined when the equipment or system is known to be operating acceptably within its design basis limits.

System -- An assembly of components, including associated instruments and controls, required to perform the safety-related function of a nuclear air treatment, heating, ventilating, and air conditioning system.

Test Boundary -- the physical limits of the component, system, or device being subjected to a specified test.

Test Canister -- a specially designed sample holder containing adsorbent for laboratory tests which can be removed from an adsorber bank, without disturbing the remainder of the adsorber, to provide representative

DOE Proceedings 16th DOE Nuclear Air Cleaning Conference, page 125, "Size Distribution of Aerosols Produced from Substitute Materials by the Laskin Cold DOP Aerosol Generator", February 1981, NTIS Springfield, VA. (W. Hinds, J. Macher, M. First).

3 GENERAL INSPECTION AND TEST REQUIREMENTS

All inspections and tests shall be conducted in accordance with these requirements and the specific requirements of Sections 6 and 8.

NOTE: Activities in this Section may involve the use of hazardous materials, operations and equipment. This Section does not purport to address all of the safety requirements associated with their use. It is the responsibility of the user of this Section to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.

3.1 TEST INSTRUMENTS

A calibration program shall be established in accordance with the Owner's Quality Assurance Program. All permanent and temporary test instruments used in the conduct of tests required by this Standard shall be in calibration. Instrument accuracy shall meet or exceed the requirements of Table 3-1.

TABLE 3-1
INSTRUMENT ACCURACY REQUIREMENTS

MEASUREMENT	RANGE	ACCURACY
Pressure	>1.0 psig (>7.0 kPa(gage))	+/- 2.0 %
Pressure	from 1.0 in wg to 1.0 psig (0.25 to 7.0 kPa(gage))	+/- 0.1 in wg (+/-0.025 kPa)
Pressure	from 0.1 in wg to 1.0 in wg (25 to 250 Pa(gage))	+/- 0.01 in wg (+/-2.5 Pa)
Temperature	variable	+/- 2.0 °F (+/- 1.0 °C)
Temperature*	variable	+/- 0.5 °F (+/- 0.25 °C)
Vibration	variable	(per para. 3.1.4.1)
Flow	variable	+/- 5.0 %
Velocity (airflow)	variable	+/- 3.0 %
Speed	variable	+/- 2.0 %
Time	variable	+/- 1.0 sec
Electrical voltage	variable	+/- 1.0 %
Electrical resistance	variable	+/- 1.0 %
Challenge aerosol concentration		(per para. 3.1.4.2)
Challenge gas concentration		(per para. 3.1.4.3)

* Required for pressure testing in Mandatory Appendix II.

samples for laboratory testing.

2 Reference Documents

The following documents supplement this Standard and are a part of it to the extent indicated in the text. The issue of the referenced document noted below shall be in effect. If no date is listed, then the issue of the referenced document in effect at the time shall apply.

2.1 AMERICAN CONFERENCE OF GOVERNMENT INDUSTRIAL HYGIENISTS (ACGIH)

INDUSTRIAL VENTILATION: A Manual of Recommended Practice.

2.2 AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 3803-1989, Standard Test Method for Nuclear Grade Activated Carbon.

2.3 AMERICAN NUCLEAR SOCIETY (ANS)

ANS 3.1 , Selection Qualification and Training of Nuclear Power Plant Personnel. (latest edition)

2.4 American Society of Mechanical Engineers (ASME)

ASME AG-1-1994, Code On Nuclear Air And Gas Treatment

ANSI/ASME NQA-1-1989, Quality Assurance Program Requirements for Nuclear Facilities.

ASME N509-1989, Nuclear Power Plant Air Cleaning Units and Components

ASME N510-1989, Testing of Nuclear Air Treatment Systems

2.5 SHEET METAL AND AIR-CONDITIONING CONTRACTORS' NATIONAL ASSOCIATION, INC (SMACNA)

HVAC Systems Testing, Adjusting, and Balancing 1983.

2.6 ASSOCIATED AIR BALANCE COUNCIL (AABC)

National Standard of Total System Balance 1989.

2.7 NATIONAL ENVIRONMENTAL BALANCING BUREAU (NEBB)

Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems 1991.

2.8 DEPARTMENT OF ENERGY,(DOE)

3.1.1 Range Requirements

The full scale range of instruments shall be limited as necessary to ensure that the readings are within the accuracy requirements of Table 3-1.

3.1.2 Instrument Fluctuation

Symmetrical damping devices or averaging techniques may be used to reduce random signal fluctuations. Hydraulic instruments may be damped by using gauge snubbers or by throttling valves in instrument lines.

3.1.3 Evaluation Following Test Instrument Loss, Damage or Calibration Failure

When a test instrument is lost, damaged, or otherwise fails to meet the requirements of Table 3-1 during calibration, all test results obtained using the instrument shall be evaluated, dating back to the time of the previous calibration. If the evaluation does not confirm that the instrument met the acceptance criteria for the test(s) in question, the test(s) shall be repeated with calibrated instruments.

3.1.4 Specific Instrument Accuracy Requirements

3.1.4.1 Vibration Instrument

Vibration instrument accuracy shall be at least +/- 10%. The minimum frequency response range of the vibration measuring instrument shall be approximately one third of the minimum shaft speed. For rotating components, the maximum frequency response range shall be at least two times the rotational shaft speed of the component being measured. For reciprocating components, the maximum frequency response range shall be at least two times the speed of the crankshaft, times the number of unique planes occupied by a piston throw.

3.1.4.2 Challenge Aerosol Measuring Instrument

The Challenge Aerosol Measuring Instrument shall be verified to have a linear range of at least 10^5 times the minimum detectible quantity of the instrument with an accuracy in accordance with the Facility Project Specifications and Owner's Quality Assurance Program.

3.1.4.3 Challenge Gas Measuring Instrument

The Challenge Gas Measuring Instrument shall be verified to be capable of distinguishing challenge gas from background and measuring challenge gas over a linear range of at least 10^5 times the minimum detectible quantity of the instrument with an accuracy in accordance with the Facility Project Specifications and Owner's Quality Assurance Program.

4 REFERENCE VALUES

4.1 Establishment of Reference Values

Reference values are determined during acceptance testing (ASME AG-1 Section TA-4000), when the equipment or system is proven to be operating within the acceptable limits of the Owner's Design Specification. Operating tests and inspections specified in ASME AG-1 Section TA-4000 are performed under conditions readily reproducible during subsequent in-service tests to allow for direct comparison of test results. All test results and associated analyses are included in the test procedure documentation.

4.2 Re-establishment of Reference Values Following Component Replacement, Repair, or Modification

Following component replacement, repair, or modification requiring disassembly, an analysis shall be conducted to determine the effect on current reference values. Whenever the analysis indicates any of the reference values have been affected, new reference values shall be established in accordance with paragraph 4.1 or the previous reference values re-verified. Analysis of the new reference values shall verify that the component conforms to acceptance criteria prior to accepting it as fully operational. The analysis to determine the effect on reference values shall be documented.

5 INSPECTIONS AND TEST REQUIREMENTS

Equipment shall be evaluated as separate components and as functioning parts of an integrated system. The Owner shall define system test boundaries and evaluate system performance with respect to system functional requirement in accordance with the Owners Design Specifications. The following categories of tests shall be implemented as applicable and in accordance with this Section.

(a) Periodic in-service tests (Section 8).
(b) Tests following an abnormal incident (Section 9).
(c) Tests following component replacement, repair, modification or maintenance (paragraph 4.2).

Test designations associated with tests required by this Standard are listed in Table 3-2.

TABLE 3-2
TEST DESIGNATIONS

TEST	DESIGNATOR
Differential pressure test	DP
Differential temperature test	DT
Flow rate test	Qf
Functional test*	F
In-place leak test	IP
Laboratory analysis (adsorbent methyl-iodide penetration)	LAB
Electrical performance test	AMP
Leak test	PL
Rotational speed test	N
Bearing temperature test	Tb
Vibration test	Vb
Visual inspection	VT
Flow Distribution Test	Qf

* Functional tests consist of various mechanical actuation and performance verifications and are detailed separately in each test section.

5.1 Inspection and Test Parameters

Parameters which need to be observed, calculated and recorded in order to meet the requirements of this Section shall be identified for each system based upon the functional requirements of the Owner's Design Specification.

5.2 System Operating Conditions

Operating conditions required for in-service testing shall be determined for each system. These conditions and acceptance criteria shall be based upon the requirements of the Owner's Design Specification.

5.3 Procedure Requirements

The Owner shall be responsible for the development and implementation of written test procedures that meet the requirements of this Standard. Each equipment test Section consists of generic (Section 7) and specific (Section 8) test requirements and acceptance criteria which apply to each of the systems in the facility. The Owner shall document which requirements are applicable.

5.4 In-Service Tests

In-service tests shall be conducted at intervals not to exceed those specified in Section 8 or the Owners Design Specification, whichever is most limiting. When a test is not practical during facility operation or cannot be conducted due to excessive personnel hazard, the justification for postponement shall be documented and the test shall be completed after entering a condition in which the test can be conducted. When the in-service test interval expires during a period in which the component or system is not required for standby or normal operation, the test shall be conducted prior to returning equipment to normal operation. In-service test intervals are defined in Table 3-3.

TABLE 3-3
IN-SERVICE TEST INTERVALS

INTERVAL	TEST FREQUENCY	SYMBOL
Monthly	Once per 31 days	M
Quarterly	Once per 92 days	Q
Yearly	Once per 366 days	Y

6 GENERIC TESTS

Generic tests as specified in Sections 6.1 through 6.3 shall also be used in Section 8 where applicable.

6.1 Visual Inspection (VT)

Visual inspections shall be conducted in accordance with ASME AG-1 Section AA-5000 and the applicable portions of Mandatory Appendix I. The periodic in-service visual inspections listed in Section 8 shall verify that no unacceptable damage or degradation, which could impair function, has occurred to the equipment or system since the last inspection.

6.2 Pressure Boundary Tests

Pressure boundary tests consist of leak tests for ducts and housings, including fan and damper housings.

6.2.1 Leak tests for duct and housing sections shall be conducted using either the pressure decay method or the constant pressure method to verify that the leak rate for the duct or housing does not exceed the allowable limits established for the system. Testing shall be conducted in accordance with Mandatory Appendix II. Leak testing performed to satisfy ASME AG-1 Section SA may be used to meet these test requirements when the test method is compatible with Mandatory Appendix II.

An optional leak test for HEPA filter and adsorber mounting frames may be conducted, in conjunction with the housing leak test, by blanking off the frame openings and pressurizing the isolated test boundary. This procedure is useful for detecting small leaks in the mounting frame following repair or modification of a mounting frame or mounting frame interface. This test is used to verify that there are no defects in a frame that may cause failure of the in-place leak test. Testing shall be conducted in accordance with Non-Mandatory Appendix A.

6.3 Vibration Test (Vb)

Vibration measurements shall be taken on the accessible motor, fan, compressor and pump bearing housings in at least two different orthogonal planes approximately perpendicular to the line of the rotating shaft. When the bearing housing is not accessible, the frame of the component may be used if it will be representative of bearing housing vibration. When portable vibration instruments are used, reference points shall be clearly identified on the component being measured to permit duplication in both location and plane.

7 ACCEPTANCE CRITERIA

Results of tests described in Section 8 shall be subject to the acceptance criteria in Section 7 and to the applicable operating and design criteria specified by the Owner's Design Specification. Test results are considered acceptable if the component or system is not impaired or degraded to the point that it cannot perform its intended function. Acceptance criteria are specified in Section 8 only when they affect the quality of other tests. When test results do not meet the applicable acceptance criteria, the corrective actions required by Section 10 shall be initiated. In-service test results shall be compared to the acceptance test reference values and previous in-service test results. Comparison shall include a trend analysis designed to predict degradation rates of the components under test. Projected degradation rates that indicate probable loss of intended design function prior to the next scheduled in-service test shall require corrective action prior to the predicted loss of intended design function in accordance with Section 10.

7.1 Visual Inspection

Visual inspections are acceptable when there are no visual indications of improper installation, physical damage, structural distress or degradation that would impair the ability of the equipment or system to perform its intended function.

7.2 Pressure Boundary Tests

Pressure boundary tests are acceptable when there is no permanent structural deformation or leaks in excess of the limits specified in the applicable Sections of ASME AG-1 and the Owner's Design Specification.

7.3 Functional Tests

Functional tests are acceptable when they meet the requirements of the applicable Sections of ASME AG-1 and the Owner's Design Specification.

8 IN-SERVICE TEST REQUIREMENTS

8.1 General

In-service tests shall be conducted at the required time intervals after the completion of the field acceptance tests outlined in ASME AG-1 Article TA-4000. These tests shall be conducted at intervals not to exceed those stated in each Section of this Standard. When the in-service test interval is exceeded, the affected equipment shall be unavailable for service until the required in-service test can be successfully completed. In-service tests are not required to be maintained during periods when the equipment is not required to be available for operation as specified by the Owner's Design Specification. However, these in-service tests are required to be successfully completed prior to returning the equipment to normal or standby service.

8.2 FAN IN-SERVICE TESTS.

This Section provides the in-service test requirements for fans and related accessories. Integrated system testing shall be conducted in accordance with Section 8.10.

8.2.1 In-service Test Requirements

In-service tests listed in Table 8-1 shall be conducted at the specified interval and test results verified to be within the acceptance limits of the Owner's Design Specification and Section 7 and compared to the reference values obtained in acceptance tests in ASME AG-1 Article TA-4100.

TABLE 8-1
FAN IN-SERVICE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE	INTERVAL
Visual inspection	VT		*	Q
Leak test	PL	*		10Y
Mechanical run test	F		*	Q
Flow rate test	Qf	*		2Y
Static pressure test	DP	*		2Y
Rotational speed test	N	*		2Y
Vibration test	Vb	*		Q

8.2.2 Visual Inspection (VT)

A visual inspection of the fan and associated components shall be conducted in accordance with Section 6.1 and Mandatory Appendix I (I-1100).

8.2.3 Pressure Boundary Test

8.2.3.1 Leak Test (PL)

When a fan housing is part of the system pressure boundary, a pressure boundary leak test shall be conducted to verify the leak tightness of the fan housing, shaft seal and attached interfaces in accordance with paragraph 6.2.1 and Mandatory Appendix II. The fan housing, shaft seal and attached interfaces may be tested concurrent with the duct and housing leak test specified in paragraph 8.4.3.1. However, the shaft seal leak rate shall be evaluated (qualitative) independently of the overall system leak rate.

8.2.4 System Functional Tests

Sections 8.2.4.1 through 8.2.4.5 shall be conducted in the same time frame.

8.2.4.1 Mechanical Run Test (F)

The fan shall be operated at the design flow rate for at least 15 minutes and stable system operation (no surging) verified.

8.2.4.2 Flow Rate Test (Qf)

The fan flow rate shall be measured. Recommended procedures include "ACGIH Industrial Ventilation" or equivalent.

8.2.4.3 Static Pressure Test (DP)

The fan inlet and outlet static pressure and velocity pressure shall be measured and the overall fan static pressure determined.

8.2.4.4 Rotational Speed Test (N)

When a fan does not have a direct drive coupling to the motor, the rotational speed of the fan shaft shall be measured.

8.2.4.5 Vibration Test (Vb)

The vibration of each fan and motor bearing shall be measured in accordance with Section 6.3.

8.3 DAMPER IN-SERVICE TESTS

This Section provides the in-service test requirements for dampers and related accessories. Integrated system testing shall be conducted in accordance with Section 8.10.

8.3.1 In-service Test Requirements

In-service tests listed in Table 8-2 shall be conducted at the specified interval and test results verified to be within the acceptance limits of the Owner's Design Specification and Section 7, and be compared to the reference values obtained in the acceptance tests in ASME AG-1 Article TA-4200.

8.3.2 Visual Inspection (VT)

A visual inspection of the dampers and associated components shall be conducted in accordance with Section 6.1 and Mandatory Appendix I (I-1200).

8.3.3 Pressure Boundary Tests.

8.3.3.1. Leak Test, Damper Seat (PL)

When dampers have seat leak rate limits, a dynamic pressure boundary leak test shall be conducted in the direction the damper is expected to function, in accordance with paragraph 6.2.1 and Mandatory Appendix II. Seat leakage shall be tested by blanking off or otherwise isolating a duct Section upstream of the damper. The leak test shall be performed with the damper cycled closed using its normal closing mechanism (exclusive of any additional assistance).

TABLE 8-2
DAMPER IN-SERVICE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE	INTERVAL
Visual inspection	VT		*	2Y
Leak test	PL	*		2Y
Position indication test	F		*	2Y
Exercise test	F		*	2Y
Flow Control test	F		*	2Y
Static timing test	F	*		Q
Fire damper test	F		*	2Y
Dynamic time test	F	*		2Y
Interlock test	F		*	2Y

8.3.4 Component Functional Tests

Component functional tests shall verify that the damper is operational prior to conducting the system functional tests specified in Section 8.3.5.

8.3.4.1 Position Indication Test (F)

Dampers having remote position indicators shall be observed during operation to verify that the damper position corresponds to the remote indicator.

8.3.4.2 Exercise Test (F)

Power operated dampers shall be fully cycled using a control switch or other actuating device to verify operation. Manual dampers, which have a shut off function shall be fully cycled to verify operation. Fire dampers shall be tested in accordance with paragraph 8.3.5.2.

8.3.4.3 Static Timing Test (F)

Power operated dampers that are required to operate within a specified time limit shall be tested by measuring the time to fully open or fully close (as required by the Owners Design Specification).

8.3.5 System Functional Tests

8.3.5.1 Flow Control Test (F)

Power operated dampers that control airflow shall be observed under throttled flow conditions to verify freedom of movement and stable operation.

8.3.5.2 Fire Damper Test (F)

Fire dampers shall be tested, using a normal or simulated actuation signal, to verify activation under design flow.

8.3.5.3 Dynamic Timing Test (F)

Isolation dampers having a required actuation response time shall be timed to the fully open or fully closed position (as required by the Owners Design Specification) under design flow rate conditions.

8.3.5.4 Interlock Test (F)

Dampers that have an opening or closing function interlocked with other components, (e.g. fan, other dampers), shall be tested to verify interlock action.

8.4 DUCT AND HOUSING IN-SERVICE TESTS

This Section provides the in-service test requirements for ducts and housings.

8.4.1 In-service Test Requirements

In-service tests listed in Table 8-3 shall be conducted at the specified interval and test results verified to be within the acceptance limits of the Owner's Design Specification and Section 7. Test results shall be compared to the reference values obtained in the acceptance tests in ASME AG-1 Article TA-4300.

TABLE 8-3

DUCT AND HOUSING IN-SERVICE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE	INTERVAL
Visual inspection	VT		*	2Y*
Leak test	PL	*		10Y

* Loop seal water level in duct or housing drain lines shall be maintained to ensure the integrity of the system pressure boundary at all times. More frequent inspection of the water level in the loop seal may be required, depending on the system design.

8.4.2 Visual Inspection (VT)

A visual inspection of the ducts, housings, and associated attachments shall be conducted in accordance with Section 6.1 and Mandatory Appendix I (I-1300).

8.4.3 Pressure Boundary Tests

8.4.3.1 Leak Test (PL)

A pressure boundary leak test shall be conducted on filter housings in accordance with Section 6.2 and Mandatory Appendix II.

8.5 REFRIGERATION EQUIPMENT IN-SERVICE TESTS

This Section provides the in-service test requirements for refrigeration equipment. Integrated system testing shall be conducted in accordance with Section 8.10.

8.5.1 In-service Test Requirements

In-service tests listed in Table 8-4 shall be conducted at the specified interval and test results verified to be within the acceptance limits of the Owner's Design Specification and Section 7. Test results shall be compared to the reference values obtained in the acceptance tests in ASME AG-1 Article TA-4400.

TABLE 8-4
REFRIGERATION EQUIPMENT IN-SERVICE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE	INTERVAL
Visual inspection	VT		*	Q
Leak tests	VT	*		Q
Valve position indication test	F		*	2Y
Valve exercise test	F		*	2Y
Valve timing test	F	*		Q
Flow Control valve test	F		*	Q
Mechanical run test	F		*	Q
Performance test	F	*		Q
Vibration test	Vb	*		Q
Rotational Speed test	N	*		2Y

8.5.2 Visual Inspection (VT)

A visual inspection of the refrigeration equipment components shall be conducted in accordance with Section 6.1 and Mandatory Appendix I (I-1400).

8.5.3 Pressure Boundary Tests

8.5.3.1 Leak Test, Refrigerant Piping and Coils (VT)

With the refrigerant system under normal operating pressure, refrigerant fluid levels shall be monitored to verify no unacceptable refrigerant leaks.

8.5.3.2 Leak Test, Hydronic Piping and Coils (VT)

Hydronic piping and coils shall be observed to verify no unacceptable fluid leaks. Testing shall be conducted by inspecting the fluid system, under normal operating pressure, for evidence of leaks.

8.5.4 Component Functional Tests

Fans shall be tested in accordance with Section 8.2.

8.5.4.1 Valve Position Indication Test (F)

Valves with position indicators shall be observed during valve full stroke operation to verify that the valve position corresponds to the remote indication.

8.5.4.2 Valve Exercise Test (F)

Power operated valves shall be fully stroked using their remote control switch or other actuation device to verify operation. Manual valves shall be fully stroked to verify freedom of movement.

8.5.4.3 Valve Timing Test (F)

Power operated valves that are required to operate within a specified time limit shall be tested by measuring the stroke time.

8.5.5 System Functional Tests

8.5.5.1 Flow Control Valve Test (F)

Power operated valves, controlled by flow instrumentation, shall be observed under throttled flow conditions to verify freedom of movement and stable operation.

8.5.5.2 Mechanical Run Test (F)

The refrigeration compressor shall be operated with the system operating in the normal heat load range for at least 15 minutes and stable system operation verified.

8.5.5.3 Performance Test (F)

The refrigeration compressor inlet and outlet pressure and temperature shall be measured with the refrigeration equipment operating at achievable load points.

8.5.5.4 Vibration Test (Vb)

The vibration on each accessible bearing of the compressor and associated motor in the refrigeration system shall be measured in accordance with Section 6.3.

8.5.5.5 Rotational Speed Test (N)

For refrigerant compressors that have variable speed drives, or that do not otherwise have direct drive operations, the rotational speed of the compressor shaft shall be measured (not required for hermetically sealed compressors).

8.6 CONDITIONING EQUIPMENT IN-SERVICE TESTS

This Section provides the in-service test requirements for conditioning equipment. Integrated system testing shall be conducted in accordance with Section 8.10.

8.6.1 In-Service Test Requirements

In-service tests listed in Table 8-5 shall be conducted at the specified interval and test results verified to be within the acceptance limits of the Owner's Design Specification, Section 7 and compared to the reference values obtained in the acceptance tests in ASME AG-1 Article TA-4500.

TABLE 8-5
CONDITIONING EQUIPMENT IN-SERVICE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE	INTERVAL
Visual inspection	VT		*	Q
Leak test	VT	*		Q
Valve performance tests	F		*	2Y
Mechanical run test	F		*	Q
Performance test	F	*		2Y
Rotational speed test	N	*		2Y
Vibration test	Vb	*		Q
Elect heater performance test	AMP	*		2Y
Hydronic heating and cooling performance test	F	*		2Y

8.6.2 Visual Inspection (VT)

A visual inspection of the conditioning equipment components shall be conducted in accordance with Section 6.1 and Mandatory Appendix (I-1500).

8.6.3 Pressure Boundary Test

8.6.3.1 Leak Test, Hydronic Piping and Coils (VT)

With the conditioning system at normal operating pressure, hydronic piping, coils, and pressure vessels shall be observed to verify no unacceptable fluid leaks.

8.6.4 Component Functional Test

Fans shall be tested in accordance with Section 8.2. Refrigeration components shall be tested in accordance with Section 8.5.

8.6.4.1 Valve Performance Tests (F)

Conditioning system valves shall be tested in accordance with Sections 8.5.4.1, 8.5.4.2 and 8.5.4.3

8.6.5 System Functional Tests

8.6.5.1 Hydronic System Flow Balance Verification Test

A verification of the hydronic system flow balance shall be conducted. Recommended procedures include SMACNA, NEBB, AABC, or equivalent.

8.6.5.2 Flow Control Valve Test (F)

Power operated valves, controlled by flow instrumentation, shall be observed under throttled flow conditions to verify freedom of movement, stable operation, and ability to maintain the required flow rate.

8.6.5.3 Mechanical Run Test (F)

The conditioning system pumps shall be operated, at the reference flow rate, for at least 15 minutes and stable system operation verified.

8.6.5.4 Performance Test (F)

With the conditioning system pump operating at the reference flow rate, pump differential pressure and flow rate shall be measured.

8.6.5.5 Rotational Speed Test (N)

For conditioning system pumps that have variable speed drives, or that do not otherwise have direct drive operations, the rotational speed of the pump shaft shall be measured.

8.6.5.6 Vibration Test (Vb)

The vibration of each bearing on the pump and associated motor in the conditioning system shall be measured in accordance with Section 6.3.

8.6.5.7 Electric Heater Test (AMP)

With design flow rate through the heater bank, the electrical supply voltage, amperage, phase balance, and differential temperature shall be measured.

8.6.5.8 Hydronic Heating and Cooling Performance Test (F)

With the conditioning system operating at design air and hydronic flow rate, at the available heat load conditions, the air side flow, differential pressure and differential temperature, and the hydronic side flow, differential temperature and differential pressure shall be measured.

8.7 MOISTURE SEPARATOR, PREFILTER, HEPA FILTER BANK IN-SERVICE TESTS

This Section provides the in-service test requirements for installed moisture separator, pre-filter, and HEPA filter banks.

8.7.1 In-Service Test Requirements

In-service tests listed in Table 8-6 shall be conducted at the specified interval and test results verified to be within the acceptance limits of the Owner's Design Specification, Section 7 and compared to the reference values obtained in the acceptance tests in ASME AG-1 Article TA-4600.

TABLE 8-6
MOISTURE SEPARATOR, PREFILTER, HEPA FILTER BANK
IN-SERVICE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE	INTERVAL
Visual inspection	VT		*	2Y
Differential pressure test	DP	*		M
In-place leak test	IP		*	2Y*

*In-place leak tests are not required on systems used for 100% recirculation (e.g. Reactor containment cleanup units).

8.7.2 Visual Inspection (VT)

A visual inspection of the installed moisture separator, prefilter and HEPA filter banks shall be conducted in accordance with Section 6.1 and Mandatory Appendix I (I-1600).

8.7.3 System Functional Tests

8.7.3.1 Differential Pressure Test (DP)

With the system operating at design flow rate (+/- 10%), the differential pressure across each moisture separator, prefilter, and HEPA filter bank shall be measured.

8.7.3.2 In-Place Leak Test (IP)

With the system operating at design flow rate (+/- 10%), the challenge aerosol leak rate of each HEPA filter bank shall be measured in accordance with Mandatory Appendix IV.

8.8 TYPE II and TYPE III ADSORBER BANK IN-SERVICE TESTS

This Section provides the in-service test requirements for installed type II and type III adsorber banks.

8.8.1 In-service Test Requirements

In-service tests listed in Table 8-7 shall be conducted at the specified interval and verified to be within the acceptance limits of the Owner's Design Specification, Section 7, and compared to the reference values obtained in the acceptance tests in ASME AG-1 Article TA-4700.

TABLE 8-7
TYPE II, TYPE III ADSORBER BANK IN-SERVICE TESTS

TEST	DESIGNATOR	MEASURE	OBSERVE	INTERVAL
Visual inspection	VT		*	2Y
Differential pressure test	DP	*		M
In-place leak test*	IP	*		2Y
Electric Heater Performance Test	F	*		2Y

*In-place leak tests are not required on systems used for 100% recirculation (e.g. Reactor containment cleanup units).

8.8.2 Visual Inspection (VT)

A visual inspection of the type II and type III adsorber banks shall be conducted in accordance with Section 6.1 and Mandatory Appendix I (I-1700).

8.8.3 System Functional Tests

8.8.3.1 Differential Pressure Test (DP)

With the system operating at design flow rate (+/- 10%), the differential pressure across each adsorber bank shall be measured.

8.8.3.2 In-Place Leak Test (IP)

With the system operating at design flow rate (+/- 10%), the challenge gas leak rate of each adsorber bank shall be measured in accordance with Mandatory Appendix V.

8.8.3.3 Electric Heater Performance Test

With design air flow (+/- 10%) through each heater bank, the electrical supply voltage, amperage, phase balance of each heater circuit, and differential temperature and air flow across the heater coil shall be measured.

8.9 **ADSORBENT IN-SERVICE TESTS**

This Section provides the in-service laboratory test requirements for radioactive iodine penetration of the adsorbent bed used in carbon adsorber systems.

8.9.1 In-service Test Requirements

In-service laboratory tests shall be conducted, using representative samples of adsorbent, at least every 2 years, or 720* hours of accumulated service time, whichever is sooner. This test measures the penetration of radioiodine through adsorbent. Laboratory test results shall be evaluated to the acceptance limits of the Owner's Design Specification. Sample locations shall be selected to assure samples are representative of the overall condition of the adsorbent in the adsorber bank.

*NOTE: A documented history of adsorbent degradation may be used as a basis for review of the Design Specification or Technical Specification to establish a longer adsorbent sample interval.

8.9.2 Laboratory Analysis (LAB)

A laboratory analysis of the adsorbent shall be conducted in accordance with ASTM D-3803-89, to measure the ability of the adsorbent to remove radioiodine. Test bed depth used in the laboratory test shall be the same as the nominal adsorber depth in the adsorber bank being tested. Samples shall be representative of the oldest adsorbent in the bank and drawn from the bank test canisters, or from the bank itself. An in-place leak test of the bank shall be conducted following sample removal in accordance with Section 8.8, unless it can be demonstrated that the removal of the sample does not create a potential leak path around or through the adsorber bank. Sample adsorbent loaded in replacement test canisters shall be representative of the oldest adsorbent in the bank. If new adsorbent is used to replace the adsorbent removed for sampling, it shall not be used in future samples.

8.10 INTEGRATED SYSTEM TESTS

Each system shall be tested to verify that the functional performance at design operating conditions is achieved. Integrated system tests shall be conducted to challenge all integrated control functions including interlocks, and manual, or automatic actuation circuits, (damper position changes, fan starts and stops, compressor and pump starts or stops, valve position changes, heater energization or de-energization). These actuations can be from a number of different sources including radiation sensors, temperature sensors, chlorine sensors, pressure sensors, manual controls and emergency safeguard signals. Sensor operation shall be verified in addition to control circuitry. Integrated testing shall also include an overall system leak test to verify there are no unacceptable bypasses of the HEPA filter or adsorber banks. Integrated system testing shall verify that the intended design function of the system is achieved in accordance with the Owner's Design Specification. The maximum test interval for integrated system tests shall be 2 years.

8.10.1 Fan Integrated System Test Requirements (F)

Fans designed to respond automatically to a process or emergency actuation signal shall be tested. Sequencing of starts, stops and speed changes shall be conducted utilizing an actual or simulated actuation signal.

8.10.2 Air System Flow Balance Verification Test (Qf)

A verification of the system airflow balance shall be conducted. Recommended procedures include SMACNA, NEBB, ACGIH, AABC, or equivalent.

8.10.3 Damper Integrated System Test Requirements (F)

Dampers designed to respond automatically to a process or emergency actuation signal shall be tested. Sequencing of damper positions shall be conducted utilizing an actual or simulated actuation signal.

8.10.4 Refrigeration and Conditioning Integrated System Test Requirements (F)

Refrigeration and Conditioning equipment designed to respond automatically to a process or emergency actuation signal shall be tested. Sequencing of equipment operation (start, stop, speed change, valve operation or isolation heater operation) shall be conducted utilizing an actual or simulated actuation signal.

8.10.5 HEPA Filter and Adsorber Bank Integrated System Test Requirements (F)

All potential HEPA filter bank and adsorber bank bypass flow paths shall be challenged to verify that leak rates are within the Owner's Design Specification. Bypass flow paths may be challenged during the in-place leak testing, specified in Sections 8.7.3.2 and 8.8.3.2, by ensuring that the challenge aerosol or gas injection and sample ports encompass all potential bypass leak paths (reference Mandatory Appendix IV, step V-1100). If a potential bypass flow path is not challenged during these in-place tests, a separate test shall be performed, using the techniques outlined in Appendix IV or V, to verify that the HEPA or adsorber banks are not being bypassed in excess of the limits specified in the Owner's Design Specification.

9 TESTING FOLLOWING AN ABNORMAL INCIDENT

Following an abnormal incident in which the system has been challenged at or near its design capability, the applicable acceptance tests in ASME AG-1 Article TA-4000 shall be conducted to verify that the system is fully operational. Examples of abnormal incidents include a Design Basis or severe accident exposure of the HEPA filter or adsorber banks to radioactive particles or iodine (that may saturate the HEPA filter or adsorber banks), exposure to smoke, or chemical contaminants, flooding, fire, seismic event or over-pressurization. This requirement shall apply only to those components that may have been affected by the incident. An evaluation shall be conducted and documented to determine the extent of testing required.

Following exposure to smoke, solvent, paints, or other organic fumes or vapors, which could degrade the performance of the adsorbent, the adsorbent shall be replaced or verified functional by a laboratory test in accordance with Section 8.9.2.

10 CORRECTIVE ACTION REQUIREMENTS

Corrective action is required when test results do not meet the acceptance criteria specified. For equipment that is replaced, modified, or repaired, such that the reference values may change, a new set of reference values shall be obtained in accordance with the requirements of Section 4.2 and ASME AG-1 Article TA-4000. Additional guidance for corrective actions is included in Non-Mandatory Appendix B.

11 QUALITY ASSURANCE

11.1 General

Field testing of nuclear air treatment, heating, ventilating, and air conditioning systems shall be conducted in accordance with the quality assurance requirements of ASME AG-1, Article AA-8000, ANSI/ASME NQA-1, and NQA-2.

11.2 Personnel

Tests shall be conducted by personnel who have demonstrated competence to perform the specific tests, as evidenced by documented experience and training. Personnel shall be certified in accordance with ANSI/ASME NQA-1 or ANS 3.1, and in accordance with the Owner's Quality Assurance Program Requirements.

11.3 Documentation

In-service test procedures shall document the test results specified in Section 8 and include a record of test failures with subsequent corrective actions and analysis of test data trends. These records shall be maintained for the life of the facility.

11.3.1 Procedures

Written test procedures shall document the in-service testing performed and the test results obtained in accordance with Section 8 of this Standard.

11.3.2 Reports

A written report shall be provided to document the in-service testing performed in accordance with Section 8 of this Standard. The report shall contain, as a minimum, the following:

(a) The system name, test/inspection procedure(s) used, date of test results and the test performer's signature;
(b) Identification of instruments, equipment, tools and documents to the extent that they, or their equivalent, can be identified for future examinations;
(c) Observations and dimensional checks specified by the respective test data and any reports developed during the inspection and testing;
(d) Conclusions and recommendations by visual examinations and testing personnel;
(e) Reference to previous reports, if this report is for reinspection and testing.

APPENDIX I
MANDATORY
VISUAL INSPECTION CHECKLIST

I-1000 General

A specific inspection checklist for each component in the system shall be included in the in-service test procedures. This Appendix lists typical items for each component to be visually inspected in Section 8 (In-service Tests). The inspection shall be conducted in accordance with Section 6.1. The acceptance criteria for these inspections shall be in accordance with Section 7 and Section 7.1.

I-1100 Fan Inspection Checklist

a. Housing and duct interface
b. Fan belt and shaft guards
c. Interferences with moving parts
d. Fan shaft seal
e. Belt adjustment and condition
f. Lubricant levels
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Control system components
l. Pneumatic connections
m. Access for tests and maintenance

I-1200 Damper Inspection Checklist

a. Housing and duct interface
b. Actuator linkage, motor, controller
c. Interferences with moving parts
d. Damper shaft seal
e. Blade edge seals, damper seat
f. Limit switches
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Pneumatic connections
l. Access for tests and maintenance

I-1300 Duct, Housing and Mounting Frame Inspection Checklist

a. Housing and duct connections (no caulking)
b. Provision for opening access doors from both inside and outside
c. Access door seals, gaskets
d. Access door latches
e. Housing internal access ladders and platforms

f. Sample and injection ports, location and caps
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation, connections
j. Electrical connections
k. Housing/duct penetration seals
l. Loop seals (water level), drain connections
m. Lighting conduits, socket housing seals (flush mounted)
n. HEPA/adsorber mounting frame continuous seal welds
o. Mounting frame penetrations seal welded
p. Mounting frame seating surface (weld splatter, flatness, scratches)
q. Sample canister installation
r. Mounting frame clamping devices
s. Access for tests and maintenance
t. Lighting for test and maintenance available

I-1400 Refrigeration Equipment Inspection Checklist

a. Housing or duct interface with refrigeration equipment
b. Fan, pump, compressor belt and coupling guards
c. Interferences with moving parts
d. Belt adjustment and condition
e. Fluid leaks
f. Lubricant levels
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Control system components
l. Pneumatic connections and tubing (No crimping)
m. Access for tests and maintenance

I-1500 Conditioning Equipment Inspection Checklist

a. Housing or duct interface with conditioning equipment
b. Belt and coupling guards
c. Interferences with moving parts
d. Belt tightness
e. Fluid leaks
f. Lubricant levels
g. Supports and attachments
h. Bolting and fasteners
i. Instrumentation
j. Electrical connections
k. Control system components
l. Pneumatic connections and tubing (No crimping)
m. Drains and spray nozzles not plugged
n. Access for tests and maintenance

I-1600 Moisture Separator Bank, Prefilter Bank, HEPA Filter Bank Inspection Checklist

a. Moisture separator media, frame, clamps and gaskets
b. Moisture separator water collection system and drains
c. Prefilter media, frame, clamps and gaskets
d. HEPA filter media, frame, clamps and gaskets
e. Sealant or caulking (none allowed)
f. Moisture separator, prefilter, HEPA orientation (vertical)
g. Bolting and fasteners.
h. Access for tests and maintenance

I-1700 Type II, Type III Adsorber Bank Inspection Checklist

a. Type II media, frame, screen, clamps and gaskets
b. Sealant or caulking (none allowed)
c. Type III media, screens, frame
d. Test canisters
e. Bulk loading equipment
f. Fire protection system piping, nozzles, instrumentation
g. Bolting and fasteners
h. Access for tests and maintenance

APPENDIX II
MANDATORY
DUCT AND HOUSING LEAK TEST PROCEDURE

II-1000 General

This procedure is used to test the leak tightness of the ducts and housings including installed fan housings, damper housings and fan and damper shaft seals.

II-1100 Summary of Method

Ducts and housings that form the pressure boundary of the system shall be leak tested, with air, using one of the methods listed in this procedure. Either method may be used and will produce a similar test result. The constant pressure method is useful for testing small volumes and is conducted at the maximum operating pressure for the system. The pressure decay method is useful in testing large volumes and is conducted by pressurizing to 1.25 times the maximum operating pressure, then allowing the pressure to decay for a fixed period of time, or until the pressure decreases to 80% of the maximum operating pressure, whichever occurs first. Fans, dampers, and other components that are part of the pressure boundary shall be installed and tested with the pressure boundary to verify interface connection leak tightness. If the measured leak rate is in excess of the acceptance criteria, the leaks shall be located by one of the methods listed in this procedure. After leaks are repaired, the duct and housing shall be re-tested to verify leak tightness.

NOTE: This test procedure is written as if the operating pressure were positive, but it would be identical for negative pressure systems with appropriate change in signs used in the data collection and calculations.

II-2000 Prerequisites

Construction, modifications and repairs affecting the test boundary shall be complete and the inlet and discharge openings of the duct or housing sealed before the test is started. All electrical, piping, and instrument connections shall be complete and all permanent seals shall be installed before the test is started. For pressure decay testing, the volume of the pressure test boundary must be calculated.

II-3000 Test Equipment

a. Pressurization source (Pneumatic, test fan with flow control, etc.).

b. Covers to seal test boundaries.

c. Clock or timer accurate to +/- 1.0 second.

d. Pressure indicating device accurate to +/- 0.1 in.w.g. (0.025

kPa(gage)).

e. Flowmeter or Totalizing Gas Volume meter accurate to +/-5% (constant pressure method).

f. Temperature indicating device accurate to +/- 0.5 °F (0.25°C).

g. Bubble solution for detecting air leaks (bubble method).

h. Optional portable electronic sound detection equipment (audible leak method).

i. Barometer

II-4000 Procedure

II-4100 Constant Pressure Test

a. Connect the pressurization source to the duct or housing.

b. Connect the flowmeter or totalizing gas volume meter between the pressurization source and the housing (downstream of the throttling valve, if used).

c. Install temperature and pressure indicating devices so that they will indicate representative temperature and pressure inside the duct or housing being tested.

d. Seal test boundaries and close access doors in the normal manner. Do not use temporary sealants, duct tape, or similar temporary materials except for sealing the temporary blank-off panels.

e. Start the pressurization source and operate it until the maximum operating pressure is achieved. Maintain pressure constant with the flow control device until temperature remains constant within +/- 0.5 °F (0.25 °C) for a minimum of 10 minutes. Record the initial stabilized pressure, temperature, and barometric pressure.

f. Measure the flow rate of the air being added to or removed from the duct or housing while maintaining the maximum operating pressure within +/- 0.1 in. w. g. (0.025 kPa(gage)). When using the flow meter, record flow readings once a minute for a 5 minute continuous period and average the readings to calculate the measured leak rate. When using a totalizing gas volume meter, measure the total volume of air for a 10 minute continuous period and divide the measured volume by time (10 minutes) to calculate the measured leak rate. Record final pressure, temperature and barometric pressure.

g. Convert the final calculated leak rate to standard cubic feet per minute (cubic meters per second) in accordance with the method illustrated in "Industrial Ventilation" (ref. Section 2).

II-4200 Pressure Decay Test

a. Connect the pressurization source (with a leak tight shutoff valve) to the duct or housing.

b. Install the temperature and pressure indicating devices where they will indicate the representative temperature and pressure inside the duct or housing being tested.

c. Seal test boundaries and close access doors in the normal manner. Do not use temporary sealants, duct tape, or similar temporary materials except for sealing the temporary blank-off panels.

d. Start the pressurization source and operate until the pressure is 1.25 times the maximum operating pressure (but not to exceed the structural capability pressure). Maintain this pressure constant with a flow control device until temperature remains constant within +/- 0.5 °F (0.25 °C) for a minimum of 10 minutes. Close shutoff valve.

NOTE(1): If the structural capability pressure for the duct or housing is less than 1.25 times the maximum operating pressure, the final test pressure shall be calculated as follows to achieve an average test pressure equal to the maximum operating pressure:

$$Pf = 0.8(OP_{max}) + (1.25(OP_{max}) - SCP)$$

where: Pf = final test pressure
OP_{max} = maximum operating pressure
SCP = structural capability pressure

e. Record the initial time, pressure, temperature, and barometric pressure.

f. Record pressure readings once a minute until pressure decays to 80% of the maximum operating pressure, or for a minimum of 15 minutes (see NOTE(1) in step d above).

h. Record final time, pressure, temperature, and barometric pressure.

i. Calculate leak rate from the following equation in English Units:

$$Q_{ave} = \left(\frac{Pi}{Ti} - \frac{Pf}{Tf} \right) * \frac{V}{R*\Delta t*0.075}$$

Metric Units:

$$Q_{ave} = (1.39 * 10^{-5}) * \left(\frac{Pi}{Ti} - \frac{Pf}{Tf}\right) * \frac{V}{R*\Delta t}$$

where:

Q_{ave}= Average leak rate, scfm (sm^3/s). (air density 0.075 lb/ft3)

V = Volume within test boundary, ft^3 (m^3).

P_i = Initial pressure within test boundary, lb/ft^2 ABS (Pa(absolute)).

P_f = Final pressure within test boundary, lb/ft^2 ABS (Pa(absolute).

T_i = Absolute Temperature at start of test, °R (°K).

T_f = Absolute Temperature at end of test, °R (°K).

Δt = $t_i - t_f$ Time difference (minutes).

t_i = Time at start of test (minutes).

t_f = Time at end of test (minutes).

R = Gas Constant for Air; 53.35 $\frac{ft\text{-}lb}{lb\text{-}°R}$, (0.286 $\frac{kJ}{kg\text{-}°K}$)

II-4300 Acceptance Criteria

If the calculated leak rate exceeds the Owner's acceptance criteria, locate leaks in accordance with one of the techniques outlined in II-4400 or II-4500.

II-4400 Bubble Leak Location Method

a. Pressurize the test boundary to the maximum operating pressure for the system.

b. With the test boundary under continuous pressure, apply bubble solution to areas to be tested. Identify places where bubbles are found and perform corrective actions.

c. Following corrective actions, retest in accordance with II-4100 or II-4200.

II-4500 Audible Leak Location Method

a. Pressurize the test boundary to the maximum operating pressure for the system.

b. With the test boundary continuously pressurized, locate audible leaks (electronic sound detection equipment optional) and perform corrective actions.

c. Following corrective action, retest in accordance with II-4100 or II-4200.

APPENDIX III
MANDATORY
AIRFLOW DISTRIBUTION TEST PROCEDURE

III-1000 General

This procedure is used to measure the air flow distribution across the face of moisture separator, prefilter, HEPA filter, and adsorber banks. Uniform air velocity distribution ensures maximum air treatment efficiency and uniform loading of air treatment components.

III-1100 Summary of Method

The system is operated at design flow rate. Airflow velocity readings are measured downstream of each moisture separator, prefilter, and HEPA filter in the bank. For adsorbers, readings shall be taken in line with the flow slots. Each reading is compared to the average for the bank.

III-2000 Prerequisites

System operating within +/- 10% design flow rate.

III-3000 Test Equipment

Rotating vane, heated wire or heated thermocouple anemometer, pitot tube, or other suitable air velocity measuring device as appropriate for the anticipated velocities.

III-4000 Procedure

a. For each moisture separator, prefilter and HEPA filter, measure the air velocity at the approximate centers of equal areas with at least 1 measurement per each moisture separator, prefilter, and HEPA filter, and a minimum of 9 measurements per bank. Adsorber velocity measurements shall be made in the approximate center of the flow slots. For flow slots greater than 24 inches long (60 cm), measurements shall be nominally every 12 inches (30 cm) along the length of the slot.

b. Calculate the average velocity (V_{ave}) using the following formula:

$$V_{ave} = \frac{\sum_1^n V_i}{n}$$

where:

$\sum_1^n$ = sum of readings from 1 to n

V_i = individual velocity readings
n = number of readings

c. Identify the highest and lowest velocity readings and calculate the percentage they vary from the average calculated above.

APPENDIX IV
MANDATORY
HEPA FILTER BANK IN-PLACE LEAK TEST PROCEDURE

IV-1000 General

This procedure is used to leak test HEPA banks.

IV-1100 Summary of Method

The system is operated at design flow rate. Challenge aerosol is injected upstream of each bank through the injection ports qualified in Acceptance Testing in ANSI/ASME AG-1 Appendix TA-V. The concentration of the challenge aerosol is measured upstream and downstream of the HEPA bank. The ratio of the downstream and upstream concentrations represents the HEPA filter bank leak rate.

IV-2000 Prerequisites

Airflow distribution shall be verified in accordance with Appendix III. The injection port shall be qualified to provide uniform air-aerosol mixing in accordance with ASME AG-1 Appendix TA-V.

IV-3000 Test Equipment

a. Challenge aerosol generator.

b. Challenge aerosol measuring instrument.

c. Flow measuring device.

IV-4000 Procedure

a. Connect challenge aerosol or gas generator to the qualified injection port.

b. Place the challenge aerosol or gas measuring instrument sample probes upstream and downstream of the bank to be tested with adequate hose length to reach all areas of the bank.

c. Start the system and verify stable flow rate within +/- 10% of design flow rate.

d. Measure the upstream and downstream aerosol background concentration. The pre-injection background levels shall be stable to ensure correct instrument response and shall not interfere with the detector's ability to detect leaks in excess of the maximum allowed by the acceptance criteria.

e. Start the challenge aerosol injection.

f. Record the upstream and downstream concentrations. Repeat until at least three of the readings are stable.

g. Stop the injection.

h. Using the final set of readings meeting the stability and tolerance criteria, calculate the bank leak rate using the formula below:

$$L = (100)\frac{C_d}{C_u}$$

L = % Leak
C_d = Downstream concentration
C_u = Upstream concentration

APPENDIX V
MANDATORY
ADSORBER BANK IN-PLACE LEAK TEST PROCEDURE

V-1000 General

This procedure is used to leak test adsorber banks.

V-1100 Summary of Method

The system is operated at design flow rate. Challenge gas is injected upstream of each bank through the injection port qualified in ASME AG-1 Appendix TA-V. The concentration of challenge gas is measured upstream and downstream of the bank. The ratio of the downstream and upstream concentrations represents the bank leak rate.

V-2000 Prerequisites

Airflow distribution shall be verified in accordance with Appendix III. The injection port shall be qualified to provide uniform air-aerosol mixing in accordance with ASME AG-1 Appendix TA-V.

V-3000 Test Equipment

a. Challenge gas generator.

b. Challenge gas measuring instrument.

c. Flow measuring device.

V-4000 Procedure

a. Connect challenge gas generator to the qualified injection port.

b. Place the challenge gas measuring instrument sample probes upstream and downstream of the bank to be tested. The sample tubing shall be of equal lengths and bore and as short as possible to minimize the measuring instrument response time. The upstream sample probe shall be located in approximately the center of the bank. The downstream sample probe shall be located in a downstream sample manifold or downstream of a mixing source such as a turbulent fan discharge.

c. Start the system and verify stable flow rate and within +/-10% of design flow rate.

d. Measure the upstream and downstream challenge gas background concentration. The pre-injection background levels shall be stable to ensure correct instrument response and shall not interfere with the detector's ability to detect challenge gas leaks less than the maximum allowed by the acceptance criteria.

e. Start the challenge gas injection.

f. Record the upstream and downstream concentrations, as rapidly as instrument response time allows, until sufficient data has been recorded to allow calculation of adsorber bank leak rate. Care must be taken to obtain sufficient readings quickly after injection.

g. Terminate challenge gas injection.

h. Using the upstream and downstream concentration data, calculate the adsorber bank leak rate using the formula below.

$$L = (100)\frac{C_d}{C_u}$$

L = % Leak
C_d = Downstream concentration
C_u = Upstream concentration

APPENDIX A
NON-MANDATORY
MOUNTING FRAME PRESSURE LEAK TEST PROCEDURE

A-1000 General

This optional test is used to identify leaks through seal welds of the HEPA filter or adsorber mounting frames. The presence of these leaks may be evident when conducting the in-place leak tests on the HEPA filter and adsorber banks. A good visual verification per Appendix I, steps I-1600 and I-1700, is usually adequate. This procedure is provided for use when the frame leaks need to be located.

A-1100 Summary of Method

Temporary blanks, with gaskets, are installed in place of the HEPA filters or adsorbers on the mounting frame in the system. The pressure boundary is then secured by blanking off upstream of the mounting frame in the housing or associated ducts. This modified pressure boundary is then pressurized using the techniques outlined in Appendix II and any leaks in the mounting frame welded interface is detected using the techniques in Appendix II, steps II-4400 or II-4500.

A-2000 Prerequisites

Construction, modifications and repairs affecting the test boundary shall be complete and temporary blanks, with gaskets, installed on the gasket side of the mounting frame. The opening of the duct or housing upstream of the mounting frame shall be blanked off to form a modified pressure boundary.

A-3000 Test Equipment

a. Pressurization source (test fan with flow control).

b. Covers to seal test boundaries.

c. Pressure indicating device accurate to +/- 0.1 in. w.g. (0.025 kPa(gage)).

A-4000 Procedure

a. Connect the pressurization source to the duct or housing pressure boundary.

b. Install pressure indicating device so that it will indicate the pressure inside the duct or housing being tested.

c. Close access doors.

d. Start the fan and operate until the pressure is greater than or equal to the maximum operating differential pressure for the filter bank (not to exceed the structural capability pressure for the duct and housing assembly). Maintain pressure for the duration of the inspection.

e. Inspect the mounting frame welds and attachments for leaks using the methods outlined in Appendix II, steps II-4400 or II-4500.

APPENDIX B
NON-MANDATORY
CORRECTIVE ACTION GUIDANCE

Corrective action may consist of replacement, repair, modification, maintenance, or analysis to demonstrate that the equipment will fulfill its design function. A revised set of reference values, as described in Section 4, shall be established after the corrective action has been taken.

Results of a failed test shall not be resolved simply by a successful repetition of the test. A successful repetition of the test shall be preceded by corrective action.

If the cause of the test failure cannot be determined by inspection or analysis, corrective action may consist of re-calibration of test instruments and subsequent re-testing. If it is determined that the test failure is due to an equipment malfunction, instead of difficulties with the test equipment, or test procedure, the equipment shall be declared unavailable for service until the specific cause has been determined and the condition corrected.

APPENDIX C
NON-MANDATORY
CHALLENGE GAS SUBSTITUTE SELECTION CRITERIA

Alternative test agents (challenge gas) may be used to perform In-place testing of adsorbers, as required in Mandatory Appendix V, when their selection is based upon meeting the following characteristics:

1. The test agent gives the same In-place Leak Test results as one of the following: R-11, R-12, R-112, or R-112a.
2. The test agent has similar retention times on activated carbons, at the same concentration levels, as one of the following: R-11, R-12, R-112, or R-112a.
3. The test agent has similar lower detection limit sensitivity and precision in the concentration range of use as one of the following: R-11, R-12, R-112, or R-112a.
4. The test agent exhibits chemical and radiological stability under the test conditions.
5. The test agent causes no degradation of the carbon and its impregnant(s) or of other Nuclear Air Treatment System components under the test conditions.
6. The test agent is listed in the Environmental Protection Agency "Toxic Substance Control Act" (TSCA) inventory for commercial use.

APPENDIX D
NON-MANDATORY
TEST PROGRAM DEVELOPMENT GUIDANCE

D-1000 OVERVIEW:

The scope of the periodic in-service test program for nuclear safety-related air treatment, heating, ventilating, and air conditioning systems should be developed commensurate with the safety significance of the system performance function(s). The overall depth of the performance monitoring effort should be flexible, with various tests being added, modified, or deleted as results and industry experience warrant. This Appendix will attempt to provide the user with guidance in developing a test program which will meet the requirements of the Standard.

D-2000 DEFINITIONS:

The following definitions are applicable to this Appendix:

Analyzed System Configuration: The alignment and condition (on or off) of various components, handswitches, controls, valves, piping, etc., that have been analyzed as being capable of accomplishing a specific system function.

Analyzed System Performance: The predicted performance as determined in the appropriate analysis (safety, system, or component analysis) or the acceptable limit as defined in the Technical Specification Basis. This value is in the conservative direction when related to the design limit, with the difference between the two defining the analysis margin.

Design Basis: "That information which identifies the specific functions to be performed by a structure, system, or component of a facility, and the specific values or range of values chosen for controlling parameters as reference bounds for the design. These values may be (1) restraints derived from generally accepted "state of the art" practices for achieving functional goals, or (2) requirements derived from analysis (based on calculation and/or experiment) of the effects of a postulated accident for which the structure, system, or component must meet its functional goals". (REF: 10CFR50.2)

Parameters: The variables or measurable qualities of a system or component that define acceptable operation or can be restricted to ensure that performance remains within design limits.

System Performance Function: The goal or task which the system is required to accomplish or support.

Examples of System Performance Functions, which might be applicable to nuclear air treatment, heating, ventilating and air conditioning systems include:

I. Provide a habitable environment (temperature, humidity, filtration, ventilation) for facility personnel.
II. Provide an acceptable environment (temperature, humidity, ventilation) to support equipment operability and Environmental Qualification requirements.

III. Prevent the uncontrolled release of airborne radioactivity and limit offsite dose in accordance with 10CFR50 Appendix I, 10CFR20 and 10CFR100.

D-3000 TEST PROGRAM DEVELOPMENT:

The Owner should perform a detailed review of all design basis documentation applicable to each safety-related system. Subsequent to this review, a Test Basis Document should be prepared for each nuclear safety-related air treatment, heating, ventilating, and air conditioning system in the facility to identify the following:

1. System safety-related performance function(s)
2. Analyzed system configuration for each identified performance function.
3. The critical performance parameters which will define acceptable system operation for each performance function.
4. The Parameter design limits. These are the design or analysis limits which govern the system performance and bound the system.

NOTE: The Nuclear Management and Resources Council, Inc (NUMARC) sponsored document "Design Basis Document Guidelines", NUMARC 90-12, October 1990 and USNRC NUREG-1397, "An Assessment of Design Control Practices and Design Reconstitution Programs in the Nuclear Power Industry", February 1991, can provide further detail on methods for determining the various design basis functions.

D-4000 SAMPLE TEST PROGRAM:

Given a sample Control Room Complex Emergency HVAC System, consisting of a fan, ductwork, dampers, chilled water cooling coils, nuclear air filtration unit (electric preheater, prefilter, HEPA filters, Adsorber), controls, etc., the System Test Basis Document might be structured as follows:

A. System Performance Functions:

1. Provide a habitable environment for control room complex personnel in the event of a design basis accident
2. Maintain the control room complex environment to ensure equipment operability.
3. Limit radiological dose to control room complex personnel in accordance with GDC-19 requirements

B. Analyzed System Configuration:

To achieve Performance Functions A1, A2 and A3:

One Essential Air Filtration unit in service, normal ventilation system isolated and an essential chilled water system in service.

C. Critical Performance Parameters and Parameter Design Limits:

Performance Function	Performance Parameters	Parameter Design Limit
A1 and A2	Heat Removal:	850,000 Btuh
	* Total System Airflow	30,000 SCFM (min)
	* Air Temperature at coil outlet	60 °F (Max)
	* Chilled Water Flow to coil	114 GPM (Min)
	* Chilled Water Supply Temperature	45 °F (Max)
	* Control Room Ambient Air Temperature	80 °F (Max)
A3	Radiation Protection:	
	* Outside Airflow (pressurization)	400 SCFM (Min)
	* Outside Airflow	900 SCFM (Max)
	* HEPA Filter Bypass Leakage	1% (Max)
	* Adsorber Bypass Leakage	1% (Max)
	* Adsorbent Methyl Iodide Removal Efficiency	99% (Min)
	* Humidity Control At Adsorber	70% (Max)
	* Control Room Complex Pressure	+0.25 in. wg (relative to all adjacent areas)
	* Isolation Damper Leakage	Bubbletight @ 15 in wg
	* Isolation Damper Closure Time	25 seconds (Max)
	* Filter Unit Total Pressure Drop	8.0 in. wg (Max)

Based upon the identified Critical Performance Parameters for the sample Control Room Complex Emergency HVAC System, the following periodic in-service test program would be appropriate:

Test Section	Test Description	Test Applicable to System?	Test Frequency
8.2	FANS	YES	
8.2.2	Visual Inspection (VT)	YES	Q
8.2.3	Pressure Boundary Test		
8.2.3.1	Leak Test (PL)	YES	10Y
8.2.4.1	Mechanical Run Test (F)	YES	Q

Test Section	Test Description	Test Applicable to System?	Test Frequency
8.2.4.2	Flow Rate Test (Qf)	YES	2Y
8.2.4.3	Static Pressure Test (DP)	YES	2Y
8.2.4.4	Rotational Speed Test (N)	YES	2Y
8.2.4.5	Vibration Test (Vb)	YES	Q
8.3	DAMPERS	YES	
8.3.2	Visual Inspection (VT)	YES	2Y
8.3.3.1	Leak Test Damper Seat (PL)	YES	2Y
8.3.4.1	Position Indication Test (F)	YES	2Y
8.3.4.2	Exercise Test (F)	YES	2Y
8.3.4.3	Static Timing Test(F)	YES	Q
8.3.5.1	Flow Control Test (F)	YES	2Y
8.3.5.2	Fire Damper Test (F)	YES	2Y
8.3.5.3	Dynamic Timing Test (F)	YES	2Y
8.3.5.4	Interlock Test (F)	YES	2Y
8.4	DUCT AND HOUSING	YES	
8.4.2	Visual Inspection (VT)	YES	2Y
8.4.3.1	Leak Test (PL)	YES	10Y
8.5	REFRIGERATION EQUIPMENT	NOTE 1	
8.5.2	Visual Inspection (VT)		
8.5.3.1	Leak Test, Refrigerant Piping and Coil (PL)		
8.5.3.2	Leak Test, Hydronic Piping and Coils (PL)		
8.5.4.1	Valve Position Indication (F)		
8.5.4.2	Valve Exercise Test (F)		
8.5.4.3	Valve Timing Test (F)		
8.5.5.1	Flow Control Valve Test (F)		
8.5.5.2	Mechanical Run Test (F)		
8.5.5.3	Performance Test (F)		
8.5.5.4	Vibration Test (Vb)		
8.5.5.5	Rotational Speed Test (N)		
8.6	CONDITIONING EQUIPMENT	NOTE 2	
8.6.2	Visual Inspection (VT)		
8.6.3.1	Leak Test, Hydronic Piping and Coils (PL)		
8.6.4.1	Valve Performance Tests (F)		
8.6.5.1	Hydronic System Flow Balance Verification (Qf)		
8.6.5.2	Flow Control Valve Test (F)		
8.6.5.3	Mechanical Run Test (F)		

8.6.5.4	Performance Test (F)		
8.6.5.5	Rotational Speed Test (N)		
8.6.5.6	Vibration Test (Vb)		
8.6.5.7	Electric Heater Test (AMP)		
8.6.5.8	Hydronic Heating and Cooling Performance Test (F)	YES	2Y
8.7	MOISTURE SEPARATOR, PREFILTER, HEPA FILTER BANK		
8.7.2	Visual Inspection (VT)	YES	2Y
8.7.3.1	Differential Pressure Test (DP)	YES	M
8.7.3.2	In-Place Leak Test (IP)	YES	2Y
8.8	TYPE II and TYPE III ADSORBER BANK		
8.8.2	Visual Inspection (VT)	YES	2Y

Test Section	Test Description	Test Applicable to System?	Test Frequency
8.8.3.1	Differential Pressure Test (DP)	YES	M
8.8.3.2	In-Place Leak Test (IP)	YES	2Y
8.8.3.3	Electric Heater Performance	YES	2Y
8.9	ADSORBENT		
8.9.2	Laboratory Analysis (LAB)	YES	2Y
8.10	INTEGRATED SYSTEM TESTS	NOTE 3	
8.10.1	Fan Integrated System Tests (F)	YES	2Y
8.10.2	Air System Flow Balance Verification (Qf)	YES	2Y
8.10.2	Damper Integrated System Test (F)	YES	2Y
8.10.3	Refrigeration and Conditioning Integrated System Test (F)	NOTE 1	
8.10.4	HEPA Filter and Adsorber Bank Integrated Test (F)	YES	2Y

NOTES:

1. Refrigeration Equipment is scoped and tested with the Essential Chilled Water System.
2. Conditioning Equipment, with the exception of the Control Room Complex Essential Cooling Coil, is scoped and tested with the Essential Chilled Water System.

3. Measurements for Control Room Complex pressure and ambient room temperature are incorporated into 8.10, Integrated System Testing.

DISCUSSION

PEST: I am a member of the ASME Committee on Nuclear and Gas Treatment and serve as vice-chairman of the Subcommittee on Field Test Procedures, and chairman of the Subgroup of the same name. I am employed at the Palo Verde Nuclear Generating Station, operated by Arizona Public Service Co., the nation's largest electrical power producing site. At this session we will be discussing the proposed AG-1 Code, Section TA, Acceptance Testing, and the proposed Standard N511, Periodic In-Service Testings of Nuclear Air Treatment, Heating, Ventilating and Air Conditioning Systems. I plan to give a brief history of the two documents, why they are needed., and familiarize you with the development process. After a brief review of the contents of the documents, I will ask the panel for comments.

In 1971, a group was organized to develop standards for high reliability air cleaning equipment and a performance test. The result was ANSI/ASME N510, published in 1975 and ANSI/ASME N509, published in 1976. These two standards were updated in 1980, again in 1989, and reaffirmed recently. It appears that they will live on for some time as they are now considered international standards.

The scope was expanded to include ancillary components and systems and the development of an equipment code. The first edition of the code, AG-1, was issued in 1986 and reapproved in 1988 and 1994. Section TA has been in preparation for a number of years. Approximately three years ago, draft Section TA covering acceptance and in-service testing was approved by the CONAGT Main Committee but rejected by the Board of Nuclear Codes and Standards with instructions to make Section TA cover acceptance testing, only. CONAGT resolved to provide a separate standard for in-service testing. Section TA, revision 03-06-96, was sent to the Main Committee for letter ballot but was not approved. It is the subcommittee's intent to prepare responses to negative ballots, and submit a redraft to the Main Committee for approval by August 2, 1996. This means that it could be in print by late 1997.

The proposed in-service testing standard, designated N511-19XX, has just completed the first subcommittee ballot and some changes are needed. The subcommittee intends to prepare responses to all comments, review newly-derived issues, and distribute a new draft for subcommittee ballot by approximately August 15. We believe that the information gained from this session will help us prepare a quality document in a short time. N511 is intended for application to systems built according to provisions of the AG-1 code. This is the same relationship as N510 to N509.

As we review these documents together I am going to read certain paragraphs and tell you what is going to be changed. To TA 2000 we will be adding the latest edition of the references. For TA 3500, the second sentence which reads, "Test results are considered acceptable if the component or system is not impaired or degraded to the point that it cannot perform its intended function" will be deleted. The consensus was that the phrase did not give the correct emphasis. To TA 4010, a note will be added that repairs or maintenance procedures that do not affect test acceptance values will not require a retest. For TA 4436, the first sentence will read, "Correct direction of rotation shall be verified for compressor motors." Because it is not wise to start and stop a compressor motor just to see if it is rotating in the correct direction and because some compressor motors are hidden within the system, verification will have to be performed by electrical means. In the second sentence, we will change restart to start. A caution note will be added to TA 4736 to require monitoring air temperature leaving the heater to avoid challenging the fire protection systems and causing automatic actuations. To TA 4740, acceptance criteria, will be added paragraph 4744, Electrical Heater Performance Test Acceptance Criteria. For TA 4940 after the words "flow path" will be added the words, "housing, by-pass ducts, and associated dampers." In

Appendix TA-1, page 41, a sentence will be changed to read, " provisions for access for performing tests and maintenance." These are all the changes to the balloted Section TA document.

The copy of N511 in your hands is about two revisions old. We have had several word smithing sessions. Appendix A will be deleted. In Section 8.10.2, there will be further work on air balance verification. This was brought up this week in our subcommittee meeting. There was a lot of discussion about what you have to do to certify that the system is balanced. Do you do a traverse at the fan or do you have to go back through the branch ducts and the diffusers? Do you perform temperature surveys? We also need to consider test requirements for medium efficiency filters in N511 and the matter of the test designators that were transferred from Section TA. Through this session, we can smooth out the document before it gets to the Main Committee.

Panel Members are Curt Graves, NUCON, International, Paul Burwinkel, Georgia Power, Vince Kluge, Palo Verde Nuclear Generating Station, and Len Leonard, Leonard Designs. Now, we will open the session for discussion.

SCRIPSICK: I am not certain I have reviewed the entire document. There are sections in N509 that pertain to testing HEPA filter systems. An example is the mandatory appendix for qualification of injection and sampling manifolds Does that topic appear in either of the two documents, or are there still going to be some provisions in N509 for testing?

PEST: The housing group will try to include some information on locations for sample manifolds.

KLUGE: I think that section TA can only address the sections of AG-1 that have been approved Manifolds are within the housing group, and that section has not been issued. But when it is, it will be addressed.

SCRIPSICK: It seems to me that considerations for sampling downstream should be an essential part, just as aerosol mixing is included in a mandatory appendix.

PEST: As I see it, N509 would continue to contain acceptance criteria for injection points but the in-service document would describe how you test it.

SCRIPSICK: There is a requirement of ±20% for air flow distribution and air/aerosol mixing on the upstream side but not for sampling downstream, I don't see any reason to treat it differently.

GRAVES: This document is still a work in progress, as other code sections are developed this group will take over the testing portion for them. Until a code section is developed that addresses the component that needs to be tested, this group does not produce anything, although they can anticipate. Did I hear you say sampling manifolds are in the housing section?

KOVACH, L: The basic idea is that the qualification requirements for mixing and test manifolds are in the TA section because if you qualify them on the original system, as it was built, it is not expected that they will change in use. TA requires you redo the qualification procedure if you make changes. Therefore, after you qualify the injection and test locations, N511 gives you the surveillance tests that you need thereafter It is not expected that it would change as long as you maintain the same flow rate and configuration. But if you change the configuration, you would have to do the TA-type acceptance testing.

This will make N511 less free-standing, because it could be applied to systems that are already qualified according to TA.

SCRIPSICK: My point is that TA does not consider the downstream side, once you qualify the downstream sampling location, you do not have to do it again. That is a major modification. I was not involved and do not know the history, but it seems to me that this is a good point to bring in all the considerations of downstream sampling. I do not understand the reason for treating the two differently.

KOVACH, L: TA covers everything relating to sampling locations that was in N509.

SCRIPSICK: But the qualification criteria for downstream sampling are not in TA.

KOVACH, L: I am not sure, I think it may be in there.

SCRIPSICK: Traditionally, it has been in N509.

KOVACH, L: It is not in N511 because it is expected that it will have already been taken care of.

SCRIPSICK: So it should be in TA, but I do not see it in TA. The concentration profile has to be ±5% to qualify a standard probe and the in-service probe or manifold has to be within ±5% of the standard probe.

KOVACH, L: What you have to understand is that there is segmentation now. Some of the things that you saw in N509 may now be in three or four different AG-1 sections. Now, when you build a housing, you will qualify the various injection ports and sampling locations with the housing. That is how it should be done, not after you build the unit. You do not start drilling holes in the housing like Woody Woodpecker to try to find the best location to test.

SCRIPSICK: I think that same logic should apply to the selection of the injection port.

KOVACH, L: You have be careful because the manufacturer of the housing may not construct the whole system, someone else may put in the HEPA filters, *etc* Therefore, you must have enough flexibility to allow for commercial practice and make sure that you do not put in any code section specifications that belong to another manufacturing or supply step.

WILHELM: What are the results of the tests done up till now? What is the percentage of reactor filters or systems that really failed? Around twenty years ago, a paper was given that showed 15% of filters failed the test. I do not know the current percentage of failed filters. The in-place test is rather complicated and expensive. Is it really necessary, judging from the results you have today?

GRAVES: The point of the in-place test is to verify that after filter change-out or some other event the system still functions properly and there is no leak. In any case, NRC dictates that tests be performed at nuclear power plants. It is not a test of individual filters, it is a system test to make sure there is no bypass leakage or potential contamination path. It is assumed that the filters left the factory in good shape, and that they looked good when they were installed. After they are installed you want to know that the system does not have bypass leakage. I do not have any idea what percentage of filters failed as a result of the performance of these tests.

HAYES: Can you tell me whether section TA or N511 has any test associated with the integrity of a particular building or area boundary, such as a control room, auxiliary building, shield building, annulus reactor building? If they are included, what are the tests?

KLUGE: That would occur under integrated system testing, but currently, there is nothing specific as far as identifying such items as control room pressure envelope testing, or auxiliary building testing. However, in non-mandatory Appendix C, there is guidance on developing your own in-house program. N511 gives the levels of testing required and then you have to adapt it to your own facility, using your own design basis and the critical functions of your system. We identified pressure envelope testing as one of the things that should be addressed.

WEIDLER: I would like to hear some discussion from the panel regarding the benefits of Section TA and N511 versus the requirements of N509 and N510.

LEONARD: As we see it, TA and N511 will perform the same function for AG-1 systems that N510 performs for N509 systems. You have a design document, AG-1, and an acceptance test, TA, and an in-service test, N511.

BURWINKEL: A benefit of the TA section is that it addresses a large number of components of the overall systems in addition to the filter housing, as N510 tended to do just filter housing. There are sections on refrigerating equipment, there are sections on system performance, not just filtration.

PEST: I may add that when you are using N510 and N509 you are usually testing or building a flange-to-flange component, whereas Section TA, being an in-service testing document, encompasses the ancillary and working parts of the entire system, including any systems that may interact with your air conditioning unit. The advantage of N511 over N510 is that it will help when the NRC maintenance rule takes effect. Some people had thought the maintenance rule only applied to highly important systems, but we are finding out that it is not so. N510 is too restrictive, so we see that we have some room to grow with N511.

FIRST: We have heard a lot through the years about the difficulties of applying the latest versions of N510 and AG-1 to existing power plants that have Technical Specifications based on earlier documents; even in some cases predating the establishment of codes and standards. How are we going to adapt these new versions to the older plants? How are we making them user-friendly so that they can bring their testing procedures into the 1996 era from, say, 1976? This is always a matter of great concern to the users of these documents. Has some thought been given to how they will be made more adaptable than prior documents?

BURWINKEL: For years we have hidden behind the excuse that our Tech. Specs. have out-of-date parameters that conflict with the latest standards and codes. A couple of things ought to be done, first, I think it is the utilitys' responsibility to modify their Tech. Specs. so that they are accurate and current. When that is done, the Tech. Specs. are usually brought up to the latest codes and standards. Second, there is an initiative for utilities to adopt improved tech. specs. that coincide with the latest codes and standards.

GRAVES: I think what Dr. First was asking was, how do you use the new documents with old equipment, and what headaches will you run into there? You will always have those headaches. Some of the older equipment that was not designed to N509 requirements, and certainly not to the AG-1 code, is not easily testable in accordance with the latest versions of these documents. Careful thought is required to meet the intent, but there may be cases where you can not meet the letter of the test requirements. Tech. Spec. fixes might be helpful, but we are sometimes just stuck.

SCRIPSICK: One of the reasons I am interested in downstream sampling is that I see the uncertainty in test results from HEPA filter in-place testing as having several components. One is the air/aerosol mixing test requirement, ±20%. Another is air flow uniformity, a third is an error associated with downstream sampling. Combine all those uncertainties and you come up with an overall uncertainty that is related to the test result, what I call testing geometry effects, poor mixing upstream or downstream and non-representative sampling. Instead of looking independently at specific criteria of ±20% for concentration profile, ±20% for air flow across the bank, and criteria for downstream distribution, why not combine them and come up with an estimate of overall uncertainty? For non-standard systems this has the benefit that should you be out of specification for one or two items, or even three, you may be within your performance acceptance limit, by an increment that is related to the uncertainty because of offsetting effects. Instead of having a test result of 0.05% for non-standard systems that determines that the system performance is acceptable, it might be 0.01 or 0.02%. By having that offset, you account for some of the differences relative to the specifications. That is a plug for my paper tomorrow, but I would appreciate any reaction on that kind of an approach.

BURWINKEL: I do not believe that we can look at the errors in the sampling procedure and the errors in the challenge agent, and balance them off. If you do not have good air/aerosol mixing you may very well not be challenging a part of the bed that is not leak-tight. When I am not challenging part of the bed, I am not getting any test agent downstream. Because of that I do not see a ready relationship to not challenging part of the bed and having fewer errors in the sample. I do not really see a relationship between the two.

GRAVES: It is clear that for the test to mean something you have got to challenge the filtration device in question. If you can't do it correctly, you need to do something about how you are testing it. You need to make corrections there.

SCRIPSICK: I agree. One of the things our analysis has brought out is that ±20% for air/aerosol mixing is an extremely important criterion. On the other hand, ±20% for air flow uniformity distribution over the bank does not seem to make much difference in our analysis. I can understand that from the error propagation analysis that we have done. I also understand it from the context that the tests are performed in. When you have a non-uniform air-flow distribution for your test, the challenge is going to be non-uniform so that contributes to the uncertainty of your test result.

GRAVES: Not necessarily. You may have a non-uniform distribution because of where you are injecting.

SCRIPSICK: No, I am referring to the air flow distribution, not the air/aerosol mixing. It is quite likely that when your test aerosol is not completely mixed you are going to have a difference between the test aerosol distribution over the bank and your air distribution over the bank. That is a serious problem. In the algorithm that we have developed, air/aerosol uniformity comes out to be extremely important. When you do a very good job on that you are going a long way in reducing the uncertainty in your test result measurement. But airflow distribution over the bank does not play as important a role.

KOVACH, L: Please remember that we are dealing not only with particulate filters in these systems, but adsorption systems, also. In adsorption systems, ±20% flow does have a significant effect. Remember that these requirements are based on the MPP system tests that are in MPP-type air cleaning systems, most of which do contain adsorption units that are very strongly affected by airflow velocity and the capacity of the total test. If we are applying the requirement solely for the aerosol filtration test, your comment that the air/aerosol mixing is far more important than the airflow velocity uniformity through the HEPA filters is certainly correct. But when we are dealing with adsorption systems, airflow velocity becomes very important also.

PORCO: From what I understand your code sections address qualification testing of equipment. It also addresses initial installation testing of the equipment and in-service testing. Can we have a discussion on what are the differences and how your code sections address those differences?

KLUGE: The individual sections of AG-1 have their own requirements for factory qualification tests for individual components. What we are addressing in TA is the installed system, and the acceptance tests required to verify that it meets design requirements. N511 covers periodic retesting to verify the system continues to meet design requirements . You will find factory testing in the individual sections of the code, not within TA.

PEST: N511 will have surveillance requirements. When you do your TA acceptance testing you establish your baseline test reference values for acceptability. Requirements for a trending program are in N511 so you will be able to balance new test values against those in the past. When you have a degrading trend, you know that corrective actions have to take place We looked at all the acceptance tests in TA and tried to include them in N511 for periodic reverification.

FRETTHOLD: Will N511 be any more user-friendly than the N510? We are being asked to comply with N510 but we are saying we use it as a guide.

KLUGE: We hope N511 will be more user-friendly. We are including guidance for development of individual test programs, adapted to facility requirements. Because we are looking at a much larger user group than just the nuclear power plants, we could not mandate a hard and fast test program that everyone must follow. It would not be practical, we would have a document that no one could use. So we addressed the types of tests that should be looked at based on the equipment you have in your own facility. And we have added guidance for developing the necessary level of testing. We are very open for further comments that can be incorporated into the document as it goes through the development stage.

WEIDLER: I would like to get to the bottom line, when these documents are issued, how do they help or change the testing program at McGuire Nuclear Station?

KLUGE: I believe that would depend on whether the individual utility changes its commitment to the new documents. It is not mandatory. I believe it would require a change to Tech. Specs. , if the plant is specifically committed to testing in accordance with N509 and N510. Is that what you are asking?

WEIDLER: That is it. Given the current regulatory climate we still have to do the tests in the Tech. Specs. We would be doing additional tests unless we changed the Tech. Specs., which, as everybody knows, is a fairly lengthy and difficult process.

KLUGE: Under the new improved Tech. Specs., the process is easier because the specific surveillance requirements have been taken out of the body of the Tech. Specs. and put under a filter ventilation test program. This would be like a basis document and it is much easier to make changes in that portion than it was in Tech. Specs. If one adopts improved Tech. Specs., it would be much easier to commit to the new documents with your own level of testing.

GHOST: One of the things that I came across while doing a life extension study was a requirement for housing leak testing every ten years. Most of the plants in the US are over ten years old. 324Does it mean that we have to leak test all the housings?

BURWINKEL: Today, a lot of housings are pressure tested once and never again. We felt this was not adequate to assure that the housings were not leaking. At my site, it has been ten years since we have leak tested housings. We have found a few minor problems, not by testing, but by visual inspections. The subcommittee felt that a pressure test on a filter housing at ten-year intervals was not an unreasonable requirement. It would give us greater confidence that our housings were leak-tight.

GHOST: The older plants are not really set up to do housing leak testing. Is there a basis, besides experience, for ten years? Are we looking at a few plants and saying yes, we did testing on so many plants, and ten years is a realistic basis?

PEST: In other words, is it an arbitrary number that we just selected, or was there some mathematical basis?

BURWINKEL: Ten years was arrived at out of the experience of people on the subcommittee and it seems to have been accepted favorably by the people balloting.

GHOST: Is it possible to make it variable, ten to fifteen years, instead of a finite number? This is a suggestion.

GRAVES: You might prepare expansion of what you are saying and give it to this committee to look at. They will address your comment and get back to you.

GHOST: HEPA filters have a finite life, anywhere from five to fifteen years, by test. Invariably, in-place testing has shown that they are acceptable, but structurally they are weak and they can fail. Have we addressed it by requiring a visual inspection program, to say that even at fifteen years we need to do something prior to testing?

PEST: That would come under the HEPA filter section and filter qualification. If you are performing a visual inspection prior to doing a leak test and notice that the filters have been there for ten years and the glass media appears to be cracking at the base of the units because of high humidity you would want to replace them.

GHOST: That calls for an inspection on a frequency basis?

PEST: Yes, but I do not think we have anything right now that says that after testing a hundred HEPA filters we found that after five years they need to be changed even though the gasket is seal and the media is fine. One of the other committees is looking at HEPA filter aging, and something should coming out about it.

GHOST: Will it be addressed in the TA section?

PEST: It would be addressed in AG-1, I believe.

KOVACH, L: I was involved in coming up with the ten year interval and the way we came up with it was that the proposal was between nine and eleven. So we hired a few statisticians and came up with a reasonable average, that is how we got to ten years. It took several years to resolve and it delayed issuance of the code for some time, but finally we were assured that ten years is reasonable. The reason for retesting housings is not because the structure itself fails, but because of door gaskets and flexible connections deteriorating. Not too long ago I had a chance to walk by a relatively new system. The housing was also used as an air organ, in various places, air was being sucked in at the doors and it was whistling different tunes. The requirement is real. Whether ten years is too long or too short, is certainly subject to question. It relates to how and how often you perform your visual inspections. I have seen systems where the latches float, instead of locking the door; they just hang in the gravity-dictated position rather than in a locked position. It is a question of how to care for the little failures; you do not have to go in for a general repair as often. Certainly 10 years is arbitrary, most requirements are arbitrary, but I believe it is quite reasonable. If anything it may be worthwhile to reduce it. If some old systems do not meet the test requirement, these old systems do not meet their purpose, either. I mean, if they are leaking air, how can we be assured that they are meeting their requirements? Let me comment also on the second question. I do not think that visual inspection alone can tell you that HEPA filters have aged to the point that structurally they may not be able to meet expected pressure, droplet, and thermal challenges. The F sections have to come up with an estimated life for a retest of media strength, etc. I think it is a weak point of the code, at the present time, and it is a weak point of a lot of HEPA filter installations, all over the world, because people assume that as long as the filter passes an in-place test it will perform its intended function in case of an accident challenge.

PORCO: I would like to comment also on the housing leakage issue, and the HEPA filter life issue. AG-1 has a requirement for environmental qualification of safety systems, and that qualification also includes environmental maintenance requirements. For instance, if you are looking at door gaskets when addressing the life of housings, you need to determine the useful environmental life of that component. Using a data base and the Ardenius equation, the gasket life can be predicted. Also, there are requirements on environmental qualification of the HEPA filters that should be addressed. The environmental conditions are going to change for each application. You must address high temperature, you must address all your environmental conditions, address all your materials, and make sure that either the materials last the life of the plant, normal maintenance life, or an environmental maintenance change-out must be established. That is in the standards now. There was environmental qualification on older plants, but possibly the environmental maintenance cycle did not get into the normal plant cycle. I am not sure, but I think that might be where you come up with the ten years. But if you are following your environmental qualification reports, you should be replacing gaskets and other materials before they wear out.

SCRIPSICK: I think the remarks about age are very important. The in-place test, as we perform it, is a snapshot. It tells you what the system is doing that day under normal conditions. It does not provide any information on how the system is going to perform when it is stressed or how it might perform under normal conditions the next day. I see two opportunities to help get some idea of the capability of the components under normal and off-normal conditions. One, is to take some of the filters we have in service now, knowing their exposure histories and their service life histories, and put them back through the qualification test to see how much their performance has degraded compared to the requirements of the design qualification. That is, when you subject them to a heated air test, do they degrade more than three percent or how much is performance changed when you take them up to ten inches of differential pressure. Another opportunity is for careful interpretation of results and, maybe, modification of the tests we are doing. Bergman is going to give a paper tomorrow about the efficiency of filters in-place. I think careful examination of tests like these can provide information about the remaining structural strength of HEPA filter units. As a future development, I think we should look in that direction to garner as much information as we can from the in-place test. One end-point is to try to determine whether the bank we are testing can withstand off-normal conditions.

BATTERSBY: I have a question about retesting existing duct work that has been in service ten years or so. If you do the recommended pressure test would you be in danger of spreading contamination through any leaks that may exist from duct work up stream of the filter bank? Perhaps the retest should be done under negative pressure, rather than positive.

LEONARD: Normally, leak tests are performed on a system in the pressure mode in which they operate, a negative pressure system would be subjected to negative pressure tests. Positive pressure systems (I can't think of any that operate that way) would be the only ones that would be tested under positive pressure. It would require a careful survey by the radiation control people and the whole HVAC engineering group to verify that it would not spread contamination. One thing that the committee looked at, and the basis, I think, for the ten year test interval, was the experience of people on the committee looking at systems in the plants that have been in operation for five, ten, fifteen years. When you look at a system after five years, it does not take a rocket scientist to determine that it is not in the same condition that it was when it was installed and tested.

BERGMAN: I want to add to some comments that Ron Scripsick made about aging. Last conference, John Fretthold, Humphrey Gilbert, and I presented a paper on aging effects of HEPA filters. We searched manufacturers and facilities around the US and attempted to do an aging study. We found that, after ten years, a filter has about half the strength it had initially and it has no water repellency left, things of that nature. We found from some manufacturers basically brand new filters that had strengths that were a fraction of some of the filters that were over ten years old. Through a laboratory analysis we found out there was insufficient binder in the medium to hold the fibers together, and that these filters were practically falling apart. Instead of worrying about setting age limits, let's take a real hard look at the test standards we have. I would like to put in a plug in for Dr. Ricketts' paper, later on this week, about qualification tests. I am not an expert on QA, but to me any QA system that is based on a manufacturer hand picking the best filters to bring them to a qualification test every five years, with no checks in between, is insanity. To expect any reliability under this kind of procedure is nuts. All you have to do is refer to our paper from the last Air Cleaning Conference to see the insanity of the present qualification program.

PEST: The rest of this panel session will be on testing air and gas treatment systems. We have the floor open for questions to the panel on any of the topics of the N511 in-service testing document, and Section TA on acceptance testing, from the AG-1 Code.

How much benefit do you think a utility or a nuclear facility owner would get by moving to AG-1 and N511 as opposed to remaining with N509 and N510? I am trying to learn if there is any benefit as far as clarity goes, because regulatory officials rely on the Regulatory Guide 1.52 that cites ANSI N510-1975 and N509-1976. Since 1976 there have been many changes, yet the Regulatory Guide fails to reflect them. Do you think that moving to N511 will cause the NRC to re-evaluate their position?

GRAVES: For a utility to move to any of these documents from N509 and N510 involves technical, political, and financial considerations. A lot of the N509 built equipment is already difficult to test by N510 methods and it might be that a more particular TA or N511 would cause more problems and people might resist changing. I think TA and N511 will be more particular and more helpful, but there will be less margin, less wiggle room, about what should or shouldn't be done. If the equipment is marginal, these documents are not going to be well received. But they ought to be evaluated as best for equipment. It is going to end up being a political and economic question, I think. We encourage everyone to look at these documents, because they are going to be a lot more helpful and there will be less chance to miss something important in testing and operability of equipment.

LEONARD: I think that they would be better off because they would have a better integrated package than they now have with N509 and N510. I think the package is tied together better. As Curt pointed out, they supplement one another better than N509 and N510 do now.

PEST: Does the panel think that N511 may, in the future, be expanded with an appendix to address the testing of portable filtration systems? I would like to get some guidance because there is not very much available on portable HEPA filters. Do you think some clarification should be made in N511?

KLUGE: N511 is currently set up just to look at permanently installed systems that are designed according to AG-1 requirements. It would be possible to have a non-mandatory appendix that gives guidance on testing such systems. I do not know how much demand there would be for it, or if it would be better to put out some other kind of guidance document specifically addressing those types of systems.

GRAVES: In the absence of a well-designed fabrication document for that equipment, folks could probably use some guidance. Hard and fast testing requirements are not going to help the manufacturers of portables and vacuum cleaners because there is such a variety of equipment out there. Some suggestions might be in order, but hard and fast rules are going to be a problem for them.

KRANZ: I am going to change gears here and start talking about adsorber testing, in-place leak testing. As of January 1, 1997 Freon will not be allowed into our facility My question to the panel and the audience is, what challenge gases are people using now? What challenge gases are people looking to use? I did not notice in N511 specific challenge gases mentioned. Did I miss it?

PEST: I believe it is in there.

KLUGE: There is an appendix in both TA and N511 which spells out the critical characteristics that have to be met for an alternative challenge agent. But no specific agents are mentioned by name in those documents.

KRANZ: What are people using or looking at using? We are between a rock and a hard place if our facilities are not going to allow us R11 in 1997. The bottom line is, if we use a different challenge gas, will the tests be accepted by the NRC?

GRAVES: Some people are using HCFC123. At the last Air Cleaning Conference, Bela Kovach, of our organization, gave a paper on it. Some are using a compound called 1-Bromo butane. I do not know if it will be widely accepted in the nuclear business, but HCFC123 looks like a good candidate that meets the list of criteria in appendix TA-C. It is always risky to speak for the NRC (there are representatives here who can do that) but my understanding is that when the industry standards people recognize a compound, it is acceptable as far as the NRC is concerned. When N510 is the required, or appropriate, standard, whatever N510 says is okay with the NRC.

LEONARD: The appendix that is in TA and N511 was the basis for a code question response on N510 So it is applicable to N510, also.

HAYES: The guide for any facility is their technical specifications. If you have a problem you need to request a Tech. Spec. change and give the basis for the change. As many of you know, we had a problem with verbatim compliance with the test methods for laboratory testing of charcoal. So it is imperative that we determine what your technical specifications say. If they require you to test a particular way and there is no flexibility, then you need a technical specification change

FIRST: Further to this same discussion, I am a member of the committee and urged that certain compounds be named as those that have been found acceptable, without indicating that they are the only ones that could be used Certainly, the criteria that have been published clearly define the characteristics. But few people are able to make this judgement on their own or have the facilities to do so. It seems to me that the standard should provide some guidance in terms of acceptable compounds as examples of what will work. I hope that change can be made, because I, among others, get calls from people wanting to know what is a representative compound that they can use I do not see why we make a mystery out of it. I want to ask the panel a question. We hear a great deal about international standards and how the international standards organization operates. Having documents approved as international standards is often discussed by code and standard writing committees. Variations of our codes and standards have been adopted by other countries. How can we go about making U.S. standards international standards? And is this highly desirable?

WEIDLER: It is my understanding from ASME that if it can be shown that our standard is being used in countries other than the United States, they are designated international standards. ASME itself is now called ASME International and their boiler code is used in countries other than the US.

PORCO: The code section you have prepared addresses primarily systems for commercial nuclear power plants. Did you take into consideration other systems used at DOE sites and military installations, and can they be easily adapted for those systems?

LEONARD: Insofar as we had input from those sites, we did try to make the document broad enough to cover them We have representation from DOE on the testing subgroup and subcommittee We hope we have managed it.

PEST: Yes, we do try to make the code and standard all-inclusive and not be tied down to a specific function.

SCRIPSICK: I have just tracked the history of these standards for my office. The '75, '76 and '80 versions of N509 and N510 were for "nuclear facilities." There was a change in '89, they were now for "nuclear power facilities." This was a change in scope. Now, I am not certain what AG-1 says. It looks like it has been broadened to include all nuclear facilities.

PEST: That is true. There has been some switching around of names, and we try to emphasize that the documents can go across barriers. It might even work out that they can be used in the general commercial area, not just nuclear facilities.

KLUGE: I would like to add that the current scope statement for both Section TA and N511 refers to nuclear facilities, and not specifically to nuclear power facilities.

SCRIPSICK: The speaker was very careful to point out that TA is a code and N511 is a standard. The difference is that one is for acceptance testing, and the other for in-service testing. Why is in-service testing a standard? Is a standard a lesser requirement than a code, or a law? Why was the distinction made?

PEST: When we took all the in-service testing material out of Section TA, and began composing N511, the first thing that we did was to change all the "shall"s that we could, and make them "should"s since a standard is better cast in a more generic overview of what is going on. However, you have to remember that it is the facility's design basis that really dictates what you have to do in the testing. Technical Specifications are spelled out.

KLUGE: The original draft of Section TA addressed both acceptance testing and in-service testing. However when that got up to the level of the BNCS we had to separate acceptance testing from surveillance testing. I do not know what was involved behind it, but that is where the split took place.

GRAVES: Part of the requirement was to make the documents more user-friendly. A document covering both was very confusing. This makes it much simpler.

PEST: I do not know whether I agree. I think Section TA could have handled both rather than make a whole new document. But I am glad that we didn't have to undertake a massive reconstruction of N510.

WEIDLER: One of the driving forces behind the Board's decision to split TA into two documents is that in-service testing is in one section of the code and acceptance testing is in another. In order to follow the format guidelines that ASME has adopted for the overall code, we had to split the TA draft into two different documents.

GHOSH: In the last sentence of section 8.10 in N511 it says that the integrated system test should be once every two years. Under the sub-heading you have air system flow balance verification tests. Is it implied that the flow balance is being tested every two years?

KLUGE: We have had some heated discussions at the committee level on that particular subject. The document will not require a full-blown air balance, such as would be done at start-up. Guidance will be developed that will allow the user to verify system balance by looking at the end functions. For example, if temperature is the critical function, temperature surveys will serve to verify a balanced condition. If pressure is the critical function, non-ducted airflow testing could be utilized. Guidance will be provided, and there will not be a requirement for a full re-balancing of the system.

GHOSH: Will that section be expanded?

KLUGE: That section will be revised, and there will probably be a non-mandatory appendix that will give detailed guidance.

DEVENA: Section 8.6 of N511 covers hydraulics. This is in somewhat the same light as the previous question, are we looking at a complete flow balance of the water systems? To what depth do we go with that? Originally, the whole system was aligned and balanced in the emergency flow mode, quite exhausting and quite extensive. I am not sure that you could come up with the same type of conditions by looking at individual components within the water system. If this is going to be a requirement, I think it goes far beyond just a component that will be looking at water balance. It is like a whole ESW system. You change the flow one place and you might not be able to get it at the other place unless it is lined up like it normally is for the emergency flow condition.

KLUGE: I think we will need additional guidance on the level of hydraulic balance within the document. The bottom line is, can you meet your design basis for heat rejection? If you are never doing any kind of verification of what your flows are, there has to be some kind of test data you can look at to see if you can meet your design basis. Also in Table 8-5, there is a two-year requirement for a cooling coil performance test. I believe the two years came from a recommendation by the maintenance rule that everything seems to go on a twenty-four month cycle. The maintenance rule that became law on the 9th of July will directly affect this type of testing. That is where the twenty-four month recommendation came from.

KRANZ: Did you say N509 and N510 are going to be reissued?

PEST: They have been reaffirmed.

PORCO: ASME N510 has been reaffirmed. When you receive your copy from ASME it will have the reaffirmation sticker. N509 has not been formally issued as reaffirmed, but it will be shortly.

SCRIPSICK: What is the distinction in TA and N511 about test requirements being observed or measured? What is the distinction? Maybe it is defined in sections of AG-1. Why is the acceptance test for HEPA filters a measurement requirement, whereas the in-service test is an observation requirement with a two-year period?

KLUGE: You made a good catch, that is a measured requirement.

SCRIPSICK: So there is a mistake in Table 8-6?

KLUGE: Yes.

SCRIPSICK: What is the distinction between measured and observed? I do not understand how they contrast.

KLUGE: The distinction between observed and measured is that a visual inspection is observed whereas anything that has a definite acceptance value would be a measured test.

GHOST: Previously, the requirement for personnel qualification was to be certified according to ANSI 45.2. Now you have NQA-1 and ANS standard 93.1. Is there a reason for not including 45.2?

KLUGE: The qualification criteria in this section came directly from section AA of the AG-1 code.

PEST: ANSI 45.2 is an old document, I am not sure it is still valid.

KLUGE: The specific wording is from Section AA 7220 regarding personnel qualifications. It states that all personnel performing on-site inspections and testing of AG-1 equipment shall be qualified in accordance with ANSI-ASME NQA1-1, supplements 2S-1 and 2S-2. So we just brought down the personnel qualification requirements from the code.

PEST: Is NQA-1 as stringent as N45.2?

GRAVES: I think they are about the same.

ORZECHOWSKI: Your scope is changed to include all nuclear facilities. What is your definition of nuclear facilities?

GRAVES: I think we mean any place that has fissionable material. We define nuclear facility as any facility that operates under radiological conditions. I imagine that would encompass just about all facilities that are licensed. We mean this for nuclear power plants, plutonium facilities, waste handling facilities, or any facility like that has air cleaning equipment, or the need for air cleaning equipment. We hope the standard will address the kinds of needs they all have. I do not know what guidance BNCS or ASME gave on this, so we may have weasel-worded it a little bit by using the term nuclear facility.

ORZECHOWSKI: I am working at the Nordion facility where we produce radio isotopes using an accelerator. Are we a nuclear facility? What do we base this on, how can we define ourselves? Going even further, I can ask whether nuclear medicine departments in hospitals are nuclear facilities. Now you are shifting from a very specific application to power plants to all nuclear facilities. There has to be some definition of what is covered. I do not know that such a definition exists. If you rely on the issuance of a license, hospitals have a license, but are they nuclear facilities? I do not know.

GRAVES: That is a good point. You could say, yes, they are, because they are regulated by NRC and follow other requirements. They would be welcome to use this document. It might not do them much good because they may be covered elsewhere. The regulating bodies may dictate to them something that precludes their use of the AG-1 code. But there is no reason why, for any given application, the AG-1 code could not be used. There is nothing to rule it out as applicable to that kind of facility. If there is a chance of airborne contamination, this code would apply, or it could apply.

PYLE: What is the intention for the air/aerosol mixing test procedure when you have a small facility where you might have a single HEPA filter as a HEPA filter bank? Would it be applied to a single

GRAVES: I am on the ventilation air cleaning committee, and may disagree with others. I think there should be some evaluation of air/aerosol uniformity, even for a single HEPA filter. That is an opinion that may not reflect what the TA group would say.

LEONARD: In a change from N510, where single HEPA filter systems are exempt, the exemption has been taken away in TA and N511.

PYLE: Therefore, you are saying it would apply?

PEST: You would have to make an air/aerosol mixing uniformity test for a single HEPA filter. Due to system configuration, the distribution may not be uniform and that would necessitate performing the test.

PYLE: Self-contained units would probably fail this test. Is this correct?

LEONARD: Yes, they almost surely will fail.

ANON: There is action in the committees to designate another category for this type of filter. And removing the exemption in N510 makes it necessary to address this issue. I think we are going to let the filter committee see if it warrants bringing out a new classification of filters.

SCRIPSICK: I agree with Curt Graves that there should be testing requirements for acceptance of single-filter systems. Some are being accepted by exemption because the procedures for air/aerosol mixing and for air flow distribution for filter banks at the center of each filter requires a measurement . Therefore, when you have only one filter you just take one measurement, even though that procedure does not apply. If we eliminate the single-filter exemption, we will have to make allowances in the procedure. I propose that we look at it.

BURWINKEL: Currently TA has a requirement for a minimum of nine readings, with the exemption for testing a single filter removed. It would require you to take nine readings in front of a single filter.

LEONARD: That is in mandatory Appendix 4, Section 4-4000.

DEVENA: Prior in-service testing documents contain a distinction between air cleaning equipment totally contained inside a containment, where it does not exhaust to the atmosphere. Does this new document allow the same exemption for filtration systems inside containment?

PEST: You mean, exempt from in-place testing?

DEVENA: Yes.

GRAVES: Are you talking about a Tech. Spec. issue? If your Tech Spec does not require it, you do not need to do it. These documents are not intended to supersede your Tech. Specs., just help to test, design, and manufacture equipment. If you are not required in your Tech. Spec. to test them, you could still use this document, but you might use it in a somewhat different way, and you might establish acceptance criteria that would be a little bit different.

DEVENA: Our Tech. Specs. presently reference R.G.1.52, which references the two ANSI standards where you get the exemption on units that are totally enclosed inside the containment. It is not specifically the Tech. Spec. that addresses it, it refers to it by reference. The same exemption is not referenced in the new documents.

BURWINKEL: If your system is entirely inside a containment, is it safety related?

DEVENA: No.

BURWINKEL: These documents refer to safety-related systems. Because we did not find any examples where there was a safety-related system fully contained inside containment, we did not see any reason to carry that provision forward.

KLUGE: In Table 8-7, in the current version of N511, there is the caveat that in-place leak tests are not required for systems used for 100% re-circulation. An example is a reactor containment clean-up system. That is why the exemption is in N511.

GRAVES: N511 is directed to once-through types of equipment.

KLUGE: I would like to encourage everyone to take home the copy of the N511 document, read it over, and provide us with feedback so we can make it an industry-useful document.

GRAVES: Does TA go back to the Main Committee after addressing negatives?

PEST: Yes. Section TA will be ready to go to the Main Committee by August 2. We are looking to October to get the results. If the Main Committee approves, it will go to the BNCS. I do not know how long the BNCS usually takes to make a decision. Last time it was pretty fast.

This Panel Session was an opportunity for our Committee to let you have a look at these documents. We got some very interesting comments and questions which we appreciate. We are looking for your support and contributions to make these documents user-friendly and to provide the help you and your neighbors need.

SESSION 5

WORKING LUNCH

Tuesday July 16, 1996

Co-Chairmen: M.W. First
J.L. Kovach

Invited Speaker: **John D. Wagoner**, Manager
Department of Energy, Richland

PROGRESS AND CHALLENGES IN CLEANING UP HANFORD

J.D. Wagoner

INTRODUCTION

FIRST: On my extreme left is Lou Kovach of NUCON International. You have heard from him previously during this conference, I think most of you know him. I mentioned yesterday morning that he has been very intensively involved in certain of Hanford's innovative operations. Because he has been so intimately involved in Hanford for the past couple of years, I thought it would be appropriate if he would introduce our luncheon speaker.

KOVACH, L: Ladies and gentlemen, I have a Department of Energy biography on John Wagoner, but I would like to start off by ignoring it for a minute and just tell you that I have seen John facing pronuclear civilians, antinuclear civilians, Native American tribe representatives, and then some people even worse, technical staff at Hanford, some of the contractors, National Laboratory representatives, headquarters people, and common folks like us. And there were always a lot of people who were trying to complain about something that the Department of Energy was doing at Hanford. And he always managed very graciously to field the questions and not get mad. And, really, what I admire about him the most is keeping cool in talking about things that sometimes are totally off the wall, and sometimes highly technical. And I know that I could not do that. I'm sure most of you are aware of my temperament. But John has been manager of the US Department of Energy's Richland Operations Office since July of 1990. He is responsible for the Department's mission at the 560 square mile Hanford Site reservation. The Hanford mission is to clean up the environmental legacy from the defense production of the cold and the warm wars of the past. He has worked on many different activities, starting with the Schenectady Naval Reactor's Office through various projects at Oak Ridge. At one time, it looked like, he had managed to escape the nuclear business for a while, and he was project manager for the strategic petroleum reserve. I am sure, John, you think back to those days as more peaceful than some of the nuclear activities He was deputy manager of the Savannah River Operations Office and worked in the US Navy supply corps. Again, I am not sure if he is happy that he made the decision, but he resigned his lieutenant commander's commission in '71 to accept a civilian appointment at the AEC. In 1983 John got the Secretary of Energy's meritorial service award, and received superior performance awards from the Secretary of Energy in 1990 and 1991. He is from my neighbor state, (not from Serbia or Austria), Indiana and is a good boilermaker from Purdue University. It is a pleasure for me to introduce John D. Wagoner

WAGONER: Thank you very much. This is a special privilege for me. This is the first Nuclear Air Cleaning Conference I have ever addressed. My talk will not be about nuclear air cleaning, but maybe you will see some parallels and some areas of interest, as we go talk about what I like to talk about, which is the Hanford Project, or Project Hanford, as we are now calling it The talk that I'll give today will try to get across a few simple key points. I will describe, of course, what the job is that we are doing at Hanford. And those of you who are working there either all the time or part of the time, I hope you will bear with me if it is redundant with what you already know. The message that I want to get across about that is that the job is getting done. One of the other important parts of it is most of it, I believe, will be complete within ten years. And in order to complete that ten-year vision, we have an awful lot of very difficult problems to resolve. I am sure that a number of you can contribute to doing that. So we'll start with the next slide to try to put things in perspective. I understand that a few of you have signed up for a Hanford site tour, I certainly encourage you to do that. One of the things I believe we have been able to do to better communicate with the public is to make the site accessible.

24th DOE/NRC Nuclear Air Cleaning and Treatment Conference

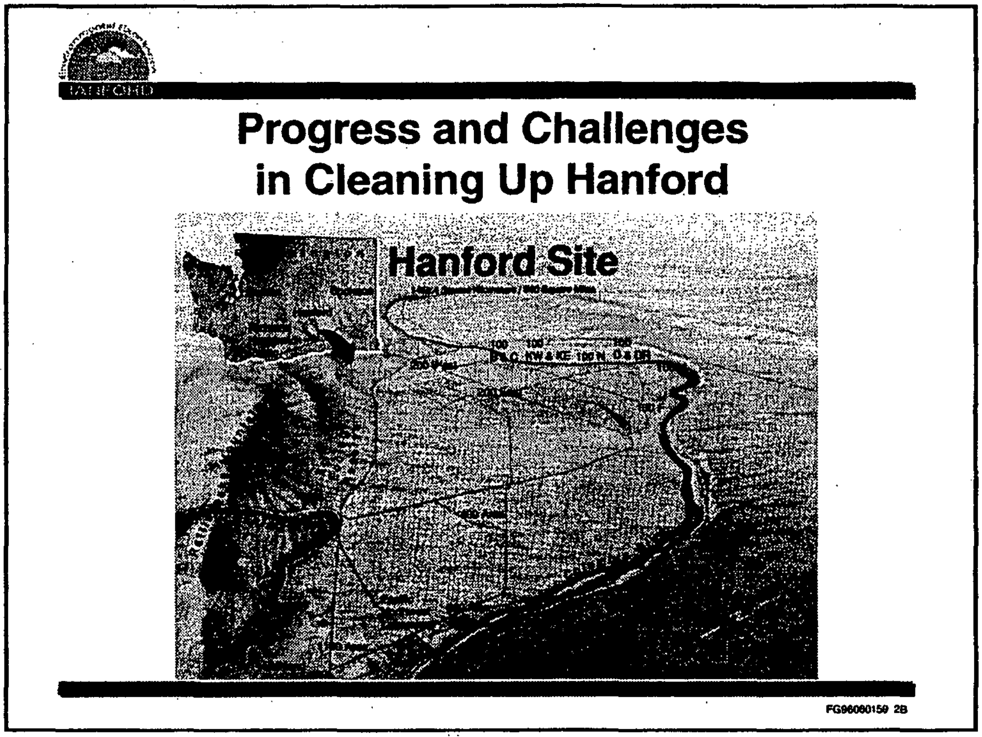
Environmental Excellence

HANFORD

John D. Wagoner, Manager

Richland Operations Office
U.S. Department of Energy

July 16, 1996

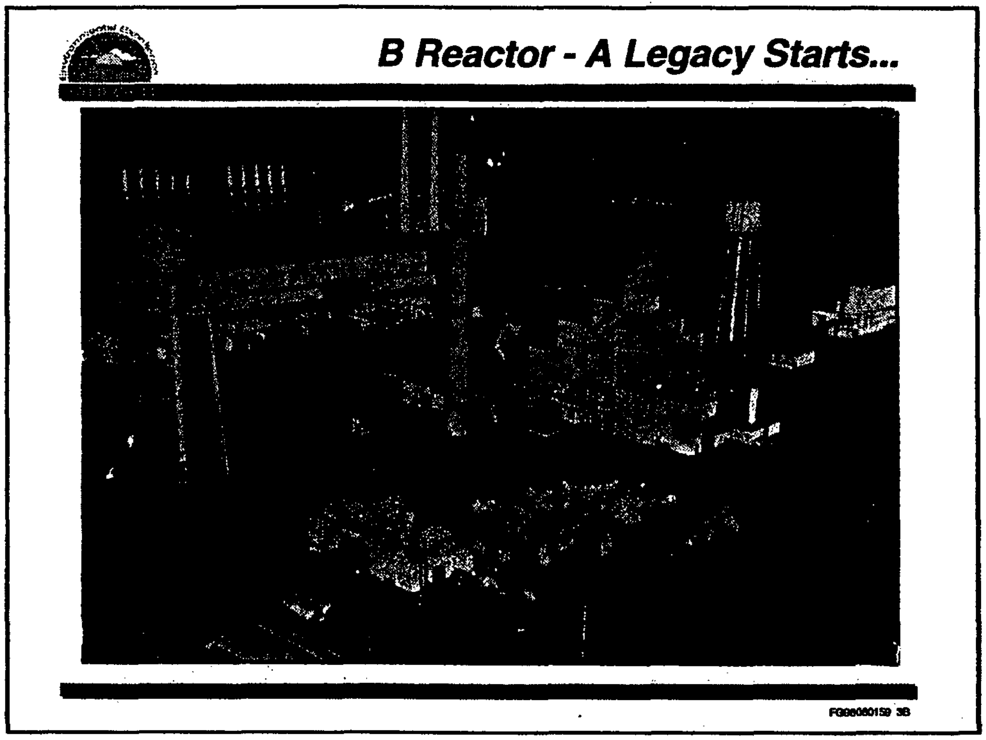


HANFORD

Progress and Challenges in Cleaning Up Hanford

FG96060159 2B

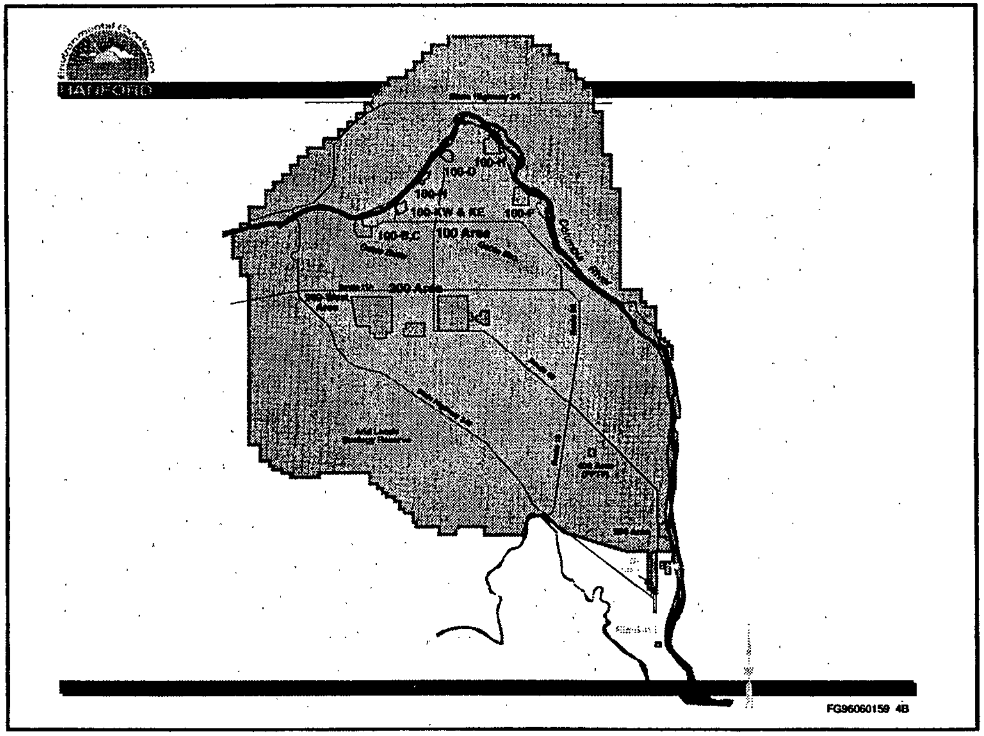
Hanford was established in secrecy during the Second World War to produce plutonium for America's nuclear weapons. Peak production years were reached in the 1960's when 9 production reactors were in operation at the Site. All weapons material production was halted in the late 1980s and the Site is now engaged in the world's largest environmental cleanup project.



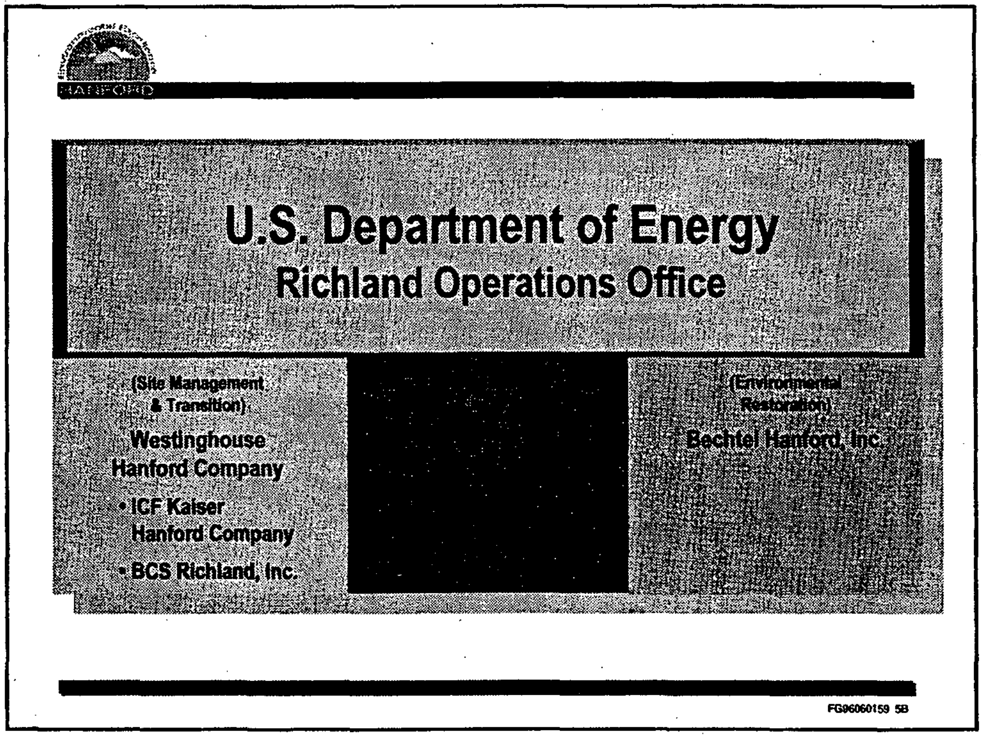
B Reactor - A Legacy Starts...

FG98080159 3B

The famous `B' Reactor along the Columbia River on the Hanford site where plutonium was produced for the Atomic bomb dropped on Nagasaki, Japan. The world's first nuclear reactor, it was constructed and operational within 14 months in 1944.



Approximately half the size of the state of Rhode Island, the 560 square mile Hanford Nuclear Reservation played a key role in bringing World War II to a close. In decades to follow through 1989, during the Cold War, Hanford produced most of the nation's plutonium for defense purposes. The year 1989 marked a turning point in the Hanford's mission from defense production to environmental cleanup.



U.S. Department of Energy

Richland Operations Office

(Site Management & Transition)

Westinghouse Hanford Company

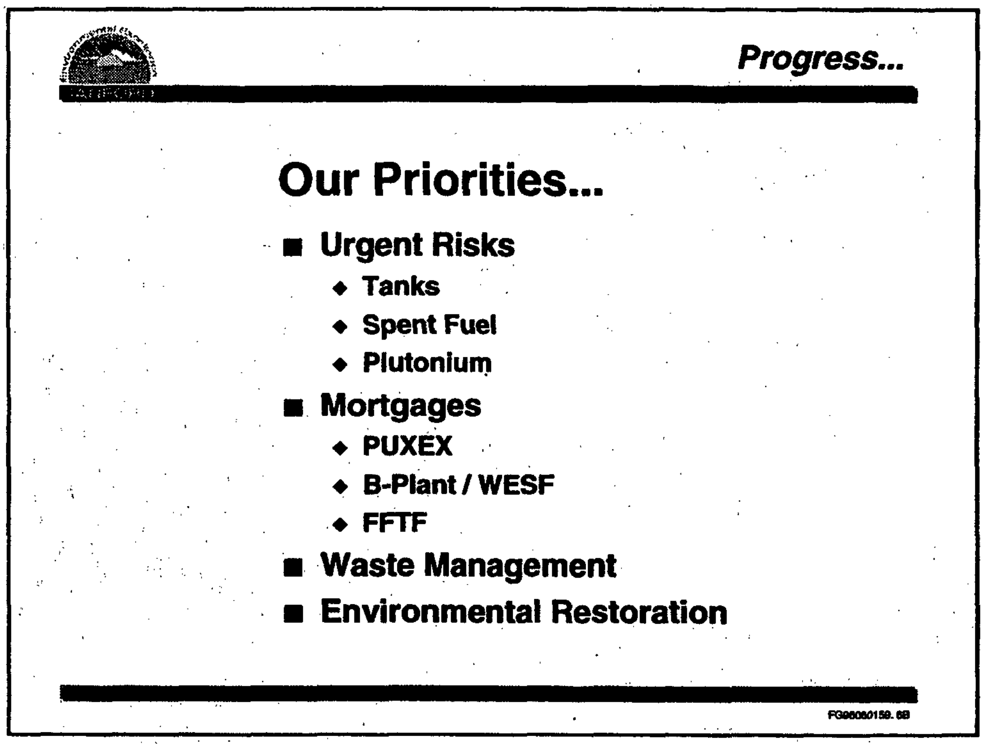
- ICF Kaiser Hanford Company
- BCS Richland, Inc.

(Environmental Restoration)

Bechtel Hanford, Inc.

FG96060159 5B

Today our cleanup challenge is managed by Westinghouse Hanford Corporation and its subcontractors. A site wide environmental restoration project is managed separately by Bechtel Hanford, Inc. Supporting both Westinghouse and Bechtel, as well as DOE nationwide programs, is the Pacific Northwest National Laboratory with scientific research and technology development.



Progress...

Our Priorities...

- Urgent Risks
    - Tanks
    - Spent Fuel
    - Plutonium
- Mortgages
    - PUXEX
    - B-Plant / WESF
    - FFTF
- Waste Management
- Environmental Restoration

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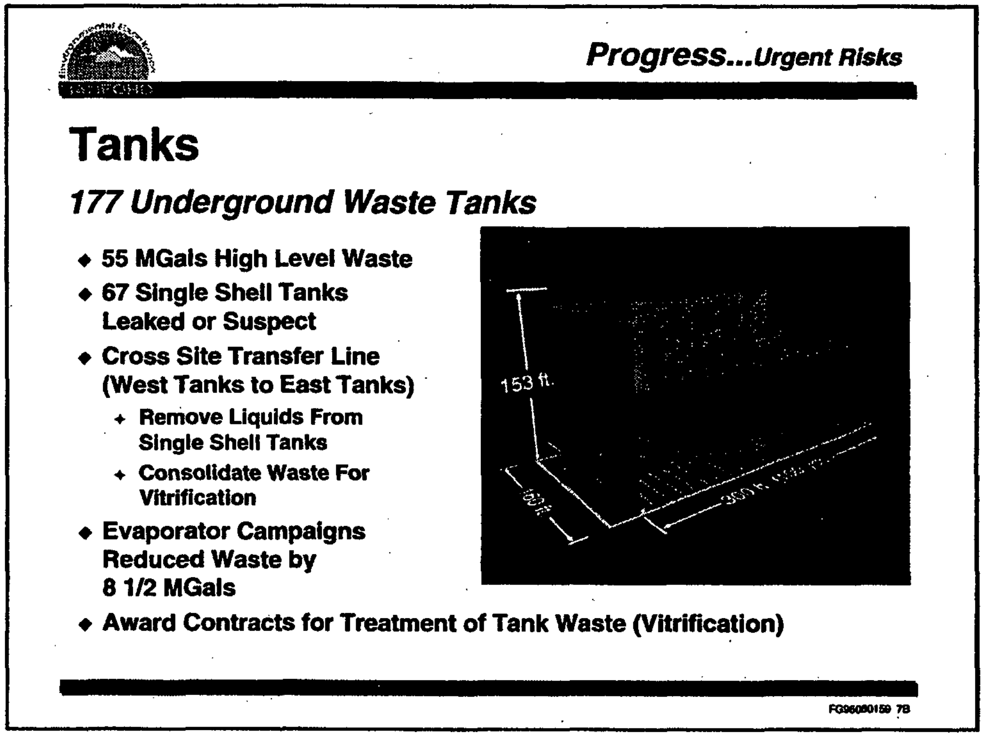
The U.S. Department of Energy and its contractors have tackled the environmental cleanup challenge within the framework of set priorities.



Progress...Urgent Risks

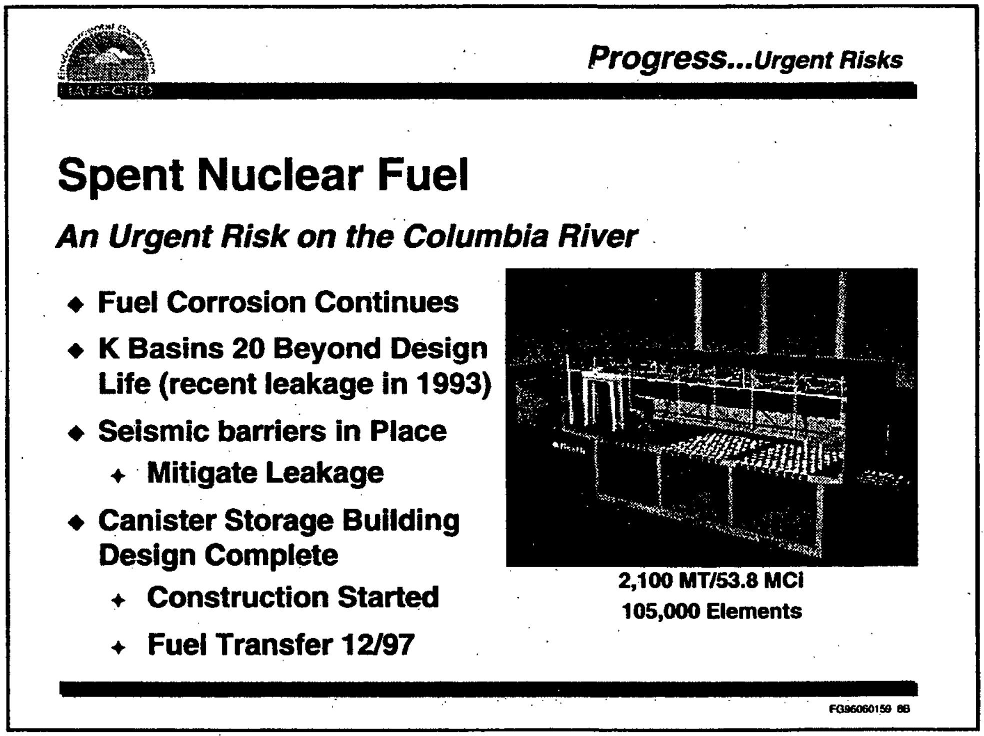
Tanks

177 Underground Waste Tanks

- **55 MGals High Level Waste**
- **67 Single Shell Tanks Leaked or Suspect**
- **Cross Site Transfer Line (West Tanks to East Tanks)**
  - **Remove Liquids From Single Shell Tanks**
  - **Consolidate Waste For Vitrification**
- **Evaporator Campaigns Reduced Waste by 8 1/2 MGals**
- **Award Contracts for Treatment of Tank Waste (Vitrification)**

Formidable challenges in our underground waste storage tanks cleanup effort are being met with innovative approaches and technology. With the construction of a cross-site transfer line we will be able to remove liquids from tanks known to leak to more reliable double-shell tanks.

Additionally, our `Evaporator Campaigns' have freed-up additional space to receive waste, thereby saving $600 million in otherwise needed new tank construction. Since 1994 eight million gallons of liquids have been evaporated.



Progress...Urgent Risks

Spent Nuclear Fuel

An Urgent Risk on the Columbia River

- **Fuel Corrosion Continues**
- **K Basins 20 Beyond Design Life (recent leakage in 1993)**
- **Seismic barriers in Place**
  - **Mitigate Leakage**
- **Canister Storage Building Design Complete**
  - **Construction Started**
  - **Fuel Transfer 12/97**

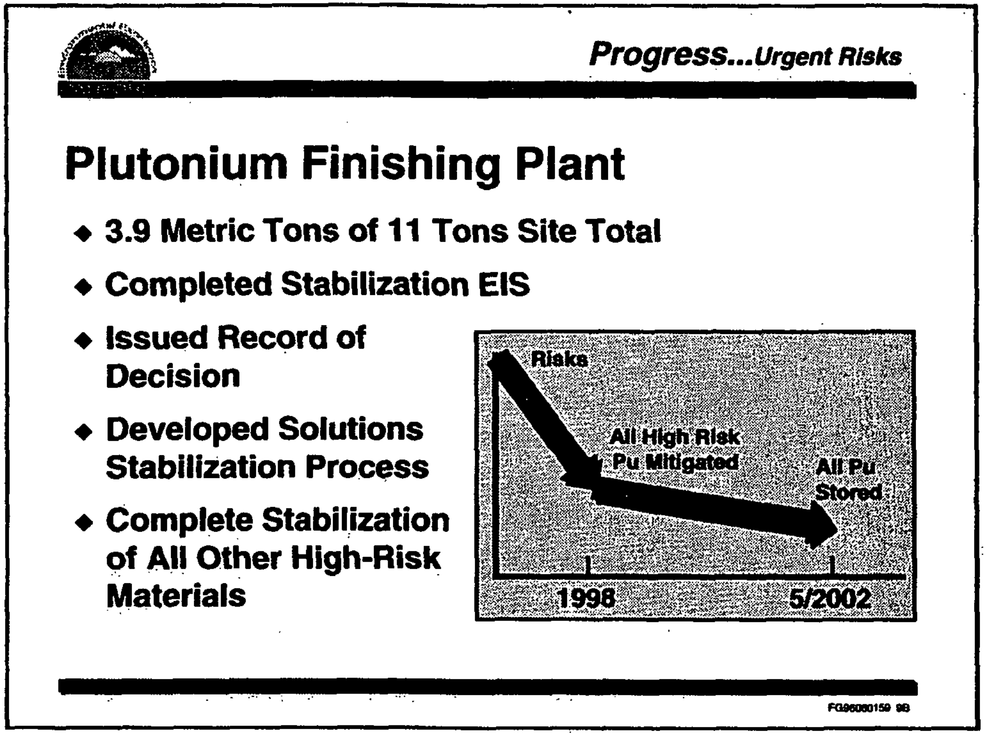
2,100 MT/53.8 MCi
105,000 Elements

FG96060159 8B

Based in part on advice from our stakeholders, we have identified spent fuel stored in basins near the Columbia River as a priority project to reduce urgent risks at Hanford. The basins in which the 2100 tons of spent fuel reside are 20 beyond their design life and one has a history of leakage of some 15 million gallons.

In a very creative way DOE and its contractors have come up with an accelerated plan to remove the spent fuel from the basins and place it in dry storage on the central plateau. One creative way we were able to speed up the project was by using an existing foundation for a cancelled project for the new Canister Storage Building needed to house the spent fuel rods when they are removed from the basins.

Meanwhile we have mitigated the leakage problem with the installation of seismic barriers.



Progress...Urgent Risks

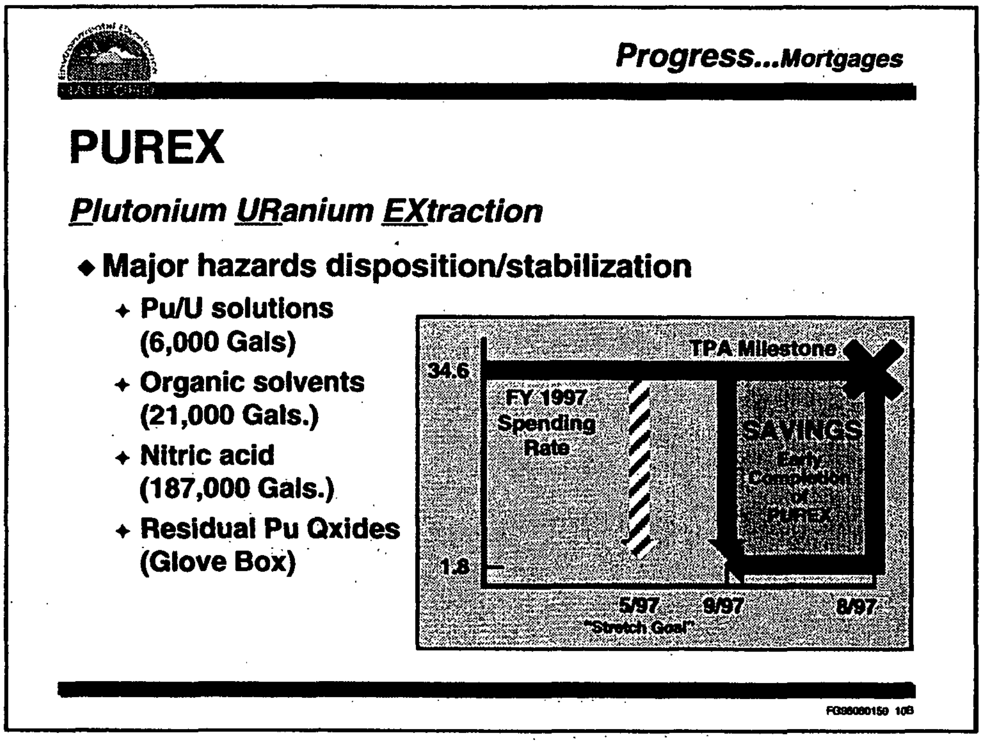
Plutonium Finishing Plant

- 3.9 Metric Tons of 11 Tons Site Total
- Completed Stabilization EIS
- Issued Record of Decision
- Developed Solutions Stabilization Process
- Complete Stabilization of All Other High-Risk Materials

FG96080159 98

We have made significant progress in deactivating this facility. We have completed the plutonium stabilization EIS, issued a Record of Decision, and began a stabilization campaign for all high-risk materials in the facility which will stabilize liquids in FY98 and all material by 2002.

This puts us in a position to mitigate plutonium risks at PFP in 1998 and have all plutonium stored by 2002.



Progress...Mortgages

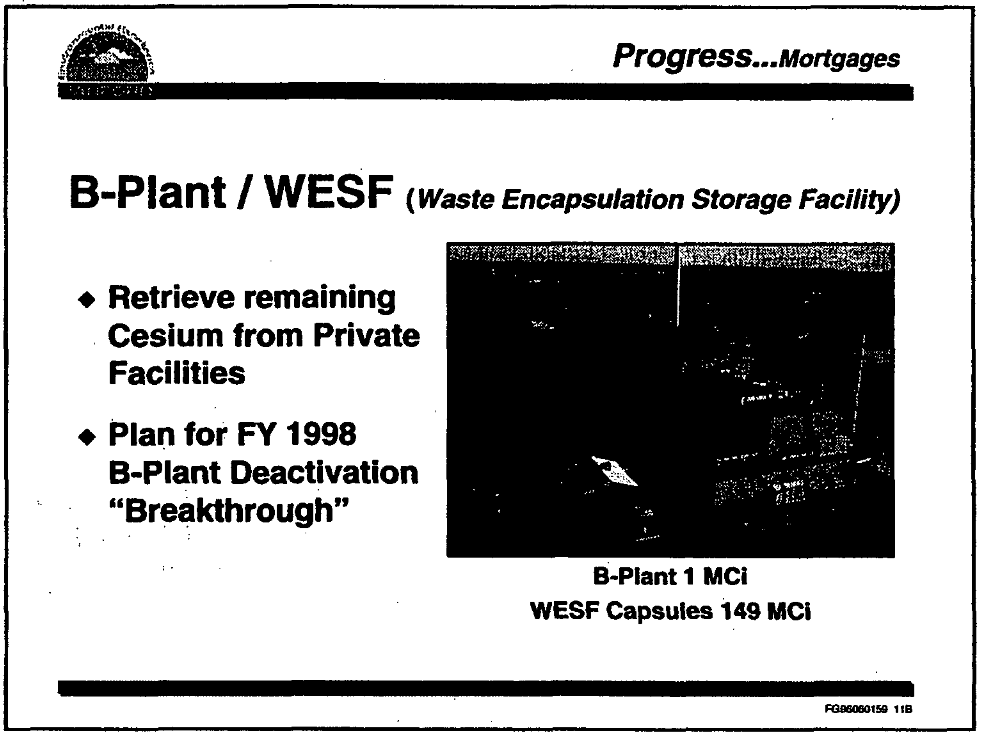
PUREX

***P**lutonium **UR**anium **EX**traction*

- **Major hazards disposition/stabilization**
  - **Pu/U solutions (6,000 Gals)**
  - **Organic solvents (21,000 Gals.)**
  - **Nitric acid (187,000 Gals.)**
  - **Residual Pu Oxides (Glove Box)**

FG96060159 10B

At PUREX we have successfully removed major hazards from the facility in preparation for proceeding with final decontamination and decommissioning. Among the materials dispositioned are: 6,000 gallons of plutonium/uranium solutions; 21,000 gallons of organic solvents, 187,000 gallons of slightly contaminated nitric acid; and residual plutonium oxides from glove boxes.



Progress...Mortgages

B-Plant / WESF (*Waste Encapsulation Storage Facility)*

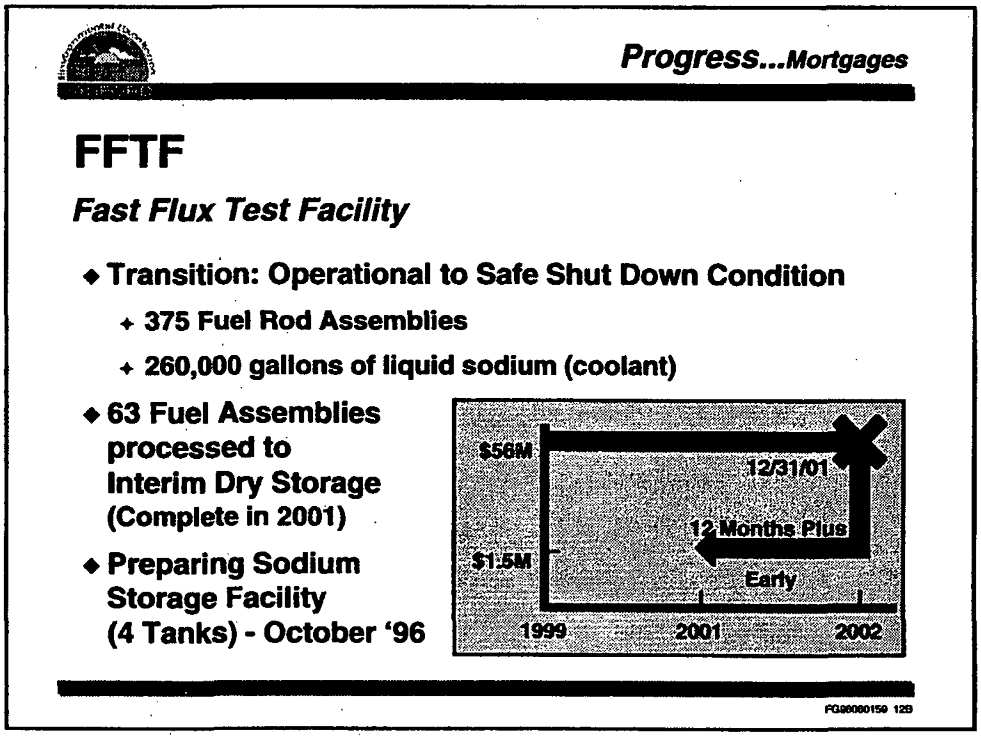
- **Retrieve remaining Cesium from Private Facilities**
- **Plan for FY 1998 B-Plant Deactivation "Breakthrough"**

B-Plant 1 MCi
WESF Capsules 149 MCi

FG96060159 11B

We successfully recovered 25 cesium capsules from a commercial facility in Virginia thus completing the recall of more than 700 capsules which had been leased to commercial companies.

Work on decoupling WESF and B-Plant continued at an aggressive pace and we are poised for a "breakthrough" in B-Plant Deactivation in FY 1998.



Progress...Mortgages

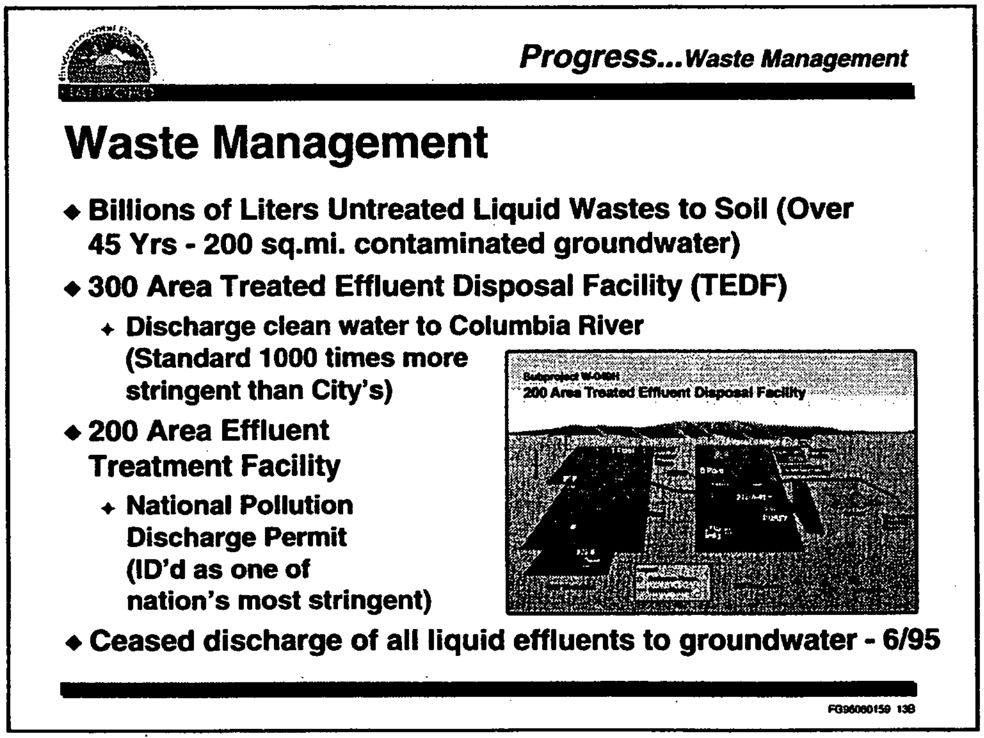
FFTF

Fast Flux Test Facility

- Transition: Operational to Safe Shut Down Condition
  - 375 Fuel Rod Assemblies
  - 260,000 gallons of liquid sodium (coolant)
- 63 Fuel Assemblies processed to Interim Dry Storage (Complete in 2001)
- Preparing Sodium Storage Facility (4 Tanks) - October '96

FG96080159 12B

The FFTF continues to be transitioned to a safe shutdown condition in preparation for final decommissioning and decontamination. Work that is not irreversible, such as fuel washing, continues as we await the Secretary of Energy's decision as to whether of not FFTF will be considered as a tritium producer.



Progress...Waste Management

Waste Management

- Billions of Liters Untreated Liquid Wastes to Soil (Over 45 Yrs - 200 sq.mi. contaminated groundwater)
- 300 Area Treated Effluent Disposal Facility (TEDF)
  - Discharge clean water to Columbia River (Standard 1000 times more stringent than City's)
- 200 Area Effluent Treatment Facility
  - National Pollution Discharge Permit (ID'd as one of nation's most stringent)
- Ceased discharge of all liquid effluents to groundwater - 6/95

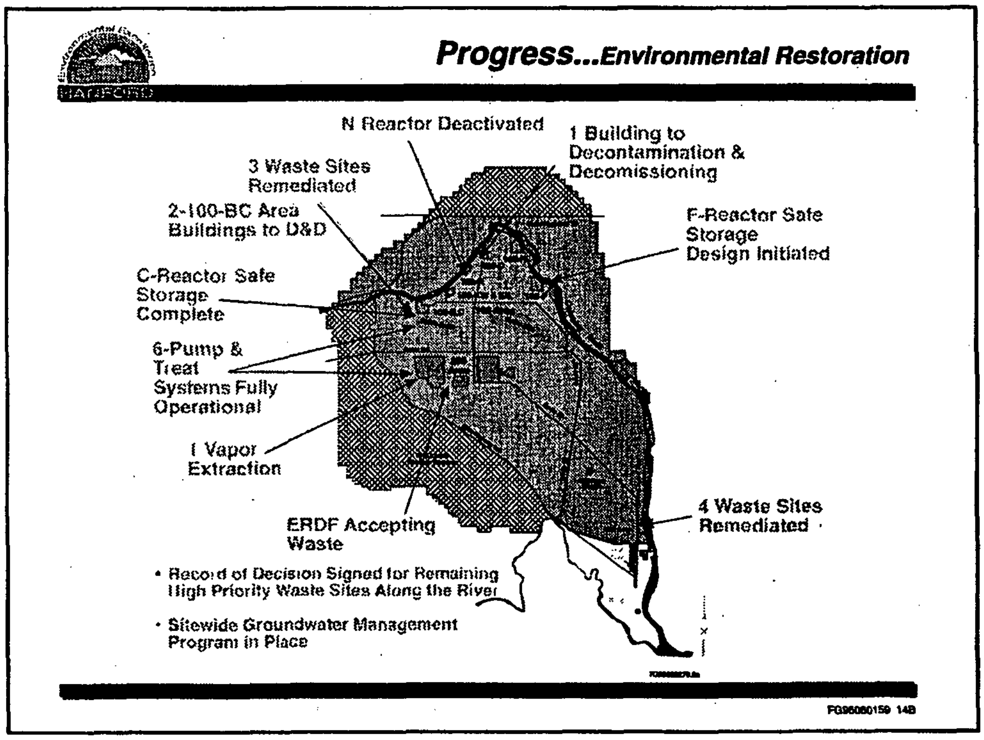
FG96060159 13B

Exceptional progress has been achieved in the treatment of liquid effluents at Hanford. We brought on line the 300 Area Treated Effluent Disposal Facility and 200 Area Effluent Treatment Facility.

We ceased all unpermitted discharge of effluents to groundwater in June, 1995.

Our discharges to the Columbia River from the 300 Area meet standards 1,000 times more stringent than city requirements.

Our National Pollution Discharge Permit is one of the most stringent in the nation.



Progress...Environmental Restoration

N Reactor Deactivated

1 Building to Decontamination & Decomissioning

3 Waste Sites Remediated

2-100-BC Area Buildings to D&D

F-Reactor Safe Storage Design Initiated

C-Reactor Safe Storage Complete

6-Pump & Treat Systems Fully Operational

1 Vapor Extraction

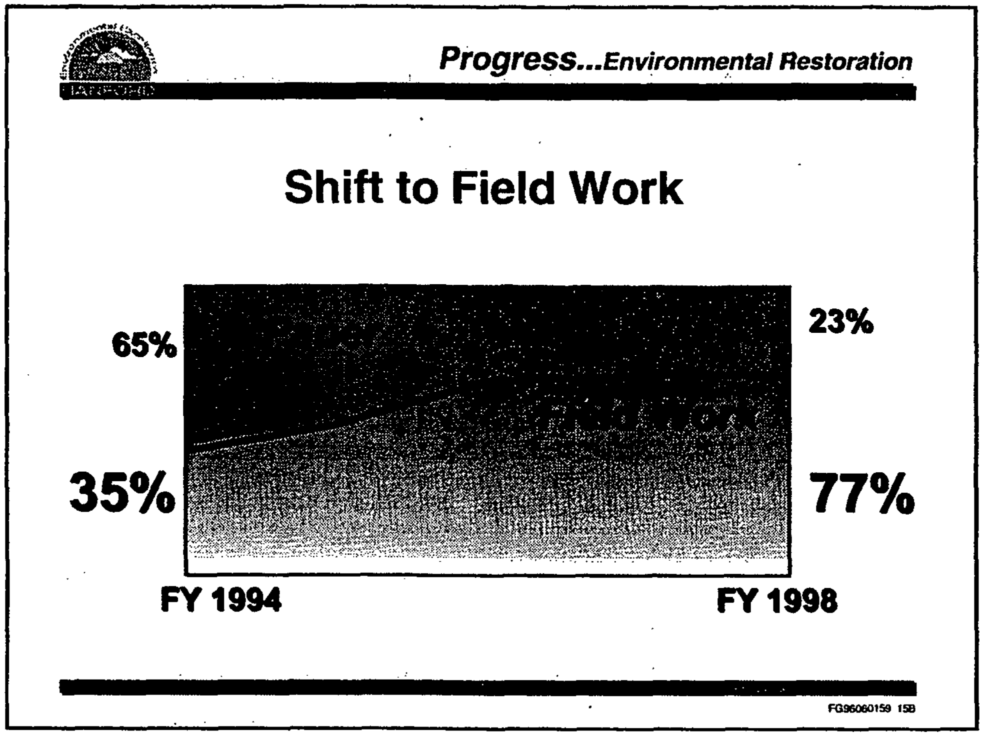
ERDF Accepting Waste

4 Waste Sites Remediated

- Record of Decision Signed for Remaining High Priority Waste Sites Along the River
- Sitewide Groundwater Management Program in Place

FG96080159 14B

BHI, our Environmental Restoration contractor, is responsible for cleanup of groundwater, contaminated soils, and inactive nuclear facilities. A major focus of the ER program is protecting the Columbia River by cleaning up contamination along a 20-mile stretch of land along the river where nine nuclear reactors are located.

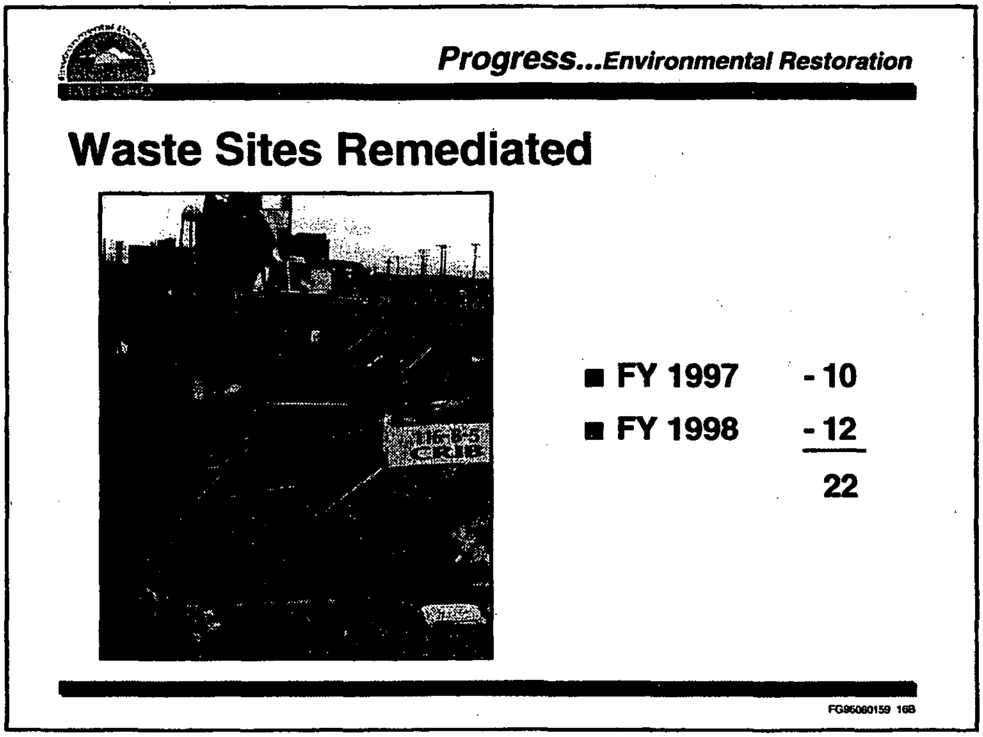


Progress...Environmental Restoration

Shift to Field Work

FG96060159 15B

Since the start of ER cleanup activities in July, 1994, cleanup dollars expenditures have shifted from 65% paperwork to 77% actual field work.



Progress...Environmental Restoration

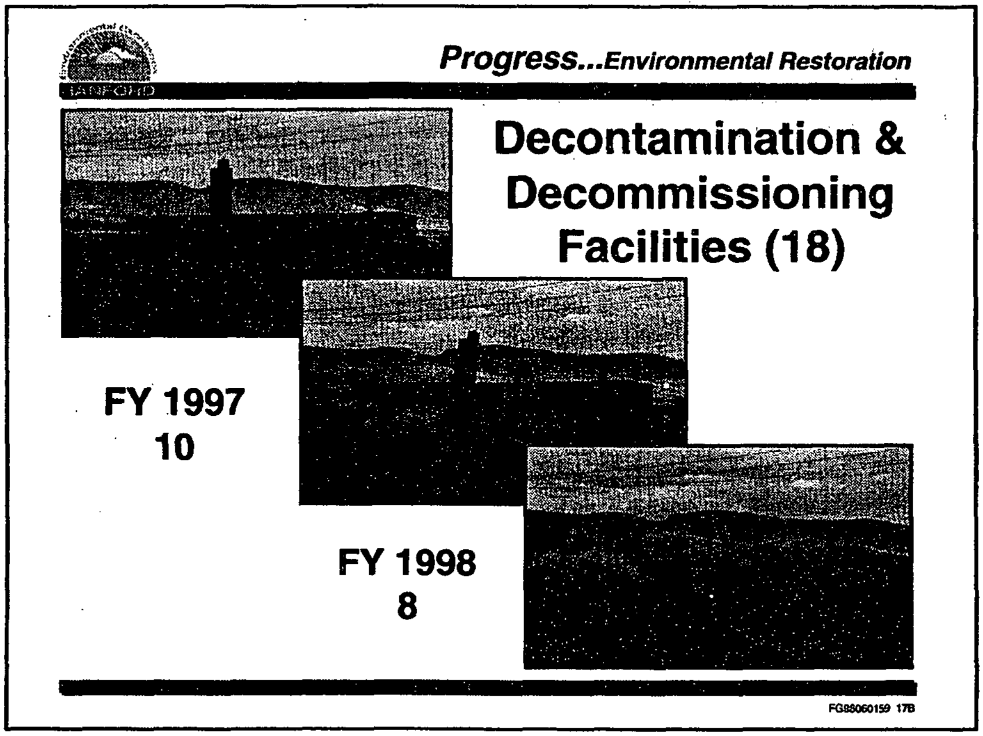
Waste Sites Remediated

- FY 1997 - 10
- FY 1998 - 12

22

FG96060159 16B

And with more dollars spent on cleanup, we see an increase in progress of actual waste sites remediated. Uncovered cribs and trenches and other waste sites along the Columbia River have produced 37,000 tons of contaminated soils and materials.



Progress...Environmental Restoration

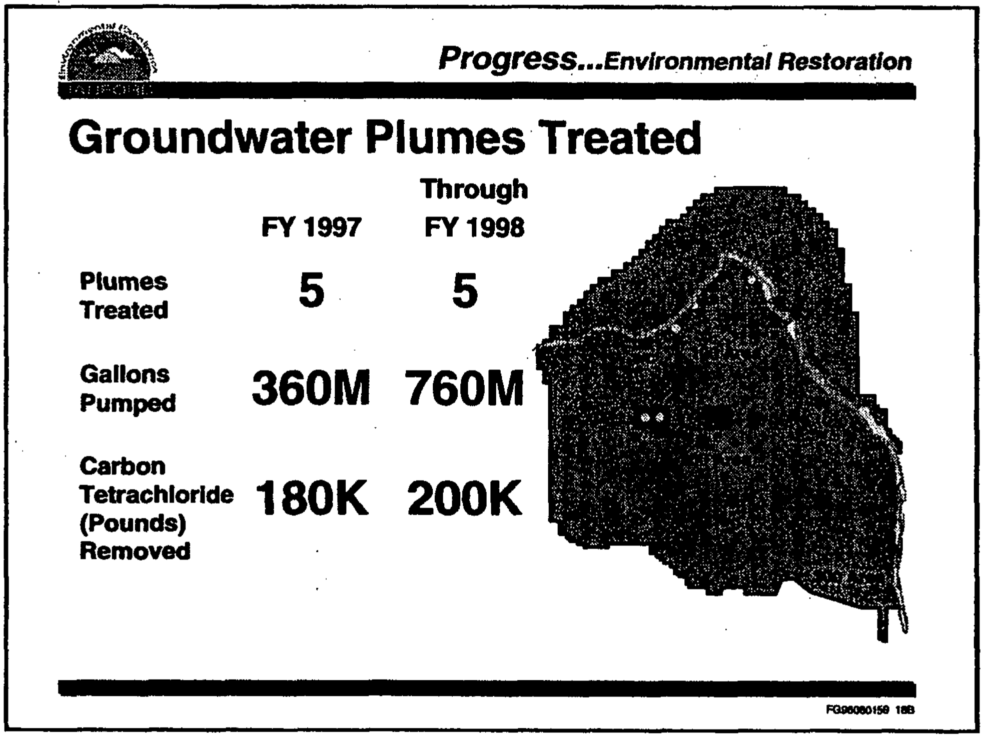
Decontamination & Decommissioning Facilities (18)

FY 1997
10

FY 1998
8

FG88060159 17B

Removing Hanford's aging surplus nuclear facilities is the ultimate goal of the D & D program. Here we see the demolition of the 190-D Pump House remaining framework after decontamination.



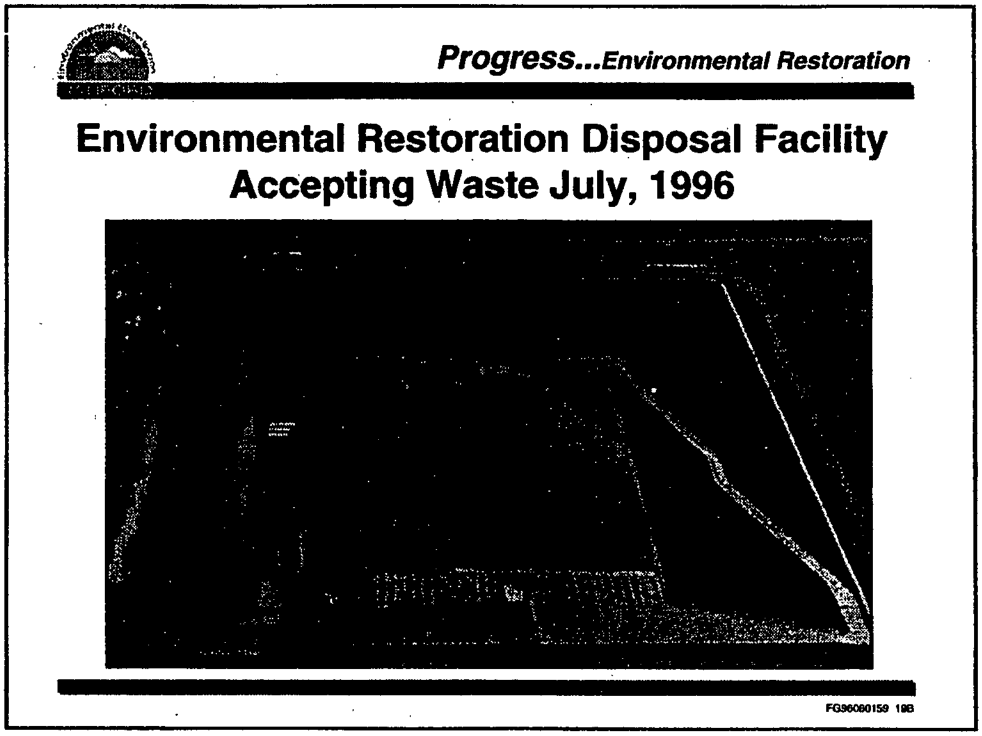
Progress...Environmental Restoration

Groundwater Plumes Treated

	FY 1997	Through FY 1998
Plumes Treated	5	5
Gallons Pumped	360M	760M
Carbon Tetrachloride (Pounds) Removed	180K	200K

FG98080159 18B

Containing and preventing the spread of contaminated groundwater, while removing contaminants from aquifers, are major objectives of the ER Groundwater Remediation project. In 1996 the project pumped and treated 83 million gallons of groundwater and removed 159,000 lbs. Of carbon tetrachloride by vapor extraction.

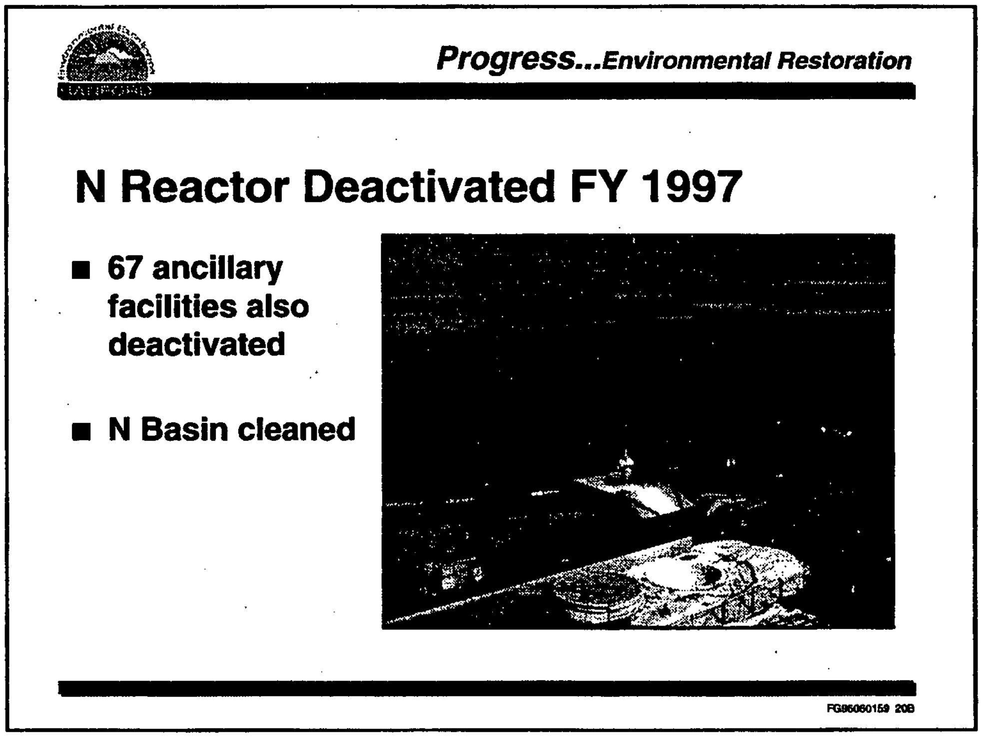


Progress...Environmental Restoration

Environmental Restoration Disposal Facility Accepting Waste July, 1996

FG96080159 19B

Designed to receive low level waste from site cleanup projects, ERDF is operating 3 months ahead of schedule and roughly $80 million under budget. These first two `cells' of a possible 12 can safely hold 1.2 million cubic yards of material, equivalent in size to 95 Goodyear blimps.



Progress...Environmental Restoration

N Reactor Deactivated FY 1997

- **67 ancillary facilities also deactivated**
- **N Basin cleaned**

FG96060159 208

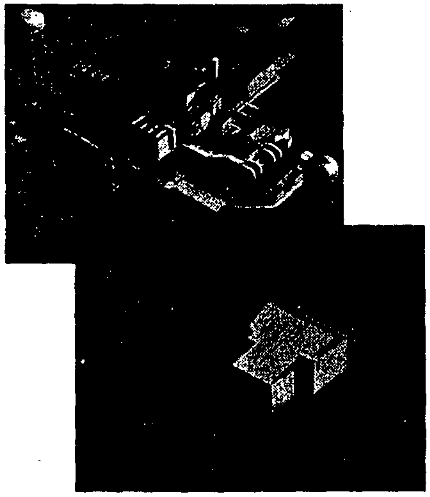
Deactivation of the 'N' Reactor and its supporting facilities is in the DOE spotlight. This effort presents a challenge as to how similar work will be conducted at other DOE weapons sites.

HANFORD

Progress...Environmental Restoration

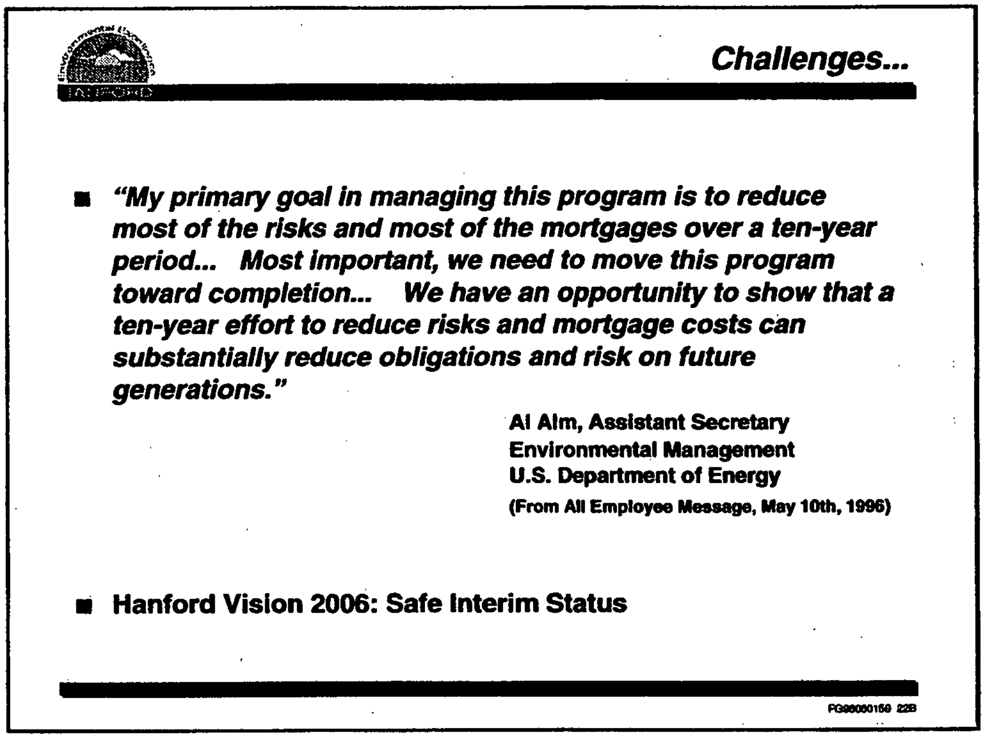
C Reactor Safe Interim Storage FY 1998

- **Long Term Safe Storage**
  - **Low Risk**
  - **No Maintenance**
- **Demonstration Platform for Technology Transfer**



FG98060159 21B

Placing the `C' Reactor's core in an Interim Safe Storage mode for up to 75 years, pending final disposition, is a DOE pilot project that will demonstrate 19 technologies in the process. The concept and successfully demonstrated technologies may be duplicated at other sites.



Challenges...

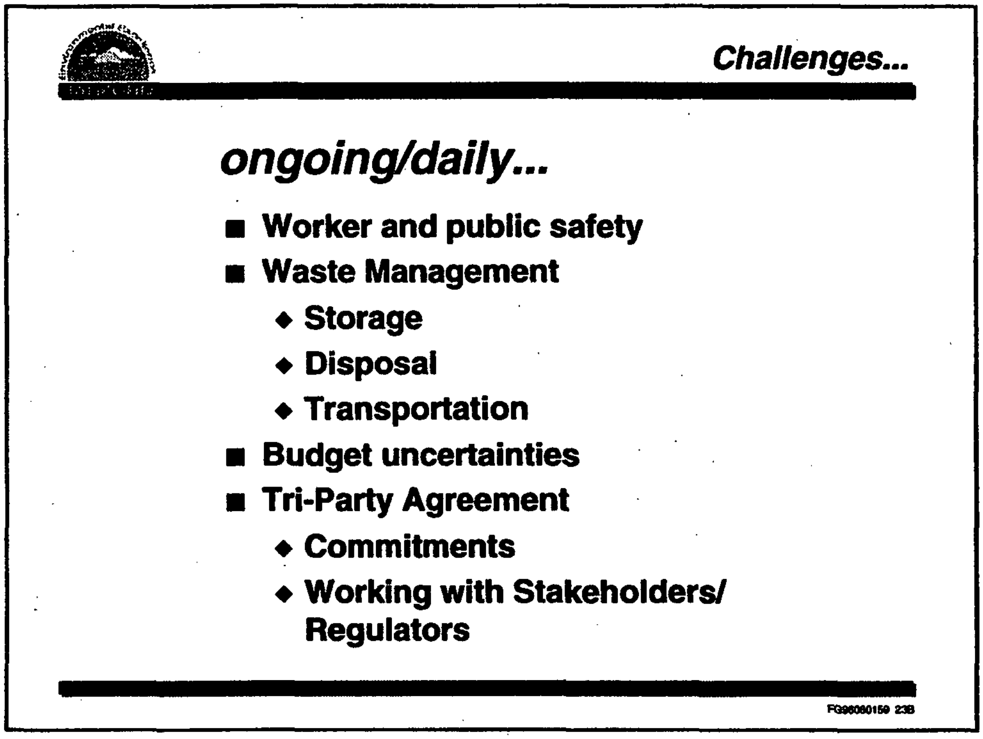
- ***"My primary goal in managing this program is to reduce most of the risks and most of the mortgages over a ten-year period... Most important, we need to move this program toward completion... We have an opportunity to show that a ten-year effort to reduce risks and mortgage costs can substantially reduce obligations and risk on future generations."***

Al Alm, Assistant Secretary
Environmental Management
U.S. Department of Energy
(From All Employee Message, May 10th, 1996)

- **Hanford Vision 2006: Safe Interim Status**

FG96060158 22B

Mr. Al Alm, our new Assistant Secretary for Environmental Management, has presented a challenge to all DOE sites. Within the next 10 years, a majority of cleanup projects throughout the DOE complex is to be completed. D & D, soil remediation, and groundwater cleanup are targeted categories for this deadline.



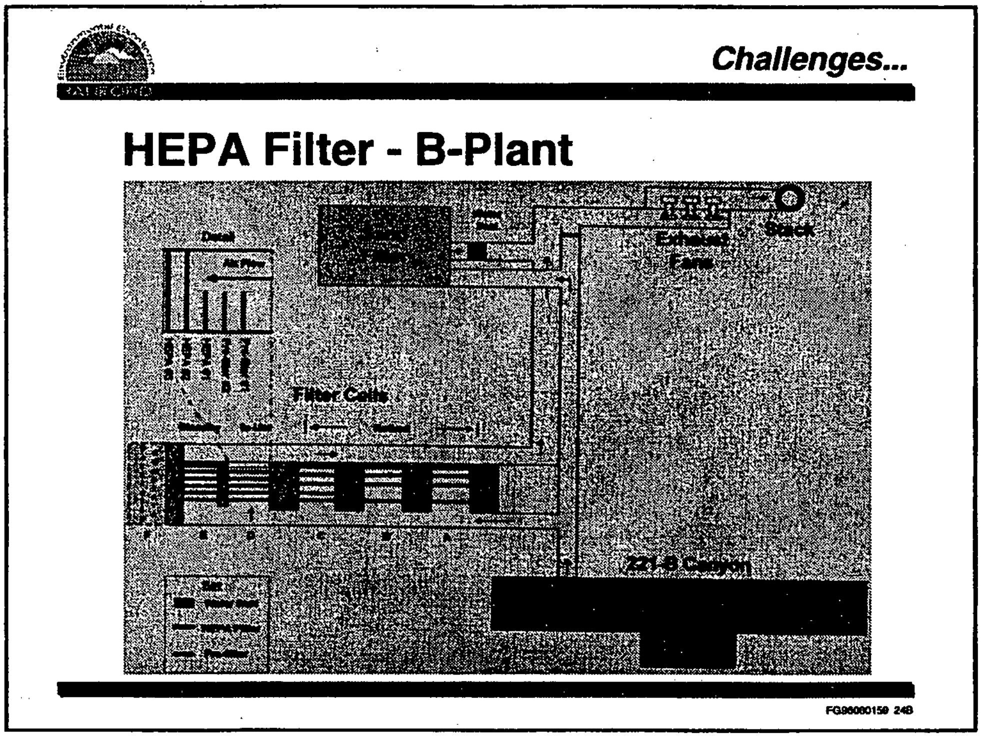
Challenges...

ongoing/daily...

- **Worker and public safety**
- **Waste Management**
  - **Storage**
  - **Disposal**
  - **Transportation**
- **Budget uncertainties**
- **Tri-Party Agreement**
  - **Commitments**
  - **Working with Stakeholders/ Regulators**

FG96080159 23B

Of prime concern in meeting that challenge is the safety of the workers and the public. Cleanup operations must be conducted in a manner that eliminates or minimizes risk to our workforce and the community. Companion to that ongoing challenge is the transportation, storage, and disposition of waste, dealing with varying budgets, and meeting our obligations to regulators and stakeholders.

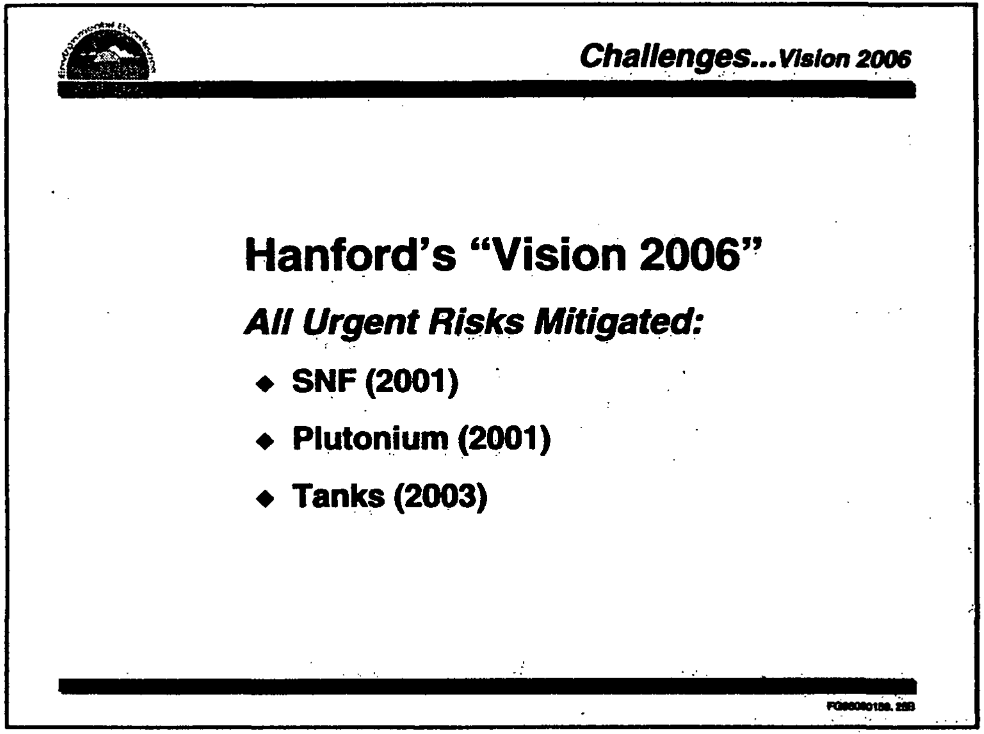


Challenges...

HEPA Filter - B-Plant

FG96060159 24B

As an example of our worker safety focus, we currently are using the main HEPA Filter System to remove any radionuclides from the air in facilities. Currently, a new HEPA system is being designed with a target installation of September, 1998.



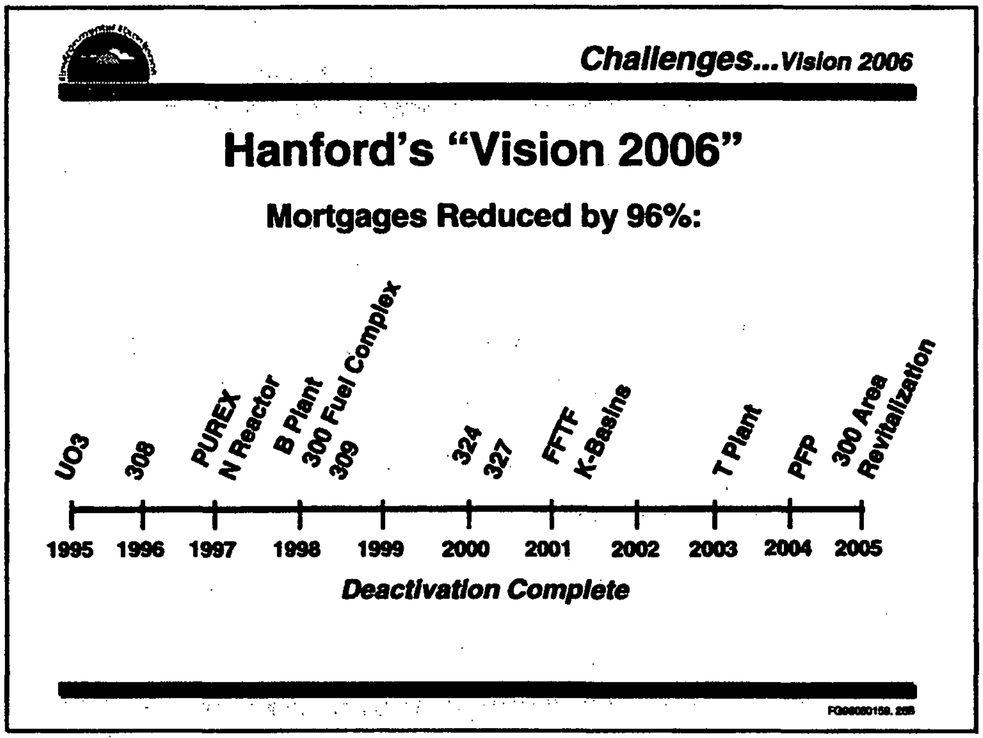
Challenges...Vision 2006

Hanford's "Vision 2006"

All Urgent Risks Mitigated:

- **SNF (2001)**
- **Plutonium (2001)**
- **Tanks (2003)**

Our answer to Mr. Alm's challenge is Hanford's "Vision 2006". Within the first three years of the plan all urgent risks will be mitigated...



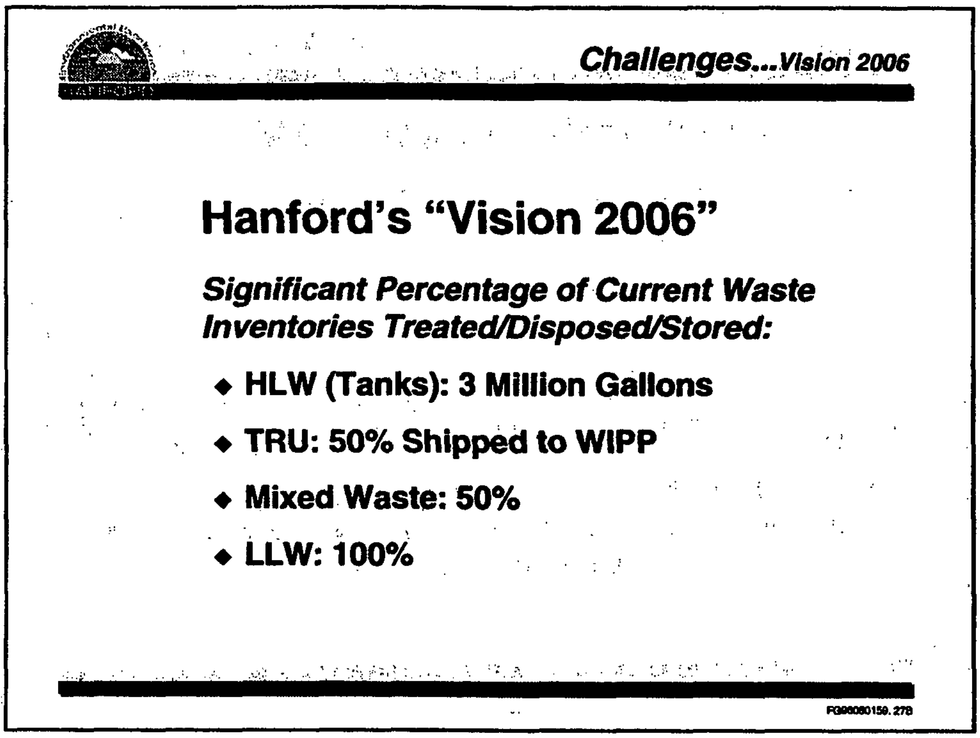
Challenges...Vision 2006

Hanford's "Vision 2006"

Mortgages Reduced by 96%:

Deactivation Complete

... our mortgages on major facilities will be reduced by 96%, and ...



Challenges...Vision 2006

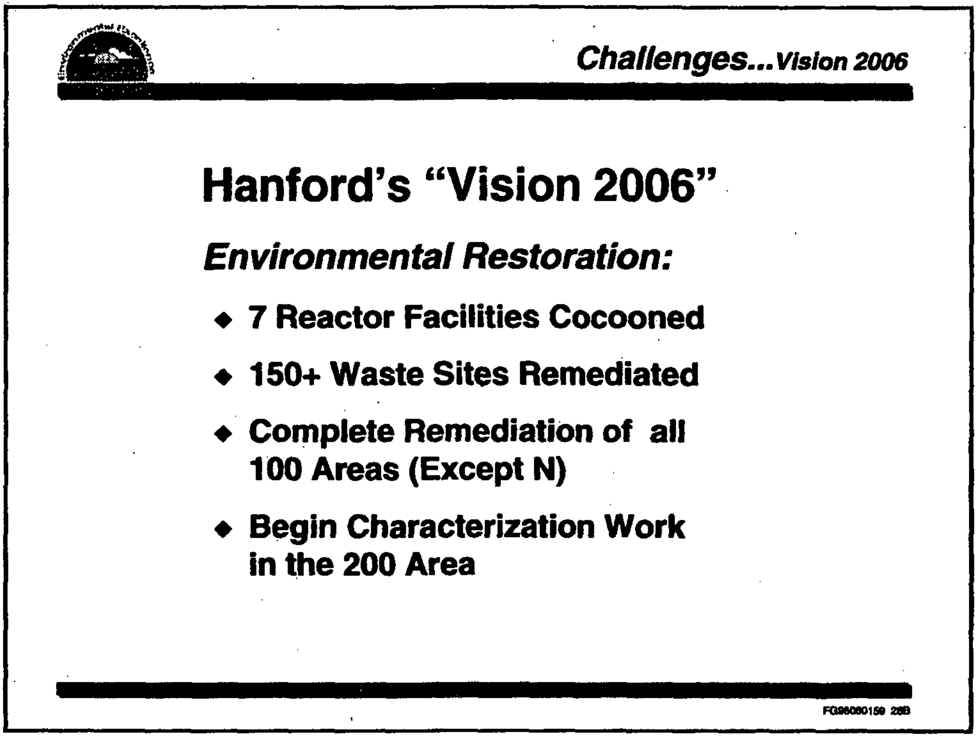
Hanford's "Vision 2006"

Significant Percentage of Current Waste Inventories Treated/Disposed/Stored:

- **HLW (Tanks): 3 Million Gallons**
- **TRU: 50% Shipped to WIPP**
- **Mixed Waste: 50%**
- **LLW: 100%**

FG96080159.278

... significant impact will be made on our current waste inventories.



Challenges...Vision 2006

Hanford's "Vision 2006"

Environmental Restoration:

- **7 Reactor Facilities Cocooned**
- **150+ Waste Sites Remediated**
- **Complete Remediation of all 100 Areas (Except N)**
- **Begin Characterization Work in the 200 Area**

FG98080159 28B

Our ER efforts will have placed 7 reactors in Interim Safe Storage and remediated more than 150 waste sites.

Questions

Environmental Excellence

HANFORD

and Answers

As we have seen, our past progress is notable, but our future challenge is just as noteworthy. I am very confident that our excellent contractors workforce will not only meet the challenge over the next ten years, but will exceed expectations in the process.

DISCUSSION

FIRST: Mr. Wagoner, I've heard all kinds of numbers for when this clean up is going to take place and how much it's going to cost. I recall about five years ago we had thirty years and thirty billion. And then it went up to fifty years and a hundred billion. And now I just heard ten years, but I didn't hear how many billions. But it would be, I'm sure, of interest for us to know how firm the ten year commitment is, and some idea of what the financial implications are.

WAGONER: For Hanford we have requested for the 1997 budget year just under one point four billion dollars. And for fiscal '98, including the financing of the privatized tank waste contracts, that would be a little over one point five billion. So it would run in that range between one and one point five billion per year, between now and 2006.

WEBER: I am curious to know what is the magnitude of the TRU waste, which is in suspense awaiting whether WIPP opens or not. Of that figure, are you able to estimate what proportion of the material has already been drummed?

WAGONER: I should have, but I do not have the figure off the top of my head in terms of the total volume. Most of it is going to have to be repackaged. And for that purpose we built the waste receiving and packaging facility. We are just now completing construction. I think it's essentially complete. And there we will be able to bring the waste in that's retrieved. The TRU waste of Hanford, for the most part, is buried in shallow pits that are retrievable. That will be brought into the facility, it will go through examination, characterization, depending upon what is seen through the non-destructive evaluation. Glove boxes are there to repackage the material and put it into suitable drums, meeting WIPP's acceptance criteria, whenever those get finalized. Bar-coded and then put in a position ready to load for shipment to WIPP. But I do not have the overall figure. If you are interested I can get that for you. On the TRU waste also, in all fairness, it's important to distinguish that we are talking about the so-called retrievable waste, which was placed there after 1970.

BELLAMY: The congressional mandate to complete the DOE/West Valley project would suggest to me that the vitrification of the tank waste that you have proposed, could be done at West Valley at a very significant savings to the taxpayer, if I understood your answer to Dr. First's question properly. Why isn't West Valley being used for that purpose?

WAGONER: I am not sure that the life of the melter at West Valley would be able to handle the Hanford waste. My understanding is that it will have a limited life. It's only got one tank to process, basically, at West Valley. It is the same basic design concept as DWPF, and that melter will have to be replaced periodically. Then you have the issue of transportation, what would be the suitable container for transportation to West Valley. We only need to treat in the high-level waste melter the high level fraction of the waste, so it would suggest you need a pre-treatment facility to separate the high level and low level fractions that would have to be at Hanford anyway. So it's difficult to see that you would find sufficient economy to overcome all those problems to ship it across the country. What we are doing in our approach to privatization is to ask instead for industry to show what they could provide using the technologies that have been previously developed, a lot of it outside of this country. So those are the proposals we are currently evaluating.

SESSION 6

INTERNATIONAL PANEL REPORTS ON NUCLEAR AIR AND GAS CLEANING ACTIVITIES FROM AROUND THE WORLD

Tuesday July 16, 1996
Co-Chairmen: R. Weidler
J.G. Wilhelm

Panel Members: R.R. Bellamy
J. Dyment
T. Fukasawa
R. Lee
R. Porco
J. Slawski
J.G. Wilhelm

PANEL DISCUSSION

INTRODUCTION

WEIDLER: Welcome to the International Panel session. We have a very distinguished panel today. We have Mr. Fukasawa from Hitachi Limited, Mr. Rich Porco from Ellis and Watts, Dr. Ronald Bellamy from the US Nuclear Regulatory Commission. Dr. Juergen Wilhelm, consultant from Germany, Mr. James Slawski, US Department of Energy, Mr. John Dyment, the Atomic Weapons Establishment in the UK, and Dr. Richard Lee from the US Nuclear Regulatory Commission. Each of these gentlemen has something to say, then we will open the floor to questions.

BELLAMY: I have three very brief comments that I would like to make concerning regulatory issues that could be interpreted to have an international flavor. And then Dr. Lee will follow me with some very specific international issues that the regulatory agency is involved in. The first I'd like to mention is an issue that has become of great importance to us over the last year, with our change in chairman. The present chairwoman of the Nuclear Regulatory Commission is a firm believer in verbatim compliance. Whatever the technical specifications or the regulations say, it is the way to do it, and it is the only way to do it. She is not a believer in waivers or exemptions. The present philosophy is that if there is something of such importance that it requires a waiver and exemption, then it must be something that you need to take a look at in the regulation. Maybe the regulation or the actual basis for what you're doing needs to be changed. The second issue has to do with a lot of the work that's been on-going over the past several years with respect to source terms, with respect to changes in the regulatory requirements, and the potential for, I don't want to use the term back-fit, but the potential for modifications to existing filter systems. There's been some discussion on can we remove components, can we remove some HEPA filters, can we remove some activated carbon I'm not going to stand here and give you any of the answers to those questions, but simply to point it out to you that is an issue that will need to be addressed. And perhaps there's some lessons to be learned from some of the international experience that we will be discussing this afternoon. The third and final issue that I will very briefly mention is the topic of one of the open end papers this afternoon, and that has to do with the criteria for laboratory testing of carbon that has been in-place. The Nuclear Regulatory Commission has, contrary to what I started this brief remarks with, has approved some emergency tech spec changes and waivers over the past several months. And Mr. Lyons will be discussing that issue in great detail this afternoon. So perhaps there is some international experience that we can learn and gain from. And we can use that as we move forward in this area.

LEE: Let me tell you something on the international scene, what the agency is doing, plus the emphasis based on the office of research of the NRC. Since the NRC was formed in 1975, after we split from the AEC, the agency has maintained many bi-lateral agreements with European countries, Asian countries, and most recently the so-called former Eastern European Countries, in cooperative research. And I think there are some areas that will be of interest to the participants of this conference, in the area of aerosol treatment (*i.e.*, before you can treat it you need to know more about the sources and so forth). And I think after the TMI accident in the early 80's, the Office of Research initiated a whole series of bi-lateral agreements with European countries, and Asian countries, in cooperative research and focus on so-called severe accident research. Severe accidents are beyond design-based accidents, and we are dealing in an area where current filters are designed for design base accidents, to handle severe accidents. We know that under severe accident conditions, the aerosol loading on these filters will render them useless. Now, with the revision of the source term, we have not (because the agency is busy addressing other issues) gone back to look at the performance of filters. And I don't know, Ron, whether Region I is looking into it or not. Instead of assuming 95% of gaseous iodine (that filters have to treat), now our new source terms set iodine at 95% aerosol. So this has implications on the operating plants. And as Ron pointed out, the utilities may come in and ask for different things (related to filter performance requirement), and some of the proposals are actually in-house now So we will be discussing with the Office of Nuclear Reactor Regulation, how to deal with these proposals. Now back to the international arena, under the severe accident agreements, we have been doing a lot of research with Japan, basically with JAERI, the Japan Atomic Energy Research Institute. It started with thermal-hydraulics cooperative research, basically looking at design base loss-of-coolant accidents; now we have extended it into severe accident research. In the severe accident research area, we also have joint agreement with NUPEC, another research organization in Japan, which we deal directly with on hydrogen issues. On hydrogen issues, we are basically dealing with failing the containment very early, very quickly, and not necessarily looking into what the hydrogen burn would do to the aerosols. In Germany, of course, we have a lot of cooperative research agreement with KfK, which now has been renamed as FZK. We also deal with GRS, *etc.* In the late 80's, we started to cooperate with France. That was the first time the agency started to cooperate with France, basically with the CEA (the French Atomic Energy Commission) And I want to point out that there is a lot of activity now going on in France in the source term area (such as aerosol research in the Grenoble research center). The one major project that the agency is tracking now is the PHEBUS-FP project, located in the Cadarache Nuclear Center in the south of France. In '93, they ran the first test, using fresh fuel. In that test, initially the test results showed that 10% of the iodine coming out was gaseous iodine. That caused concern to us, because at that time a Commission paper was pending to revise the source term and we said 5% (gaseous iodine) was the maximum. The preliminary results turned out to be not true, because the initial measurement has error and it is somewhere between two and less than ten percentage gaseous iodine. The next test is going to be run some time this month, actually within a week. And that test is going to be using spent fuel from the BR3 Belgium reactor; fuel is three feet long, and there are about twenty-one rods (one control rod and twenty fuel rods). Of course, if the test doesn't run by July, it will start to conflict with the vacation schedules so it will be postponed until September. I have to tell you that Korea is launching a very ambitious program for the next ten years, spending close to a billion dollars in research to get itself in a position to compete with Japan and the US in future reactors. And the research they started ranges from thermal-hydraulics to severe accidents. So there are a lot of activities going on internationally. I think some of the results from these activities should be of interest to this conference. The agency is also faced with a very important decision, that is on the maintenance of expertise. There's a lot of dialogue now, not just within the US, but with the Europeans, concerning how we can maintain expertise. Another reason we have all these cooperative research agreements is because the budgets are decreasing, so we need to share the research knowledge. And this expertise maintenance is directly related to how we're going to fund, what type of program we will fund in different national laboratories, and what scientists we need to maintain in case there is an accident in a plant, and we need to call upon these people to address the problem. With these remarks, I would like to turn the podium back to the Chairman.

DYMENT: I'm going to try, in the space of 10 minutes to give you a very quick overview of the British Nuclear Industry, where it's come from and where it's going, as a background to the air cleaning problems. In trying to do this I feel a bit like the man on the radio who does a Shakespeare play in 30 seconds.

WORLD SCENE:
This micro-history slide of UK and world nuclear power (from the Nuclear Engineering Handbook, 1995) shows the numbers of reactor units commissioned in first power in various countries during the four decades starting 1956/65. As you see the UK was virtually the sole player in the first decade with around 20 units. In the second decade the rest of the world commissioned over 100 while the UK dropped back to 6. In step with the rest of the world, the UK increased again (second generation reactors) in the 76/85 decade to 10 or so units and dropped back again in the last 10 years.

UK SCENE:
The current UK situation is that 10% of inland energy consumed comes from nuclear power, and 25% of electrical energy generated is nuclear. The generating plant consists of 8 Magnox stations (uranium metal fuel clad in alloy), 7 AGR stations (e/uranium oxide fuel clad in stainless steel), both types with carbon dioxide coolant. Finally, we have 1 PWR station. Reprocessing of these various fuels takes place largely at the Sellafield sites of British Nuclear Fuels. Some reprocessing also takes place at the Dounreay site of AEA. A "drystore" option for the long-term storage of spent fuel has been considered as an alternative to reprocessing.

DECOMMISSIONING:
Various strategies for decommissioning obsolete generating stations are under discussion; the issues centre largely on the (duration of the) delay before dismantling and the safe encapsulation of the installation meanwhile. Decommissioning of redundant nuclear facilities other than power reactors is well advanced within several organizations, *e.g.* decommissioning of the Capenhurst diffusion enrichment plant is complete and the bulk of the metals has been recycled.

WASTE:
Low level nuclear waste is currently disposed of at the Drigg repository, operated by BNFL. Intermediate level waste is currently stored at the sites where it is generated, pending construction of a deep disposal facility by NIREX, the Nuclear Industry Radioactive Waste Executive. The commissioning date for this facility is still some 15 years away. High level waste is currently stored on the site of origin pending vitrification which is in progress.

PROGRESS TOWARDS DISPOSAL:
NIREX is investigating the hydro geological characteristics of a proposed disposal site near Sellafield by means of a "Rock Characterization Facility" (RCF) which is currently being designed. Authority to proceed with construction has not yet been obtained.

NUCLEAR AIR CLEANING:
Many or most UK nuclear air cleaning installations employ HEPA filters. The majority of these use the square deep-pleat format mounted in bag-change housings. There are some plenum chamber mounted installations but they are perceived to present greater problems at changeout and *in situ* testing. Circular (cylindrical) format HEPA filters are now being used to a large extent in new plants. They have 950litre/sec airflow capacity (>2000CFM) and will fit into a standard waste drum. They are also acknowledged to be much more compatible with remote changeout requirements than square format units. In-place or *in situ* testing of HEPA filters is routine at all nuclear sites.

UK NUCLEAR POLICY:
The UK government has published two documents on nuclear policy in the last year, one relating to nuclear power, the other to nuclear waste. The former, the Nuclear Review, had 3 key conclusions:

Firstly, that nuclear power will continue to play a key role in meeting UK energy needs. Secondly, that public sector intervention in the electricity market is unwarranted. Thirdly, that as many UK Nuclear Stations as practical should be moved to the private sector.

Accordingly, the more modern AGR and PWR stations have now joined the fossil fuel generators in the private sector as "British Energy", with only the older Magnox stations remaining in the public sector as "Magnox Electric".

The key findings of the second policy statement, the Waste Management Review, were as follows:

1. Deep disposal of ILW continues to be Government policy; Nirex should implement plans for the repository without delay.
2. Deep disposal of vitrified HLW is a favored option.
3. A range of potentially acceptable decommissioning strategies is recognised, including "Safestore" concepts.
4. In general, radioactive wastes should not be imported/exported to/from the UK.
5. Waste substitution is an acceptable option provided there is environmental neutrality for the UK.

WEIDLER: Our next speaker Richard Porco from Ellis & Watts, Richard is going to talk about developments in China and Korea.

PORCO: One of the questions that I am asked very often is why do we, on the ASME code committees, work so diligently to develop standards, when in the US we're not working on any new nuclear power plants. We put a lot of effort into our work, and other than the DOE, commercial power plants are mainly working on retrofits or upgrades. The amount of work that goes into the codes and standards seems phenomenal to support that effort. Why we work on the codes that diligently and what we're supporting is a very vibrant commercial nuclear power industry in the Orient. I think most of you are aware of Korea's aggressive nuclear program. The key to Korea, China, and other emerging countries is to develop an infrastructure to support the rapid growth necessary. Parts of that infrastructure would be would be communications, another is the road systems. The main part is energy. This is a slide of Korea's operating plants. They currently have eleven operating plants that generate more than 9,100 megawatts. The first unit Kori Unit was brought online for commercial operation in 1978, and over the period of the next sixteen years, KEPCO brought on ten more reactors with the last one, YGN Unit 4, coming online this year KEPCO also plans on bringing another nine reactors online within the next seven years. At least 6 more are planned, including a reactor for North Korea. This pace seems phenomenal compared to the pace the U.S. built reactors in the 70's and 80's. Korea is actually supporting this effort, and it has helped their economy grow quite rapidly. Other countries that are looking at this rapid growth and trying to imitate Korea are Turkey, Thailand, India, and Pakistan. Japan has always had an aggressive nuclear program, and I think Dr. Fukasawa will also talk about Japan.

I'm going to discuss nuclear energy in the People's Republic of China. Since the 1970's China started to talk to the world about its civilian nuclear power applications. So far, China has three reactors. The 300MWe indigenous pressure water reactor at Quinshan and the two 950MWe French PWRs at Guangdong near Daya Bay supply less than 1% of China's electricity. The successful entry of the three reactors into commercial service in 1994 has stimulated a sense of confidence in nuclear power within China. China's gross national product has increased more than 400% since 1980. Shortages of electricity estimated to average around 20% are blamed on China's new industrial enterprises operating below their potential capacity. To achieve GNP annual growth at the projected rate of 7-10% per year for the rest of the 1990's and the first decade of the twenty-first century, the increase in the electrical production will be required. Right now there are four additional plants under construction in China. Quinshan Units 2 and 3 are under construction and construction of two more plants at Quangdong, LINGAO Units 1 and 2, has begun In addition, reactors are planned for Quinshan Units 4 and 5, these are Canadian CANDU 6 reactors. And two more at Wufangding, and these are PWR's. They are Russian UVER-type under an agreement with the St Petersburg Atomic Energy Development Company Korea has also entered into agreements with the China National Nuclear Corporation, and they are working on what they consider the Korean standardized nuclear power plant, which is similar to Bechtel's Standard Nuclear Unit Power Plant (SNUPPS) and other standardized nuclear power plants we had in the 80's. The Korean standardized plant is based on UGN 3 and 4 and ULCHIN 3 and 4 plants Proposed sites are Shangdong and Fujian Provinces. Each site is different enough to affect the design of most of the equipment. The same thing will be true when they are adapted for the China market. In addition, there are seven additional sites under consideration. The whole area along the coast of China is looking to support and finance a nuclear reactor in their Province. There is a possibility for thirty to forty reactors. The problem here is obviously financing. Even if China achieves 50% of its projections, it would still be a major accomplishment. The purpose of showing you all this is that there is a commercial nuclear market out there. And there is also a major need for our codes, standards, developments and equipment.

WEIDLER: Thank you Mr. Porco. Our next speaker will be Dr. Wilhelm.

Provisions for Containment Venting in Germany.

J.G. Wilhelm, Consultant

Abstract.

In this short paper an overlook is given of the systems developed in Germany for filtered containment venting and their implementation in nuclear power plants. More information on the development can be found in the Poceedings of the DOE/NRC Aircleaning Conferences (1, 2, 3)

In Germany, 28.8 % of the electric energy is produced by 19 nuclear power reactors. No new power reactor is expected to be built at least within the next ten years, but France and Germany cooperate in the development of a future European Power Reactor (ERP). This reactor type will be fitted with a core catcher and passive cooling in order to avoid serious consequences of a hypothetical core meltdown accident so that provisions for containment venting are not required.

In May 1990, the German Reactor Safety Commission specified the requirements on removal systems for filtered containment venting. Some data for LWRs are given in Tab. 1.

Reactor Type	PWR	BWR
Total mass of particles to be removed (kg) (including a safety factor of 50 %)	60	30
Decay heat (kW)		
Aerosols	2	180
Gaseous iodine	5	7
Content of steam in off-gas (%)	< 100	<100
Droplet aerosol by condensation (g/m^3) *	< 5	< 5
Beginning of venting after core meltdown	2 -3 d	> 4 h
End of containment venting	7 d	7d
Removal efficiency (%)		
Aerosols	≥ 99,9	≥ 99,9
Iodine, elemental	≥ 90,0	≥ 90,0
Iodine, organic	0,0	0,0

* in tubes, fittings and containment

Tab. 1 Requirements and conditions for filtered containment venting in Germany

Backfitting measures allowing filtered containment venting have already been taken in the exsisting German power reactors. For the removal of droplets, mist and particles in the µm and submicrometer ranges, filter units were developed on the basis of packs of metal fiber fleeces with decreasing fiber diameters. These filter units were designed on the basis of experience first gained in droplet and mist removal with a metal fiber droplet separator of extremely high efficiency, to be installed upstream of HEPA filters of conventional design. When the factory producing the fiber fleeces from a special stainless steel was able to reduce the fiber diameter down to 2 µm, the target of the original development was extended to build a droplet-, mist- and particle filter unit, completely made from stainless steel. The tests with aerosols of droplets, mist and particles showed that removal efficiencies > 99,99 % could be reached by the proper selection of the fiber diameters and the depth and arrangement of the different fleeces. Also it could be demonstrated that, even under extreme droplet and mist loading of the atmosphere to be filtered, no water reached the final section of the filter unit provided to remove dry aerosol particles with diameters in the submicron range.The design of the combined metal filter units allows to transfer the mechanical strength from the fiber media to perforated sheet metal or heavy wire mesh. Organic material is not used. In this way, the problems connected to the decreasing tensile strength of the HEPA filter media due to pleating and effects of wetting and heating, primarily challenging the organic binder of the media, could be avoided.

Filter units of the metal fiber type described were built to clean up the containment venting off-gas both by dry and wet filter methods. The "dry filter method" has been developed in two versions, named the Krantz/RWE system and the Krantz/KfK system. The Krantz/RWE system is shown in Fig. 1. The filter unit for aerosols is installed inside the containment and upstream of the pressur relief trottling valve for the off-gas. The dimensions of a typical module are given in Fig. 2 which includes also data on the required and proved performance. The loading capacity for particle aerosols is tested with a plama torch generated tin dioxide of 0.5 µm MMD. Uranine is used for the final test of the removal efficiency of each unit fabricatet. The decontamination factors are normally above 10,000. The expected diameters of particles, airborne in a PWR containment atmosphere at the start of filtered venting, are much larger when calculated with the NAUA-Code. In terms of the removal efficiency and pressure drop of the filter unit, the test aerosols are much harder to trap.

In Fig. 3 the dimensions and data are given for an iodine sorption filter module. The iodine sorbens is a zeolite, used in form of ball shaped granules with diameters between 1 and 3.5 mm. To prevent potential catalytic reactions between hydrogen and oxygen on the surface of the sorbens , an binary doped zeolite named Baylith ID 625 is used. The iodine is trapped mainly in the form of silver iodide. The iodine filter module is situated in the auxilary building behind the pressure relief throttling valve. The isenthopic expansion of the vented hot gas-steam mixture on the pressure relief valve down to nearly atmospheric pressure will result in a dry off-gas, containing overheated steam. During the first operational period of the originally cool iodine filter, condensation is avoided by the heat of adsorption of steam on the dry zeolite sorbens.Three German PWRs are fitted with the filter systems shown in Fig. 1.

In Fig. 4 the Krantz/KfK dry filter system for the filtered containment venting is represented. In this version of the dry filter method, the droplet separator and aerosol filter modules are combined with the iodine filter modules and the whole filter unit is arranged in the auxiliary building downstream of the pressure relief valve. The dimensions and the required and proved data of a filter unit, built for a volumetric flow rate of 18,000 m_n^3/h, are given in Fig. 5. Again, three German PWRs are equipped with this dry filter system. The avantages of both dry filter systems are mainly a result of the exclusive use of passive components. Emergency power and the supply of cooling water and chemical additives are not needed and an extremely high stability at different temperatures and radiation levels can be achieved

Also a "wet filter method" to clean the vented off-gas during a core meltdown accident was developed in Germany. This removal system includes a Venturi scrubber and a metal fiber droplet-, mist- and particle filter unit, in principle the same as mentioned before. The Venturi nozzels, scrubbing solution and the filter unit are inside of a pressure vessel. Because the scrubber is arranged upstream of the pressure relief valve (Fig. 6), it is working at a pressure near the containment pressure. During venting, the scrubber is operating in a sliding pressure mode. A large exchange area of the scrubbing solution, sucked into the throats of the Venturi nozzels, is generatet by a very high difference of the velocity between the vented gas-steam mixture and the fine droplets of the entrained scrubbing solution. Another scrubber version can be operated close to atmospheric pressure and was developed for containments with a low design pressure. To remove iodine, the scrubbing solution contains sodium hydroxide and sodium thiosulfate. To reach a high removal efficiency for organic iodine, a dry iodine filter can be integrated in the final assembly. Removal efficiencies for aerosols of > 99.95 % and > 99 % for elemental iodine have been published (3). Thirteen nuclear power reactors in Germany are already equipped with the scrubber-filter system.

The Multiway Sorption Filter is a shaft type filter housing built to pass the exhaust air stream to be cleaned two times through the same sorption material, saving up to around 50 % of the material needed to operate with a high decontamination factor during a long time of operation. It was originally developed for radioiodine removal. The activated carbon, contained in the lower part of the filter housing and previously used as long as possible for iodine removal in the upper part of the housing, is still good enough for pre-adsorption of air pollutants. The construction of this counter current filter guarantees an exact bed depth and stay time. It is now widely used in German power reaktor stations and, as a fall out of a nuclear development, in the conventional industry. In a radioactive waste burning plant, the MWS filter is used in the off gas system to reduce the dioxine to less than 0.5 nanogram per cubicmeter. No change of the charcoal layer was necessary during an operation period of more then three years.

References:

(1) H.-G.Dillmann, J.G. Wilhelm, "Investigations into the design of a filter system for PWR containment venting", CONF-900813, Vol. 2, p. 898 (1990).

(2) H.-G. Dillmann, H. Pasler, J.G. Wilhelm, "Off-gas cleaning devieces for containment venting", CONF-880820, Vol. 2, p. 709 (1988).

(3) B. Eckardt," Containment venting sliding pressure venting process for PWR and BWR plants - process design and test results", CONF-900813, Vol. 2, p. 876 (1990)

Filtered Containment Venting

The Dry Filter Method

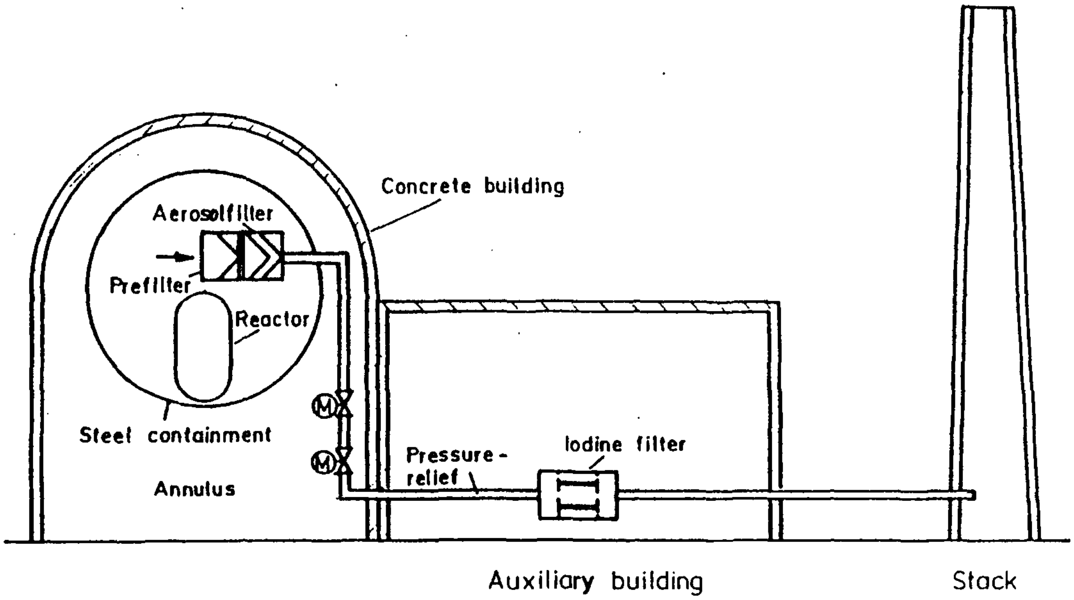
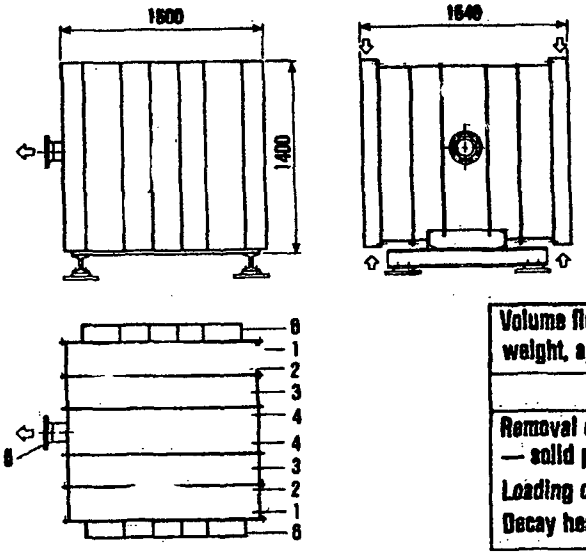


Fig. 1 The Krantz/RWE System

Metal fiber filter module



Legend

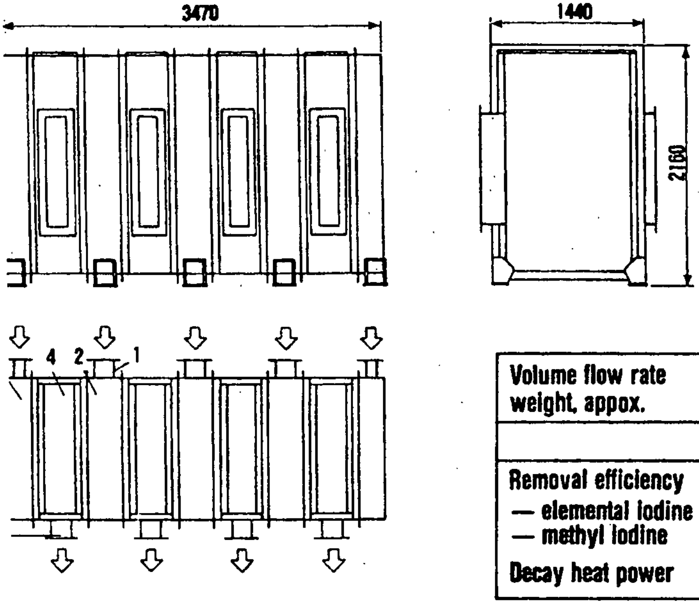
1 Droplet separator
2,3 Prefilter
4 Finefilter
5 Exhaust pipe
6 Inlet

Volume flow rate	m_n^3/h	9333	
weight, appox.	kg	2000	
		Required	Proved
Removal efficiency — solid particle	%	99.9	99.99
Loading capacity, SnO_2	kg	60	80
Decay heat power	kw	2	20

Fig. 2

Filtered Contaiment Venting

The Dry Filter Method



Legend

1	Feed pipe
2,3	Inlet chamber
4	Iodine filter
5	Exhaust pipe

Volume flow rate weight, appox.	m_n^3/h kg	28000 8200	
		Required	Proved
Removal efficiency — elemental iodine — methyl iodine	 % %	 90.0 0.0	 99.97 97.40
Decay heat power	kw	5	10

Fig. 3 **Iodine sorption filter module**

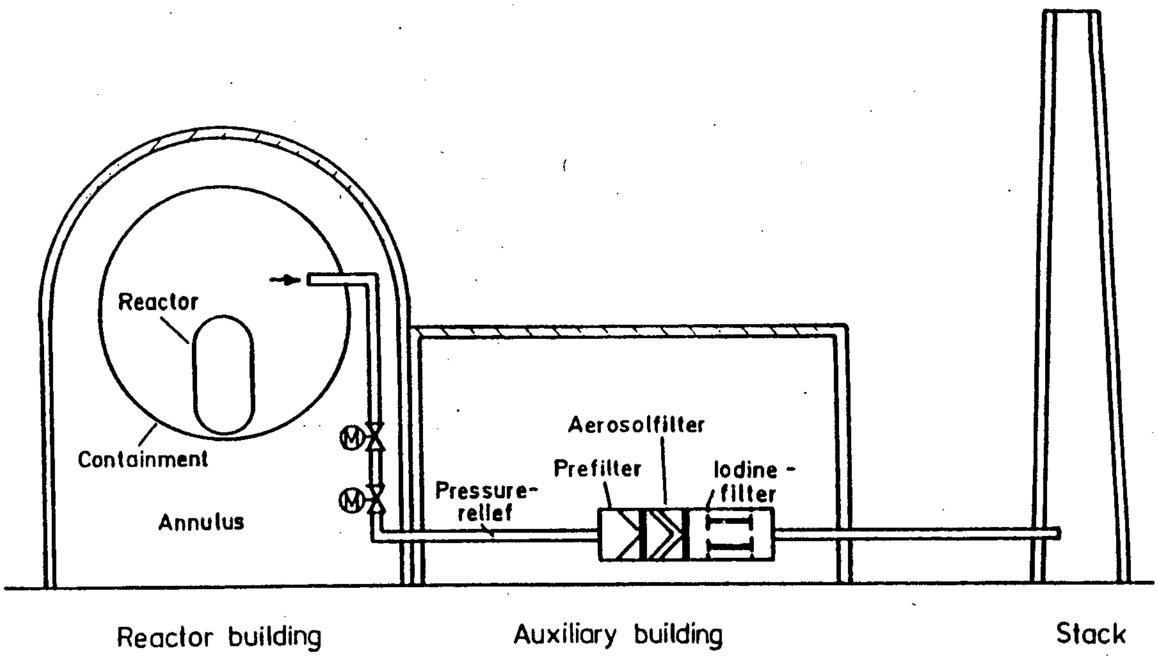
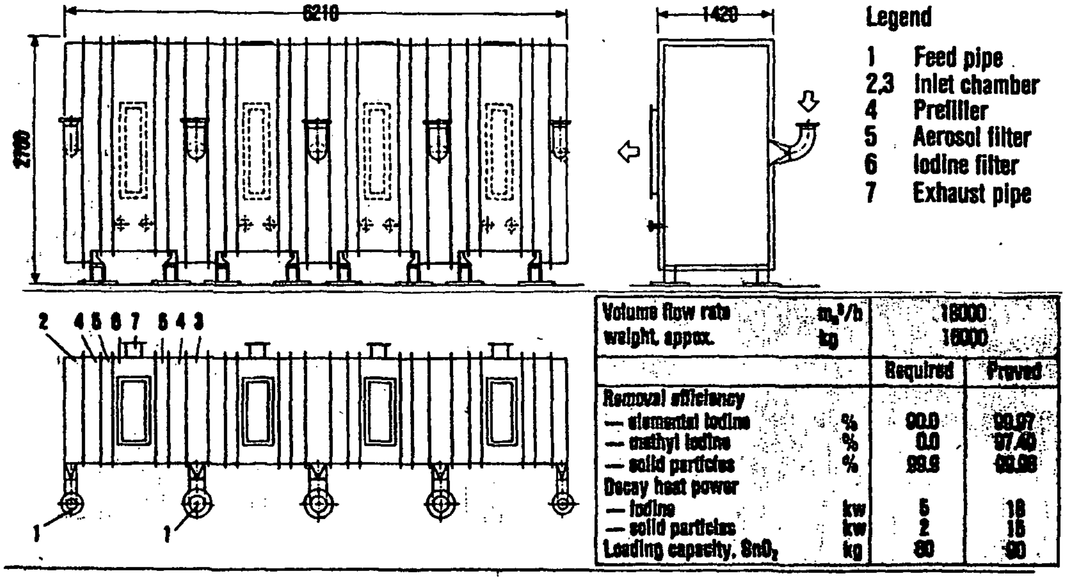


Fig. 4 The Krantz/KfK System

Filtered Contaiment Venting

The Dry Filter Method

Combined metal fiber and zeolite iodine filter module



Volume flow rate	m_n^3/h	18000	
weight, appox.	kg	16000	
		Required	Proved
Removal efficiency			
— elemental iodine	%	90.0	99.97
— methyl iodine	%	0.0	97.40
— solid particles	%	99.9	99.98
Decay heat power			
— iodine	kw	5	18
— solid particles	kw	2	15
Loading capacity, SnO_2	kg	80	90

Fig. 5

The Wet Sliding Pressure Venting Process

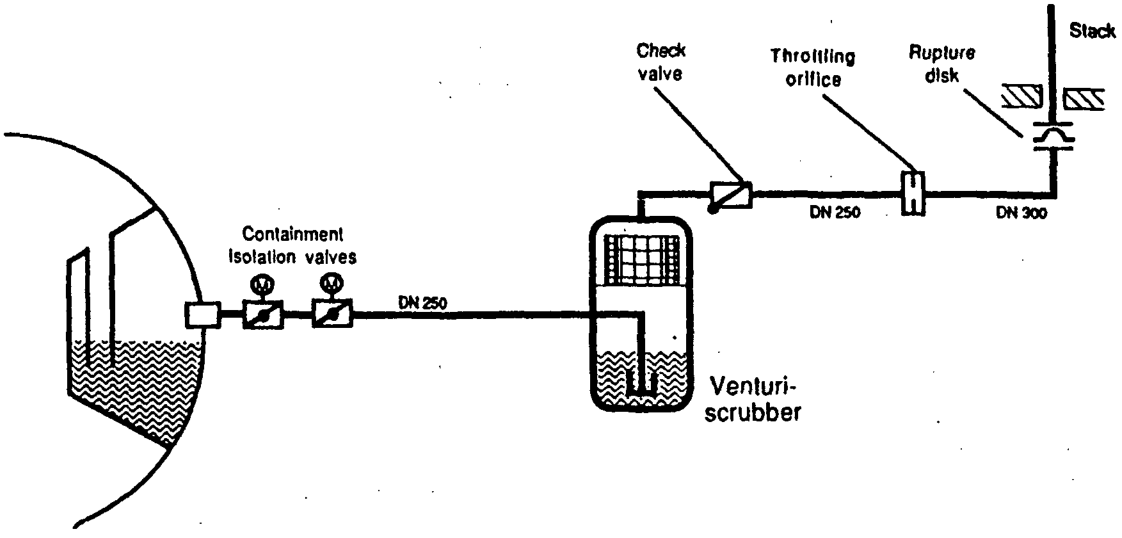


Fig. 6 Flow Diagram of One Version by Siemens

FUKASAWA: The title of my talk is the present status of the Japanese nuclear industry This includes off-gas treatment activities, but is mainly about nuclear power generation on these items written here This figure shows you the capacity and operation data for nuclear power units in the world, on which I would like to show you Japan's nuclear position in the world For plant capacity, Japan is in the third position in the world. These data I explain here are nuclear electricity share and average capacity factor. For both data, Japan is in the thirteenth position in the world. For plant capacity factor, Japan exhibited 80.2% in fiscal year 1995, excluding 18.3% periodical inspection stop. So 1.5%, or 0.3 events per unit per year, is unplanned outage frequency, which I think the smallest value in the world. This figure shows nuclear power plants in Japan. Fifty operation units include 26 BWR's in green color, twenty-two PWR's in blue color, and one gas cooled reactor in Tokai-one unit, and one prototype ATR, Fugen here. Among 4 nuclear units under construction there is one prototype FBR, Monju here, and 2 advanced BWR's here, Kashiwazaki-Kariwa-6 and 7 units. Two units are on order, and an additional fourteen units are being considered now. Fuel cycle facilities are operated or under construction at the very northern part of Japan's main island Honshu. The facilities are centrifugal uranium enrichment, Purex reprocessing, low-level waste shallow disposal, and high level vitrified waste storage. I will show you briefly the status of the Fugen, Monju, advanced BWR's, GCR, and fuel cycle facilities. This is the Japanese prototype advanced thermal reactor Fugen of PNC, which has U or MOX fuel, a heavy water moderator and the light water coolant. I think ATR is useful for Pu consumption before FBR, but no further ATR development was decided last August Hitachi was one of the main contractors of ATR, so I was so sad to hear this news. This is the Japanese prototype fast breeder reactor Monju. Because of the lack of energy resources, Japan is proceeding FBR project. Monju achieved initial criticality in April 1995. But six months later a leak of non-radioactive sodium occurred. The leak portion was just part of the secondary loop. The leak portion is here, and the missing part was found at the bottom of the super heater. The sodium leak occurred exactly on December 8, 1995. I cited these figures from Nuclear News. The leak position was about one meter from the concrete wall of the containment vessel room. The leaked sodium amount was seven hundred kilograms, and four hundred fifty kilograms have been recovered by now, two hundred kilograms were dispersed to the environment, and twenty kilograms are still in the ducts. Sodium flow vibration and repeated thermal stress broke the thermocouple tube and caused the sodium leakage. This missing part was found in this distributor at the bottom of the super heater. Now the public concern is focused on this subject. I hope Japan can continue the FBR development program. The is the world's first advanced BWR's Kashiwazaki-Kariwa-6 and 7 units. The schedule is shown here. This month, the first one will become full power and this winter commercial operation. The characteristics of ABR are the internal pump, the fine motion control rod drive, and the reinforced concrete primary containment vessel. This is the joint venture of General Electric, Toshiba and Hitachi companies. The decommissioning program for nuclear reactors is also proceeding in Japan. For Japan power demonstration reactor of JAERI, the decommissioning was finished this March after testing such a device for remote removal of in core components. For the first commercial reactor, Tokai-1 of JAPCO, Japan Atomic Power Company, the decommissioning was decided last month. Among a hundred and sixty thousand tons of generated waste, they think eighty-five percent can be treated as non-radioactive. This figure shows the progress in fuel cycle facilities. The uranium enrichment plant started operation in 1992. Final capacity will be fifteen hundred tons SWU per year. The low level waste disposal center started operation in 1992. Final capacity will be three million drums disposal. One drum is two hundred liters or fifty-five gallons. The high level waste management center started operation in 1995. Final capacity will be three thousand canisters storage. The reprocessing plant will start operation in 2003. Final capacity will be three thousand tons heavy metal for spent fuel pool and eight hundred tons of heavy metal per year for the reprocessing I show you two R&D activities in the field of nuclear fuel cycle. The partitioning and transmutation program aims at reducing toxicity of high level waste by recovering long-lived nuclides and converting them into short-lived nuclides. We call this the Omega Project which has been done for about ten years now. PNC presented the actinides recycle program two years ago The concept of actinides recycle is described here which aims at the effective use of minor actinides such as neptunium, americium, and curium in the future FBR cycle. Finally, I will explain the systems and recent activities for off-gas treatment in Japan. For nuclear power plants, the United States is our teacher. We are also looking for the leak test method without using Freon for standby gas treatment system. Source term evaluation is also being done with non-volatile cesium iodide. For reprocessing plants, the Rokkasho processing plant will adopt German silver adsorbent of iodine removal. In this case, Germany is our teacher. For the recycle equipment test facility for FBR fuel reprocessing of PNC, they will also adopt silver adsorbent. Tokai reprocessing plant now in operation removes iodine by the alkaline scrubbing method, and is now considering the iodine removal from the solution by silver precipitate. Crypton evolved removal is also being considered by PNC. For enrichment and fabrication plants, uranium recovery from HEPA is considered by vibration and acid leach methods.

WEIDLER: Thank you Mr. Fukasawa. Our next speaker is James Slawski from US Department of Energy and then we will open the floor to questions.

SLAWSKI: I think I need to say that anything I say at this meeting is my thoughts and I do not speak officially for the Department of Energy. That should cover what Ron said earlier this week in so many words. I have been focusing my work in this area on standards, picking up some old DOE standards and revising them and now working with ASME, the CONAGT Committee on working on their standards, specifically the one on HEPA filters We are proceeding at this time with the resolution of the DOE draft standard for specifications. We have redlined strike out or revision one of the draft that we put out last year After our meeting earlier this week we will be doing revision two of that. From that time we will be going through on a line by line comparison between that and the FC Section of AG-1. I am quite aware that there is a Federal Law that where it is practicable we adopt a non-government standard and I am working to head in that direction for the department. At this time, I'm aware that the Department of Energy does not have a driver, it does not have a mandatory requirement on filters. We seem to be operating on inertia based on work that people like Humphrey Gilbert started years ago. We are talking about having a shell statement which could be a DOE order, a policy statement. We could get something added in to 10CFR830, the Quality Assurance Rule. Other considerations are 10CFR834, Radiological Protection for the Public, and 10CFR835, Radiological Protection for Occupational Safety and Health. These are just things that we are considering at this point. We are aware also that we need a technical basis for maximum life of filters and we are concerned about those factors that I hear from people in this meeting. Our interest, we have radiological as well as non-radiological concerns in this area. On the radiological side, the overwhelming driver, my understanding is, the binder on the media as it's exposed to radiation. We also have other organic compounds, the plywood and the box itself, the glues that hold the plys together, the glues that hold the filter pack to the case and then the seal to the edge of the case, the gasket. We are looking for a technical basis to evaluate those for the life expectancy or maximum life that we might derive. Rocky Flats has been funded to do some studies on aging and we are very interested to see the outcomes of that We are finally we are working on getting out the draft for the air cleaning handbook, and our target is to get that out for review by the end of this calendar year. And Werner Bergman is getting optimistic that will happen. Those are my comments at this point.

DISCUSSION

WEIDLER: Thank you very much. Now I open the floor to questions.

FIRST: I do not want to sound repetitive, I asked this same question this morning, but what is the panel's view of the of prospects for international standards with regard to nuclear air and gas cleaning, particularly, and other aspects of nuclear constructions in general?

PORCO: I can only speak from certain countries but Korea has adopted the ASME codes and ASME AG-1 in a requirement in their equipment specifications. China has adopted them on certain projects, very cautiously. In other words they will invoke codes and standards and then depending on how much money they really cost they may reduce the qualification requirements. Taiwan has adopted the ASME requirements. The proposed plants in Thailand and Turkey have either ASME requirements or Canadian standards which are, in my opinion, based on the ASME standards. Some of the other panel members may want to comment.

WILHELM: Well in Europe, we have the Eurotome and Eurotome is in charge of all the regulations that should be the same. It is not at the moment with respect to filter testing also, but it continues to unify Europe with respect to health physics with respect to radioactive material or not. I see a good future for a generation over Europe because as I told before France and Germany together developed a pressurized reactor. And if you start this way you will also unify your air cleaning systems, and what you ask for the air cleaning system. At the moment it is not the case. At the moment Germany has its own regulation, France has its own regulation, too.

DYMENT: Looking at what has happened in the past on standards in filter testing, one can look for example at the ASHRAE standard which started out as 52-68. Over the years it has gradually become adopted very widely, and two or three years ago it was accepted as a European standard. So it seems that if a standard works and continues to be accepted, it will become more widely used. Eventually it may become *de facto* an international standard. I think that for nuclear structures and testing procedures, it could be that the regulatory frameworks in different parts of the world would require differing standards to be applied. I think therefore that it would be difficult for standard documents from one country to be applicable in another without modification or adaptation. Looking at what we were discussing this morning on *in situ* testing standards, in the UK our *in situ* procedures are not national standards. Various organizations and sites have developed their own procedures for these tasks; they may ultimately come together as a national standard or more likely as a European standard. Whether it would grow from there to be an ISO standard remains to be seen, but it is going to be a long term process and we can just wait and see.

FUKASAWA: As I said to you, Japan deferred US standard for orchestratement in nuclear facilities. But in general I think Japan's rule is more severe because, for example, Japan has many earthquakes, small , large and so on.

WEIDLER: As you can see, Dr. First, that is a difficult question to answer. Not impossible, but it will take a lot of work in the years ahead.

RICKETTS: I wonder if I might change the topic of conversation a little bit. I'd like to address several questions to representatives of the NRC, either Dr. Bellamy or Dr. Lee, or whomever else might be able to answer. I'm asking in the context of using regulatory guidelines to drive changes in component performance standards that would be documented in the form of codes and standards, in particular, HEPA filters. And I'm wondering what timetable the NRC has for updating, revising and releasing their regulatory guidelines. I'm thinking in terms of Regulatory Guides 1.52, 1.14, and maybe 1.76.

BELLAMY: To be very honest with you, I had hoped beyond my wildest dreams that question would not come up at this conference. I have no clue as to when, or even if, the agency will be revising Reg. Guide 1.52. I would hazard to say that it's not even on the active working list as far as I'm aware of. So I think the direct answer to your question is we're not working on it and not in the near future. That was the second part of your comment. My personal opinion on the first part of your comment would be that I wouldn't look to the regulatory agencies to drive what the criteria should be for the components. I would turn that around and I would say that the ASME committee, other industry groups, such as NHUG, should be coming up with those criteria, and then coming to us and saying here is the industry consensus, here is what we think is appropriate. Since we are working actively on those committees and on those groups we should then say yeah, verily, and endorse it. I would turn the first part around that way and throw the onus back on the industry as a whole. I am speaking for four people, anybody disagree or have any....unless Dr. Lee knows something else about revising Reg. Guide 1.52, I don't believe that's on our agenda.

WEIDLER: I would just have one comment, Dr Bellamy. I would love to see the NRC review and adopt AG-1. Is there any plan in that future?

BELLAMY: Not that I am aware of. My understanding of the situation is that we would take a look at specific sections of that and if the need arose we would endorse them in individual regulatory guides. But again, we're discussing an area that does not have a very high priority right now with the agency. Jim Lyons, please...bail me out.

LYONS: With respect to AG-1, in the improved standard Tech. Specs., it is one of the options that you can use to reference it, instead of other standards. So, in a sense, the staff, by issuing the improved standard Tech. Specs. says this is an option, it's something that we would accept.

RICKETTS: I wonder if I could follow up a little bit. Doesn't the NRC essentially in the end carry the ultimate responsibility for the public health and safety with regard to nuclear facilities? In that respect, don't they really need to take the lead on something like this in their guidelines?

BELLAMY: Obviously the answer to your first question is yes, our charter is to protect public health and safety. But I think before I would be comfortable in recommending to our management that we take that step of generating any new criteria or revised criteria, I think we first have to make the case that what we now have out there is not adequate to protect public health and safety. And I know that I would not be able to justify such a statement at this present time. When the Atomic Energy Commission was split back in 1975, the purpose of that split was very clearly to separate the promotion arm of the nuclear industry from the regulatory arm of the nuclear industry. And I personally would have a difficult time somewhat justifying why the generation of new components, so to speak, would not be more in the lines of promotion of nuclear power. And therefore I would probably try to turn your question around to let the Department of Energy address it.

RICKETTS: While we have you up there, I wonder if you could address one last question. Could you clarify the relationship between NRC and DOE regarding whether DOE is subject to NRC guidelines as far as facility operation goes?

BELLAMY: Jim, I think you are probably better to address that than I am. I could answer it but, please, try first.

SLAWSKI: I am not sure I know the answer to that because it is really far outside my turf.

BELLAMY: Then I guess my answer to that would be, I am not aware that the Department of Energy takes the NRC criteria, regulations, regulatory guides, standard view plans, whatever, and implements them on a one-to-one basis. My experience has been that they take the criteria and they use whatever they think is appropriate. When it fits it fits, and when it doesn't, it doesn't.

HAYES: I am aware that at the present time I believe we have two resident inspectors, one at the Portsmouth facility and one at the Paducah facility I don't know exactly how that originated but it's my understanding that we do have some people there. It is similar to having resident inspectors at power plants And I also know that there has been under discussion in the Congress the question of having the NRC oversee certain activities at DOE facilities, but that is still in the formative stages at this point.

BELLAMY: Jack is correct, there are four residents at the two GDP facilities. When these resident inspectors come up with findings or violations, there is a major discussion going on now as to exactly what they would be called and how the Department of Energy addresses them

ANON: Did you say Portsmouth and Paducah? Aren't those United States Enrichment Corporation facilities?

BELLAMY: That is correct

KOVACH: I always like to come to these meetings and try to explain to DOE and NRC what they are really doing We do not have enough time to explain to them what is it that they should be doing, because that takes a long time and they will not listen. Again, US Enrichment Corporation is in the process of privatization. The DOE philosophy and the DOE interagency agreement is that privatized facilities will be phased over to NRC for regulation. I think I mentioned it in my ramblings the first day that the tank waste remediation system privatization initiative, that John Wagoner talked about also, is, except for the early demonstration phase 1A, proposed to be under NRC regulation and not DOE regulation. In the meantime DOE will be in charge of only radiological safety regulation. All other regulations will be turned over in the privatized sites to OSHA, Ecology, or Department of Health, as an example, in Washington, just like any other private organization. So that is the reason why you start seeing NRC residents at some of the facilities. There is an interagency group composed of NRC Headquarters, DOE headquarters, and some of the DOE site operations offices, trying to streamline the phase-in of the new NRC regulations. That is also the reason for some of the discrepancies as to who is doing what. As far as revisions of regulatory guides or making changes in the regulatory guides, I think it was pointed out several times in the past, that there are mistakes in them. Basically, they are unenforceable as they are, and really, if the Chairman of the Nuclear Regulatory Commission is interested in a verbatim enforcement of everybody who claimed Regulatory Guide 1 52 compliance she would probably have to shut down half of the operating nuclear power plants immediately. So we still have discretionary enforcement of some of the regulations I am greatly troubled, though, when both in public meetings and in an open forum, like the conference here, or in not closed meetings, but open to the public in discussions with NRC personnel, you hear statements, “well, yes this is technically indefensible but this is what we are doing.” I think once we get to this point the technical basis of this whole industry is going down hill real fast. This is an area where I feel we definitely have to change As far as international cooperation, I think in some areas in standardization it will be difficult, in some areas not so difficult. A few years ago we had an OECD group that started to recommend common standards, at least common test conditions, for testing iodine adsorbents (temperature, humidity and so on). I think most European countries went along with the recommendations. In the US, however, we still have about fifteen different test conditions and that's just on Tuesdays; on Wednesdays we have a few more. And some of these are realistic and some of them have absolutely nothing to do with reality When we are talking about international standardization it also means that we have to give up some of our stupid US standards here, and accept some of the foreign ones that are good, and vice versa. You do not realize how difficult it is until you start supplying the same material to different countries, and you look at the test methodologies and it's relatively easy to find that one of them is really, really good and easy to consistently perform, you don't need two lawyers to interpret it, you don't need a lawyer for yourself and one for the regulatory agency It's clearly written, it's readable and that's the one that really should be adopted, instead of everybody trying to come up with a slightly different one, often without understanding the basic technical concepts on which the particular test procedure is based. So this is just a little additional rambling relating to standards and how we are interpreting some of the wording of these standards and codes. And I hope you forgive me for the repetition that you heard in some areas.

CAMPBELL: I would like to know if other countries have documents similar to the DOE Air Cleaning Handbook? And if they do, would it be possible to get copies?

DYMENT: We do not have an Air Cleaning Handbook. We have spent quite a lot of time looking at your Air Cleaning Handbook. We do have various other documentation, though. In particular we have a nuclear industry purchasing specification for HEPA filters, which was arrived at after a consensus over many years. And there are various other documents as I've said earlier, which taken together would form the seeds of a handbook but that process has not yet occurred.

PORCO: In China and also in Korea you will find the DOE Air Cleaning Handbook.

CAMPBELL: What I hear is that, there is no equivalent to the DOE Air Cleaning Handbook anywhere else, from what we know?

PORCO: They are currently using the DOE handbook as a reference, and as you know it is out of date and is being revised.

WEIDLER: A quick summary. I would say that what we heard in our tour of the nuclear world for this afternoon is that we have a lot of pleas for international standards, that we have a plea for redeveloping our technical expertise, at least in the United States, and that we have a lot of concern for the regulations. The one on the standards I will convey to the Board of the Nuclear Codes and Standards and I know they are interested in this subject. I want to thank this panel, we've enjoyed it.

SESSION 7

OPEN END

Tuesday July 16, 1996
Co-Chairmen: K. Duval
M.W. First

STANDARDIZED METHODS FOR IN-PLACE FILTER TESTING
M. Dykes, J.K. Fretthold, and J. Slawski

CHARCOAL FILTER TESTING
J. Lyons

INTRODUCTION

FIRST: This is the Open End session. It is intended for short presentations and presentations on projects that are in progress but the information that has been gathered so far is interesting enough to present it to this audience. The Open End is also intended for people who have serious questions about issues or equipment and who wish to ask the audience if anyone has a solution or can suggest one from basic principles. This session contains a variety of topics. We have two speakers. My Co-Chairmen on this session is Kenneth Duvall from the Department of Energy. He is with the Office of Environmental Guidance. You may recall Ken was the DOE representative at the 23rd Conference.

DUVALL: Our first speaker is Jan Fretthold. He is affiliated with the Rocky Flats Environmental Technology Safe Sites of Colorado and his discussion is going to focus on the standardized methods for in-place filter testing.

STANDARDIZED METHODS FOR IN-PLACE FILTER TESTING

M. Dykes, *Westinghouse Savannah River Co.*
J.K. Fretthold, *Safe Sites of Colorado, Rocky Flats Environmental Technology Site*
J. Slawski, *US Department of Energy*

Complex - Wide Conference on In-Place filter testing

Monday, March 25 - Friday, March 29, 1996

Westinghouse Savannah River Company, Aiken, SC

As a response to the Defense Nuclear Facilities Safety Board (DNFSB) staff's suggestion on the sharing of testing technology, a conference has been scheduled at the Savannah River Site to begin exchange of information.

Who Should Attend:
- Field in-place test personnel and their management
- Purchasing Representative familiar with blanket-type subcontracting
- Technical Representative familiar with HEPA Filter requirements and specification

Conference Participants Will Share Information For The Following Objectives:

- Work together to develop and standardize a complex-wide procurement specification for HEPA Filters
- Develop an in-place test procedure that will include all requirements that each particular site may have
- Develop a training for future test personnel
- Develop a guide for in-place tests of Non-ASME N509 Systems

As part of the conference, if available, please bring copies of the following documents:

- In-Place test method/procedures
- Purchase specification for HEPA filters for your site
- Receiving inspection procedures/description
- Storage procedure/methods
- In-Place personnel training methods
- Certification requirement for test personnel
- Form of documentation of In-Place test
- Description or photographs of testing equipment
- Test of vacuum, air movers, exhausters

- Information on aerosol generators
- Information on your site's use of different aerosol agents (e.g. EMERY,DOP,DOS)
- Information on your use of private test company (contracting out the in-place testing)
- Respirator testing...documentation of the technical basis for method used

COMPLEX-WIDE CONFERENCE ON IN-PLACE FILTER TEST

CONFERENCE MINUTES

Monday, March 25, 1996

Meeting began at 9:00 a.m. Welcome was given by Maynor Dykes, SRS.

This week's agenda was reviewed and all attendees (28) were introduced.

Purchase Requisitions

Maynor Dykes reviewed the procurement specification used by the Savanna River Site. This was a detailed review to show how current standards are used to control supplier quality. The group was told that this was the specification that will be used in the formation of BOA (Basic Ordering Agreement) to provide HEPA filters on a "as needed" basis to government owned/contractors operated (GOCO) facility throughout the Department of Energy complex. Seven GOCO facilities will participate in the BOA.

Other areas highlighted in this review were:

- All HEPA filters are Level 1 procurement and require Level B storage.
- All HEPA filters receive a visual inspection by qualified trained inspectors prior to storage.

Meeting was adjourned at 11:30 p.m. For lunch.

Jon Fretthold, Rocky Flats, reviewed his company's Procurement Specification.
A lengthy discussion was raised of shelf life of a filter. This is a problem were there is no technical guidelines. Jon stated that his company used ten (10) years with a five (5) year requalification. Reasoning behind the use of 10 years explained. Other area discussed by Jon were:

- Level B storage, controlled by filter systems personal
- Filter Inspections are performed by the FTF test personal

V. Martinez, Los Alamos National Laboratory, described his company's procurement specification. Victor stated basically all of the specification and purchase requisitions included the same information. Purchase requisitions are written, then forwarded to purchasing and bids go out. At receiving, QA and visual inspection are performed. Filters are reinspected after received from Rocky Flats. Filters are stored in warehouses and installed as needed. Victor indicated that 1-2% of their filters are rejected each year at receiving. Most of these are administrative problems.

J. Kriskovich, Westinghouse Hanford, stated they were in the process of updating their specification. They are using AG-1 as a base. Jim feels that all filters should not be tested. There is a 1-3% failure rate od Hanford filters at the Rocky Flats test station. At Hanford, visual and beach tests are performed. Receiving personal do all inspections. Hanford has a 1% defective rate at receiving. Most damage is caused by shipping and forklift.

Meeting adjourned at 4:00 p.m.

Tuesday, March 26, 1996

Maynor Dykes, SRS gave opening remarks and introduced Roger Zavadoski, DNFSB.

Roger described the DNFSB and its purpose. "The board consists of 100 members. Roger is the technical staff member that deals with filtered ventilation systems. Roger discussion included the following:

- Protection of the public.
- The role of HEPA filters in D&D.
- Safety Class sys. reduced to Safety Significant - loss of margin of safety.
- The role of the Filter Test Facility; filter QPL; effects of aging, wetting, radiation.

In-Place Testing

Maynor Dykes described the SRS test program highlighting test procedures and test personnel training. He answered questions from the group concerning test frequencies of portable air movers and fixed exhaust systems.

There was a full conference discussion with each GOCO site describing their In-Place test program, procedures and training. There were many difference in training of test personnel. Some sites had no classroom training and depended on "on-the-job" training. There were several problems seen in using Union personnel as testers.

Each site discussed the instrumentation used in their test programs. All sites basically used the same type penetrometer with exception of Los Alamos. There was a long discussion on aerosols with no decision being reached on which was best DOP was being used at Rocky Flats, INEL & SRS; Emery 3004 was being used at LANL and

LLNL; Emery was used at Hanford. ASME N510 was discussed and the conference thought a rewrite was in order.

Wednesday, March 27, 1996

Instrumentation
- NIST Calibration
- Bench Test

It appeared that all sites were using the same photometer with the exception of Los Alamos was using the laser field testing.

Questions were asked concerning calibration of the photometer. Do we require NIST calibration? Do we bench test the photometer on regular intervals, how often do we calibrate to NIST requirement? Do we use a NIST transfer method on our contaminated instruments?

Oak Ridge reviewed these calibration methods stating the Instrumentation Control Division on-site performs calibration to an ATI procedure and it is good for one year. They seldom send there field instruments off-site because of the potential contamination problem. They do not perform bench tests. The FTF instruments are sent off-site for calibration. Oak Ridge uses Thompson's Calibration Laboratory for their off-site calibration.

LLNL described their calibration procedure stating their instruments are sent to ATI for NIST calibration. They have four sets of instruments and a small test station with a known aerosol source. When an instrument gives a suspect reading, it is taken through a bench test procedure.

Hanford requires annual calibration. The Instrument Tech. Group maintains their test equipment and test instrument are sent off-site for recalibration. Hanford uses PNL (Pacific Northwest Laboratory), which is at Hanford, for recalibration. Hanford performs bench testing.

Los Alamos requires annual calibration on their lasers. Sizing is performed on a quarterly basis.

SRS required annual calibration. Instruments are sent to ATI for NIST certifications. SRS maintains two NIST calibration instrument for bench test and calibration transfer on the highly contaminated instruments. When instruments are returned from calibration, the documentation is reviewed, particularly the "As Found" section. If a problem is seen in this section, retests are performed on systems where this instrument was used.
Rocky Flats has personal trained by ATI to calibrate and rebuild their instruments. This is performed on an annual basis.

SRS asked if anyone was checking the penetrometer flow. SRS had discovered a problem with flow on new instruments. All sites indicated they did perform flow checks.

The group agreed that we need to know more about calibration. They wanted to know if their instruments were calibrated to a know traceable concentration of aerosol. Maynor Dykes, SRS, agreed to investigate this problem.

There was a long discussion on penetrometer failure while in service. Hanford stated that they had problems with motors freezing. Some sites had problems in movement and handling. One site leaves instruments in the building where tests are performed to prevent damage. One site stated it was rare to have damage to an instrument from transportation by their group.

All sites have the required documentation in their record keeping.

Thursday, March 28, 1996

In-Place Test Personnel

There was a great deal of discussion on training. Training problems was seen as one of the major problems in HEPA filter testing. Some facility do not have in-house training programs. Others have full classroom training followed by on-the-job and JPM (Job Performance Measures). Testing was required at each level of training. Off-site training at Harvard or NUCON was the only requirement by some. Most sites considered off-site training as "basic" and feel that they could not provide much help in testing their systems. Most sites do not use ASME N510 criteria since they could not test their system to standards. The use of Union personnel as testers was reviewed and seen as a problem since supervision has no control over the people or who received the test assignment. The conference group thinks we should have DOE assistance in development of a training policy. Since test requirements are basically the same at all sites, there was no reason why training should not be alike. At the present time, there is no certification for in-place test personnel.

Site Training Program Qualifications:
- Oak Ridge - Has no in-house training program. Requires training from Harvard or NUCON and on-the-job training.
- Rocky Flats - Requires two-four days supervisor administered training for Union people then on-the-job training for each system.
- Livermore - Requires Harvard training with one year on-the-job.
- LANL - Requires 39 hours classroom, 9 JPMS and 2 years on-the-job.
- SRS - Requires 39 hours classroom, 9 JPMS and 2 years on-the-job. Requalification is required every two years after qualification.
- Hanford - Union tech. OJT by supervisor,Qual. cards.

Test of Air Mover, Vacuum and Portable Exhausters

No one knew of any technical specification for testing portable equipment. Most sites perform tests alike and require qualified HEPA filters.

SRS requires qualification of all portable equipment before purchase. All equipment failing qualification testing will not be purchased. The SRS Filters Test Group has final approval of all portable air movers.

At all other sites, the test personnel have no say in procurement of equipment. Problems arise in this policy because some of the equipment can not be tested or altered so that basic testing can be performed. One site had to alter a vacuum cleaner to eliminate carbon fibers getting into the test instrument.

Private Test Companies

A very short discussion. No one had experience with private companies. Problem areas include security clearances and training on special filtration systems.

Friday, March 29, 1996

Conference Review

The positive response to this conference was outstanding. Everyone agreed that the conference was a great success and should continue. The indicated it was long overdue. All agreed this was the best method to transfer technical in-place testing knowledge throughout the DOE complex. A large number stated this was a training experience where they learned how to better perform their job function as a tester or supervisor.

The group saw the need for better standards, procedures and training of test personnel. It was very evident that most sites are basically doing business alike but with different approaches. It is now known that procedures common to all sites can be written and used effectively.

Many problems were identified at this conference. The one most common to all sites was, the test groups have no authority even though their job function is required by DOE. They cannot require correction of deficiencies and are not included in designs or procurement.

Everyone agreed that DOE should provide direction and support to the test groups. It was agreed that the FTF groups should continue to function. Every site saw a cost savings (waste reduction) in their programs by requiring retest at these facilities.

During the conference, participants were asked to write some of their major concerns. Given below are these concerns:

- Lack of official DOE policy regarding testing at FTF's.
- Lack of DOE or Site specification for portable HEPA systems or filters for these systems.
- Lack of minimum training requirements for filter testing personnel; no DOE guidance.
- Referencing of ASME N510 for the testing of DOE filter systems results in auditing confusion and problems demonstrating compliance with referenced requirements.
- Lack of DOE guidance document or standard for testing of filter systems unique to DOE sites.
- Procurement of HEPA filters by personnel not knowledgeable of requirement for Nuclear Air Cleaning Components.
- Systems have old filters, >20 years. They are routinely tested and pass but the quality of media is in question. Testers have no authority to require replacement.
- Lack of DOE policy concerning shelf and service life of a HEPA filter.
- There is no formal DOE policy that requires facility managers to correct deficiencies found by the test groups.
- How will QPL be handled?
- If testing stations go away, who will perform a calibration efficiency (versus a leak test) tests.
- When will the whole filtration area stop being the unwanted step child at DOE?
- Will the conference continue? How Often? Where?
- There is a large disparity on how you meet or not meet an OSR (TSR, BIO, etc.) requirement.

The conference adjourned at 11:30 a.m.

<u>Future Actions:</u>

Establish a Complex wide (DOE) policy on :
    Training requirements for filter test tech.
    Test tech. certification
    Test aerosol
    In-place test procedure - mandatory / optional requirements.
    Receiving inspection / QA
    Filter specification (ASME / DOE)
    QPL requirements for filters
    Use of FILTER TEST FACILITIES
    Filter service life

List of attendees:

Maynor Dykes	WSRC
Ernest R. Brinkley	WSRC
Gary Mullis	WSRC
Dave Simpson	WSRC
Kurt Breitinger	WSRC
Richard Proctor	WSRC
Jim Kriskovich	WHC
Charles DuPré	Kaiser Hill/Rocky Flats
Brian Mokler	LANL
Lawrnel Harrison	INEL
John Comer	WHC
Roger Zavadoski	DNSFB
Bruce Bettencourt	LLNL
Wayne R. Krause	LLNL
Greg Helland	LANL
J.C. "Tony" Gross	Lockhead Martin/OR
George M. May	Lockhead Martin/OR
David L. Monroe	Lockhead Martin/OR
Gary N. Norman	ORNL
Terry Schubert	Lockhead Martin/OR
Jim Slawski	DOE DP-45 (GTN)
Jack Jacox	Jacox Associates
Micheal Brandon	RMRS/Rocky Flats
Richard A. Caufield	Dyn Corp/Rocky Flats
J.K. Fretthold	SSOC/Rocky Flats
Werner Bergman	LLNL
Victor A. Martinez	LANL

DISCUSSION

DUVALL: Some time ago at Rocky Flats it was reported that there was significant plutonium discovered in the ventilation system on the walls downstream from the HEPA filters. And I am wondering what was concluded as to how that happened and did it have any bearing on the testing of the filters after that?

FRETTHOLD: Downstream from the filters?

DUVALL: Yes, there was a significant amount of plutonium that was lining the ventilation walls and there was some concern about criticality. In fact, I think that subsequently there were liners put on the ducts.

FRETTHOLD: That was upstream from the filter system between the glove boxes and the final filter plenum entrance. And here again it was a build up that had occurred because of the different processes. The basic systems are designed to move air, not particles. The original concept was, let's stop the particles at the glove box. Unfortunately, not every glove box operation had a filter at that point. Consequently, depending on the type of material, there was a migration into the duct work. Usually there was a reasonable velocity to carry the material, but as soon as any change in direction occurs or where you had a change in velocity you would have material fall out. They went through the system with an external counting device and identified where they had roughly the material. I won't say it was accurate because of background, reflections, and everything else that they were dealing with. But from that point on they could identify the worst locations and they went in with various small vacuum cleaners, scrapers, various other things and removed material from the worst locations. I do not have the numbers handy but I believe they removed one-tenth of what they estimated was there. It was a very successful operation.

BERGMAN: I want to add a comment to yours. I have not seen a report but I have had personal communications with people who know the major sources for this buildup. Regarding the question by Ken Duvall on Pu accumulation in the ventilation ducts at Rocky Flats let me offer the following: The HEPA filters used in glove boxes would plug rapidly and restrict the air flow into the box. This caused insufficient vacuum within the box and occasionally allowed Pu to escape from the box. To prevent this from happening, some workers would punch holes in the glove box HEPA filters to allow air to pass through the plugged HEPA filters.

FRETTHOLD: This took place during the early 60's, and then it stopped. The glove box filter was used as a pre-filter but was not a filter for which credit was taken from a testing standpoint. We had a lot of production going on, so the filters would load up fairly fast. There was a butterfly valve just downstream from the filter which could be opened to a certain point to maintain a negative pressure on the glove box. What you reported was early practice. It was definitely stopped and better maintenance instituted for filter systems and glove boxes.

DERDERIAN: In defense of DOE management, I would like to say that we are beginning to move in a direction that will resolve some of these important issues. Tip Rollins' group in EM is now tasked with coming through with a comprehensive report that will address the filter testing facilities. It will address QPL testing, it will address a number of technical issues that have not been addressed before. I find myself defending management, a very awkward position to be in for an engineer.

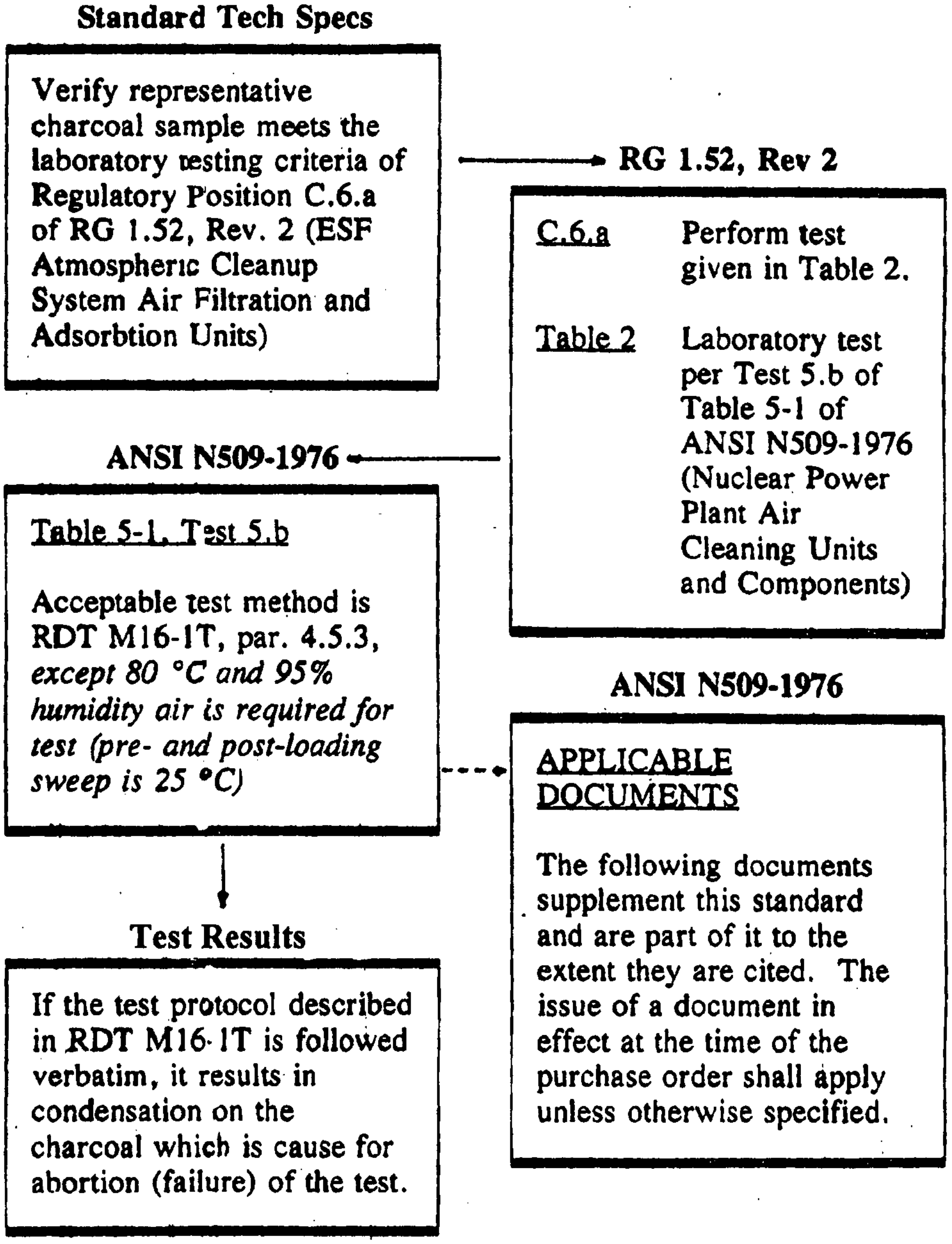
FIRST: I was very much interested in your exposition, particularly the aspect of training and certification of personnel. My first introduction to the Committee on Nuclear Air and Gas Treatment standards was to prepare a standard for personnel who did in-place testing. I spent six or seven frustrating years revising that document, because every time I revised it, the utility industry found good reasons why it was not sufficient. We finally had a conference with industry representatives who told us all the things that they wanted to have changed. We dutifully made the changes but then they told us they would not accept the standard under any circumstance. This remains a real problem. I did get the proposed personnel standard published, not in the air cleaning conferences, but in a special conference that took place in France on the subject of high efficiency filtration. If your group ever wants a personnel standard for certification, we have a good start and you can fight with the utility industry from now on.

DUVALL: Our next speaker is from NRC. He is James Lyons, section chief of the plant systems branch. His discussion will be on charcoal filter testing.

CHARCOAL FILTER TESTING

James Lyons
US Nuclear Regulatory Commission
Washington, DC

Yesterday Dr. Kovach was saying that he could count on two fingers the number of NRC personnel who had experience in air cleaning. I will admit that I am not one of those two, this is certainly not my field of expertise. I have been involved in this for about a year. At Plant Systems Branch we are in charge of the systems aspects of all the ventilation systems. We have inherited the issue of charcoal filter testing and have been working closely with Jack Hayes, who has been involved with it for a number of years. Earlier this year a couple of plants went through this process. If you start stepping through the standard Tech Specs, and a lot of plants only reference Reg. Guide 1.52, Rev 2, what you end up doing is taking yourself there. Figure 1 is somewhat confusing. In fact, I tried to make it this way because as I go forward to talk to my management, one of the things that I want to do is convince them that this is a confusing process. When you go to Reg Guide 1.52, section C.6.a, it says perform the test according to Table 2. When you go to Table 2, it says to do your laboratory test per Test 5.B of Table 5.1 of ANSI N-509-1976. When you go there, it says an acceptable test method is RDT-M16-1T, paragraph 4.5.3, except that 80°C and 95% RH is required for the test, but the pre- and post-loading sweep is at 25°C. That leads you to a test as we all know, that is going to fail. This problem has been around for quite a while. As Ron Bellamy discussed earlier, one of the problems we have is that in the current climate at the NRC verbatim compliance with Tech. Specs. is required. It does not matter that the tests you are performing actually give you a better picture of what your charcoal can do than the test that would be required by your Tech. Specs. This is what I am trying to correct. That is my goal, or one of my goals, right now and I have a couple of other issues that I am working on, too. Basically, what I am going forward with to my management is that, because of the confusion that surrounds the requirement for testing carbon, it takes you through this torturous path, and some plants are not in verbatim compliance with their Tech. Specs. However, in most cases, the tests that people are doing, (I think in all cases, but I have not been able to go through and actually check this to make sure) are more accurate than if they did the test in accordance with their Tech. Specs. We processed emergency Tech. Specs. changes for three plants, Davis Besse, Onconee, and Summer. Summer was the first. Also, Brunswick, in order to restart, flew a test sample up to Ohio to be tested in accordance with their Tech. Specs., because they wanted to be able to start up. We are trying to get around that. There is a second issue here, as far back as '87, through work that CONAGT and INEL did for the NRC, it was determined the that there were some problems with the testing protocol of the '79 version of ASTM D 3803. We put out an informational notice that recommended that when the revision to D 3803 came out, which was the '89 revision, that people should start using that test protocol. We see that some people have gone to that test protocol, but a number have not. I see two issues that I would like to correct. One, is this verbatim compliance with Tech. Specs. and, two, is to get everybody testing to D 3803 - 1989. I am working on a paper that will tell the Commission what is going on and to see which way the wind is blowing when that floats up there. Eventually, what I want to do is put out some sort of generic communication, either a generic letter, or an administrative letter. I really think a generic letter is probably the best way to go. That would give the agency's position on this issue. As part of the generic letter process we would have to issue it for public comment. When you see the generic letter you will have an opportunity to comment on it. Your first indication of where we are going will be when the Commission paper is issued; it will probably be within the next month. As we worked on how to resolve this issue, we met with NHUG in April. They provided some good information and were very supportive of going to the D 3803-1989 standard. It has been really good to work with a group that is proactive in trying to solve some of the problems we are having in this area. Maybe utility representatives that are here that are not part of NHUG, or not supporting their meeting, which is next week, might want to think of trying to support that group. It is a very good group Another thing that I am working on is improved standard Tech. Specs. We are going to add a reviewer's note that will explain this issue very briefly to the Tech. Spec. reviewer at the NRC and, at the same time, will tell industry that we would like to see people go to D 3803-1989. One of the things we are looking at doing is to change the safety factor of 5-7 to determine the penetration, back down to a safety factor of about two. That may help people go to the standard. A lot of talk has been about fixing Reg. Guide 1.52 Rev 2, why we don't update it and put out Rev 3. There was a draft Rev 3 that the NRC put together a few years ago, but it did not go very far because of priorities. I do not know what is takes to get it to a higher level of priority. Maybe, as a result of this Commission paper and the actions that I am working on the effort might be able to be revived and we might be able to move forward on it. I can not guarantee anything, but I would hope to get out an updated version of the Reg. Guide, so that we do not have an agency position that is not right.



Standard Tech Specs

Verify representative charcoal sample meets the laboratory testing criteria of Regulatory Position C.6.a of RG 1.52, Rev. 2 (ESF Atmospheric Cleanup System Air Filtration and Adsorbtion Units)

RG 1.52, Rev 2

C.6.a — Perform test given in Table 2.

Table 2 — Laboratory test per Test 5.b of Table 5-1 of ANSI N509-1976 (Nuclear Power Plant Air Cleaning Units and Components)

ANSI N509-1976

Table 5-1, Test 5.b

Acceptable test method is RDT M16-1T, par. 4.5.3, *except 80 °C and 95% humidity air is required for test (pre- and post-loading sweep is 25 °C)*

ANSI N509-1976

APPLICABLE DOCUMENTS

The following documents supplement this standard and are part of it to the extent they are cited. The issue of a document in effect at the time of the purchase order shall apply unless otherwise specified.

Test Results

If the test protocol described in RDT M16-1T is followed verbatim, it results in condensation on the charcoal which is cause for abortion (failure) of the test.

Figure 1

DISCUSSION

KOVACH: One of the reasons why I was upset with the hassle that we went through on charcoal testing was not the question of violating technical specifications. I expect that when you set technical specifications, people should be paying attention to them and they should be following them, I have no argument with that aspect of it. My major technical heartache related to the regulatory guide changing the standards and values for temperature and humidity, and therefore the NRC expecting that a temperature change from 80°C to 25°C, at the exact same relative humidity, would be technically feasible. Certainly you can run a test at 25°C and 95% RH but you have to have the carbon come to thermal and humidity equilibrium and maintain them throughout the test period. But I can't see why anybody who has a basic physical chemistry understanding of relative humidity and its dependence on temperature, would expect an instantaneous change from 25°C, 95% RH to 80°C ,95% RH and then back again to occur without condensing water in the bed. This is where I have a problem. Certainly you can run tests under three different conditions, but there has to be a time for change of equilibrium in between, you can't just make a turn on a switch and suddenly change from 25°C to 80°C and back to 25°C while maintaining the same relative humidity. This is a physical impossibility.

LYONS: I agree with that. In defense of the NRC we were referencing the standard.

KOVACH: But the standard does not tell you that you have to do it instantaneously.

LYONS: The words are directly out of the table in the standard.

KOVACH: I understand that, but how can you end up with the intent of the latest version of D3803 if you start interpreting the wording in your own way. Even though there is a code of federal regulation that contains an acceptable test, that does not exclude other acceptable tests that are more appropriate from a scientific standpoint than the exact wording as it reads now.

LYONS: It does not. In fact, people that have Tech. Specs., that either call for specific temperatures or cite other standards are the ones that don't get involved with D-3803 It is a problem with the wording that then becomes involved with a legal interpretation. N-509 leaves you with 80°C and 95% RH with a pre- and post- setting of 25°C. We have to fix it.

KOVACH: Another thing the industry's regulations writers have to understand is that when you cite standards that are in draft form, such as RDT M161-T, the T stands for tentative, because it is still evolving. There may be technical mistakes that have not been corrected. It is very hazardous to cite draft documents and then enforce them years later. The last issue of RDT M161-T looks very different from the original issue.

LYONS: What I have learned as I walk myself through some of these documents is that both the industry's and the staff's position on what is an appropriate test, and what conditions produce the most conservative results, have changed over the years. We have tended to flip-flop and that got us into this problem. When we issued Information Notice 87-32, the staff was trying to correct the problem. However, I do not think we were able to correct it as forcefully as we would have liked to have done and even then we would have been in the same predicament that you are pointing out. However, it would have probably worked out okay at that point.

SESSION 8

HVAC & DECOMMISSIONING

Wednesday July 17, 1996
Co-Chairmen: J.D. Paul
R. Porco

HVAC

CONTROL ROOM ENVELOPE UNFILTERED AIR INLEAKAGE TEST PROTOCOLS
P.L. Lagus and R.A. Grot

VARIABLE PATTERN CONTAMINATION CONTROL UNDER POSITIVE PRESSURE
H.M. Philippi

AEROSOL DEPOSITION IN BENDS WITH TURBULENT FLOW
A.R. McFarland, H. Gong, W.B. Wente, N.K. Anand, and A. Muyshondt

DECOMMISSIONING

ATMOSPHERIC DISCHARGES FROM NUCLEAR FACILITIES DURING DECOMMISSIONING: GERMAN EXPERIENCES AND CONCEPTS
H. Braun, R. Görtz, and L. Weil

HEATING, VENTILATING, AND AIR CONDITIONING DEACTIVATION THERMAL ANALYSIS OF PUREX PLANT
W.W. Chen and R.A. Gregonis

CONTROL ROOM ENVELOPE UNFILTERED AIR INLEAKAGE TEST PROTOCOLS

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ABSTRACT

In 1983, the Advisory Committee on Reactor Safeguards (ACRS) recommended that the US NRC develop a control room HVAC performance testing protocol. To date no such protocol has been forthcoming. Beginning in mid-1994, an effort was funded by NRC under a Small Business Innovation Research (SBIR) grant to develop several simplified test protocols based on the principles of tracer gas testing in order to *measure* the total unfiltered inleakage entering a CRE during emergency mode operation of the control room ventilation system. These would allow accurate assessment of unfiltered air inleakage as required in SRP 6.4.

The continuing lack of a standard protocol is unfortunate since one of the significant parameters required to calculate operator dose is the amount of unfiltered air inleakage into the control room. Often it is *assumed* that, if the Control Room Envelope (CRE) is maintained at +1/8 in. w.g. differential pressure relative to the surroundings, no significant unfiltered inleakage can occur it is further assumed that inleakage due to door openings is the only source of unfiltered air.

The specific technical objectives of the effort were:

1) to define three simple tracer gas tests that would allow accurate measurement of CRE unfiltered air inleakage,

2) to define those additional engineering parameters knowledge of which would be required for each basic type of emergency ventilation system to allow measurement of unfiltered inleakage,

3) to provide a thorough error analysis of the inleakage measurement technique(s) so that defensible bounds could be placed on any resulting data, and

4) to generate test protocols based on the above three objectives that would allow measurement of unfiltered air inleakage by responsible plant personnel.

This paper summarizes the test protocols that were developed and discusses the accuracy to be expected from each of them.

1.0 INTRODUCTION

In 1983, the Advisory Committee On Reactor Safeguards (ACRS) provided a series of recommendations to the NRC regarding control room habitability (Hayes, et al., 1984). One of the ACRS concerns was that NRC did not have a protocol for testing control room heating ventilating and air conditioning (HVAC) systems. It was recommended that the NRC develop such a protocol. Writing in the 18th DOE Nuclear Airborne Waste Management & Air Cleaning Conference, members of the ACRS observed "The NRC staff needs to expedite it's efforts to develop a protocol for testing control room HVAC and air cleaning systems. Such tests should be conducted under realistic operating conditions......all parts of the systems including dampers, ducts, etc. should be tested simultaneously as an integral unit.....particular attention should be given to assure that sections of such systems that are under negative pressure will not bring in contaminants which later can be transferred to the control room." (Moeller and Kotra, 1984).

As of early 1995, no control room HVAC performance testing protocol has been put forward by NRC. This lack of a standard test protocol is particularly unfortunate in light of the methodology used to calculate control room staff doses (Murphy and Campe, 1974, Stage, 1995). One of the significant parameters contained within either formalism is the amount of unfiltered air inleakage into the control room.

Present practice appears to assess inleakage based on models of air flow through cracks combined with assumed pressure differences. Often it is *assumed* that if the CRE is maintained at +1/8 in. w.g. differential pressure relative to the surroundings, no significant unfiltered inleakage can occur and that inleakage due to door openings is the only source of unfiltered air. Theoretically this can be true *only* if no portion of the return leg (or legs) of the CRE emergency ventilation system lies outside the CRE.

Negative differential pressure portions of return ducting, fan shaft seals, expansion boots, control dampers, ventilation fan or filter access panels, actuator shaft seals, and miscellaneous unsealed penetrations that lie outside the CRE can contribute substantial unfiltered air inleakage. Other sources of unfiltered air inleakage include improperly seated low leakage intake dampers and leakage from HVAC supply ductwork that traverses the CRE, but provides airflow to non-CRE portions of the building.

Sometimes, unfiltered air inleakage is extrapolated from simple fan pressurization test data. Such an extrapolation is usually unwarranted since the pressure conditions that exist in a ventilation system/control room envelope under emergency operating conditions may not be the same as those generated by a fan pressurization test. ASTM Standard E779-87 (ASTM, 1992) which covers fan pressurization testing provides an explicit warning that extrapolation of fan pressurization data to actual operating conditions *is not feasible*.

It is often claimed that unfiltered air inleakage can be discerned by visual inspection coupled with a ventilation system walkdown. Sometimes this walkdown is augmented by use of smoke tracing to identify inleakage pathways. Since visual inspection is not quantitative, it can only discover obvious (open) leakage pathways and cannot deduce the magnitude of potential inleakage due to any pathway so discovered. For inleakage sites that are hidden from view, visual inspection cannot discern their existence much less quantitatively assess the magnitude of any air inleakage into a CRE.

Smoke testing was originally developed for use in visualizing airflows in mines and has proven to be useful in following airflow patterns within a limited volume. However, it provides no *quantitative* estimate of actual unfiltered inleakage. In addition, care must be exercised in the interpretation of smoke flow patterns since the results often respond to localized airflows occurring at specific points within the CRE. Frequently, false indications of flow are caused by temperature gradients or transient atmospheric conditions that have nothing to do with actual inleakage.

In light of the above enumerated deficiencies of existing CRE inleakage testing techniques, a protocol based on the principles of tracer gas ventilation testing was felt to be appropriate. Tracer gas ventilation tests directly respond to the volumetric ventilation performance in the structure under test and hence do not possess the intrinsic drawbacks of the other methods.

The specific technical objectives of this effort were:

1. to define three simple tracer gas tests that would allow accurate measurement of control room emergency ventilation system operating characteristics, specifically unfiltered air inleakage, on a reconnaissance basis,
2. to categorize the various types of emergency ventilation systems and, having done so, to define those additional engineering parameters that may be required in addition to tracer gas data to allow interpretation of tracer gas data in terms of unfiltered inleakage,
3. to provide a thorough error analysis of the inleakage measurement technique(s) so that defensible bounds may be placed on any resulting data, and
4. to generate test protocols based on the above three objectives that would allow the performance by responsible plant personnel of a simple tracer test to measure unfiltered air inleakage.

Note that the test protocol developed in this effort would not, in general, disclose the actual location(s) of unfiltered inleakage, but only the total amount. For a reconnaissance measurement, this quantity is sufficient to decide if the unfiltered inleakage presents a problem in terms of compliance with GDC 19. To provide quantitative information as to leak location and magnitude requires more sophisticated testing than is being discussed in this paper.

2.0 TECHNICAL BACKGROUND

Tracer gases have been used to measure air infiltration and ventilation characteristics of buildings for over 30 years. Tracer gas techniques have been successfully used in other areas of ventilation engineering and industrial hygiene to provide accurate characterization of HVAC performance under actual operating conditions (Lagus and Persily, 1985, Grot and Lagus, 1991).

Within the nuclear power community, tracer gas techniques have been used since the early 1980's to measure, for instance, airflow patterns to investigate health and safety monitor locations (Hickey, et al., 1991) as well as to understand potential gaseous radioactive contaminant migration within selected buildings (Vavasseur, 1985, Lagus et al., 1988). Recently the results of a series of tracer gas measurements designed to measure total unfiltered inleakage into a nuclear power plant control room have been published (Lagus et al., 1992).

2.1 MEASURING BUILDING AIR FLOWS USING TRACER GASES

There are three principal tracer gas techniques for quantifying air flow rates within a structure; namely, the tracer dilution method, the constant injection method, and the constant concentration method. All are based on applying the conservation of mass equation to a tracer gas concentration established in a test volume. The tracer dilution method is a direct way of measuring the air flow rate extant within a test volume under ambient flow conditions by measuring the decay in tracer concentration within the volume as a function of time. The constant injection method is an indirect method, i.e., it measures the equilibrium tracer concentration within a ventilated area. This concentration can be related to the air flow rate if the tracer release rate is known. The constant concentration method is primarily a research method at this time and will not be discussed further. All three of these techniques are incorporated in the most recent revision of ASTM Standard E741-93 "Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution" (ASTM, 1993).

The mass balance equation and its various solutions that lead to the tests described above, have been provided in previous papers (Lagus and Persily, 1985, Grot and Lagus, 1991) and hence will not be reproduced here. These methods allow determination of either A or q. The air exchange or infiltration rate, A, is given by $A(t) = q(t)/V$ where A is in air changes per hour (h^{-1} or ACH), V is the test volume, and q(t) is the volumetric airflow rate into (or out of) the test volume. In the simplest case, the value of A represents the flowrate of "dilution air" entering the volume during the test interval. Note that this "dilution air" can be actual outside fresh air or, more generally, it can be air whose origin is not within the test volume.

2.2 TRACER GAS MEASUREMENT TECHNIQUES

Instrumental techniques used to measure tracer gas concentrations are listed in Table 2.1, along with some of the gases appropriate to each measuring instrument. All of the gases listed have been used for airflow measurements either within buildings or within individual rooms. Several characteristics of nuclear power plant CREs influence the manner in which tracer techniques are applied. First, because of the large volumes, the quantity (and therefore cost) of tracer gas required for a test becomes important. The expense depends on the cost per unit volume of tracer gas, the CRE volume, and the magnitude of the lowest tracer concentration measurable. Table 2.2 shows the range of maximum volumes that can be measured for one dollars worth of tracer gas (1994 prices). These volumes range from about 9000 Ft^3 for helium to about 5.6×10^{10} Ft^3 for SF6.

Carbon dioxide exhibits an atmospheric background of approximately 350 ppm and is also generated by both combustion sources and human metabolism. Accordingly, it is difficult to assure that a non-variable background of CO2 is maintained during a particular testing interval. In fact, detailed review and studies undertaken by the National Institute for Standards and Technology (NIST) have concluded that except for a limited set of circumstances, the use of CO2 as a ventilation tracer gas is inappropriate (Persily, 1993).

Nitrous oxide has been used as a tracer gas primarily by European researchers. However, N2O exhibits a Threshold Limit Value (TLV) of 50 ppm and hence may not be an appropriate choice for control room testing where test duration may approach eight hours. In the United States, health concerns related to the TLV of N2O have resulted in little use of N2O as a tracer.

The fact that SF6, some halocarbons and some perfluorocarbons can be measured to levels of 10 parts per trillion and below yields maximum measurable volumes in the range of 5×10^8 to 5.6×10^{10} Ft^3 per dollars worth of tracer gas. From Table 2.2 it is apparent that these gases (analyzed at the five to ten part per trillion level or even the part per billion level) are most appropriate for the large volumes encountered in Control Room Envelopes.

2.3 TRACER GAS MIXING

Because of the relatively large volume of the CRE, mixing of tracer gas is an important issue. Mixing by molecular diffusion is a slow process; however, even in naturally ventilated enclosures, there are significant convective mixing mechanisms. In mechanically ventilated environments, the air distribution system has been shown to be effective at mixing of the tracer gas (Grot and Persily, 1986). Experimentally, portable fans have been used to augment mixing of tracer at the expense of altering internal air movement patterns. The attainment of a uniform concentration can also be assisted by injecting tracer gas at several locations.

The issue of mixing of tracer gas in the CRE volume is of critical importance to the measurement and interpretation of concentration decay measurements in the determination of unfiltered inleakage. In order for the solutions to the mass conservation equation to be valid for the *entire* CRE volume it is required that the tracer be well mixed, i.e., the measured concentration anywhere in the volume is only a function of time. In practice, concentration homogeneity is taken to be +/- 10 % or better throughout the test volume (as specified in ASTM Standard E741).

A number of selected references in the published literature provide data supporting the feasibility of attaining "good mixing" of tracer within a test volume. In general, these references provide experimental tracer concentration data which show that mixing occurs fairly rapidly (within thirty minutes to, at most, one hour) in ventilated rooms or entire buildings ranging in volumes from 76 m^3 up to over of 10^5 m^3 (Alevantis and Hayward, 1990, Evans and Shaw, 1988, Shaw et al., 1993, Reardon et al., 1994).

Previous measurements by the authors in two control rooms (one a single story CRE with a volume of approximately 1700 m^3 and the other a two story CRE with a volume of approximately 4000 m^3) that were mechanically ventilated, demonstrated that it was possible to attain concentration variations of less than +/- 2% in the single story CRE and less than +/- 5% in the two story CRE, by including of a number of auxiliary mixing fans at various points with the volumes.

ASTM Standard E741 suggests that inleakage can be measured using a tracer gas technique with an error of 10% or less of the measured value. The experimental conditions considered in the examples of this study suggest that errors of half (i.e. approximately 5%) of this value are attainable.

Note that most of the instrumental techniques utilize electron capture detector gas chromatography for measurements in large volumes primarily due to tracer gas cost considerations. However, measurements have been performed in large buildings using other techniques such as infrared absorption (Potter et al., 1983, Zeurcher and Feustel, 1983) and flame ionization gas chromatography (Prior et al., 1983).

3.0 CONTROL ROOM ENVELOPE TEST METHODS

Four basic types of CRE emergency ventilation systems were considered:

1. Isolation of normal ventilation with filtered pressurization,
2. Isolation of normal ventilation with filtered recirculation,
3. Isolation of normal ventilation with filtered pressurization and recirculation,
4. Bottled Air for Pressurization.

All four basic ventilation types are amenable to a tracer gas decay test to determine unfiltered inleakage. Type 2 above can be measured by a simple tracer decay test, while types 1, 3, and 4 require both a tracer decay test and an independent measure of the pressurization flowrate.

3.1 TRACER DECAY TEST

The tracer decay test method requires only the measurement of relative tracer gas concentrations, as opposed to absolute concentrations, and the analysis required to determine A is straightforward. Equation (1) serves as a starting point for an actual test.

$$A = 1/t \ln (C_0/C) \qquad (1)$$

In practice one obtains a series of concentration versus time points and then performs regression analysis on the logarithm of concentration versus time to find the best straight line fit to the form of the equation given by equation (7). The slope of this regression yields the air exchange rate, A. Knowledge of the volume, V, allows calculation of the leakage flowrate q since

$q = A*V$.

In the case of a CRE with makeup flow, the value of q (or A) determined is the total air inleakage rate. This will consist of the unfiltered inleakage and the actual makeup flow rate. For this case an independent determination of the makeup (or pressurization) flowrate, q_{makeup}, is required. The unfiltered inleakage is then determined as follows;

$$q_{unfiltered} = q - q_{makeup} \qquad (2)$$

where q is the rate determined from the tracer concentration decay measurement (and is equal to A*V) and now represents the total "fresh air" inleakage rate into the CRE. Equation (2) can be written

$$q_{unfiltered} = A{*}V - q_{makeup} \qquad (3)$$

In the case of a CRE with recirculation only (no makeup) then q (or A) measures the unfiltered inleakage *directly* and q_{makeup} would be identically equal to zero.

Standard statistical arguments applied to equation (3) lead to the following estimate of the uncertainty in the determination of $q_{unfiltered}$:

$$S_{qu} = \mathrm{SQRT}\{ (S_A)^2 + (S_V)^2 + (S_{qm})^2 \} \qquad (4)$$

where S_{qu} = Probable error in the value of $q_{unfiltered}$
S_A = Probable error in the value of A
S_V = Probable error in the value of V
S_{qm} = Probable error in the value of q_{makeup}

In Figures 1 to 5 the probable error in a given value of unfiltered inleakage for several assumed error values in measured concentration, CRE volume and inleakage rate. The assumed measurement errors attendant to each case are described below:

- CASE I Error in V = 2%, Error in q_{makeup} = 3%, Error in A = 2%
- CASE II Error in V = 3%, Error in q_{makeup} = 5%, Error in A = 5%
- CASE III Error in V = 3%, No Makeup flow, Error in A =5%
- CASE IV Error in V = 5%, Error in q_{makeup} = 10%, Error in A = 10%
- CASE V Error in V = 5%, No Makeup flow, Error in A =10%

As can be readily seen, the error in the measured value of $q_{unfiltered}$ is never very large. The error in the measured value of unfiltered inleakage is smaller for those cases having recirculation only (no makeup air). For relatively modest measurement errors in the variables needed to obtain unfiltered inleakage, the error in the resulting unfiltered inleakage remains moderate. Note that the measurement errors in Cases I, II, and III above are considered more representative of actual practice than those in Cases IV and V.

It is possible to use equation (1) to estimate the length of time required for a given measurement error. Taking differentials of C and A and rearranging, one arrives at

$$\text{TEST TIME} = \{2*(dC/C)\}/\{(dA/A)*A\} \qquad (5)$$

where (dC/C) = Concentration measurement error
(dA/A) = Total air exchange rate measurement error

Note that the test times calculated from equation (5) use the *end* points of the measured concentration decay, i.e. the calculation assumes that only two points are used to determine the slope of the line. By performing a regression analysis on a number of concentration data points as described above, it is possible to reduce the probable error in the measured value of A or the time required to achieve a given value of probable error.

To illustrate this, a number of regression analyses were undertaken on simulated concentration decay data to calculate the probable error in the "measured" value of A as a function of elapsed time. Two series of calculations were performed for several inleakage rates (corresponding to makeup rates from 100 to 800 CFM) assuming one data point every thirty minutes and also one every fifteen minutes. An additional series of calculations was undertaken in which the inleakage rate was fixed and the number of data points sampled at each measurement time was systematically increased.

Figures 6 and 7 show probable error for various inleakage rates as a function of total test time. For a sampling interval of thirty minutes, for all cases considered, the probable error does not drop below 15% in less than six hours. Decreasing the sampling time to fifteen minutes decreases the probable error to less than fifteen percent in a four hour test. Note also that as the inleakage rate *increases*, the probable error for a given test time *decreases*. For these simulations the measurement error was assumed to be +/- 2%.

Figure 8 demonstrates the effect of increasing the number of concentration data points taken at each sampling interval. This plot illustrates calculations for A = 0.125 ACH. For higher air leakage rates, the corresponding test times to attain a given probable error will decrease. Based on this calculation it appears that sampling at eight points every half hour will ensure that the probable error will lie below 5% within four hours assuming that the uncertainty in concentration is +/- 2%.

Figure 9 provides a similar calculation assuming the concentration measurement uncertainty is +/- 5%. In this case, by taking eight concentration data points per measurement interval, the probable error in the inleakage rate will be less than 10% for test times of four hours or more.

To assure that good mixing has been achieved, a careful experimenter should obtain at least four spatially separated samples at each sampling time. Based on the above examples, a four hour test will generate an inleakage value that is precise to within +/- 10% if the individual concentration data points differ by less than +/- 5%. Higher precision is possible if the scatter in the concentration data points at each time interval is less (i.e. mixing is better).

During the actual testing, ingress and egress to the CRE should be kept to an absolute minimum. Any necessary ingress and egress should be through a single door and accomplished as rapidly as possible. No more than two door openings should be allowed during each hour of testing. At no time during a test should *two* doors to the CRE be opened simultaneously. **If two doors to the CRE are opened simultaneously, any test results should be considered invalid.**

All internal ventilation fans (such as bathroom and kitchen ventilators) in the CRE should be turned off unless they remain in operation during an emergency. These fans should be disabled in such a way as to ensure that the fans will not be accidentally energized during a test.

To assist in attainment of a well mixed volume within the CRE, one auxiliary mixing fan should be provided for each 1,000 to 2000 ft^2 of CRE floor area. Fans should be arranged throughout the CRE area to enhance air movement within the CRE. For CREs having drop ceilings, experience has shown that removal of a small fraction (5% to 10%) of the ceiling panels coupled with the placement of several of the required mixing fans above the drop ceiling will enhance air flow across the drop ceiling boundary and hence, overall air mixing within the CRE. Air samples from above the drop ceiling should be analyzed to demonstrate that good mixing has been achieved.

3.1.1 TRACER DECAY TEST PROCEDURE

Tracer gas is injected into a CRE emergency ventilation supply duct at a rate calculated to achieve a desired concentration. Experience has shown that for mechanically ventilated structures, injection of a diluted mixture of tracer gas over approximately thirty minutes enhances the mixing of gas with the test volume.

Air samples from at least four, and as many as eight, spatially diverse locations within the CRE, should be obtained at thirty minute intervals. For most conditions likely to be encountered in testing unfiltered inleakage a maximum test duration of four hours should be used. Note that it is possible to terminate a test in less than four hours if the actual regression data indicate that a 95% probable error of less than 10% (5%) has been achieved in less time.

If the CRE incorporates makeup flow in its emergency operating mode, then this makeup flowrate should be measured using a pitot tube or hot wire traverse or a tracer flow technique both *before* and *after* the tracer decay test, and the results averaged.

3.1.2 CALCULATIONS

If the CRE does not provide makeup flow in the emergency ventilation mode, the value of A calculated by regression of the tracer concentration decay data is also the *unfiltered inleakage.*

If the CRE does provide makeup flow in the emergency mode, then the values of makeup flow measured Pre and Post test are averaged:

$$q_{makeup} = (\text{Pretest Makeup Flow} + \text{Post Test Makeup Flow})/2 \qquad (6)$$

The unfiltered inleakage is then given by equation (3) rewritten here as equation (7):

$$q_{unfiltered} = A^{*}V - q_{makeup} \qquad (7)$$

Note that regression analysis should be performed after the first three sampling intervals and should be continued for each subsequent sample interval. When then 95% probable error calculated in the regression drops below 10% (or 5%), air sampling and analysis may be discontinued. As noted above, the maximum test interval contemplated in the tracer decay test is approximately four hours.

3.2 CONSTANT FLOWRATE TEST PROCEDURE

The constant flowrate test is an alternate technique that avoids the requirement for accurate knowledge of the CRE volume. Uncertainty in the accurate knowledge of CRE volume can contribute to the uncertainty in the final measured result. Also, for CRE's that exhibit high makeup air flowrates (values of A greater than approximately 1.5, or makeup flows of 2500 CFM for a 100,000 cubic foot CRE), tracer concentration decay may occur very quickly. Also, the tracer gas analyzer may not possess a sufficiently broad measurement range to encompass data taken over a four hour interval.

Accordingly a tracer test that uses a constant flowrate injection of tracer gas into the CRE while measuring the resulting concentrations at selected locations can be used. For the following derivation the return air system is included in the CRE volume. If it is assumed that the volume is well mixed, one can apply conservation of mass to the elements of a CRE shown in Figure 10, and arrive at equation (8):

$$Q_{in} = Q_{sup} \left((C_{sup}/C_r) - 1 \right) \qquad (8)$$

where Q_{in} = Inleakage (anywhere into CRE)
Q_{sup} = Total Supply Flowrate
C_{sup} = Equilibrium Concentration in Supply duct
C_r = Equilibrium Concentration at end of return duct

In deriving equation (8) it is assumed that tracer is injected at a constant flowrate into the supply duct.

Note that this expression does not require knowledge of the control room volume. Standard statistical arguments applied to equation (8) lead to the following estimate of the uncertainty in Q_{in} :

$$S_{inleak} = \mathrm{SQRT}\{ (S_{qsup})^2 + (S_{csup})^2 + (S_r)^2 \} \qquad (9)$$

where S_{inleak} = Probable error in the value of Q_{in}
S_{qsup} = Probable error in the value of Q_{sup}
S_{csup} = Probable error in the value of C_{sup}
S_r = Probable error in the value of C_r

Note that there are the same number of terms in equation (9) as in equation (4), but two of them are related to the gas analyzer measurement error and one to the error in flowrate measurement. These errors are intrinsically more amenable to statistical treatment than is the control room envelope volume.

Figures 11 and 12 provide a graphical illustration of the uncertainty in the measured inleakage value using this technique. Note that what is plotted is the minimum measurable inleakage as a function of total supply flowrate (Makeup flowrate plus return flowrate). Any value of inleakage greater than the minimum shown can be determined reliably by this method. The fact that there is a minimum value of inleakage measurable by this technique arises from the ability of the measurement device to discriminate between two concentrations that are close in value. This technique is complementary to that provided in Section 3.1 and is provided as a way to eliminate the uncertainty engendered by imprecise knowledge of the control room envelope volume and to allow testing in CREs possessing a high value of makeup air flowrate.

3.2.1 CONSTANT FLOW TEST PROCEDURE

Tracer gas is injected into a CRE emergency ventilation supply duct at a rate calculated to achieve a desired concentration. For this test the target tracer gas concentration should lie in the middle of the measurement range of the gas analyzer.

An approximate value of the total air change rate is calculated based on a measured or assumed value of the makeup flowrate. This value, A_A, can be used to estimate the length of time that must elapse before concentration equilibrium will occur within the CRE. If one starts with a zero initial concentration and injects at a constant rate, it can be shown that the tracer gas will reach 95% of the equilibrium concentration within the CRE volume after a time equal to $3/A_A$.

Air samples from at least four spatially diverse locations within the CRE should be obtained at thirty minute intervals. Air samples must also be taken from the supply duct as well as the beginning and end of the return duct of the control room emergency ventilation system. For most conditions likely to be encountered in testing unfiltered inleakage, a maximum test duration of four hours should be used.

The total mechanical air supply flowrate (makeup plus recirculation) into the CRE should be measured using a pitot tube or hot wire traverse or a tracer flow technique.

3.2.2 CALCULATIONS

Tracer gas concentration data are treated by forming the mean of five measurements for each of the two concentration values, C_{sup} and C_r. The CRE Supply Rate is calculated by averaging the Pre and Post Test Supply Flowrates as follows:

$$Q_{sup} = (\text{Pretest Supply Flow} + \text{Post Test Supply Flow})/2 \qquad (10)$$

The unfiltered inleakage is then given by inserting these concentration values and flowrate into equation (8) to obtain Q_{in}.

3.3 DIRECT TRACER GAS INLEAKAGE TEST

Direct measurement of leakage (leak testing) using a tracer gas (usually helium and, less frequently, sulfur hexafluoride) is a powerful technique that is used extensively in the micro-electronics and defense/aerospace industries. In this technique, an object to be tested is either filled with tracer gas and the periphery monitored for leaking tracer, or the exterior is flooded with tracer gas and the interior is sampled for the presence of tracer gas. The measurement of non-zero quantities of tracer gas in either of these situations provides unambiguous evidence for the existence of leakage. The resulting tracer gas concentration can be used to infer leakage rate for a suitably designed experiment.

It is possible to apply this same reasoning to nuclear power plant CRE's. If one imagines a ventilated test volume surrounded by tracer gas as shown in Figure 13, leakage into the volume can be determined using conservation of mass. For this case;

$$Q_{in} = (C/C_0) \times Q_{makeup} \qquad (11)$$

where Q_{in} = unfiltered inleakage rate

Q_{makeup} = makeup flowrate

C = tracer concentration in CRE

C_0 = tracer concentration outside CRE.

In practice it is possible to challenge one boundary of the CRE at a time (if necessary for experimental convenience) with a concentration of tracer gas. Any tracer measured within the CRE would provide unambiguous evidence of inleakage through that boundary. Furthermore, by measuring the challenge concentration and the makeup flowrate within the CRE it is possible to calculate an inleakage rate across this boundary using equation (11) above.

An experimental complication to this technique is the potential for exhaust reentrainment to occur. If air containing tracer gas is exhausted from the CRE, it may reenter the CRE from the outside via the makeup fan. This reentrainment would render the results of any calculation based on equation (11) meaningless.

For those CRE's that possess filtered makeup air (i.e. filtered pressurization emergency ventilation system), it is possible to use a perfluorocarbon tracer and eliminate the possibility of reentrainment into the CRE. It has been documented that perfluorocarbon vapors exhibit exceptionally long hold-up times on carbon. Perfluordimethlycyclobutane (PDCB) exhibits at least thirty minutes hold-up in a nuclear industry standard two inch bed, while perfluoromethylcyclohexane (PMCH) exhibits a hold-up that is easily six times this value (Pearson et al., 1992). These vapors also possess a high detection sensitivity (approaching that of SF6) when analyzed using the techniques of electron capture gas chromatography.

Accordingly, if one were to challenge the exterior of a CRE with a moderate concentration of PMCH, one could sample inside the CRE for up to three hours without any concern about reentrainment of tracer gas. Measurement of PMCH within the CRE would provide unambiguous evidence of inleakage. Use of equation (11) above would allow a calculation of inleakage to be made.

For CREs that are wholly located within a plant building, it may be possible to seed the HVAC system that supplies the regions surrounding the CRE directly with tracer gas. Injection of a constant, known flowrate of tracer gas into the supply systems coupled with measurement of the resulting concentration in the regions surrounding the CRE would allow use of equation (8) to infer unfiltered inleakage.

Note that it is possible to use builders plastic (Visqueen) mounted on a lightweight wooden or metal framework to create a test volume surrounding some of the boundary walls of the CRE. This could be useful if one of the boundaries was, for instance, an outside wall or a roof. Mixing of the tracer gas within this plastic tent could be easily accomplished using several oscillating fans. The structure itself would not have to last longer than a few days. Using a combination of injection into rooms adjacent to the CRE and into fabricated plastic tents that enclose adjacent regions not contained within rooms, allows tracer inleakage testing to be performed on many CREs that rely on filtered pressurization during emergency operation.

3.3.1 DIRECT INLEAKAGE TEST PROCEDURE

Tracer gas is injected into the supply that provides ventilation air to the region surrounding the CRE (or into a specially fabricated plastic tent) at a rate calculated to achieve a desired concentration. For this test the target tracer gas concentration within the region(s) surrounding the CRE should be approximately 1 ppm. Anticipated concentrations within the CRE should lie in the middle of the measurement range of a second gas analyzer.

An approximate value of the total air change rate is calculated based on a measured or assumed value of the makeup flowrate. This value, A_A, can be used to estimate the length of time that must elapse before concentration equilibrium will occur within the CRE. If one starts with a zero initial concentration and injects at a constant rate, it can be shown that the tracer gas will reach 95% of the equilibrium concentration within the CRE volume after a time equal to $3/A_A$.

Air samples from at least four spatially diverse locations within the CRE should be obtained at thirty minute intervals. Air samples must also be taken from each region surrounding the CRE as well as on the delivery side of the charcoal filter in the control room emergency ventilation system. If significant breakthrough of tracer is detected at this point, the test must be terminated. For most conditions likely to be encountered in testing unfiltered inleakage a maximum test duration of three hours should be used.

The makeup flowrate supplied to the CRE should be measured using a pitot tube or hot wire traverse or a tracer flow technique.

3.3.2 CALCULATIONS

Tracer gas concentration data are treated by forming the mean of the final CRE concentration measurements and the final surrounding region concentration measurements to provide values of C and C_0 as required in equation (11).

The CRE Makeup Rate is calculated by averaging the Pre and Post Test Makeup Flowrates as follows:

$$Q_{makeup} = (\text{Pretest Makeup Flow} + \text{Post Test Makeup Flow})/2 \qquad (12)$$

The unfiltered inleakage, Q_{in}, is then calculated from equation (11).

4.0 CONCLUSIONS AND RECOMMENDATIONS

The preceding has provided a brief introduction to the principles of tracer gas ventilation measurements. Three different methods that allow assessment of unfiltered inleakage into a nuclear power plant Control Room Envelope (CRE) using tracer gas techniques have been described. It has been shown that unfiltered inleakage within a CRE *can* be measured in a straightforward manner to better than +/- 10% in periods of less than eight hours.

The ability to measure actual inleakage in an operating ventilation system relates directly to the entire issue of safety and habitability of operating nuclear power plants during accident conditions as specified in GDC 19. An experimental method (or methods) to measure inleakage will result in more reliable estimates of Control Room Envelope integrity, and hence operator safety, in the event of a toxic gas release or radiological accident. The ability to reliably demonstrate the safety of control room occupants under accident conditions will provide immeasurable benefits both to the federal government and to the nuclear power generating industry.

5.0 ACKNOWLEDGMENT

This work was supported in part by a US Nuclear Regulatory Commission Small Business Innovation Research (SBIR) Grant, number NRC-04-94-070.

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TABLE 2.1

TRACER GASES AND MEASUREMENT DEVICES

Techniques	Gases
Thermal Conductivity Detector	H_2, He, CO_2
Electron Capture Gas Chromatograph	SF_6, Refrigerants, Perfluorocarbons
Flame Ionization Gas Chromatograph	C_2H_6
Infrared Absorption Continuous Analyzer	CO, CO_2, SF_6, N_2O, C_2H_6, CH_4

TABLE 2.2

RELATIVE GAS COSTS TAKING DETECTABILITY INTO ACCOUNT*

Gas	Detectable Concentration (ppm)	Maximum Measurable Volume per Dollar Ft^3	m^3
He	300	9.3×10^3	2.6×10^2
CO2	350**	3.2×10^4	8.9×10^2
N2O	1	2.8×10^6	7.9×10^4
SF6	5×10^{-6} (a)	5.6×10^{10}	1.6×10^9
SF6	1 (b)	5.6×10^4	1.6×10^3
CBrF3	5×10^{-5}	5.0×10^8	1.4×10^7
PDCB (c)	10×10^{-6}	1.3×10^9	3.7×10^7

* Based on 1994 Gas Prices for Size 1A Gas Cylinders. (1 Kgm liquid for PDCB)

** Average Background Concentration in the atmosphere.

(a) Detection by Electron Capture Gas Chromatography.

(b) Detection by Continuous IR Monitor.

(c) Perfluorodimethylcyclobutane

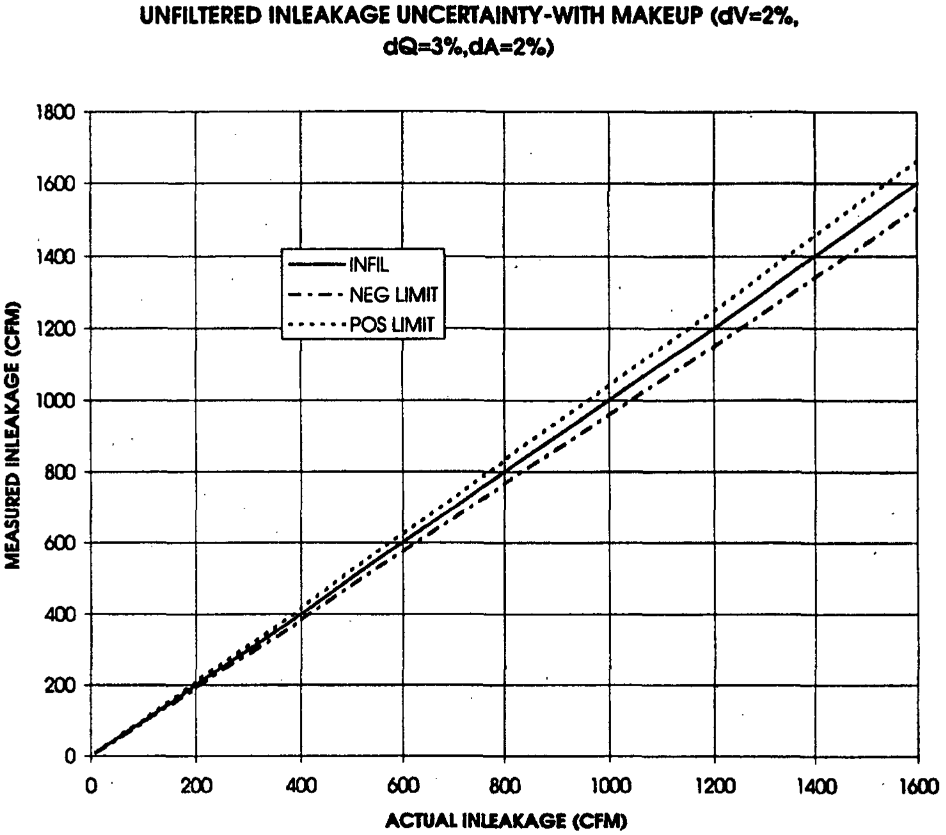


Figure 1. Unfiltered Inleakage with Makeup-Case I

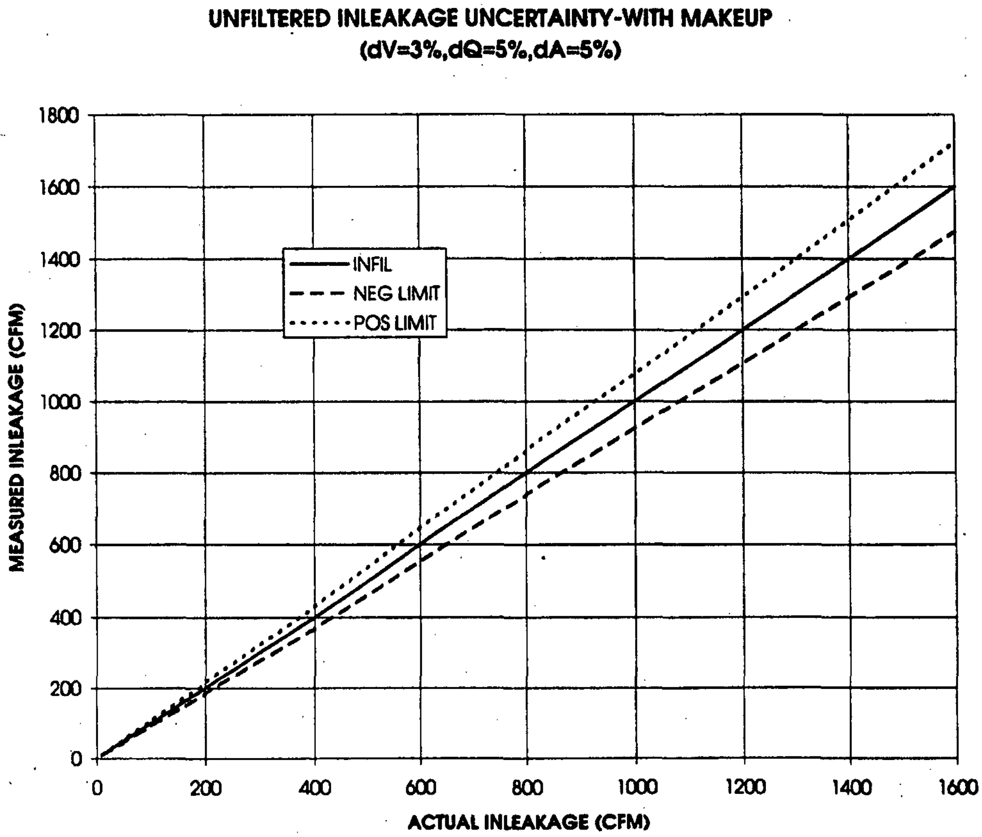


Figure 2. Unfiltered Inleakage with Makeup-Case II

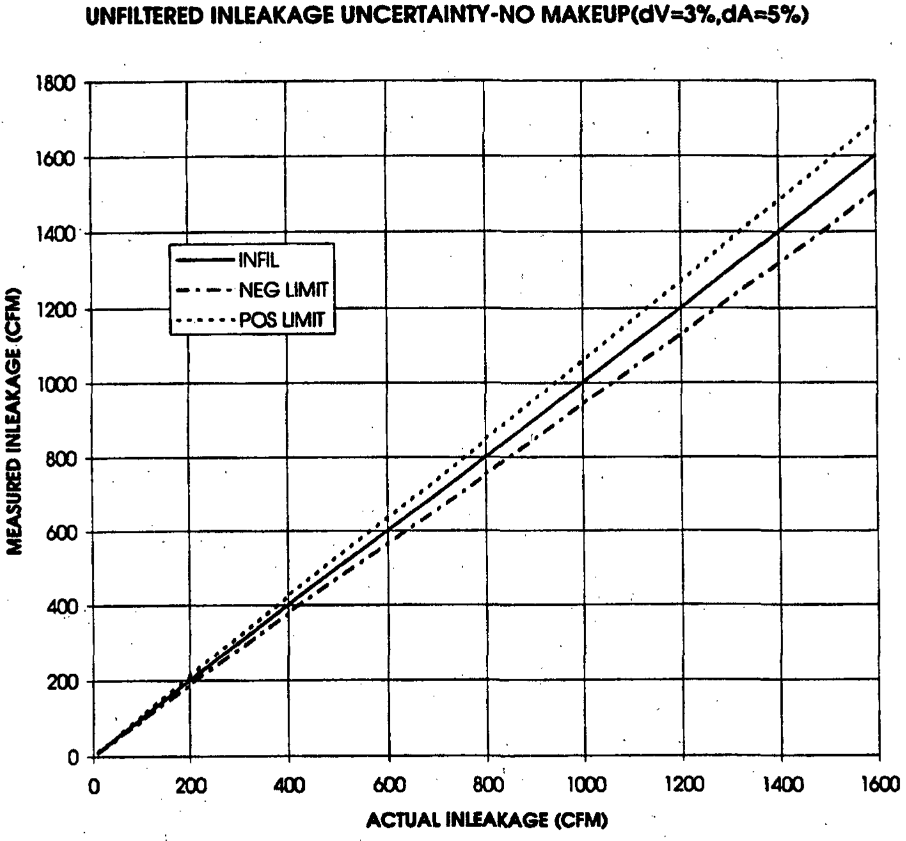

UNFILTERED INLEAKAGE UNCERTAINTY-NO MAKEUP(dV=3%,dA=5%)

Figure 3. Unfiltered Inleakage no Makeup-Case III

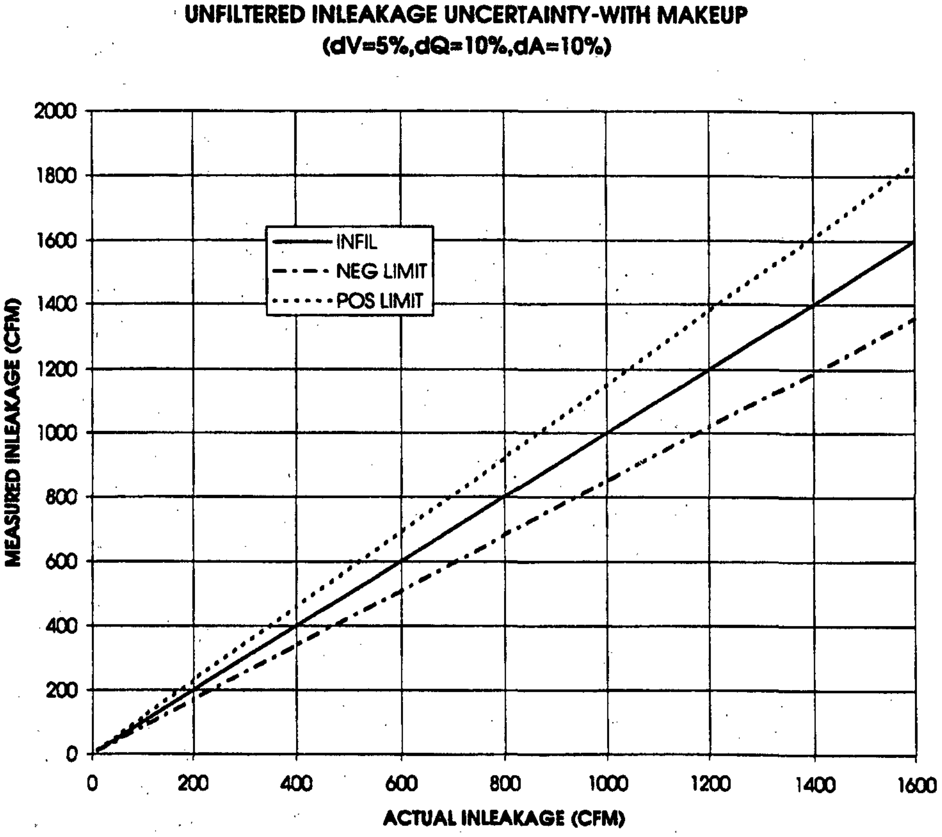

UNFILTERED INLEAKAGE UNCERTAINTY-WITH MAKEUP
(dV=5%,dQ=10%,dA=10%)

Figure 4. Unfiltered Inleakage with makeup-Case IV

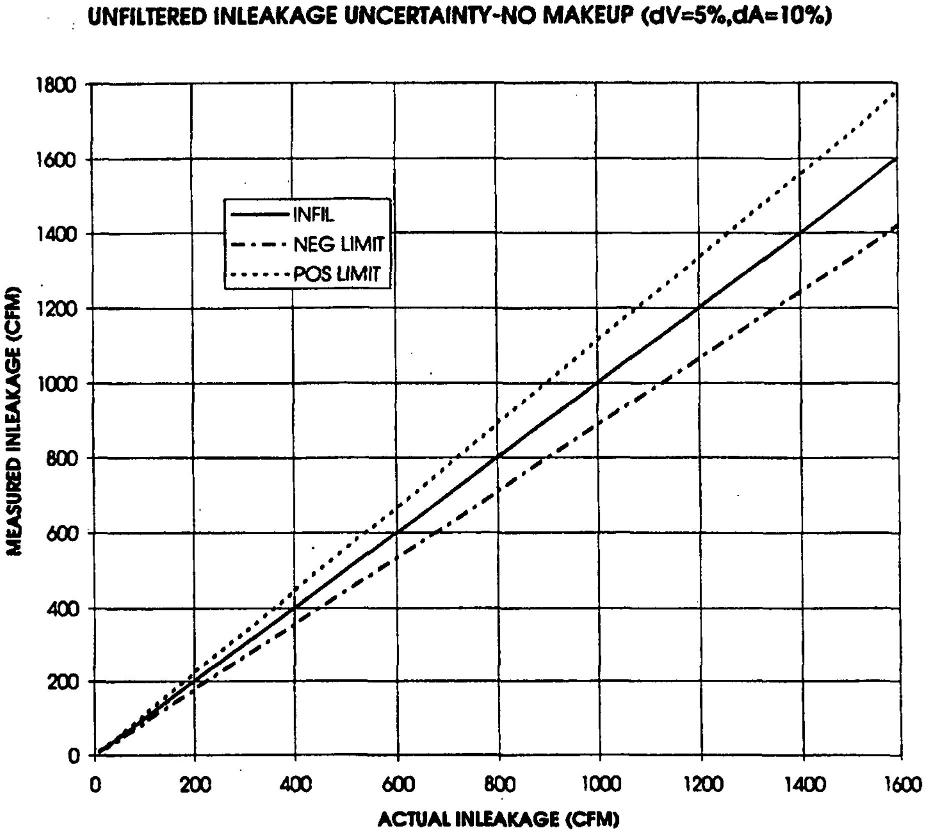


Figure 5. Unfiltered Inleakage no Makeup-Case V

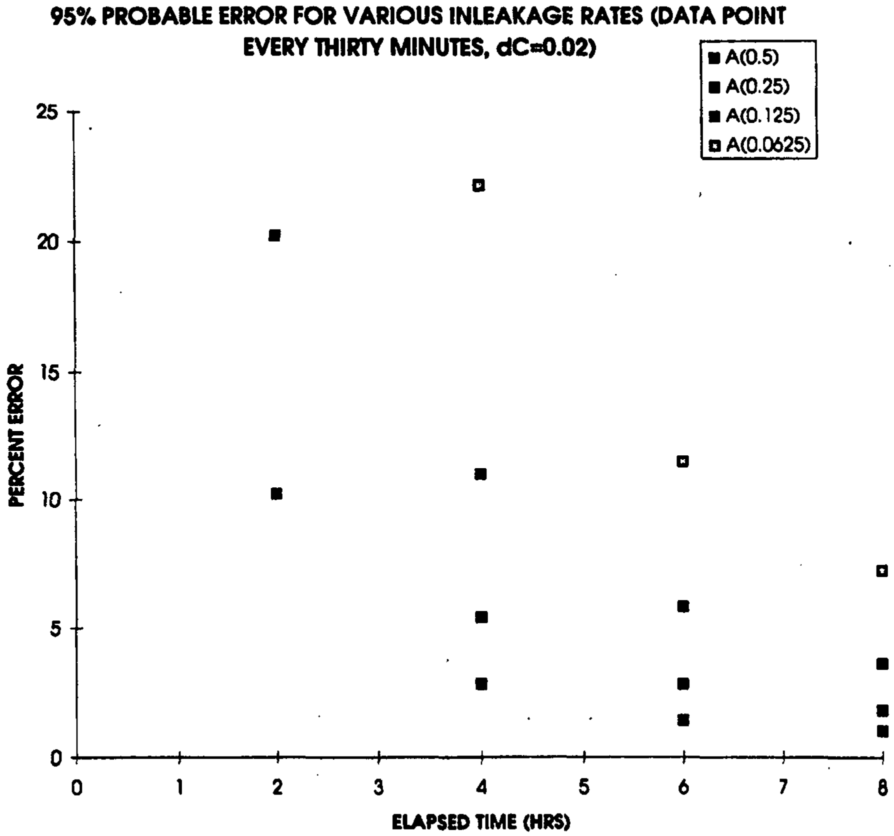
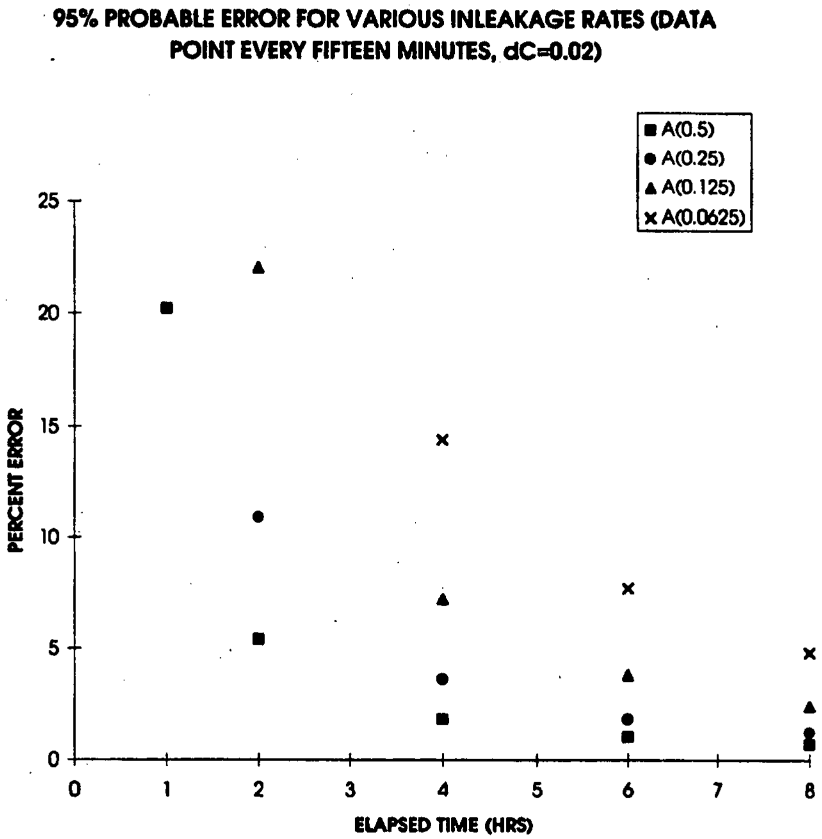
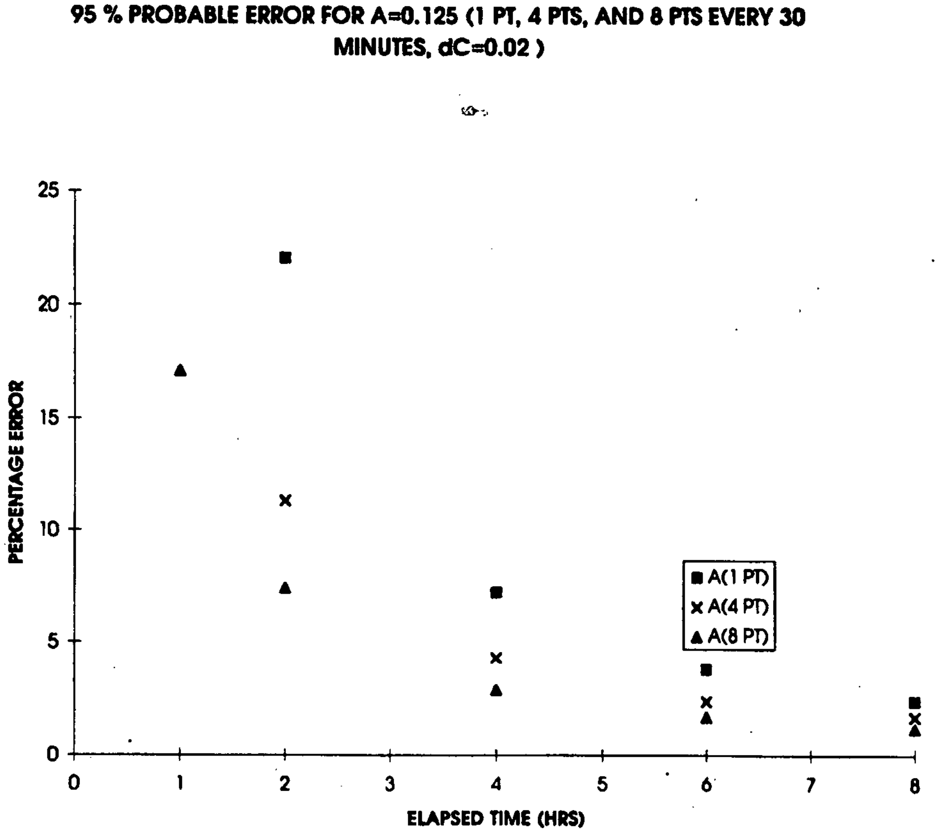


Figure 6. Probable Error-Data Point Every Thirty Minutes



95% PROBABLE ERROR FOR VARIOUS INLEAKAGE RATES (DATA POINT EVERY FIFTEEN MINUTES, dC=0.02)

Figure 7. Probable Error-Data Point Every Fifteen Minutes



95 % PROBABLE ERROR FOR A=0.125 (1 PT, 4 PTS, AND 8 PTS EVERY 30 MINUTES, dC=0.02)

Figure 8. Probable Error-Multiple Points, dC=0.02

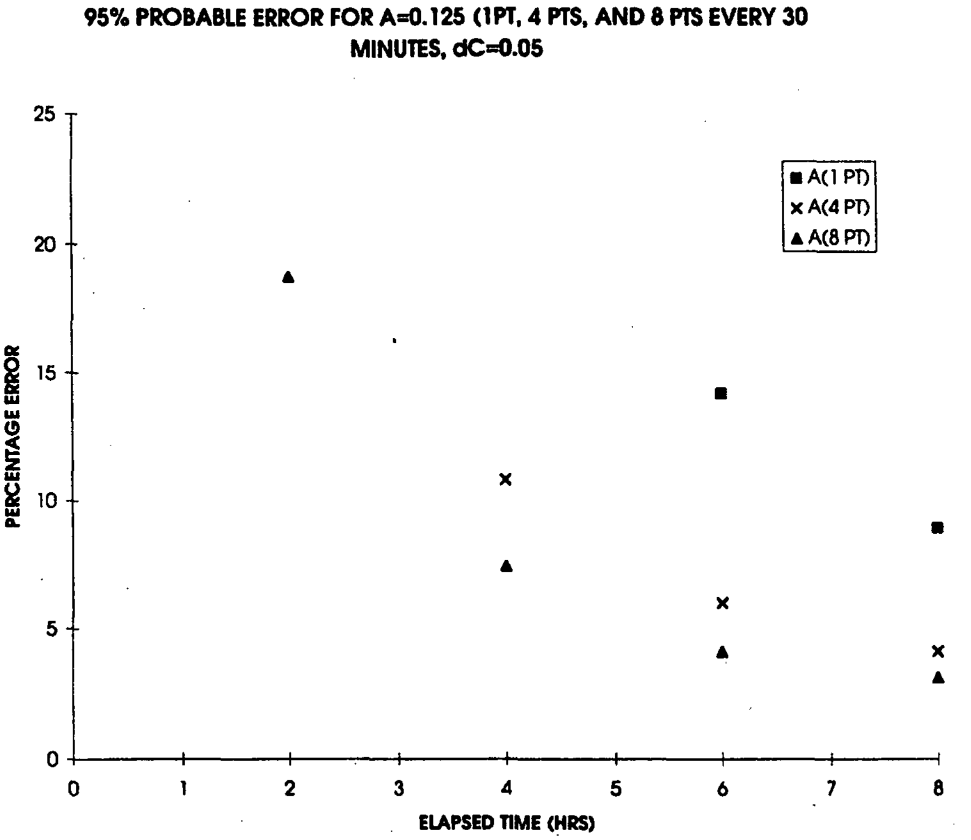


Figure 9. Probable Error- Multiple Points, dC=0.05

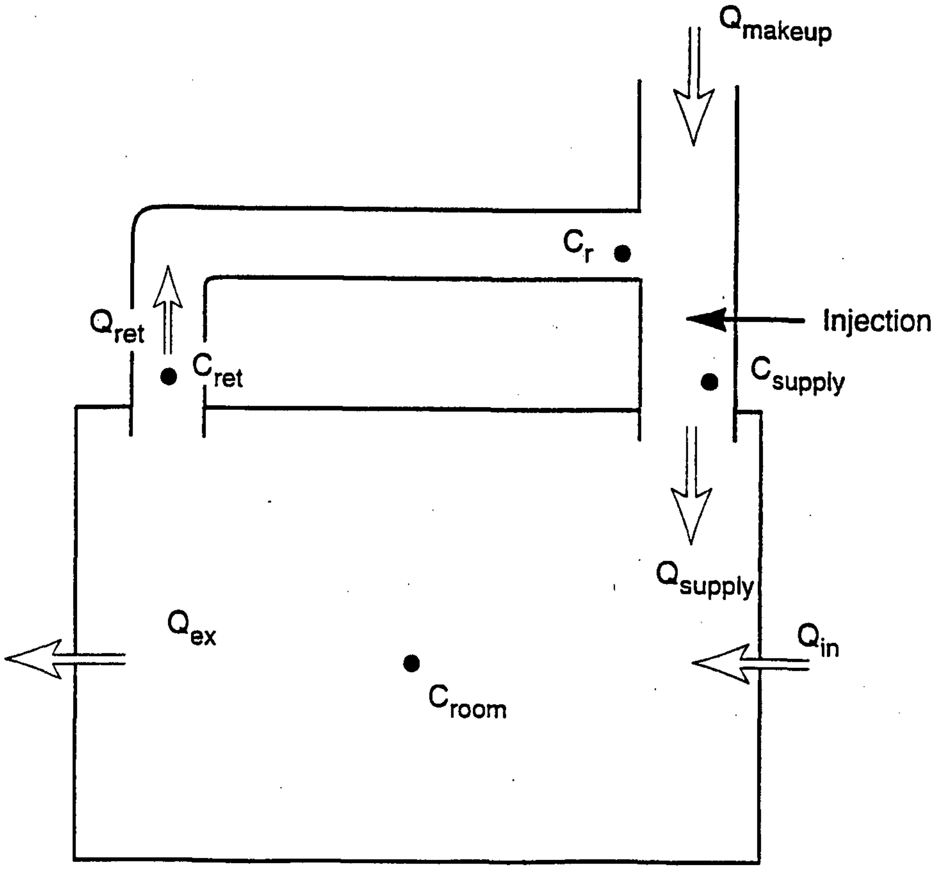


Figure 10. Control Room Envelope Test Parameters

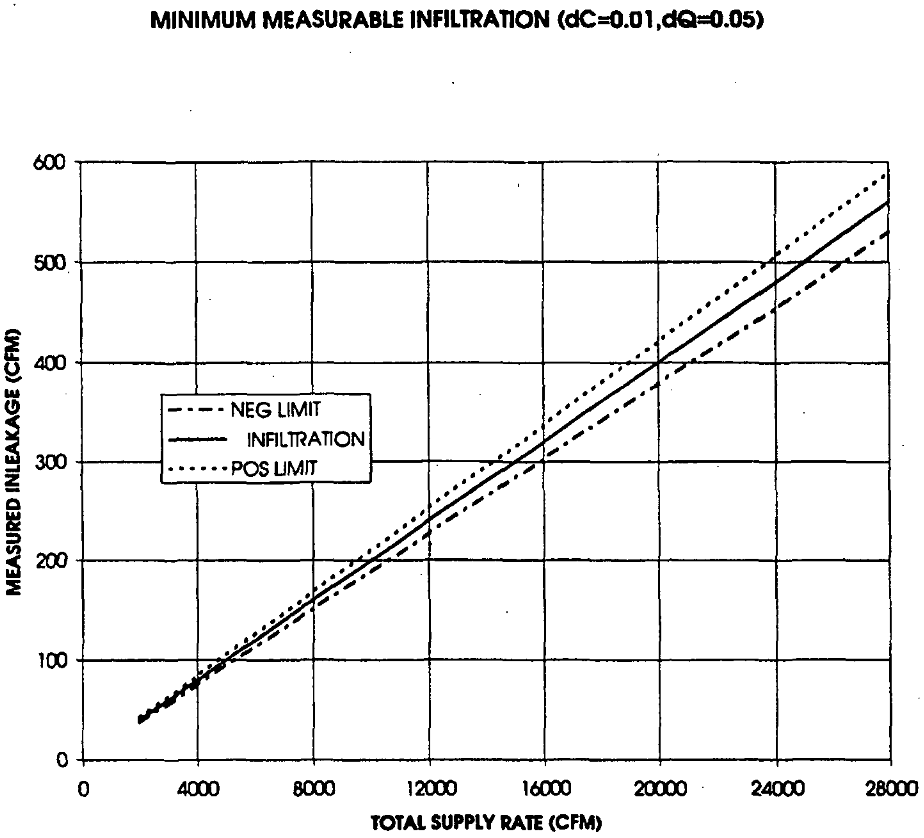


Figure 11. Minimum Measurable Inleakage, dC=0.01, dQ=0.05

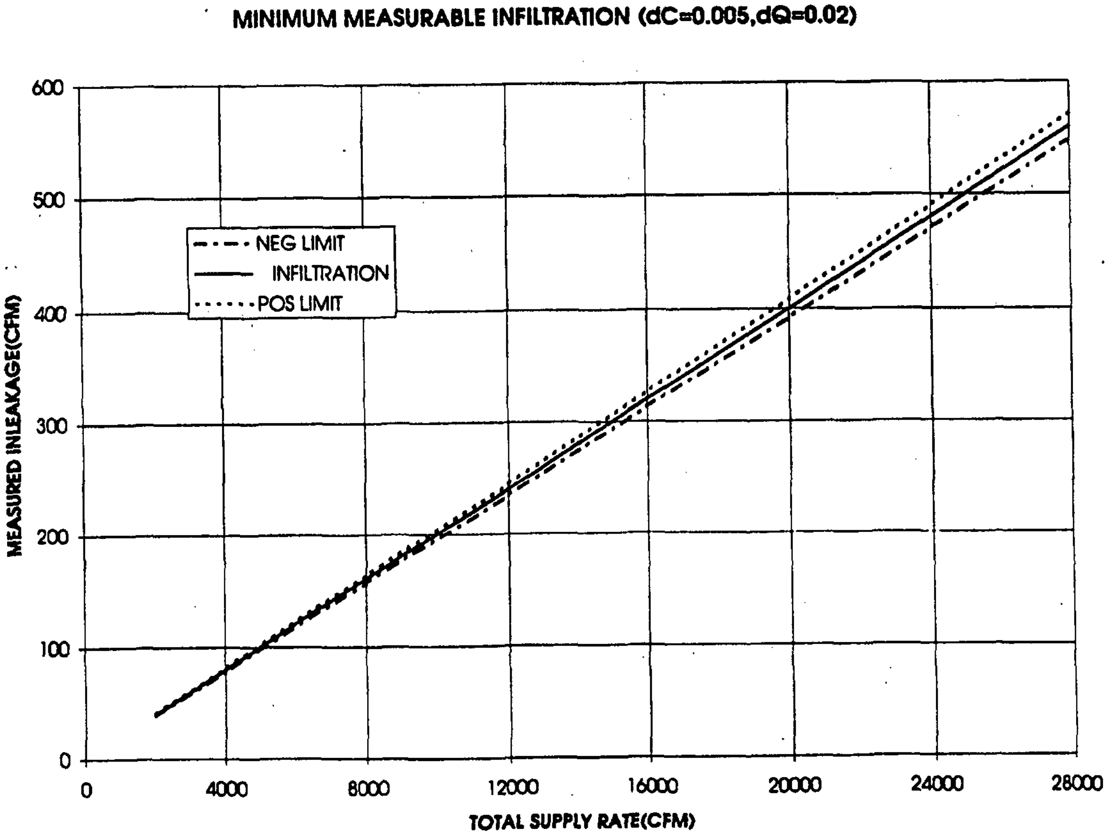


Figure 12. Minimum Measurable Inleakage, dC=0.005, dQ=0.02

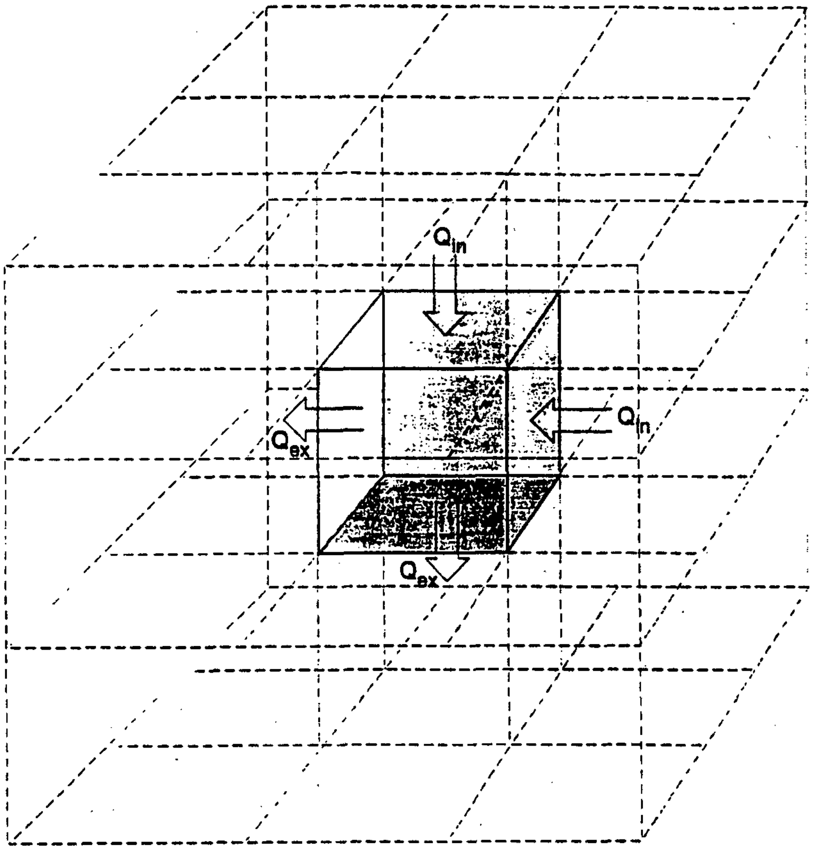


Figure 13. Control Room Envelope and Surrounding Regions

DISCUSSION

PORCO: I will exercise the chairman's prerogative and ask you a couple of very quick questions. How many control rooms has your protocol been applied to? How good was the data correlation? If you would, also mention how you achieved the good mixing that you mentioned in your paper.

LAGUS: We have done three plants, two systems in two of them and one in one of them including a control room. In terms of the uniformity test protocols, we were getting mixing of better than about 3%.

PORCO: What was your correlation between plants?

LAGUS: I do not understand what you mean by correlation between the plants.

PORCO: Was your inleakage consistent at different plants?

LAGUS: Very different from plant to plant.

PORCO: By about how much?

LAGUS: By a factor of six.

PORCO: The last part of my question was about mixing, how do you achieve good mixing of the tracer gas?

LAGUS: We achieved mixing by careful placement of the rather large twenty-four inch diameter mixing fans. We used six or eight of them in conjunction with the control room recirculation system to provide additional mixing. We would make measurements at a minimum of six or eight points at diverse locations and then run standard deviations on the numbers. In a single source control we were able to obtain mixing with relative standard deviations on the order of 3%. We did one at a two story control room where we got mixing of about 5%.

PHILIPPI: How does the control room leakage measurement protocol accommodate wind pressure changes from the outside, or pressure excursions in adjacent rooms? How do they affect the leakage of your control room?

LAGUS: On these tests we normally measure the control room envelope differential pressure between the inside and the outside, however that happens to be defined for a particular plant. Instead of accommodating, we basically measure it. What we are asking is, how does the system perform as it is being used? We have no control over the wind. What we have to do is be a) aware of the wind, b) be aware of the pressure characteristics, and then c) measure the performance of the system as it is being affected by the external variables. For instance, we try to minimize ingress and egress and things like that, but naturally occurring variables are the same variables that a plant is going to be subjected to. So, we are much more interested in finding out how it behaves under those circumstances than trying to make calculations or allowances for it. What you are going to find is that the effects of wind are certainly going to be a secondary effect, simply because, for most of the winds, you are not going to have wind pressures that are comparable to the kinds of pressures that one actually tries to generate inside a control room.

ENGELMANN: We know that there is in-leakage into ventilation systems when operating even in recirculation mode. Also, the air exchange of the room is enhoused with fans or recirculation are operating. Will you please discuss how you account for this?

LAGUS: The tracer technique incorporates all inleakage paths into the control room envelope (CRE), even those due to the CRE ventilation system, if that system or part of it is located outside the CRE boundary. Since the tracer technique allows one to measure the inleakage under actual operating conditions, if air exchange (unfiltered inleakage) is enhanced by operation of fans or recirculation, the data will reflect that. In fact we have undertaken a test in one control room in which the difference in inleakage was measured between the case of the pressurizing fan operating and not operating.

VARIABLE PATTERN CONTAMINATION CONTROL UNDER POSITIVE PRESSURE

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Abstract

Airborne contamination control in nuclear and biological laboratories is traditionally achieved by directing the space ventilation air at subatmospheric pressures in one fixed flow pattern. However, biological and nuclear contamination flow control in the new Biological Research Facility, to be commissioned at the Chalk River Laboratories in 1996, will have the flexibility to institute a number of contamination control patterns, all achieved at positive (above atmospheric) pressures. This flexibility feature, made possible by means of a digitally controlled ventilation system, changes the facility ventilation system from being a relatively rigid building service operated by plant personnel into a flexible building service which can be operated by the facility research personnel. This paper focuses on and describes the application of these unique contamination control features in the design of the new Biological Research Facility.

I. Introduction

Airborne contamination control in nuclear and biological laboratories is traditionally achieved by directing the space ventilation air at subatmospheric pressures in one fixed flow pattern. However, in the new Biological Research Facility (BRF) to be commissioned at the Chalk River Laboratories in 1996, the ventilation system will have the flexibility to effect a number of contamination control patterns at positive (above atmospheric) pressures. This pattern flexibility feature, made possible by means of a digitally controlled ventilation system, provides the researcher with the ability to design contamination control patterns which serve the unique requirements of each research program and to accommodate abnormal ventilation system conditions. The ventilation system is therefore no longer a relatively rigid building service operated by plant personnel, but it can become the direct responsibility of the research personnel who are intimately aware of animal welfare and the research program requirements. The requirement to pressurize the facility arises from the fact that the animal housing rooms, laboratories which may temporarily house animals and the animal care support rooms must be pressurized with High-Efficiency Particulate Air (HEPA) filter ventilation air in order to minimize the intrusion of air-borne contamination (viruses and bacteria) from the outside.

This paper focuses on and describes this unique contamination control approach as it is applied in the BRF. (Ref. Figure 1 Main Floor Plan & Figure 2 Upper Floor Plan). The BRF classification, hazards, special requirements and a brief ventilation system description are given to provide a facility overview and an appreciation of its contamination control issues.

II. Facility Usage, Hazards, Classification & Requirements

The new BRF will be used to conduct animal-based biological research work on rodents using carcinogens, radiation and radioisotopes. The research is primarily to study the carcinogenic effects of ionizing radiation separately and in combination with other materials and the facility is intended to support these studies at the molecular, cellular and whole-animal levels.

Hazardous materials used in the research laboratories are limited to small quantities of:

- carcinogenic tumor initiators (DMBA and MNNG) and promoters (TPA and Mezerein);
- Radioisotopes (Tritiated water, tritiated organic compounds, C-14 amino acid or other C-14 compounds); and
- uranium oxide (dust).

The external beam radiation facilities utilizes Co-60 and Sr-90. (1)

The facility is classified as CRL Category 2, that is, one where the potential for a significant hazard is limited to the facility and its operators. (2)

The BRF specification included the following requirements to provide

- animal housing and care to meet and exceed current Canadian Council on Animal Care standards (3);
- a research environment consistent with quality-assured research programs;
- effective, predictable and flexible contamination control means under both normal * and abnormal ** operating conditions;
- a safe, licensable laboratory; and
- ALARA working conditions for the facility operating and research staff.

III. Ventilation System Description

Ventilation System:

The supply side of the ventilation system consists of two parallel roof-mounted draw-through air-handling and air-conditioning units, each rated at 50% of the total building ventilation air supply rate. Each unit has means to prefilter, heat, cool/dehumidify, reheat, supply and final filter the building fresh air supply to meet the building space air change and environmental conditioning requirements. Supply air terminal reheat is provided to meet the specific temperature requirements of each room and laboratory. The ventilation exhaust side consists of the following six main exhaust systems:

E-1/2/3	General Building Exhaust ***
E-4/5/6	Fumehood and BSC Exhaust ***
E-7/8/9	Carcinogen Area Exhaust ***
E-10	Janitor and Washroom Exhaust,
E-12/13	Scavenger and Solvent Storage Exhaust and
E-14/15	Cage Washer Exhaust

---

* Normal operating conditions are day-to-day operations when all electrical power demands are met from the local electrical power utility, all ventilation system equipment is functioning or available and all ventilation and contamination control requirements are achieved.

** Abnormal operating conditions are when the facility is on limited standby diesel-generated electrical power or when vital ventilation equipment is not available because of failure or maintenance outage.

*** Any two fans can achieve full system exhaust rate.

Due to severe budget limitations this project could not support the provision of 100% standby boilers, diesel generated electrical power and ventilation system redundancy. Alternative design features, described in Section VII, were therefore provided to ensure continuous normal operating condition ventilation rates to all rooms housing animals under both maintenance outage and power-failure abnormal condition scenarios.

Ventilation System Control:

Ventilation system supply and exhaust flow control is by Direct Digital Control (DDC). The DDC system to operator interface is by means of a central computer unit (CCU), which is basically a personal computer complete with a keyboard , screen and various in/output devices. The CCU directs and monitors a number of remote processing units, which in turn regulate the terminal equipment controllers.

The system is programmed to automatically regulate the ventilation system variable volume ventilation (VAV) boxes, equipment start/stop and damper or valve open/shut functions to one specific contamination control pattern until it is manually or automatically told to change to another pattern. Each pattern is a memorized number of ventilation system VAV box-flow-rate set points together with preset start-stop functions for several lesser ventilation systems. Pattern changes are initiated automatically when an abnormal condition is detected or manually to suit a different research program requirement. The system continually monitors specific system conditions and will automatically change to a suitable abnormal conditions pattern.

The facility operator can automatically or manually monitor and record facility environmental conditions, select preprogrammed operational scenarios or manually adjust individual system parameters and receive system annunciation and failure alarms. The remote processing units will stand alone and provide local system control even though they are disconnected from the CCU.

IV. Ventilation System Balancing

Balancing the BRF ventilation system supply and exhaust flow rates is vital to understanding, developing and documenting the various ventilation air flow patterns required to meet the normal and abnormal facility operations requirements. A basic spread sheet was prepared to account for and balance the supply, exhaust and in/out leakage for each of 68 spaces in the facility. Spaces varied in size from a 37 m-(120') long irradiation room to a 1 m-(3.3') deep janitor's closet under normal conditions. This basic normal operations ventilation system balance pattern is the starting point for the development alternative normal and abnormal operations patterns. All patterns have to be checked against the capabilities of the fan systems and the 110 space supply and exhaust VAV boxes. It should be noted that the accuracy and control range of VAV boxes is ± 24 L/s (50 cfm) of their set point down to about 20% of their rated flow. A number of VAV boxes serving nonanimal related spaces may be shut off under abnormal conditions. Figure 3 is a typical balancing spread sheet for rooms Y144, Y146 and Y148. Note that all the exhaust, transfer, out-leakage, supply and in-leakage rates are rigorously accounted for. It is through this form of accounting that any room rate changes being considered for a new pattern can be assessed for their impact on the whole building ventilation system capability.

V. Facility Contamination Control Features:

A broad range of contamination control features that affect all aspects of facility operations, covering all contamination routes into, within and out of the facility were incorporated into the BRF design. All rooms are color-coded denoting the space usage, contamination potential and appropriate material and personnel traffic limitations. Special consideration was taken in the design of ventilation, mechanical and electrical services for each color-coded area so that their peculiar requirements were met.

The main features are:

Facility Personnel and Material Traffic Contamination Control:

The BRF is connected to an adjacent Biology Laboratory Building by a second floor bridge. Entry is electronically controlled and research personnel entering the facility shower and change into appropriate clothing on the second floor level before proceeding to the main floor.

Shipping and receiving entrances, at the main floor level, are equipped with fumigation, sterilization and storage facilities to control the entry and exit of contaminated materials.

Facility Contamination Arising from Maintenance Operations:

The facility building upper level plan (Figure 2) shows that an area almost as large as the entire building plan is provided for mechanical and electrical services. A considerable effort has gone into separating service equipment and piping from the animal and laboratory spaces. The location of ventilation equipment, ducting, dampers, piping, valves, power supplies, electrical panels, controls and instrumentation outside of the animal and laboratory spaces minimizes the probability that maintenance personnel will have to enter them.

Airborne Contamination Entry from Outside:

The number of window and door penetrations in the facility exterior building wall have been kept to a minimum and, by keeping the building at above atmospheric pressure with an over-supply of HEPA-filtered and temperature/humidity-conditioned air, out-leakage at the building perimeter minimizes the entry of airborne contaminants from outside the building.

Airborne Contamination Movement Within the Building:

The uncontrolled movement of facility ventilation air is minimized by placing great emphasis on sealing all wall, ceiling and floor penetrations. The controlled movement of facility ventilation air is effected by regulating the relative rates of room supply and exhaust. This regulation of room ventilation air supply and exhaust rates is used to produce directional air flow patterns and air change rates customized for the specific research program requirements. For example, in Figure 4 the animal holding rooms, Y144 and Y148, are over-supplied to leak ventilation air into the adjacent ante room, Y146, which in turn leaks it to an adjacent corridor.

Airborne Contamination Movement When a Door Between Adjacent Rooms is Opened:

There is a relatively small contingent of personnel (3 to 5 people) in charge of the facility. Entry into the facility by other research, operating and maintenance personnel is very restricted. Facility operating personnel are trained to work to formal procedures and are aware of the special requirements of the animal based research facility. Room-to-room traffic is kept to a minimum: thus doors between adjacent spaces are closed most of the time and only opened for very short periods throughout a typical work day for very specific purposes. It is recognized that the rate of flow through an open door is too small to prevent upstream contamination movement. However, adjacent spaces such as the ante rooms, serve as air-locks that minimize/restrict the spread/flow of contamination to areas that are beyond the immediate attention of the trained personnel entering or leaving the area.

Work Station Airborne Contamination Control:

Work stations such as Class II B2 Bio-safety cabinets (BSC) and fume hoods, located inside the above atmospheric pressure rooms and laboratories, serve to control the spread of contamination from the stations by maintaining inflow velocities consistent with proper cabinet and fume-hood operation practices.

Animal Cage Airborne Contamination Control:

Recent developments in small animal cages rack designs, Figure 5, have included a means of connecting each rack of cages directly to the building HVAC system, thereby isolating each animal cage from the ones adjacent to it and providing each cage with a known ventilation supply and exhaust rate. As this development becomes the norm for up-to-date animal care, this facility will be able to accommodate the change from room supply and exhaust ventilation to a combination of room and direct cage rack ventilation. An additional complexity is introduced here in that the number of racks in each animal holding room is a variable that must be accommodated by the room ventilation supply and exhaust control system. The BRF animal housing room and laboratory ventilation systems have the ability to divert room ventilation air to and from one to six cage racks in each housing room.

VI. Normal Operations Contamination Control Pattern Variations

Typical Pattern With Direct Room Ventilation

The Figure 4 Normal Operations #1a Pattern Diagrammatic Flow Sheet shows Rooms Y144, Y146 and Y148 with direct room ventilation. The excess supply air is shown as out-leakage and is added to the exhaust total to create a supply and exhaust balance in the room. The out-leakage of course becomes part of the supply balance in the adjacent Y146 room. Any number of Normal Operations ventilation patterns can be devised to suit current research programs. For example, Room Y144 could be balanced to leak inwards from Room Y146.

Typical Pattern with Direct Cage Ventilation

Figure 6 shows the Normal Operations #1b Pattern Diagrammatic Flow Sheet for Animal Housing Room Y144 when it is equipped with six directly ventilated cage racks rated at 28 L/s (60 cfm) supply and exhaust. The total animal housing room rack exhaust and supply rates of 170 L/s (360 cfm) are diverted from the direct room supply and exhaust ventilation rates. The room ventilation air change rate is however not allowed to drop below a prescribed value. A number of contamination control patterns with direct cage ventilation for from one to six cage racks to suit current research programs will be required for each room equipped with ventilated cage rack supply and exhaust services.

VII. Abnormal Operations Contamination Control Pattern Variations

The ability to provide flexible ventilation/contamination control patterns provides a method of dealing with abnormal power and equipment outage conditions. Figure 7 shows the Abnormal Conditions Pattern #2 diagrammatic arrangement for Animal Housing Rooms, Y144. Y146 and Y148, where the fume-hood exhaust rate in Room Y146 is reduced to conserve supply air for the animal related spaces. The DDC-controlled ventilation system is thereby able to provide normal contamination control patterns in animal-related rooms, and rooms that can tolerate ventilation changes are either shut down or their rates are significantly reduced during the abnormal condition.

VIII. Conclusion

Variable contamination control pattern capability provides facility operations flexibility that meets current and future animal welfare and research program environmental requirements. It takes facility ventilation systems from being a relatively rigid building service operated by plant operating personnel and gives facility research personnel the responsibility for and means to provide quality-assured animal, personnel and program environments.

IX. References

1 NSN-ESRSD-140	AECL, CRL Environmental Safety & Regulatory Services, Safety Analysis Report of the Biological Research Facility (BRF)
2 SRC-R-1	AECL Safety Review Committee Requirements for Review and Approval of New Facilities
3 CCAC	Canadian Council on Animal Care Guideline

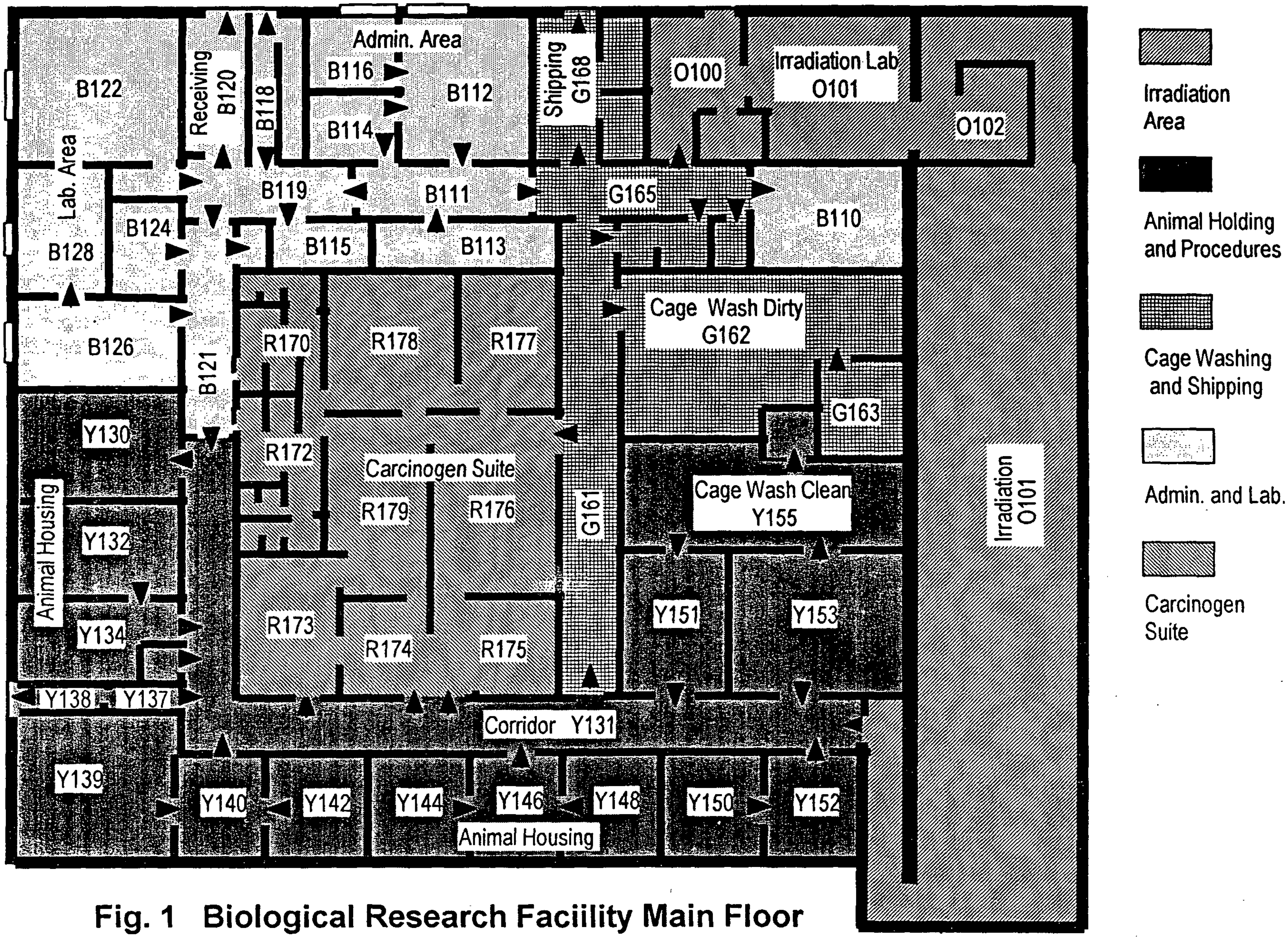

Fig. 1 Biological Research Faciility Main Floor

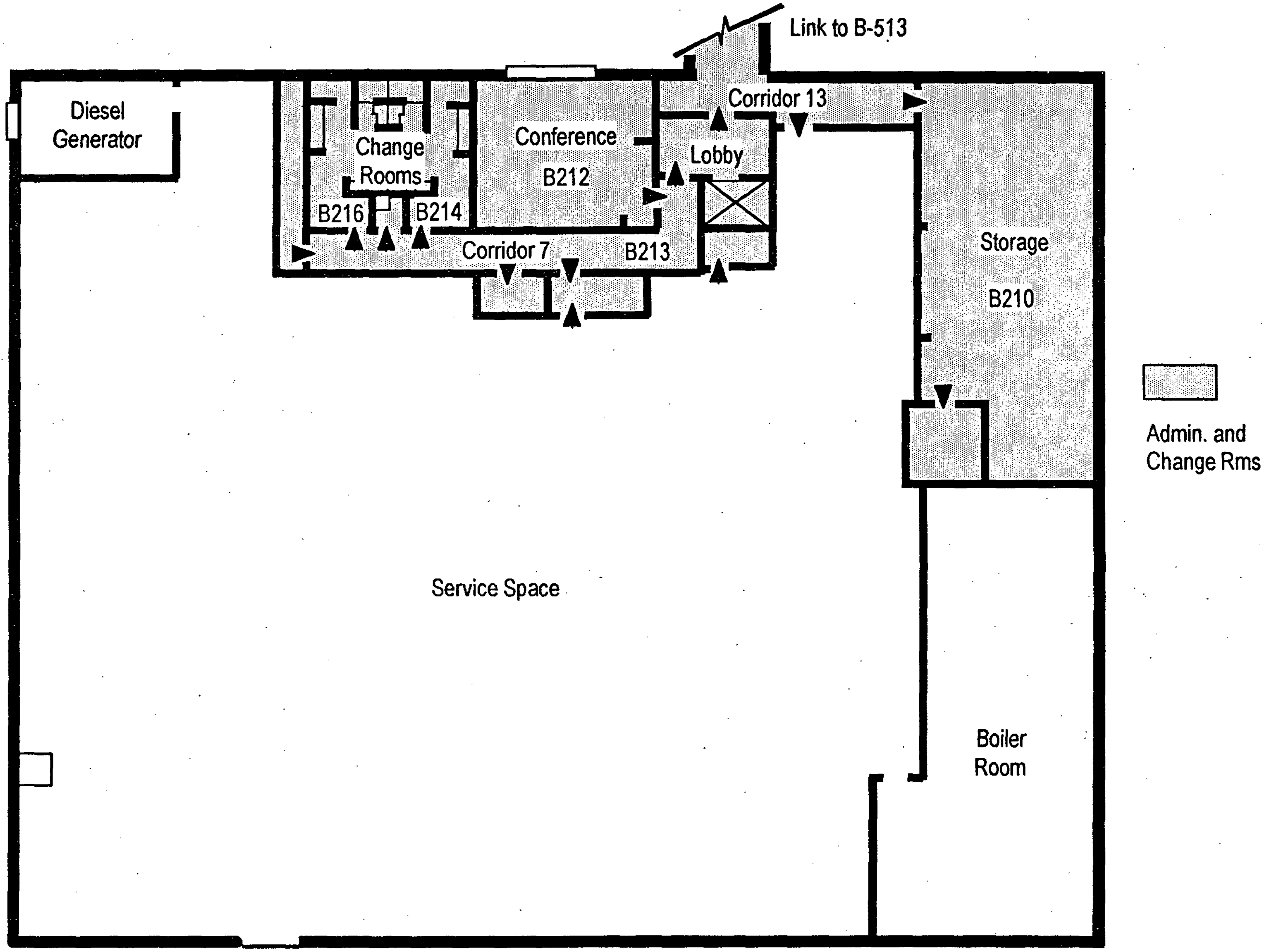

Fig. 2 Biological Research Faciility Upper Floor

Rm Y144		Exhaust Fan System (litres / sec.)									OUTFLOW (litres / sec.)			INFLOW (litres / sec.)			
Housing AB		VAV #	E-123	E-456	E-789	E-10	E-1213	E-14	E-15	Transf	Exh.	Transf	Exfilt.	VAV #	Supply	Transf	Infilt.
Length (m)	Room	Y144EB1	198											Y144SB1	245		
4.0	Doors																
Width (m)	146												47				
4.0	sealed145																
Height (m)	Transfer																
2.6	Rack	Y144EB2	0											Y144SB2	0		
Vol. (m3)	Fume:																
41.6	Fume Hood																
Room	BSc																
Chg./Hr	Canopy																
21.2	Room Totals		198	0	0	0	0	0	0	0	198	0	47		245	0	0

Rm Y146		Exhaust Fan System (litres / sec.)									OUTFLOW (litres / sec.)			INFLOW (litres / sec.)			
AnteRoom AB		VAV #	E-123	E-456	E-789	E-10	E-1213	E-14	E-15	Transf	Exh.	Transf	Exfilt.	VAV #	Supply	Transf	Infilt.
Length (m)	Room													Y146SB1	496		
4.0	Doors																
Width (m)	147												47				
3.6	146 148																94
Height (m)	Transfer																
2.6	Rack	Y146EB2	0											Y146SB2	0		
Vol. (m3)	Fume:																
37.4	Fume Hood	Y146EB1		543													
Room	BSc																
Chg./Hr	Canopy																
56.7	Room Totals		0	543	0	0	0	0	0	0	543	0	47		496	0	94

Rm Y148		Exhaust Fan System (litres / sec.)									OUTFLOW (litres / sec.)			INFLOW (litres / sec.)			
Housing AD		VAV #	E-123	E-456	E-789	E-10	E-1213	E-14	E-15	Transf	Exh.	Transf	Exfilt.	VAV #	Supply	Transf	Infilt.
Length (m)	Room	Y148EB1	198											Y148SB1	245		
4.0	Doors																
Width (m)	148												47				
4.0	sealed149																
Height (m)	Transfer																
2.6	Rack	Y148EB2	0											Y148SB2	0		
Vol. (m3)	Fume:																
41.6	Fume Hood																
Room	BSc																
Chg./Hr	Canopy																
21.2	Room Totals		198	0	0	0	0	0	0	0	198	0	47		245	0	0

FIG. 3 BRF - Normal Contamination Control Pattern #1a (No Ventilated Racks)

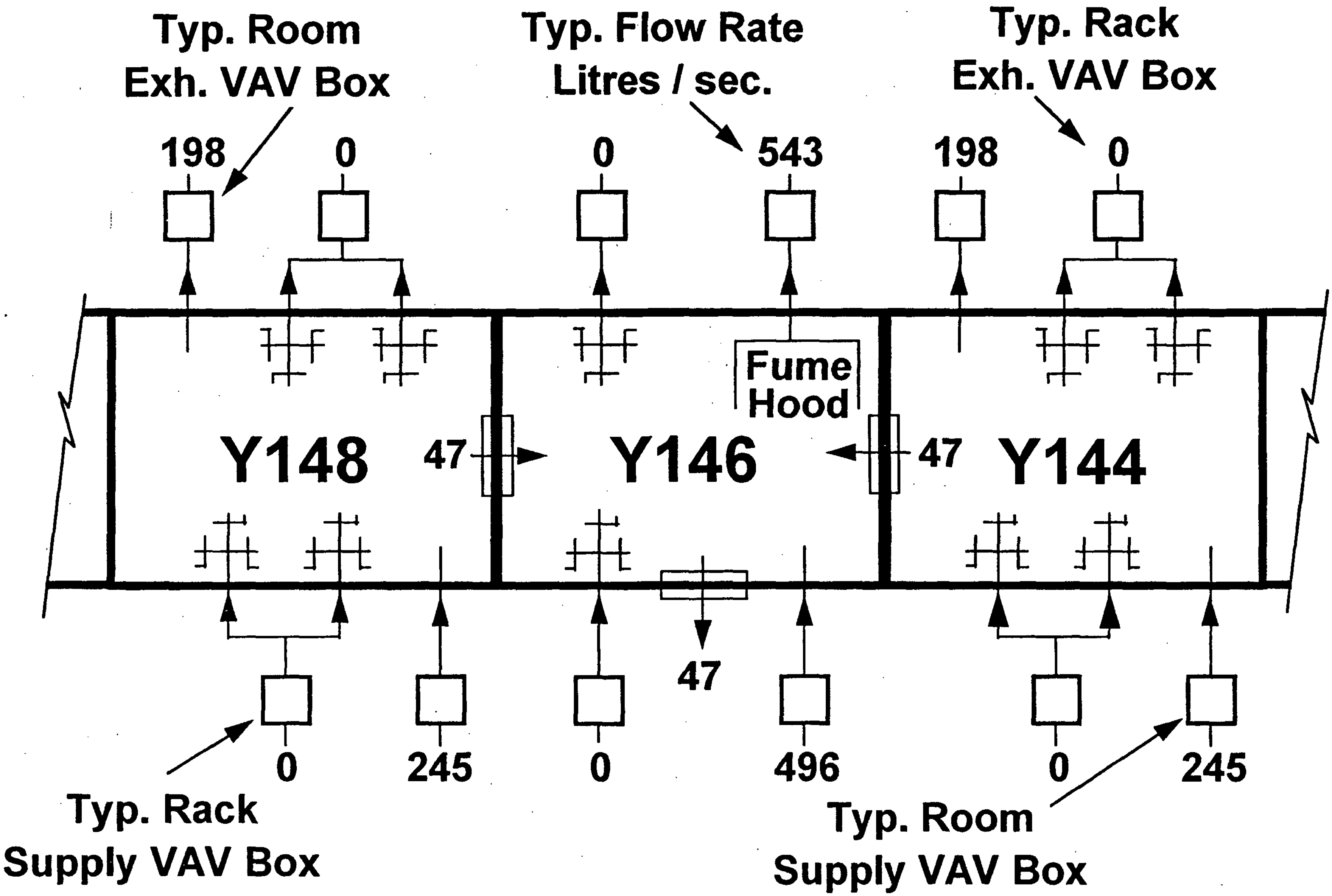

FIG. 4 Bioological Research FacilityNormal Conditions Pattern #1a Rooms. Y144, Y146 and Y148 Flow Sheet Diag.

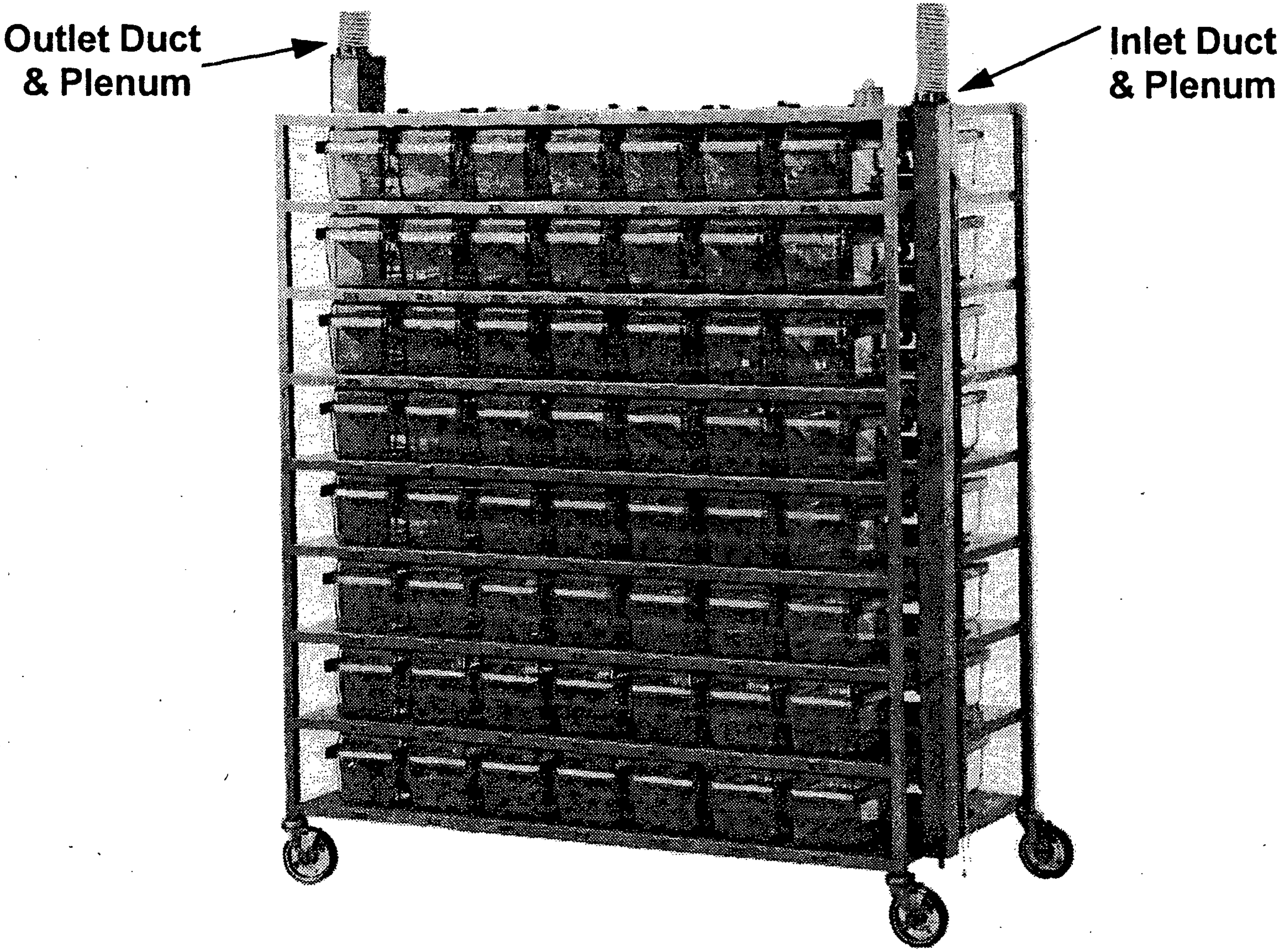

FIG. 5 Biological Research Facility Directly Ventilated Animal Cage Rack

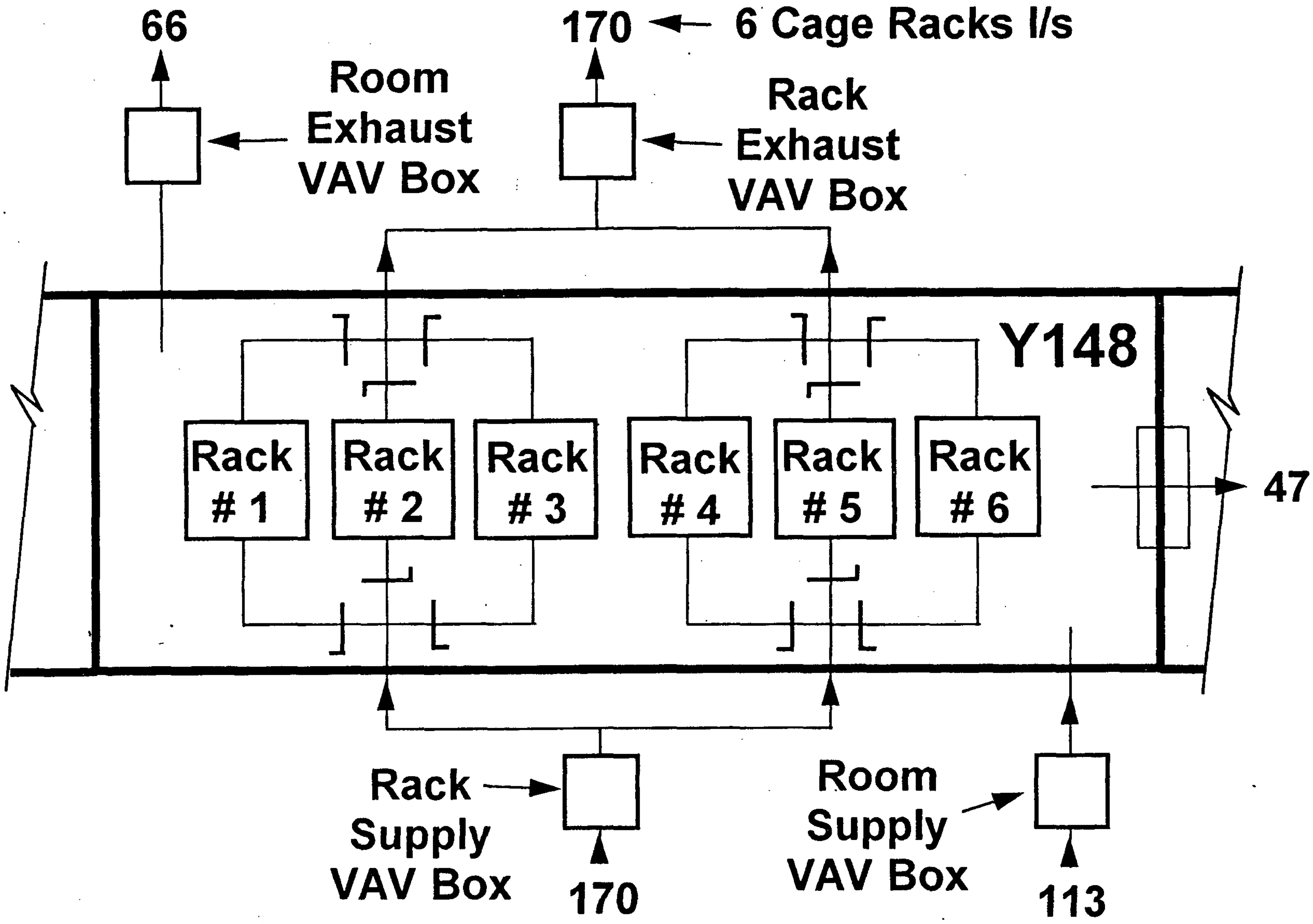

FIG. 6 Biological Research Facility Normal Conditions
Pattern #1B Room. Y144 Flow Sheet Diag.

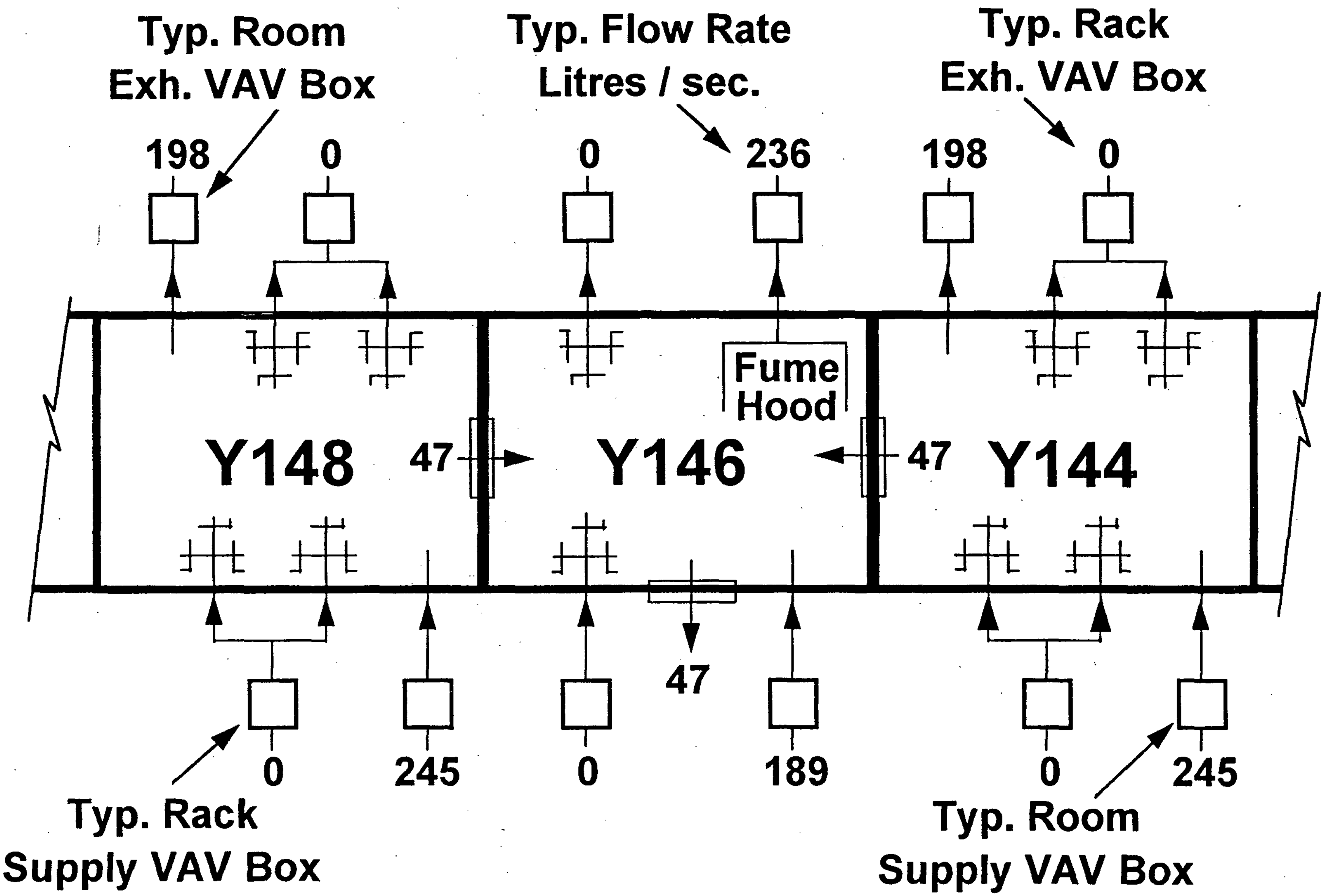

FIG. 7 Biological Research Facility Abnormal Conditions Pattern #2 Room. Y144 Flow Sheet Diag.

AEROSOL DEPOSITION IN BENDS WITH TURBULENT FLOW[1]

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Abstract

The losses of aerosol particles in bends were determined numerically for a broad range of design and operational conditions. Experimental data were used to check the validity of the numerical model, where the latter employs a commercially available computational fluid dynamics code for characterizing the fluid flow field and Lagrangian particle tracking technique for characterizing aerosol losses. Physical experiments have been conducted to examine the effect of curvature ratio and distortion of the cross section of bends. If it curvature ratio ($\delta = R/a$) is greater than about 4, it has little effect on deposition, which is in contrast with the recommendation given in ANSI N13.1-1969 for a minimum curvature ratio of 10. Also, experimental results show that if the tube cross section is flattened by 25% or less, the flattening also has little effect on deposition. Results of numerical tests have been used to develop a correlation of aerosol penetration through a bend as a function of Stokes number (*Stk*), curvature ratio (δ) and the bend angle (θ).

I. Introduction

Aerosol losses in bends can be significant. For example, the wall loss of 10 μm aerodynamic diameter aerosol particles in a 25.4 mm (1-inch) diameter 90° bend at a flow rate of 57 L/min (2-cfm) is calculated to be 9.5% by the DEPOSITION code (Anand et al., 1993). The code predicts the same losses would occur in 95 m of vertical tubing of the same size at the same flow rate. A typical system that continuously extracts a sample from a stack or duct will have at least one bend, which is generally needed to change the flow direction of the sampled stream from parallel to the duct axis to perpendicular to the axis. For batch sampling applications, such as US Environmental Protection Agency (EPA) Methods 5 and 17 (US EPA, 1995a and 1995b), the losses of aerosol particles in a transport system are of little consequence because the inside walls are washed at the completion of a

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[1] Funding for this study provided by the U.S. NRC under Grant NRC-04-94-099 and by the Amarillo National Resource Center for Plutonium (ANRCP). ANRCP funding was awarded through the University of Texas under Contract UTA95-0278. Dr. Stephen A. McGuire is the Project Officer for the NRC Grant, and Dr. Howard Liljestrand if the Principal Investigator for the ANRCP Grant.

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batch test to recover inadvertently deposited aerosol sample. In contrast, for continuous emission sampling (CES), the system must operate for extended time periods and may be required to provide samples for near-real time data on aerosol concentration in the stack or duct (continuous emission monitoring, CEM). Any losses on the internal walls of a sampling system degrade the quality of emission or concentration data. For sampling potentially significant nuclear sources, EPA requires that methodology for CES must follow the protocol of the American National Standards Institute N13 1-1969 (ANSI, 1969), which stipulates that an evaluation shall be made of aerosol losses in a sampling system. However, EPA also permits US Department of Energy facilities (DOE) to use Alternate Reference Methodologies (EPA, 1994). The Alternate Reference Methodologies require that at least 50% of 10 µm aerodynamic diameter (AD) aerosol particles must penetrate through a transport system from the free stream in a stack or duct to the collector or analyzer. Use of the DEPOSITION software for determining compliance with this requirement is part of the Alternate Reference Methodologies.

The DEPOSITION software includes submodels for predicting losses in probes, straight transport lines, bends, and expansion and contraction fittings. For the bends, the software currently uses the model of Cheng and Wang (1981) for laminar flow and the model of Pui et al. (1987) for turbulent flow. Because most flows in sample transport systems are turbulent, the model of Cheng and Wang is not generally applicable. The model of Pui et al. only takes into account the effect of the Stokes number, and as it shall be shown herein, the curvature ratio and bend angle also affect deposition in turbulent flow. In this study, we established a numerical base for penetration of elbows and used that data base to develop a correlation model to predict particle penetration. Such a model could be used in the DEPOSITION software.

In the numerical modeling effort, we have assumed that geometrical extent of the a bend encompasses only the region where the centerline of the bend is curved, Figure 1a. On the other hand, tests with physical models involved geometries where the extent of the bends reached the same two points in space, Figure 1b. The reason for using different geometries is that the purpose of the numerical work is to establish a data base for the correlation model. When a user employs the correlation model, deposition in any straight tubing attached to the bend will be analyzed separately from the bend itself. But, when we seek to compare the effects of curvature ratio on deposition, it is necessary to add straight tubing onto bends with small values of δ to provide a common basis of comparison, so that a bend with a short curvature ratio will not have an apparent advantage over a curve with a large curvature ratio as a result of the smaller distance that the flow travels in the bend

Flow Considerations.

Flow through straight tubes is generally characterized by the Reynolds number, with the flow being considered laminar when the Reynolds number, $Re = \rho U d_t/\mu$, is less than about 2300, turbulent when the flow is greater than about 3000 and transitional between those values. Here: ρ = fluid density; U = average (spatial) fluid velocity; d_t = tube diameter; and, μ = fluid viscosity. On the other hand, flow through bends of circular tubing depends upon both the Reynolds number and the curvature of the bend and can be characterized the Dean number, De, which is:

$$De = \frac{Re}{\delta^{1/2}} \tag{1}$$

where: $\delta = R/a$; R = radius of curvature of the bend; and $a = d_t/2$ = tube internal radius. The parameter δ is the curvature ratio of the bend. Flow is considered laminar for $De \leq 370$, which corresponds to a Reynolds number of 1170 for a curvature ratio of 10; however, the secondary flow in a bend causes the overall flow to be more stable. The critical Reynolds number can be as large as 7800 for a curvature ratio of 7 (Soh and Berger, 1984).

In general, flow through a bend is developing, so aerosol particle deposition should vary with length along the bend. For this reason, angle of the bend was treated as a variable in this investigation.

Particle deposition.

Landahl and Herrmann (1949) proposed a model for deposition of aerosol particles in a bend, where the deposition depended only on Stokes number (*Stk*). The Stokes number is defined as:

$$Stk = \frac{C \rho_p D_p^2 U}{9 \mu d_t} \tag{2}$$

where: C = Cunningham's slip correction (Fuchs, 1964); ρ_p = particle density; D_p = particle diameter; and, μ = dynamic viscosity of air. Davis (1964) used aerosol particles to visualize the secondary flow patterns due to laminar flow in pipes with a bend angles ranging from 30° to 180°; however, no data on the particle loss in the pipe were gathered. Cheng and Wang (1975) developed a model for the impaction efficiency of aerosol particles in 90° bends. Their model was based on an analytical laminar flow solution and the correlation they developed gave penetration as a function of the Stokes number, curvature ratio, and bend angle. Crane and Evans (1977) performed numerical calculations to predict the behavior of aerosol particles in laminar flow in 90° bends. They examined curvature ratios ranging from 4 to 20 and their results showed reasonable agreement with those of Cheng and Wang (1975). Chen and Wang (1981) re-examined the deposition of particles in pipe bends. They concluded that in the laminar flow regime, the aerosol particle deposition was mainly a function of Stokes number and flow Reynolds number for curvature ratios between 4 and 20. Pui et al. (1987) experimentally evaluated the deposition of aerosol particles in a 90° bends for Reynolds numbers of 100, 1000, 6000, and 10,000; and curvature ratios of 5.7 and 7. They suggested the penetration does not depend on either curvature ratio or Reynolds number and offered the following correlation for predicting the aerosol particle penetration in 90° elbows:

$$P = 10^{-0\ 963\, Stk} \tag{3}$$

where: P is the aerosol particle penetration. Tsai and Pui (1990) used a three-dimensional numerical procedure to examine the aerosol particle deposition for laminar flow in a pipe with a 90° bend. They found significant variation in the deposition efficiency as a function of curvature ratio. They also noticed an influence of the inflow velocity profile on the deposition efficiency. Their results using a parabolic inlet velocity profile agree well with the results of Cheng and Wang (1981).

Goals of the Present Study

There have been significant recent developments in numerical predictions of three dimensional flow fields and in particle tracking. For example, FLUENT, which is a commercially-available finite volume code (Fluent, Inc., Lebanon, NH) accommodates prediction of three dimensional turbulent flow fields using advanced turbulence models Abuzeid et al. (1991) developed a numerical scheme for particle tracking in turbulent flows. Gong et al. (1993) used the Abuzeid approach to model aerosol sampling by a shrouded probe in an axi-symmetric (two-dimensional) turbulent flow field. Good agreement was obtained with experimental data. In the present study, that model was extended to particle tracking in three-dimensional flows, and it was used in combination with a three-dimensional flow field to predict particle losses in bends. At the present time, the only model for predicting aerosol particle penetration in turbulent flow through bends is the empirical correlation of Pui et al. (1987). A goal of this study was to evaluate the effects of bend angle, curvature ratio, Reynolds number and Stokes number, and to develop a correlation that would taken into account the necessary parameters. Also, we sought to determine experimentally the effects of curvature ratio and flattening of the cross section of a bend, and to generalize those results as design criteria.

II. Methodology

Physical experiments.

The bends were fabricated by milling the correct curvature ratio into a split block of wax, then adding tube stubs to either end of the bend. Care was taken that the transitions between the bends and the tube stubs were smooth. For all bends, tube diameter was 16 mm and the distance from the entrance plane of the bend to the centerline of the exit tube was 151 mm. The layout was setup so a bend with a value of $\delta = 20$ would require no additional straight sections; whereas, for all other bends, with smaller values of δ, straight tube stubs were added. To investigate the effect of flattening of the bend cross section, we fabricated six identical 90° bends from 16 mm diameter tubing that had curvature ratios of 10. At the 45° location, the bends were pinched to reduce the diameter in the radial direction.

The apparatus used in testing bends is shown in Figure 2. Monodisperse aerosols were generated with a vibrating orifice aerosol generator (Berglund and Liu, 1973) from a solution of a non-volatile oil (oleic acid) and an analytical tracer (sodium fluorescein) dissolved in a volatile solvent (isopropyl alcohol). A particle size of 10 μm aerodynamic diameter (AD) was used for all tests. The monodisperse aerosol was drawn into a mixing chamber plenum with a blower. A clean-up filter, which was placed in front of the blower, collected the excess aerosol.

An upstream aerosol sample was collected by replacing the bend with a sampling filter. The bend was then inserted into the flow system and an aerosol sampling filter was used to collect a downstream sample. Analytical tracer was eluted from the filters and quantified. The penetration, P, was determined from:

$$P = \frac{c_e}{c_i} \tag{4}$$

where: c_e = aerosol concentration at the exit section of the elbow; and, c_i = aerosol concentration at the inlet section. The flow rate through the system was measured with a calibrated rotameter and corrected for the actual pressure level in the system. Four replicate experiments were conducted for each set of experimental conditions.

Numerical Calculations.

Flow fields were setup through use of FLUENT. Because the flow in bends can be turbulent, with swirl, the traditional engineering κ-ϵ turbulent closure model is not adequate. Instead, a more accurate model, the Reynolds stress model (RSM), was used to describe the turbulent behavior of the flow. In the RSM, each Reynolds stress component, the turbulence dissipation rate and the velocity components are calculated. An example of the flow field in a bend is shown in Figure 3, where the velocity vectors are illustrated for a location that is two tube diameters downstream of the bend exit plane.

Particle trajectories in bends were calculated by solving the particle equations of motion as affected by the gravitational force, particle inertial force and fluid drag. In the equation for particle motion, the instantaneous fluid velocity is needed, which consists of mean and turbulent components. The mean velocity is available from the flow field computation, and the fluctuating component is generated from Gaussian random sampling of Reynolds stresses. The duration of interaction between particle and turbulence eddy is determined by the eddy lifetime, which, in turn is determined by the turbulent kinetic energy and the dissipation rate. The penetration of aerosol through a bend is calculated by tracking a large number of simultaneously released particles and determining which are deposited on the walls and which penetrate the bend.

A series of numerical experiments were conducted to establish a grid independent solution. Based on these studies, a grid size of 103×21×25 was used. A similar set of numerical experiments was use to establish the time steps for particle tracking. A time step of 10^{-5} s was selected, which ensures at a particle travels at least 5 steps within a turbulence eddy.

Computations were carried out for bends with curvature ratios of 2, 4, and 10; and for bend angles of 45°, 90° and 180° at a Reynolds number of 8210. The effect of varying the Reynolds number was investigated by maintaining the Stokes number constant and varying the Reynolds number over the range of 3200 to 19,800.

III. Results

Validation of the Numerical Model. Initially, we attempted to use a particle tracking model that is imbedded in the FLUENT software; however, the agreement with experiment was not satisfactory. As a consequence we developed the three dimensional extension to the model of Gong et al. (1993). A comparison of the numerical predictions with experimental results is given in Table 1. Results are shown for different bend angles, curvature ratios and mean flow velocities. For a given set of conditions, the relative difference between the experimental value and th numerical predicition is 5%. The numerical value is higher, and the standard error of the estimate is 4%. for example, if the numerically predicted penetration is 50%, the experimental value will be about 52.5%, with an error of ±2%.

Effect of Turbulence on Particle Deposition

A flow field was setup for a 45° bend with a curvature ratio of 10, and for a Reynolds number of 8210. The penetration of particles of 5, 10 and 15 µm AD was then determined with and without the turbulence model for particle tracking. The results, which are shown in Table 2, illustrate the need for including the effects of turbulence on particle motion. For example, at a particle size of 10 µm AD, the predicted penetration is 80% without including turbulence and 62% with turbulence. Neglecting the efect of turbulence on particle motion would cause unacceptable errors in the analyses.

Effect of Reynolds Number on Aerosol Penetration

Numerical predictions were made of the effect of flow Reynolds number on aerosol penetration through a 90° bend that has a curvature ratio of 10. In the calculational procedure, the Stokes number was held constant and the Reynolds number varied from 3200 to 19,800. The results, which are shown in Figure 4, suggest that the effect of Reynolds number is sufficiently small such that it can be neglected. Over the range of Reynolds numbers tested, at a Stokes number of 0.67, the penetration ranges from 22% to 27%; and, at a Stokes number of 0 074, the penetration varies from 87.5 to 89.5%.

Experimental Results Showing the Effect of Curvature Ratio on Penetration

With reference to Figure 5, results are shown on the effect of curvature ratio on penetration for a range of Stokes numbers. The Stokes number was varied by changing the flow rate through a bend. Bends were designed as illustrated in Figure 1b to allow direct comparisons on the effect of curvature ratio, i.e., tube stubs were added to bends with short radii of curvature. The results show that increasing the curvature ratio improves the aerosol penetration. For example, at a Stokes number of 0.3, a bend with a curvature ratio of unity has a penetration of 32%, a bend with $\delta = 2$ has $P = 42\%$, and if $\delta = 4$, $P = 50\%$. However as δ is increased from 4 to 20, the penetration only changes from 50% to 58%. Also, there is very little difference in penetration between bends with curvature ratios of 4 and 10. These results suggest that a bend with a curvature ratio of 4 should be satisfactory for aerosol transport. The curvature ratio of 10 recommended in ANSI N13.1-1969 is probably too conservative.

Experimental Study of the Effect of Flattening of the Bend Cross Section

Test conducted on pinched bends provided the results shown in Figure 6 . The degree of flattening is the amount by which a diameter was reduced, divided by the original tube diameter. The bends used in these tests had initial diameters of 16 mm with curvature ratios of 10. The data show that the penetration decreases with flattening; however, if the flattening is less than about 25%, the effect is quite small. For example, at a Stokes number of 0.3, the penetration decreases from 52% to 45% as the degree of flattening is increased from 0% to 25%. On the other hand, as the flattening is increased from 25% to 50%, the penetration decreases from 45% to 16%. These data suggest that if a bend is somewhat flattened (less than 25%) during the fabrication process, the aerosol penetration characteristics would not be significantly impacted.

Numerical Modeling of Aerosol Penetration

Computational results were generated for a range of Stokes numbers ($0.07 \leq Stk \leq 1.2$); for bend angles of 45°, 90° and 180°; and for curvature ratios of 2, 4 and 10. The results are presented in Figures 7a, 7b, and 7c in the form of penetration as a function of Stokes number for constant values of the curvature ratio. With reference to Figure 7a, which is for a bend angle of 45°, it appears that curvature ratio has a pronounced effect on penetration; however, that is illusionary because of the smaller path length through which the aerosol must flow in the smaller curvature ratio bends. The experimental data shown in Figure 5 present a more appropriate view of the effect of curvature ratio, where those data are based on all bends starting and ending at the same points in space.

The data shown in Figures 7a, 7b and 7c have been used to generate a correlation of aerosol penetration as a function of Stokes number, curvature ratio and bend angle. We chose a functional form for the correlation that would have the appropriate limiting conditions over the range of the correlation of $P \rightarrow 0$ for large Stokes number, and $P \rightarrow 1$ for small Stokes number. The functional form that we selected is·

$$\ln P = \frac{c_1 + c_2 \ln Stk + c_3 \ln^2 Stk + c_4 \theta}{1 + c_5 \ln Stk + c_6 \ln^2 Stk + c_7 \theta} \tag{5}$$

where each c_i is a function of the curvature ratio, δ. A three-dimensional surface fitting program (TableCurve 3D, Jandel Scientific, San Rafael, CA) was used to generate least squares fits of the data for each curvature ratio. The results are shown in Figures 8a, 8b and 8c for curvature ratios of 2, 4 and 10, respectively. Values of the coefficients as functions of the curvature ratio were then obtained by using a two dimensional curve fitting program that was based on use of least squares (TableCurve 2D, Jandel Scientific). The results are:

$$\begin{aligned}
c_1 &= 6.77 - 12.8\exp(-\delta)\\
c_2 &= -9.18 + 62.4\exp(-\delta)\\
c_3 &= 11.3 - 66.3\exp(-\delta)\\
c_4 &= -0.00393 + \frac{0.0277}{\delta}\\
c_5 &= -2.23 + \frac{8.49}{\delta^2}\\
c_6 &= 2.39 - 13.94\exp(-\delta)\\
c_7 &= 0.0055 - 0.0609\exp(-\delta)
\end{aligned}$$

A comparison of predictions from the correlation model (Equation 5) with those from Pui et al. model (Equation 3) is shown in Figure 9. Good agreement is obtained between the two models for the case of $\delta = 10$; however, the model of Pui et al. under predicts the correlation model for the case of $\delta = 2$.

The need for inclusion of bend angle into the correlation model can be demonstrated by reference to Figure 10, where computational results are shown for the average deposition of aerosol per radian of bend angle, as a function of Stokes number. The developing nature of the flow causes the aerosol loss/radian to be less in a 45° bend than in a 90° bend for most Stokes numbers, although at a Stokes number of 1.2, the deposition/radian for a 45° bend is somewhat larger than in a 90° bend. For Stokes numbers less than 0.3, the aerosol particle loss/radian is about the same in either a 90° bend or a 180° bend; however, for larger Stokes numbers, the aerosol losses/radian can be considerably less in a 180° bend than in a 90° bend. This suggests that in most cases, the penetration of aerosol through a 180° bend cannot be treated as the product of the penetration of two 90° bends in series, nor can the penetration through a 45° bend be treated as the square root of the penetration through a 90° bend. Rather, the bend angle needs to be considered as a variable.

IV. Summary and Conclusions

This study employed a combination of numerical and experimental techniques to characterize aerosol penetration through bends. Agreement was achieved between numerical and physical experiments when the numerical approach was based on use of a specially developed three dimensional particle tracking technique. It was also demonstrated that turbulence needs to be included in a particle tracking model.

The effect of Reynolds number upon particle deposition was examined numerically through calculations made with the Stokes number and curvature ratio held constant. Based on experimental evidence, Pui et al. (1987) stated that there is no Reynolds number effect. Although the numerical results show some dependency of penetration upon flow Reynolds number, the effect does not seem to be sufficiently significant to warrant its inclusion in any correlation model. For Stokes numbers of 0.07 to 0.7 and a curvature ratio of 10, the aerosol penetration does not change by more than 5% when the Reynolds number is varied from 3200 to 19,800.

Physical experiments were conducted to investigate the effect of curvature ratio on aerosol penetration. The bends were constructed such that each bend had the same initial and final spatial co-ordinates, regardless of the curvature ratio. There is a continuum of change of penetration with bend angle, where the aerosol penetration increases with the curvature ratio. However, the change is much greater for curvature ratios less than 4 than it is for the larger curvature ratios. ANSI N13.1-1969 recommends that the curvature ratio should be at least 10, but the results of this study suggest that the value could be four.

When bends are fabricated from straight tubing, there is a tendency for the tubing to flatten. The flattening can be minimized by filling a tube with oil prior to bendin it, and maintaining the oil at a high pressure during the bending operation. Because that approach is expensive as compared with simpler techniques (that can cause flattening) we experimentally evaluated the effect of flattening upon aerosol penetration. Ninety degree bends were pinched at the 45° location and tested for aerosol penetration. The degree of flattening of the bends was from 0% to 50%, where the degree of flattening is the ratio of the change in diameter (caused by the pinching) divided by the initial diameter. If the degree of flattening is less than about 25%, it does not have a substantial impact on aerosol penetration.

Numerical experiments were carried out to characterize the penetration of aerosols through bends. The geometrical extent of the bends covered only the region of tubing where the radius of curvature is non-zero. Calculations were conducted for a range of Stokes numbers, curvature ratios and bend angles. Results were used to generate a correlation model that designers and users of aerosol transport systems can employ to predict aerosol penetration. The correlation is valid for $0.07 \leq Stk \leq 1.2$; $45° \leq \theta \leq 180°$; and $2 \leq \delta \leq 10$. Of immediate interest to us is the use of such a model in DEPOSITION software. A comparison of the correlation model with the empirical model of Pui et al. shows good agreement for $\delta = 10$; however, the model of Pui et al. under predicts the present correlation for $\delta = 2$. Also, the model of Pui et al. is limited to 90° bends..

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Table 1. A comparison of experimental data and numerical predictions of aerosol penetration through bends. Additional length was added to the inlet and outlet sections of the numerical configurations so the geometries would be similar for both numerical and experimental testing.

Elbow Angle	Curvature Ratio, $\delta = R_t/a$	Velocity, m/s	Numerically Predicted Penetration	Experimentally Observed Penetration[1]
45°	10	7.7	62.7%	61.8±2.1%%
90°	10	7.7	51.0%	58.3±1.7%
180°	10	7.7	27.7%	28.5±0.9%
90°	2	7.7	42.9%	39.8±1.1%
90°	4	7.7	47.2%	54.1±0.6%
90°	10	18.6	12.2%	12.1±0.3%

[1] The value following the ± sign is one standard deviation.

Table 2. A comparison of numerically predicted aerosol penetration through a 45° bend with and without the turbulence in the particle tracking model. The curvature ratio is 10 and the flow Reynolds number is 8210. Inlet and outlet tube sections were added to the geometrical configuration to make it similar to that shown in Figure 1b rather than Figure 1a.

Particle Diameter, µm AD	Penetration without Turbulence in the Particle Tracker	Penetration with Turbulence in the Particle Tracker
5	97%	82%
10	80%	62%
15	46%	35%

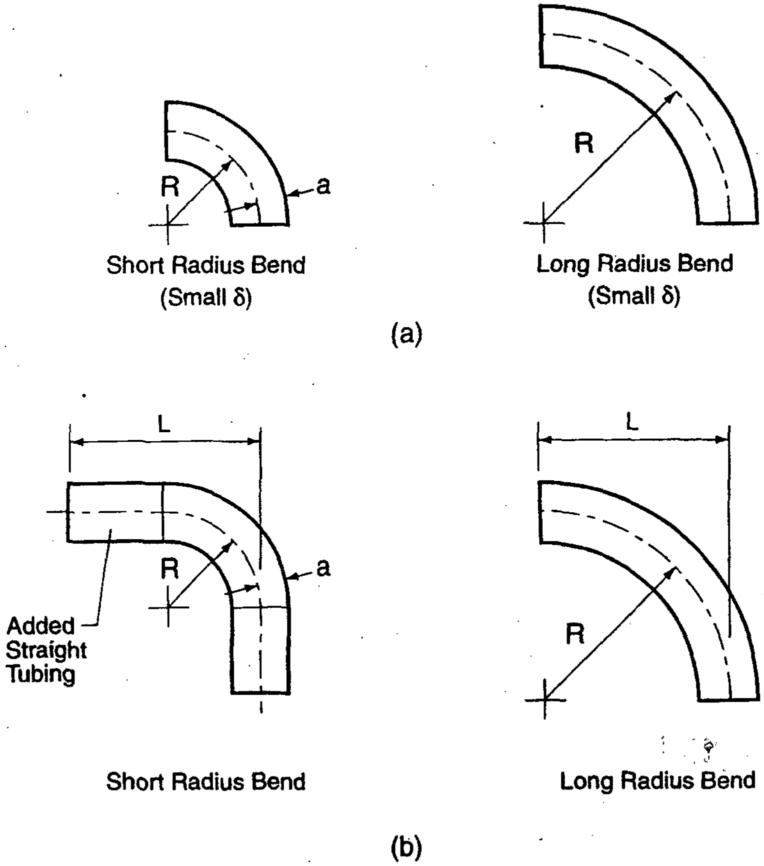


Figure 1. Geometries of bends used in a) numerical modeling, and b) physical testing.

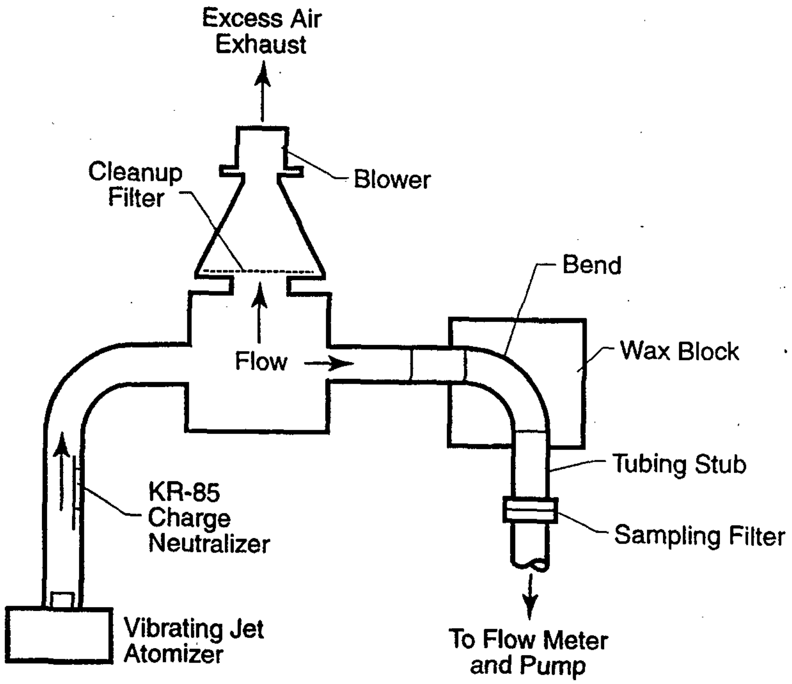


Figure 2. Experimental apparatus used in testing aerosol losses in bends.

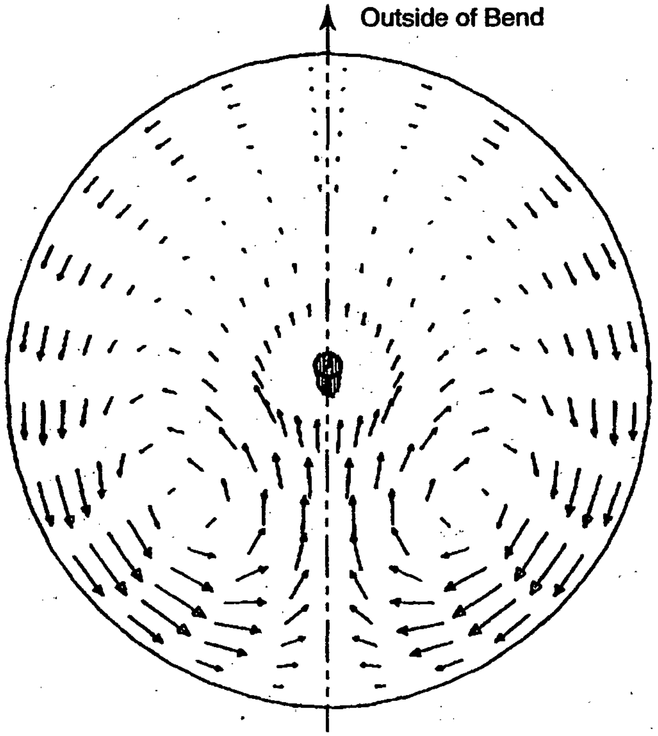


Figure 3. Secondary flow field at a distance of two diameters downstream from the exit plane of a 90° bend. The tube size is 16 mm, the Reynolds number is 8210, and the curvature ratio is 10.

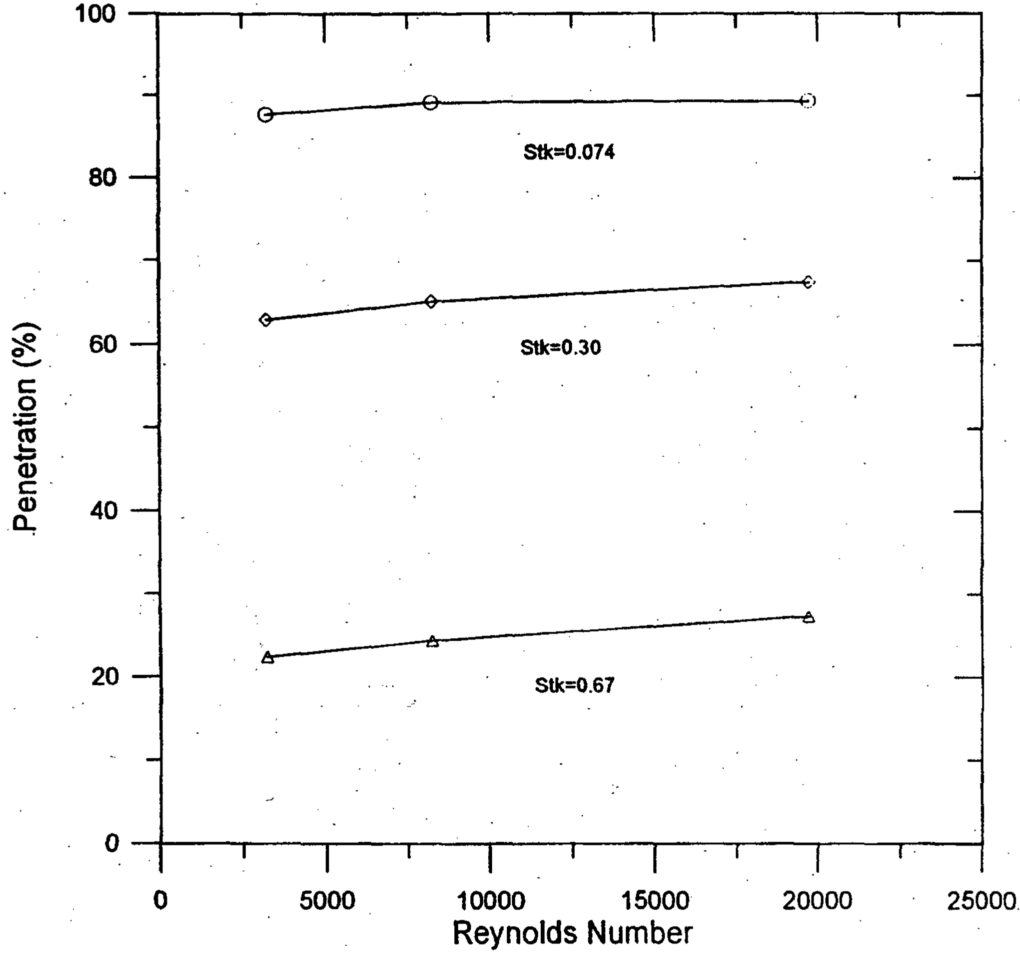


Figure 4. Numerical prediction of the effect of flow Reynolds number on aerosol penetration through a 90° bend with a curvature ratio of 10.

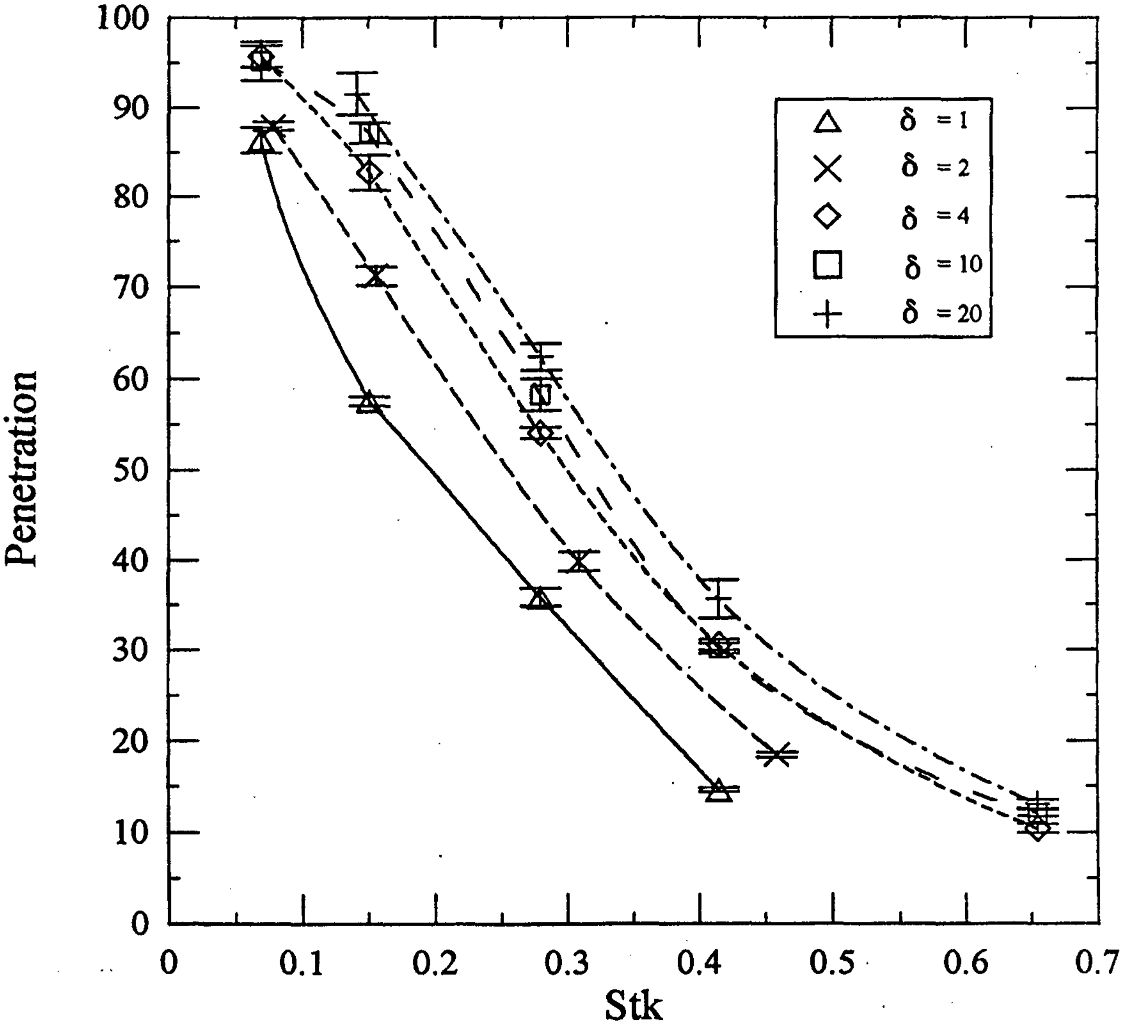


Figure 5. Experimental results showing the effect of curvature ratio on aerosol penetration through bends. The bends were designed as illustrated in Figure 1b, i.e., tube stubs were added to the bends with short radii of curvature.

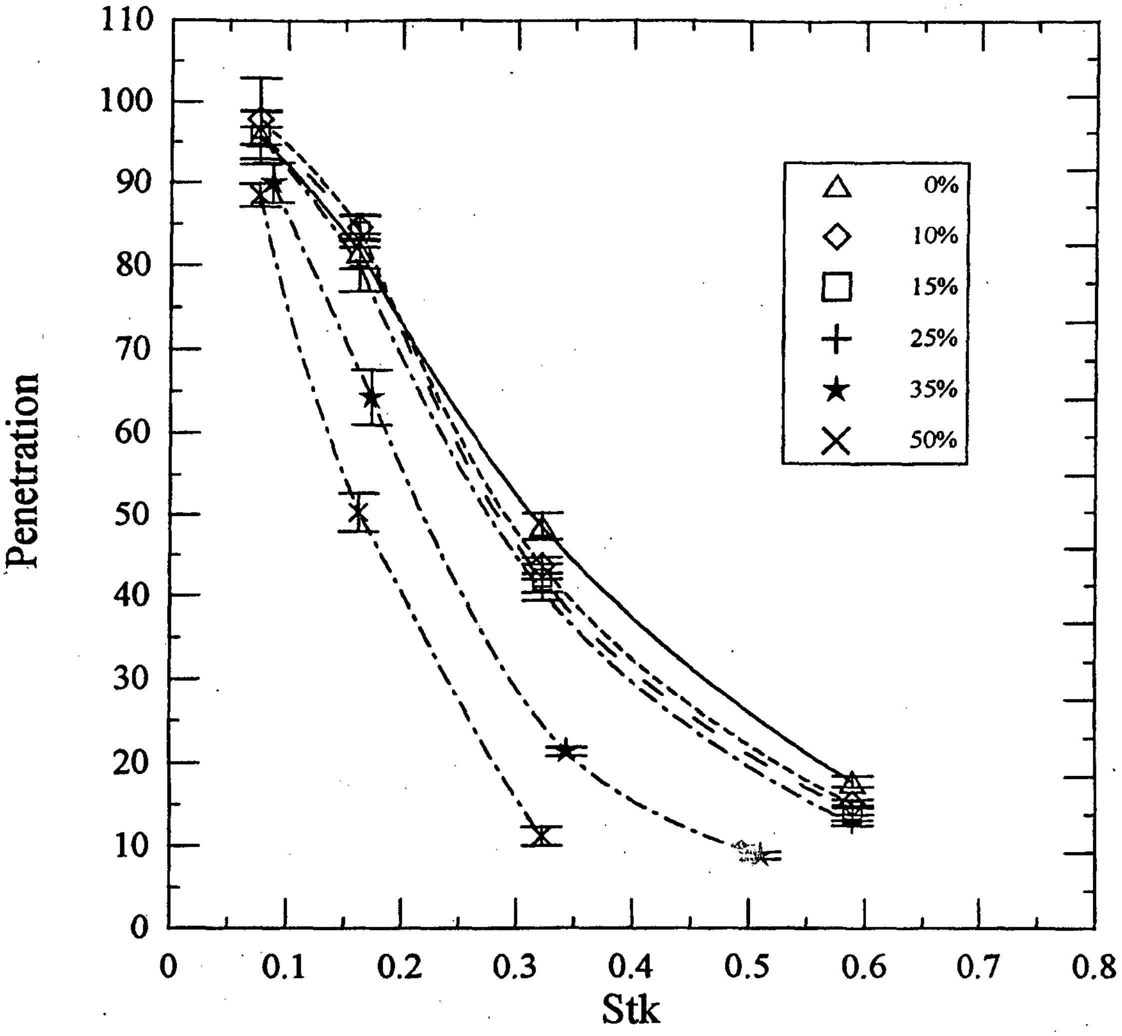
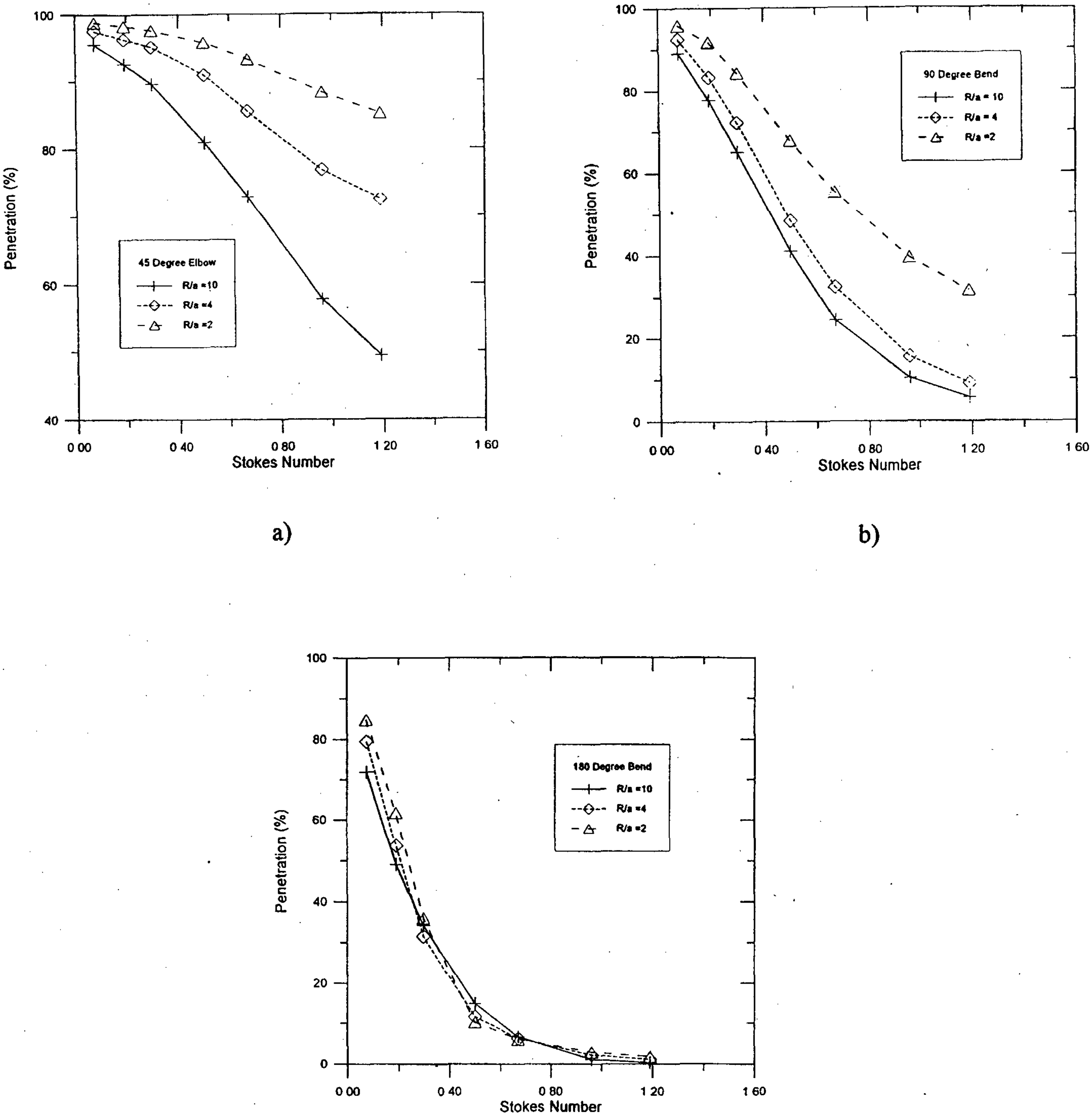


Figure 6. The effect of flattening the cross section of a bend. A 90° bend was pinched at the 45° location. The degree of flattening is the amount by which the tube diameter was reduced divided by the initial diameter. Data are for a tube that was initially 16 mm diameter with a curvature ratio of 10. Particle size used in the testing was 10 μm AD.



a)

b)

c)

Figure 7. Numerical results that show penetration as a function of Stokes number for constant values of curvature ratio and $Re = 8210$. a) Bend angle of 45° b) Bend angle of 90°. c) Bend angle of 180°.

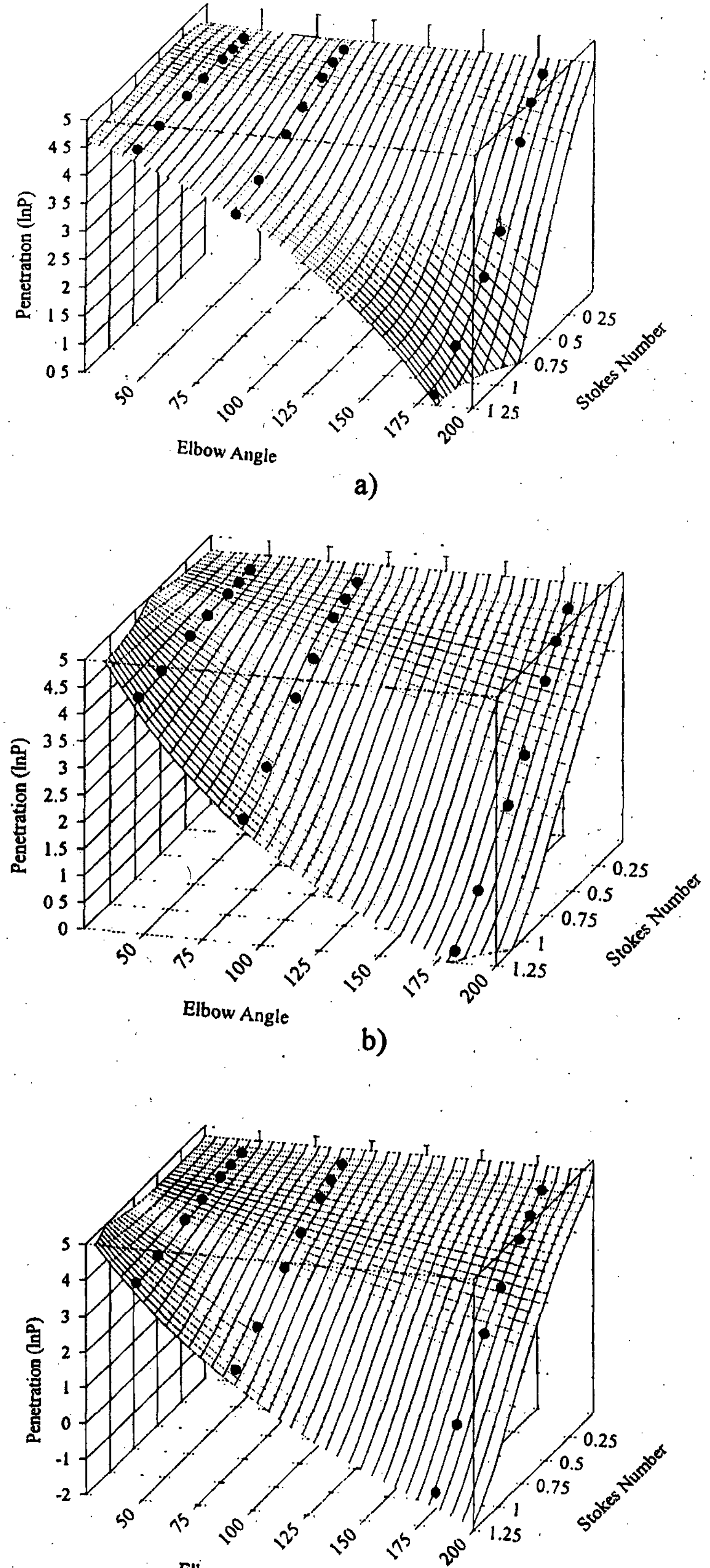


Figure 8. Surface fitting of penetration as a function of Stokes number and bend angle, for constant values of curvature ratio. a) $\delta = 2$, b) $\delta = 4$, and c) $\delta = 10$.

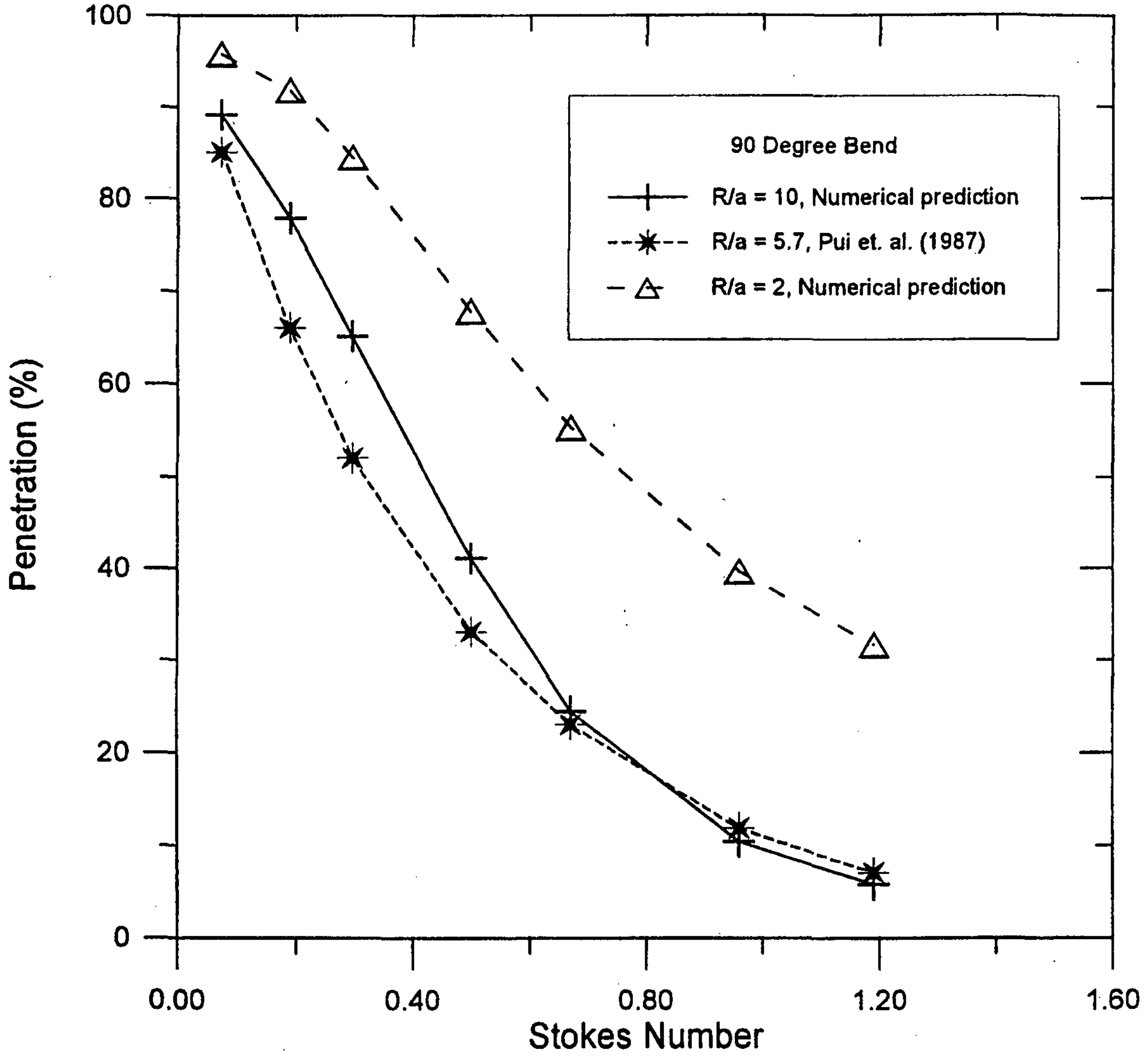


Figure 9. A comparison of the predictions of the correlation model (Equation 5) and the model of Pui et al. (1987).

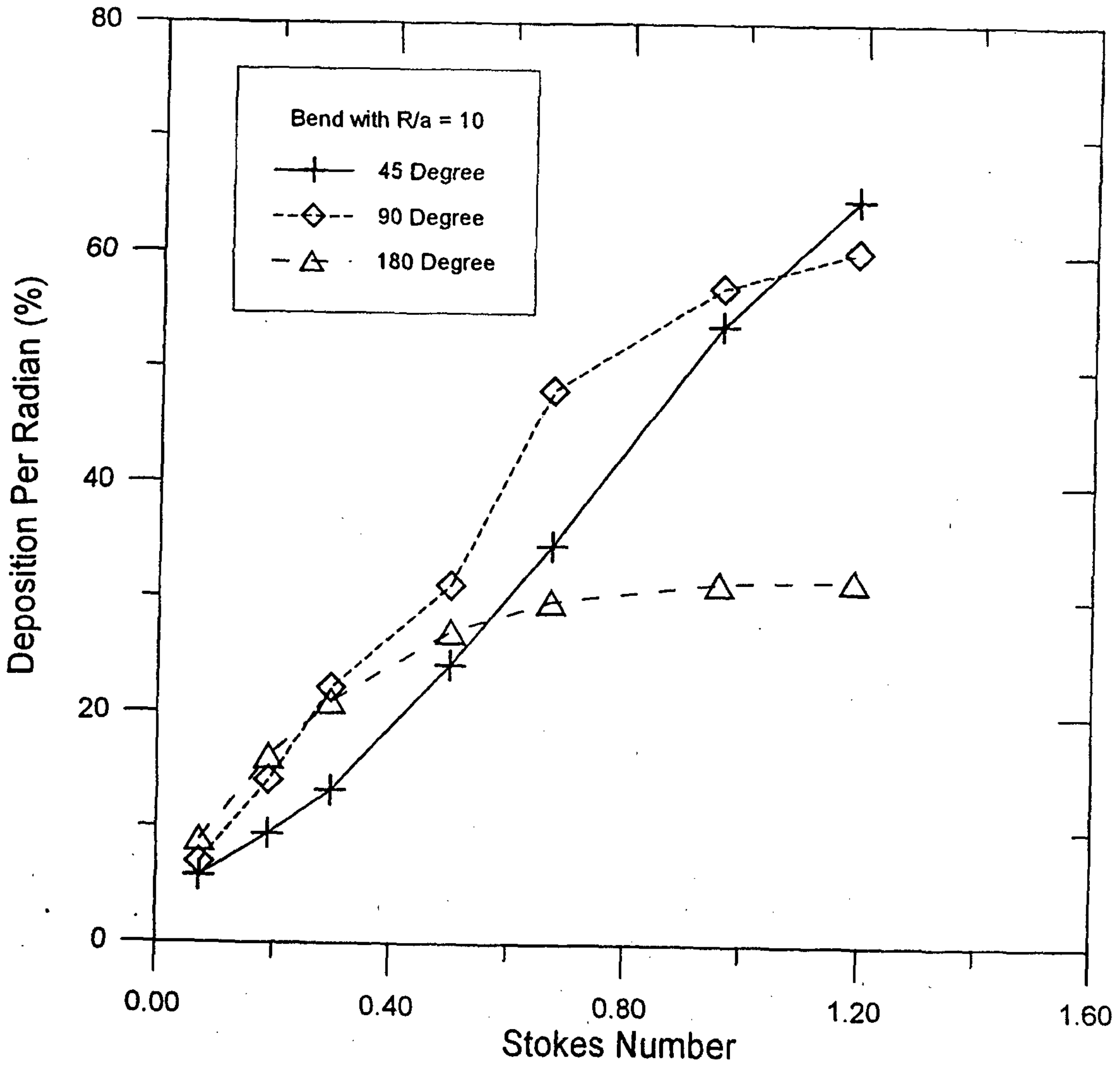


Figure 10. Effect of bend angle on deposition rate. The deposition per radian is the total aerosol lost to the internal wall of a bend divided by the bend angle.

DISCUSSION

FLEMING: How do you account for the effects of your filter sampling on your flow patterns in the downstream portion of the tube? How does that affect your flow patterns through the tube, and how do you sort that out?

MCFARLAND: What we do is assume that the sample transport line ends where the filter starts. Therefore, we make our predictions up to and including any sort of a transition, for example, an expansion or a contraction right ahead of the filter. However, the transport of aerosol from the free stream excludes the filter itself.

ADAMS: As most filter lines are lined and heated, would that have an effect on any of the data collection?

MCFARLAND: If a sample transport line was heated, I assume it is to prevent condensation of reactive gases or of water. In the code that we developed, the DEPOSITION code, we have built into it a sampling temperature and sample line pressure. The sample line pressure does not have a great impact on particle sampling transmission through a line. On the other hand, the temperature can have an effect. The temperature will influence the viscosity, which in turn will influence the particle DEPOSITION. But that is built into the deposition code, or at least into codes numbered 3.1 or higher. I am going to add that we have developed a Windows version of the DEPOSITION code. Those of you who have used the DEPOSITION code have a version which is DOS-only. The code in Windows-form is currently being reviewed by the sponsors of the work. I assume that we should be ready to release it within a couple months. If there is anyone that is interested in a copy, at no charge, leave a card with me and I will send you a free copy at the time that we do the release.

ENGELMANN: If you used the Reynolds number at the pinched bend, would you then find the deposition to be dependent upon Reynolds number? Have you any data on deposition downstream of the pinched bend? One might think it to be greater than deposition in straight tubes without bends.

MCFARLAND: In answer to the first question, we have not examined the effect of Reynolds number on a pinched bend. The data that we have on pinched bends is experimental, whereas our data on the effect of Reynolds numbers on un-pinched bends is numerical. With respect to the second question, the losses in a pinched bend are the sum of those in the pinched region and the regions of circular cross section in the bend. No experiments were conducted to directly compare losses downstream of pinched bends with the losses downstream of un-pinched bends; however, the data in Figure 4 show there are similar overall losses in bends that are pinched ≤ 25%, which suggests there may not be much difference between the losses downstream of pinched and un-pinched bends. Your comment on the losses in bends being greater than losses in straight tubes is well taken. Often the losses in bends are a couple of orders of magnitude greater than the losses in an equal length of straight vertical tubing.

ATMOSPHERIC DISCHARGES FROM NUCLEAR FACILITIES DURING DECOMMISSIONING: GERMAN EXPERIENCES AND CONCEPTS

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Abstract

In Germany, a substantial amount of experience is available with planning, licensing and realization of decommissioning projects. In total, a number of 18 nuclear power plants including prototype facilities as well as 6 research reactors and 3 fuel cycle facilities have been shut down finally and are at different stages of decommissioning. Only recently the final „green field" stage of the Niederaichbach Nuclear Power Plant total dismantlement project has been achieved.

From the regulatory point of view, a survey of the decommissioning experience in Germany is presented highlighting the aspects of production and retention of airborne radioactivity. Nuclear air cleaning technology, discharge limits prescribed in licences and actual discharges are presented. As compared to operation, the composition of the discharged radioactivity is different as well as the off-gas discharge rate. In practically all cases, there is no significant amount of short-lived radionuclides. The discussion further includes lessons learned, for example inadvertant discharges of radionuclides expected not to be in the plants inventory. It is demonstrated that, as for operation of nuclear power plants, the limits prescribed in the Ordinance on Radiological Protection can be met using existing air cleaning technology. Optmization of protection results in public exposures substantially below the limits.

In the frame of the regulatory investigation programme a study has been conducted to assess the airborne radioactivity created during certain decommissioning activities like decontamination, segmentation and handling of contaminated or activated parts. The essential results of this study are presented, which are supposed to support planning for decommissioning. for LWRs, Co-60 and Cs-137 are expected to be the dominant radionuclides in airborne discharges.

I. Introduction

During the operational phase of nuclear installations radioactive substances are discharged to the environment in liquid and airborne form. These discharges are subject to licensing and to surveillance and control.

When operation is terminated the transition to decommissioning takes place. This implies in general that plant states are essentially modified, media no longer required are removed and new systems for decommissioning purposes installed. Along with the technical changes, regulatory conditions change. In many cases, a new license is required. As the dominant mechanisms of discharge are different from operation as well, discharge limits or more general criteria for discharges prescribed in the license for decommissioning are in most cases different from those valid for operation.

In this paper, information is provided on German experiences and insights with the assessment, control and regulation of airborne discharges from nuclear installations in the phase of decommissioning. The discussion comprises an overview on plants being shut down permanently, the mechanisms leading to airborne radioactivity inside the plant, technology of discharge control, discharge limits, actual discharges and further regulatory aspects.

II. Nuclear Power Plants in Germany

II.I Overview

The situation concerning the use of nuclear power in the Federal Republic of Germany (early 1995) is as follows (1):

19 nuclear power plants with a capacity of 21,824 MWe gross (20,735 MWe net) are in operation,

1 nuclear power plant unit with 1,302 MWe (gross capacity) is shut down for an undefined period, following court order,

1 nuclear power plant unit with 806 MWe gross was out of operation in 1993 and 1994 for hot repair works and adaptations,

15 nuclear power plant units with 3,330 MWe (gross) in total are finally shut down, i.e. decommissioning has been started, applied for or planned,

for

6 nuclear power plant units, the construction and assembly works have been stopped or the application for construction and operation has been revoked.

II.II Plants finally shut-down in Germany

The decommissioning of the first nuclear power plant of the Federal Republic of Germany, **Versuchsatomkraftwerk Kahl (VAK Experimental Reactor)** was decided in 1985. The decommissioning concept provides the total dismantling of the plant. The first two decommissioning licences for decommissioning allow the dismantling of internal and external systems of the controlled area, the handling with contaminated tools and equipment and with low activity secondary radioactive waste. Furthermore, procedures and equipment for the dismounting, disassembling, and packaging of contaminated and activated parts of the facility were tested. On 25th September 1993, the third licence for decommissioning according to section 7 of the Atomic Energy Act (Atomgesetz, AtG) was issued. Action against this third licence was dismissed by the Higher Administrative Court of the State of Bavaria on 17th August 1994, which means that the disassembling of the reactor pressure vessel and the biological shield as well as the clearance for reuse or disposal, of non-hazardous substances which have been authorized as non-radioactive waste has been approved. It is planned to finish decommissioning, including site restoration, by the year 2000.

For the **Mehrzweckforschungsreaktor (MZFR Research Reactor)**, which was finally shut down in 1984, it was decided in 1989, after comparison of various decommissioning options, to perform the immediate and complete dismantling of the installation. The dismantling of the MZFR takes place stepwise, each step requiring a licence according to Atomic Energy Act. On the basis of the five issued decommissioning licences for MZFR, the decontamination of the heat removal system and the moderator system, the dismantling of equipment, such as equipment of the turbine building, electric installations, reactor auxiliary and supporting systems, water treatment system as well as the dismantling of the cooling tower was performed or initiated. The dismantling including restoration of the site should be finished by the year 2001 after altogether 6 partial steps. On 15th April 1994, the fourth, on 30th May 1994, the fifth partial licence for the decommissioning of the MZFR were issued, approving further dismantling works.

Rheinsberg Nuclear Power Plant (KKR) with a gross capacity of 70 MWe (reactor WWER) was finally shut down in 1990. Application for decommissing of the plant was made on 30th March 1992. The first licence for decommissioning was granted on 28th April 1995. Demolition work has been started.

Total dismantling is planned for **Gundremmingen Nuclear Power Plant Unit A (KRB-A)** which was shut down in 1977. Dismantling is taking place in several project phases which are based on the corresponding atomic energy law licences. Phase I, in which lowly contaminated components and the steam- and feedwater circuits in the turbine building were dismounted, was finished in 1989. In phase II, the disassembling of highlier contaminated reactor coolant contacted components and systems from the reactor building was performed. In phase III, the last dismantling step, the disassembling of the reactor pressure vessel and its equipment including the reactor shield, will be provided. Based on the licence for phase III issued on 12th August 1992, the disassembly of the reactor equipment was partly achieved in 1994 (e. g. 2 steam dryer units).

The **Jülich Atomversuchskraftwerk (AVR-Reactor, an experimental high temperature gas-cooled reactor with pebble bed)**, shut down in 1988, shall be transferred to safe enclosure after disassembly of equipment parts such as turbine, generator, condenser and condensate treatment system. The competent regulatory authority has approved the decommissioning concept and the safe enclosure in 1991. In the period from April to June 1992, the available 5,704 unused fresh fuel spheres balls were removed from the AVR-facility. The licence for decommissioning, unloading of the reactor core, dismantling and disassembling of equipment and safe enclosure of the AVR was issued on 9th March 1994.

The unloading of the spherical fuel elements out of the reactor into the central interim storage facility in the Jülich Research Centre was started.

The **Lingen Nuclear Power Plant (KWL)** was decommissioned in 1977 after 9 years of operation. Based on the licence of 21st November 1985, the facility was transferred to safe enclosure, which began in 1988. The safe enclosure involves the reactor building and the auxiliary building including the connecting building. All controlled areas situated outside this area were decontaminated, cancelled, and partly dismounted. The safe enclosure is monitored from the adjacent Emsland Nuclear Power Plant. After about 25 years of safe enclosure operation, it is planned to start the complete dismantling of the plant.

The **Heißdampfreaktor Großwelzheim (HDR, a nuclear superheated BWR)** finally shut down in 1971, was used after shut down for non-nuclear investigations and R&D on behavior of nuclear installations in the case of severe accidents. Decommissioning of the reactor was approved on 16th February 1983. The above-mentioned test programme was finished in 1991. Complete dismantling of the facility is planned until 1998. A second licence for decommissioning was granted on 29th December 1994 which also covers the disassembling of the reactor pressure vessel and parts of the primary circuit.

The **Niederaichbach Nuclear Power Plant (KKN, a heavy water moderated, gas cooled pressure tube reactor)**, which was decommissioned in 1974, is the first NPP in the Federal Republic of Germany being completely dismantled. The NPP was permanently shut down and transferred into safe enclosure in 1983, dismantling began in 1987. The dismantling of inactive and contaminated parts of the facility, except from activated areas near the core, was finished in 1990. The dismantling of the activated parts was finished at the end of 1993. Evidence taking measurements performed in the facility for clearance of the buildings were completed. The Ministry of State for Regional Development and Environmental Aspects of the State of Bavaria dismissed the KKN plant from the application of the Atomic Energy Act on 17th August 1994 and reported that the plant is released for conventional dismantling according to building law. Thus, the complete dismantling of a nuclear power plant was performed for the first time in Europe. The site restoration was celebrated on the 17th August 1995. The radioactive waste amounted to about 2% of the overall amount of decommissioning wastes.

The units 1 to 4 of the **Greifswald Nuclear Power Plant (KGR, WWER type, W-230 reactor)**, were shut down in 1990.

The dismantling of all five units will be achieved without preceding safe enclosure. An application for decommissioning and dismantling of plant units was submitted on 17th June 1994. The first licence for decommissioning was granted by 30th June 1995. Demolition of the facility has started..

Adjacent to the Greifswald site, an intermediate storage and waste treatment facility is under construction (Zwischenlager Nord, ZLN).

The **Kompakte Natriumgekühlte Kernreaktoranlage (KNK II, a sodium cooled Fast Breeder Research Reactor)** was finally shut down in 1991, after finishing its test programme. The shut-down was started with the removal of the fuel elements. The decommissioning concept provides for a stepwise disassembly up to the full dismantling of the plant. The first licence for decommissioning of the facility was granted on 26th August 1993, the second one on 30th May 1994. Since 26th May 1994, the nuclear fuel is completely removed . The third licence for decommissioning was granted on 21st February 1995 approving, among other points, the taking out of operation of the secondary coolant circuit as well as construction, operation and dismantling of a drumming station for the disposal of the secondary natrium. An application for granting the fourth licence for decommissioning has already been submitted.

The **Thorium Hochtemperaturreaktor (THTR-300, a gas cooled high temperature reactor)** was shut down for being decommissioned in 1989. For the facility a period of safe enclosure is planned. On 17th March 1992, the Federal Office for Radiation Protection granted the licence for the storage of irradiated fuel elements from THTR-300 in the **Ahaus Fuel Element Interim Storage Facility (BZA)**.

The first licence for decommissioning, unloading of the reactor core and dismantling of equipment components was issued on 22nd October 1993. Since then, the spherical fuel elements have continuously been removed from the core. The core content had fully been removed by the end of 1994. All 305 Castor containers with fuel elements have been stored in the Ahaus Interim Storage Facility until April 1995.

In 1995, it was decided to finally shut down the Würgassen NPP, a BWR with an electrical power of 670 MW, which had been in operation from 1971 to 1994. Planning for decommissioning is underway.

Obviously, there is a substantial amount of decommissioning experience in Germany. It covers all stages of decommissioning like immediate dismantlement, safe enclosure and dismantlement after safe enclosure and combinations of these basic patterns.

III. Decommissioning operations creating airborne radioactivity

III.I General

Before decommissioning commences, it is assumed that the nuclear fuel and other media not required during decommissioning are removed from the plant in the frame of the operating license. In real cases of decommissioning, however, this is not always fulfilled.

In a nuclear power plant, the remaining inventory of radioactivity is then given by activated RPV and RPV-internals, the activated part of the biological shield, contaminated systems and components and, finally, contaminated building structures.

Decommissioning operations can be roughly divided into dismantling, decontamination, handling and waste management. Each of these areas of activities consists of numerous subtasks characterized by technology and application. During practically all of them airborne radioactivity is created. Thermal cutting techniques like plasma arc cutting or oxy-acthylene cutting for example procuce significant amounts of aerosols. Practically relevant examples of decommissioning operations and aspects of airborne radioactivity are discussed in chapter 4.

III.II Study results

In a study, (2) this has been assessed on a generic basis for the case of the total dismantlement of a modern 1300 MWe PWR. Essential results obtained for the atmospheric discharges and the resulting exposure to the public are summarized in table 1. Even if the variability in generically postulated methods and data is taken into account, the central finding that public exposure is substantially below the prescribed limits given in the next chapter remains valid.

Table 1: Dismantlement of a modern 1300 MWe PWR;
estimates of atmospheric discharges and dose calculations as given in a generic study (2)

Radionuclide	Atmospherically discharged radioactivity (Bq)	Calculated effective dose (µSv)
Co-60	$5{,}4 \cdot 10^6$	$1{,}4 \cdot 10^{-2}$
CS-137	$1{,}7 \cdot 10^7$	$7{,}8 \cdot 10^{-2}$
Cs-134	10^4	$6{,}4 \cdot 10^{-5}$
Mn-54	10^5	$1{,}5 \cdot 10^{-5}$
Eu-152	10^4	$2{,}4 \cdot 10^{-6}$
Ni-59	10^3	$7{,}3 \cdot 10^{-9}$
Ni-63	10^5	$1{,}4 \cdot 10^{-6}$
Nb-94	10^3	$1 \cdot 10^{-5}$
Fe-55	$3 \cdot 10^5$	$4 \cdot 10^{-6}$

IV. Regulatory aspects

According to section 7 para 3 of the Atomic Energy Act the decommissioning of a nuclear installation as well the safe enclosure of a finally decommissioned installation or the dismantling of the installations or of parts thereof require a license.

The level of protection against exposure of the public from discharges in air or water is defined in section 45 of the Ordinance on Radiological Protection (ORP). The dose limits per calendar year are:

1.	Effective dose, partial body dose for gonads, uterus, red bone marrow	0.3 mSv
2.	Partial body dose for all organs and tissues unless specified in 1. or 3.	0.9 mSv
3.	Partial body dose for bone surface, skin	1.8 mSv

In section 28 of the ORP it is furthermore required to keep exposures even below these limits as low as practicable.

In the licensing procedure for decommissioning discharge limits are defined in compliance with these requirements.

V. Selected information on decommissioning projects

V.I General Remarks

For the retention of the airborne radioactive particulates, which are released in dismantling operations in shut down nuclear power plants, firstly the filter systems installed during power operation and still operated at present are available (3). These are filter trains of the vent air filter system, the system exhaust air filter system and the subatmospheric pressure maintenance system which, for particulate removal, are provided with a prefilter, two category C particulate air filters, and one high-efficiency particulate air (HEPA) filter. The effective removal efficiencies of these filter trains with respect to the spectrum of particulates reaching them are well above the decontamination factor of 3×10^3 which is guaranteed solely for the new HEPA filter for the particles of the most penetrating size. On account of the series connection with the prefilter, the two category C particulate air filters, growing dust loading as well as the actual spectrum of particulates taken into account, total decontamination factors $> 10^6$ can be anticipated. So, these filter systems alone offer an effective protection against inadmissible emissions of radioactive particulates arising in decommissioning operations.

In the course of dismounting work additional measures are taken with the goal to support the air filter systems mentioned above and to further reduce discharges to the environment. These measures consist in

- keeping as low as possible the source term,
- retaining the released particulates by exhausting them where they are produced, and
- removing most of them in filter units installed in addition.

the goal pursued is not only to minimize the emission of radioactivity, but, at the same time, to avoid the spread of contaminations from dismounting work and, besides, to reduce internal exposure of the dismounting staff resulting from inhalation. Attaining these goals justifies additional expenditure which, in some cases, might be quite considerable.

The extent of additional measures required is quite different in the three most important dismantling phases, namely dismounting of the contaminated primary system, of the activated reactor pressure vessel with internals, and of the reinforced concrete of building structures, especially the biological shield. A great volume of coarse dust with low specific activities and easily to manage arises in dismantling concrete structures, whereas the most stringent requirements have to be met in dismantling the reactor pressure vessel and ist internals. In the latter case specific activities on the order of 10^8 Bq/g might have to be expected (4). The requirements to be fulfilled in dismantling contaminated systems are on a level between the two cases mentioned above. It should be taken into account also that dismounting of the primary loops is often preceded by chemical decontamination as practiced for instance under the MZFR decommissioning project (5). The primary objective pursued is to allow for manual dismounting with acceptable low radiation exposure of the staff. At the same time, smaller source terms will arise from dismounting work and hence a positive effect on the emissions to the atmosphere is achieved as well.

V.II Engineering Measures for Minimizing Radioactive Particulate Emissions

Emission control starts already with the minimization of the source term resulting from cutting operations. This means that to the extent feasible by the respective dismounting work cutting techniques will be applied which will produce no or only very few aerosols. Thus, preference will for instance be given to techniques such as mechanical cutting, shearing, and abrasive cutting. In cases where the application of thermal cutting techniques cannot be avoided, the relevant parameters will be optimized such that the least possible amount of aerosols is produced (6).

In order to remove the radioactive particulates released, the atmosphere has to be exhausted and filtered. In standard cases it will be sufficient to install a hood above the workstation. However, in this way only about 90% of the particulates are normally safely retained which is equivalent to a decontamintion factor of as little as 10. It is known that subsequent filtration produces much higher efficiencies. Consequently, in order to improve primary dust removal, the completest possible exhaust has to be aimed at. This is feasible by setting up a tent or housing around the workstation which is frequently practiced. This concept was implemented in a very sophisticated manner in the course of the meanwhile completed dismounting of the Niederaichbach Nuclear Power Plant (KKN). For remotely cutting up the pressurized tube reactor with its highly complex core structure an additional containment within the reactor containment was installed around the reactor tank (7, 8). Existing structures of the building were used for construction. In this additional containment kept at a negative pressure with respect to the containment atmosphere directed air flow was maintained. The vent air was cleaned in a purpose-built filter bench, 30,000 m^3/h through-put, and then carried into the vent air system of the containment for secondary cleaning. This solution to the problem is represented schematically in Fig. 1. It allowed to avoid the very expensive dismounting under water and thus helped saving a considerable amount of costs. In this context, operations were facilitated by the fact that the maximum specific activations were on the order of 10^5 Bq/g only due to the short operation period of the plant.

By contrast, the highly activated reactor pressure vessel with internals will normally be dismounted under water using remotely handled tools (9). This necessitates, as a rule, installation of a suitable water tank around the reactor pressure vessel. Water in that case does not only serve to remove the aerosols generated in the cutting operations but it acts also as a shield protecting the operating staff. Typical experiments have made evident that 10^{-3} to 10^{-4} of the kerf material removed in the cutting operations is released as aerosols above the water surface (10, 11). As a rule, these aerosols will be exhausted above the water surface and removed in particulate air filters as for instance practiced in the course of decommissioning of the Gundremmingen Nuclear Power Plant, Unit A (12).

A great variety of commercial filter techniques are suited for removal of the dusts and aerosols, respectively, released in cutting up operations. Experience accumulated in the recenlty completed demolition of the Niederaichbach Nuclear Power Plant proved that cleanable particulate air filters should be best suited for this purpose. They comprise two series-connected particulate air filters operated at reduced volume flow rate of approx. 1000 m^3/h per standard sized filter element. The first filter is cleaned by cyclic backflushing whereas the second serves as a safety device. Since the late seventies the successful application of particulate air filters provided with cleanup device has been reported in Germany (13, 14). Cleanable particulate air filter systems are available on the market. Work on their improvement is under way (15, 16).

It is generally known that the outstanding feature of such a filter combination are extremely high decontamination factors. Besides, very great amounts of dust can be removed. Consequently, the operating costs are justified which are caused mainly by filter changeout and disposal of the loaded filters (17). Finally, cleanable particulate air filter systems are suited to remove all particles of the spectrum encountered in decommissioning work.

During decommissioning of KKN several small mobile particulate air filter systems were used as well as the already mentioned stationary system with a throughput of 30,000 m^3/h. It was possible by these additional filter devices to keep extremely low the monthly emissions of particulate ß-radioactivity during the whole period of decommissioning from July 1988 until June 1994. Figure 2 shows the respective values of releases (18). As a rule, they range from 10^3 to 5×10^4 Bq, with the maximum values measured during the phase of dismounting of the activated pressurized tube reactor. The radiation burdens resulting from these emissions at the point of maximum deposition are negligible compared with exposure to natural radiation, a finding that is consistent with the general estimate provided in chapter 3.2. This experience shows that particulate removal during dismounting of nuclear power plants can be very effectively controlled with the engineering tools presently available.

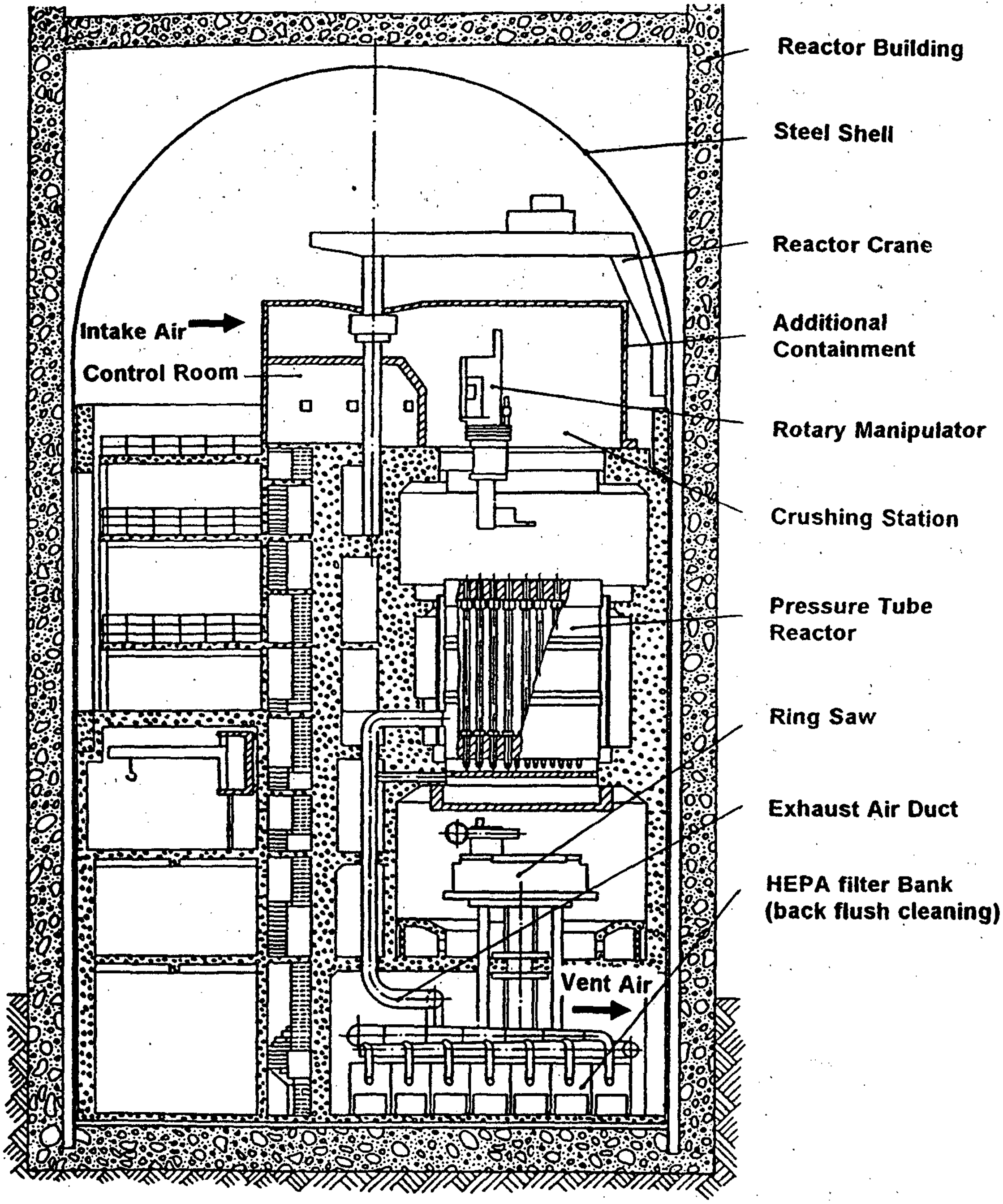

Fig. 1: Additional containment for the dismantling of the activated pressure tube reactor of KKN.

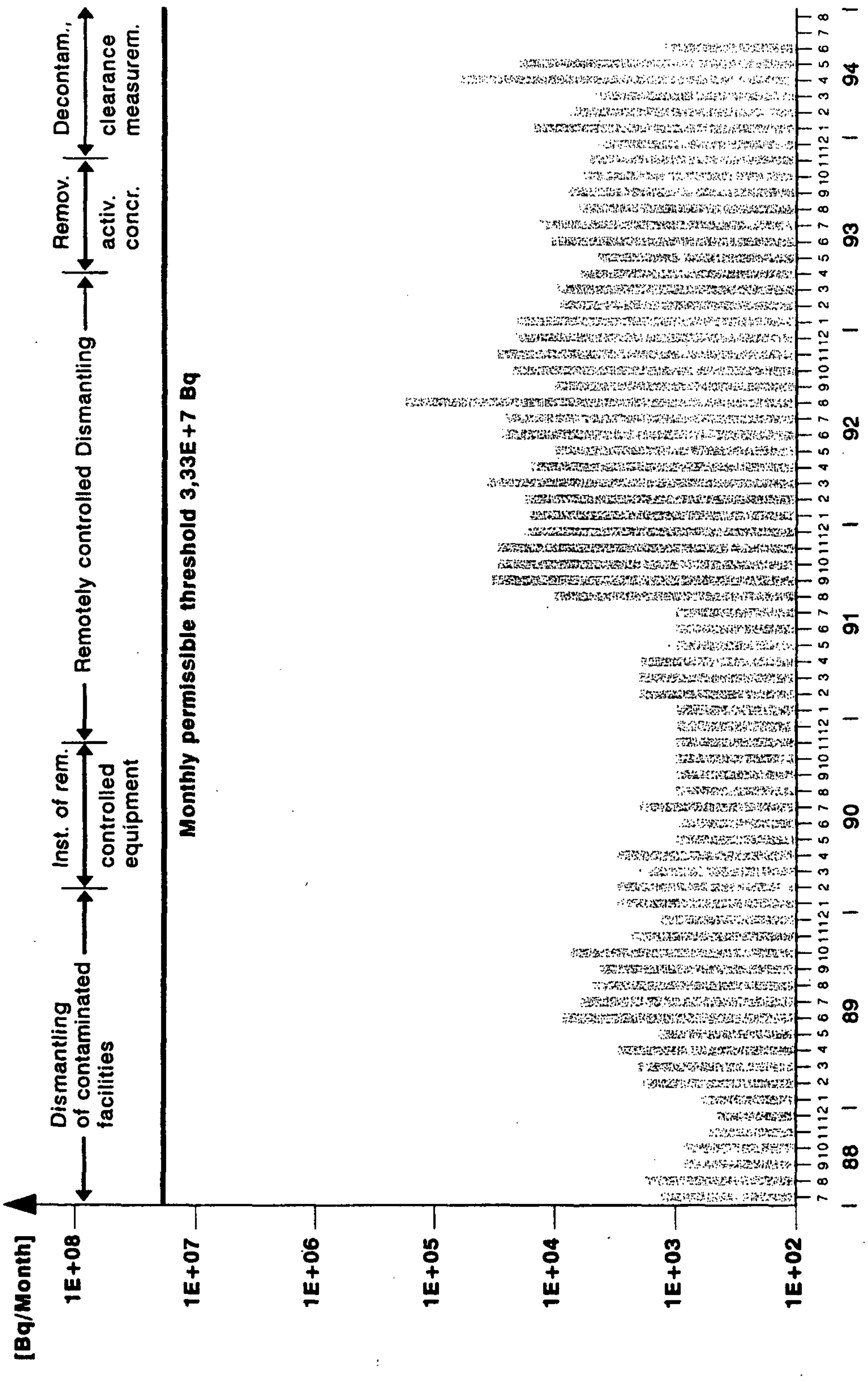

Fig. 2: Monthly emissions of particulate radioactivity during the decommissioning of KKN.

VI. Summary and conclusions

Atmospheric discharges from nuclear facilities finally shut-down are subject to regulation and control as during operation.

The nature of the discharges during decommissioning are in general different. Short-lived radionuclides have decayed and media (nuclear fuel, coolant, operational waste) no longer required are removed from the site and treated or stored elsewhere. In general, long-lived radionuclides in aerosol form are the most relevant group governing the atmospheric discharges during decomissioning.

The processes that lead to the formation of airborne radioactivity during decommissioning operations are quite well known. Generally speaking, they are segmentation, decontamination, handling and conditioning of radioactive parts and components. Thermal cutting of metal components is of special relevance.

As confirmed by the substantial amount of decommissioning experience in Germany, the technology is available for control and retention of airborne radionuclides. It generally consists of a combination of in-situ exhaust with prefiltering and aerosol filters for the overall atmospheric discharges.

Experience shows that in actual decommissioning projects the legal requirements of observing dose limits and keeping exposures below these limits as low as practicable are met. Public exposure due to atmospheric discharges is negligable. Theoretical studies demonstrate that this can be achieved as well in the substantial amount of decommissioning work that will be faced in the decades ahead, when the modern nuclear power plants approach the end of their projected life time and might be taken out of service.

Acknowledgement

The authors gratefully acknowledge the support provided by Mr. V. Rüdinger from KBG (Kernkraftwerk Betriebsgesellschaft mbH) in terms of technical information on decommissioning projects.

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DISCUSSION

BERGMAN: What is the experience with the cleanable HEPA filter? Has there been any damage to the media? Is the media the reinforced type?

WILHELM: Often cleanable HEPA filters are used in Germany without prefilters to remove industrial dust in the g/m^3 range. On the downstream side the medium of the cleanable HEPA filters is reinforced with a glass fiber web, such as the medium of the Lydair 3255 LW 1, or with a web from organic fibers, for example of polycarbonate fibers. It is also important that the pleats be round at the edge. We tried cleanable HEPA filters in different factories including the production of cement. They operated well and had long services lives. Using optimized HEPA fillers and cleaning methods, even the loss of removal efficeincy down to around 99% after large numbers of cleaning cycles could be avoided

BERGMAN: A couple of conferences ago we presented a comparison of cleanable steel HEPA filters and standard glass HEPA filters. With a standard very gentle reverse pulse, we had dozens and dozens of holes; all the bottom pleats were blown out. Is the reason your filter survives the reverse air blast because it is a very, very slow and gentle reverse flow?

WILHELM: The method and the flow velocity during loading and cleaning of the HEPA filter are optimized. The flow velocity is not very slow during the reverse air blast. The larger particles should not be removed upstream of the HEPA filters because they produce the removable filter cake on the surface of the medium and thus prevent the very small particles from penetrating deeper into the medium. Small particles, deposited in the depth of the medium, normally will not cause the formation of a removable filter cake. Therefore, also the filtration speed should be limited. With a loading of particles only with diameters around 1μm we did not have good results with cleaning cycles.

FUKASAWA: Which nuclides were easy to be discharged to the atmosphere? Did you estimate the discharged ratio i.e., the discharged radionuclides/total amount of the facility?

WILHELM: According to the paper Co-60 and Cs-137 are the most important radionuclides for airborne discharge during decommissioning. The data for the ratio of discharged radionuclides in relation to the inventory are not available.

HEATING, VENTILATING, AND AIR CONDITIONING DEACTIVATION THERMAL ANALYSIS OF PUREX PLANT

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ABSTRACT

Thermal analysis was performed for the proposed Plutonium Uranium Extraction Plant exhaust system after deactivation. The purpose of the analysis was to determine if enough condensation will occur to plug or damage the filtration components. A heat transfer and fluid flow analysis was performed to evaluate the thermal characteristics of the underground duct system, the deep-bed glass fiber filter No. 2, and the high-efficiency particulate air filters in the fourth filter building. The analysis is based on extreme variations of air temperature, relative humidity, and dew point temperature using 15 years of Hanford Site weather data as a basis. The results will be used to evaluate the need for the electric heaters proposed for the canyon exhaust to prevent condensation.

Results of the analysis indicate that a condition may exist in the underground ductwork where the duct temperature can lead or lag changes in the ambient air temperature. This condition may contribute to condensation on the inside surfaces of the underground exhaust duct. A worst case conservative analysis was performed assuming that all of the water is removed from the moist air over the inside surface of the concrete duct area in the fully developed turbulent boundary layer while the moist air in the free stream will not condense. The total moisture accumulated in 24 hours is negligible. Water puddling would not be expected. The results of the analyses agree with plant operating experiences.

The filters were designed to resist high humidity and direct wetting, filter plugging caused by slight condensation in the upstream duct is not a concern.

I. INTRODUCTION

This paper documents the results of a thermal analysis that was performed for the proposed Plutonium Uranium Extraction (PUREX) Plant exhaust system after deactivation. The analysis was performed to determine if enough condensation will occur in the concrete duct to raise a concern and to plug or damage the filtration components. A thermal and fluid flow analysis was performed to evaluate the temperature characteristics of the underground duct system, the deep-bed glass fiber (DBGF) filter No. 2, and the high-efficiency particulate air (HEPA) filters in the fourth filter building (Figure 1). The analysis is based on the extreme variations of air temperature, relative humidity, and dew point temperature using 15 years of Hanford Site weather data as a basis. The results will be used to evaluate the need for the electric heaters being considered for the PUREX canyon exhaust to prevent condensation.

The pressure drop of moist air through the filter media because of the Joule-Thomson effect is addressed. Calculations that demonstrate the effect are presented.

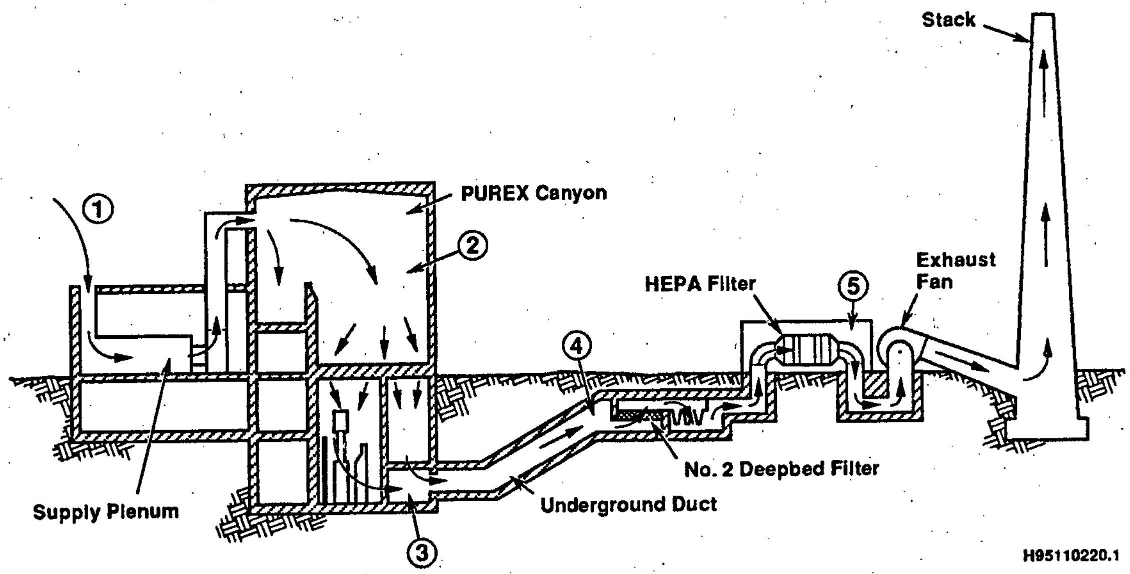

Figure 1. Operating System.

II. SYSTEM BACKGROUND

The ventilation system for the deactivated PUREX plant will consist of a draw-through system as shown in Figure 1. One of 3 canyon exhaust fans with a capacity of 40,000 ft^3/min (18.88 m^3/sec) will maintain negative pressure on the canyon, which provides the motive force to bring outside air into the plant. The proposed design cascades ventilation air through various zones within the plant to the PUREX canyon where it exits through the air tunnel to the underground duct work. The exhaust air passes through the DBGF filter No. 2, the fourth filter building containing HEPA filters, and the main stack to the atmosphere.

III. OPERATING EXPERIENCES

Before 1982, air washers in the supply air inlet plenums were used throughout the year. Large quantities of moisture were added to the air stream providing a mechanism for condensation far greater than what will occur during the surveillance and maintenance period. Available operating history shows no record of filter plugging or large accumulations caused by water condensation. Drains in the underground filter plenums eliminated condensate water that may have formed, but no water was entrained into the air stream to plug the deep bed or HEPA Filters.

The east and west sample gallery hood exhaust system exhausts to underground HEPA filter housings. The cover blocks of the filter housings are exposed to the ambient temperature. During HEPA filter replacements in 1987 and 1992, no high water marks or water damage were observed on any of the filters or plenum walls.

On several occasions in 1992, contamination was found to be dripping from the exhaust duct of the sample gallery hood when the spray washers were turned on. The dripping was attributed to a chemical compound in the ductwork that had an affinity for water. Since 1992, the spray washers have been left off from early spring until late fall. This eliminated the contamination dripping from the duct work. It also provided a 3-year spring/summer operating history that duplicates the sample gallery exhaust (SGE) ventilation during deactivation. No dripping or wetting of the ductwork, piping, and walls has been detected or reported.

During the winter, the sample gallery reheat coil supplies 70 °F (21.11 °C) air to the sample gallery. The walls, which maintain a temperature of 55 °F (12.78 °C), because of the earth's insulating effect, have shown no condensation or dripping. This provides the confidence necessary to predict that the sample gallery will not experience any condensation throughout the year.

IV. ANALYSIS PROCEDURES

The thermal and fluid flow characteristics were evaluated to determine the worst case variations at different locations along the flow path from the PUREX canyon to the 291-AE building (Figure 1). The basic mechanisms for condensation and frost formation were evaluated. The effects of heating and cooling in the underground portions of the ductwork were also described and evaluated. The temperature variations between the duct and exhaust air are investigated to determine if condensation and/or frost formation are likely under these conditions.

Condensation or Moisture Formation

Condensation Principle

Condensation or moisture formation may occur from the humid air under certain flow and thermal conditions. When moist air is exposed to a surface that is colder than the dew point temperature of the air, a trace of moisture film will appear on the surface (McQuiston and Parker 1988). This phase change is called condensation. The dew point (DP) temperature on the wall surface is the controlling factor for condensation to occur. The following conditions prevent condensation from forming:

- The unsaturated air temperature equals the duct surface temperature.
- The unsaturated air temperature is colder than the duct surface temperature.
- The air dew point temperature is colder than the duct surface temperature.

The thermodynamic process of atmospheric air flowing through the PUREX exhaust system is essentially a heating and cooling process without changing the humidity ratio; only sensible heat is added or removed. Therefore, the moist air that flows through the cold duct does not necessarily produce condensation.

Condensation Rate

Based on the Hanford Site weather data for 24 hours on December 11, 1994, the data indicated the dry-bulb temperature in the range of 30 to 33 °F, while the relative humidity was between 95 and 99 percent. The cumulative condensate was calculated based on persistent air temperature of 33 °F (0.56 °C) and relative humidity of 98 percent, for 24 hours, while the duct wall temperature (32 °F or 0 °C) was assumed to fall below the air dew point temperature of 32.5 °F (0.28 °C).

Because the condensation rate was calculated based on the variation of the humidity ratio, a worse $\Delta w = 0.000325$ lb of H_2O per lb of dry air was calculated for 24 hours.

The average specific volume of the air was determined at 12.5 ft^3/lb (0.78 m^3/kg), the mass flow rate was calculated as 3,200 lb/min (1,451.5 kg/min).

Because moist air condensation occurs only during contact with the cool wall surface, most of the free-stream air flows through the duct without producing condensation. The actual condensation occurs only for the moist air inside the laminar sublayer in a fully developed turbulent boundary layer. However, it is conservatively assumed that the moist air inside the fully developed turbulent boundary will be condensed.

For the fully developed boundary layer, the Reynolds number is calculated based on boundary layer length of 50 ft (15.24 m) at 3,787,698. The boundary layer thickness, δ, was calculated at 11 in. (27.94 cm). The total volume for condensation is 3,200 ft^3 (90.6 m^3). The total condensation rate for all the air moisture in 24 hours is 608 lb (275.8 kg).

The total surface area that this amount of condensate will cover in 24 hours is 1,600 ft^2 (148.6 m^2). Therefore, the condensate rate over unit duct surface area is 0.016 lb of $H_2O/hr-ft^2$ (0.078 kg of $H_2O/hr-m^2$) or a total of the moisture at 0.38 lb H_2O/ft^2 (1.85 kg H_2O/m^2) per day on the duct wall surface.

The remaining non-condensed moist air outside the boundary layer will flow through the duct. The condensate on the wall surface causes no concern because the accumulated quantity is small; dripping or puddling is not expected.

If the Amercoat on the concrete has deteriorated or the concrete interior is not in a saturated state, the sorption characteristics, capillary suction, and moisture transfer capabilities of the concrete may be able to absorb a small amount of moisture (Jonasson 1985).

For the concrete surface in the air duct, this rate of condensation cannot produce dropwise condensation. The moisture will be spread over the concrete surface with a thin layer of film with no dripping or puddling.

As a result of the assumed condensation, the humidity ratio or moisture contents in the flowing air will be reduced when the air flows through the DBGF filter No. 2.

Fog and Frost Formation

Fog is a disperse system consisting of liquid drops suspended in a gas. The conversion of vapor to fog is a discontinuous process occurring under critical conditions when vapor reaches the supersaturation state (Amelin 1967). The air flow in this study has not experienced any isentropic expansion into the wet region in the enthalpy/entropy diagram (Obert 1960) and the supersaturation condition has never been attained. Thus, fog formation inside the air duct is not possible.

If the fog or gaseous suspensions are flowing from the environment into the plant with the moist air, the warming effect inside the building and air duct will evaporate the moist fog. The fog can be sustained only if a source within the plant continuously supplies the moisture and the temperature in the duct is much colder than the outside air. As the moist air flows through a complicated and winding path inside the plant, the moist drops may impact a surface and deposit along the pathway. Because the fog conditions at the Hanford Site lasted only few hours, a limited amount of moisture was deposited in the air duct.

Frost forms when the moist air is exposed to a surface that is colder than the dew point temperature of the air, which must be far below 32 °F (0 °C). Under this condition, the moisture content of the air passes directly from the gaseous state to the solid state forming a porous layer of frost on the cooled surface. The rates of increase of the frost thickness require a continuous cooler temperature and high-humidity environment. Otherwise, the frost begins to melt and evaporates into the air stream. When the air/frost interface temperature temporarily warms back to 32 °F

(0 °C), even in a high-humidity environment, the frost layer will occasionally undergo cycles of melting and refreezing (Trammell 1968). Considering the high affinity the air has for moisture, the frost melts and is evaporated by the dry air.

Air and Duct Temperature

The worst temperature variations contained in the Hanford Site weather data for the past 15 years were reviewed. The two wettest years, and the two coldest years, and the 1994 winter data were used as the basis for performing the heat transfer analyses. Heat transfer calculations and numerical examples for the conditions described are presented in the following paragraphs.

Transient Heat Conduction

Based on the weather data for the coldest and wettest years at the Hanford Site, transient heat conduction calculations were performed to determine the worse environmental temperature conditions and the depth the freezing layer penetrates into the soil resulting from the worst weather scenario (Schneider 1955).

Two examples are used to demonstrate the depth the frozen layer penetrates into the underground soil under extreme weather conditions.

Example 1: On a cold winter day, after a sudden change in weather conditions, the surface temperature of the plant environment drops to 18 °F (-7.8 °C). These cold conditions continue for 14 days. The temperature of the ground before the weather change is assumed to be 35 °F (1.7 °C). After this period, the temperature is calculated at different distances from the surface (Schneider 1955):

x = 4 ft (1.220 m), T = 32.1°F (0.08 °C).
x = 5 ft (1.524 m), T = 33.6°F (0.89 °C).
x = 6 ft (1.829 m), T = 34.3°F (1.28 °C).

Example 2: During the winter, a sudden cold wave reduces the ambient air temperature to 0 °F (-17.8°C). If the earth was at a uniform temperature of 40 °F (4.4 °C) before the onset of the cold wave, the freezing temperature penetrations were calculated to different depth after various hours,

6 hours, $x = 0.9 \times 2\sqrt{1.8 \times 6} = 5.9$ in (14.98 cm).
12 hours, $x = 0.9 \times 2\sqrt{1.8 \times 12} = 8.4$ in (21.34 cm).
24 hours, $x = 0.9 \times 2\sqrt{1.8 \times 24} = 11.8$ in (29.97 cm).

This indicates that the frozen layer penetrates less than 1 ft (0.3048 m) in 24 hours.

Flowing Air Temperature

The winter atmospheric air flows from the PUREX canyon building and enters the inclined air duct system. The wall surface temperature of the air duct was assumed to be 55 °F (12.8 °C) at 30 ft (9.144 m) below grade and cooled to near the environment temperature at the upper section close to the grade level. Heat transfer calculations were performed to determine the temperature increase of the flowing air at the turbulent boundary layer because of the warmer wall.

This section calculates the moist air temperature change caused by the effect of the warm concrete duct wall. The underground concrete duct cross-section area varies from the lower portion of 11 ft x 5 ft-9 in. (3.35 m x 1.75 m) to the upper portion of 8 ft x 8 ft (2.44 m x 2.44 m). The upper section is near the grade level, so its temperature is closer to the environmental temperature.

Consider a 40,000-ft^3/min (1,132 m^3/min) flow rate, the flow velocity through an 11 ft x 5 ft-9 in. (3.35 m x 1.75 m) duct is 10.54 ft/sec (3.21 m/sec). The equivalent hydraulic diameter is 90.6 in. (2.3 m). The Reynolds number is 578,529, which falls within the turbulent flow region. Assume that the Prandtl number is 0.7 for air. The heat transfer coefficient was calculated at 0.0196 Btu/hr-in^2-°F (16.02 W/m^2-K) using the correlation (Lancet 1959) $Nu = 0.042\ (Re)^{0.8}\ (Pr)^{1/3}$.

Assuming that the moist air at 32 °F (0 °C) flows through the concrete duct section at 55 °F (12.8 °C), the heat balance equation may be applied to calculate the flowing-air temperature at 34.4 °F (1.33 °C). This demonstrates that the air temperature in the boundary layer will be warmed up to 34.4 °F (1.33 °C), while the air temperature outside of the thin boundary layer remains at 32 °F (0 °C).

Duct Wall Temperature

Another calculation shows the cooling effect on the wall surface if cool air is flowing continuously through the duct. The convective cooling from the wall requires temperature gradient in the concrete wall to initiate the conduction heat flow. Hand calculations appeared to be fairly involved. A transient heat transfer analysis using a simplified finite-element model (ANSYS 1993) was performed to determine the temperature distributions throughout a concrete section.

The warm wall surface of the underground duct may be cooled if air at 32 °F flows through continuously. However, at a great distance from the surface, the duct surrounding remains at 55 °F (12.8 °C).

The finite-element mesh denoting the node and element numbering is shown in Figure 2. The three-dimensional thermal solid elements (solid70) have eight nodes with a single degree of freedom, temperature, at each node was used. Convective boundary condition, with heat transfer coefficient of 0.0196 Btu/in^2-hr-°F (16.02 W/m^2-K), was applied at the inside wall surface. Concrete material properties were used.

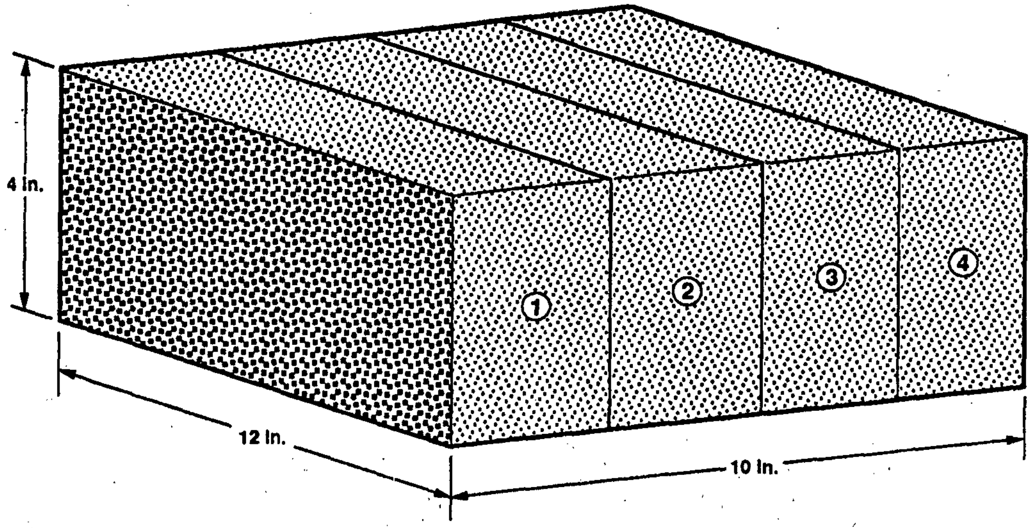

Figure 2. ANSYS Finite-Element Model.

A small initial temperature gradient was applied to start the transient solution. Results indicate that the temperature distribution throughout the section of the wall reached a steady-state temperature of approximately 42 °F (5.56 °C) after 4 hours.

Filter System Condensation

This section describes possible condensation and moisture effects on the filter systems.

Prefilter (Deep Bed Filter No. 2)

If condensation were assumed to have occurred at the cold wall surfaces in the upper portion of the inclined air duct system, the moisture content of the air would be reduced and further effect of condensation on the deep bed filter would be decreased because the air entering the filter is dryer.

Generally, sufficient moisture in droplet form is hazardous to a filter system. However, the filters are designed to resist moisture as long as plugging does not occur. Filtration is achieved by various mechanisms depending on the particle size and flow velocity (Davies 1973). The penetration mechanism is controlled by either molecular diffusion, interception, Brownian motion, or inertial impacting depending on the air flow velocity.

In good-quality filters with low resistance and high efficiency against submicron particles, the air flow obeys Darcy's law, which is usually considered to be valid for creeping flow with low Reynolds number. The low-Reynolds-number flow is dominated by viscous force. The viscous effect between the air particles and the filter fibers may keep the filter surface temperature from decreasing below the air temperature. As a result, the filter surface temperature is generally close to the air flow temperature.

High-Efficiency Particulate Air Filter

If condensation occurs in the underground duct work, the air flowing through the HEPA filters in the 291-AE building will be dryer.

Before the air reaches the HEPA filters, it has to flow through the concrete duct that has a wall surface temperature close to that of the inlet plenum wall located at the entrance to the HEPA filter. The temperature of the plenum wall should be the same as or colder than that of the HEPA filter. If the plenum wall temperature is at or colder than the dew point of the flowing air, condensation will occur at the plenum.

Condensation will not take place in the filters whether or not condensation occurs at the plenum. The air will simply flow through the filters. The HEPA filter media is treated with a water-resistant binder and will tolerate both high humidity and direct wetting (Flanders 1988). Several tests (First and Leith 1976) indicated that no degradation in filtering ability occurs after exposure to a steam-droplet atmosphere.

Joule-Thomson Effects

The Joule-Thomson experiment (Jones and Hawkins 1960, Kestin 1979) may resemble the moist air flowing through filter media and produce condensation. The basic condition for the Joule-Thomson effect to cause cooling is that the initial temperature of the gas must be below the maximum inversion air temperature, which is 628 °F (331 °C). The temperature of the flowing air is below the maximum inversion temperature.

If air is compressed to a pressure of 200 atm (2,940 psi or 20,265 KPa) and a temperature of 126 °F (52 °C), after throttling to a pressure of 1 atm (14.7 psi or

101.325 KPa), it will be cooled to 73 °F (23 °C). For a small pressure drop of few inches or centimeters, such as flow through porous media, the temperature drop and the air cooling effect of the Joule-Thomson phenomenon are negligible.

Frost Formation on HEPA Filters

The possible frost conditions in the HEPA filter building are evaluated under the assumed frozen temperature in the environment. Two conditions may subject a cool surface to frost formation: when the surface has been exposed to nocturnal radiation and when a surface that has cooled below 32 °F (0 °C) contacts the moist air with a dew-point temperature higher than the surface temperature.

The first condition is unlikely to occur because the HEPA filters are housed in a building and not exposed to nocturnal radiation. Therefore, the cooling will not be present inside the building.

The second condition becomes possible when a surface cools to a subzero temperature that is below the dew point of the moist air. If the wall surface temperature of the HEPA filter building is cooled down well below the freezing point, the concrete duct and inlet plenum surface temperature will be near or at the freezing point temperature. Under this condition, the water vapor leaving the air and attaching to the surface may pass directly from gaseous to solid state forming a porous layer of frost.

Tests (Brian et al. 1970) indicate that continuous frost formation requires a subzero temperature and high specific humidity. After the frost formation, frost growth requires a sustained cooling mechanism, a continuous temperature decrease of the cooled surface, and an increase of the specific humidity of the air stream. In the absence of this persistent cooling phenomenon, frost buildup is not possible (Trammell 1968). If at any time the surface temperature reaches 32 °F (0 °C), melting will occur (Jones and Parker 1975). Based on temperature fluctuations from the Hanford weather data, frost may have formed on cold surfaces as a transient condition.

If condensation has already occurred as the cold air flows through the concrete duct or inlet plenum, the same amount of air that flows into the HEPA filters would have reduced the moisture content or humidity ratio. With a reduced humidity ratio because moisture is lost in the duct, the effect on the filters is not a concern.

V. RESULTS AND DISCUSSIONS

The results of a transient heat conduction analysis show that the depth of frozen soil, resulting from a subfreezing surface temperature of 18 °F (-7.78 °C) penetrates 6 ft (1.83 m) below grade after 14 days. These results agree with the publications from the U.S. Weather Bureau map that show the average and maximum depths of frost penetration as 12 and 36 in. (30.48 and 91.44 cm), respectively, in southeastern Washington State (Strock 1965). This indicates that only a small upper section of the air duct perimeter near the grade level may temporarily come close to the freezing temperature under the possible worst environmental condition.

An extreme weather condition that may never occur at the Hanford Site also was analyzed. A plant environmental surface temperature of -27 °F (-32.8 °C) lasting for 60 days was assumed. Results indicate that the frozen layer may penetrate into the soil to a depth of 7 ft (2.134 m).

The earth has been shown to maintain a constant temperature of 55 °F (12.78 °C) throughout the year at the lower section of the air duct. Cool moist air at 32 °F (0 °C) flowing through the 55 °F (12.78 °C) air duct can warm up only 2 °F (1.11 °C) near the boundary layer, while a large quantity of air at the free stream remains at 32 °F (0 °C). A continuous flow of cold air at 32 °F (0 °C) may lower the wall temperature to 42 °F (5.56 °C) when reaching a steady-state condition in 4 hours. The 42 °F (5.56 °C) temperature is above the dew point of the air.

If the air flows at a velocity of 10.54 ft/sec (3.213 m/sec), the time for air to travel from the duct entrance to deep bed filter no. 2 takes approximately 25 seconds. The duct wall temperature cannot be cooled much lower than the steady-state temperature. Condensation in the lower section of the air duct during the winter is not possible.

A condition may exist in the underground ductwork where the duct temperature can lead or lag the changes in the ambient air temperature because of the thermal storage characteristics of the underground duct. This condition may contribute to condensation on the inside surfaces of the underground exhaust duct.

The coldest and wettest weather data for the past 15 years have shown that only short periods in the early spring and winter of 1994 could contribute to some slight condensation that is barely enough to dampen the duct wall surfaces.

However, the condensation rate was conservatively calculated based on the worst recorded data during the 1994 winter. The dry-bulb temperature occurred between 30 to 33 °F (-1.1 to 0.56 °C), while the relative humidity was between 95 and 99 percent for 24 hours, assuming that the moist air flowing through the boundary layer in the concrete duct is condensed during the 24 hours. Results indicated that only 0.38 lb (0.172 kg) of moisture may be accumulated on 1 ft^2 (0.093 m^2) in 24 hours. A large amount of flowing air in the free stream does not condense.

This small amount of moisture may be evaporated under the condition of temperature variations without producing significant wetting. From the plant operating histories, no significant condensation has been observed, even when the water spray system was in operation.

If condensation occurs on the concrete duct-wall surfaces, the humidity ratio for the air downstream is reduced. As a result, the filter housing temperature is above the dew point temperature of the air; therefore, condensation does not take place. The potential for condensation on the HEPA filter housing surfaces will be less of a concern.

The pressure drop through the filter system is not sufficient to cause any temperature drop and condensation. In addition, the filters are designed to resist high humidity and direct wetting (Burchsted 1978, Flanders 1988), so a small amount of moisture would be of no concern.

Frost formation on the HEPA filters is not possible because frost forms only on much colder surfaces, such as the duct wall or inlet plenum, before the cold air flows into the filters. No enduring mechanisms, such as continuous cooling and a high-humidity environment, exist to build up such effects on the HEPA filters.

VI. CONCLUSION

Condensation heat transfer and fluid flow analyses were completed to evaluate the effects of condensate in the underground duct and filters in the PUREX plant. The results of the analysis indicate that the ductwork upstream of the DBGF filters bed No. 2 is the most likely place for condensation to form.

A worst case conservative analysis was performed assuming that all of the water is removed from the moist air over the inside surface of the concrete duct area in the fully developed turbulent boundary layer while the moist air in the free stream will not condense. The total moisture accumulated in 24 hours is 0.38 lb H_2O/ft^2 (1.85 kg H_2O/m^2), which is barely enough to dampen the concrete wall surfaces. Water dripping and puddling is not expected.

Turbulent heat transfer analysis has shown that 32 °F (0 °C) air flowing through the duct will be warmed to 34.4 °F (1.33 °C) inside the thin laminar sublayer, while the air in the free stream remains at 32 °F (0 °C). Further analysis has indicated that the surface of the duct wall may be cooled to 42 °F (5.56 °C) after reaching a steady state condition in 4 hours.

Based on an air flow velocity through the concrete duct at 10.54 ft/sec (3.213 m/s), the air has a resident time of approximately 25 seconds traveling from the underground duct entrance to the DBGF No. 2 filter. Therefore, the lead/lag temperature characteristics of the underground duct are of short duration allowing the duct to follow changes in air temperature rather closely. This reduces the condition for possible condensation. On the other hand, condensation occurring in the ductwork upstream of the DBGF No. 2 filter will provide dryer air in the downstream duct and filters.

If no condensation occurs before the deep bed filters, the same moist air flows through the concrete duct, the HEPA filter building, and the exhaust system without further condensation. The pressure drop through the filter system is not sufficient to cause any temperature drop that will initiate condensation. However, the filters were designed to resist high humidity and direct wetting (Burchsted 1978, Flanders 1988), filter plugging caused by condensation is not a concern. Tests (First and Leith 1976) indicated no degradation in filtering ability after exposure to a steam-droplet atmosphere. The results of the analyses also agree with the operating experiences. Therefore, it is concluded that no electrical heating system is required for the PUREX canyon exhaust to prevent condensation.

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DISCUSSION

FRETTHOLD: Are you planning on changing out all of your filters prior to going into this condition, so you start with new filters?

GREGONIS: No, we are not. We test our HEPA filters annually and we have recently replaced up to five banks. Because the system for our filter building was built for 120,000 CFM we have ten banks. Five will be available on-line and five will be off-line. If we have a problem we will just valve in another bank and then replace them during that time.

FRETTHOLD: You are running your filters at your 40,000 CMF instead of 120,000?

GREGONIS: That is correct.

FRETTHOLD: You plan to down rate the filter by going to twice the number of filters?

GREGONIS: That is the plan. This system has been online since '83. Based on its' history has been pretty reliable. Have not had a major problem. So the thought is that it will continue.

FRETTHOLD: Where will supply air come from? It is not supplied with a fan, is it just drawn in through the supply?

GREGONIS: It is drawn through the system by the negative pressure in the canyon, basically it is infiltration. We will have prescribed paths for the air to enter.

BERGMAN: I was looking through your references and I did not see any reference to the excellent work done by Dr. Wilhelm and his group at KfK about moisture accumulation on filters. If I recall right, just a little bit of particle deposition will literally suck the moisture out of the air, even when it is below saturation and when you have a powerful enough fan it will suck the innards out of the filter. That is one thing. A second item is that we were shown at a prior conference that even when you leave a HEPA filter sit in storage, it loses all its water repellency after about ten years. In that case, the image of the filter is not that of a water repellant substance, but a sponge that will literally soak up the water. My question is, have you considered any of these facts from previous literature reports?

GREGONIS: We have a extensive list of research on that. There was a paper presented by Dr. First that showed a case where they were testing a droplet retrainer, I believe, and that paper pretty much showed that water was not a problem. In addition, we go through a deep bed before we go through the HEPA filter. So the dust loading on the HEPA filters is basically nil.

BERGMAN: All studies before the KfK studies during the mid-80's had been done with brand new filters. Again I point out, it does not take a lot of dust, just a little bit of dust immediately changes the characteristics from a brand new filter to an aged filter. And again, the image is a sponge even though you have a very clean environment, the fact that you lose the organic water repellency characteristic transforms the filter into a sponge. And so I would recommend you to refer to some of the pioneering work in Germany, and include that in your references because by not doing so, you may have a little surprise.

GREGONIS: Just a comment based on our operating experience. They used to run the spray washers year-round and the mechanism for condensation was that the filter housings are out in the ambient temperature. I have been in almost all the filter housings, and been involved in filter changes. We did not see any degradation or ruptures. Therefore, in our deactivation state, where we are not putting any water in, but are just taking ambient air and running it through the plant and out again, I feel we have a pretty good basis for utilizing these filters. However we will study the matter you presented.

ENGELMANN: Whether there can be condensation on the filter depends almost entirely upon the absolute humidity of the air and the filter temperature. A simple and adequate approach is to estimate or measure the absolute humidity within the building and that of the makeup air to calculate what is presented to the filter. A simple solution (if there is a problem) is to add more makeup air which at Hanford, has low humidity. Heating of the air did not merit consideration as a solution, unless there are expected to be major activities with much evaporation within the building.

SESSION 9

COMPUTER MODELING APPLICATIONS & ADSORPTION

Wednesday July 17, 1996
Co-Chairmen: R. Lee
D.W. Moeller

COMPUTER MODELING APPLICATIONS

FILTRATION THEORY USING COMPUTER SIMULATIONS
W. Bergman and I. Corey

STUDY ON COLLECTION EFFICIENCY OF FISSION PRODUCTS BY SPRAY: EXPERIMENTAL DEVICE AND MODELING
D. Ducret, D. Roblot, J. Vendel, Y.

ADSORPTION

CHARACTERIZATION AND RESTORATION OF PERFORMANCE OF "AGED" RADIOIODINE REMOVING ACTIVATED CARBONS
W.P. Freeman

EFFECTS OF WELDING FUMES ON NUCLEAR AIR CLEANING SYSTEM CARBON ADSORBER BANKS
P.W. Roberson

FILTRATION THEORY USING COMPUTER SIMULATIONS*

by

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Lawrence Livermore National Laboratory
Livermore, CA 94550

Abstract

We have used commercially available fluid dynamics codes based on Navier-Stokes theory and the Langevin particle equation of motion to compute the particle capture efficiency and pressure drop through selected two- and three-dimensional fiber arrays. The approach we used was to first compute the air velocity vector field throughout a defined region containing the fiber matrix. The particle capture in the fiber matrix is then computed by superimposing the Langevin particle equation of motion over the flow velocity field. Using the Langevin equation combines the particle Brownian motion, inertia and interception mechanisms in a single equation. In contrast, most previous investigations treat the different capture mechanisms separately. We have computed the particle capture efficiency and the pressure drop through one, 2-D and two, 3-D fiber matrix elements.

I. Introduction

Developing an accurate theoretical model of particle filtration is extremely difficult because of the complex nature of the filtration process, which involves particle transport in a fluid moving through a complex filter geometry. Figure 1 illustrates the complicated structure of a typical filter medium made from glass fibers. The fluid and suspended particles flowing through this fiber maze follow an extremely tortuous path controlled by the fluid dynamics and the particle equations of motion. Other type of filter structures such as spheres or granules and irregular porous structures are also frequently used in filtration.

The previous approach for modeling the particle filtration process has been to represent the complicated filter structure by a single element and then compute the fluid flow and particle transport around the one element.(1,2) The particle transport was computed by separately adding the contributions due to diffusion and inertia to the integrated trajectory. More recently, investigators have begun to model filtration in terms of parallel fibers arranged in a symmetric two-dimensional configuration.(3) Although this is an improvement over the single collector model, the filtration is still limited to 2-D flows through overly simplistic filter geometries.

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*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-ENG.48.

Figure 1. Scanning electron micrograph of glass fiber media used in high efficiency particulate air (HEPA) filters.

The problem with these previous approaches is that only general trends can be obtained from the computations, and considerable amount of experimental studies are still needed to substantiate the computations for specific filter designs and operating parameters. For that reason, filter designs and operational parameters generally are established through extensive experimental studies. This approach is both costly and time consuming. Perhaps even more important, the previous theoretical models restrict the development of new filters to existing production designs and available materials rather than what is theoretically possible. To overcome these deficiencies we have developed a filter simulation model that can simulate the filtration of suspended particles through more realistic filter structures, although not yet as complicated as that shown in Figure 1. The complexity of the fluid flow and particle trajectories through the filter media shown in Figure 1 greatly exceed present computer hardware and software capabilities, even when using advanced mainframe computers.

II. Development of Filtration Simulation Model

We have used commercially available fluid dynamics codes, NEKTON version 2.85, (Fluent Inc. 10 Cavendish Ct. Lebanon, NH 03766) and FIDAP version 6.0, (Fluid Dynamics International, Inc. Evanston, Il, 60201) and the particle equation of motion to compute the particle capture efficiency and pressure drop through selected two- and three-dimensional fiber arrays. The approach we used was to first compute the air velocity vector field throughout a defined region containing the fiber matrix. This was the most difficult and time consuming task in our study. Each combination of inlet air velocity and fiber matrix required a significant effort to set up the fluid problem and to compute the velocity field. All of the air flow calculations in this report were conducted with a uniform inlet velocity directed at the fiber matrix, and we allowed the exit velocity to vary. We did not force the fluid to be periodic (equal velocity fields at the inlet and exit) through the fiber matrix because of the additional work required to establish periodic flow.

The most difficult and time consuming step of the simulation is computing the velocity and pressure fields using computational fluid dynamics (CFD) computations. We have used the commercial CFD solvers, NEXTON and FIDAP, which are based on Navier-Stokes equations. The large memory requirements (50MB) and the long processing times (20 hours) for the CFD computations limit the size of the filter model that can be studied to filter structures with about 100 fibers when using computer workstations. Using PCs would restrict the filter to about 10 fibers, while a supercomputer could compute structures with up to 1,000 fibers.

The filtration computer simulations require a UNIX based hardware platform with a minimum of 48MB of memory to run. We computed the filtration simulations that are shown in this report using the SGI Indigo platform from Silicon Graphics. The following are the software and hardware requirements:

Table 1. Hardware and Software Requirements For Computer Simulations

COMPONENT	REQUIREMENT
Graphics	Requires open/GL Graphics. 8 bit -planes is adequate
CFD Solver	A CFD solver is required. Any 3D CFD solver can be used, e.g. NEKTON or FIDAP. A mesh generator may also be required, e.g. TrueGrid.
Visualization	SGI's Explorer was used
Main Memory	48MB
Disk Storage	10MB minimum, primarily for flow fields

Figure 2 shows an example of the two-dimensional air flow calculations through a matrix of 2μm and 4μm diameter fibers. The inlet flow velocity was 20 cm/s. We were also able to compute the three-dimensional flow fields through the staggered hexagonal array in Figure 3 and the crossed fiber array in Figure 4. The direction of flow is in the X-direction. Once the air flow velocity field is determined, the differential pressure is also fixed and is read directly from the computer output.

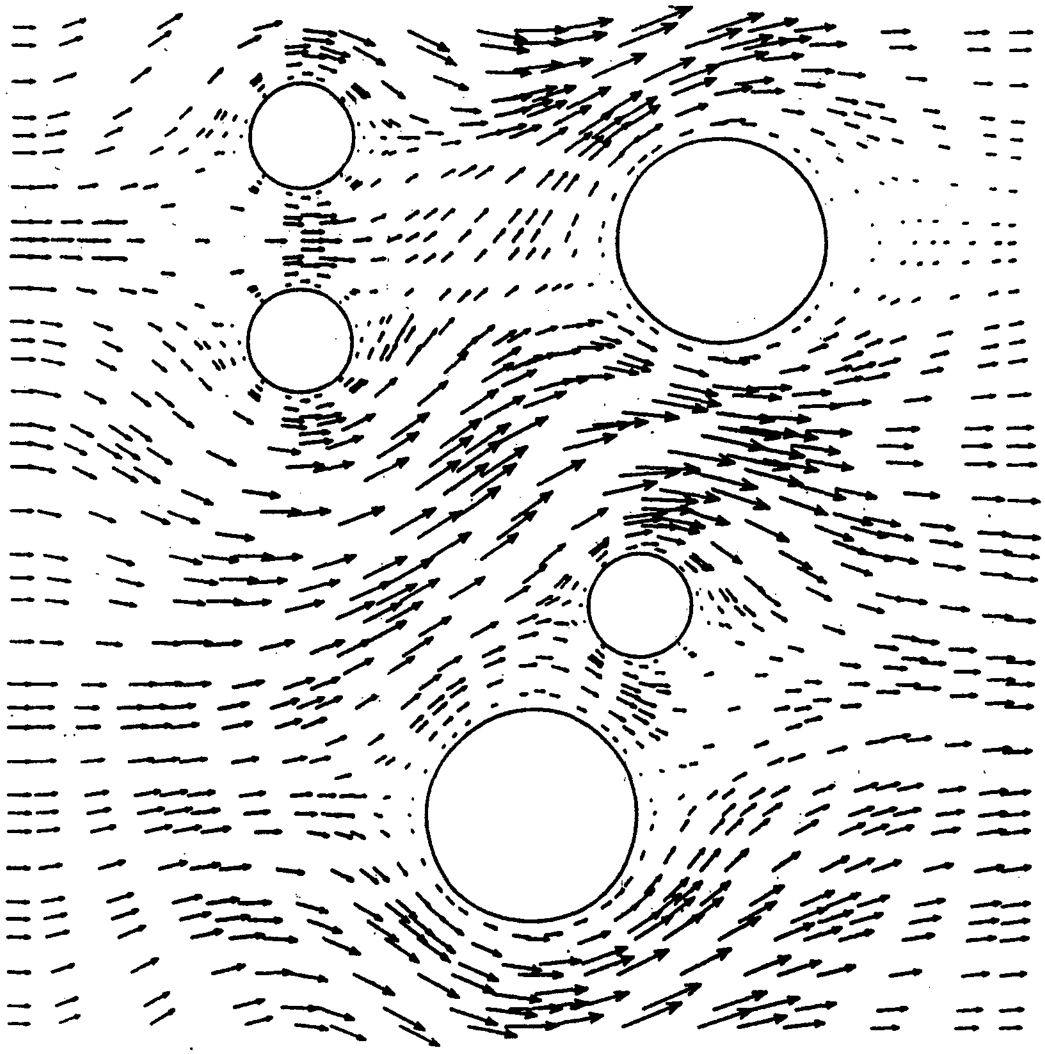


Figure 2 Air velocity vector field through 2-D fiber matrix at 20 cm/s initial velocity. The fiber matrix is 20μm x 20μm with 2 μm and 4μm diameter fibers. The fiber volume fraction is 0.0864.

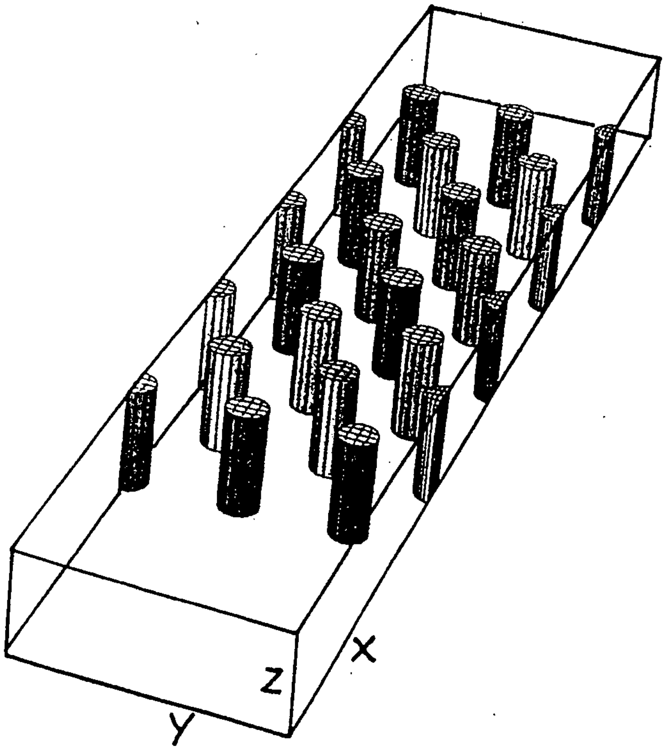


Figure 3 3-D fiber matrix with $1\mu m$ diameter fibers arranged in a staggered hexagonal array. The fiber matrix L x W x H is $23.0\mu m$ x $6.5\mu m$ x $5.0\mu m$. The fiber volume fraction is 0.0825, and air flow is in X direction.

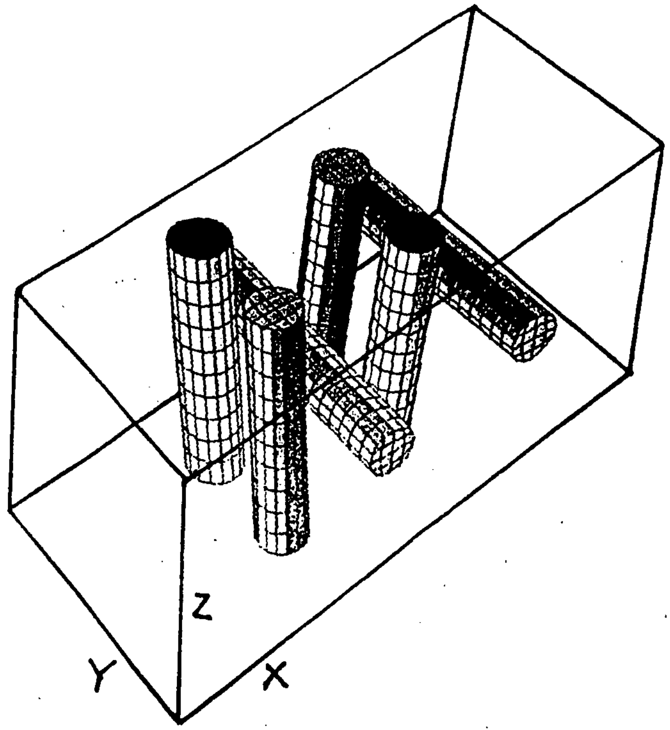


Figure 4 3-D fiber matrix with $1\mu m$ fibers arranged in a crossed fiber array. The fiber matrix L x W x H is $11\mu m$ x $5\mu m$ x $5\mu m$. The fiber volume fraction is 0.0843 and air flow is in X direction.

The particle capture in the fiber matrix is then computed by superimposing the particle equation of motion over the flow velocity field. The resulting particle dynamics is given by:

$$\frac{d\underline{v}}{dt} = B(\underline{u}-\underline{v}) + \underline{A}(t) \qquad (1)$$

where,

$\underline{v}$ = particle velocity vector
$\underline{u}$ = fluid velocity vector
B = friction coefficient
$\underline{A}(t)$ = random Brownian acceleration, time dependent
t = time

The friction coefficient B is defined as

$$B = \frac{6\pi \ \mu a_p}{C_s \ m} \qquad (2)$$

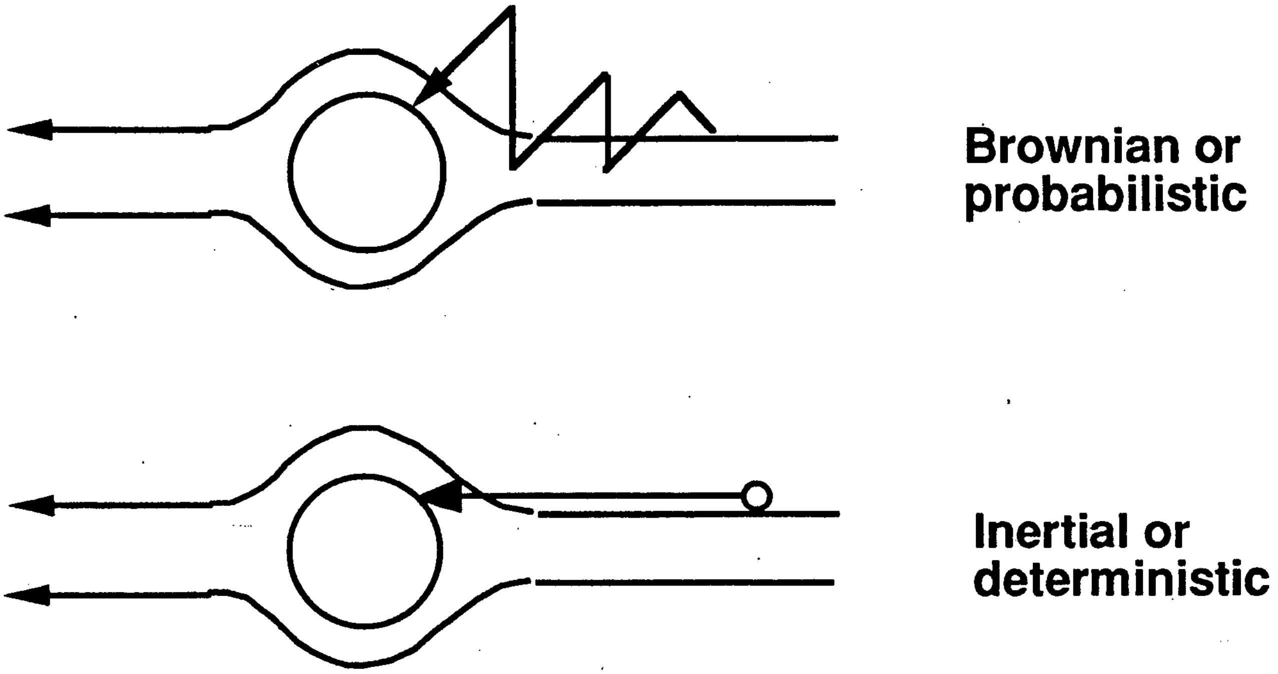
where,

μ = fluid viscosity
a_p = particle radius
m = particle mass
C_s = Cunningham slip correction factor

The solution of Equation 1, called the Langevin equation, can be obtained assuming a constant fluid velocity and a constant value of B.

Ramarao et al have solved Equation 1 using the method proposed by Chandrasekhar for two-dimensional particle trajectories.(4,5) We have extended this method to three dimensions in the present study. The principle of superimposing particle motion over the flow field is illustrated in Figure 5, where the net particle motion is the sum of a deterministic term and a probabilistic term.

Figure 6 shows the results of three, two-dimensional particle trajectories computed for the flow field in Figure 2 using Equation 1. Figure 7 shows the results of three, three-dimensional trajectories computed for the crossed fiber matrix. The inlet air velocity in both figures is 20 cm/s. The particle size in each of the three trajectory calculations was chosen to represent what is generally treated as three separate particle capture mechanisms: Brownian motion, interception and inertia. This artificial separation is not required for the general approach in Equation 1. Particle capture by the filter fiber only occurs if the particle trajectory contacts the fiber surface. Once particle contact is made, we assume the particle is captured and held tight. This assumption is valid for particles smaller than 5 µm at lower air flows.



$$\underbrace{\frac{d\vec{u}}{dt}}_{\text{particle motion}} = \underbrace{B(\vec{v}-\vec{u})}_{\text{deterministic}} + \underbrace{\vec{A}(t)}_{\text{probabilistic}} \qquad \text{Langevin eq.}$$

Figure 5. Particle motion is determined by the superposition of the Brownian (probabilistic) motion and the inertial (deterministic) motion over the flow field.

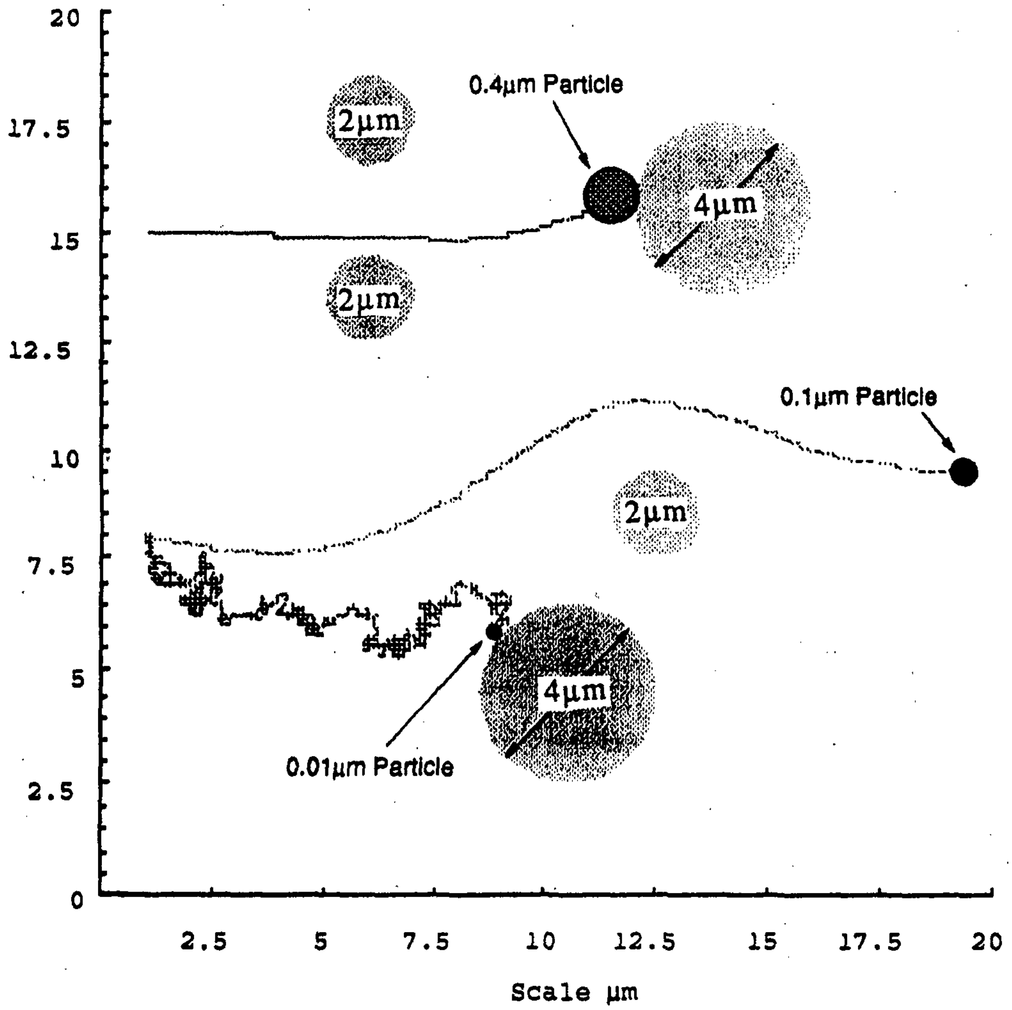


Figure 6 Trajectories of three different diameter particles through the fiber matrix in Figure 2. Particle diameters were selected to illustrate conventional mechanical collection mechanisms: 0.01µm for Brownian motion, 0.1µm for interception, and 0.4µm for inertia.

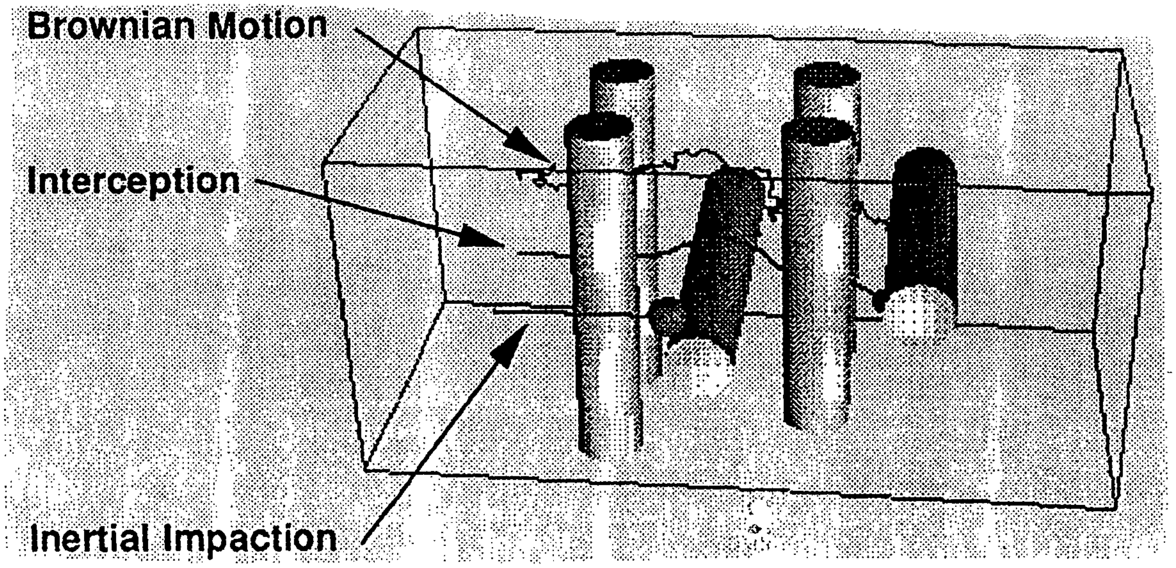


Figure 7 Trajectories of three different diameter particles through the fiber matrix shown in Figure 4 with the inlet air velocity at 20 cm/s. The diameter of the particles were selected to illustrate the conventional collection mechanisms due to Brownian motion, interception and inertial impaction. Note that the particle sizes are not to scale to allow visualization.

To determine the particle capture efficiency of a given fiber matrix for comparison with experimental measurements, it is necessary to compute thousands of trajectories for each particle size. For each trajectory calculation, the initial starting location is determined by a random number generation in the Y-Z plane. Figure 8 shows the cumulative efficiency of 0.3 μm diameter particles (density 1 g/cm^3) passing through the crossed fiber matrix as illustrated in Figure 7 with an inlet air velocity of 20 cm/s. Performing similar calculations at other particle sizes allows us to plot the efficiency versus particle size.

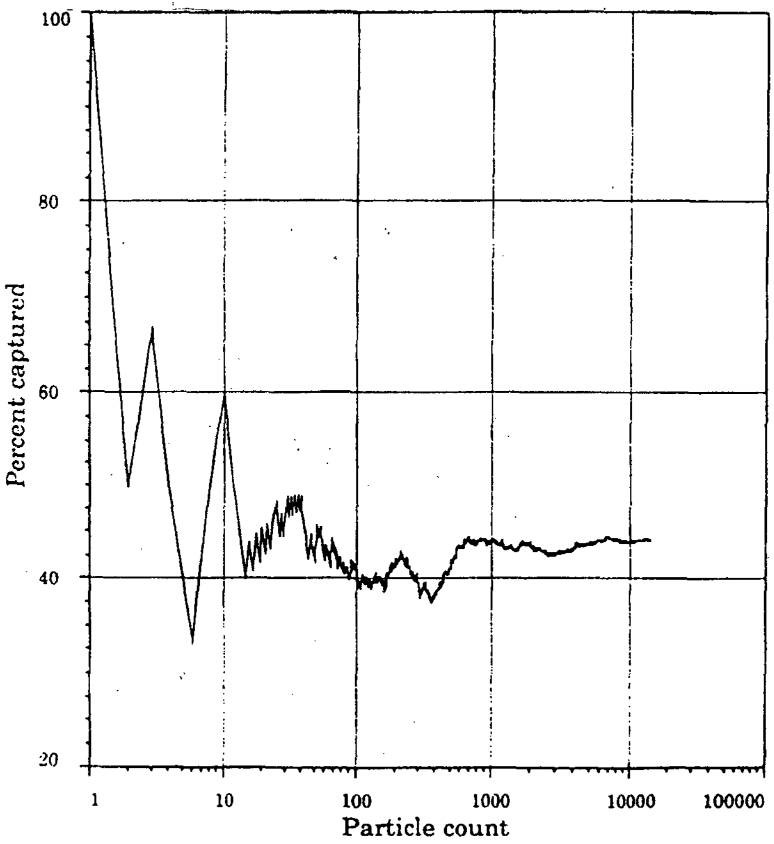


Figure 8 Cumulative efficiency of increasing number of 0.3μm diameter particles (density 1 g/cm^3) passing through the crossed fiber matrix in Figure 4 with a uniform inlet air velocity of 20 cm/s.

III. Sample Computations of Filter Efficiencies

The computation of the filter efficiency for a given fiber configuration and a given air flow requires three sequential steps: (1) compute the fluid flow field using CFD calculations, (2) compute the particle trajectory using Equation 1, and (3) compute the trajectories of many particles at random positions at the filter inlet to obtain an average efficiency. These calculations will yield the efficiency at a given particle size. For filter efficiency as a function of particle size, steps 2 and 3 must be repeated for each particle size. For efficiency at different air flows, all three steps must be computed.

Figure 9 shows the results of the efficiency calculations for the crossed fiber array at 20 cm/s. Figure 10 shows the efficiency of the same crossed fiber array at 2 cm/s. Note that the capture efficiency for the larger particles increases while the efficiency for the smaller particles decreases as the air velocity is increased. Figure 11 shows the particle capture efficiency for the staggered hexagonal array at 3 cm/s.

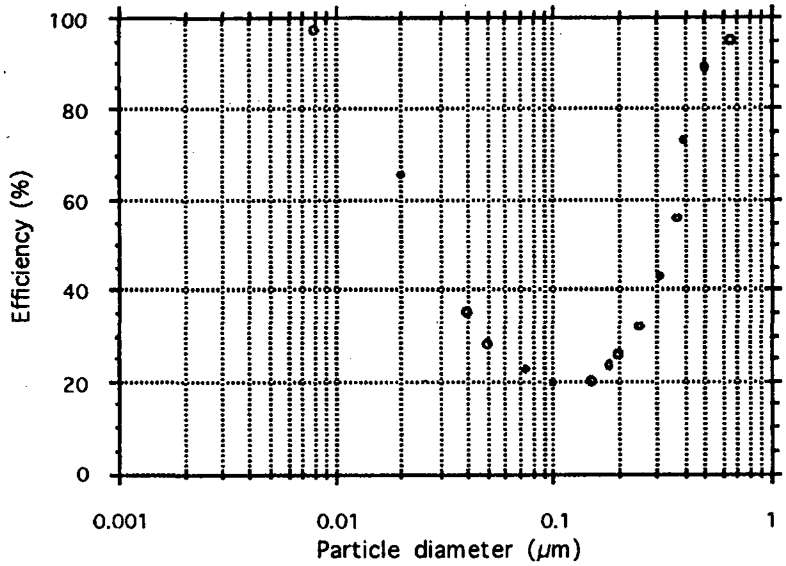


Figure 9 Filter efficiency computed for different particle diameters (density 1 g/cm^3) passing through the crossed fiber matrix in Figure 4 with uniform inlet air velocity of 20 cm/s. The pressure drop across the fiber matrix element is 4.4 x 10^{-5} inches of water.

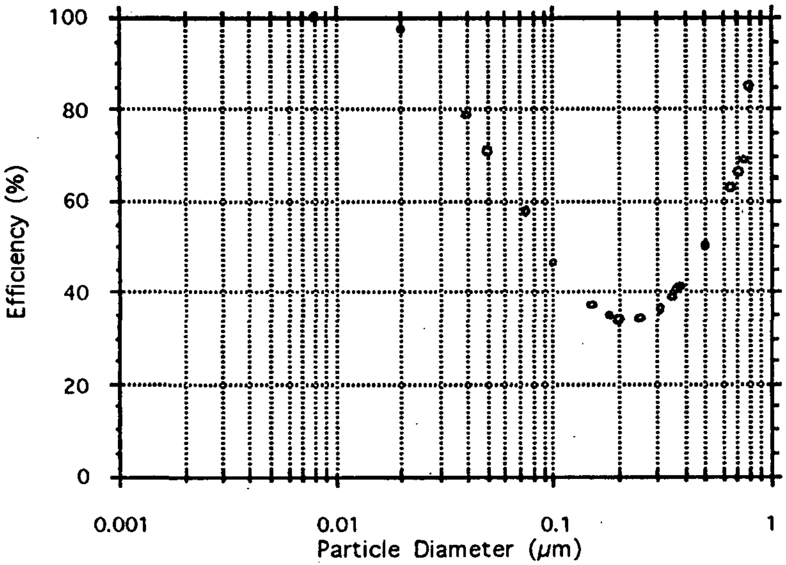


Figure 10 Filter efficiency computed for different particle diameters (density 1 g/cm^3) through the crossed fiber matrix in Figure 4 with a uniform inlet air velocity of 20 cm/s. The pressure drop across the fiber matrix element is 4.4 x 10^{-6} inches of water.

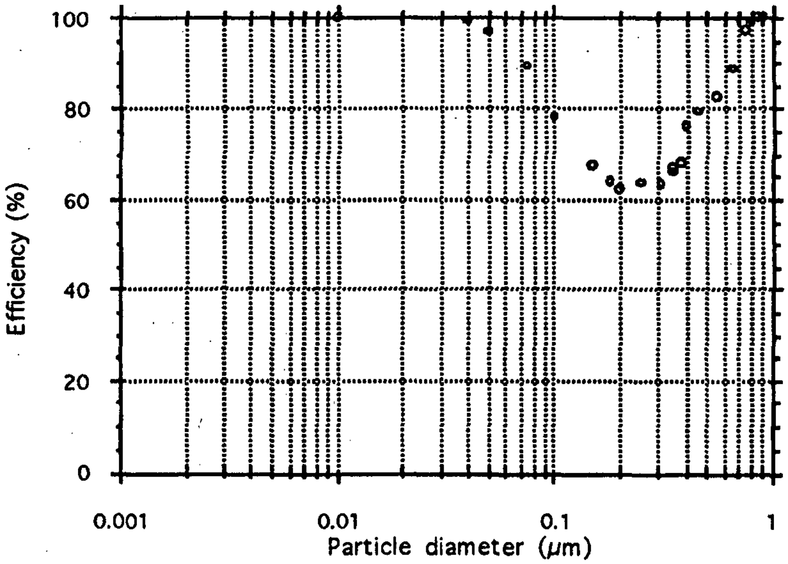


Figure 11 Filter efficiency computed for different particle diameters (density 1 g/cm^3) through the staggered hexagonal array in Figure 3 with a uniform inlet air velocity of 3 cm/s. The pressure drop across the fiber matrix element is 3.2 x 10^{-5} inches of water.

Although it is feasible to compute the particle capture efficiency and pressure drop across simple fiber matrices as shown in this report, we are a long way from computing the efficiency and pressure drop for commercially available filters. The primary limitation here is an efficient method for computing the fluid flow through the more complicated fiber matrix in real filters.

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DISCUSSION

WEBER: I think that the work that Werner is doing is a real service to the industry and I hope that he will be able to carry out his plan to bring it to full fruition. I have a couple of questions for the author. Do you have a way of measuring the fiber diameters in a large assembly?

BERGMAN: We determine fiber diameters from electron micrographs followed by computer scanning and generate histograms of the number of fibers versus size. For three dimensional analysis, we solidity the filter element with an epoxy, take slices of the element at increasing depths and then take SEM photos. For quicker, less expensive analysis, we simply took SEM pictures of the media surface.

WEBER: I noticed that the fiber diameters you cited were greater than 1μm yet we know that the glass fibers optimally used are less than that in many cases. Was there a particular reason for the choice of diameter in your calculations?

BERGMAN: Yes. Below 1μm you have non-continuum fluid dynamics that is often called "slip" flow. All of the conventional fluid dynamics codes are based on a continuum fluids. To address the slip flow, we first compute the flow using continuum mechanics and then close to the fiber, we introduce an empirical term. This approach is not rigorously correct, but it yields better results than ignoring slip. Using a noncontinuous fluid dynamics package in filtration modeling would greatly exceed the capacity of the largest computer.

WEBER: Finally, I am wondering how long through the useful life of a filter it would be until cake build-up or the presence of previously deposited particles would affect the result, or would start to dominate the result?

BERGMAN: We did not do these computations. From the pictures of particle trajectories, you can see that it is possible to model filter clogging. Let me illustrate how this can be done. For the initial particle capture and deposits, we assume the general fluid dynamics flow is not affected by the deposits. However, once the deposits become sizable, you have to recompute the fluid field with the altered filter geometry. Particle trajectories are then computed for the new fluid velocity field and a new increment of deposits formed. The cycle of forming particle deposits and computing new flow fields is repeated many times. Considering that it may take 20-40 hours of computer processing on a silicon graphics workstation to compute the flow field in a 100 fiber filter element, we are a long way from realistic filter clogging simulations.

KOVACH, B: The work you did is great but did you consider the influence of a vibrating fiber due to high velocity airflow? Would it increase or decrease the efficiency? Is your video movie available for use by others?

BERGMAN: As soon the work is finished we will make copies available. With regard to vibrating fibers, I am not aware of any studies. However, if you look at the period of vibration, I suspect the period would be much longer than the effective residence time of a particle in the vicinity of a fiber. I have a difficult time imagining a fiber vibrating at a speed that is comparable to the particle velocity, but then I've been surprised more times than not.

THOMAS: Previously, I tried to use equations by Drs. Liu and Rubo to determine filter efficiency, but I ran into a problem trying to determine their parameter for collector diameter. I used an average fiber diameter, but I was wondering if you have determined any kind of average filter fiber diameter based on information from people that make filter papers?

BERGMAN: Although we can determine fiber size distribution precisely, the problem is that the paper is very heterogeneous. The fiber diameter distribution and fiber volume fraction can vary greatly depending on where the measurments are taken in the filter paper. The common practice is to use an "inhomogeneity factor" and an average fiber diameter derived from SEM pictures in a specific filter equation for pressure drop. The inhomogeneity factor is used to force agreement between the equation and experiment. Since all of the pressure drop theories (Karmen-Kozenly, Kuwabara, etc.) have pressure drop varying inversely proportional to fiber diameter squared, the most common average is the weighted average of diameter squared. The weighting factor generally is a function of the site distribution and the distribution of fiber volume fraction throughout the filter. A more practical approach is to use an "effective" diameter which is the diameter determined from the pressure drop equation with experimental pressure drop data.

DYMENT: Does the speaker consider an attempt should be made to include electrostatic forces? Can the techniques described be used to produce designs of filter media having extended dust capacity?

BERGMAN: We have added electrostatic forces in the computer models but have not run many cases. I should add that any number of additional capture mechanisms can be easily added to the code because once you have established the flow field and the mechanical trajectory, it is a minor step to add additional capture mechanisms. The current stage of computer simulation can be used to investigate extended life, but it is not practical because of the excessive time required to compute. The problem is that each time the morphology of the particle deposits changes it perturbs the air flow and therefore requires a new flow field computation. An entire series of flow computations would be required for each filter media structure. This would require an enormous amount of computation and is not practical at the present time.

DYMENT: I have been fascinated by your demonstration, I think it is a major step forward. Filtration is an extremely complex process. Do you imagine we use the filters that electrical effects are significant because you are studying what we call mechanical effects. Do you think that electrical effects can be important in real filters? That is my first question. My second question concerns the graded papers we were talking about at the last conference which have a somewhat higher dust holding capacity. Do you anticipate that you can use these techniques to give us target designs for filters which will hold larger quantities of particles before their resistance rises to the point at which we have to change them?

BERGMAN: If conditions are favorable for electrical effects, then they will be very important in filtration. Conditions that favor electrical effects are dry air, charged particles, and high filter electrical resistance. Thus I would expect electrical effects would enhance the performance of real filters in dry air powder handling or processing operations. Applications involving aqueous oil mists or ambient aerosols would have little electrical effects. The computer simulations can be used to answer performance and design questions, but only for very simple systems at the present time. Even the simple filtration problems illustrated in this paper require 3-4 days of work. Setting up the basic filter structure represents currently about 10% of the effort. Fluid dynamics represents 80% of the full effort. The particle trajectories represent 9% and the remaining 1% is the electrostatics. The purpose of this presentation is to begin the process of developing a CAD/CAM system where engineers can sit at their computers and calculate the filter efficiency for graded efficiency filters, unusual structures, filter clogging, whatever it is you want. Major advances in both computer software and hardware will be required this goal.

24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

* * *

STUDY ON COLLECTION EFFICIENCY OF FISSION PRODUCTS BY SPRAY : EXPERIMENTAL DEVICE AND MODELLING

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ABSTRACT

Consequences of an hypothetical overheating reactor accident in nuclear power plants can be limited by spraying cold water drops into containment building. The spray reduces the pressure and the temperature levels by condensation of steam and leads to the washout of fission products (aerosols and gaseous iodine). The present study includes a large program devoted to the evaluation of realistic washout rates.

An experimental device (named CARAIDAS) was designed and built in order to determine the collection efficiency of aerosols and iodine absorption by drops with representative conditions of post-accident atmosphere. This experimental device is presented in the paper and more particularly :

- the experimental enclosure in which representative thermodynamic conditions can be achieved,
- the monosized drops generator, the drops diameter measurement and the drops collector,
- the cesium iodide aerosols generator and the aerosols measurements

Modelling of steam condensation on drops, aerosols collection and iodine absorption are described. First experimental and code results on drops and aerosols behaviour are compared.

NOMENCLATURE :

C	: concentration	$(mol.m^{-3})$
Cp	: calorific capacity	$(J.kg^{-1}.K^{-1})$
C_{th}	: heat accomodation coefficient	(-)
Cu	: Cunningham correction coefficient	(-)
d	: diameter	(m)
Dif	: diffusion coefficient	$(m.s^{-1})$
dm	: drop mass increase	(kg)
E	: collection efficiency	(-)
h	: heat transfer coefficient	$(W.m^{-2}.K^{-1})$
H_v	: enthalpy of water vaporization	$(J.mol^{-1})$
k	: mass transfer coefficient	$(m.s^{-2})$
L	: free path of gaseous molecules	(m)
m	: mass	(kg)
M	: molar mass	$(kg.mol^{-1})$

N	: mass flux density	$(mol.m^{-2}.s^{-1})$
P	: pressure	(Pa)
Psat	: saturation vapor pressure	(Pa)
q	: heat flux density	$(W.m^{-2})$
T	: temperature	(K)
v	: drop velocity	$(m.s^{-1})$
λ	: thermal conductivity	$(W.m^{-1}.K^{-1})$
ρ	: density	$(kg.m^{-3})$
μ	: dynamic viscosity	(Pa.s)

Dimensionless numbers :

Knusend number :	$Kn = \frac{2L}{d_p}$	(-)
Nusselt number :	$Nu = \frac{h.d_d}{\lambda}$	(-)
Prandtl number :	$Pr = \frac{Cp.\mu}{\lambda}$	(-)
Reynolds number :	$Re = \frac{\rho_g.v.d_d}{\mu_g}$	(-)
Schmidt number :	$Sc = \frac{\mu}{\rho.Dif}$	(-)
Sherwood number :	$Sh = \frac{k.d_d}{Dif}$	(-)
Stokes number :	$Stk = \frac{d_p^2.\rho_p.v}{9.\mu_g.d_d}$	(-)

Subscripts :

d : drop
g : gaseous
i : gas-drop interface
I : iodine
p : particle
pot : potential
vis : viscous
w : water
diffu : brownian diffusion
difph : diffusiophoresis
imp : impaction
int : interception
therph : thermophoresis
tot : total

I. INTRODUCTION

Consequences of an hypothetical overheating reactor accident in a nuclear power plant can be limited by spraying cold water drops into the containment building. The spray reduces the pressure and the temperature levels inside the containment building by steam condensation on drops. With this thermalhydraulic function, spray leads to the washout of fission products (aerosols and iodine) emitted in the reactor building atmosphere. Today, this spray system is taken into account in different safety codes, using washout rates which have been determined during global experiments. These washout rates provide conservative assumptions. This present study integrates into a large program devoted to the evaluation of more realistic washout rates. First, we develop an experimental device and a modelling in order to determine aerosols collection efficiencies and iodine absorption in severe accident representative conditions.

II. EXPERIMENTAL DEVICE

In order to comply with experimental device design requirements(1), different devices have been developped, tested and set up on CARAIDAS (figure 1) :

- experimental enclosure in which representative thermodynamic conditions could be achieved,
- the monosized drops generator, the drops diameter measurements and the drops collector,
- the cesium iodide aerosols generator, concentration and size distribution measurements.

II.1. Experimental enclosure

Experimental enclosure is a five meters high cylinder with an inner diameter of 0.6 meter. The vessel is heated up by circulating a thermofluid through the double-wall unit. This system is split into three sections to ensure uniform temperatures overall the vessel height. The vessel has 8 windows (100 mm diameter) and several penetrations (50 mm diameter) for instrumentation purposes.

The thermofluid circuit comprises :

- a pump with a flow rate of 12 m^3/h,
- an electric heater (40 kW) using a PID regulation can heat up the thermofluid at a maximum of 160°C. The temperature in the main pipe is monitored by two sensors (Pt100, class A),
- the thermofluid repartition into the three sections is ensured by one valve and one flow meter for each section.

Homogeneous thermodynamic working conditions are obtained by using an air-steam circulation with:

- a varying flow rate fan (0 to 50 m^3/h),
- an electric heater (5 kW), using a PID regulation, can heat up air-steam mixture with a temperature range between 20 to 160°C ; the temperature is monitored by two Pt100 sensors (class A),
- an absolute pressure PID regulation in the range of 1 to 8 bars is carried out by using two valves (one for pressurized air alimentation and one for release),

The steam saturation rate in the vessel is also controlled by a PID regulator. Steam is produced by an electric generator and injected using a valve controlled by the regulator. Steam saturation rate range is between a few per cent and 95 %. Highest saturation limit is 95 % to avoid condensation particularly on windows.

This air-steam circulation ensures a good mixture in the vessel. When nominal working conditions (P, T, S) are reached, air-steam circulation is stopped and then the vessel is isolated by two valves. Several sensors are installed on the vessel to check air-steam mixture homogeneity :

- five gas temperature sensors (Pt100, class A),
- three inner vessel wall sensors (Pt100, class A),

- one pressure transducer (0-10 bars),
- three steam saturation ratio measurements by dew point measurement,
- one steam partial pressure measurement by sampling some gas and condensation by cooling.

All of these experimental data are displayed and saved by using a PC supervisor.

II.2. Drops devices

Drops generator is above the experimental enclosure because this device must be at ambient temperature and this, whatever enclosure temperature. In order to produce monosized drops, the generator (figure 2) is based on a break-up process of a jet into drops by applying a periodic disturbance. This principle of generation induces a one drop diameter spacing. This small drops spacing is not large enough to avoid drops coalescence, so an electrostatic sorting out drops is set up. A stream of uniformly charged drops is shaped by applying a potential difference between a ring electrode and the feeding tube. When a negative impulsion is applied to the ring electrode, an uncharged drop is produced. The deflection plates placed downstream, which are under electrical potential difference, create an electric field. Charged drops passing through this electrical field are deflected and collected. Uncharged drops are not deflected and they are injected in the experimental enclosure. The rate of injection of uncharged drops is variable from 1 to 1/1000. This device is able to produce monosized water drops with a diameter between 100 and 500 μm. Drops injection temperature is measured by a Pt100 sensor on the feeding tube. Drops injection temperature can be set between 20°C to 80°C by a small electric heater.

After injection in the vessel, drops diameter is modified by steam condensation or evaporation as function of thermodynamic conditions. So, three drops diameter measurements are forecast for three falling drops heights: $z=0$, $z=2.51$ and $z=4.39$ meters. These measurements are based on drops shadows axial transmittance. A stroboscopic incoherent light source is placed in front of linear camera (CCD). When a drop comes in front of the CCD camera, analogic signals from photodiodes are obtained and then numerized. Numerical drop shadow is processing in order to calculate the real drop diameter.

At the end of the fall, drops must be collected to measure aerosols mass in drops, so a drops collector ensures three functions :
- drops collection,
- dynamic containment of drops collection surface,
- sample output.

Drops are collected on fiberglass filters, 80 mm diameter, 1.55 mm thickness and temperature proof under 200°C. These filters can soak up water drops volume (a few milliliters). The collected aerosols mass by drops during fall is dissolved in 10 ml of distilled water and measured by fluorimetric method. Aerosols sedimentation on collection surface is avoided by a dynamic containment : clean air is blown throught collection filter and get back by a circular aspiration on the top of the dynamic containment device not to modify aerosols concentration in the experimental vessel. Extraction of several samples during test is been able by a pressure thruster which shifts drops collector from experimental vessel to the SAS where it can be brought out and put a new drops collector in place.

II.3. Aerosols devices

Aerosols generation is based on mechanical spraying by rotative disk, of cesium iodide solution tagged by soda fluorescein. Rotational device is an air turbine because high rotation speed is needful

(3000 rounds per second). Rotation speed is set by air pressure inlet the turbine and monitored by an electromagnetic indicator. Spraying disk (8 mm diameter) is fed up with cesium iodide solution with steady state flow rate. Sprayed droplets diameter which is function of rotation speed and solution flow rate, is about 20 μm. After evaporation, dry aerosols diameter is function of cesium iodide concentration :

$$d_p = d_{droplet}\left(\frac{[ICs]_{solution}}{\rho_{ICs}}\right)^{1/3} \qquad \text{eq.1}$$

With this specific generator, it is possible to produce aerosols with temperature (20-160°C) and pressure (1-7 bars). Aerosols diameter range is between 0.5 and 5 μm with a geometric standard deviation lower than 1.7 and aerosols mass flow rate is roughly 0.1 g/h.

Four aerosols samples are set up on experimental enclosure to check homogeneity of concentration and particles size distribution. Aerosols concentrations are measured on fiberglass filters of 25 mm diameter. Each sample is going on one or two minutes with a 1 l/min flow rate. The filtered aerosols mass is measured by fluorimetric method.

Particles size distribution measurements are given by inertial impactor in vessel pressure and temperature conditions. Aerosols are discriminated among eight size ranges corresponding to aerodynamic diameters from 0.35 to 7.5 μm. Data processing is performed by a classical log-probability graph. This method gives aerosols mass median diameter and geometric standard deviation.

This experimental device allows to measure experimental drops diameter evolution and collected aerosols mass by drops as function of different experimental conditions representative of severe accident scenarios. At the same time we develop a modelling of this experimental device.

III. Modelling

Drops characteristics (temperature, size, iodine and particles concentration) are modified during the fall. Three phenomena of transfer between the gas and the monosized drops are to be modelled :

- heat and steam transfer,
- gaseous iodine transfer,
- particles collection.

Steam condensation, iodine absorption and particles collection are coupled together because some of collection mechanisms depend on steam condensation flow rate.
The basic assumption of these following models is that water drops are supposed independant.

III.1. Steam and heat transfer

Steam and heat transfer from the gaseous phase to the liquid one is modelled by the double film theory (figure 3). Steam mass transfer is located in the gaseous film and heat transfer takes place through the whole double film. Beyond this double film, temperatures and concentrations are supposed steady.

The steam flow rate is the following one : $N_w = k_{g,w} \times \left(\frac{P_w}{RT_g} - \frac{Psat(T_i)}{RT_i}\right)$ eq.2

where $k_{g,w}$ is the ratio between the diffusion coefficient of steam in air and the thickness of the gaseous film. This transfer coefficient is computed thanks to a correlation given by BEARD and PRUPPACHER⁽²⁾: $Sh_{g,w} = 1.61 + 0.718 \times Re_d^{1/2} \times Sc_{g,w}^{1/3}$

The heat flow rate through the gaseous film is :

$$q = \underbrace{h_g \times (T_g - T_i)}_{\text{convective exchanges}} + \underbrace{N_w \times H_v}_{\text{condensation contribution}}$$

h_g is also computed by a correlation (BEARD and PRUPPACHER⁽²⁾) :

$$Nu_{g,w} = 2 + 0.69 \times Re_d^{1/2} \times Pr_g^{1/3}$$

This flow rate q is equal to the one of the drop side : $q = h_d \times (T_i - T_d)$

h_d is computed by HENDOU's correlations⁽³⁾.

Finally:

$$\underbrace{h_g \times (T_g - T_i)}_{\text{convective exchanges}} + \underbrace{N_w \times H_v}_{\text{condensation contribution}} = h_d \times (T_i - T_d) \qquad \text{eq.3}$$

So coupling equation eq.2 and equation eq.3, T_i and N_W are determined by a numerical method (Newton-Raphson). The knowledge of the steam flow rate and of the convective exchanges value allows to compute the drops growth during a lapse of time called dt :

$$d_d(t+dt) = \left(d_d^3(t) + \frac{6 \times d_d^2(t) \times dt \times N_w \times H_v}{\rho_d} \right)^{1/3}$$

Then drop heating is computed using the heat balance on the drop between t and t+dt :

$$m \times Cp_d \times dT_d = h_g \times (T_g - T_i) \times \pi \times d_d^2 \times dt + dm \times H_v$$

$$\text{with:} \quad dm = \frac{\pi \times d_d^2 \times dt \times N_w \times H_v}{\rho_d}$$

So :

$$T_d(t+dt) = T_d(t) + \frac{h_g \times (T_g - T_i) \times \pi \times d_d^2 \times dt + dm \times H_v}{m \times Cp_d}$$

III.2. Iodine transfer

The energetic iodine flow rate contribution is disregarded. Iodine transfer from the gaseous phase to the liquid one is firstable controlled by diffusion through the gaseous film, since by the thermodynamic equilibrium between the both phases which depends on the temperature at the interface, and at least by chemical reactions which take place into the drops.

At low steam flow rates, iodine transfer through the gaseous film is estimated as :

$$N_I = k_{g,I} \times (C_{g,I} - C_{gi,I})$$

This flow is equal to the one through the liquid film : $N_I = k_{d,I} \times (C_{di,I} - C_{d,I})$

Finally :

$$k_{g,I} \times (C_{g,I} - C_{gi,I}) = k_{d,I} \times (C_{di,I} - C_{d,I}) \qquad \text{eq.4}$$

The unknown values are C_{gi} and. C_{di}. They are linked by the thermodynamic equilibrium at the interface and by chemical reactions. Hydrolysis of molecular iodine and HOI dissociation are only considered. The other reactions are slow regarding to the fall time of drops (few seconds in CARAIDAS).

- gas-liquid equilibrium : $I_{2,gas} \leftrightarrow I_{2,liq}$ $$Ki = \frac{[I_{2\,liq}]}{[I_{2\,gas}]} \quad \text{eq.5}$$

- iodine hydrolysis : $I_{2,liq} + H_2O \leftrightarrow HOI + I^- + H^+$ $$K_1 = \frac{[HOI] \times [I^-] \times [H^+]}{[I_{2,liq}]} \quad \text{eq.6}$$

- hypoiodous acid dissociation : $HOI \leftrightarrow OI^- + H^+$ $$K_2 = \frac{[OI^-] \times [H^+]}{[HOI]} \quad \text{eq.7}$$

The concentration in protons is supposed to be a constant value. The reaction equilibrium constants are given by GAUVAIN and FILIPPI(4).

Equations eq.5 and eq.6 allow to express $C_{di,I}$ (which is : $[HOI]+[OI^-]+[I^-]+[I_{2,liq}]$) as a function of $C_{gi,I}$:

$$C_{d_i,I} = Ki \times C_{g_i,I} + 2 \times \frac{\sqrt{K_1 \times \left(K_2 + [H^+]\right) \times Ki \times C_{g_i,I} \times 1000}}{[H^+]}$$

This expression is used in the place of C_{di} in equation eq.4. Solving equation eq.4 provides C_{di} and so N_I. At least, the updated concentration in iodine into the drop is computed :

$$C_{d,I}(t+dt) = C_{d,I}(t) + \frac{\pi \times d_d^2(t) \times dt \times N_I}{\left(\frac{\pi \times d_d^3(t)}{6}\right)}$$

III.3. Particles collection

Aerosols collection models are completly different than those for iodine absorption. They are based on semi-empirical correlations to calculate collection efficiencies for different mechanisms. Collection efficiency is defined as the ratio of aerosol mass collected by a drop and the aerosols mass in swept out volume. Five mechanisms of particles collection are listed :

- impaction
- interception
- diffusiophoresis
- thermophoresis
- brownian diffusion

Mechanical effects

- *impaction* : drops fall induces fluid flow variations. High inertia particles turn off flow lines around the drop and then are collected on the drop. The efficiency of this mechanism increases with drop velocity and particle mass. POWERS and BURSON(5) suggest :

$$E_{imp} = \frac{E_{vis,imp} + \frac{Re_d\, E_{pot,imp}}{60}}{1 + \frac{Re_d}{60}}$$

if $Stk \leq 0.0833$ then $E_{pot,imp} = 0$

if $0.0833 \leq Stk \leq 0.2$ then $E_{pot,imp} = 8.57\left(\frac{Stk}{Stk+0.5}\right)^2 (Stk - 0.0833)$

if $Stk \geq 0.2$ then $E_{pot,imp} = \left(\frac{Stk}{Stk+0.5}\right)^2$

if $Stk \leq 1.214$ then $E_{visc,imp} = 0$

if $Stk \geq 1.214$ then $E_{visc,imp} = \left(1 + \frac{0.75 \ln(2\,Stk)}{Stk - 1.214}\right)^{-2}$

- *interception*: this mechanism is only based on a geometric effect. If a particle on a flow line meet the drop, it is collected. POWERS and BURSON(5) propose :

$$E_{int} = \frac{E_{vis,int} + \frac{Re_d\, E_{pot,int}}{60}}{1 + \frac{Re_d}{60}}$$

with $$E_{visc,int} = \left(1 + \frac{d_p}{d_d}\right)^2 \left[1 - \frac{1.5}{1 + \frac{d_p}{d_d}} + 0.5\left(1 + \frac{d_p}{d_d}\right)^3\right]$$

and $$E_{pot,int} = 3\frac{d_p}{d_d}$$

Phoretic effects : the temperature gradient and the steam flow around drops respectively induce thermophoresis and diffusiophoresis.

- *diffusiophoresis* : steam condensation on cold water drops induces a steam flow towards drops. This flow drags along particles. WALDMANN and SCHMITT(6) suggest a formula corrected by the ventilation coefficient of PRUPPACHER(7):

$$E_{difph} = 4.f_v \frac{\sqrt{M_w}}{x_w\sqrt{M_w} + x_a\sqrt{M_a}} \frac{Dif_w}{V \times d_d} \ln\left(\frac{P - Psat(T_i)}{P - P_w}\right)$$

if $Sc_{g,w}^{1/3} . Re_d^{1/2} < 1.4$ then $$f_v = 2.\left(1 + 0.108\left(Sc_{g,w}^{1/3}\ Re_d^{1/2}\right)^2\right)$$

if $Sc_{g,w}^{1/3} . Re_d^{1/2} \geq 1.4$ then $$f_v = 2.\left(0.78 + 0.308\left(Sc_{g,w}^{1/3}\ Re_d^{1/2}\right)\right)$$

- *thermophoresis* : it occurs when particles set in a temperature gradient. Impacts of gas on the warm side are more important than on the cold side of the particle. As a result, this difference creates a force which drags along particles towards cold drops.

$$E_{therph} = \frac{4\,C_{th}\,\mu_g\,f_h\left(T_g - T_d\right)}{C_g\,T_g\,V.d_d}$$

C_{th} is the dimensionless coefficient of TALBOT$^{(8)}$ and f_h is the heat ventilation coefficient of PRUPPACHER$^{(7)}$:

$$C_{th} = \frac{2 \times 1.147\left(\frac{\lambda_g}{\lambda_p} + 2.2\,Kn\right)Cu}{\left(1 + 3 \times 1.146\,Kn\right) \times \left(1 + 2\frac{\lambda_g}{\lambda_p} + 2 \times 2.2\,Kn\right)}$$

if $Pr_g^{1/3} . Re_d^{1/2} < 1.4$ then $$f_h = 2.\left(1 + 0.108\left(Pr_g^{1/3}\ Re_d^{1/2}\right)^2\right)$$

if $Pr_g^{1/3} . Re_d^{1/2} \geq 1.4$ then $$f_h = 2.\left(0.78 + 0.308\left(Pr_g^{1/3}\ Re_d^{1/2}\right)\right)$$

At least, we describe brownian diffusion collection by modelling efficiency as PRUPPACHER$^{(7)}$ suggests :

if $Re_d < 1$ then $$E_{diffu} = \frac{4 \times Dif_p \times 2\left(1 + 0.5\,Re_d^{1/2}\ Sc_p^{1/3}\right)}{V.d_d}$$

if $Re_d \geq 1$ then $$E_{diffu} = \frac{4 \times Dif_p \times 2\left(1 + 0.3\,Re_d^{1/2}\ Sc_p^{1/3}\right)}{V.d_d}$$

The total efficiency is supposed to be the sum of the five elementary efficiencies :

$$E_{tot} = \sum_{i=1}^{5} E_i(d_p)$$

The emitted particles are polydisperse. The efficiency is computed for each particle size class. So, for the whole distribution :

$$E = \sum_{d_p\,min}^{d_p\,max} E_{tot}(d_p) \times f(d_p) \times \log(\Delta d_p)$$

The collected particles mass during a lapse dt is :

$$M_p(dt) = \sum_{d_p\,min}^{d_p\,max} E_{tot}(d_p) \times f(d_p) \times \log(\Delta d_p) \times \frac{\pi d_d^2(t)}{4} \times v \times dt \times C_p$$

Finally, the mass collected during the drop fall is :

$$Mp = \sum_{t=0}^{t_{fall}} \left(\sum_{d_p\,min}^{d_p\,max} E(d_p) \times f(d_p) \times \log(\Delta d_p) \times \frac{\pi d_d^2(t)}{4} \times v \right) dt \times C_p$$

IV CODE RESULTS

From the modelling of the different phenomena involving in the washout of fission products by spraying water drops, the drops and particles behaviours in CARAIDAS are estimated.

IV.1. Drops behaviour

The different evolutions of drops diameter and drops temperature as function of falling height are plotted on the figures 4, 5 and 6. The thermodynamic conditions of gas are steady during the drop fall: 5 bars pressure, 140°C temperature and several steam saturation rates. The initial diameters are 100, 300, and 500 μm.

At the drop fall beginning, the steam flow rate and the heat flow rate induce growth and heating of drops. When the steam saturation rate is equal to 1, this condensation phenomenon occurs on a varying height (3, 20 and 60 centimeters) according to the initial diameter (100, 300 and 500 μm). When the steam saturation decreases, the condensation height also decreases. After, the diameter and temperature of the drops are steady if $S=1$. On the other hand, evaporation phenomenon appears if $S<1$: there is an equilibrium between the heat flow brought to the drop by convective exchanges and the heat flow lost by the drop because of evaporation. Thus, drop temperature is steady but the diameter decreases. We consider that the drop completely disappears when its diameter is smaller than five micrometers.

All these computations show that thermodynamic equilibrium between the drops and the gaseous mixture is quickly reached when the steam saturation rate is equal to 1. On the other hand, when the gas is not saturated ($S<1$), the temperature speedly becomes steady whereas there is no balanced size.

IV.2. Aerosols behaviour

The modelling of drops behaviour coupled with the correlations providing particles elementary collection efficiencies allows to compute the average efficiency on a 5 meters fall. Different experimental conditions and particles diameters are tested for 100 μm diameter drops :

- figure 7 : In this case of atmospheric conditions ($P=1$ bar and $T=20$°C) with $S=1$, phoretic effects are negligible. Impaction and interception are the main mechanisms for the largest aerosols. For the smallest ones, brownian diffusion collection is the main mechanism. As a result, the average total efficiency is minimal (10^{-3}) for the aerosols which the diameter is around 0.5 μm.

- figure 8 : For these conditions, characteristic of spray scenarios (5 bars, 140°C and S=1), phoretic effects are not any more negligible. Thermophoresis is always the minority effect whatever the particles diameter. Diffusiophoresis efficiency which does not depend on particles diameter is slightly higher than the other ones when the total efficiency is minimal. Impaction, interception and diffusion mechanisms efficiencies do not vary a lot as function of thermodynamic conditions.
- figure 9 : The conditions are the same than ones of figure 8 excepted the initial drop temperature which is 80°C in this case. These values square with a scenario of recirculation. Despite lower values, diffusiophoresis efficiency is always the higher effect when the total efficiency is minimal. The decrease is due to the lower difference between gas and drops temperatures at the top of the vessel. The steam flow rate is lower so phoretic effects decrease.

Similary calculations are plotted on figures 10, 11 and 12 for 500 μm diameter drops. For ambient conditions (figure 10), phoretic effects are also negligible. The minimal efficiency (10^{-3}) resulting from impaction, interception and brownian diffusion mechanisms, is placed for aerosols which the size is lower than 0.1 μm.
In conditions characteric of spray scenarios (figure 11 and figure 12), diffusiophoresis is the main effect for aerosols which the diameter is lower than 1 μm. Thus, the minimal efficiency reached 10^{-2} thanks to the phoretic effects.

The previous curves represent the average efficiencies on a five meters fall. But these efficiencies change a lot as function of falling height because of the evolution of the steam flow rate and the temperature gradients around drops.
On figure 13 and figure 14, all the efficiencies and drops temperature are plotted for two particles diameters : 0.1 and 5 μm. We clearly observe that the phoretic effects are very important at the beginning of the fall but stop when temperature becomes steady.
Mechanical effects, do not depend a lot on temperature, are almost steady during the fall. The slight variations are only due to the changing drop size and to the drop velocity evolution. The temperature equilibrium is quickly reached so the efficiencies steady values are close to the average values dropped on figure 11.

V. EXPERIMENTAL RESULTS

Acquisition of experimental results on the device CARAIDAS allows to qualify the modelling of the different phenomena involved in the fission products washout by spray.
We only present the first experimental results. At the moment, an important campaign of tests is going on.

The three falling height drops diameter measurements and drop behaviour modelling are plotted on the figures 15, 16, 17 and 18 for different experimental conditions. Each experimental drops diameter is the average value of about fifty experimental points. Because of the slight decrease of diameter in some tests, the average values are accompanied with a confidence interval. If n is the number of experimental measurements, x_i a measurement i and x_a the average value on the measurements, we obtain :

the estimated standard deviation: $$s = \sqrt{\frac{\sum_{n=1}^{n} (x_i - x_a)^2}{n-1}}$$

the confidence interval on x_a: $i = 2 \times \frac{2s}{\sqrt{n}}$

(there are ninetyfive chances in a hundred that x_a is included in this interval)

Any confidence interval is drawn because it is very small (a few micrometers) in relation to the drops diameter decrease. So we can conclude that experimental measurement decreases are significant.
There is a good agreement between calculations and experiments whatever thermodynamic conditions (figure 15, 16, 17 and 18). Even when the drop evaporates a lot (dry warm air on figure 18), the divergences between the code and the experimental data are low.
More experimental results, with condensation thermodynamic conditions, will be getting but we can expected a good agreement also.

VI. CONCLUSION

The experimental device CARAIDAS is operational for aerosols experiments, so particles collection efficiencies as function of different working conditions representative of severe accident will be determined. Experimental aerosols tests are going on. In the same time, we have developped a model. Experimental collection efficiencies and code results will be used in order to propose qualified collection efficiencies correlations. At the end of this program more realistic washout rates could be computed as function of accident scenarios. Iodine experimental tests will be done after aerosols tests.

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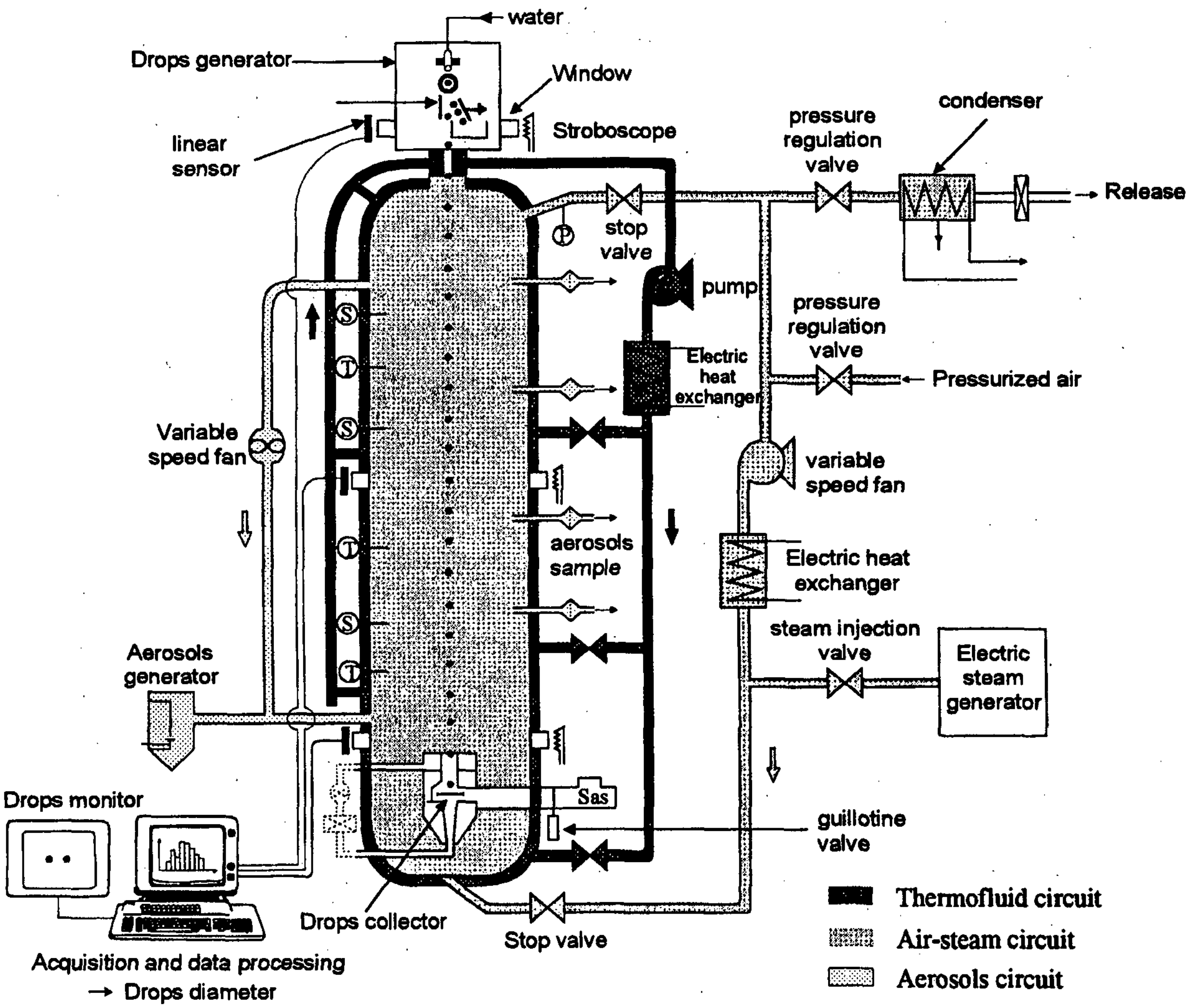
figure 1: Experimental device scheme



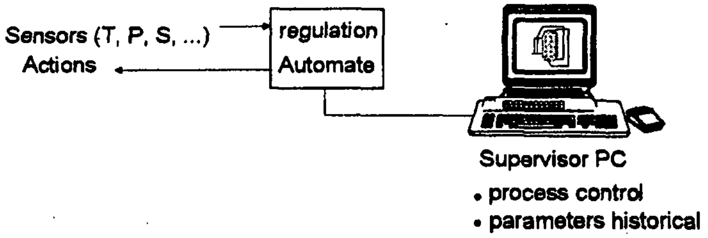


Figure 2 : Electrostatic sorting out drops generator

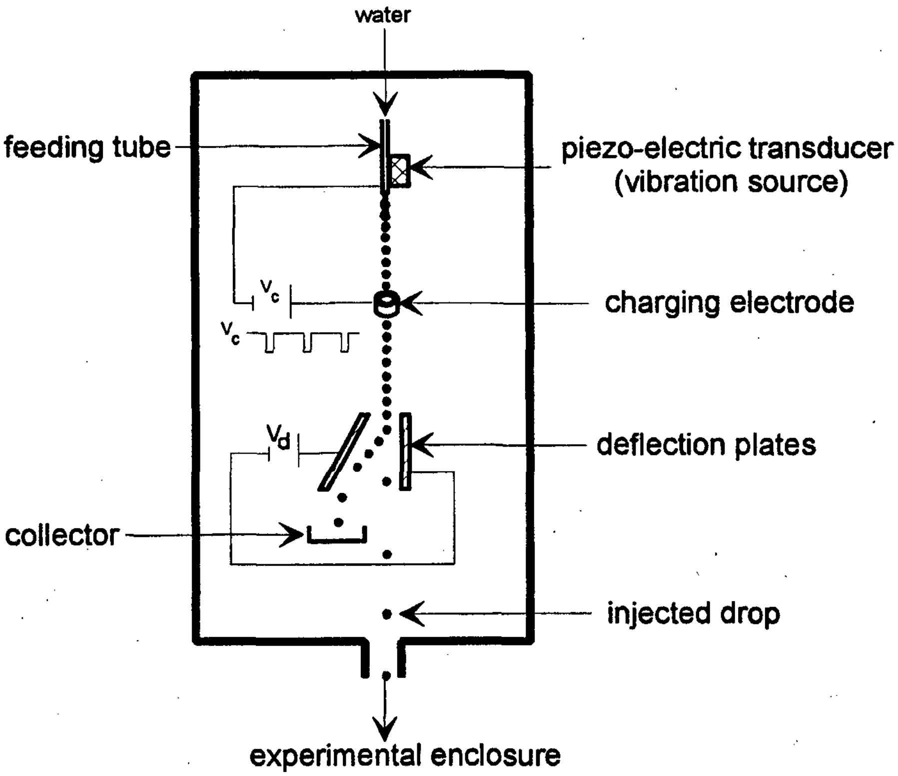


Figure 3: Double-film theory scheme

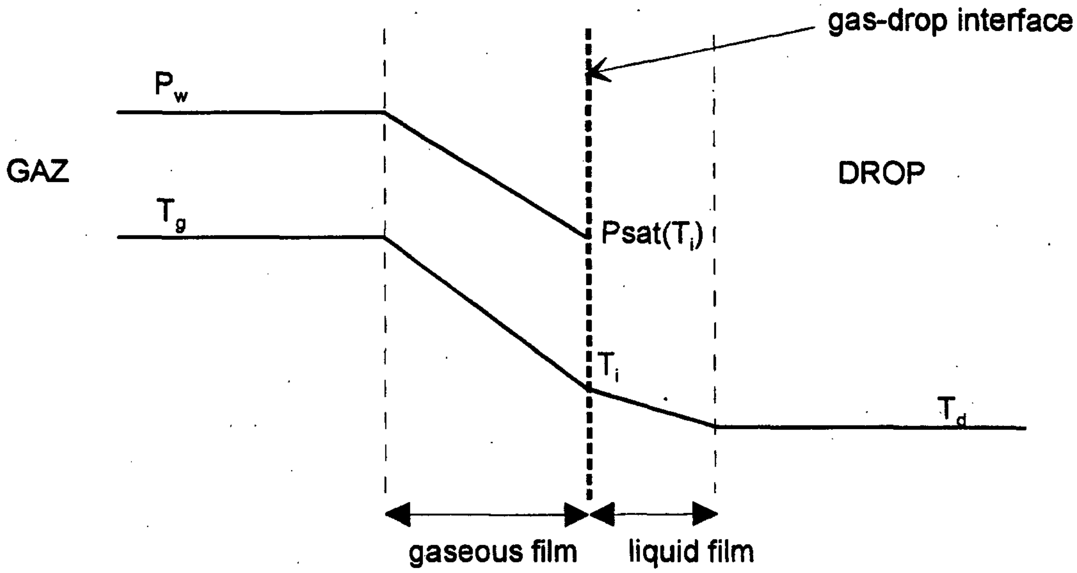


Fig. 4a: Drop diameter versus falling height - Initial drop diameter : 100 µm

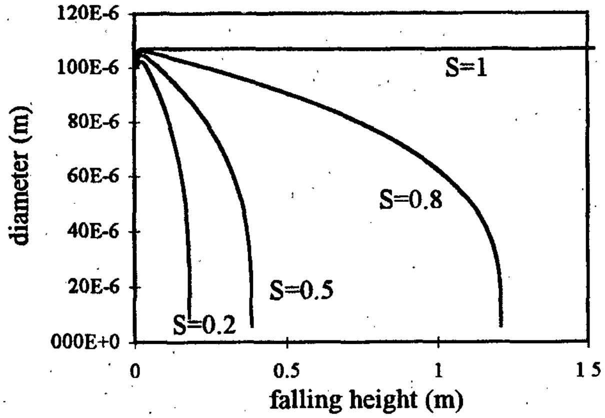


Fig. 4b: Drop temperature versus falling height - Initial drop diameter : 100 µm

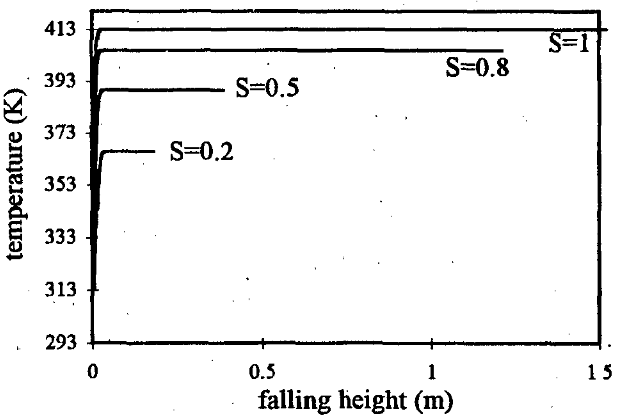


Fig. 5a: Drop diameter versus falling height - Initial drop diameter : 300 µm

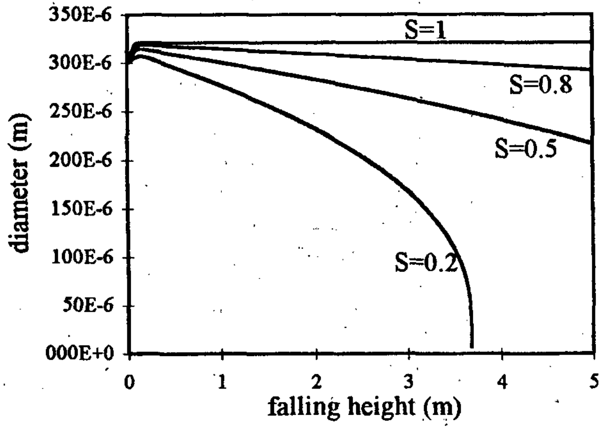


Fig. 5b: Drop temperature versus falling height - Initial drop diameter : 300 µm

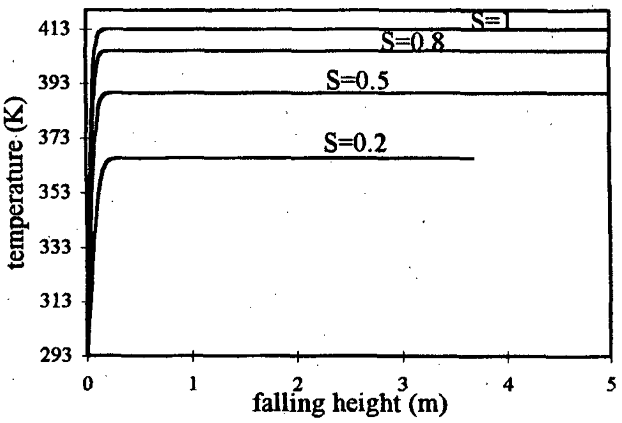


Fig. 6a: Drop diameter versus falling height - Initial drop diameter : 500 µm

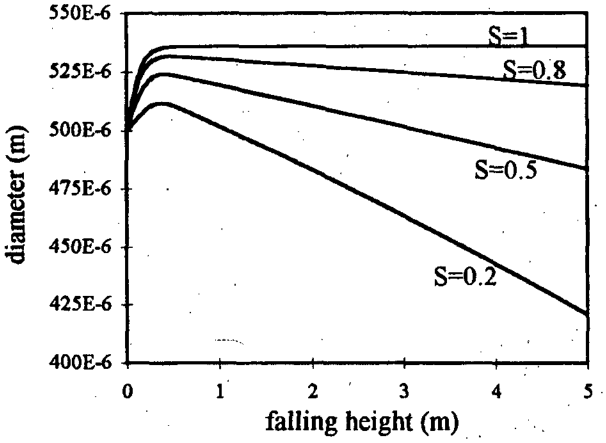


Fig. 6b: Drop temperature versus falling height - Initial drop diameter : 500 µm

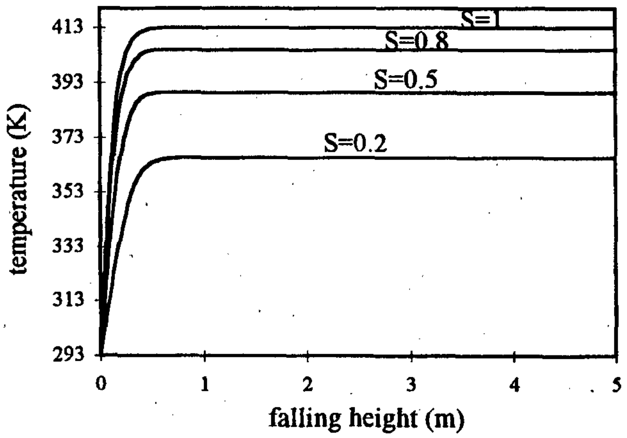


Figure 7: Collection efficiency versus aerosol diameter
P = 1 bar, Tdrop = Tgas = 20 °C, S = 1, Ddrop = 100 µm

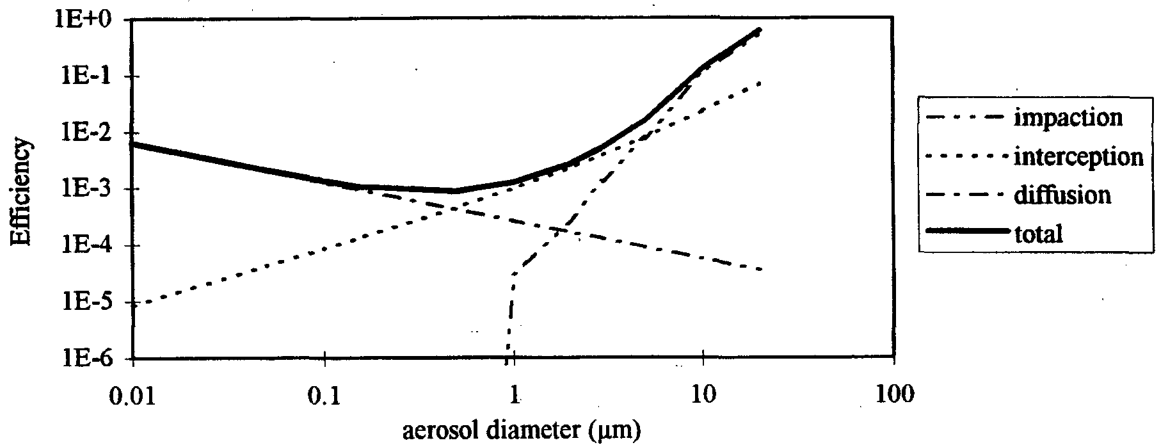


Figure 8: Collection efficiency versus aerosol diameter
P = 1 bar, Tgas = 140 °C, Tdrop = 20 °C, S = 1, Ddrop = 100 µm

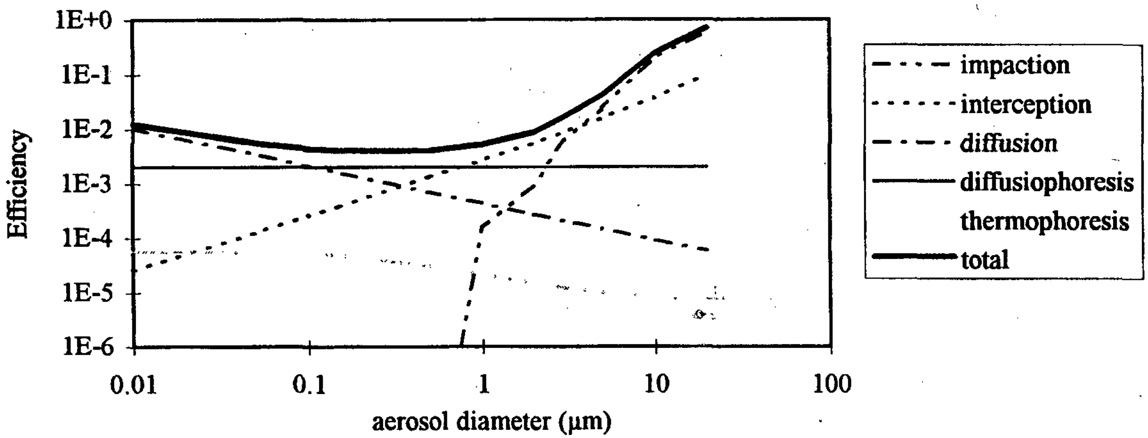


Figure 9: Collection efficiency versus aerosol diameter
P = 5 bars, Tgas = 140 °C, Tdrop = 80 °C, S = 1, Ddrop = 100 µm

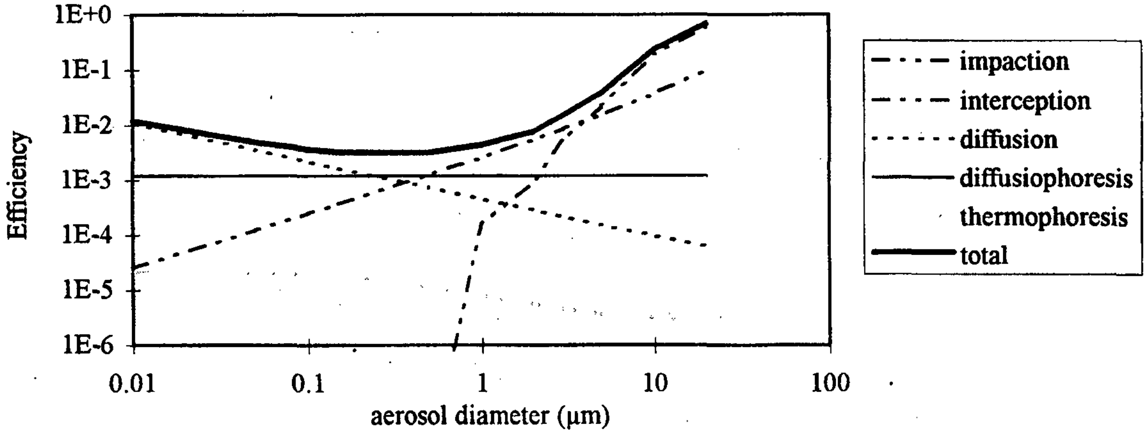


Figure 10: Collection efficiency versus aerosol diameter
P = 1 bar, Tdrop = Tgas = 20 °C, S = 1, Ddrop = 500 µm

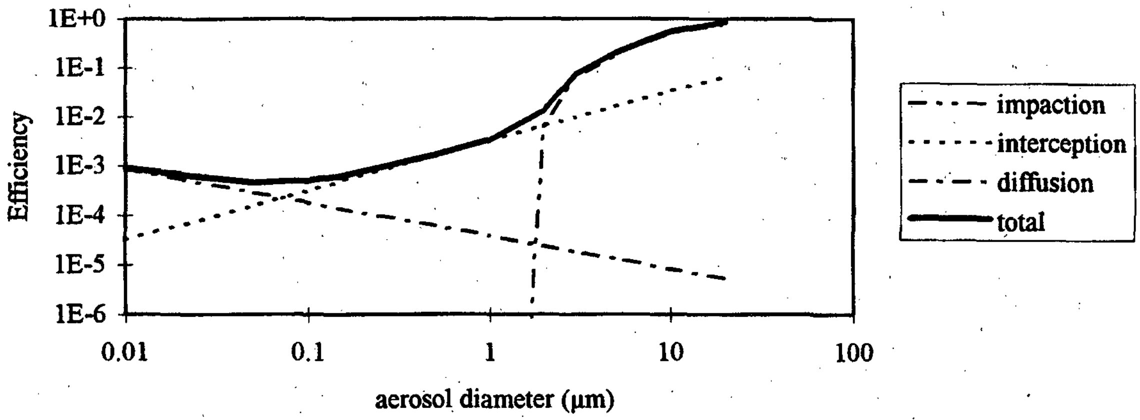


Figure 11: Collection efficiency versus aerosol diameter
P = 5 bars, Tgas = 140 °C, Tdrop = 20 °C, S = 1, Ddrop =500 µm

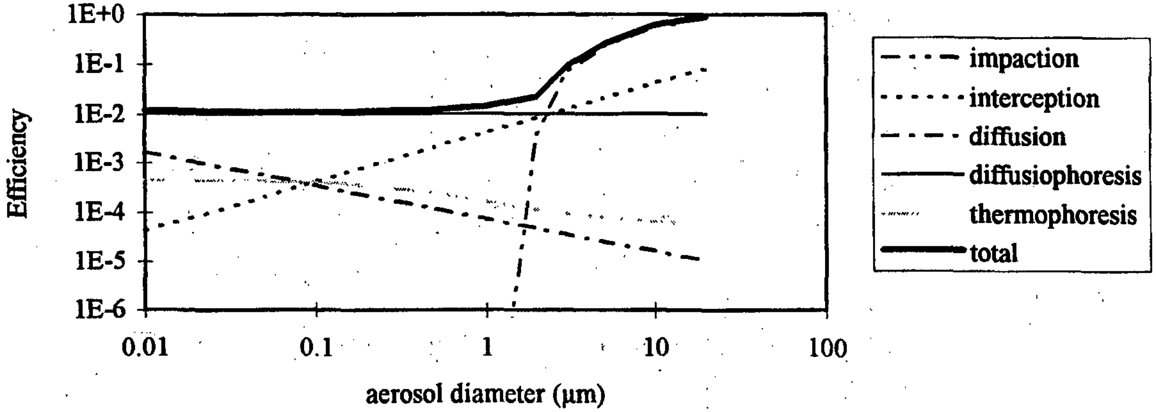


Figure 12: Collection efficiency versus aerosol diameter
P = 5 bars, Tgas = 140 °C, Tdrop = 80 °C, S = 1, Ddrop = 500 µm

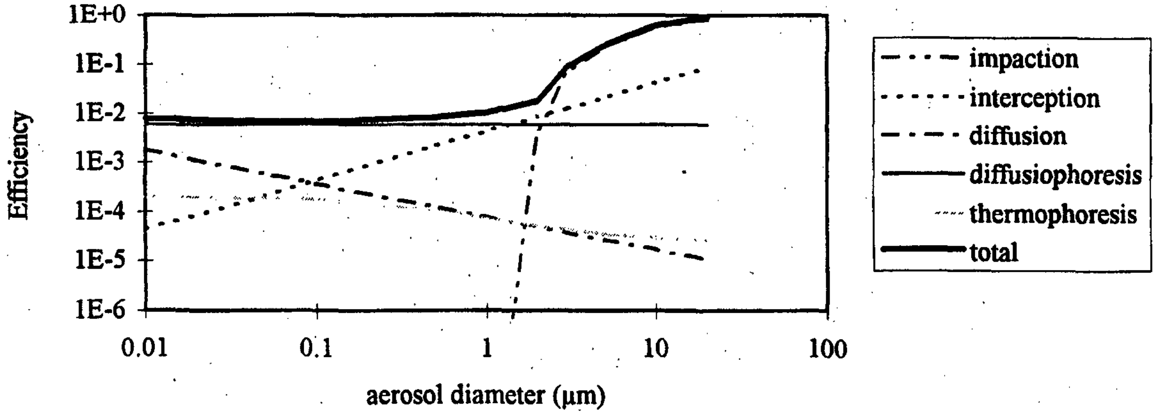


Figure 13: Elementary efficiency versus falling height
P = 5 bars, Tgas = 140 °C, Tdrop = 20 °C, S = 1
Ddrop = 500 µm, Daerosol = 0.1 µm

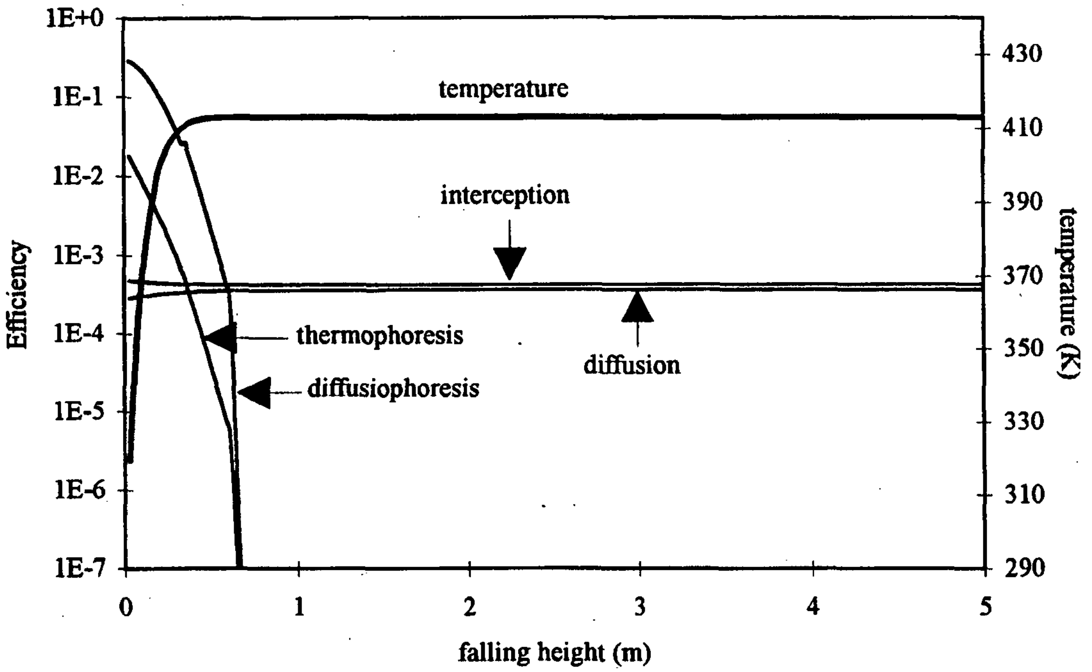


Figure 14: Elementary efficiency versus falling height
P = 5 bars, Tgas = 140 °C, Tdrop = 20 °C, S = 1
Ddrop = 500 µm, Daerosol = 5 µm

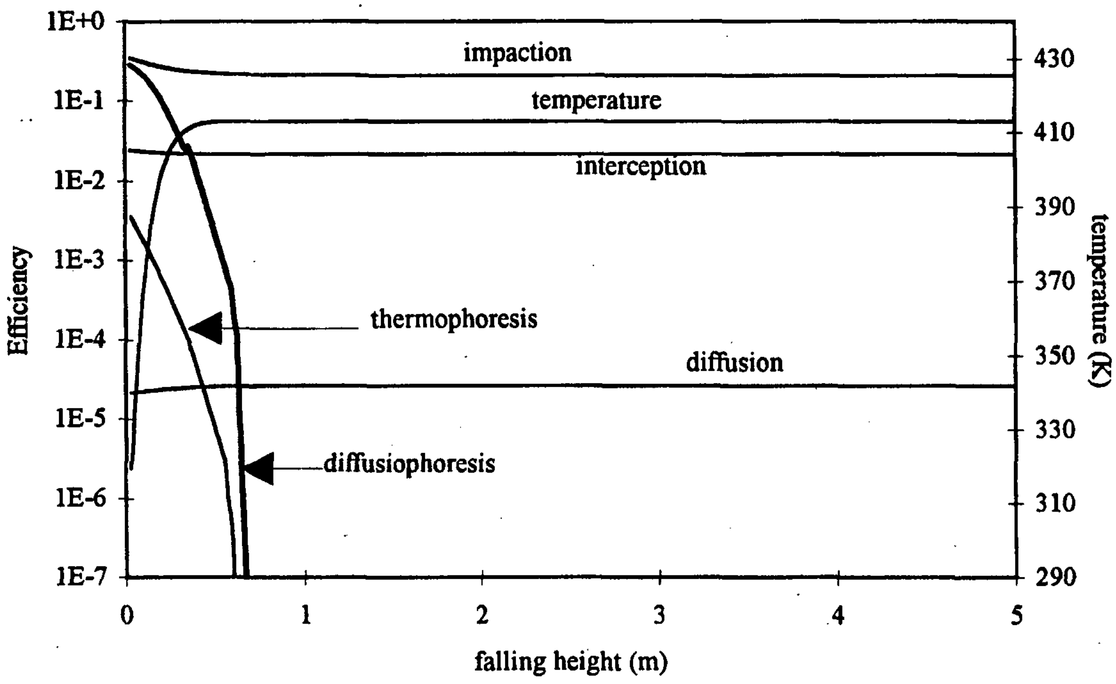


Figure 15: Drop diameter versus falling height
S = 32 %, P = 1 bar, Tgas = 21 °C, Tdrop = 20 °C

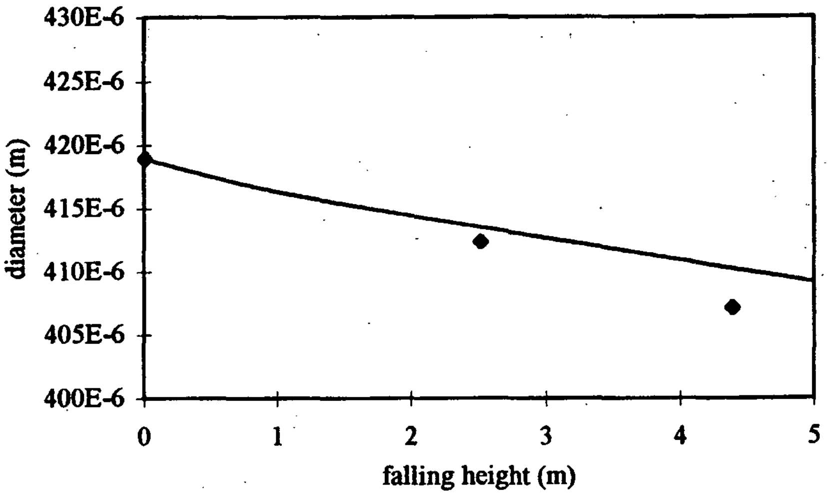


Figure 16: Drop diameter versus falling height
S = 12 %, P = 1 bar, Tgas = 47 °C, Tdrop = 20 °C

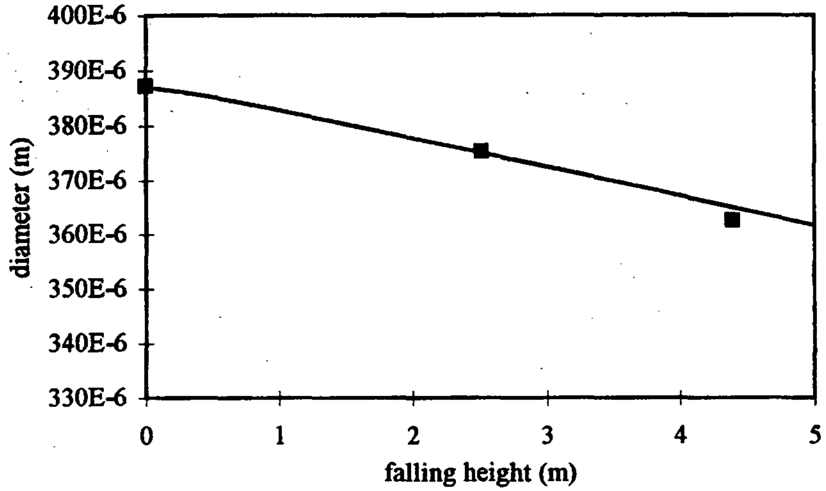


Figure 17: Drop diameter versus falling height
S = 1 %, P = 1 bar, Tgas = 105 °C, Tdrop = 30 °C

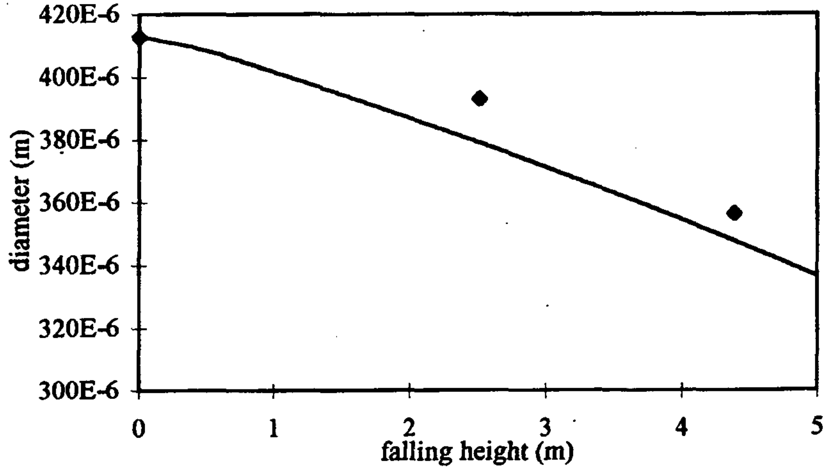
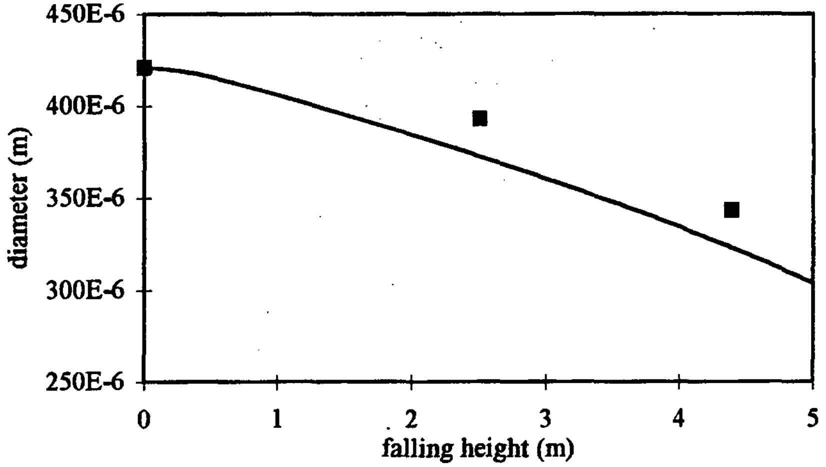


Figure 18: Drop diameter versus falling height
S = 1 %, P = 1 bar, Tgas = 146 °C, Tdrop = 30 °C



DISCUSSION

LEE: Are you aware that we requested the Phebus project at Cadarache to install a single drop aerosol experiment (instead of using a spray) during the test in the containment to assess current modeling of spray scrubbing of iodine?

DUCRET: I do not really know the answer because it is on another project.

LEE: Because the containment of Phebus is very small, if they are going to use a spray, the spray cone will practically cover everything in the containment. Therefore, if you look at the cross section (of the spray) versus the surface area and the volume (of the containment) it will be greatly distorted no matter what kind of spray is used, and the results will probably not be useful for validating the models for spray scrubbing of iodine. For this reason, we proposed to the CEA to use a single drop type experiment.

CHARACTERIZATION AND RESTORATION OF PERFORMANCE OF "AGED" RADIOIODINE REMOVING ACTIVATED CARBONS

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Abstract

The degradation of radioiodine removal performance for impregnated activated carbons because of ageing is well established. However, the causes for this degradation remain unclear. One theory is that this reduction in performance from the ageing process results from an oxidation of the surface of the carbon. Radioiodine removing activated carbons that failed radioiodine removal tests showed an oxidized surface that had become hydrophilic compared with new carbons. We attempted to restore the performance of these "failed" carbons with a combination of thermal and chemical treatment. The results of these investigations are presented and discussed with the view of extending the life of radioiodine removing activated carbons.

Introduction

Experience has shown that the performance of activated carbons for radioiodine removal decreases with time by a process known as ageing. This ageing process can occur in storage and has lead to the recommended shelf life of five years currently accepted in the U.S. after which the carbon should be retested for radioiodine removal. Carbons that do not meet the retesting requirements and thus cannot be used though "new" have become known as "spinster" carbons. It is generally believed that these "spinster" carbons fail after prolonged storage due to a change in the surface oxides present on the carbon. NUCON® and others [1,2] have used a combination of thermal and chemical treatments to restore the performance of these "failed" carbons. The results of these investigations are presented and discussed.

Methodology

Except where noted, ASTM D3803-89 [3] was used to determine the methyl iodide removal efficiency at 30°C and 95% relative humidity. Heat treatments were performed using a rotary kiln. Carbon impregnations were performed using the incipient wetness technique.

Presentation of Results

Results of tests performed in the NUCON® laboratory are shown in Table 1 for treatment of "spinster" carbon. Shown in Table 2 are results of treatments of a spent carbon from a German plant[2].

Discussion of Results

The German test results in Table 2 show the methyl iodide removal efficiencies after different types of treatment techniques performed on a spent (i.e., a carbon that has seen service) carbon sample. These treatments included; desorption with steam at 130 °C, with nitrogen at 200, 300 and 450 °C and with carbon dioxide at 180 °C; extraction with hexane and heptane at 25 °C and extraction with supercritical carbon dioxide at 40 and 60 °C; and desorption with nitrogen at 450 °C followed by potassium iodide impregnation. Although their radioiodine test method differs from the ASTM method, the success of their thermal treatment using N_2 at 450°C with or without a following impregnation, prompted similar treatments in our laboratory on "spinster" carbon samples.

The results of these tests with "spinster carbons", shown in Table 1, indicate that desorption at 850°C with nitrogen followed by impregnation with TEDA restores the carbon to a greater than 99% efficiency. This is NUCON®'s lower limit for an acceptable test result using ASTM D3803-89. Hydrazine treatment of spent carbons has also been suggested as a treatment to restore the performance of aged carbons[1]. However, as shown in Table 1, hydrazine gave no improvement over TEDA impregnation.

This high temperature treatment with N_2 has been shown to drive surface oxides off the carbon[4] and, following impregnation, restores the carbon to "new" carbon performance. This treatment method may be a cost-effective way to restore the performance of "spinster carbons"especially when compared with new carbon replacement costs.

References

1. Deitz, V. R., " Charcoal Performance Under Accident Conditions in Light- Water Reactors", NUREG/CR-3990, NRL Memo Rpt 5528 (March 1985)

2. Lasch, M., et al, " Exhaustion of activated carbon for iodine retention in nuclear power plants", VGB *Krartwerkstech*, 1994, 74(11) 988-90

3. ASTM D3803-89, "Standard Test Method for Nuclear-GRade Activated Carbon", *Annual Book of ASTM Sandards*, Vol 15.01

4. Boehm, H. P., "Chemical Identification of Surface Groups", *Institute of Inorganic Chemistry, University of Heidelberg, Germany*

TABLE 1
Methyl Iodide Removal Efficiency After Treament of "Spinster" Carbon

Sample ID	Treatment	Methyl Iodide Removal Efficiency, %
4501	As Is	90.7
4501	N_2, 450 °C, KI+TEDA	98.0
4501	N_2, 700 °C, KI+TEDA	98.4
4501	N_2, 800 °C, KI+TEDA	98.6
4501	N_2, 850 °C, TEDA	99.3
I122	TEDA	97.1
I416	Hydrazine, TEDA	97.0

Radioiodine Test Conditions: ASTM D3803-89, 30 °C, 95% Relative Humidity

TABLE 2
German Studies of Depleted Carbon for Iodine Retention

Sample #	Treament	Methyl Iodide Removal Efficiency, %
1	Steam, 130 °C	98.86
2	N_2, 200 °C	99.27
3	CO_2, 180 °C	98.86
4	Supercritical CO_2, 40 °C	99.97
5	Supercritical CO_2, 60 °C	99.87
6	n-Hexane, 25 °C	99.83
7	n-Heptane, 25 °C	99.90
8	N_2, 300 °C	99.978
9	N_2, 450 °C	99.999
10	N_2, 450 °C, KI	99.999+

Radioiodine Test Conditions: 30 °C, 0 42 m/s, 1 2 sec Residence Time

DISCUSSION

RICKETTS: I wonder if you could comment about how long these regeneration processes take and whether there are any significant differences between the various processes as far as costs go?

KOVACH, L: Yes, certainly there are differences. I do not know how familiar everybody is with how activated carbon is made. You process activated carbon at high temperature and at best the residence time may be from 1-3 hours in rotary furnaces but you may also be dealing with 10 - 24 hours residence time at these temperatures for some products. In the case discussed in the paper residence times are much shorter, a half-hour at temperature for the nitrogen treatment. If we are looking at supercritical extraction with carbon dioxide it becomes more complicated because there has been a significantly more strict controlled pressure boundary on the system than just a straight rotary furnace with an inert gas. Organic extractions are again more expensive because you have to recover the organic from the material and then you have to dry it again. So the lowest cost products are still made by nitrogen treatment. I would say by almost an order of magnitude lower cost than any of the other ones. Temperature is nothing other than an energy cost, it is really not significant. It is just as easy to run at 850°C as at 450°C, the residence times would be the same for all cases. In the US, straight impregnation cost is probably somewhere in the neighborhood of $0.50/lb for labor and material but excluding the cost of carbon used. The nitrogen treatment is the one that looks most promising, both from a cost and a benefit standpoint.

RICKETTS: Are you passing nitrogen through the carbon during the regeneration process?

KOVACH, L: It is not directly passed through, although we are currently doing some tests where we are passing it through the carbon. In a rotary furnace you are dealing with partial exposure, i.e., carbon is scattered up on the walls and it falls back so there is exposure partly to the nitrogen stream. But it is not continuous, so it is not like a fixed bed with hot nitrogen going through it, it is a rotating bed and it falls back in the tube while it is exposed to nitrogen.

EFFECTS OF WELDING FUMES ON NUCLEAR AIR CLEANING SYSTEM CARBON ADSORBER BANKS

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Abstract

Standard Technical Specifications for nuclear air cleaning systems include the requirement to perform a full battery of surveillance tests following "fire, painting, or chemical release" in areas communicating with the affected system. In order to conservatively implement this requirement, many plants have categorized welding as a chemical release process, and instituted controls to ensure that welding fumes do not interact with carbon adsorbers in a filter system.

After reviewing research data that indicated that welding had a minimal impact on adsorber iodine removal efficiency, McGuire Nuclear Station decided to pursue further testing with the goal of establishing a "welding threshold". It was anticipated that some quantity of weld electrodes could be determined that had a corresponding detrimental impact on iodine removal efficiency for the exposed adsorber. This value could then be used to determine a conservative sampling schedule that would allow the station to perform laboratory testing to ensure system degradation did not occur, without incurring the penalty of a full battery of surveillance tests.

A series of tests was designed to demonstrate carbon efficiency versus cumulative welding fume exposure. Three series of tests were performed, one for each of the three different types of commonly encountered weld electrodes (E7018, E308 and E309). Each test series used a test filter train with a freshly loaded carbon adsorber and 20 pounds of electrode. Welding was performed with all airborne welding by-products directed through the filter train. Carbon sampling was performed at baseline conditions, and every five pounds of electrode thereafter. Two different laboratory tests were performed for each sample; one in accordance with ASTM 3803/1989 at 95% relative humidity and 30 degrees C, and another using the less rigorous conditions of 70% relative humidity and 80 degrees C.

Review of the test data for all three types of electrodes failed to show a significant correlation between carbon efficiency degradation and welding fume exposure. Accordingly, welding is no longer categorized as a 'chemical release process' at McGuire Nuclear Station, and limits on welding fume interaction with ventilation systems have been eliminated.

Introduction

Historically, at McGuire Nuclear Station, the generation of welding fumes has been considered to have a potentially detrimental effect on the carbon adsorbers of nuclear air cleaning system filter packages. Accordingly, their communication with operating filter systems has been administratively controlled; if welding fume exposure for a given system is unavoidable, that system would conservatively be considered inoperable and subject to the full battery of surveillance tests to demonstrate its return to operability.

Normally, these administrative controls do not place an undue burden on coordination between work and system operation. However, upcoming steam generator replacement projects at two of Duke Power Company's nuclear sites led to a re-examination of the welding fume impact issue.

During an outage, the Containment Purge filter trains at McGuire are essentially under continuous operation, either in 100% (dual train), or 50% (single train) mode. There are no designed system bypasses, so it is anticipated that essentially ALL of the gases generated by welding processes in containment will communicate with the operating filters. In order to avoid unnecessarily declaring filter trains inoperable based on 'suspected impact,' a site project was undertaken by the System Engineering and Operations groups to attempt to establish a correlation between the amount of fumes generated by welding and the resulting degradation in filter system methyl iodine removal efficiency.

Project Goal and Scope

The original project goal was to determine the point at which filter system adsorber performance deterioration occurred in a small test system, and then correlate this point to the cumulative weld fume exposure. Conservative extrapolations of this small test filter package data to actual systems would then be developed. It was anticipated that a 'pounds of electrode consumed per filter system flow rate' limit could be devised. This would be analogous to the painting 'rule of thumb' of 100 sqft per 1000 cfm that is widely used in the nuclear industry to perform carbon sampling and laboratory testing.

It was recognized that many hundreds of pounds of welding electrode would be used during the steam generator replacements, (and in the preceding outage, which incorporated as much structural prestaging as possible). Much of this welding would be 'stick', or electrode welding, (more formally called 'shielded metal arc welding', or SMAW). Other welding processes using an inert gas purge (i.e., MIG, TIG) are comparatively insignificant fume producers, and are not generally considered to be 'chemical releases.' Electrode welding was the only issue considered unresolved, and therefore was the sole focus of the project.

Test Method, Execution and Observations

Test Parameter Determination

The McGuire Training Support division has a small test filter train which was made available for use in project. The system is a portable and self-contained filter package manufactured by Charcoal Service Corporation of Bath, NC. This package consists of:

a) an 8" diameter intake duct (including flow orifice and manual throttle damper),
b) a filter housing, containing:
    one 24"x24"x2" prefilter,
    one 24"x24"x12" HEPA filter, and
    one carbon adsorber with approximately 75 pounds of carbon
      arrayed in 1 and 3/8" thick pleats, and
c) a belt driven centrifugal fan with a 120 VAC, 1.5 HP motor.

The nominal flow rate through the system is 500 cfm; manufacturer's supplied data for the adsorber states a residence time of 0.125 seconds at a flow rate of 1000 cfm (or, 0.25 seconds at 500 cfm).

Each of the two containment purge filter package carbon adsorbers holds approximately 2200 pounds of activated impregnated carbon, and has a nominal individual train flowrate of 14,000 cfm and 0.25 second residence time. A conservative approximation of the actual amount of welding electrode that might be consumed during an outage was 500 pounds. Comparing sizes of the test filter package to an individual containment purge package (based on either flow rate or the roughly equivalent carbon weight ratio) led to the choice of 20 pounds of electrode as the appropriate challenge for the test filter package. This equates to subjecting a single containment purge package to the fumes of approximately 585 pounds of welding electrode. Added conservatism is given by the fact that containment purge train operation is normally rotated during an outage, and routine lab tests of representative carbon samples are required after every 720 hours of system operation..

At McGuire, three different types of electrodes are used in 'stick welding' applications. They are:

1) AWS Classification E7018 for carbon steel to carbon steel welding,
2) AWS Classification E308 for stainless steel to stainless steel welding, and
3) AWS Classification E309 for stainless steel to carbon steel welding.

Due to the questions about the varying chemical compositions of the fluxes and the possibility of differing carbon degradation trends, it was decided that all three types would be tested (20 pounds of each). The carbon adsorber would be reloaded prior to each test series to quantify individual impacts.

Carbon to be used in each test series was the same nuclear grade-adsorbent as used in McGuire's safety filter systems. Purchase specifications state that it shall be impregnated to a range of 4.8 to 5% TEDA, and conform to all the physical and test standards as required by ANSI N509-1980, Table 5.1. The supplier for the carbon used was Carbon Applications, Inc. of Columbus, Ohio.

In order to add further conservatism and fully allow for any interaction between the welding fumes and the adsorber bed, a maximum test filter package flow rate of 250 cfm was established, which translates into a residence time of at least 0.50 seconds. In order to trend and correlate carbon degradation versus welding exposure, a carbon sampling frequency of a) prior to exposing the carbon to fumes, as a baseline, and b) following the consumption of every five pounds of electrode was assigned.

Test Execution

The general approach for each of the three test series was the same. The adsorber was loaded with new carbon, a baseline sample was obtained, and the filter package was started. The flow rate was throttled to a nominal 240 cfm. Welding was performed in the inlet plenum of the 8" ductwork to ensure that all fumes were drawn into the test filter package. The full length of the electrode was used for welding, regardless of whether restriking was required (impurities in the weld beads being generated were of no consequence to the test program). Representative carbon samples were removed from the adsorber following the consumption of each 5 pounds of electrode.

E308 Test Series: The original loaded carbon weight was 79 lbs. A gradually increasing prefilter differential pressure was observed during welding; its affect on flow was offset by adjusting the manual throttle damper in the inlet duct. Flow varied from 236 to 246 cfm. The total weight of E308 electrode was made up of 15 lbs. of 1/8" dia. and 5 lbs. of 3/32" dia.

E309 Test Series: The newly loaded carbon weight was 75 lbs. Prefilter differential pressure continued to rise during the test. Manual throttle damper adjustment was still sufficient to maintain nominal flow. Calculated flow for the series held steady at 242 cfm. E309 electrode weight was comprised of 16 lbs. of 1/8" and 4 lbs. of 3/32" dia.

E7018 Test Series: The test filter package prefilter was changed out along with carbon. Reloaded carbon weight was 80 lbs. The starting position for the throttle damper was further closed to account for the decreased D/P of the new prefilter. Flow varied from 229 to 239 while compensating for the initial particulate loading of the prefilter with damper adjustment. The breakdown of electrode sizes for the E7018 series was 5 lbs. of 3/32" dia., 7 lbs. of 1/8" dia., and 8 lbs. of 5/32" dia.

Test Results

Laboratory analysis of the carbon samples was performed by NCS Corporation of Columbus, Ohio. Each carbon sample was tested under two sets of conditions. The first was the Technical Specification dictated test of 80°C/95% Relative Humidity. The acceptance limit for this test is 99.00 % efficiency. The second test was the more conservative ASTM D3803-1989 test which incorporates a 16 hour pre-equilibration period and 30°C/95% RH test conditions.

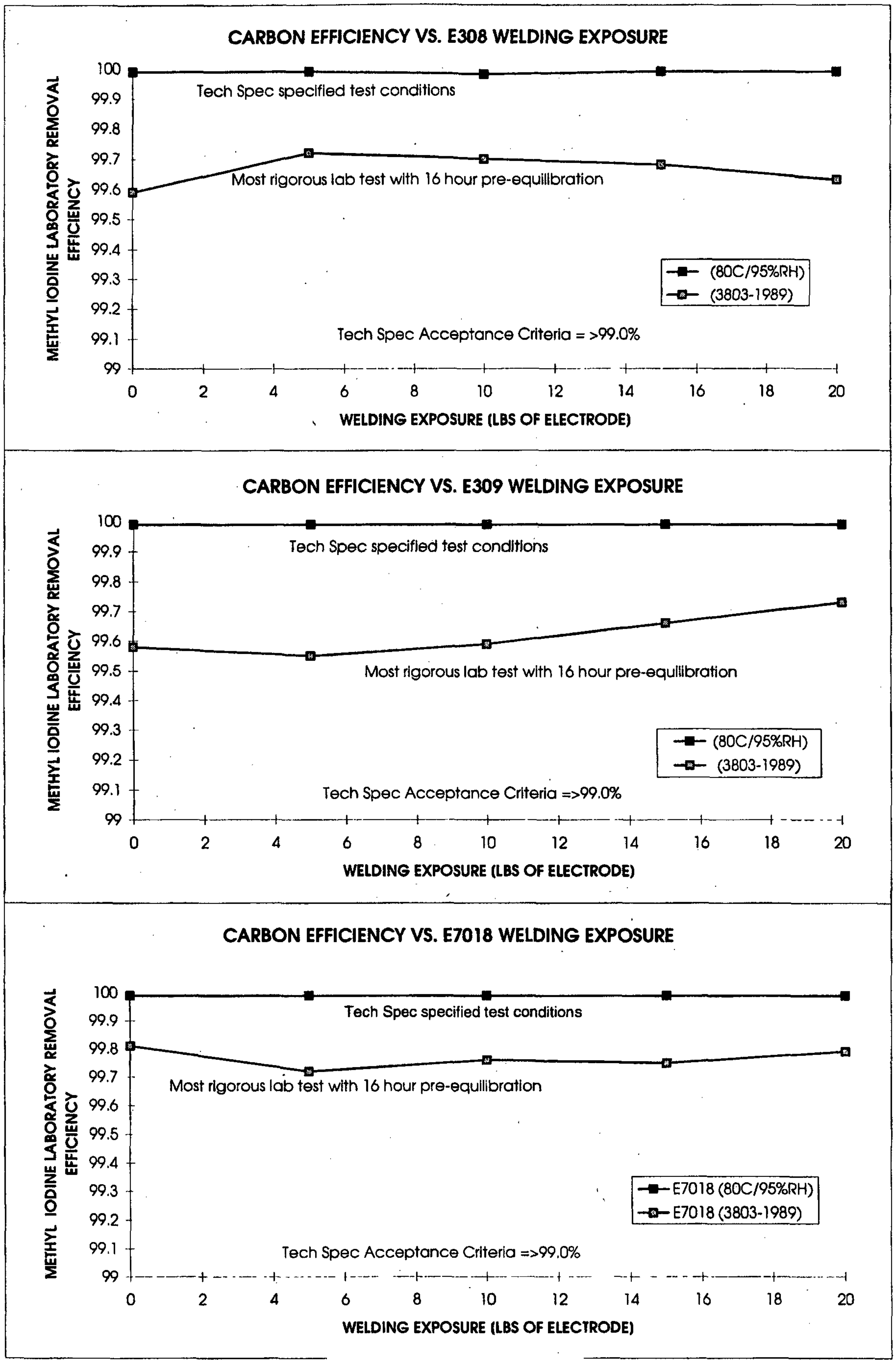
The results of the laboratory testing performed at five pound intervals for the three types of electrodes are presented in the following table.

Welding Exposure (Lbs. of Electrode)	Carbon Laboratory Efficiencies (%): Electrode Type / Lab Test Conditions					
	E308		E309		E7018	
	(80C/95%RH)	(3803-1989)	(80C/95%RH)	(3803-1989)	(80C/95%RH)	(3803-1989)
0	99.99	99.59	99.99	99.58	99.99	99.81
5	99.99	99.72	99.99	99.55	99.99	99.72
10	99.98	99.70	99.99	99.59	99.99	99.76
15	99.99	99.68	99.99	99.66	99.99	99.75
20	99.99	99.63	99.99	99.73	99.99	99.79

Review of the above data shows that even under heavy exposure to welding fumes, the ability of the adsorber to filter methyl iodine was not significantly affected. This general observation is applicable to the test results of each of the three types of electrodes.

The graphical presentation of the same data is provided for each electrode test series on the facing page; Graphs 1, 2, and 3.

Graphs 1, 2, and 3



CARBON EFFICIENCY VS. E308 WELDING EXPOSURE

CARBON EFFICIENCY VS. E309 WELDING EXPOSURE

CARBON EFFICIENCY VS. E7018 WELDING EXPOSURE

Conclusions

Review of the laboratory test data for the three test series showed uniformly non-existent impact for the methyl iodine penetration tests performed at Tech Spec dictated conditions. With one exception (whose results were 99.98% efficient), all test results following increasing exposure to welding fumes showed the same performance as the baseline. This consistency, and lack of an identifiable deterioration trend, was a pleasant surprise.

Turning to the results for the carbon samples when tested according to ASTM 3803-1989, more variation was noted. An average efficiency for each test series was calculated, along with a standard deviation. For the 15 samples, 10 fell within a single standard deviation of the average, and for the remaining five, the worst "outlier" was 1.5 standard deviations off the average. It is interesting to note that this point (Series E309, Sample #5) showed an increase in efficiency over the baseline test.

Based on the trends established by the sampling and lab results for each test series, it does not appear that the airborne byproducts of electrode welding have a statistically significant impact on the performance of a filter package adsorber. No correlation of adsorber performance degradation vs. welding exposure was established. It was, however, noted that the visible smoke from electrode arcing is a particulate that does have a cumulative effect on prefilters, and therefore, potentially, on total system flow and/or HEPA filter D/P. The routine monitoring of operating filter systems at McGuire is considered adequate to identify any flow impacts of increasing D/P due to welding or other dust/particulate generating activities.

Accordingly, electrode welding is no longer considered a chemical release process at McGuire Nuclear Station.

Acknowledgments

The author would like to acknowledge and extend his appreciation to David G. Davenport for his leadership and coordination efforts in conducting this project. Additional thanks are also extended to John Pearson of NCS, for his usual excellent support.

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ASTM D3803-1989, "Standard Test Method for Nuclear Grade Activated Carbon".

American Welding Society, "Characterization of Arc Welding Fumes", 1983.

Ghosh, D. "Effects on the efficiency of activated carbon on exposure to welding fumes"; Proceedings of the 23rd DOE/NRC Nuclear Air Cleaning Conference, Conf-940738, Pg. 639, (1994).

DISCUSSION

ADAMS: Was there an interval after you exposed the carbon to the electrode contaminants when there was free flow of air through it? For example, after you exposed it for five electrodes, after you exposed it for ten electrodes, etc. After you completed five electrodes, for example, how much air flowed, or how soon did you pull a sample before you began the next electrode exposure?

ROBERSON: Let me clarify the question; as opposed to five electrodes it is five pounds of electrodes. We are looking in the neighborhood of fifteen electrodes per pound, so it's a little heavier exposure than that. We did not allow any specified amount of time between when the welder finished and we were ready to open the package up and pull the adsorber sample. It did not exceed 15 min.

ADAMS: Did flow continue through the unit while you were pulling the sample?

ROBERSON: Flow continued for an unspecified but relatively insignificant amount of time. The overall consumption of the weld rod, i.e., the number of pounds of weld rod, would take several hours between each sample, but when the welding was completed, sampling was promptly scheduled right after that.

ADAMS: Was the charcoal and filter package unit that you used a qualified ANSI N-509 unit?

ROBERSON: Yes.

ADAMS: How long did air pass through the unit after pulling a sample and beginning the next loading set?

ROBERSON: Unspecified, but in general the run time did not exceed an additional 15 minutes.

HAYES: Was the charcoal that you utilized brand new charcoal?

ROBERSON: Yes.

HAYES: Can you estimate the impact of welding on the charcoal if the test charcoal had not been new but aged for a year or longer?

ROBERSON: Although I would not expect different behavior, the project scope did not focus on carbon age impact. On a practical level, we have applied this relaxed policy on welding through the past outage, which included significant structural pre-staging work for the upcoming S/G outage. Ages of the carbon beds for the two trains of containment purge are approximately one and eight years. Sampling and lab results based on system run time confirmed no degradation on either train, new or old.

HAYES: You indicated that there was a trend that once you got initial degradation the efficiency may have picked up slightly, although within the error that you are talking about, you might even say it was flat. I am wondering if the deterioration, once the charcoal has been exposed, caused the process to somehow speed up one way or the other.

PEST: Can you elaborate on the sampling process? Did you use a grain thief, did you use a test canister?

ROBERSON: We used a grain thief and used a blended sample pulled from a number of pleats to obtain a standard sample.

FRANKLIN: Did you sample the air leaving the filter unit during or after welding?

ROBERSON: No, there was no attempt to quantify what kind of effluent came out of the filter package after all the weld fumes had passed through the pre-filter, HEPA filter, and adsorber.

HARRIS: There is a perceptible dust loading on the pre-filter. Was there an additional loading on the HEPA filter?

ROBERSON: It was minor. There was some but, I do not recall the exact number. From recollection, if the filter pressure drop started at 1.0 in. w., it was 1.1 in. w. at the conclusion.

GOLDEN: Regarding Jack Hayes' question on the aging of charcoal and how that was affected, I want to refer to a paper presented at the last air cleaning conference. The same conclusion was reached.

GHOSH: We did not check into the aging effects of the carbon in the test you are referring to. We used new carbon. We had test canisters and kept pulling the test canisters out. We did a combination of different tests and we tried to use the same type of carbon. The aging effect has not been addressed.

ROBERSON: At a practical level, we have been through one outage while constructing prestaging of structural steel with a lot of welding. We have done the required monthly sampling and continue to see good performance by the containment purge systems with five to seven year old carbon.

BARROW: In both units, we have reloaded carbon on "A" train but the Bravo train of each unit is approximately eight years old. Neither train has shown any degradation by carbon testing.

GHOSH: We use a test to validate that the building fumes had no effect on carbon. We have had two or three tests since we gave our paper and we did not show any degradation of the carbon. That confirms your results. In response to one of the questions somebody asked during my test, we monitored the gases in the inlet and outlet and found that the welding fumes were passing through the bed.

PEST: On the basis of the tests that you have done on your containment purge systems, do they seem to be operating well? What test parameters on your radioiodine test are you referring to, the regulatory required (80°C/70 % RH, or the new D3803-1989?

ROBERSON: We do dual testing with all of our systems. D3803 is used for trending and predicting end-of-life.

CASS: How "clean" was the material that was used as the base for the welding? Burnished, sandblasted clean or oily, dirty, rusty, painted metal, as is usually found in operating plants? Could obscure fumes, i.e. burnt smoke, affect the carbon? Was this considered or evaluated?

ROBERSON: Over the full range of the electrode test series (60#), a variety of welding "base metal" was used, some was painted, some rusty, and (for the stainless steel) some clean. Differences based on different base metal conditions was not specifically identified as a variable, but (by sheer coincidence), a range of base metal conditions was used. Specific documentation (or reconstruction) cannot be provided concerning which 5# increment of electrode consumption used which base metal.

BASIS FOR AND PRACTICAL METHODS OF CONTROLLING PAINTING ACTIVITIES AT THE SEQUOYAH NUCLEAR PLANT

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Abstract

Sequoyah Nuclear Plant (SQN) follows the guidance presented in Regulatory Guide (R.G.) 1.52, "Design, Testing, and Maintenance Criteria for Atmospheric Cleanup System Air Filtration and Adsorption System Units of Light-Water-Cooled Nuclear Power Plants" in protecting its charcoal filter trains from the effects of painting and other chemical releases. SQN, as well as other nuclear facilities around the country, have the problem of how to address the issue of protection of Engineered Safety Feature (ESF) filter systems from degradation due to communication with airborne hydrocarbons (i.e., primarily paints and solvents). R.G. 1.52 (and a similar statement from R.G. 1.140) states in part, "Testing should be performed ... following painting, fire, or chemical release in any ventilation zone communicating with the system...," and requires that a test be performed upon any kind of painting or chemical release. This is considered overly restrictive if the activity is minor and in a location remote from the charcoal filters.

Charcoal filters used in air cleaning systems are required to filter out radioactive iodine from an airstream before its release from the plant to the environment. Charcoal filters will age with time because of their ability to adsorb many different types of material. This aging affects the charcoal by lowering its iodine retention efficiency, and therefore the charcoal needs to be protected from the effects of chemicals such as paint fumes.

An integrated approach was used to determine a basis for and methods of controlling painting (and other chemical releases) for the protection of charcoal filters. The areas investigated were:

1. Test charcoal efficiency after exposure to known contaminants
2. Charcoal and its ability to adsorb contaminants
3. Other utility experience
4. Potential contaminants in paint and their release rates
5. Air change rates
6. Procedural and administrative controls

The TVA SQN testing results supported previous industry papers addressing hydrocarbon effects on charcoal. The results indicated charcoal (TVA uses TEDA and KI impregnated charcoal) can meet its required efficiencies after some exposure to hydrocarbons. Industry information indicates that charcoal may start having lowered efficiencies with as little as 5 percent, by weight, in contaminants absorbed by the charcoal. SQN has chosen 0.5 percent as its administrative limit for charcoal contaminants. The administrative controls, implemented as a result of this effort, have been well received by the plant (craft, operations, management, and engineers) and have not exposed the filters to any excessive amounts contaminants.

Background

SQN follows the guidance presented in R.G. 1.52, "Design, Testing, and Maintenance Criteria for Atmospheric Cleanup System Air Filtration and Adsorption System Units of Light-Water-Cooled Nuclear Power Plants" in respect to the design, operation and maintenance of the installed air cleaning systems. Charcoal filters are an integral part of air cleaning systems and are used to filter radioactive iodine from an airstream before its release from the plant to the environment. Charcoal filters will age with time because of their ability to adsorb many different types of material. Additionally, contaminants such as paint fumes, cleaning solvent fumes, and sealing material offgases will damage and contaminate charcoal which lowers its iodine adsorption efficiency. This aging affects the charcoal by lowering its iodine retention efficiency, and therefore the charcoal needs to be protected from the effects of chemicals such as paint fumes. SQN, as well as other nuclear facilities around the country, have the problem of how to address the issue of protection of Engineered Safety Feature (ESF) air cleaning and non-ESF air cleaning filter systems from degradation due to the effects of painting and other chemical releases (i.e., primarily paints and solvents). One method of addressing this problem is to strictly control painting activities in areas of the plant where such activities could jeopardize the efficiency of charcoal filters installed in air cleaning filter systems.

The NRC recognizes this ability of charcoal filters to adsorb materials and requires testing be performed when filters are exposed to chemicals. NRC R.G. 1.52 (and a similar statement from R.G. 1.140) states in part, "Testing should be performed ... following painting, fire, or chemical release in any ventilation zone communicating with the system...," and requires that a test be performed upon any kind of painting or chemical release. A strict interpretation of this statement requires that a test be performed upon any kind of painting or chemical release. This is considered overly restrictive if the activity that could release chemical fumes (i.e., painting) is minor and in a location remote from the charcoal filters. Therefore, an engineering basis is required addressing the effects of painting activities on charcoal.

SQN has five installed filter systems that contain charcoal filters and hence the need for a process to control paints and other chemicals that may harm the installed charcoal filters. The following are descriptions of the systems affected at SQN:

> The Auxiliary Building Gas Treatment System (ABGTS) is used to filter radioactive particulates and iodine from the exhaust airstream and maintain the Auxiliary Building at a negative pressure with respect to outdoors. It is an ESF filter system in standby and only operated occasionally for testing. It performs its function following a LOCA, a fuel handling accident, and an Auxiliary Building isolation. The purpose of maintaining a negative pressure is to prevent unfiltered outleakage. The capacity of the system is 9000 CFM/train.
>
> The Emergency Gas Treatment System (EGTS) is used to filter radioactive particulates and iodine from the exhaust airstream and maintain the Reactor Building annulus at a negative pressure with respect to outdoors. It is an ESF filter system in standby and only operated occasionally for testing. It performs its function following a LOCA. The purpose of maintaining a negative pressure is to prevent unfiltered outleakage. The capacity of the system is 4000 CFM/train.
>
> The Containment Purge (CP) System is used to filter radioactive particulates and iodine from the exhaust airstream before it is released to the atmosphere. It is a non-ESF filter system that is operated continuously during outages and occasionally during plant power operation. It is required during purging activities while at power and during refueling operations although no credit is taken for the filters in calculations of offsite doses. The capacity of the system is 14000 cfm/train.
>
> The Control Building air cleaning system is used to filter out radioactive particulates and iodine from the outdoor pressurizing airstream before its entry into the main control room. It is an ESF filter system in standby and only operated occasionally for testing. It is required for any event in which radioactive particulates and/or iodine can be released (i.e., Fuel Handling Accident, LOCA, and waste gas decay tank rupture). The capacity of the system is 4000 CFM/train.

The Post Accident Sampling Facility (PASF) Ventilation System is used when the sampling facility is utilized or following an accident. It is a non-ESF filter system and is operated for testing and when the sampling facility is being used. The PASF filters radioactive particulates and/or iodine from the exhaust airstream. The capacity of the system is 2000 CFM/train.

Investigation

The investigation utilized an integrated approach to providing an engineering basis. The six areas investigated were:

1. Test charcoal efficiency after exposure to known contaminants
2. Charcoal and its ability to adsorb contaminants
3. Other utility experience
4. Potential contaminants in paint and their release rates
5. Air change rates
6. Procedural and administrative controls

The purpose of the six areas is:

1. To corroborate charcoal's documented efficiency performance following exposure to contaminants
2. To determine the upper limit of contaminants charcoal can adsorb and still fulfill its safety function
3. To determine if the nuclear industry has a common approach
4. To determine the amount of contaminants which will become airborne in paint used
5. To determine minimum time required to purge areas of contaminants before operating ESF filter systems
6. To determine if existing controls are adequate

Test Charcoal Efficiency

Spare charcoal, at the plant site, was intentionally exposed to known quantities of paint to corroborate charcoal's documented efficiency performance following exposure to contaminants. The test setup consisted of a leak-tight enclosure (for the painting and sealing activities), a filter housing capable of containing one Type II charcoal adsorber tray (containing charcoal impregnated with TEDA and KI), and a fan. The test setup was interconnected with flexible ducting and the fan was equipped with a damper to adjust airflow.

The materials chosen for the testing were the two types of paint most commonly used at the plant and the RTV most commonly used at the plant. Five tests were performed with paints and two tests were performed with RTV. This charcoal was then tested in accordance with technical specifications requirements to determine the charcoal efficiency. Testing was conducted in early 1989 in accordance with ASTM D 3803-1979. Test results are contained in Table 1.

The acceptance criteria for charcoals at SQN varies from 90 percent for CP to 99.875 percent for EGTS. The test results show that the charcoal still met all acceptance criteria. The most severe test was PNT-4 using a highly volatile paint. This released approximately 8.76 lb. of volatiles onto the charcoal. Using 55 lbs. of charcoal per tray, this is a percentage of (8.76/55) x (100)) = 15.93 percent. Thus, the testing supports previous literature published and the present limits of the TVA procedure (1/2 of 1 percent by weight).

Table 1 Testing Results

Test #	Material	Contaminants pounds	Charcoal pounds	Percent by Weight	Charcoal Efficiency percent
PNT 1	Low volatile paint	1.08	55	1.96	>99.9
PNT 2	Low volatile paint	2.16	55	3.93	>99.9
PNT 4	Highly volatile paint	8.76	55	15.93	>99.9
PNT 5	Low volatile paint	1.08	55	1.96	>99.9
Seal 1	RTV	0.01	55	0	>99.9
Seal 2	RTV	0.59	55	1.07	>99.9

Test PNT-3 was not performed.

The testing indicated that the charcoal met all acceptance criteria for iodine efficiency. The testing indicated that charcoal can still perform adequately after being exposed to fumes from painting and sealing activities.

Charcoal and Its ability to Adsorb Contaminants

Industry-issued papers were researched and used to determine the amount of material that a charcoal filter can adsorb and still meet its iodine efficiency requirements. Published information indicates that unimpregnated charcoal can handle approximately 6.8 percent to 11.5 percent of its weight, in contaminants, before it will fail its iodine retention test(9). Other information indicates that charcoal will maintain its efficiency with contaminant loadings of 5 to 30 percent(6, 7). The papers also indicated that water vapor in conjunction with the hydrocarbon contaminants degrades the charcoal at the highest rate(10). It also indicated that charcoals impregnated with both TEDA and KI have the greatest resistance to the effects of water vapor and hydrocarbon contaminants(10). SQN charcoal is purchased with both TEDA and KI. Thus, it follows that a conservative exposure level for known contaminants should be chosen at 5 percent or less by weight of the charcoal.

Other Utility Experience

Experience of utilities, other than TVA, was used in developing the direction and type of controls that are now in place at SQN. Engineers at other nuclear facilities around the country were contacted to determine how they address protecting ESF (and non-ESF) filters from contamination by hydrocarbons which are formed during painting(1,5,11). It is interesting to note that in a 1989 survey 54 percent of the utilities contacted allowed some exposure of their charcoal filters to paint fumes before a test was required. A 1996 survey indicates that 75 per cent of utilities now allow some exposure (some as much as 2500 square feet)(14). Industry practices to protect charcoal adsorbers from contamination include the use of painting permits and coordination of use of cleaning solvents and sealing materials with the testing and running of air cleaning systems. No plant contacted allowed any intentional exposure of charcoal filters to paint or other hydrocarbon fumes. Other methods of controlling painting activities included:

a. Painting in tents using a portable sacrificial charcoal bed. The sacrificial charcoal was in service until the paint had cured.
b. Run the normal ventilation system to remove paint fumes from the area prior to operation of a filter system.
c. Allow painting and if the system is operated then test the system within the Technical Specification time limits.

Potential Contaminants in Paint and Their Release Rates

There are many different materials used at a nuclear plant. Material data sheets, supplied by the paint (or chemical) manufacturer were used to determine the amount of material that can offgas from paints as the paint cures. This information can be used to determine the level of exposure of a charcoal filter to contaminants. The materials that were evaluated were the paints and sealants that were most commonly used. The Material Safety Data Sheets (MSDS) for the most common materials used were then obtained as the amount of volatiles are shown in the MSDS. The paints and sealants used range from a high of about 60 percent volatile (8.76 pounds of solvent per gallon of paint) to a low of about 4 percent volatile (approximately 0.54 pounds of solvent per gallon of paint). The paints evaluated have short cure times, however some paints require cure times of approximately 20 hours.

Air Change Rates

Air change rates are useful in determining the time required to remove paint fumes from an area prior to operating a filter system that serves the area. Air changes are easily calculated by using building volumes and ventilation air flow rates. Air change rates for the various elevations of the auxiliary building ranged from 1.9 air changes per hour (ACH) to 6.6 ACH. The air changes for the reactor building were considerably less; however the ACH for the reactor building is moot as all ventilation air must be exhausted through the containment purge air filters.

The ACH can then be used to determine the minimum time for ventilation system operation following completion of paint curing (or other activity that releases hydrocarbons) to remove fumes. ASTM E741 - 83 can be used to determine the time frame. This ASTM standard uses the following equation (eq 1) to determine dilution of a gas:

$$C = Co \exp(-It) \qquad (1)$$

where

C = fume concentration at time t
Co = fume concentration at time (t) = 0 percent
I = ACH, and
t = time, hrs.

Therefore to determine the time required to reduce the concentration of fumes (i.e., hydrocarbons) in the air by 95 percent, the following is calculated:

$$C = 1.0 - 0.95 = 0.05$$
$$Co = 1 \text{ or } 100\%$$
$$I = 1.9 \text{ ACH} \quad \text{chosen as the most conservative value}$$

solving for t renders

$$C = Co \exp(-It)$$
$$0.05 = 1.00 \exp(-1.9t)$$
$$1.58 \text{ hours} = t$$

For conservatism, the number is rounded to two hours and then a margin of two hours is added. This then results in a four hour run time for the ventilation system following completion of the activity.

Procedural and Administrative Controls

Procedures at the plant control activities by requiring permits for activities that can release airborne hydrocarbons into zones served by ESF (and non-ESF) air cleaning systems. Review of the earlier version of the TVA procedure, AI-29, "Aromatic and Ester Hydrocarbon Release Permit" indicated it was adequate for its intended function. The procedure prevented any activities whenever filter systems were operating or could potentially operate. This presented the plant with a multitude of scheduling and coordination problems for the smallest of activities. An example is the painting of a weld on a baseplate (approximate total area of one square foot). This activity would be required to be scheduled several weeks in advance and still may have been cancelled on the day it was scheduled. The permits are issued on a daily basis and require Operations notification prior to issuance. A 24-hour waiting period was required following any activity that released fumes prior to operating any filter system. Review of the permits indicated that the vast majority of permits issued were for areas approximately 10 square feet or less. The permit process did not allow for evaluations of the activity should a filter system be operated while a painting activity was ongoing. Other areas noted for improvement in the permit process were the need for:

a. Clearer identification of the areas where permits were required
b. Identification of areas outside the building that could have an effect on the filters (some filters took suction from the outside atmosphere)
c. Identification of the vent systems operated during any activity

Results

Testing of Charcoal

Testing performed at SQN corroborated industry information on charcoals and the effects of contaminants. The tested charcoal was able to meet required efficiencies after being exposed to as much as 15.9 percent of its weight in contaminants. The tests were not all inclusive but did coincide with previous papers published.

Charcoal and Its ability to Adsorb Contaminants

Previously it was noted that a conservative level of contaminants is 5 percent by weight of charcoal. Based on a 5 percent by weight ratio, the following systems would then have the capacities indicated. Note that there is approximately 55 pounds of charcoal per charcoal tray and three trays per 1000 CFM. Each value is based on one train of equipment.

For conservatism, a safety factor of 10, below the maximum permissible level of contaminants, is used to assure that the charcoal shall not be exposed to amounts of contaminants that can degrade its performance. This accounts for normal aging and spurious system starts that may increase exposures of charcoal to contaminants. Also, with the potential questions of obtaining accurate test results using ASTM D 3803-79, the additional conservatism will help ensure that charcoal will not be exposed to excessive amounts of contaminants. Therefore, the maximum amount of documented exposure to a charcoal filter, conservatively chosen, is 0.5 percent of the weight of the charcoal.

A sample calculation to determine the amount of contaminants permitted on the PASF is:

Procedural Limits, lbs = (2000 cfm) (3 charcoal trays/1000 cfm) (55 lbs charcoal/tray) (.05) (1/10)
= 1.65 lbs
Results are contained in Table 2.

Table 2 Exposure Limits for Charcoal

System	Airflow CFM	Charcoal weight pounds	Maximum Amount of Contaminants pounds	Procedural Limits pounds
ABGTS	9000	1485	74	7.4
EGTS*	4000	660	33	3.3
CP	14000	2310	115	11.5
Cont. Purge	4000	660	33	3.3
PASF	2000	330	16	1.6

*Has two banks of charcoal. Calculation is based on one bank.

Other Utility Experience

The nuclear industry does have a consistent approach in that it does protect ESF charcoal filters in air cleaning systems. However, the degree of protection varies with the utility as seen by the fact that utilities will allow exposure of filters to fumes (some areas as much as 2500 square feet). Incorporated into the procedure is an allowance of up to 10 square feet of area which can be painted (or equivalent area for solvents or other chemicals) without the need for a permit. This is a consistent approach with other utilities in that a small amount of exposure (fumes equivalent to 10 square feet of painted surface area) does not automatically require an efficiency test be performed. Determination of this value (10 square feet) was based on an evaluation of the square foot areas designated on permits issued prior to this allowance. Another feature incorporated into the procedure is use of a tent with a sacrificial bed of charcoal. Painting or other activities are performed inside the tent. Air is exhausted from the tent and passed through the sacrificial charcoal filter to remove contaminants.

Potential Contaminants in Paint and Their Release Rates

It has been previously stated that 20 hours is required to cure paints. Many of the paints used cure in a time frame less than the 20 hours. Solvents evaporate immediately (i.e., in a few minutes) and would be removed from the area by the ventilation system. With the weight of solvents known, conservatively assuming that all solvents are released from the paints, and knowing the coverage area of the paints Table 3, "Permissible Level of Contaminants" is developed. The table shows the relationship between the maximum allowable contaminants and surface area for paints and sealants and the volume for solvents. The paint weights are based on weight of volatiles offgased from paints. Sealants are taken to be the same as low volatile paints.

TABLE 3 Permissible Level of Contaminants

System	Maximum Amount of Contaminants pounds	Maximum Area for Painting Highly volatile Paints, FT2 Note 1	Maximum Area for Painting Low Volatile Paints, ft2 Note 2	Maximum amount of solvent gallons Note 3
ABGTS	7.4	125	685	0.9
EGTS	3.3	55	300	0.4
CP	11.5	200	1050	1.4
Cont. Bldg	3.3	55	300	0.4
PASF	1.6	28	150	0.2

Note 1. Area = (lb. contaminants/8.76 lb/gal) (150 ft2/gal)
Note 2. Area = (lb. contaminants/0.54 lb/gal) (50 ft2/gal)
Note 3. Volume = (lb. contaminants/8 lb/gal)

Air Change Rates

The minimum time to run the Auxiliary Building ventilation is 24 hours. The 24 hours is based on 20 hours for the majority of hydrocarbons to offgas (95 percent) and 4 hours to purge the building. The minimum time to run the ventilation system for solvents is 4 hours after use of the solvent has been discontinued; however for simplicity, the air cleaning systems are not run for 24 hours following any activity. If the system is operated, an evaluation of the effects of the activity is required.

Procedural and Administrative Controls

The improvements in the administrative controls implemented in the work control process are:

a. allowing up to 10 square feet of surface to be painted, cleaned, or weld inspected without the use of a permit
b clearly identifying areas that require permits for the protection of filters
c. requiring an evaluation of the effects of the activity should a filter system be operated during the performance of that activity
d. requiring that an exposure log be kept to record the cumulative amount of exposure for each system
e. defined the use of tents for controlling activities that may release hydrocarbons
f. establishing limits for exposure of the filters
g. integrating Operators in the permit process

Filters are never intentionally exposed to hydrocarbon fumes. Activities are scheduled to operate systems at times when painting or other hydrocarbon releasing activities have ceased. For exposures above the acceptable levels, the unit (charcoal) will be tested, and any further exposure will be prevented or require additional charcoal tests. Prior to making the procedural changes, SQN was issuing approximately 900 permits a year. The number of permits issued per year has dropped to less than 100. An exception to never intentionally exposing filters to contaminants is the Containment Purge system. This system operates during refueling outages to ventilate containment. There is no practical way to protect the filters, and as a result, charcoal tests are scheduled following the outage. The current permit in use at SQN is contained in Attachment 1.

Conclusions

The TVA Sequoyah testing results supported previous industry papers addressing hydrocarbon effects on charcoal. The results indicated charcoal can meet its required efficiencies after exposure to hydrocarbons. Industry information indicates that charcoal may start having lowered efficiencies with as little as 5 percent, by weight, in contaminants absorbed by the charcoal. SQN has chosen 0.5 percent as its administrative limit for charcoal contaminants. The administrative controls, implemented as a result of this effort, have been well received by the plant (craft, operations, management, and engineers) and has not allowed any excessive exposures of contaminants with the filters.

References

1. Sequoyah Nuclear Plant Condition Adverse to Quality Report, CAQR SOP890064, Revision 0.

2. Administrative Instruction AI-29, "Aromatic and Ester Hydrocarbon Release Permit" (replaced by Site Standard Practice SSP-7.4, "Work Permits")

3. Regulatory Guide 1.52, "Design, Testing, and Maintenance Criteria for Atmospheric Cleanup System Air Filtration and Adsorption System Units of Light-Water-Cooled Nuclear Power Plants"

4. Regulatory Guide 1.140, "Design, Maintenance, and Testing Criteria for Normal Exhaust System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants"

5. "Diablo Canyon Power Plant Guidelines for Protection of Carbon Filters" by Ginter, W., paper submitted at the 19th DOE/NRC Nuclear Air Cleaning Conference.

6. "Manufacture, Structure, Properties, and Application in the Nuclear Industry A Presentation for ASTM-D33," April 1986, Aimsworth, D., Sutcliffe Speakman, Inc. Carbon has a capacity of 5 percent-30 percent weight before being exhausted (and therefore failing its test).

7. "Evaluation and Control of Poisoning of Impregnated Carbons Used for Organic Iodide Removal" by Kovach, J. L., and Rankovic, L., paper submitted at the 15th DOE Nuclear Air Cleaning Conference. One case of failed charcoal due to 5 percent by weight of organics present. Testing indicated charcoal can hold up to 260 mg/g (26 percent) organics and still pass testing.

8. Sequoyah Nuclear Plant Site Standard Practice (SSP) 7.4, "Work Permits"

9. KFK 2449 "Iodine Filters in Nuclear Power Stations," Wilhelm, J. G., April 1977. This report indicated that iodine efficiencies were lowered drastically with solvent loadings varying from 6.8 percent to 11.5 percent. The paper noted that impregnated charcoal maintains higher efficiencies when exposed to solvent vapors than does unimpregnated charcoal.

10. "Charcoal Performance Under Accident Conditions in Light-Water Reactors," NUREG/CR-3990 (NRL Memo Rpt 5528), March 1985. This report indicates that charcoal impregnated with TEDA and KI exhibit less penetration than other charcoals. This report also indicates the adverse synergistic effect of high moisture and hydrocarbon contaminants degrading the charcoal when exposed at the same time.

11. David Besse, Procedure ISG-15, Rev. 1. Procedure allows 50 ft2 exposure. There must be three air changes before system runs.

12. ASTM E 741-83 "Standard Test Method for Determining Air Leakage Rate By Tracer Dilution"

13. Sequoyah Nuclear Plant Technical Specifications, T.S. 3.6.1.8, EGTS; 3.7.7, CREVS; 3.7.8 and 3.9.12, ABGTS

14. LIS Survey Regarding Charcoal Filters (#96077), June 10, 1996

Attachment 1

SQN	WORK PERMITS	SSP-7.4 Rev 6 Page 18 of 25

APPENDIX C
Page 1 of 7

PAINTING, CLEANING, SEALING, AND OTHER VOLATILE HYDROCARBON USE PERMIT [C.3]

**Permit Number #________________

**ISSUED BY________________/________/________ **Vent System Affected__________
Tech Support Date Time

NOTE. This permit is valid only for the date and location shown The original permit is to remain with the work package. A copy of every permit is to be sent to Tech Support for exposure log entries after SOS signoff.

UNIT WORK LOCATION (BUILDING) (ELEVATION)

____ ____________________________________

Brief Description of Work:______________________________

Material:____________________________________

***This permit starts:________________

***This permit expires:________________

*Volume of solvent used or area painted. Estimated__________
Actual__________
☐ Solvent
☐ Sealant
☐ Paint

Affected ventilation system operated during time this permit was in effect.
☐ YES ☐ NO

If system operated, evaluation by System Engineer; otherwise, N/A.

________________/________
SOS or Designee Date

________________/________ Evaluation Attached ☐
System Engineer Date

NOTE: Touch up painting (less than 10 square feet) or weld inspections do not require a permit.

YES	NO	CERTIFICATION
____	____	All material which may constitute a fire hazard has been removed from the area or adequately protected. Transient fire loads have been evaluated by Fire Operations and specified controls initiated per SSP-12.15, Appendix E. All firefighting equipment is available as required by the program for control of ignition sources and I have instructed my men on how a fire is to be reported.
____	____	As the Foreman (supervisor), I recognize that work areas will require reinspection for fumes which may constitute a hazard and I will personally reinspect the area at least once during the shift for which this permit is valid.

________________________________ __________
Responsible Foreman or Supervisor (Signed & Printed) Date

NOTE ONLY one permit is needed if using a tent. No exposure is assumed to occur to charcoal filters if a tent is used. The use of a tent still requires a permit.

* Not required if enclosures and portable charcoal filters are used.
** Completed by Tech Support. (See Table C-1)
*** The permit will be valid for one job at one location. It shall be valid for one day, three working shifts. Permits can be obtained up to three days in advance. (Exception see note)
Posting Requirements: Retain with work document during and following work.

DISCUSSION

BARROW: Did you perform a D3803-89 test?

CAMPBELL: The test conditions are 80°C and 70% RH. 70% RH is used as we have humidity control. This is in accordance with the plant technical specifications.

GOLDEN: Prior to implementing this program did you have any failures of your charcoal system test that were directly attributed to painting?

CAMPBELL: No, we did not, but our management is conservative in some of their evaluations. We have had some events from exposure to welding fumes and we have had some small electrical equipment catch fire while running the systems. In each case, we would pull a sample. We would change out the charcoal but we would pull a sample on the charcoal that we were changing out and each time the charcoal that we discarded still passed our Tech. Spec. Test. So, we have not had any failures. The only reasons that we have replaced charcoal in the past eight years, that I know of, is because of permanent sets in the gaskets that prevent us from replacing the tray after we pull the charcoal sample. We cannot pass our bypass leakage test then we change out all the charcoal in the system to maintain the same lot number in the entire system.

ROBERSON: Does the "less than 10" non-permit criterion mean that these fume exposures are not cumulatively tracked?

CAMPBELL: One of the reasons that we chose 10 ft^2 is because of the 0.5% by weight that we allow on our filter systems. Because we are not controlling below 10 ft^2, there can be exposures that occur without knowing it. So we chose an order of magnitude below what has previously been published regarding charcoal failure to allow us a margin so that we will not have to worry whether or not we should test our charcoal. Also, we have looked at the run times when this has happened and we have an ability to call up run times on all our filter systems on our plant computer. If systems have run spuriously, it will be only for 15-30 min., rarely longer than an hour. That does not always happened with containment isolation so there are factors that go into whether or not the systems are exposed. In addition to choosing 10 ft^2 we looked at number of square feet that were allowed on previous permits and the vast majority were for 3 - 4 ft^2. We also talked to our maintenance department and our chemistry people. The result was that we chose 10 ft^2 as a reasonable value. It has been very well received.

ROBERSON: Does the paint accumulation log only update based on the system being in service?

CAMPBELL: Yes. The systems have isolation dampers and exposure can only occur when the system is running.

HARRIS: We have a painting program in which we track the volatile organic content of each of the coatings and adhesives on the filter beds. We have noticed that even when relying on only 10 ft^2 to be painted, very few coatings come out without a one gallon kit, or a five gallon kit. If that paint is still in the ventilation zone, do you still assume that the volatiles are coming out and tracking it on your charcoal loading as well?

CAMPBELL: This is a good question. What we have implemented at in our Sequoia plants is a chemical control. Again, our Rad Con people will not allow anyone to take anything into the RCA's unless they are going to use that material. So we have controls over what is taken in. If they say they intend to paint a hundred square feet but when they give the permits back to us they report only painted ten square feet, the instructions given to our maintenance people is to show the total volume of paint they took in. We then consider making an adjustment, but as a rule, we do not. What you take in you use up because what is left is rad waste. There is no way you can really prove that it is not.

GOLDEN: You said you did your testing to the 1979 or 1980 standard. I assume, because that is what your Tech Specs called for, the 80°C test. Did you also do any parallel testing to the 1989 standard or anything more stringent like a 30°C test?

CAMPBELL: No. The testing we did was several years ago, and the ASTM 89 version was not available at that time. I was aware of the controversy around 1979 and that is another reason why we chose an order of magnitude less than what the lowest recorded values were. At every step along the way we tried to be conservative in what we were doing but maintain some flexibility. We did not have any flexibility to begin with, but we wanted something reasonable that we would not have to come back and change again in three or four years. Knowing the controversies, we tried to stay very conservative on what we are doing.

CASS: Did you considered different methods of application, roller, brush, or spray? Did you take in preparation; sandblasting, grinding, what have you?

CAMPBELL: No, we did not look at different application methods. As far as grinding or chipping away the paint, that is dust and we did not consider it.

GHOSH: Did you consider the drying time of the solvent? The solvent time varies exponentially, between two and four hours during which time most of the solvent may be reduced from 100 to 50%. In four hours it may go to 10 or 5%. Using that method, did you check how much loading is taken back from the carbons?

CAMPBELL: No, we did not check into that . The way we are looking at it is that the paints will cure exponentially. Most of the offgases will occur during the first hour and then it will decrease. We look at the run times at the end of the painting activity and we assume the paint is totally cured according to what the vendors tell us on the paint. At that point, everything that is going to offgas should have offgassed. We assume 100% for the purpose of calculating run time. We say 100% is still in the area and we run four more hours. In reality, the stuff is going to be removed continuously, it is going to be less and less over a period of time and probably at the time the paint cures there is probably very, very little fume in the area.

GHOSH: Yes, 24 hours is very safe.

CAMPBELL: Definitely. It is an easy value to remember.

GHOSH: One more thing, you use 10 square feet. Did you equate it in terms of limiting the amount in terms of gallons? That is what we did.

CAMPBELL: Yes we have, but that is not covered in the paper. We did equate it when we were talking to our maintenance people. We asked what do you want, and they said square feet. We looked at high and low volatile paints (we considered sealants the same as low volatile paints) and we agreed that 10 square feet was acceptable based on the paints we use at the plant.

GHOSH: It varies with how much thickness, how many mills.

CAMPBELL: It depends on the thickness. It doesn't show in the paper, but a low volatile paint that we use is a Keylor and Long 4500 paint, for example, that will cover 64 square feet per gallon, we say it will cover 50 square feet rather than the recommended 64 square feet and we base our calculations on that number.

SESSION 10

IODINE TREATMENT: CHEMICAL OPERATIONS AND REACTOR ACCIDENT SCENARIOS

Wednesday July 17, 1996
Co-Chairmen: R.T. Jubin
T. Fukasawa

BEHAVIOR OF IODINE IN THE DISSOLUTION OF SPENT NUCLEAR FUELS
T. Sakurai, K. Komatsu, and A. Takahashi

INFLUENCES OF IMPURITIES ON IODINE REMOVAL EFFICIENCY OF SILVER ALUMINA ADSORBENT
T. Fukasawa, K. Funabashi, and Y. Kondo

DIFFUSIONAL ANALYSIS OF THE ADSORPTION OF METHYL IODIDE ON SILVER EXCHANGED MORDENITE
R.T. Jubin and R.M. Counce

REMOVAL EFFICIENCY OF SILVER IMPREGNATED FILTER MATERIALS AND PERFORMANCE OF IODINE FILTERS IN THE OFF-GASES OF THE KARLSRUHE REPROCESSING PLANT WAK
F.J. Herrmann, B. Herrmann, V. Hoeflich, Ch. Beyer, and J. Furrer

CONTROL OF RADIO-IODINE AT THE GERMAN REPROCESSING PLANT WAK DURING OPERATION AND AFTER SHUT DOWN
F.J. Herrmann, B. Herrmann, K.D. Kuhn, A. van Schoor, M. Weishaupt, J. Furrer, and W. Knoch

OPENING COMMENTS OF SESSION CHAIRMAN

We have an important subject to discuss. This is a series of presentations on the treatment of iodine for the nuclear industry. It has been one of the mainstays of Air Cleaning Conferences in the past. A great deal of work has been reported in this area and we have five important papers that will contribute to the overall collection of literature on this subject.

BEHAVIOR OF IODINE IN THE DISSOLUTION OF SPENT NUCLEAR FUELS

by

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Abstract

The results of laboratory-scale experiments concerning the behavior of iodine in the dissolution of spent nuclear fuels, which were carried out at the Japan Atomic Energy Research Institute, are summarized. Based on previous and new experimental results, the difference in quantity of residual iodine in the fuel solution between laboratory-scale experiments and reprocessing plants is discussed. Iodine in spent fuels is converted to the following four states: (1) oxidation into I_2 by nitric acid, (2) oxidation into I_2 by nitrous acid generated in the dissolution, (3) formation of a colloid of insoluble iodides such as AgI and PdI_2, and (4) deposition on insoluble residue. Nitrous acid controls the amount of colloid formed. As a result, up to 10% of iodine in spent fuels is retained in the fuel solution, up to 3% is deposited on insoluble residue, and the balance volatilizes to the off-gas. Contrary to earlier belief, when the dissolution is carried out in 3 to 4 *M* HNO_3 at 100°C, the main iodine species in a fuel solution is a colloid, not iodate. Immediately after its formation, the colloid is unstable and decomposes partially in the hot nitric acid solution through the following reaction:

$$AgI(s) + 2HNO_3(aq) = \tfrac{1}{2}I_2(aq) + AgNO_3(aq) + NO_2(g) + H_2O(l).$$

For high concentrations of gaseous iodine, $I_2(g)$, and NO_2, this reaction is reversed towards formation of the colloid (AgI). Since these concentrations are high near the liquid surface of a plant-scale dissolver, there is a possibility that the colloid is formed there through this reversal. Simulations performed in laboratory-scale experiments demonstrated this reversal. This phenomenon can be one reason the quantity of residual iodine in spent fuels is higher in reprocessing plants than in laboratory-scale experiments.

I. Introduction

Long-lived ($T_{1/2} = 1.57 \times 10^7$ y) and hazardous, radioiodine, ^{129}I, generated in the dissolution of spent nuclear fuels should be strictly controlled in reprocessing facilities. For gaseous iodine, various kinds of silver-impregnated adsorbents have been developed to very efficiently remove it from the off-gas. Therefore, it is desirable for environmental safety that all possible iodine be expelled from fuel solutions to the dissolver off-gas (DOG) where it will be fixed on an adsorbent such as silver-impregnated silica gel (AgS). The remaining iodine, that not expelled to the DOG, migrates into the Purex process which allows its escape to the environment. Therefore, understanding the chemical species and amounts of iodine in fuel solutions as well as developing a way of expelling it therefrom are important. Extensive work has been performed by many researchers.(1)-(3)

Before our research, the main iodine species in fuel solutions was postulated to be iodate (IO_3^-) from the chemical reaction of iodine in hot nitric acid solution or uranium-nitric acid solution or both. Sparging with NOx has been recommended for iodate removal from these solutions. More than 99% of input iodine was expelled to the DOG in both laboratory- and plant-scale experiments.(1),(2),(4) According to the reports from an actual reprocessing plant, however, considerable amounts of iodine (up to 5%) remained in spent-fuel solutions and migrated to the Purex process.(5),(6) Although the causes were not clarified, this finding suggests the presence of other iodine species in spent-fuel solutions and/or the presence of some factors that influence the behavior of iodine between laboratory-scale experiments and actual reprocessing plants.

Japan has been constructing a commercial reprocessing plant having a throughput of 800 t/d. Since the release of ^{129}I into the environment is strictly regulated, we began to restudy the iodine species in spent-fuel solutions and the methods of expelling this iodine to the DOG. In beginning this study, we labeled other fission products (FPs) in spent-fuel solutions. The interactions of iodine with other FPs were examined for the first time with simulated spent-fuel solutions. These interactions had not been questioned by earlier researchers. It was found that colloids of such insoluble iodides as silver iodide (AgI) and palladium iodide (PdI_2) played an important role in the behavior of iodine in the dissolution stage.

This paper first summarizes the results of our laboratory-scale experiments. The difference in behavior of iodine in the dissolution stage between laboratory-scale experiments and the dissolution process that occurs in reprocessing plants is then discussed.

II. Main Iodine Species in Spent-Fuel Solutions

2.1 Preliminary Study with a Simulated Spent-Fuel Solution

To obtain preliminary information about iodine species in spent-fuel solutions, experiments were performed using a uranyl nitrate-nitric acid solution and a simulated spent-fuel solution that contained uranium and simulated FPs equivalent in composition to a solution of spent fuel with a burnup of 40 GWd/t. Varying amounts of potassium iodide labeled with ^{131}I were added to these solutions (30 to 50 mℓ) at 100°C and the iodine species produced were analyzed using the carbon tetrachloride extraction method. This analysis determined the quantities of dissolved iodine ($I_2(aq)$), I^-, IO_3^-, and organic iodine using an analytical scheme and considered the remaining species in the aqueous phase as non-ionic submicroparticles.(7) The following results were obtained concerning the main iodine species in the solutions.(8),(9)

(1) The main iodine species in the simulated spent-fuel solution was submicroparticles, while iodate was the main species in uranium-nitric acid solution.

(2) The quantity of iodine in the submicroparticles increased with increasing concentrations of Ag^+ and Pd^{2+}. When heated in 3 to 4 *M* HNO_3, the submicroparticles released molecular iodine (I_2).

(3) When the simulated spent-fuel solution containing the submicroparticles was subjected to ultracentrifugation of 65,000 rpm, a decrease of ^{131}I radioactivity was observed in the upper portion of the solution.

(4) A thermochemical calculation indicated that iodate cannot be the main iodine species because it is reduced to I_2 by NOx produced in dissolution of fuels.(9)

From these results, it was concluded that the submicroparticles, the main iodine species, were colloids of AgI and PdI_2. The measured solubilities of these iodides also supports this conclusion.(10)

The colloidal iodine is unstable in hot nitric acid solution immediately after its formation so it decomposes into molecular iodine:

$$AgI(s) + 2H^+ + NO_3^- = \tfrac{1}{2}I_2(aq) + Ag^+ + NO_2(g) + H_2O(l), \tag{1}$$

$$PdI_2(s) + 4H^+ + 2NO_3^- = I_2(aq) + Pd^{2+} + 2NO_2(g) + 2H_2O(l). \tag{2}$$

Concurrently with this process, however, the remaining colloidal iodine ages and changes to stable species. For decomposition of the stabilized colloidal iodine, it was found that the addition of an excess amount of iodate (e.g., HIO_3) was effective:

$$5AgI(s)+HIO_3(aq)+5HNO_3(aq) = 3I_2(aq)+5AgNO_3(aq)+3H_2O(l), \tag{3}$$

$$5PdI_2(s)+2HIO_3(aq)+10HNO_3(aq) = 6I_2(aq)+5PdNO_3(aq)+6H_2O(l). \tag{4}$$

These reactions are illustrated in Fig. 1 and essentially refer to the following reaction:

$$5I^-(^{129}I^-) + IO_3^- + 6H^+ = 3I_2(I_2^*) + 3H_2O, \tag{5}$$

where the asterisk denotes radioactive iodine, ^{129}I. Based on these results, the following two-step process for expulsion of the iodine remaining in spent-fuel solutions was proposed.(10),(11)

Step One - Heat the fuel solution without supplying NOx to decompose the colloidal iodine. When aging of colloidal iodine has proceeded after dissolution, an excess amount of iodate should be added.

Step Two - Sparge (bubble) NOx through the solution while heating to reduce the iodate($^{129}IO_3^-$) to form volatile I_2. This process is necessary because there is a possibility of formation of the iodate during Step One.

The same process was proposed by Boukis and Henrich for decomposition of non-volatile organic iodides that originated from organic impurities in nitric acid.(12)
In our experiments, however, the amounts of organic impurities were negligibly small.

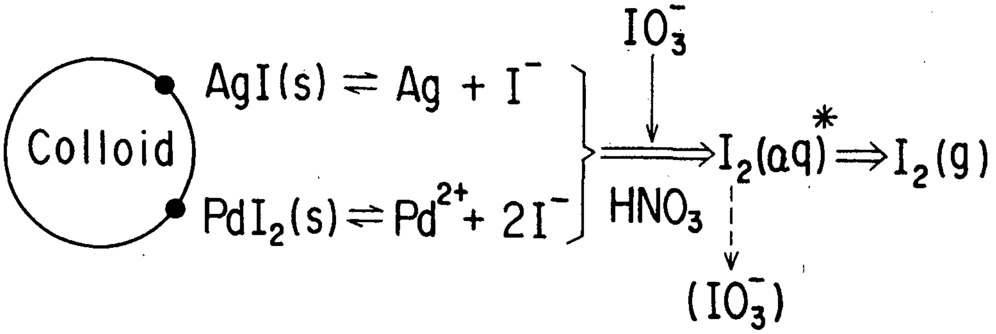
2.2 Demonstration of the Main Iodine Species Using Actual Spent-Fuel Solutions

Expulsion of iodine from solutions of spent PWR-fuel with burnups of 21 to 39 GWd/t was performed to identify the main iodine species in actual spent-fuel solutions. Two procedures were used and their efficiencies were compared.(8),(9) One procedure was conventional NOx sparging to reduce iodate to volatile iodine (I_2) through the following reaction:

$$2IO_3^- + 10NO_2 + 2H^+ + 4H_2O = 10HNO_3 + I_2. \tag{6}$$

The other procedure was as described above, viz., the addition of iodate to decompose colloidal iodine through Reactions (3) and (4). This process was also applied to the solution subjected to the NOx sparging to determine the amount of iodine remaining after NOx sparging.

The results showed that, while 27.4 to 45.7% of the initial iodine quantity in the solutions remained after NOx sparging, the iodine was completely removed by the process of adding iodate. This clearly indicates that the main iodine species in actual spent-fuel solutions is colloidal iodine, not iodate.



$$*5I^- + IO_3^- + 6H^+ \rightarrow 3I_2(aq) + 3H_2O$$

Figure 1 Mechanism for decomposition of colloids of AgI and PdI_2 by addition of iodate

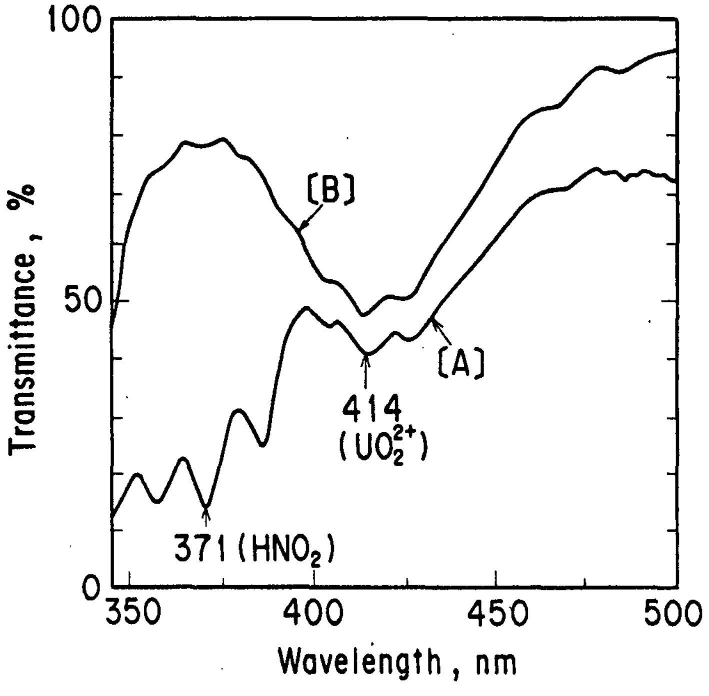


Figure 2 Influence of the dissolution rate of UO_2 on the concentration of HNO_2 produced during UO_2 dissolution in 3.5 *M* HNO_3 at 100°C
Production of HNO_2 was observed spectrophotometrically. Dissolution rate was [A] about 2 min for 0.909 g UO_2 powder and [B] 2.5 h for a 0.9321 g UO_2 pellet.

III. Distribution of Iodine in Spent-Fuel Dissolution

In the dissolution of spent fuels in laboratory-scale experiments, radioiodine in spent fuels (assumed as CsI) was distributed among the off-gas, fuel solution, and insoluble residue as follows.(11)

3.1 Volatilization into DOG

The majority of the iodine (90% or more) was expelled to the off-gas through its oxidation by HNO_3 and by the nitrous acid (HNO_2) produced in the dissolution (Figure 2):

$$I^- + 2H^+ + NO_3^- = \tfrac{1}{2}I_2(aq) + NO_2(g) + H_2O(l), \qquad (7)$$

$$I^- + 4H^+ + NO_2^- + 2NO_3^- = \tfrac{1}{2}I_2(aq) + 3NO_2(g) + 2H_2O(l). \qquad (8)$$

The dissolved iodine, $I_2(aq)$, then volatilizes and is expelled to the off-gas, leaving a small fraction as iodate in solution:

$$I_2(aq) = I_2(g), \qquad (9)$$

$$I_2(aq) + 8H^+ + 10NO_3^- = 2IO_3^- + 10NO_2(g) + 4H_2O(l). \qquad (10)$$

Since the iodate is reduced to I_2 by the NOx and HNO_2 produced in fuel dissolution, only small quantities of iodate can be produced in fuel dissolution occurring in 3 to 4 *M* HNO_3.

Of the iodine volatilized to the off-gas, 7% or less consisted of organic iodides, which were probably produced through the reactions of I^- or I_2 or both with organic impurities in the fuel solutions.(9)

3.2 Retention of Iodine Species in Spent-Fuel Solutions

Besides I_2 and a small amount of IO_3^-, colloidal iodine is produced in spent-fuel dissolution by the following reaction:

$$3I^- + Ag^+ + Pd^{2+} = AgI(s) + PdI_2(s). \qquad (11)$$

Since this reaction competes with Reaction (8), the amount of colloids produced decreased for high dissolution rates, even with high burnup fuels.(11) This occurs because high dissolution rates result in high concentrations of NOx and HNO_2. On the other hand, when the concentrations of NOx and HNO_2 are too high, secondary formation of colloidal iodine may result. In high concentrations, NOx and HNO_2 react with the iodine produced in Reactions (7) and (8) reversing Reaction (1) and forming AgI. Details are discussed below.

In experiments with simulated spent-fuel solutions, the iodine species in the solutions consisted of 60% colloidal iodine, 20% I_2, and 20% iodate.

3.3 Deposition onto Insoluble Residue or to a Precipitate or both

Part of the iodine in spent fuels is transferred to insoluble residue or to a precipitate or both via. formation of colloidal iodine. Of the iodine in spent PWR-fuels, 3% or less was deposited onto insoluble residue.(10)

In dissolution of simulated spent-fuel pellets, an increase in UO_2^{2+} concentration in the solution beyond 170 g U/ℓ resulted in the precipitation of large quantities of metal molybdates on which iodine was deposited.(13) The causes have not yet been clarified.

The behavior of iodine in the present laboratory-scale dissolution at JAERI (the Japan Atomic Energy Research Institute) with the results earlier researchers have reported is summarized in Fig. 3. The differences noted are partially attributed to differences in the concentration of nitric acid used.

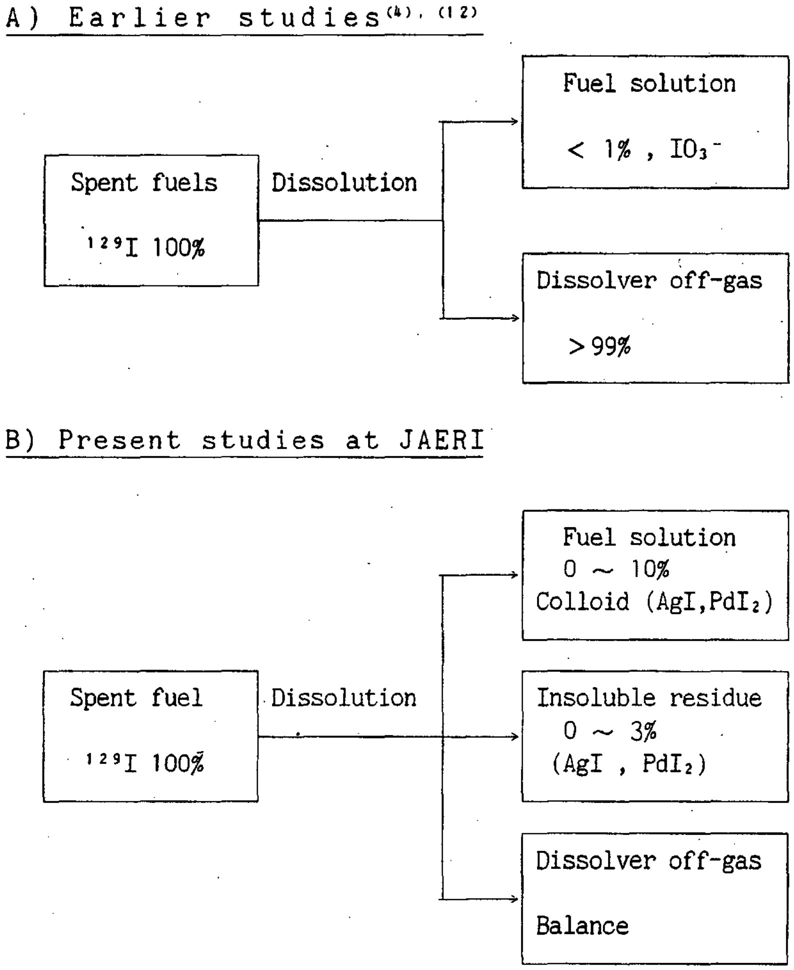


Figure 3 Distribution of iodine (^{129}I) from dissolution of spent fuels in laboratory-scale experiments

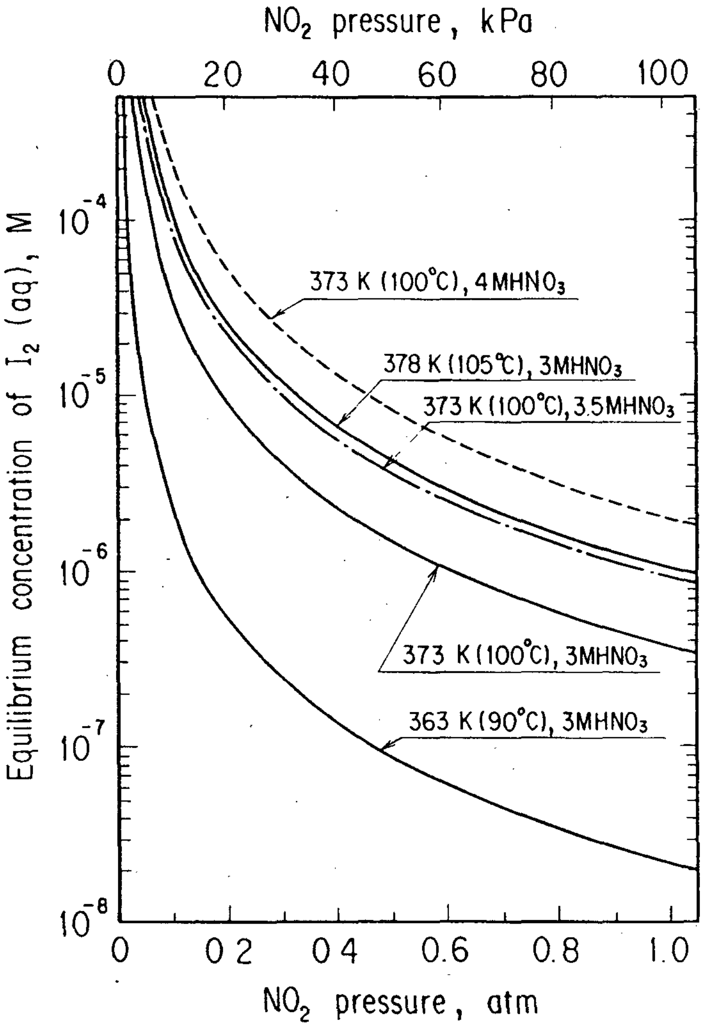


Figure 4 Relationship between dissolved iodine, $I_2(aq)$, and NO_2 in the chemical equilibrium, $AgI(s) + 2H^+ + NO_3^- = \frac{1}{2}I_2(aq) + Ag^+ + NO_2(g) + H_2O(l)$
Concentration of Ag^+ was assumed to be 2.37×10^{-4} *M* for a spent-fuel solution with a burnup of 40 GWd/t.

Table 1 Comparison of the amount of iodine in spent-fuel solutions

Scale	Literature	Burnup of fuel, GWd/t	Wt. of fuel dissolved	^{129}I in the fuel solution, %	Conditions of the dissolution
Laboratory	N. Boukis and E. Henrich (1991)(12)	45	80 g	0.7	7.5 M HNO_3 (0.22 ℓ), 97℃, 2h
	A. Leudet et al., (1983)(4)	32	Half of a fuel pin	< 1	Boiling
Plant	F. J. Herrmann et al., (1993)(5)		15 ~20t/y (WAK plant)	≲ 5	

Table 2 Calculation for secondary formation of colloid(AgI) at the liquid surface of an assumed plant-scale dissolver

Conditions of the dissolver: Size, 5 × 0.3 × 2 m;
Liquid surface, 1.5×10^4 cm^2 ; 3.5 M HNO_3 3 m^3(100℃);
Bottom air supply, 40 Nm^3/h;
Throughput of spent fuels, 5 t/d (burnup 40 GWd/t).

Concentrations at the liquid surface	Chemical equilibrium concerned	Equilibrium concentration of $I_2(aq)$	
$I_2(g)$ 88 ppm	$I_2(g) = I_2(aq)$	2.3×10^{-5}M …(a)	Since (a) > (b), AgI will be formed.
NO_2 36%	$AgI(S)+2\ HNO_3(aq) = 1/2\ I_2(aq) + AgNO_3(aq) + NO_2(g) + H_2O(l)$	7.2×10^{-6}M …(b)	

IV. Iodine Behavior Differences between Laboratory-Scale Experiments and Reprocessing Plants

Table 1 cites an instance where the quantity of iodine remaining in a spent-fuel solution is greater in a reprocessing plant than in several laboratory-scale experiments. While laboratory-scale dissolution of high burnup fuels left only 1% or less of the iodine in spent-fuel, up to 5% of the iodine remained in spent-fuel solutions at the WAK reprocessing plant. Several factors may cause this difference. Through our studies, however, we noted the possibility that colloidal iodine (AgI) is formed secondarily at the liquid surface of a plant-scale dissolver. The reasons are discussed below.

4.1 Chemical Equilibrium

As already described, colloidal iodine is partially decomposed in hot nitric acid solution through Reactions (1) and (2). However, Reaction (1) can be reversed near the liquid-gas interface of a plant-scale dissolver. The liquid surface may have high concentrations of $I_2(g)$ and NO_2 because bubbles containing these gasses rise through the liquid after formation. When dissolution of fuel proceeds continuously at a constant rate, the concentrations of $I_2(g)$, $I_2(aq)$, NO_2, Ag^+, and HNO_3 remain constant with time at the liquid surface. This condition is regarded as a state of quasi equilibrium among these species; thus, an approximate chemical equilibrium treatment is appropriate for the system. Figure 4 shows the chemical equilibrium relationships of Reaction (1), in which the abscissa denotes NO_2 pressure and the ordinate represents the corresponding concentration of dissolved iodine, $I_2(aq)$. These relationships were derived from the following commonly accepted set of thermochemical equations:(14)

$$\ln\,(K(T_2)/K(T_1)) = \int_{T1}^{T2} (\Delta H^\circ_T/RT^2)\,dT, \qquad (a)$$

$$H_T{}^\circ = H_{T1}{}^\circ + \int_{T1}^{T} \Delta C_p\,dT, \qquad (b)$$

$$C_p = A + B\,10^{-3} + C\,10^5\,T^{-2} + D\,10^{\text{[illegible]}}\,T^2, \qquad (c)$$

where $H_T{}^\circ$ is the standard enthalpy of formation at T K, C_p is the heat capacity, and A, B, C, and D are constants specific to each substance. The equilibrium constant $K(T_1) = 298$ K; $H_{298}{}^\circ$ and C_p were adopted from the literature.(15)-(17)

In a fuel solution, when the concentration of $I_2(aq)$ increases beyond the curve corresponding to its temperature and HNO_3 concentration under a specific value of P_{NO2}, colloidal AgI is formed through the reversal of Reaction (1). By assuming a simplified continuous dissolver, the concentrations of NO_2 and I_2 near the liquid surface were estimated (see below).

4.2 Concentrations of NO_2 and I_2 in a Plant-Scale Dissolver

The assumed dissolver, similar to a continuous dissolver in a reprocessing plant described in the literature,(2),(3) is 5 × 0.3 × 2 m with a liquid-gas interface of 1.5×10^4 cm^2. To stir the solution in this dissolver, 40 Nm^3/h of air is fed from the bottom. Spent fuels with a burnup of 40 GWd/t are dissolved at a rate of 5 t/d in 3 m^3 of 3.5 *M* HNO_3 at 100°C. The NOx produced consists of 80% NO_2 and 20% NO for the chemical equilibrium

$$NO(g) + 2HNO_3(aq) = 3NO_2(g) + H_2O(l)$$

at 100°C. Fuel solution containing 250 g U/ℓ overflows toward downstream processes. Calculations indicate that gaseous iodine, $I_2(g)$, and NO_2 volatilize at rates of 4.1×10^{-3} mol I_2/min and 16.6 mol NO_2/min, respectively. The bottom fed air increasingly collects these gasses as it rises through the solution. At the liquid surface, the air consists of 35.8% (0.358 atm) of NO_2 and 88.4 ppm of $I_2(g)$. The concentration of dissolved iodine, $I_2(aq)$, corresponding to 88.4 ppm $I_2(g)$, was calculated to be 2.3×10^{-5} *M* using the equilibrium constant

$$K(373) = P_{I2}/[I_2(aq)] = 3.798$$

of Reaction (9) where P_{I2} is in atm. Figure 4 shows that the concentration of $I_2(aq)$ (in 3.5 *M* HNO_3) in equilibrium with 0.358 atm NO_2 (36 kPa) is 7.2×10^{-6} *M*, which is lower than the foregoing value (2.3×10^{-5}) in equilibrium with 88.4 ppm $I_2(g)$. This excess $I_2(aq)$ causes the reversal of Reaction (1) and the secondary formation of colloids of AgI at the liquid surface of the plant-scale dissolver (Table 2).

4.3 Experiments to Reverse Reaction (1)

To verify the progression of the reversal of Reaction (1) under conditions similar to those at the liquid surface of the assumed dissolver, laboratory-scale experiments were performed using the apparatus shown in Fig. 5. A 30 mℓ volume of 3.5 *M* HNO_3 solution containing 7.5 g U/30 mℓ (250 g U/ℓ) and 0.8 mg Ag^+/30 mℓ was heated to 100°C and bubbled with nitrogen flow (22 mℓ/min) containing 88 ppm $I_2(g)$ labeled with ^{131}I and 36% NO_2 for 1 h (Run 1). After its radioactivity was measured, 20 mℓ of the solution was transferred to a centrifuge tube (solution depth, 4 cm) and subjected to centrifugation of 4,500 rpm for 5 min. The top 10 mℓ was then examined by gamma spectrometry. Table 3 lists the results. The radioactivity of the solution decreased to 8% of the initial value and a whitish yellow sediment was observed on the bottom of the centrifuge tube. This confirmed that supplying 88 ppm $I_2(g)$ and 36% NO_2 produced a colloid of AgI at 100°C; that is, Reaction (1) was reversed. In Run 2, also listed in Table 3, a higher concentration of $I_2(l)$ (263 ppm) and 38% NO_2 was fed to 30 mℓ of 3.5 *M* HNO_3 solution containing 12 mg Pd^{2+}/30 mℓ, 7.5 g U/30 mℓ, and 0.8 mg Ag^+/30 mℓ for 1 h. In this case, precipitate was observed on the bottom of the dissolver flask before centrifugation. The same sedimentation as in Run 1 was produced by the centrifugation.

The foregoing assumed dissolver is a simplified one. In actual (plant-scale) dissolvers, however, concentrations of I_2 and NO_2 would be higher near the liquid-gas interface because these gasses rise through the liquid after their formation. Due to the difference in fluid depth of spent-fuel solutions, the concentrations of these gasses at the liquid surface would be higher in a plant-scale dissolver than in a laboratory-scale dissolver. The experiments suggest that when their concentrations increase beyond the equilibrium conditions shown in Fig. 4, colloidal iodine is formed. This phenomenon can be one reason for the residual iodine quantity in spent-fuel solutions being greater in reprocessing plants than in laboratory-scale experiments.

V. Conclusions

(1) In the laboratory-scale dissolution of spent-fuels with burnups of 21 to 39 GWd/t, up to 10% of the ^{129}I in the spent fuel remains in fuel solutions, up to 3% deposits on insoluble residue, and the balance volatilizes and is expelled to the DOG.

(2) Of the iodine in the DOG, 7% or less is organic.

(3) The main iodine species in fuel solution are the colloids of

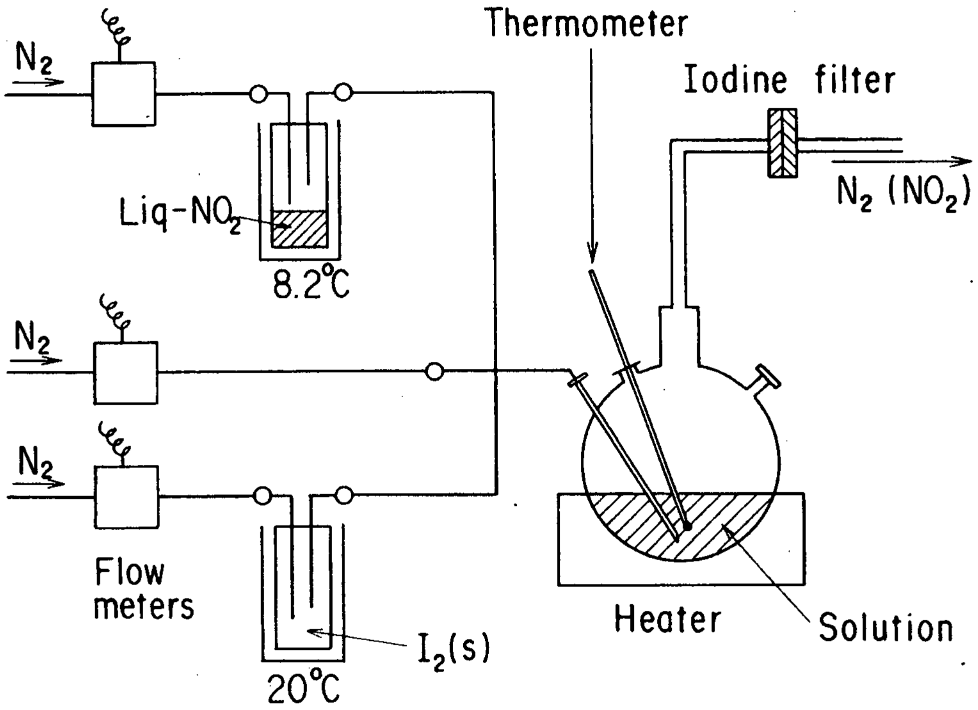


Figure 5 Experimental apparatus used for demonstrating the reversal of Reaction (1)

Table 3 Evidence of the formation of colloid by the reaction of $I_2(g)$ with NO_2 in simulated spent-fuel solutions at 100°C

[Run 1] 30 mℓ-3.5 M HNO_3 solution containing 7.5 g-U/30 mℓ and 0.8 mg-Ag^+/30 mℓ
[Run 2] 30 mℓ-3.5 M HNO_3 solution containing 7.5 g-U/30 mℓ, 0.8 mg-Ag^+/30 mℓ and 12 mg-Pd^{2+}/30 mℓ.
Time period of the supply of $I_2(g)$ and NO_2, 1h
Centrifugation, 4,500 rpm for 5 mm.

Run No.	I_2 supplied	NO_2 supplied	N_2 flow rate	Iodine remaining in the solutions		
				① Before centrifugation	② After centrifugation	Ratio of the decrease, ②/①
1	88 ppm (1.8 mg)	36 % (12 ml/min)	22 ml/min	417 μg/30 mℓ $(1.1\times10^{-4}M\text{-}I)$	32 μg/30 mℓ $(8.4\times10^{-6}M\text{-}I)$	0.08
2	263 ppm (3.3 mg)	38 % (13 ml/min)	20 ml/min	216 μg/30 mℓ* $(5.7\times10^{-5}M\text{-}I)$	13 μg/30 mℓ $(3.4\times10^{-6}M\text{-}I)$	0.06

* Before centrifugation, precipitate was observed on the bottom of the dissolver flask.

insoluble iodides, such as AgI and PdI_2.

(4) The amount of colloidal iodine tends to decrease with increasing concentrations of nitrous acid (HNO_2) and NOx produced in the dissolution. So, for spent fuels with high dissolution rates, the amount of colloidal iodine is small, even if the fuel is high burnup fuel.

(5) High concentrations of I_2 and HNO_2 (or NOx) cause formation of colloidal AgI. This is because the following reaction is reversed by conditions described above:

$$AgI(s) + 2H^+ + NO_3^- = \tfrac{1}{2}I_2(aq) + Ag^+ + NO_2(g) + H_2O(l). \qquad (1)$$

The reversal of this reaction has been confirmed experimentally.

(6) This reaction can also be reversed at the liquid surface of plant-scale dissolves where the concentrations of NO_2 and I_2 are higher than in laboratory-scale experiments. This phenomenon can be one reason the residual iodine in spent-fuel solutions is higher in a reprocessing plant than in laboratory-scale experiments.

Acknowledgements

The authors wish to express their thanks to Drs. Michio Hoshi (Director of the Department of Chemistry and Fuel Research) and Takeo Adachi (Head of Analytical Chemistry Laboratory), Japan Atomic Energy Research Institute (JAERI), for their advice and support. We also thank Mr. Haruka Shinohara (Physical Chemistry Laboratory of JAERI) for his assistance in preparation of this manuscript.

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DISCUSSION

HERRMANN: I have a question about Point B . You have marked 0-10% in the fuel solution, 0-3% in insoluble residue. Is the value of 0% not too low? Does this mean that the rest, 87%, is in the offgas?

SAKURAI: In our laboratory-scale dissolutions, iodine quantities in the fuel solution and in the insoluble residue varied in the range of 0 to 10% and 0 to 3%, respectively, largely depending upon the rate of dissolution of the spent-fuel specimens. The fuel specimen with a burnup of 39GWd/t dissolved quickly, leaving little iodine in the solution and 0.6% in the residue. But the fuel-specimen with a low burnup of 21GWd/t took a long time to dissolve and 9.7% of the iodine remained in the fuel solution, and 2.3% in the residue. As a whole, the iodine quantity volatilized into the off-gas varied between 88 and 100%.

JUBIN: I found this very interesting and I have one additional question. In your laboratory studies, have you had an opportunity to try to identify the iodine in the dissolver solution? Have you identified through your centrifugation at the end a reduction in the iodine concentration? Have you been able to conduct any experiments using spent fuel to see if it does the same? Have you had an opportunity to look for the formation of iodine in the form of the colloid in actual dissolver solution?

SAKURAI: Not directly. However, iodine species in spent-fuel solution showed the same behavior in the expulsion process as the colloid of AgI and PdI_2 did. It is almost impossible to directly identify iodine species in spent-fuel solutions because of the extremely high radioactivity of the solution and the weak radioactivity of ^{129}I. We had to identify them through their behavior in separating from the fuel solution. The expulsion of iodine was performed in two different ways for the fuel solution. The insoluble residue had already been separated by centrifugation. From their behavior in the two expulsion processes, the main iodine species in the actual spent-fuel solution was concluded to be the colloidal iodine already mentioned.

24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

INFLUENCES OF IMPURITIES ON IODINE REMOVAL EFFICIENCY OF SILVER ALUMINA ADSORBENT

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Abstract

Silver impregnated alumina adsorbent (AgA), which was developed for iodine removal from off-gas of nuclear power and reprocessing plants, has been tested laying emphasis on investigation of the influences gaseous impurities have on adsorbent chemical stability and iodine removal efficiency. The influences of the major impurities such as nitrogen oxides and water vapor were checked on the chemical state of impregnated silver compound ($AgNO_3$) and decontamination factor (DF) value.

At 150℃, a forced air flow with 1.5% nitrogen oxide ($NO/NO_2=1/1$) reduced silver nitrate to metallic silver, whereas pure air and air with 1.5% NO_2 had no effect on the chemical state of silver. Metallic silver showed a lower DF value for methyl iodide in pure air (without impurities) than silver nitrate and the lower DF of metallic silver was improved when impurities were added.

At 40℃, a forced air flow with 1.5% nitrogen dioxide (NO_2) increased the AgA weight by about 20%, which was caused by the adsorption of nitric acid solution on the AgA surface. AgA with 10wt% silver showed higher weight increase than that with 24wt% silver which had lower porosity. Adsorption of acid solution lowered the DF value, which would be due to the hindrance of contact between methyl iodide and silver.

The influences of other gaseous impurities were also investigated and AgA showed superior characteristics at high temperatures.

I. Introduction

Uranium and plutonium are important energy sources, and can be utilized more effectively by recycling them in the nuclear fuel cycle. In Japan, the first light water reactor started commercial operation in 1969. Now there are 47 reactors in operation and their total power generation capacity is 38 GW. Reprocessing of spent nuclear fuel is carried out at Tokai Reprocessing Plant where 812.9 tons of uranium was treated by the end of FY 1994. Commercial reprocessing will start at Rokkasho Plant at the beginning of the next century.

The nuclear energy industry adopts multibarrier protection towards radioactivity exposure for human beings and the environment. In particular, radioactive iodine release to the atmosphere must be surpressed because iodine is volatile and apt to concentrate in the thyroid gland. Therefore nuclear facilities, such as nuclear power plants and reprocessing plants, remove radioactive iodine from their off-gas streams.

Iodine removal methods are generally classified into two types, wet ones which absorb iodine into a solution and dry ones which adsorb iodine onto a solid material.[1-3] Both wet and dry methods must take into account the effects of impurities. For example, wet scrubbing with an alkaline solution absorbs not only iodine, but also various impurities, which sometimes leads to drops in the pH value and iodine absorption capacity of the solution. Impurities also sometimes interfere with the reaction of iodine and solid adsorbent.

The authors have been developing an inorganic adsorbent, silver impregnated alumina (AgA) for about 15 years.[4-14] This adsorbent can be applied to off-gas systems of both nuclear power plants and spent fuel reprocessing plants. The influences of impurities were checked on AgA under the various conditions possible in the above systems. This paper reports experimental results of the investigation which laid emphasis on the changes of chemical stability and iodine removal efficiency of AgA in the presence of gaseous impurities. Iodine removal efficiency was evaluated using adosorption capacity and decontamination factor (DF) which is defined as the iodine concentration at the inlet of the adsorbent column divided by that at the outlet.

II. Off-Gas Systems

The adsorbent AgA is intended for application to the tank vent system for the waste solution of boiling water reactors (BWRs), standby gas treatment system (SGTS) of BWRs, and dissolver off-gas (DOG) system of reprocessing plants. A schematic and conditions of these systems are summarized in Fig. 1 and Table 1. Systems characteristics are as follows. The tank vent filter (adsorbent) removes iodine from the off-gas which contains many contaminants and has a high humidity. The SGTS filter removes iodine over a wide range of concentrations during an accident. The DOG filter removes high concentrations of iodine in the presence of nitrogen oxides. Stability of the adsorbed iodine is an important factor for the DOG system because the main radioactive iodine isotope is I-129 (half life: $1.57 \cdot 10^7$y), whereas I-131 (8.02d) is the main radioisotope for the tank vent system and SGTS. Furthermore, iodine concentration is high (~30ppm) for the DOG, whereas it is below 0.1ppm for power plants (tank vent and SGTS). So two types of AgA were prepared, AgA with 24wt% Ag and 10wt% Ag for DOG and power plants, respectively. Operation temperatures differ for the three systems. The most severe situation seems to be that of the tank vent because of the low temperature and high humidity. Water vapor clogs the adsorbent pores. Other systems may have low temperature conditions would be exist such as during storage before and after use, and at operation standby. Nitrogen oxides of high concentration also can interfere with the reaction of iodine and impregnated silver, and change the chemical form of impregnated silver. All these factors must be considered in order to apply AgA to actual systems.

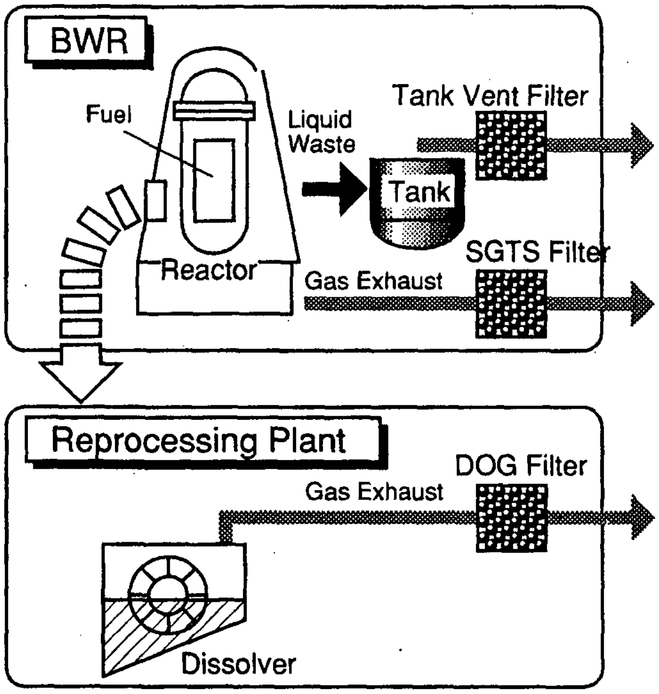
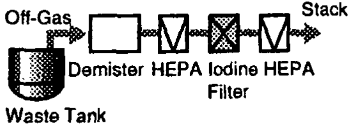
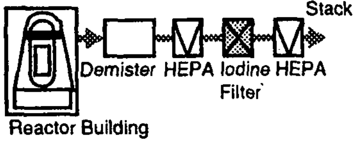
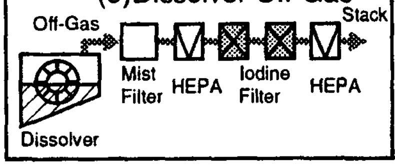


Fig. 1 Off-Gas Treatment Systems

Table 1 Off-Gas Conditions of Each System

System	Off-Gas Conditions				Requirement *filter bed depth
	Temp.	RH	[I]	[NOx]	
(1)Tank Vent  	30℃	50-90%	1ppb (10^{-3} ppm)	10ppb (10^{-2} ppm)	· High removal efficiency (DF>10 at 5cm*)
(2)SGTS  	66℃	<70%	1ppt–0.1ppm (10^{-6} -10^{-1})	10ppb (10^{-2})	· High removal efficiency (DF>34 at 5cm*)
(3)Dissolver Off-Gas  	150℃	~1%	30ppm	1.5% (1.5×10^{4})	· High removal efficiency (DF>250 at >85cm*) · High adsorption capacity

III. Experimental

The preparation of AgA was described previously.[14] Both types of AgA tested here had particle diameter of about 2mm and pore diameter of from 10 to 100 nm. Specific surface areas of 24 and 10 wt% AgA were about 10 and 40 m^2/g, and bulk densities were about 1.5 and 1.2 g/cm^3, respectively.

The test apparatus is schematically shown in Fig. 2. The iodine species were methyl iodide and molecular iodine. Concentrations of iodine and NOx, ratios of NO to NO_2 of simulated off-gas, the gas temperature and adsorbent bed depth were adjusted to get a desired condition. Iodine concentrations at the inlet and outlet of the column were measured by three methods depending on the form and concentration of iodine, that is gas chromatography with an FID or ECD detector after gas sampling, spectrophotometry using ferric thiocyanate, and inductively coupled plasme mass spectrometry after absorbing the iodine in an alkaline solution.

In order to simulate the standby condition for the DOG system, pre-blow tests were carried out. Pre-blow meant blowing of simulated off-gas without iodine through the AgA column in this study. The weight change of AgA and chemical form of silver were measured during and after pre-blow. The tests of iodine removal were carried out after pre-blow. The breakthrough test was also conducted to confirm the adsorption capacity of AgA with the 10 cm bed depth.

The influences on AgA of other gaseous impurities such as SO_2, NH_3 and CO_2 were investigated with 10 wt% Ag at relatively low temperatures and long times.

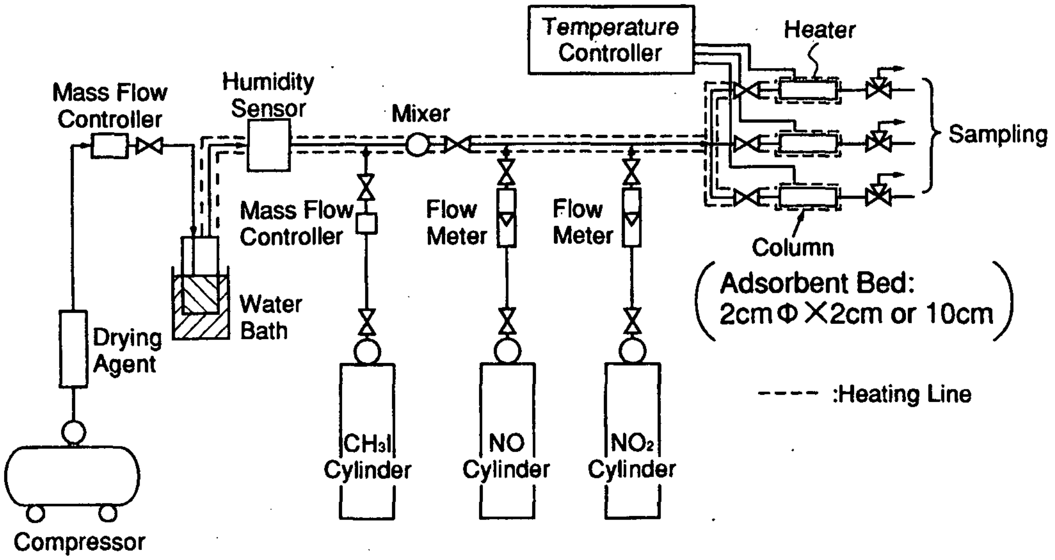


Fig. 2 Outline of the Test Apparatus

IV. Influence of NOx and H_2O on AgA

Before the iodine removal tests, pre-blow tests without iodine were carried out to clarify the influence of only gaseous impurities on the chemical form of impregnated silver. Figure 3 shows the relative weight change of AgA when 1.5% NOx (NO/NO_2=1/1) was blown in at 40 and 150℃. A forced air flow without NOx was carried out as a reference. A slight increase at 40℃ and a decrease at 150℃ were observed in the reference data, which is due to adsorption of H_2O in

the air at 40℃ and desorption of H_2O adsorbed on AgA before the test at 150℃. AgA with 10% silver showed a higher weight increase than AgA with 24% silver at 40℃, which is attributable to the higher surface area of the former. For the NOx pre-blow, weight changes were more notable than the reference case.
At 40℃, NOx (NO_2) would be absorbed in the adsorbed H_2O, which would dissolve impregnated $AgNO_3$ and enhance the H_2O adsorption. Nitrate presence which was observed in the 1.5% NO_2 pre-blow supports this mechanism. At 150℃, the weight decrease could not be explained only by the H_2O desorption. In this case, NOx (NO) reduced the impregnated $AgNO_3$ to Ag and decreased the AgA weight. X-ray diffraction (XD) patterns are shown in Fig. 4 for 24% AgA before and after the NOx pre-blow, which indicated the conversion of $AgNO_3$ to Ag by Eq. (1).

$$AgNO_3 + NO \rightarrow Ag + 2NO_2 \qquad (1)$$

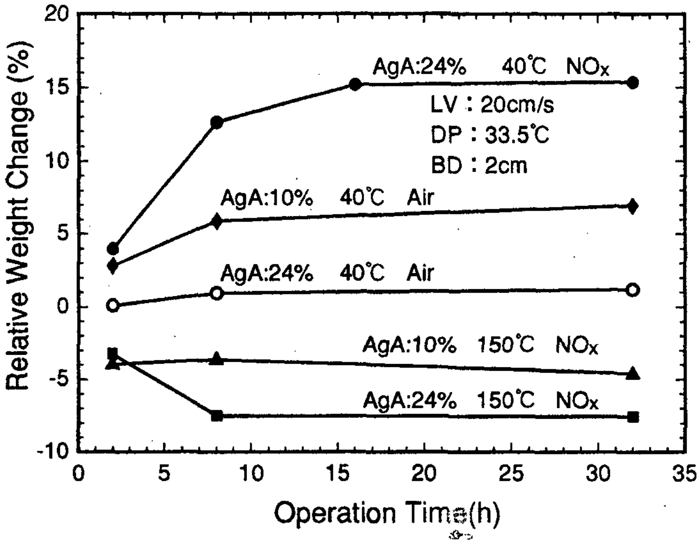


Fig. 3 Relative Weight Change of AgA during NOx Pre-Blow

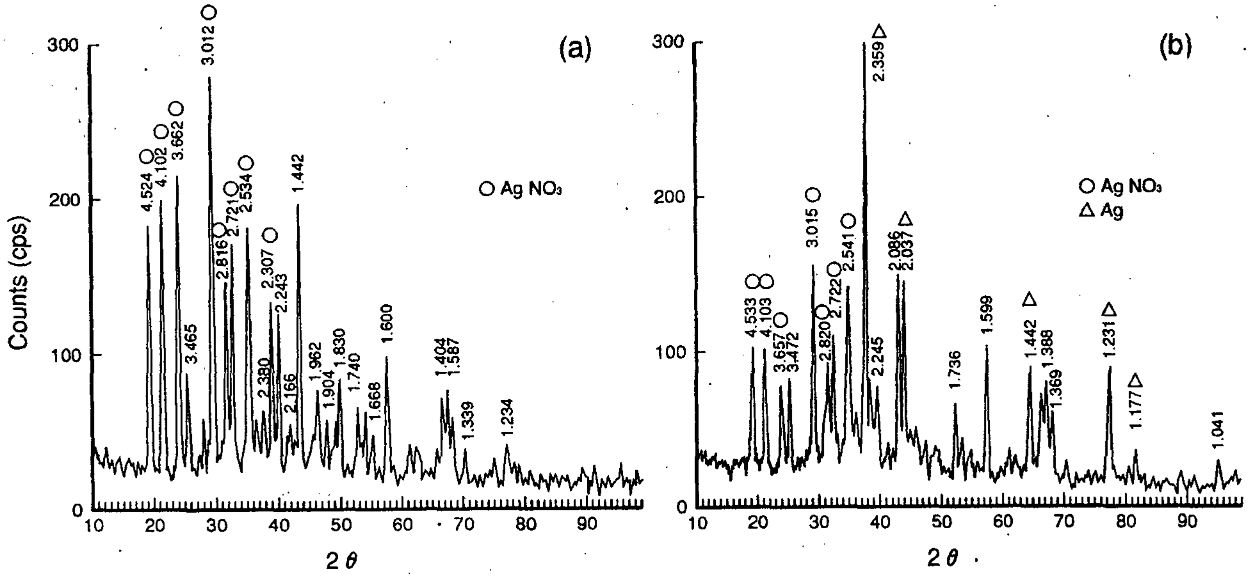


Fig. 4 XD Pattern of AgA before(a) and after(b) NOx Pre-Blow at 150℃

Figure 5 shows the weight change ratio of AgA during the 1.5% NO_2 pre-blow. The data showed that a larger increase was observed for 10% AgA than 24% AgA due to the larger surface area of the former. Compared with the data for 24% AgA in Fig. 3, NO_2 pre-blow had a larger weight increase than NOx pre-blow, which would be due to the easier solution of NO_2 into water than NOx.

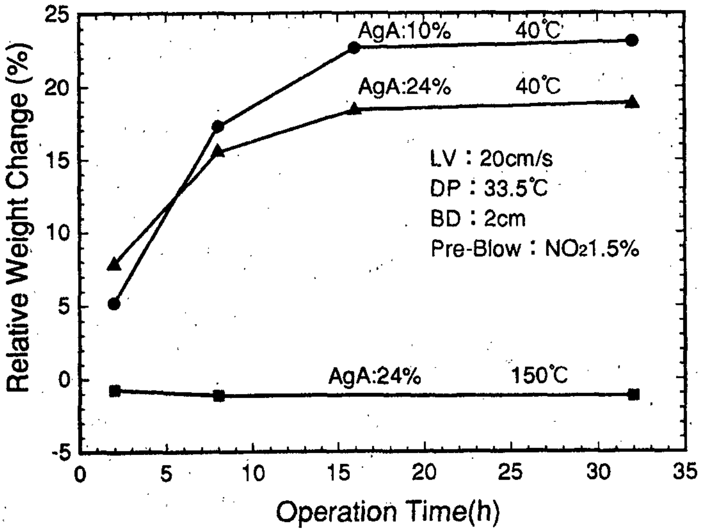


Fig. 5 Relative Weight Change of AgA during NO_2 Pre-Blow

V. Iodine Removal Efficiency after NOx Pre-Blow

Iodine removal experiments were carried out after pre-blow of simulated off-gas without iodine. Iodine was mixed with air without and in same cases with impurities. Typical iodine forms selected here were methyl iodide (CH_3I) and molecular iodine (I_2). CH_3I is the most difficult species to separate from simulated off-gas among the major organic iodines, and I_2 is the main form in the dissolver off-gas of spent fuel reprocessing[1,13]. In the experiments done here, the bed depth was quite small (2cm) to allow sensitive assessment of the change in decontamination factor (DF). It is known that the iodine adsorption band is about 5cm for AgA and a bed depth of 5cm is necessary for good iodine removal. So some cases showed rather rapid iodine breakthrough due only to the insufficient bed depth.

The DF values for CH_3I with 24% AgA are shown in Fig. 6 after various gases were pre-blown as a function of operation time. When the iodine concentration at the column outlet was under the detection limit, a DF value was calculated by substituting the detection limit for the outlet iodine concentration; these values are indicated with an upward pointing arrow in Figs. 6 and 7. The DF value was high after 1.5% NO_2 and air pre-blows. No gaseous impurities were added during the iodine removal test in these two cases. The DF values were low after 1.5% NOx (NO/NO_2=1) pre-blow (no NOx during iodine removal), and they were raised by the addition of NOx during iodine removal. The reactions of CH_3I with silver impregnated on AgA could be written as follows.

$$CH_3I + AgNO_3 \rightarrow AgI + CH_3NO_3 \quad (2)$$

$$CH_3I + Ag \rightarrow AgI + CH_3- \quad (3)$$

$$CH_3I + Ag + NO_2 + 1/2O_2 \rightarrow AgI + CH_3NO_3 \quad (4)$$

Reaction (2) is the normal iodine adsorption reaction which has a high DF. As described in the previous section, NOx pre-blow reduced $AgNO_3$ to Ag. It would be difficult for Reaction (3) to proceed because no couter ions are present for CH_3-, whereas gaseous impurities could act as couter ions as described in Reaction (4).

Figures 7 and 8 show the DF values of 10% AgA after 1.5% NOx and air pre-blows, respectively. Iodine forms of CH_3I and I_2 were examined in both figures. Temperature dependency is summarized in Fig. 8. Molecular iodine (I_2) showed no apparent DF decrease with lower temperature because the reactivity of I_2 with silver would be high. Methyl iodide (CH_3I) showed a lower DF especially at low temperatures and after NOx ($NO/NO_2=1$) pre-blow. This is because of the low reactivity of CH_3I with $AgNO_3$ and the much lower CH_3I reactivity with Ag metal at low temperatures. DF values of over 500 could be obtained for 30ppm CH_3I at 150℃ with 10% AgA in a 2cm bed depth after air pre-blow. AgA with 24% silver showed DF of over 500 even after 1.5% NOx pre-blow.

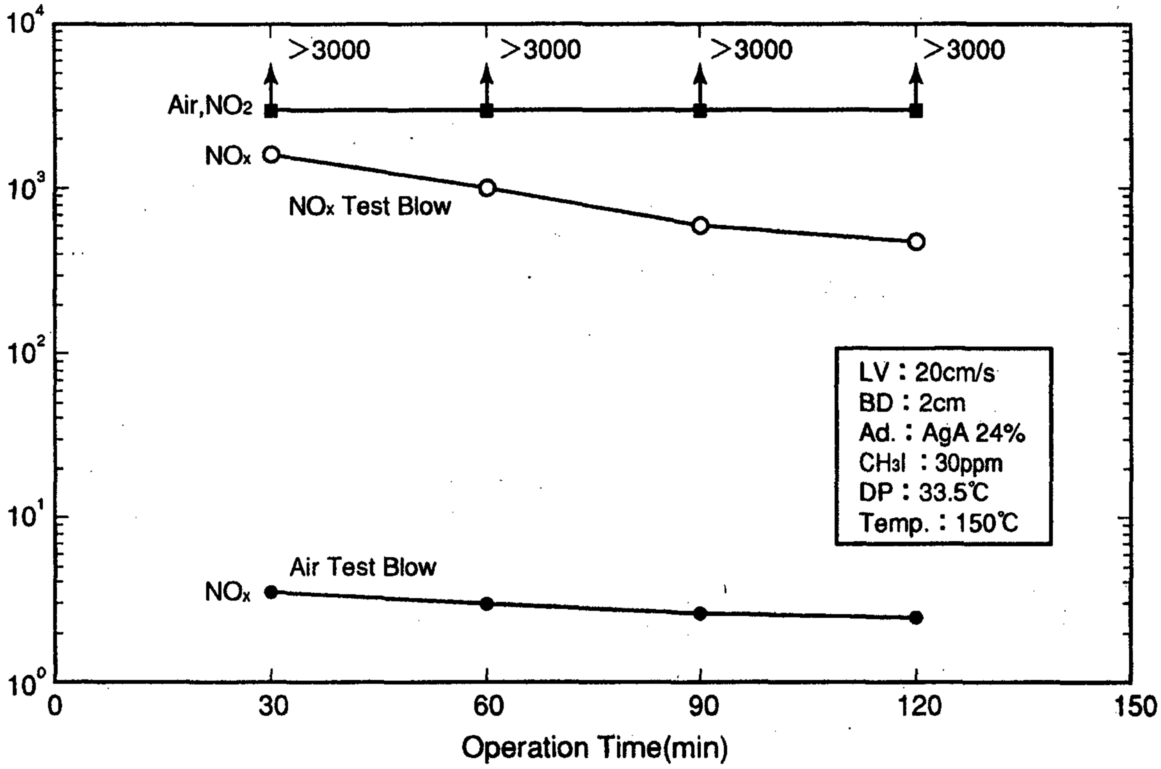


Fig. 6 DF of 24% AgA for CH_3I after Various Gases Were Pre-Blown

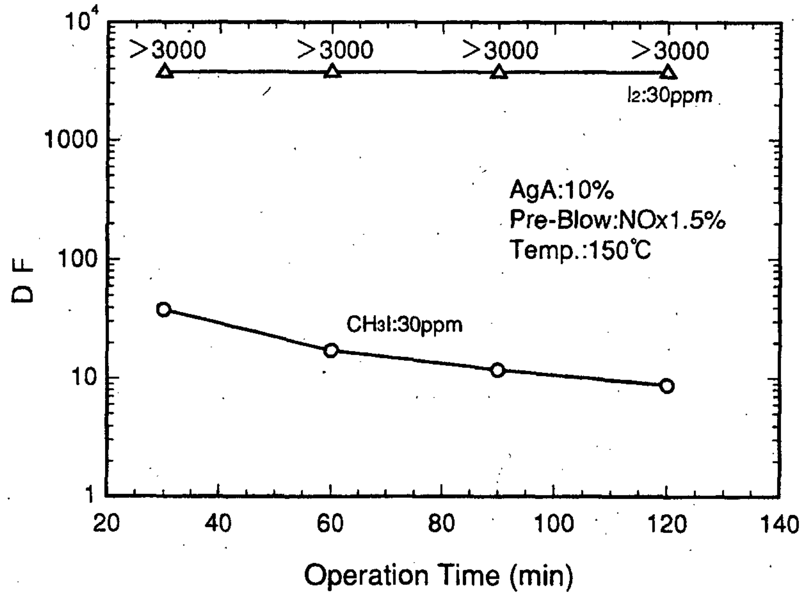


Fig. 7 DF of 10% AgA for CH_3I and I_2 after 1.5% NOx Pre-Blow

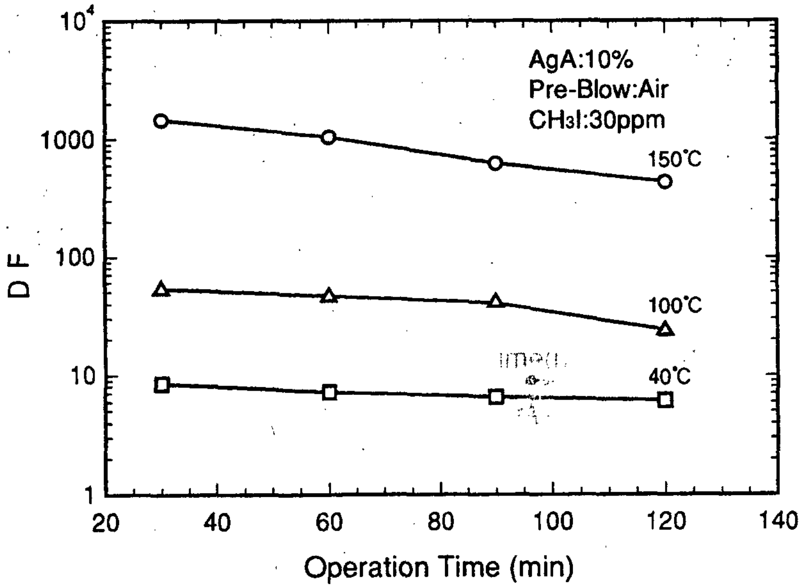


Fig. 8 DF of 10% AgA for CH_3I after Air Pre-Blow

VI. Breakthrough Property of AgA

Iodine breakthrough property was checked in order to get the iodine adsorption capability of AgA in a column. The results are shown in Fig. 9 for AgA with silver contents of 10wt% and 24wt% and CH_3I concentrations of 30 and 300ppm with air blowing. The bed depth of AgA was set at 10cm. Iodine concentration of 300ppm simulated an accelerated condition. AgA is known to show almost the same adsorption capacity for both CH_3I and I_2, and was expected to show a similar breakthrough curve.

The breakthrough point was defined in this study as the operation time where the DF value decrease was first observed. The breakthrough point depends on the iodine flow rate, and bed volume and silver content of AgA. This could be qualitatively understood by the data in Fig. 9. Iodine adsorption capacity of AgA was about 0.12 g-I/cm³-AgA(10wt%) and 0.35 g-I/cm³-AgA(24wt%). Iodine reacts with the same number of moles of silver in AgA and capacity data obtained indicated about 80% silver utilization. As mentioned before, adsorption band length is around 5cm, so breakthrough point would be full adsorption to 5cm of AgA in this experiment. Calculated breakthrough points of 24% AgA were about 140h and 14h, and those of 10% AgA were about 50h and 5h for 30ppm and 300ppm CH_3I, respectively. Corresponding experimental breakthrough points were 90h, 24h, 48h and 4h, which were not so different from the calculated points. High DF values were obtained for AgA before the breakthrough points which could be predicted by iodine adsorption capacity.

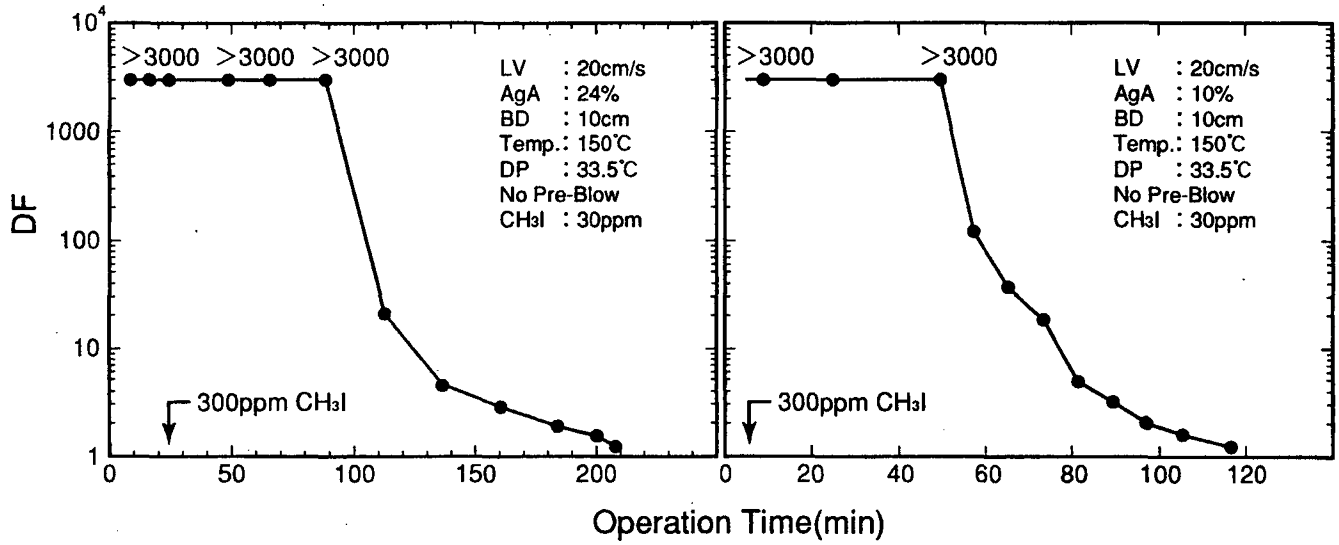


Fig. 9 Iodine Breakthrough Property of AgA

Ⅶ. Long Term Effect of Impurities at Relatively Low Temperatures

In order to check applications to the tank vent and standby gas treatment systems, long term experiments were carried out by blowing simulated off-gas containing various impurities. AgA with 10% silver was exposured for adequate time and iodine was added only at the time of the DF measurement. Impurities were removed from iodine gas to avoid their interference with the DF measurement.

The results are shown in Figs. 10 and 11 for simulated conditions of tank vent and standby systems, respectively. Simulated off-gas of the tank vent system included NOx (5ppb), SO_2 (5ppb), H_2S (<1ppb), HCl (36ppb) and NH_3 (150ppb). Temperature and relative humidity were 30℃ and 70%, respectively. Simulated off-gas of the standby system included NOx (30ppb), SO_2 (<1ppb), H_2S (<1ppb), HCl (<1ppb) and NH_3 (17ppb). Temperature and relative humidity were 66℃ and 70%, respectively. Bed depth of AgA and linear gas velocity were 5cm and 20cm/s in both cases, respectively. The DF values in Fig. 10 were lower than in Fig. 11 due to the lower temperature for the former. Long term exposures of AgA decreased the DF values in both cases, which would indicate poisoning of AgA by gaseous impurities such as NH_3, NOx and SO_2. The effects of NH_3 and SO_2 were realized by the separate experiments. Nitrogen oxide (NO) reduced $AgNO_3$ to Ag metal and hindered the smooth reaction of CH_3I with silver. The X-ray diffraction pattern showed peaks of Ag metal after exposure to simulated off-gas. But the required DF values were obtained in both cases after long exposure time.

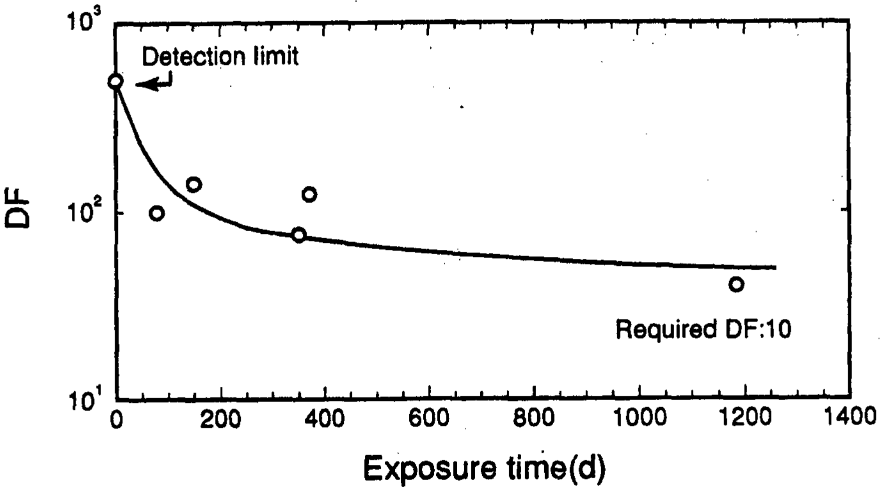


Fig. 10 Long Term DF Change for Simulated Conditions of Tank Vent System

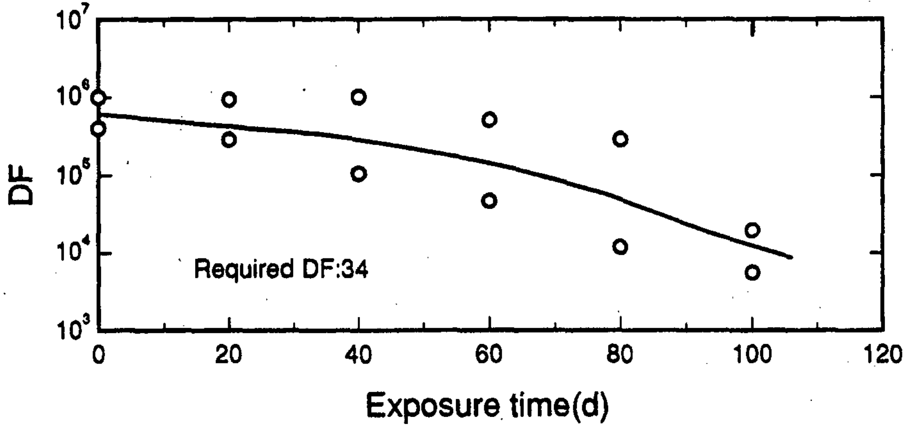


Fig. 11 Long Term DF Change for Simulated Conditions of Standby System

VIII. Conclusions

Silver impregnated alumina adsorbent (AgA), which was developed for iodine removal from off-gas of nuclear power and reprocessing plants, has been tested, placing emphasis on the investigation of influences of gaseous impurities on AgA chemical stability and iodine removal efficiency. Methyl iodide (CH_3I) and molecular iodine (I_2) were chosen as iodine forms for testing. Silver contents of AgA were 10 and 24 wt%. The main impurities are nitrogen oxides and water vapor in the dissolver off-gas of a reprocessing plant. Their influence on the chemical state of impregnated silver compound ($AgNO_3$) and decontamination factor (DF) value was checked.

At 150℃, air pre-blow with 1.5% nitrogen oxide ($NO/NO_2=1/1$) reduced silver nitrate to metallic silver, whereas pure air and air with 1.5% NO_2 had no effect on chemical state of silver. Metallic silver showed a lower DF value for methyl iodide in pure air (without impurities) than silver nitrate and the higher DF value in the presence of impurities. These phenomena could be explained by the reactivity difference of methyl iodide with silver in the presence and absence of counter ions (NO_3-, etc.) for methyl ion (CH_3-). Iodine could easily react with silver while methyl ion could react with counter ion. Methyl iodide removal by metallic silver without gaseous impurities could not offer the counter ion for methyl ion and showed a relatively low DF value.

At 40℃, air pre-blow with 1.5% nitrogen dioxide (NO_2) increased the AgA weight by about 20%, which was caused by the adsorption of nitric acid solution on the surface of AgA. AgA with 10wt% silver showed a higher weight increase than that with 24wt% silver which had lower porosity. Adsorption of acid solution lowered the DF value, which would be due to the hindrance of contact between methyl iodide and silver. AgA showed a relatively high DF at high humidity than other iodine adsorbents by keeping high reactivity of dissolved iodine with dissolved silver nitrate, but nitric acid solution would suppress both dissolutions.

The long term influence of other gaseous impurities was also investigated on 10% AgA at 30℃ and 66℃ which simulated the conditions of the tank vent and standby systems, respectively. The impurities of NH_3 and SO_2 decreased the DF value at high humidity. But DF was still over the required value after a long time. AgA indicated superior characteristics at high temperatures.

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DISCUSSION

JUBIN: When you examined the material and determined that you had metallic silver, did you have an opportunity to look at this material through an electron microscope and determine whether the silver was uniformly distributed over the material? Did it, perhaps, conglomerate into nodules of some sort?

FUKASAWA: We did not examine it by microscope in this case, but observed that the silver distribution was under the surface of the other adsorbent. Inside the adsorbent there was still silver nitrate.

HERRMANN: We agree with your experiences that elemental silver has good removal efficiency for iodine. We do not agree with your experience for the removal efficiency of elemental iodine with elemental silver. 85% of I in WAK offgas is organic iodine. With elemental silver on a carrier of silica we found better removal efficiency than with silver nitrate. I agree, we should compare plant and laboratory experiences. Laboratory experiences with I-131 indicate a higher iodine trapping performance than plant experience.

FUKASAWA: I don't know the exact conditions of your offgas, but in these cases the silver nitrate is converted to metallic silver. Without impurities during the iodine separation with metallic silver, this adsorber shows low DF. But with impurities, there should be impurities in the actual offgas, this adsorber showed high DF. So your case is, I think, the same as this case. You get high DF for I_2 with metallic silver with impurities like NO_x or humidity.

HERRMANN: The device for iodine removal is at 140° C. As impurities we have some percent of NO_2. It depends on the dissolution time. We measured it also in the effluent ventilation system where the concentration is much lower. The water content was always approximately 3% absolute, the offgas saturation after the scrubbing columns. This is what we know about the impurities we have.

FUKASAWA: In our case, NO_x concentration is 1.5%. NO is 0.75% and NO_2 is 0.75%. The minimum water content was about 1% in our iodine separation tests. With such an amount of coexisting impurities, you don't have to worry about the DF decrease in this case. In your case you can get high DF I think.

JUBIN: One other question, what is your dew point, is it 35°C?

FUKASAWA: Yes, dew point is 33.5°C at 150°C, humidity is about 1%.

DIFFUSIONAL ANALYSIS OF THE ADSORPTION OF METHYL IODIDE ON SILVER EXCHANGED MORDENITE

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Abstract

The removal of organic iodides from off-gas streams is an important step in controlling the release of radioactive iodine to the environment during the treatment of radioactive wastes or the processing of some irradiated materials. Nine-well accepted mass transfer models were evaluated for their ability to adequately explain the observed CH_3I uptake behavior onto the Ag°Z. Linear and multidimensional regression techniques were used to estimate the diffusion constants and other model parameters, which then permitted the selection of an appropriate mass transfer model.

Although a number of studies have been conducted to evaluate the loading of both elemental and methyl iodide on silver-exchanged mordenite, these studies focused primarily on the macro scale (deep bed) while evaluating the material under a broad range of process conditions and contaminants for total bed loading at the time of breakthrough. A few studies evaluated equilibrium or maximum loading. Thus, to date, only bulk loading data exist for the adsorption of CH_3I onto Ag°Z. Hence this is believed to be the first study to quantify the controlling mass transfer mechanisms of this process.

It can be concluded from the analysis of the experimental data obtained by the "single-pellet" -type experiments and for the process conditions used in this study that the overall mass transfer rate associated with the adsorption of CH_3I onto Ag°Z is affected by both micropore and macropore diffusion. The macropore diffusion rate was significantly faster than the micropore diffusion, resulting in a two-step adsorption behavior which was adequately modeled by a bimodal pore distribution model. The micropore diffusivity was determined to be on the order of 2×10^{-14} cm^2/s. The system was also shown to be isothermal under all conditions of this study.

Introduction

One of the promising solid sorbent technologies for the removal and retention of iodine in terms of performance and simplicity is the adsorption on hydrogen-reduced silver mordenite (Ag°Z). This form of the sorbent has been reported by several researchers [Thomas et al. (1977), Jubin (1980, 1982), Scheele et al. (1983), and Sheele and Burger (1987)] to be more effective in trapping I_2 and CH_3I than the ionic silver mordenite (AgZ). Although a number of studies have been conducted to evaluate the loading of both elemental and methyl iodide on silver-exchanged mordenite, they focused primarily on the macro scale (deep bed) while evaluating the material under a broad range of process conditions and contaminants for total bed loading at the time of breakthrough. Thus for the most part, only bulk loading data appear to exist in the literature for the adsorption of CH_3I onto AgZ or Ag°Z. The specific objective was to provide sufficient insight into the adsorption process to allow the determination of the primary controlling mechanisms and diffusion and/or reaction coefficients associated with the process.

Theory and Assumptions

The process of physical adsorption in porous adsorbent material is generally extremely rapid according to Kärger and Ruthven (1992). As a result, in most cases, mass or heat transfer resistances are the controlling factors for the overall rate of adsorption. Kärger and Ruthven (1992) provided an outstanding discussion on the diffusional resistances in zeolite pellets. What follows is a summary of that discussion as it applies to the problem at hand.

According to the International Union of Pure and Applied Chemistry (IUPAC) classification, pores with a diameter less than 20 Å are considered micropores while pores with a diameter greater than 500 Å are classified as macropores. The region between 20 and 500 Å is classified as mesopores (Kärger and Ruthven, 1992). The mass transport in each of these three size regions is controlled by different diffusion mechanisms. In the macropores, interactions between the pore walls and the diffusing molecule are minor and generally bulk diffusion is observed. Typically, the macropore provides only limited adsorption capacity but may significantly impact the mass transfer rates. As the size of the pore decreases, the interactions with the walls become increasingly important. In the mesopore region, diffusion control is generally associated with Knudsen diffusion; however, both surface diffusion and capillary effects may play significant roles. In the micropore region, surface forces are the most significant, as the diffusing molecule interacts with the wall more frequently than with other diffusing molecules. This form of diffusion is also known as "intracrystalline" diffusion. Micropore diffusion is also quite different from the diffusion processes in either the macropore or mesopore regions in that it is an activated process. This implies that the observed diffusion rate, if this mechanism could be isolated, would vary with temperature in accordance with an Arrhenius form equation:

$$D_c = D_\infty e^{-E_d/RT}. \tag{1}$$

Kärger and Ruthven (1992) further indicate that the analysis of loading data obtained for zeolite crystals that are "sufficiently large" can generally be accomplished through the use of the simple single micropore diffusion resistance model. However, in the case of commercial pelleted adsorbents, there is often a continuous range of pore sizes, which includes micropores, mesopores, and macropores. The analysis of many commercially available zeolite adsorbents is a bit more tractable because these materials are formed from small microporous particles of the actual zeolite crystal to produce a macroporous pellet of a manageable size. In such pellets, the pore size distribution is reported to often exhibit a bimodal-type distribution. In this situation, it is possible that the mass transport is controlled by macropore and/or micropore diffusion resistances.

General Assumptions and Simplifications

In most cases, modeling of the diffusion processes in porous media requires some type of simplifying assumptions. These generally involve the definition of structure of the adsorbent material, the nature or order of the chemical reactions and thermal effects associated with the heat of reaction and adsorption, and finally the behavior of the diffusion coefficient.

Commercially available extruded adsorbents are not of uniform size While the diameter appears to be nearly the same, the length varies greatly. It is generally accepted to use an equivalent spherical radius, $\bar{r}$, defined as the radius of a sphere having the same external surface-to-volume ratio. In the analysis of Kärger and Ruthven (1992), this is shown to be valid for small changes in conversion. In the case of an infinite cylinder and a material with the equivalent spherical radius determined as stated above, the dimensionless time required to reach 90% conversion is different by about 25%. At 50% conversion, the error is <5%.

The second assumption deals with the structure of the pellet itself, as this will in large part define the nature of the model. The structure of the solid pellet has been conceptualized in numerous ways (Ramachandran and Doraiswamy, 1982; and Kulkarni and Doraiswamy, 1986), ranging from the simplest approach of a spherical, homogenous, nonporous pellet to a porous pellet containing subparticles that may also be porous (Kärger and Ruthven, 1992). The introduction of some type of pore structure also requires an assumption concerning the pore behavior. The pore can either remain constant or change as a function of time.

A third assumption that must be validated is that the process can be considered to occur under isothermal conditions. The models described below assume that the system being studied is isothermal. However, when studying an adsorption/reaction process, the possibility that this assumptions might be invalid as a result of the heat effects from adsorption and/or reaction must be considered. In such a case, the heat effects, which may be significant, must be accounted for in the analysis used to examine the experimental data. The assumption of isothermal conditions is generally only valid when the sorption rates are relatively slow (Kärger and Ruthven, 1992).

Lee and Ruthven (1978) describe the three possible resistances to heat transfer. These are (1) the resistance to heat transfer from the external surface of the pellet to the surrounding fluid, (2) the resistance to heat transfer from the external surface of an individual particle within the pellet or, in other words, the internal heat transfer resistances; or (3) the resistance to heat conduction within the individual particle. It was shown that for all cases the heat transfer from the external surface will be slower than heat transfer between the crystals of the sample Based on this analysis, the temperature throughout the sample was uniform.

To determine the significance of the potential nonisothermal behavior, an analysis of maximum temperature variation due to the heat of adsorption and chemical reaction was made. The analysis of this system by Jubin (1995), using conservative assumptions for all variables, indicated a maximum delta temperature between the pellet and the bulk fluid as a result of both the heat of adsorption and chemical reaction of 0.37°C Based on this result, it clearly appeared that the assumption of isothermal adsorption was substantiated

Finally assumptions about the stability of the process system used in the experimental determinations are generally made. One of the common process assumptions is that of constant bulk gas-phase composition. This is either based on the use of a very large system, a true constant pressure system, or by careful control of a flowing gas stream. If this assumption is not made, then the changing composition of the gas phase must be addressed in the model.

Shrinking or Unreacted Core Model

One of the classic models used to describe noncatalytic reactions of solid particles with a surrounding fluid is the shrinking or unreacted core model. This model, as described by Levenspiel (1972, 1979), was developed by Yagi and Kunii in 1955 and contains five sequential steps for the gaseous reactant and product components.

For the reactant gases·

1. Diffusion through a boundary layer gas film which surrounds the solid particle.
2. Diffusion though the particle to the surface of the unreacted core.
3. Reaction with the solid reactant at the surface of the solid core.

And for the product gases.

4. Diffusion back through the reacted portion of the particle to the outside surface of the particle.
5. Diffusion through the boundary layer gas film surrounding the solid particle.

It was noted by Levenspiel (1972) that there may be significant variations in the relative importance of these five steps, depending on the relative magnitude of the associated resistances to mass transfer. Furthermore, in some situations, some of these steps are not relevant. For example, in the case of an irreversible reaction, steps 4 and 5 do not contribute directly to the observed resistances to the reactions The same is true of a reaction producing no gaseous products.

The basic conversion equations for the first three steps have been developed. For a gas-solid reaction of the general form

$$A(g) + bB(s) \rightarrow R(g) + S(s) \tag{2}$$

and constant-size spherical particles, the following conversion-time expressions are relevant for the first three resistances and can be used to compare the observed loading rate data with the theoretical uptake curve.

Individual Controlling Resistances

In terms of the flux, the equations describing film diffusion control can be written based on either the moles of the diffusing component, *A*, or the moles of the solid reactant, *B*, that is reacted with *A* according to Eq. (2):

$$-\frac{1}{S_{ex}}\frac{dN_B}{dt} = -\frac{1}{4\pi r_a^2}\frac{dN_B}{dt} = -\frac{b}{4\pi r_a^2}\frac{dN_A}{dt} = bk_g\left(C_{Ag} - C_{As}\right) . \tag{3}$$

For the limiting case when there is only film diffusion control, C_{As} approaches 0. And the fractional conversion, X_B, can be expressed in terms of the unreacted core radius by

$$\frac{t}{\tau_{gasfilm}} = 1 - \left(\frac{r_c}{r_a}\right)^3 = X_B , \tag{4}$$

where the time for total conversion is given by

$$\tau_{gasfilm} = \frac{\rho_B r_a}{3bk_g C_{Ag}} . \tag{5}$$

In a similar manner, expressions can be written for the case of ash diffusion alone. The resulting expression in terms of fractional conversion is

$$\frac{t}{\tau_{ash}} = 1 - 3\left(1 - X_B\right)^{2/3} + 2\left(1 - X_B\right), \tag{6}$$

where the time to complete conversion is given by

$$\tau_{ash} = \frac{\rho_B r_a^2}{6bD_e C_{Ag}}. \tag{7}$$

For chemical reaction control (rxn), the relationship for the conversion vs time is given by

$$\frac{t}{\tau_{rxn}} = 1 - \frac{r_c}{r_a} = 1 - (1 - X_B)^{1/3}, \tag{8}$$

where k_s is the assumed first-order reaction constant. The time to complete conversion is given by

$$\tau_{rxn} = \frac{\rho_B r_a}{bk_s C_{Ag}}. \tag{9}$$

Full Shrinking Core Model

In many situations, more than one of these resistances is a factor in determining the observed rate of conversion of the particle. The three individual rate expressions can be combined into a single expression (Levenspiel 1972, 1979).

$$-\frac{1}{S_{ex}}\frac{dN_B}{dt} = \left[\frac{b}{\frac{1}{k_g} + \frac{r_a\left(r_a - r_c\right)}{r_c D_e} + \frac{r_a^2}{r_c^2 k_s}}\right] C_{Ag}. \tag{10}$$

This expression can easily be converted into a more usable form for the analysis of the gravimetric loading data by expressing the unreacted core radius, r_c, in terms of conversion, found in Eq. (4), yielding

$$-\frac{1}{S_{ex}}\frac{dN_A}{dt} = \left[\frac{b}{\frac{1}{k_g} + \frac{r_a\left(1-\left(1-X_B\right)^{1/3}\right)}{\left(1-X_B\right)^{1/3} D_e} + \frac{1}{\left(1-X_B\right)^{2/3} k_s}}\right] C_{Ag}. \tag{11}$$

This is then an expression that can be used to determine the values of the three adjustable parameters through a process of curve fitting to minimize the error between experimentally obtained flux or loading data and the calculated values.

Alternately, it has been shown by Levenspiel (1972, 1979) that the total time to reach a given conversion is the sum of the times for the individual mechanisms to reach the same conversion. In other words,

$$t_{total} = t_{gasfilm} + t_{ash} + t_{rxn}. \tag{12}$$

Likewise, for the complete conversion, the time is given by

$$\tau_{total} = \tau_{gasfilm} + \tau_{ash} + \tau_{rxn}. \tag{13}$$

By replacing the expressions for the individual times to reach a set conversion given by Eqs. (4), (6), and (8) for the individual times into Eq. (12), an expression is obtained that allows the determination of the extent of the conversion for any value of time. It should be noted that the conversion is found as the root of the following equation:

$$t_{total} = X_B \tau_{gasfilm} + \left[1 - 3(1 - X_B)^{2/3} + 2(1 - X_B)\right]\tau_{ash} + \left[1 - (1 - X_B)^{1/3}\right]\tau_{rxn}. \tag{14}$$

Isothermal Models for Porous Media

The previous models do not consider the nature of the media, which in the case of zeolites may be important. Kärger and Ruthven (1992) summarize numerous studies which have focused on the adsorption from the gas phase into a porous zeolite-type structure. In general terms, these studies attempted to incorporate the porous nature of the zeolite pellets by addressing diffusional resistances arising from (1) the micropores, (2) the macropores, or (3) a combination of both macropore and micropore resistance. These models are further summarized as follows.

Micropore Diffusion Controlling

For the case of micropore diffusion alone, the following transient sorption expression is presented by Kärger and Ruthven (1992):

$$X_B = \frac{m_t}{m_\infty} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-\frac{n^2\pi^2 D_c t}{r_i^2}\right). \tag{15}$$

The two primary assumptions that must be noted are the use of constant diffusivity and that the change in the adsorbed phase concentration is small such that gas phase or surface composition remains constant (Ruthven, 1984).

This model reduces to

$$X_B = \frac{m_t}{m_\infty} = 1 - \frac{6}{\pi^2}\exp\left(-\frac{\pi^2 D_c t}{r_i^2}\right) \tag{16}$$

as the time term becomes large. Kärger and Ruthven (1992) point out that a plot of $\ln[1 - m_t/m_\infty]$ vs t should approach a straight line. This line will have a slope of $-\pi^2 D_c/r_i^2$ and an intercept of $\ln(6/\pi^2)$.

Macropore Diffusion Controlling

For macropore diffusion the solution is the same with the D_c/r_i^2 term replaced by

$$\frac{D_p}{r_a^2}\left(\frac{1}{1+K^*\left(1-\varepsilon_p\right)/\varepsilon_p}\right), \tag{17}$$

where K^* is an equilibrium constant which has an Arrhenius-type temperature dependence.

Combined Micropore and Macropore Diffusion Control

Dual-resistance systems in biporous media have been studied by several researchers Ruckenstein et al. (1971), discussing the dissertation of Vaidyanathan (1971), pointed out that the macropore diffusivity and micropore diffusivity may, in many cases, be quite different by orders of magnitude. In such a case, the observed diffusion process may be significantly affected by the particular structure of the porous solid. The model developed by Vaidyanathan (1971) appears to be the first to address the analysis of transient sorption with the competing effects of macropore diffusion and micropore diffusion combined. The assumptions made in the development of this model are as follows:

1. The system is isothermal.
2. The particle is spherical and composed of small uniform spherical microporous particles.
3. The sorbent is exposed to an infinite source of sorbate such that the surface concentration is constant.
4. The sorbent is exposed to a step change in sorbate concentration at time zero.
5. Adsorption occurs at the walls of both the macropores and the micropores.
6. Linear isotherms apply.

Ma and Lee (1976) and Lee (1978) extended the original model to address the case of a finite quantity of sorbate. Of these, the model proposed by Lee appeared to be a bit simpler and faster in terms of computer time to apply as it contained only one double summation and the others contained the ratio of two double summations. In the case of constant gas-phase concentrations, the mathematical solution developed by Lee simplifies to

$$X_B = \frac{m_t}{m_\infty} = 1 - \frac{18}{\beta + 3\alpha}\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\left(\frac{n^2\pi^2}{p_{n,m}^4}\right)\frac{e^{-p_{n,m}^2 D_c t/r_i^2}}{\Big\{\alpha + \frac{\beta}{2}\Big[1 + \frac{\cot\left(p_{n,m}\right)}{p_{n,m}}\left(p_{n,m}\cot\left(p_{n,m}\right) - 1\right)\Big]\Big]\Big\}}, \tag{18}$$

where

$$\alpha = \frac{D_c}{r_i^2}\frac{r_a^2}{D_p}, \tag{19}$$

$$\beta = \frac{3\alpha\left(1-\varepsilon_p\right)q_\infty}{\varepsilon_p C_{A,0}}, \text{ and} \tag{20}$$

$p_{n,m}$ is given by the roots of the transcendental equation

$$\alpha p_{n,m}^2 - n^2\pi^2 = \beta\left(p_{n,m}\cot\left(p_{n,m}\right) - 1\right) \tag{21}$$

Vaidyanathan (1971) discussed the physical significance of the α and β terms. α is the ratio of the time constants for macropore-to-micropore diffusion. For values of α less than 10^{-3}, macropore diffusion is much faster than micropore diffusion and the process can be considered to be a two-step process for all practical purposes For values of α greater than 10^{+2} , macropore diffusion controls (Ruckenstein et al., 1971). In the range of α between these two limiting cases, both mechanisms are important. The term $\beta/3\alpha$ represents the ratio of sorption in the micropores to macropores at equilibrium. Thus a large value would indicate sorption primarily in the micropores

Detailed description of other models that were evaluated for potential application to understand the behavior observed for this system may be found in Jubin (1995). These models include

- progressive conversion or volume reaction,
- nonisothermal micropore/macropore diffusion, and
- nonisothermal bed diffusion controlling.

Experimental Objectives

Conditions

As in numerous other studies [Jubin (1980, 1982), Burger and Scheele (1981), Scheele et al. (1983), and Scheele and Burger (1987)], methyl iodide was chosen as the chemical form for the iodine in this study because it is a more difficult form to retain in an adsorption process than elemental iodine. If CH_3I can be successfully retained on the silver mordenite, then the elemental iodine will also be retained (Scheele and Burger, 1987).

Experimental data were collected over a range of conditions selected to differentiate between the anticipated primary controlling mechanisms, and further data were collected to evaluate specific process behavior observed in the initial series of tests. The variables considered were (1) pellet diameter, (2) methyl iodide concentration, (3) gas velocity, (4) temperature, and, later in the study, (5) water vapor content of the carrier gas. The first four conditions were selected to examine the effects of these primary variables by varying each one while holding the others at a standard condition. Two duplicate tests were planned to allow a determination of the level of experimental error. Table 1 provides a listing of the ranges considered for each of the independent variables.

Following the completion of the initial series of tests, T3 to T13, 13 additional tests were conducted to explore specific aspects of this process and to gain further clarification on the behavior observed during the initial tests Four specific avenues examined (1) the effects of either increasing or decreasing the water vapor content of the air, (2) further lowering of the gas velocity, (3) lower CH_3I concentration, and (4) lower operating temperatures. Two unique runs were also conducted, the first to determine the amount of water adsorbed from the instrument air and the second to determine the CH_3I loading on the zeolite media without chemical reaction occurring. Table 2 presents a listing of the conditions studied in each test.

Table 1 General test conditions.

Variable	Range or values considered
Pellet diameter (in.)	**1/16** and 1/8
Gas velocity (m/min)	1, 2, 5, and **10**
Methyl iodide concentration (mg/m^3)	250, 500, **1000**, and 1500
Temperature (°C)	125, **150**, and 200
Water content [dew point (°C)]	–40, **–15 to –18**, –11

Note: Bold values were considered reference conditions.

Following the completion of the initial series of tests, T3 to T13, 13 additional tests were conducted to explore specific aspects of this process and to gain further clarification on the behavior observed during the initial tests. Four specific avenues examined (1) the effects of either increasing or decreasing the water vapor content of the air, (2) further lowering of the gas velocity, (3) lower CH_3I concentration, and (4) lower operating temperatures. Two unique runs were also conducted, the first to determine the amount of water adsorbed from the instrument air and the second to determine the CH_3I loading on the zeolite media without chemical reaction occurring. Table 2 presents a listing of the conditions studied in each test.

These supplemental tests specifically provided data on the impact of lower gas velocities (T15, T16, and T18) in an effort to resolve any effects of the gas film and lower CH_3I concentrations (T14) on possible reaction rate controlling conditions. The impacts of variations in the water vapor content of the gas stream were examined by adding a small additional amount of water vapor (T13) and by further drying the instrument air carrier gas (T18).

Test Equipment

Figure 1 is a schematic diagram of the process system showing the principal equipment components. The entire system was located inside a walk-in laboratory hood, with the exception of the dry air, hydrogen/argon and nitrogen cylinders, and the process control and data collection instrumentation.

To briefly describe the test system, a stream of dilute methyl iodide was fed into the test reaction chamber in which the bed containing the known quantity of selected sorbent material was located. The test bed, composed of a thin layer of Ag°Z pellets, one to two pellets deep, was supported by a stainless steel wire basket, which was lowered into a glass gas reaction chamber. In this system, a thin layer of adsorbent media was exposed to the sorbate stream such that all pellets were exposed to a uniform gas composition. Thus the effects of a changing gas composition through the test bed were considered to be negligible. This method was selected to provide a constant pressure system and to allow for the direct measurement of the quantity of iodine adsorbed on the bed rather than monitor small changes in gas composition. This is also referred to as a "single pellet system."

The glass gas reaction chamber was connected to the feed gas header. The basket itself was suspended from a tripod device which rested on the pan of the electronic balance (Sartorius Instruments Model LC620P) used to measure the weight changes of the sorbent material. This configuration allowed the basket to be free floating within the reaction chamber. Thus it was possible to directly determine the weight change of the test material in a flowing system. Weight data were collected from the electronic balance via a serial connection to an adjacent personal computer.

Table 2 Summary of single-pellet tests.

Test No.	Size (in.)	Velocity (m/min)	CH_3I concentration (mg/m^3) Planned	CH_3I concentration (mg/m^3) Actual[a]	H_2O added	Temperature (°C)	Notes
Initial series							
3	1/16	10	1000	1559		150	
4							Test aborted
5[b]	1/8	10	1000	1275		150	
6	1/16	10	1000	1505		150	
7	1/8	10	1000	1523		150	
8	1/16	5	1000	1675		150	
9							Test aborted
10[c]	1/16	10	1000	1190		200	
11	1/16	10	1500	1634		150	
12[c]	1/16	10	500	837		150	
Supplemental tests							
13[c]	1/16	10	1000	1367	yes	150	
14[c]	1/16	10	250	355		150	
15[c]	1/16	2	1000	1410		150	
16	1/16	1	1000	1124		150	
17	1/16	10	0	0		150	Air only
18	1/16	1	1000	1217	dry	150	
19	1/16	10	1500	2150		150	Short run
20	1/16	10	1500	1636		150	Short run
21[b]	1/16	10	1000			200	
22	1/8	10	1500	1367		150	
23[b]	1/16	10	1000		yes	150	Water data missing
24[b]	1/8	15	1000			150	Data questionable
25	1/16	10	1000			150	NaZ loading
26	1/16	10	1000	1059		125	

[a] Actual CH_3I concentrations determined by pressure drop in the gas supply cylinder vs time measurements.

[b] Data from runs T5, T21, T23, and T24 not used in analysis due to equipment difficulties or questions of validity or conditions.

[c] Data quality may be impacted by possible temperature shift at balance.

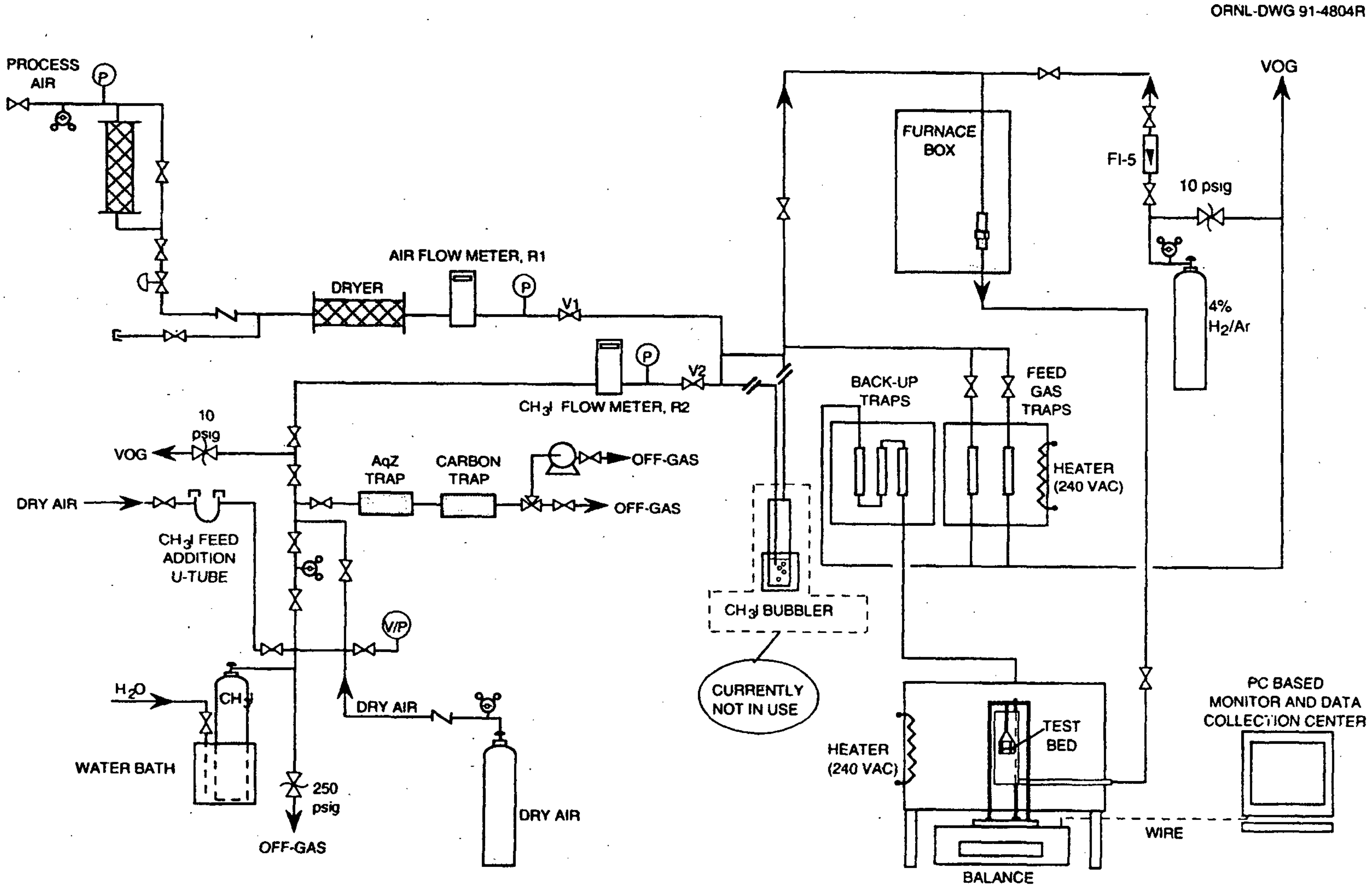

Figure 1 Schematic of experimental setup.

The glass reaction chamber was mounted in an electrically heated enclosure used to control process temperature. The heated enclosure was fabricated from a rigid insulating construction material. A secondary Plexiglas box was placed over this enclosure to prevent disturbances to the balance due to air currents in the hood. The gas that passed through the sorbent test material flowed through a series of 1-in.-I.D. backup filters loaded with either activated charcoal or silver-exchanged faujasite. The gas leaving the backup filters was discharged through the building vessel off-gas system.

The Sartorius Instruments Model LC620P poly-range electronic balance has a capacity of 120/240/620 g. Readability of the balance is 0 001/0 002/0.005 g, and standard deviation or reproducibility is ≤±0.001/0.001/0.003 g. Gas flowrates were controlled by needle valves and standard gas regulators. Gas flowrates were monitored either by calibrated rotometers or electronic mass flow meters manufactured by Omega Engineering, Inc. The Omega flow meters have an accuracy of ±2% of full scale. Temperature control was accomplished by placing the entire bed in an electrically heated insulated enclosure. Temperature was controlled by a Barber-Coleman controller coupled with a type K thermocouple junction inserted directly into the flowing gas stream above the bed of adsorbent material.

Table 3 presents, in outline form, the sequence of steps used to pretreat the AgZ prior to loading with methyl iodide and the flush or post-treatment steps to flush CH_3I from the bed and thus determine the amount chemisorbed vs physisorbed. Each of these pretreatment, loading, and post-loading steps were monitored for weight changes, with the data being stored in a computer file.

Experimental Results

Optical and Supporting Characterization Studies

Five samples of the mordenite materials used in this study were analyzed for pore size distribution, density, and characterization of the uniformity of silver and iodine distribution where applicable. The samples analyzed were the 1/16-in sodium mordenite, the 1/16- and 1/8-in. AgZ, and the 1/16- and 1/8-in. AgZ pellets from tests T19 and T20, respectively The last two samples were analyzed only for silver and iodine distribution

The topography of the material was shown in secondary electron images (SEI). Back-scattered electron images (BEI) showed variations in the image intensity across a portion of the pellet which is related to variations in the average atomic number in the region under examination. The specific distributions of silver, iodine, silicon, and aluminum across the specimen were shown by elemental maps.

In general, the BEI taken across the entire cross section of several fractured AgZ pellets showed no significant variation in the average atomic number (Walker, 1994) On one or two pellets, some localized accumulation of the silver was noted in a few small areas. Aside from these few areas, no silver gradient was noted within the pellets Prior to hydrogen pretreatment, the pellets displayed uniform distribution of the silver. However, following pretreatment with 4.5% hydrogen and subsequent loading with methyl iodide (samples from tests T19 and T20), very small particles (<1 or 2 μ) were seen on the surfaces of the larger crystalline structure. An elemental map obtained through energy-dispersive X-ray analysis of one pellet showed that these fine particles contain a higher concentration of silver than the concentration in the surrounding material. In addition to the presence of these fine silver-containing particles, there remained a relatively uniform distribution of silver across the mordenite pellet cross section. No specific area of silver depletion was detected when compared with the silver distribution prior to hydrogen pretreatment and iodine loading.

A low concentration of iodine was also observed to be uniformly distributed in the mordenite pellets analyzed from Test T19 (24% final conversion) and Test T20 (35% final conversion). Examination of the fine silver-containing particles showed that while these are rich in silver, they contained virtually no iodine. Using the same technique on the larger mordenite particles or crystals showed that they, on the other hand, contained a low concentration iodine that appeared to be uniformly distributed.

Table 3 Outline procedure for single-pellet CH_3I loading tests.

Bed pretreatment (standard for all tests)
- Drying
  - 24 h air
  - 11.4 L/min of dry instrument air
  - Temperature: 150°C
- Nitrogen temperature equilibration
  - 4+ h N_2
  - 0.4 L/min
  - Temperature: 200°C
- Silver reduction
  - 8 to 20 h 4% H_2/Ar
  - 0.4 L/min
  - Temperature: 200°C
- Second nitrogen temperature equilibration
  - 4+ h N_2
  - Same flow rate as that to be used in CH_3I loading
  - Same temperature as that to be used in CH_3I loading

Loading conditions (specific test conditions listed in Table 2)
- H_2O vapor content (dew point)
  - $>-15°C$ (7.3×10^{-5} mol/L) or $-40°C$ (5.6×10^{-6} mol/L)
- Pellet diameters
  - 1/16 or 1/8 in.
- Gas velocities
  - 1, 2, 5, or 10 m/min
- CH_3I gas concentrations
  - 250, 500, 1000, or 1500 mg/m^3
- Bed temperature
  - 125, 150, or 200°C

Air flush (standard for all tests)
- 24+ h air
- 11.4 L/min or dried instrument air
- Temperature: 150°C

The SEI of the pellets examined showed the voids and macropores present in this material. The SEI also showed that there was the possibility for significant variation from pellet to pellet. These variations fell into two categories. First there was some variation in the general structure of the pellets. Some were observed to have substantial voids in the pellet interior, while other pellets appeared to contain separate cores. The second type of variation involved the crystalline particles that comprised the overall structure. Some were well formed, and others had very rough and irregular surfaces. In addition, they appeared to vary in size and overall shape. Both the 1/16- and 1/8-in. pellets were composed of individual crystals estimated to be 4.0 μ in equivalent spherical diameter.

What appears to be a shrinking core behavior, as shown by color changes in the pellets, was observed through unpublished optical photographs made during the deep-bed studies previously completed and reported by this author [Jubin (1980, 1982)]. The test from which these pellets were taken was conducted under the following conditions: a bed temperature of 200°C, a CH_3I concentration of 1000 mg/m^3, and a gas velocity of 10 m/min at standard temperature and pressure. The loadings for the individual pellets were not determined, and only the average loading on each of the 2.54-cm-thick bed segments was measured by tracer analysis. At very low CH_3I loadings on the AgZ (~3% average conversion) the pellet from the fourth or last bed segment shows no sign of any visible ring. As the average bed segment loading increases, a clearly developed ring around the core is apparent. This is shown in Fig. 2 at an average bed segment conversion of ~19%. However, at higher average loadings (~40% conversion), the color variation across the diameter of the pellet virtually disappears (Fig. 3). In Fig. 3, which shows several pellets from the first bed segment, it appears that only a very small core remains in one pellet while in the other pellet no core is visible.

Baseline Adsorption Data

Water Uptake by AgZ

One obvious concern in analyzing the CH_3I uptake data was the possible impact of concurrent weight gain by the adsorption of water from the flowing gas stream. Test T17 was performed to measure the quantity of water adsorbed as a function of time. After approximately the first 16 h that the bed was subjected to the flowing instrument air at 150°C, an observed gain of approximately 0.05 g had occurred on the 2.5416-g bed and the loading appeared to have leveled off. After 40 h the total had risen to about 0.07 g. Over the next 50 h, the loading appeared to stabilize at a total weight gain of about 0.075 ± 0.005 g. These values must be compared with the total weight gains observed when CH_3I was present in the flowing gas stream to determine their significance and possible impact on the CH_3I loading data. The typical weight gain was on the order of 0.45 g in 60 h, as in the case of T10.

CH_3I Loading on NaZ

It was assumed at the start of this study that any weight gain on the mordenite pellet was primarily associated with chemical bonding with the silver contained in the pellet. Test T25 was conducted to determine the loading rate and quantity of CH_3I adsorbed on the unexchanged sodium form of the mordenite. In this run, 0.0807 g was loaded over the 22-h test period. Following the loading cycle, an air purge of 70 h was conducted. During this period, a net gain of 0.0353 g was observed that must be attributed to a water vapor. The total CH_3I loading should be compared with loading curves from tests such as T3, in which 0.335 g was gained over the same time period to examine the significance. Based on these data, it would appear relatively safe to assume that the observed weight gains on the beds that were measured during the CH_3I loading tests required a chemical reaction between the CH_3I and the silver.

CH_3I Adsorption Studies

Figures 4 and 5 are examples of the CH_3I loading curves that were obtained for all of the experimental runs. The air flush portions of the tests may also be included in the loading files as this phase of the tests was conducted as a continuation of the test conditions with only the CH_3I flow

Figure 2 Optical image of 1/16-in. AgZ from bed with an average conversion of ~19%.

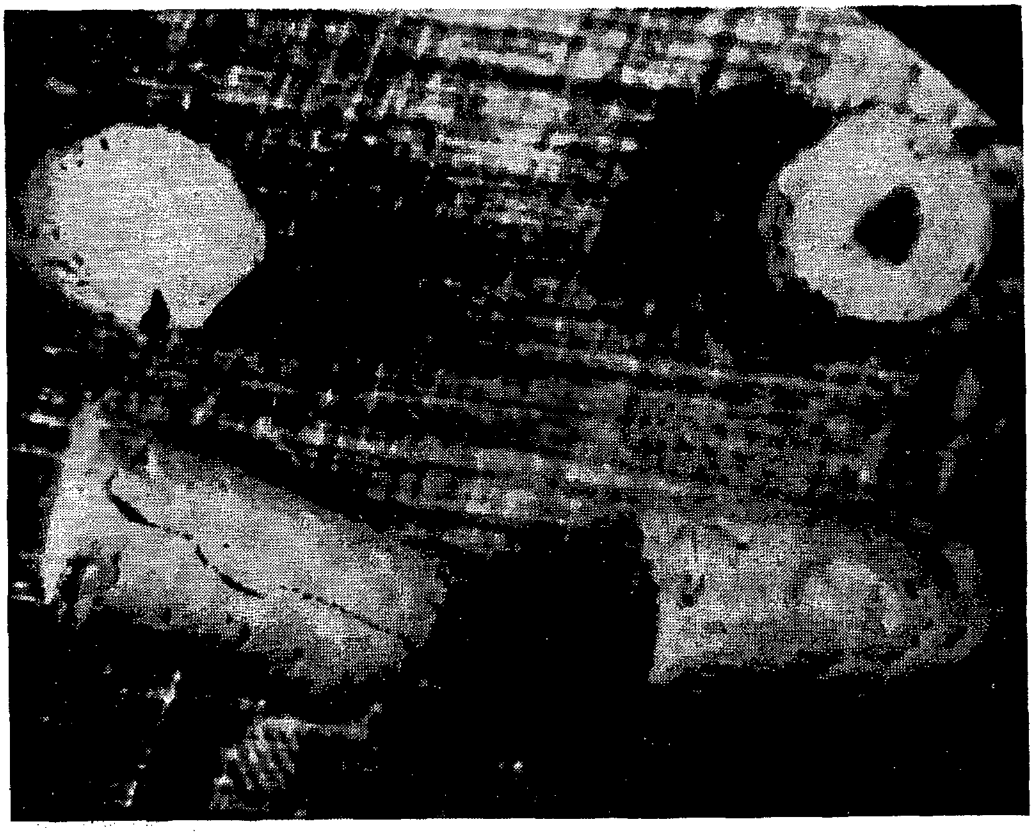

Figure 3 Optical image of 1/16-in AgZ from bed with an average conversion of ~40%.

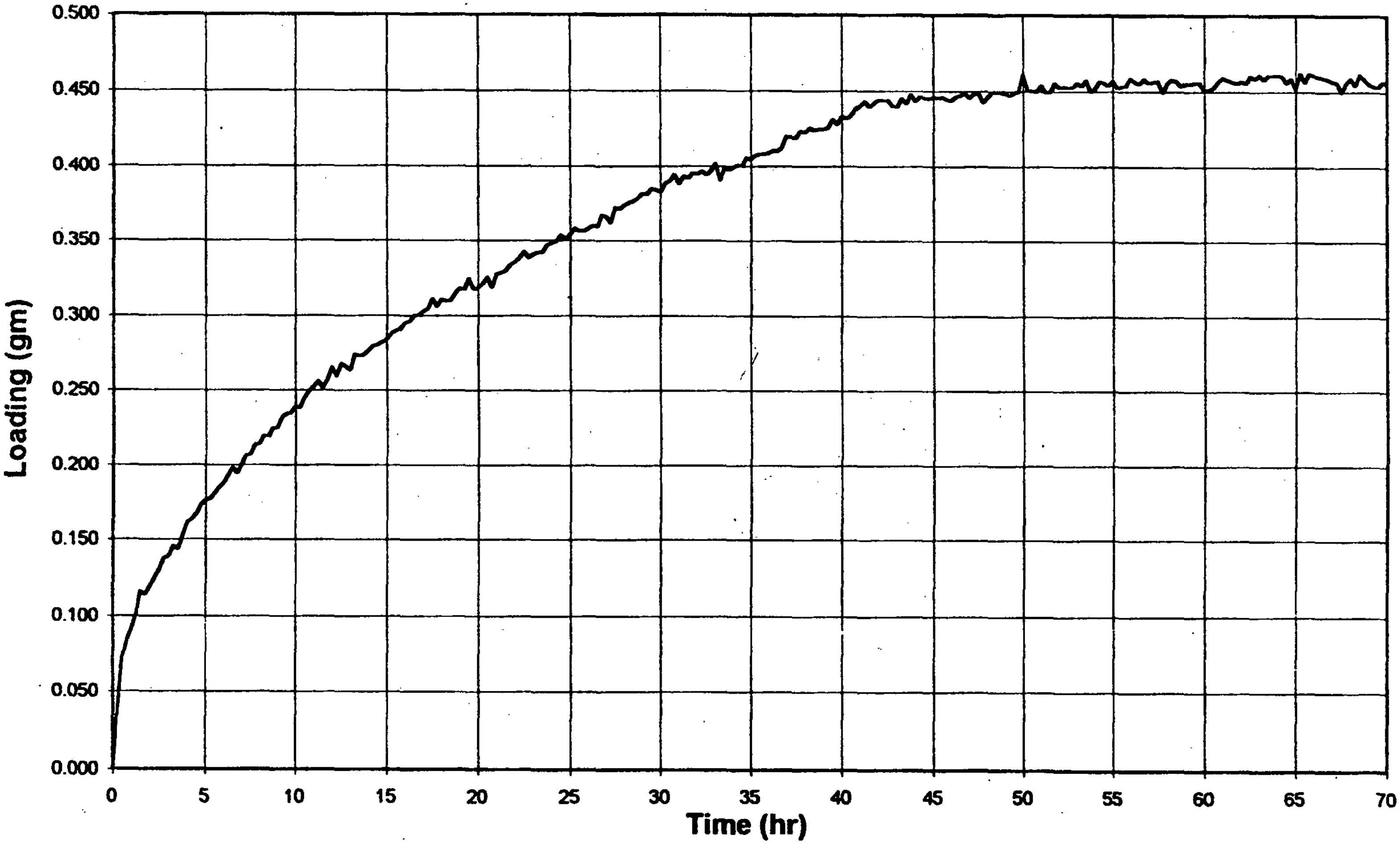

Figure 4 CH_3I loading curve from Test T3.

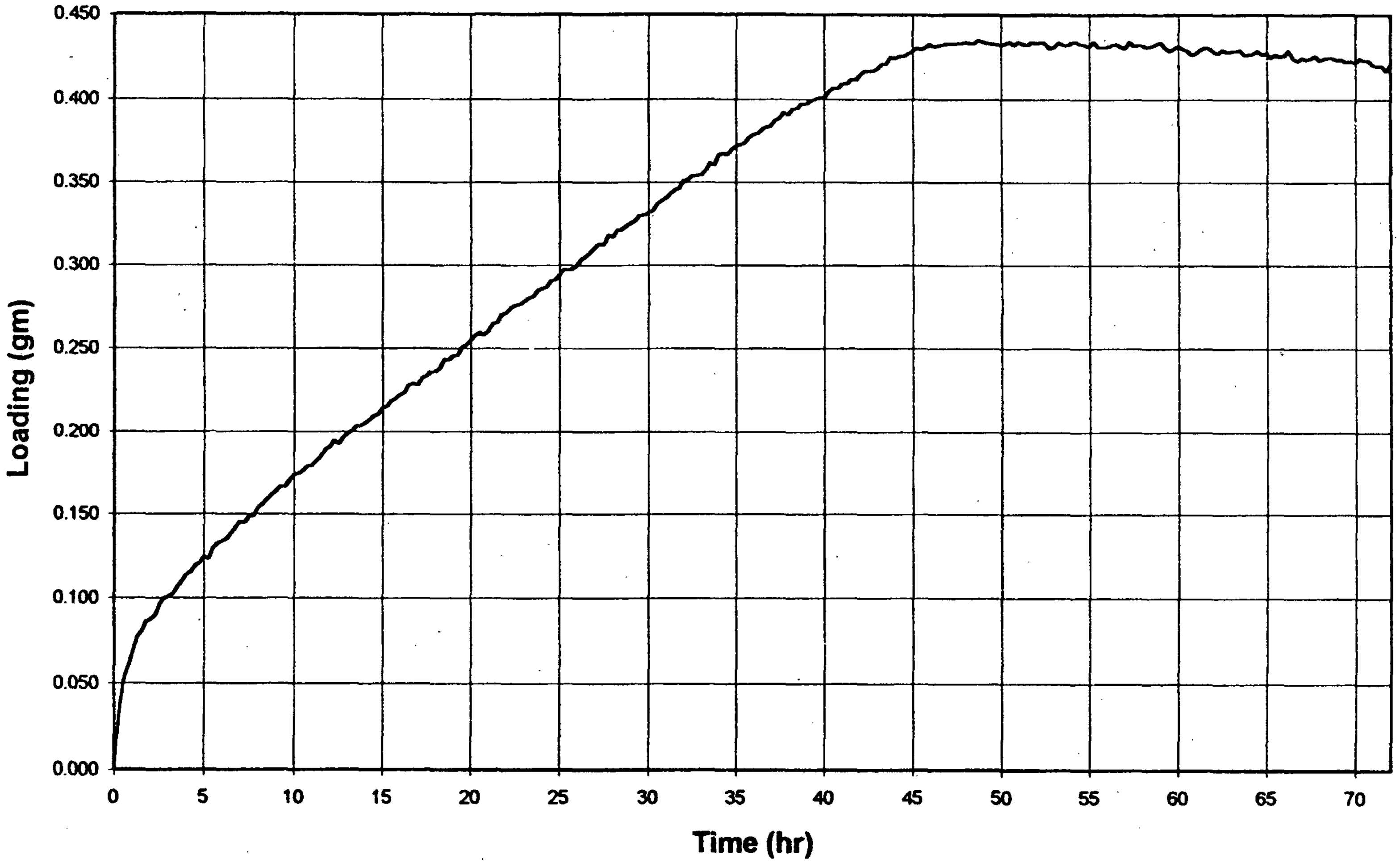

Figure 5 CH_3I loading curve from Test T22.

stopped. The total weight loss from the pellets during the air flush was generally about 1 to 2% of the total iodine loaded. A summary of the actual test conditions is presented in Table 2

Discussion

Analysis of Optimization Techniques and FORTRAN Implementation of Potential Models

To determine the mechanism(s) controlling the mass transfer of CH_3I onto the silver-exchanged mordenite, the experimentally obtained data were compared against widely accepted models of adsorption behavior. Each of the nine models from the literature was translated into appropriate FORTRAN code using Microsoft Corporation's Powerstation FORTRAN compiler, Version 1 0. In each case, the formulation of the model equations is such that given the appropriate rate-controlling parameters, the degree of conversion or a mass flux at a specific time can be directly or indirectly computed. The term "indirectly computed" means that the conversion cannot be directly computed but must be found by iteration or by some root-finding method The potential models were evaluated against the observed adsorption uptake curves. The best values for the rate-controlling parameters were determined by linear or multidimensional regression techniques using the experimentally obtained loading data as the reference.

The two primary criteria applied to the selection of the appropriate model for this system were (1) the ability of the model to account for the systematic variation in operating parameters without arbitrary changes in the adjustable parameters and (2) the determination of consistent diffusion coefficients for the experimental conditions evaluated

Two classes of data fitting models were employed in this study. The first, and by far the simplest, was the single parameter model In this case, it was a relatively simple matter to find the minimum using any of a variety of minimization techniques The FORTRAN function FMIN described by Forsythe et al. (1977) was used for all single parameter models This function used a combination of a golden section search technique and successive parabolic interpolation. This provided a very robust function not requiring the determination of derivatives

Several of the models required multidimensional minimization to extract the relevant parameters. These models included both the full shrinking core and the bimodal. The determination of "best fit" to the experimental data in the case of a multiparameter model was significantly more complex. Press et al (1992), in discussing multidimensional minimization, recommend the POWELL method as being faster in most cases and state that it can be used when derivatives are not easy to calculate.

CH_3I Adsorption–Model Comparisons

General Model Requirements

In the identification of a model to describe the adsorption of CH_3I onto silver-exchanged mordenite, it was required that certain general observations be accounted for by the selected model. These were as follows:

1. The possible formation of a rapidly shrinking shell of reacted material as observed in Figs. 2 and 3, noting, of course, that the unreacted core was no longer visible once 30-50 % conversion was achieved.

Table 4 Comparison of the simple sum of the square of the error in the conversion terms for the shrinking core models.

	Gas film		Ash diff		Rxn control		Gas film + Ash + Rxn			
Run No.	k_g (cm/s)	Error[a]	D_e (cm^2/s)	Error	k_s (cm/s)	Error	k_g (cm/s)	D_e (cm^2/s)	k_s (cm/s)	Error
T3	7 44E-02	2.46E+00	1.05E-03	6.89E-03	1.05E-01	1.16E+00	9.90E+99	1.05E-03	1.02E+06	6.89E-03
T6	7.76E-02	3.44E+00	1.33E-03	4.52E-02	1.20E-01	1.16E+00	9.90E+99	1.56E-03	8.42E-01	1.73E-02
T7	1.14E-01	1.74E-01	1.70E-03	6.41E-01	1.36E-01	1.76E-01	9.18E+99	4.72E+11	1.36E-01	1.76E-01
T8	4.20E-02	1.93E-01	3.17E-04	8.44E-01	5.00E-02	2.27E-01	9.20E+99	4.74E+11	5.00E-02	2.27E-01
T10	1.13E-01	4.56E+00	2.75E-03	4.73E-01	2.08E-01	1.85E-01	9.90E+99	8.86E-03	2.99E-01	3.13E-02
T11	8.33E-02	5.30E-01	6.85E-04	4.50E-03	1.01E-01	3.49E-01	9.90E+99	6.85E-04	1.36E+06	4.50E-03
T12	4.74E-02	2.30E-02	1.87E-04	1.91E-01	5.20E-02	1.43E-02	9.90E+99	3.01E-03	5.59E-02	1.27E-02
T13	5.52E-02	3.94E-02	4.85E-04	9.70E-01	6.76E-02	6.93E-02	9.64E+99	4.22E+12	6.76E-02	6.93E-02
T14	1.61E-01	3.17E-01	9.94E-04	8.08E-02	1.86E-01	2.03E-01	9.90E+99	1.66E-03	4.95E-01	3.26E-02
T15	4.82E-02	2.55E-02	3.32E-04	1.19E+00	5.67E-02	9.42E-02	9.89E+99	9.13E+12	5.67E-02	9.42E-02
T16	5.80E-02	4.39E-01	6.59E-04	6.81E-01	7.63E-02	6.20E-02	9.90E+99	4.12E-03	9.24E-02	1.97E-02
T18	5.08E-02	3.32E-02	3.10E-04	4.93E-01	5.87E-02	2.43E-03	9.90E+99	1.35E-02	6.03E-02	1.87E-03
T19	1.14E-01	6.12E-02	5.08E-04	1.60E-04	1.27E-01	4.93E-02	9.90E+99	5.08E-04	6.11E+06	1.60E-04
T20	2.87E-01	2.11E-01	3.88E-03	1.87E-03	3.40E-01	1.44E-01	9.90E+99	4.19E-03	5.05E+00	1.21E-03
T22	9.21E-02	1.05E+00	2.16E-03	2.98E-01	1.23E-01	3.89E-01	9.90E+99	4.38E-03	2.54E-01	9.79E-02
T26	7.36E-02	9.91E-01	5.08E-04	9.40E-02	8.67E-02	7.95E-01	9.90E+99	5.08E-04	2.07E+13	9.40E-02
Total errors		1.46E+01		6.01E+00		5.08E+00				8.87E-01

[a]Error terms are the resultant sum of the square of the error between the experimental data and the proposed model.

2 Fairly uniform iodine loading across the pellet diameter at 30 to 40% conversion of silver or greater.

3 Observation from past studies that higher loading was achieved prior to breakthrough with increased operation temperature.

Shrinking Core Model

The regression analyses for the shrinking core model is presented in Table 4. By examining this table, it is clear that the diffusion through the gas film was not the controlling mechanism In virtually every case in which the parameters for three terms of the full shrinking core model were used as adjustable parameters in the minimization of the error between the model and experimental data, the computed value for k_g was on the order of 10^{100} cm/s. This value was the upper limit set in the search routines. In the few cases where it did not reach the upper bounds, the value is still above 10^{10} cm/s. The substitution of this value in the Eq. (5) for $\tau_{gasfilm}$ and the subsequent application into summation of the resistances showed that the resistance was mathematically negligible. Further, the values of k_g determined for the gas film alone were compared with the values of k_g as estimated by use of the Sherwood number and the molecular diffusivity D_{AB}. The values of k_g estimated by the Sherwood number were on the order of 3 to 9 cm/s. However, if the assumption was made that the controlling resistance was the gas film, then the values for k_g determined by the least-squares curve fitting method ranged from 0 04 to just over 0.3 cm/s. Finally, the shape of the uptake curve was not indicative of gas film resistance control.

Thus having ruled out gas-phase control and continuing with the shrinking core analysis, there appeared to be two distinct classes of behavior or types of loading curves. The first class may be described by diffusion control through the ash layer, which appeared to describe several of the cases (e.g., T3), however,in most of the runs, the loading curve appeared to have a "knee" which the shrinking core model cannot fit. These uptake curves tended to show a rapid weight gain followed by a slower rate of weight gain. This "knee" may also be an indicator that possibly two or more mechanisms were controlling the adsorption process and that there was a transition from one to the other.

If the ring observed on the pellets, as shown in the Fig. 3, was related to the loading of iodine on the pellet, then it was easily shown that at 40% utilization the radius of the unreacted core should be ~78% of the overall pellet radius. The observed radius in Fig. 3 was only ~27% of the pellet radius for the pellet that still shows a core. This 27% equates to ~93% conversion if a strict shrinking core model was correct. It should also be recalled that the BEI of the pellets from T19 and T20 showed no significant iodine gradient, which appeared to be relatively consistent with the photographic evidence at higher iodine loadings. These data tended to lead to the conclusion that while there may initially be the appearance of the shrinking core-type behavior, there was also a second slower process that accounted for the loading above some nominal level of loading associated with the shrinking core.

The effective diffusivity calculated from the data collected over the time periods of the first 40 data points (10 h) ranges from 1.84×10^{-4} to 3.91×10^{-3} cm^2/s for the runs that did not exhibit any thermal upset in the balance. This effective diffusivity was also compared with that predicted by fundamental analysis of the zeolite pore structure and physical constants for the diffusing component. By comparison of the above effective diffusivities with the combined effective diffusivities for either the Knudsen diffusivity in the micropore/mesopore which are in the range of 5×10^{-5} to 5×10^{-4} cm^2/s or the effective molecular diffusivity of $\sim 1.4 \times 10^{-2}$ cm^2/s in the macropore range, it was observed that the value obtained by curve fitting falls between the two bounding cases. Using the shrinking core model, it was possible to find a set of parameters that seems to successfully model each individual loading curve. However, it was less obvious why some sets of data were diffusion controlled and other similar sets appeared to be reaction controlled This model by itself was unable to explain the apparent change in controlling mechanism. However, it provides strong evidence that

1. the mass transfer process was not controlled by the gas film resistance; and
2. there was a diffusional component, and the effective diffusivities in the first few hours of loading were in the range of 1.84×10^{-4} to 3.91×10^{-3} cm²/s for the runs in which the data showed no thermal upset in the balance during the initial period.

Macropore/Micropore Model

Mathematically, these two models are essentially the same. In the micropore diffusion case, the radius of the crystal is the dimensional term used, and in the macropore case, the pellet radius is the relevant term. In the case of the macropore model, the diffusivity term that is obtained from the curve fitting analysis is an effective diffusivity which contains an equilibrium constant. This equilibrium constant, under cases of a linear equilibrium, relates the adsorbed phase concentration q to the gas phase concentration C by

$$q = K^{*}C \ . \tag{22}$$

The results of both micropore and macropore models obviously yield the same error terms (Table 5) and were virtually the same as those obtained for the ash diffusion term of the shrinking core model by itself. It can be noted that neither model provided a particularly good prediction of the overall experimental behavior. However, as noted above, for large values of time, a plot of the term $\ln(1 - X_B)$ vs time should yield a straight line with a slope of $-\pi^2 D_c/r_{i2}$ and an intercept of $\ln(6/\pi^2)$ at a value of time equal to zero if micropore diffusion is the controlling mechanism.

An example of such a plot is shown in Fig. 6. Table 6 is a tabulation of the resulting micropore diffusion coefficients obtained from the slopes of this type analysis of all data sets. The correlation coefficient values, R^2, showed very high correlation for the linear regression of this data. This indicated that after the initial portion of the loading process, the effective micropore diffusivity was constant and, based on the data from this study, fairly consistent over a significant range of operating conditions. All the slopes of the uptake curve plotted as the $\ln(1 - X_B)$ vs time were obtained for values of time greater than 10 h. For all runs except for T12, T14, T16, T18, and T26, the value of D_c was between 2.19×10^{-14} and 3.34×10^{-14} cm²/s. There was no notable distinction in the values of the determined micropore diffusivity between pellet size or by the addition of supplemental water vapor or any of the variations in the pretreatment steps.

T12 and T14, which utilized low CH_3I gas concentrations, exhibited lower values of D_c, 9.32×10^{-15} and 1.13×10^{-14} cm²/s, respectively. It has also been noted that both of these runs were subject to some thermal instability in the early readings.

The value of D_c for T26 is also somewhat lower than the rest of the data sets. The calculated value is 1.06×10^{-14} cm²/s, which in this case could be attributed to the lower bed temperature used in this run since D_c in theory follows an Arrhenius-type temperature response.

T18, which was conducted with a dry air stream, exhibited the same type behavior as the other runs and had a comparable value for D_c of 1.59×10^{-14} cm²/s, which seemed to indicate that in the long time period, the adsorption rate may also be controlled by micropore diffusion.

T16 yielded values for D_c of 2.98×10^{-14} or 5.39×10^{-14} cm²/s, depending on which portion of the loading curve is being analyzed. It was noted from the run log that there was some shift in the CH_3I feed rate that may have occurred and was not detected until after the weekend. This may have occurred about the time that the shift in the slope occurred.

Table 5 Micropore and macropore model parameters for the full data sets.

	Micropore		Macropore	
Run No.	D_c (cm^2/s)	Error[a]	D_p (cm^2/s)	Error
T3	1.82E-14	1.16E-02	4.50E-09	1.16E-02
T6	2.26E-14	7.44E-02	5.57E-09	7.44E-02
T7	6.73E-15	6.68E-01	6.23E-09	6.68E-01
T8	5.66E-15	8.75E-01	1.40E-09	8.75E-01
T10	3.43E-14	6.74E-01	8.45E-09	6.74E-01
T11	1.20E-14	5.32E-03	2.97E-09	5.32E-03
T12	1.65E-15	1.95E-01	4.07E-10	1.95E-01
T13	7.18E-15	1.02E+00	1.77E-09	1.02E+00
T14	3.72E-15	8.75E-02	9.17E-10	8.75E-02
T15	4.90E-15	1.22E+00	1.21E-09	1.22E+00
T16	1.17E-14	7.49E-01	2.88E-09	7.49E-01
T18	3.81E-15	5.10E-01	9.39E-10	5.10E-01
T19	1.16E-14	1.31E-04	2.85E-09	1.31E-04
T20	1.66E-14	2.13E-03	1.54E-08	2.13E-03
T22	1.24E-14	3.47E-01	1.15E-08	3.47E-01
T26	5.80E-15	8.86E-02	1.43E-09	8.86E-02
	Error sum:	6.53E+00		6.53E+00

[a]Error terms are the resultant sum of the square of the error between the experimental data and the proposed model.

The value for the y-intercept, however, was somewhat scattered. This was attributed to other mechanisms controlling the initial portions of the uptake curve In all cases the y-intercept was numerically greater than the expected value of $\ln(6/\pi^2)$ One explanation for this observation was that the observed uptake on the pellets was slower in the initial time periods than would have been observed if all microspheres in the pellet had been exposed to a uniform value of CH_3I at time zero This could occur if there were a second diffusional process to controll the CH_3I concentration profile across the pellet during the early time periods.

The X-ray fluorescence data indicated a fairly uniform distribution of iodine across the cross section of the pellet A uniform distribution would not be observed in the case of a strictly shrinking core or in a macropore diffusion-controlled situation. This observation was consistent with micropore diffusion playing a role in the overall controlling mechanism.

Bimodal Model

By examination of Eqs. (18) through (20), it can be observed that the bimodal model is defined by three specific parameters in addition to the physical measurement of the particle sizes and porosities. These parameters are the macropore diffusivity, D_p, the micropore diffusivity, D_c, and an equilibrium

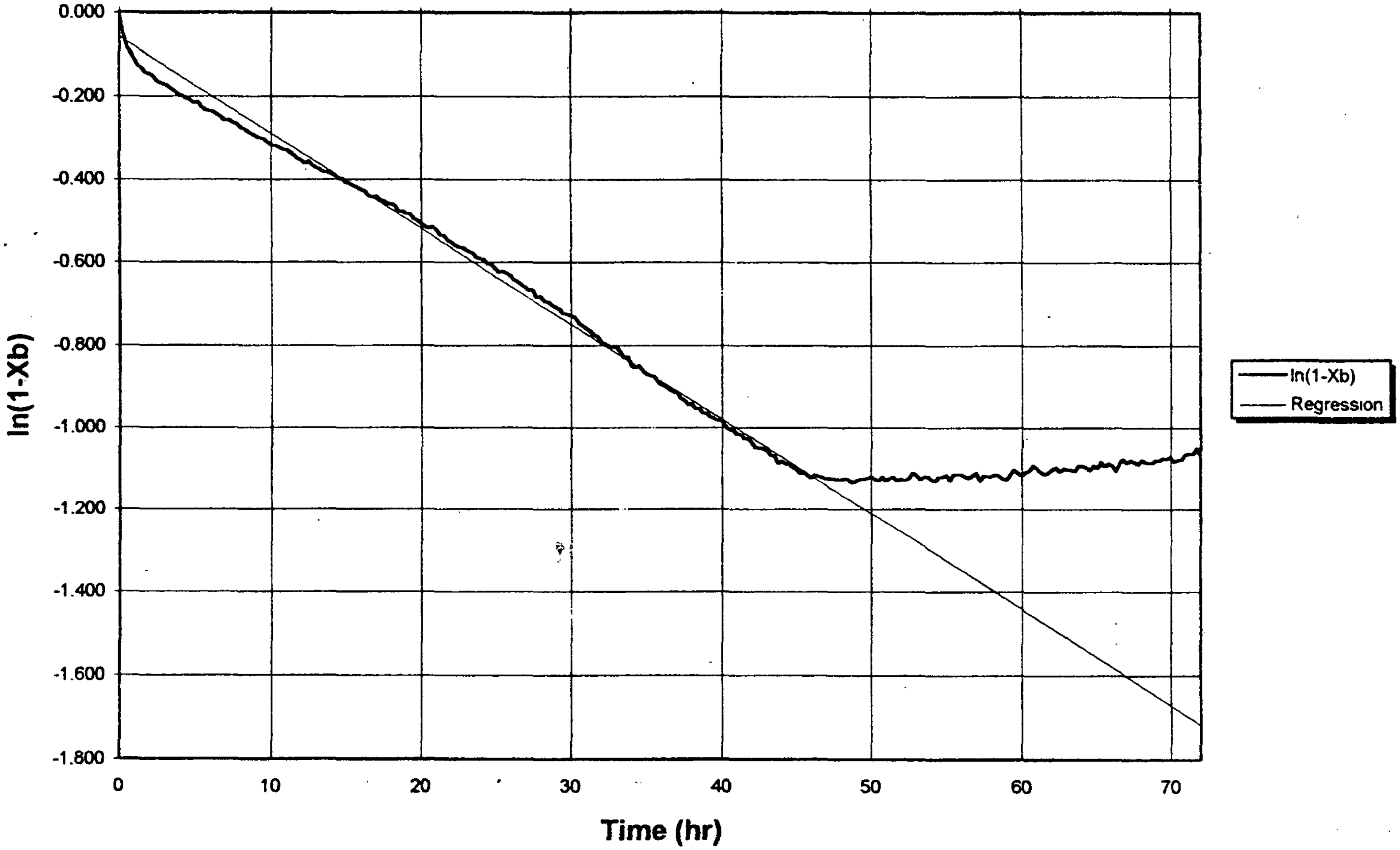

Figure 6 Determination of D_c from slope of the uptake curve plotted as $\ln(1 - X_b)$ vs time for Run T22.

Table 6: Micropore diffusivities calculated from slope of the uptake curve plotted as $\ln(1-X_B)$ vs time.

	Range considered				Weight adjustment to observed	Linear regression of $\ln(1-X_B)$			
Run No.	Beginning time (h)	End time (h)	Beginning conv. (fraction)	End conv. (fraction)	Loading (g)	Slope	Intercept	Correlation coefficient (R^2)	Regressed D_c (cm^2/s)
T3	20	40	0.505	0.685		−5.98E-06	−0.275	0.99	2.42E-14
T6	10	40	0.393	0.744		−7.76E-06	−0.25	0.997	3.15E-14
T7	30	40	0.429	0.571		−8.21E-06	0.331	0.999	3.33E-14
T8	30	80	0.363	0.854		−8.23E-06	0.488	0.998	3.34E-14
T10	10	40	0.082	0.572		−7.10E-06	0.126	0.989	2.88E-14
T10	10	40	0.136	0.621	0.025	−7.73E-06	0.0953	0.991	3.13E-14
T10	10	40	0.185	0.67	0.050	−8.49E-06	0.0669	0.993	3.44E-14
T10	10	40	0.381	0.865	0.150	−1.40E-05	0.0478	0.999	5.67E-14
T11	10	24	0.313	0.475		−5.40E-06	−0.187	0.998	2.19E-14
T12	20	60	0.146	0.384		−2.30E-06	0.00906	0.998	9.32E-15
T13	20	47.25	0.214	0.566		−6.36E-06	0.226	0.997	2.58E-14
T14	10	60	0.159	0.491		−2.78E-06	−0.0698	0.999	1.13E-14
T15	30	80	0.356	0.794		−6.33E-06	0.264	0.998	2.57E-14
T16	30	70	0.525	0.896		−1.07E-05	0.53	0.976	4.34E-14
T16	30	45	0.525	0.678		−7.36E-06	0.0543	0.999	2.98E-14
T16	45	70	0.678	0.896		−1.33E-05	1.1	0.997	5.39E-14
T18	20	70	0.223	0.624		−3.93E-06	0.0409	0.999	1.59E-14
T19[a]									
T20[a]									
T21	45.45	60	0.635	0.772		−9.10E-06	0.454	0.99	3.69E-14
T22	10	40	0.271	0.626		−6.4E-06	−0.0585	0.995	2.57E-14
T26	10	35	0.273	0.428		−2.62E-06	−0.218	0.995	1.06E-14

[a] Not determined due to short run length.

constant, q_{∞}/C_o. These parameters can be combined along with the physical measurements into the terms α and β. Clearly, however, a difficulty in this system is that α is a function of both D_p and D_c and β is a function of α. Ideally the solution to this model would be greatly simplified if D_c, D_p, and the equilibrium constant could be determined separately

Determination of the three parameters of the bimodal model, D_c, α, and β, by a multidimensional minimization operation was initially attempted. It was noted during the early attempts to conduct the minimization operations that as the initial search point was varied, the same values of the "optimum" parameters were not always obtained. As a result, each of the data sets was evaluated over the range of anticipated values for α and β for which the full bimodal model must be utilized

The ranges were selected to examine the behavior of the model between the bounding conditions and thus under conditions where both mechanisms are important. Values of α and β from 10^{-3} to 10^{+2} in six even steps on a logarithmic scale were used to create a "surface map" of the errors resulting from a one-dimensional minimization of the least-squares error with the experimental data by adjusting the micropore diffusion coefficient at each node on the map grid. It was noted in these surface plots that the determination of a "best fit" to the data was not always obvious from the surface formed as a function of α and β. It was observed that there could be numerous combinations of α and β, generated by adjusting D_c, that provided nearly the same sum of the squares of the error. The minimum values for the adjustable parameters of D_c, α, and β obtained from the surface mapping approach are summarized in Table 7. However, based on the surface contours, there could be several values of the adjustable parameters that provided good fits to the experimental data. Therefore, this method provided inadequate resolution to clearly identify any "correct" or "more correct" set of parameters to describe the adsorption process of CH_3I on Ag°Z.

The tables of D_c values determined from the surface mapping approach to locating the best fit to the experimental data were then examined for similarities with the values of D_c determined from the evaluation of the slope of the uptake curve plotted as $\ln(1 - X_B)$ vs time (Table 6). The closest values to the values of D_c determined by the slope method were selected based on the lowest sum of the squares of the errors from the tables of D_c values from the least-squares curve fitting method. As can be seen from Table 7, either the same point in terms of the adjustable parameters α and β or a nearby point yielded virtually the same error term. In most cases the selected values of D_c were associated with α values of 0.001, which indicated primarily micropore diffusion. β values were generally about 10. (Note, however, that an α value of 0.001 is the smallest value evaluated in the table.)

Ma and Lee (1976) reduced the bimodal-type curve fitting problem to one of a single parameter, the micropore diffusion coefficient, D_c, through the use of calculated values for the macropore diffusion coefficient and the use of experimentally determined values for the other parameters in α and β. For the CaX(Na) zeolite in their study, the macropore diffusivity was estimated based on the Knudsen and molecular diffusivities. A similar analysis was conducted with the data obtained in this study. The effective macropore diffusivity for the Ag°Z was calculated to be about 0.014 cm^2/s, and based on the effective Knudsen diffusivity in the mesopores, the overall macropore diffusivity was estimated to be about 5×10^{-4} cm^2/s. Finally using the value of D_c obtained from the slope of the plot of $\ln(1 - X_B)$ vs time, the effective overall macropore diffusivity along with the physical dimensions, values of α on the order of 5×10^{-6} up to about 8×10^{-5} were obtained.

The value of β appeared to be more difficult to establish. Obviously from the definition of β, it was a function of α which in turn was a function of the macropore and mesopore diffusivities. One other significant unknown remained in the β term, which was the value of the adsorption equilibrium constant. This was estimated to be about 3.4×10^5 based on the gas-phase CH_3I concentration from run T16 and the highest loading observed on the Ag°Z. The resulting value of β was about 20. β was the least well-established value, and a third optimization approach was taken to determine if a

Table 7 Bimodal model minimums based on error surface mapping.

	Best fit by mapping surface					Best fit by using closest/best match to D_c calculated by slope							
Run No.	D_c (cm^2/s)	α	β	Error[a]	β/3α	D_c (cm^2/s)	α	β	Error[a]	β/3α	r_a (cm)	r_i (cm)	D_β[b] (cm^2/s)
T3	2.95E-14	1.000	1.000	7.81E-03	0.333333	2.95E-14	1.000	1.000	7.81E-03	0.333333	0.09808	0.0002	7.09E-09
T6	3.22E-14	0.010	1.000	1.40E-02	33.33333	3.22E-14	0.010	1.000	1.40E-02	33.33333	0.09808	0.0002	7.74E-07
T7	4.23E-14	0.001	10.000	3.40E-01	3333.333	4.23E-14	0.001	10.000	3.40E-01	3333.333	0.19715	0.0002	4.11E-05
T8	3.59E-14	0.001	10.000	4.67E-01	3333.333	3.59E-14	0.001	10.000	4.67E-01	3333.333	0.09808	0.0002	8.63E-06
T10	1.49E-13	0.001	10.000	2.96E-01	3333.333	4.64E-14	0.001	1.000	3.54E-01	333.3333	0.09808	0.0002	1.12E-05
T11	2.00E-14	1.000	1.000	4.11E-03	0.333333	2.00E-14	1.000	1.000	4.11E-03	0.333333	0.09808	0.0002	4.81E-09
T12	1.45E-14	0.001	10.000	5.51E-02	3333.333	1.45E-14	0.001	10.000	5.51E-02	3333.333	0.09808	0.0002	3.49E-06
T13	4.23E-14	0.001	10.000	4.81E-01	3333.333	1.23E-14	0.001	1.000	4.81E-01	333.3333	0.09808	0.0002	2.96E-06
T14	2.60E-14	0.100	10.000	1.98E-02	33.33333	2.60E-14	0.001	10.000	2.21E-02	3333.333	0.09808	0.0002	6.25E-06
T15	3.26E-14	0.001	10.000	5.84E-01	3333.333	3.26E-14	0.001	10.000	5.84E-01	3333.333	0.09808	0.0002	7.84E-06
T16	6.27E-14	0.001	10.000	2.02E-01	3333.333	6.27E-14	0.001	10.000	2.02E-01	3333.333	0.09808	0.0002	1.51E-05
T18	2.70E-14	0.001	10.000	1.58E-01	3333.333	2.70E-14	0.001	10.000	1.58E-01	3333.333	0.09808	0.0002	6.49E-06
T19	1.95E-14	1.000	1.000	2.32E-04	0.333333	1.95E-14	1.000	1.000	2.32E-04	0.333333	0.09808	0.0002	4.69E-09
T20	2.18E-14	0.100	1.000	1.71E-03	3.333333	2.18E-14	0.100	1.000	1.71E-03	3.333333	0.19715	0.0002	2.12E-07
T22	6.50E-14	0.001	10.000	8.72E-02	3333.333	1.95E-14	0.001	1.000	1.31E-01	333.3333	0.19715	0.0002	1.89E-05
T26	6.50E-14	0.001	10.000	8.72E-02	3333.333	1.95E-14	0.001	1.000	1.31E-01	333.3333	0.09808	0.0002	4.69E-06
			Error sum:	2.81E+00					2.95E+00				

[a] Error terms are the resultant sum of the square of the error between the experimental data and the proposed model.
[b] Calculated from a by Eq. (19).

correlation existed between the observed behavior in the early time periods and the value of β with the operational or pretreatment conditions. Table 8 is a summary of the bimodal model parameters that were obtained through a one-dimensional least-squares optimization holding D_c to the values established by the slopes of the uptake curve plotted as $\ln(1 - X_B)$ vs time and α as calculated using D_c, the calculated effective macropore/mesopore diffusivity, D_p, the measured pellet diameter, and particle diameter determined from the electron microscope images as noted above. This in essence moved all of the unknowns and variabilities to the equilibrium term contained in the β expression.

Table 8 Optimized fit using bimodal model and fixed parameters of D_c based on the slope from the plot of $\ln(1 - X_B)$ vs time in the micropore model value and α based on theoretical computed values

	D_c (cm^2/s)	α	β	Error[a]
T3	2.42E-14	1.28E-05	5.52E-01	4.72E-02
T6	3.15E-14	1.67E-05	8.10E-01	1.77E-02
T7	3.33E-14	7.67E-05	6.80E+00	3.34E-01
T8	3.34E-14	1.77E-05	8.94E+00	4.64E-01
T10	5.67E-14	2.83E-05	1.88E+00	2.56E-01
T11	2.19E-14	1.16E-05	1.02E+00	3.88E-02
T12	9.32E-15	4.94E-06	4.96E+00	5.51E-02
T13	2.58E-14	1.37E-05	4.43E+00	4.70E-01
T14	1.13E-14	5.99E-06	2.46E+00	2.23E-02
T15	2.57E-14	1.36E-05	6.80E+00	5.74E-01
T16	2.98E-14	1.58E-05	2.92E+00	2.02E-01
T18	1.59E-14	8.43E-06	4.24E+00	1.58E-01
T19[b]	2.42E-14	1.28E-05	8.26E-01	6.65E-03
T20[b]	2.42E-14	5.57E-05	4.08E-01	6.41E-03
T22	2.57E-14	5.92E-05	1.98E+00	9.18E-02
T26	1.06E-14	5.81E-06	8.67E-01	2.42E-01
			Total error:	2.99E+00

[a] Error terms are the resultant sum of the square of the error between the experimental data and the proposed model.

[b] Short run D_c from Run T3 was used.

This approach produced relatively good fits to the experimental data. As can be seen by comparing the error terms contained in Table 8 with those in Table 7, the fits obtained by this method were as good as those obtained from the surface mapping approach to the locating of a global minimum. In several cases, notably T3, slightly higher errors resulted from this approach than from the approach in which multiple parameters were allowed to be adjusted, but the fit with the experimental data was still very good. The overall performance of this model using a single parameter was superior to the shrinking core model with all but one parameter fixed. There was, however, no obvious trend in the resulting values of β. These values ranged from 0.4 to about 9.

Further calculation of other parameters such as the equilibrium constant contained in the β term from the values of the parameters determined as described above was thought to be invalid for several reasons. First, when one parameter is determined from a second fitted parameter, the uncertainties tend to accumulate in the resultant value. Second, in this determination, since the value of D_c was determined from the slope of the uptake curve plotted as $\ln(1 - X_B)$ vs time and α was calculated from this value and other theoretical and measured terms, all of the uncertainties will be accumulated in the single adjustable parameter. Third, as noted from the photographs of the pellets, there can be significant variations in the structure, which in turn could impact the macropore diffusivity. Since the theoretical value of D_p was used, any variation from this value would end up being observed in the fitted value of β. It can also be shown that moderate variations in the theoretical values of D_p will not have an impact through α on the least-squares regression of the data to the proposed model (Jubin, 1995). And finally, the nature of the experiments conducted was not directed toward the determination of terms such as the equilibrium constant. Therefore, it is believed that any such secondary value would be of questionable validity.

Conclusions

This study has shown that there is a slow (micropore) diffusional process controlling the latter portion of the uptake curve . This was determined to be 2 x 10^{-14} cm^2/sec, and that the value of the diffusivity associated with this phase of the uptake was consistent over a number of runs. Based on the value of α obtained for the bimodal model, it was also shown that the process can be considered to be occurring in two steps. The time constants for the two processes are such that the macropore diffusion was virtually complete prior to any significant micropore diffusion occurring. Thus there was a shift in time prior to the start of the micropore adsorption.

One measure of this time shift was the observed shift in the y-intercept of the line describing the uptake curve plotted as $\ln(1 - X_B)$ vs time in the long time period. If no macropore diffusional resistance was observed and all microspheres were subject to a bulk gas-phase concentration equal to the bulk gas phase at time = 0, then only the micropore diffusional rate would be observed. In this case, the y-intercept would be the given by $\ln(6/\pi^2)$. However, with macropore diffusional resistance and adsorption occurring in the initial phase, there is some finite time period required before the concentration of the CH_3I becomes nonzero at any point in the pellet and even longer before it reaches the bulk equilibrium concentration. This delay shifts the start of the micropore diffusion and the associated micropore uptake. Thus for any given value of D_c obtained by the slope method, the actual conversion at a given time will be less than that predicted by micropore diffusion model alone using the derived value of D_c.

The quantity and rate at which iodine was adsorbed in the macropores is then a function of the available surface area, the nature of the macropore structure, and the quantity of available silver. Based on photographic evidence, the available surface area and the pore structure was quite variable and could not be predicted by any of the process measurements made during each of the test runs. The available silver may be related to the "nonframework" silver cations in the mordenite structure, to any silver on the surface of the mordenite crystals, and to the silver nodules that appear after the hydrogen pretreatment. This may also be quite variable and the magnitude of the variation was unknown for each run. This macropore diffusion control in the initial time period would also appear to explain the appearance of the shrinking core that vanishes by the time 20 to 30% conversion occurs. One other point on this topic is that the term macropore or bimodal, in the case of this material, is a significant simplification. The pore sizes range from 20 Å to 10 μ, with a peak in the macropore region occurring at about a pore diameter of about 1 μ. Thus a continuum of pore sizes existed.

This study has determined a consistent "micropore diffusion" rate on the order of 2×10^{-14} cm^2/s. It has also been shown that the bimodal model adequately explains the observed uptake behavior and the photographic as well as X-ray evidence. It has further been shown that the adsorption process described by this model can be considered a two-step process. This information is important since it is the rate of the second step that ultimately controls the final bed loading rate if high bed loadings are desired. There are, however, several questions concerning the impact of the many process and structural variables still remaining to be answered. But even without answers to every new question raised in this study, a significantly deeper fundamental understanding of the CH_3I adsorption processes onto Ag°Z has been achieved.

In summary, considering the potential sources for experimental variation and the model sensitivity, the values determined for the bimodal model parameters, D_c, α, and β, are very consistent and clearly appear to adequately model the uptake of CH_3I on Ag°Z over the longer time periods. In addition, the bimodal two-step process seems to explain the appearance of a "ring" or shrinking core in the pellets at low conversion and yet a uniform iodine distribution at higher loadings.

The specific conclusions drawn from this study are as follows:

1. It was shown based on both fundamental analysis and on the results of the least-squares curve fitting that the gas film resistance to mass transfer is negligible.
2. It was also shown that the system can be considered virtually isothermal. The maximum calculated temperature difference between the pellet and the bulk fluid was 0.37°C. This is an important determination in that it simplifies the modeling of the process.
3. The micropore diffusivity at 150°C as calculated from the slope of the $\ln(1 - X_B)$ vs time curve is in the range of 1.95×10^{-14} to 3.33×10^{-14} cm^2/s. The error in these values as estimated from the duplicate run at the standard conditions is about 30%.
4. The bimodal model, which includes the uptake in both the macropores and the micropores, provides the most uniform ability to model the behavior of the adsorption of CH_3I onto Ag°Z. The model parameters indicate that the uptake is occurring in a two-step manner, with the macropore uptake being much faster than the micropore uptake. This two-step process can account for the shrinking core observed at low conversions and the relatively uniform iodine concentration observed in the pellet at moderate to high concentrations.
5. The impact of the free silver observed in the mordenite structure could not be determined.

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List of Symbols

b = stoichiometric coefficient for B
C = concentration (g/cm^3)
D_{AB} = molecular diffusion coefficient (cm^2/s)
D_c = intercrystalline or micropore diffusivity (cm^2/s)
D_e = ash layer diffusion coefficient (cm^2/s)
D_p = pore or macropore diffusivity (cm^2/s)
D_∞ = pre-exponential factor in Arrhenius expression for D
E_d = diffusional activation energy (cal/mol)
K^* = Henry's law constant based on q/C (cm)
k_g = gas film mass transfer coefficient (cm/s)
k_s = reaction rate constant for the gas solid reaction (cm/s)
m_t = mass adsorbed at time t
m_∞ = mass adsorbed at time $t \rightarrow \infty$
N = moles
p = root to transcendental equations
q = adsorbed phase concentration (g/cm^3)
R = gas constant
R^2 = coefficient of determination
r_a = pellet radius (cm)
r_c = pellet core radius (cm)
r_i = particle radius (cm)
S = surface area (m^2/g) or (m^2/cm^3)
T = temperature (°C or K)
t = time (s)
X = conversion

Greek Symbols:

α = ratio of diffusional time constants $(D_c/r_i^2)/(D_p/r_a^2)$
β = parameter defined by Eq. (20)
ε_p = porosity of pellet
τ = tortuosity factor
ρ_B = molar density of B (gmol/cm^3)

Subscripts:

A = component A (generally CH_3I)
B = component B (generally silver, but in the D_{AB} term is air)
ex = external
g = bulk gas phase
0 = initial
s = surface

Superscripts:

$^\circ$ = metallic form of silver

Other Symbols and Notations:

$\bar{}$ = average value

DISCUSSION

BARLOW: What capacity do you believe you can be getting with your beds? From the knowledge you have now gained from your modeling, how much do you believe you could increase life? What is the typical utilization of the silver zeolite and does the information presented allow an estimate to be made of the maximum possible incorporation that might be achieved by an understanding of the controlling mechanisms?

JUBIN: In experimental tests with silver exchanged mordenite, loadings in the highest loaded segment of the bed have ranged from ~30% to ~60%, depending in large part on the operating conditions and bed depth. As can be observed from the thin bed loadings, completed as part of this test, silver utilizations of greater than 90% were achieved in numerous cases. The maximum loading that would be achieved in actual practice would be controlled by the bed design and by the operating conditions. By gaining an understanding of the controlling mechanisms through studies such as this one, the equipment and process conditions can be tailored to these mechanisms to achieve the highest practical utilization of the sorbent.

Removal Efficiency of Silver Impregnated Filter Materials and Performance of IodineFilters in the Off-Gases of the Karlsruhe Reprocessing Plant WAK

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Abstract

An almost quantitative retention of iodine is required in reprocessing plants. For the iodine removal in the off-gas streams of a reprocessing plant various sorption materials had been tested under realistic conditions in the Karlsruhe reprocessing plant WAK in cooperation with the Karlsruhe research center FZK. The laboratory results achieved with different iodine sorption materials justified long time performance tests in the WAK Plant. Technical iodine filters and sorption materials for measurements of iodine had been tested from 1972 through 1992. This paper gives an overview over the most important results.

Extended laboratory, pilot plant, hot cell and plant experiences have been performed concerning the behavior and the distribution of iodine-129 in chemical processing plants (Henrich 1980, 1981, 1988, 1996, and Herrmann 1992). In a conventional reprocessing plant for power reactor fuel, the bulk of iodine-129 and iodine-127 is evolved into the dissolver off-gas. The remainder is dispersed over many aqueous, organic and gaseous process and waste streams of the plant.

Iodine filters with silver nitrate impregnated silica were installed in the dissolver off-gas of the Karlsruhe reprocessing plant WAK in 1975 and in two vessel vent systems in 1988. The aim of the Karlsruhe iodine research program was an almost quantitative evolution of the iodine during the dissolution process to remove as much iodine with the solid bed filters as possible. After shut down of the WAK plant in December 1990 the removal efficiency of the iodine filters at low iodine concentrations had been investigated during the following years.

I. Introduction

In connection with iodine monitoring different methods for sampling iodine in the off-gas streams of the WAK plant were used.

Sampling with caustic scrubbers does not allow to catch the organic iodine. By this method in the off-gas of the Kalrsruhe reprocessing plant WAK only 15 % of the total measured iodine could be trapped. Parallel measurements with a discriminating sampling system for inorganic iodine confirmed that only 10 to 20 % of the total iodine in this vessel off-gas stream was inorganic (Herrmann 1990).

It is well known that sampling and filtering of iodine with charcoal allows to detect organic and inorganic iodine species only at low humidity of the off-gas. Numerous publications in the past years and the following considerations demonstrate some problems encountered utilizing charcoal as sorption material Charcoal is the most exhaustively studied adsorbent for iodine. High removal efficiencies can be obtained with plain or impregnated charcoal for elemental iodine. However acid vapors, organic vapors, and moisture seriously affect the efficiency of impregnated charcoal In either case the use of charcoal in off-gas systems containing more than 6 % nitrogen oxides is severely limited (Rodger 1969)

Results of laboratory experiences in the Karlsruhe research center (FZK) have demonstrated that during long-term measurements (about two months) the iodide impregnated charcoal looses most of the inactive iodide impregnation due to the oxidation of the iodide by the air A break-through of active iodine cannot be excluded

In the special case of the vessel off-gases of reprocessing plants which are currently saturated with water vapor from the scrubbing columns and kerosene from the solvent, sampling with charcoal is problematic The influence of the humidity on the removal efficiency of iodine samplers is reported by many authors and quantified by H Schüttelkopf At a relative humidity of >90 % iodine sampling is not effective. If 90 % humidity in the off-gas has been overstepped once, the following measuring periods are distinctly influenced It must be guaranteed that the measuring conditions have a security distance from the dew point of the gas to be measured (Schüttelkopf 1976)

Due to the problems of trapping iodine for measurements and removal of iodine in the off-gases of reprocessing plants, inorganic silver impregnated materials have been developed and were used as sampling and as filter materials in the off-gas streams of the WAK plant (Furrer 1979, Wilhelm 1976 and Herrmann 1995).

II. Testing of Silver Impregnated Iodine Sorption Materials and Iodine Filters

To optimize iodine sorption materials manufactured with different carrier materials and different silver contents, after the preliminary tests in the Karlsruhe research center, the sorption materials had been tested in by-pass streams of the WAK dissolver off-gas and the WAK vessel ventilation system, see figure 1 (Test conditions. temperature 140 °C, residence time 0 4 s, bed depth 0.1 m; gas flow rate 0 7 m^3/h, linear gas velocity 0.24 m/s)

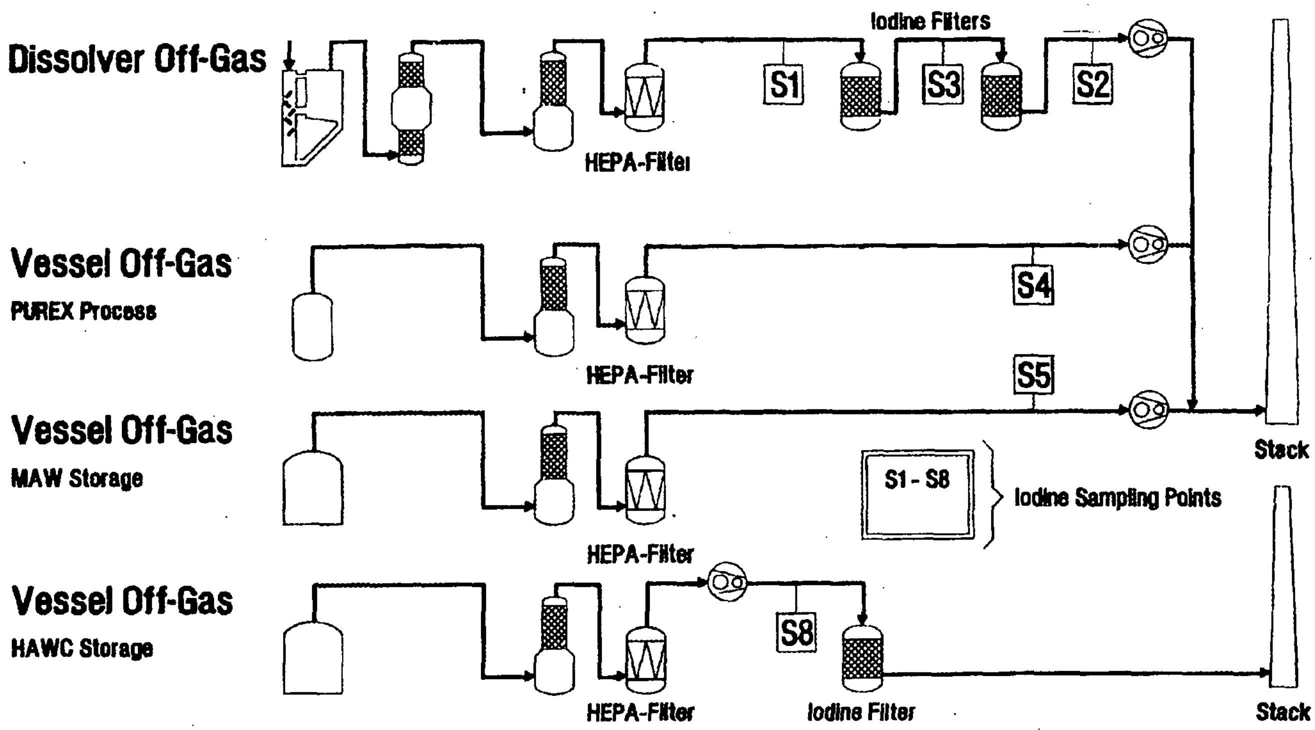

Figure 1 Offgas Cleaning of WAK with Iodine Filters and Iodine Sampling Points

For the investigations of the different sorption materials performed in the by-pass streams of the WAK dissolver off-gas (DOG) and the vessel off-gas (VOG), sampling points are located downstream the HEPA filters (upstream and downstream the iodine filters, see figure 1) They allow to determine simultaneously the iodine concentration in the off-gas and the removal efficiency of the iodine filters). The gas stream is routed through absorption columns which are located in a heating cabinet The internal diameter of the columns is 0.032 m The gas flow rate through the columns is 500 l/h (STP). The column contains six successive beds consisting of the sorption material Each bed is 0.05 m deep. The calculated residence time per bed is 0.2 s at 140°C After different exposure times the columns were removed. The beds were emptied individually and the sorption materials were measured on a Intrinsic Germanium Planar Detector to determine its iodine-129 content.

III. Evaluation of Silver Impregnated Iodine Sorption Materials

Experiments concerning the influence of the silver content of the carrier material on the iodine removal efficiency in the vessel off-gas of WAK have shown that an impregnation with 12 % silver is the optimum. Higher silver contents (for example 20 %) increase the risk of the efflorescence of the silver nitrate impregnation taking place in off-gases with 3 to 4 % of water vapor (resulting from the vapor pressure of the scrubbing columns working at 25 to 30 °C).

The essential parameters of sorption materials which may influence the removal efficiency of iodine sorption materials had been investigated All materials had been impregnated with 12 % silver in form of silver nitrate The porosity and the inner surface of the carrier material are decisive for the iodine removal efficiency. The alpha alumina shows a lower removal efficiency than the AC 6120.

The properties of the sorption material and the retained removal efficiencies are listened in table 1

Sorption material	AC6120 (Silica)	Alumina	Sinterglass
Grain size [mm]	1 - 2	2 - 4	1 - 2
Pore volume [ml/g]	0.62	0.45	0.5
BET surface [m^2/g]	65	7	0.15
Maximum of pore distribution [nm]	20 - 40	75	10,000 - 40,000
Silver content [%]	12	12	12
I-129 removal efficiency [%]			
- DOG of WAK	99.8	-----	90.0
- VOG of WAK	99.0	94.0	85.0 - 97.0

Table 1 Properties of sorption materials and iodine removal efficiencies in the off gas of WAK (Bed depth 10 cm, residence time 0.4 s; DOG = dissolver off-gas; VOG = vessel off-gas)

In an earlier paper it has been shown that it doesn't matter whether the carrier material is silica or alumina A silver impregnated gamma-Al_2O_3 (JFM 1) having a BET surface comparable to the BET surface of AC 6120, showed the same high removal efficiency as AC 6120 (Herrmann 1995) Besides temperature, residence time, silver content, iodine species and concentration in the off-gas, the decisive parameters for iodine removal efficiency are the porosity and the BET surface.

IV. Transferability of the Removal Iodine Efficiency Obtained by Small Scale Filters and Technical Filters

The decontamination factors obtained with the small scale columns (sampling filter· inner diameter 0.032 m, bed depth 0.15 m) and the technical iodine filter (annular cylinder with a bed depth of 0 15 m), are traced in figure 2 The small scale filters reveal a higher iodine removal performance than the technical iodine filter These values result from 12 measuring periods between 1989 and 1991.

The data for the iodine removal efficiency obtained by small sampling tubes (diameter 0,032 m, bed depth 0,1 m) are not directly transferable to the iodine removal performance obtained by full size iodine filters. Table 2 shows the iodine removal efficiency of a small size filter (bed depth 0,15 m, residence time 1.0 s, sorption material 0,078 kg) and a full size filter (annular cylindrical filter with a bed depth of 0.15 m and a filter diameter of 0 4 m, sorption material 35 kg).

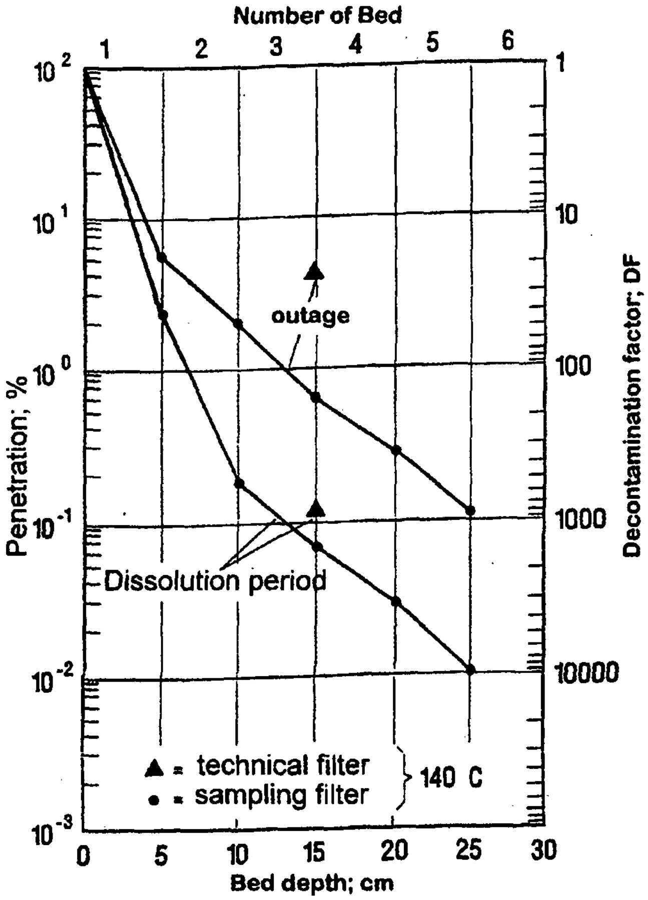

Figure 2 Removal efficiency of AC 6120 in a full size filter and in sampling filters.

	Small size filter	Full size filter
Mass of AC6120/12 % Ag	0.078	35
Bed depth [m]	0.15	0.15
Temperature [°C]	140	entrance· 130, exit: 110
Gas flow rate [m^3/h]	0.5	80 to 120
Linear velocity [m/s]	0.25	0 15
Residence time [s]	0.6	1.0
Iodine removal efficiency [%]		
- during dissolution	99.9-99.95	99.8-99.9
- during outage	98.7-99.3	94-96

Table 2 Comparison of iodine removal efficiency of a small scale and a full size iodine filter with AC6120/12% Ag in the dissolver off gas of WAK

The iodine removal efficiency of the full size filter is distinctly lower than the removal efficiency of the small size filters The lower removal efficiency of the technical filter can be explained by channeling effects. The differences between laboratory scale filters and full size filters must be taken into consideration for the design of iodine filters in the off-gases of reprocessing plants

V. Performance of Iodine Filters in the Off-Gas Streams of the WAK Plant

V.1 Dissolver Off-Gas

Two silver impregnated iodine filters in series were in operation in the dissolver off-gas of the WAK plant from 1975 through 1993. The filter material was a silver nitrate impregnated silica (AC 6120/12 % Ag) The filters worked at 110° to 130°C.

The dissolver off-gas filters were annular filters with the following characteristics:

Outer diameter	400 mm
Inner diameter	106 mm
Thickness of annular section	147 mm
Active filter volume	54 l
Number of filters	2 filters in series
Sorption material	AC 6120, 35 kg per filter
Gas temperature	inlet 130 °C, outlet 110 °C
Dissolver off-gas flow rate	80 to 120 m^3/h.
Residence time (off-gas)	1.4 s

The sorption material of the first filter was changed when the iodine removal efficiency of the first filter dropped significantly. Under normal operation conditions the iodine filters worked two years without interruption

During dissolution periods the highest removal efficiencies of 99 to 99 9 % for the first iodine filter had been measured. The average iodine concentrations in the dissolver off-gas upstream of the iodine filter was in the range between 1 and 5 mg/m^3 obtained by discontinuous measurements The peak values during dissolution were not measured because of the radiation power at the sampling points They are in the order of 100 mg/m^3 During outage periods the removal efficiency of the first iodine filter was 97 %.

The removal efficiency of the second iodine filter was 90 % during dissolution period and 50 % during outage periods The average decontamination factor of the second filter between 1989 and 1991 (two years of operation and one year after shutdown) was 4.

Downstream of the two iodine filters iodine-129 concentrations of about 0.005 mg/m^3 were observed during dissolution periods.

During the 15 years of operation a high stoichiometric loading up to 80 % of the first iodine filter had been achieved. The measured values of iodine loading were 17 GBq to 24 GBq The corresponding service lives were 2 to 4 years for the iodine filter material.

V.2 Vessel Ventilation System of the PUREX Process

In 1987 a prototype iodine filter with a throughput of 35 m³/h and the following dimensions has been installed in a side stream of the vessel off-gas of the PUREX process

Diameter	355 mm
Bed depth	150 mm
Sorption material	8.5 kg AC 6120 / 12 % Ag
Operating temperature	140°C
Gas velocity	14 cm/s
Residence time	1 s

The decontamination factor was determined by weekly measurements of the iodine concentration upstream and downstream the prototype iodine filter The removal efficiency of the prototype filter in this off-gas stream was 90 to 95 %.

The decontamination factors are influenced by the iodine concentrations and by the nature of the iodine species present in the vessel off-gas. Iodine loading after 2 5 years of operation was 21.4 MBq (3 27 g of iodine-129) for the total filter. This corresponds to a stoichiometric loading of 0.33 %.

V.3 Vessel Ventilation System of the Liquid High Active Waste Storage

Up to now the iodine filter with AC6120/12 % Ag in the vessel vent system of the liquid high active waste storage is operating at about 40 °C and a gas flow rate of 180 m³/h up to now An iodine removal efficiency of 90 % to 94 % is attained.

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DISCUSSION

JUBIN: A point of clarification concerning the difference between your technical filter and your sampling filter, you indicated that the sampling filter always had better performance than the technical filter. Was the technical filter exposed to other contaminants for a longer period of time than the sampling filter? The question is, did they have the same history? Can this be attributed to the length of time the sampling filters were in service or to other contaminants?

HERRMANN: The technical filter has always had distinctly lower removal efficiency than the sampling filter, even for the same experimental conditions and exposure times. Experiments performed with sampling filters of different sizes (diameter 25mm and 33mm) showed the same phenomena. The smaller the filter diameter, the better the removal efficiency. When sampling filters and technical filters had the same service life, the sampling filters always showed a better iodine removal efficiency.

SAKURAI: You use the two DOG filters in series at the WAK reprocessing plant. Why is the DF lower for the second filter than for the first one? Is it a commonly observed phenomenon?

HERRMANN: This has commonly been observed. The iodine concentration entering the second filter is by 3 orders of magnitude lower than the iodine concentration entering the first filter. The iodine species are probably different.

Control of Radio-Iodine at the German Reprocessing Plant WAK during Operation and after Shutdown

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Abstract

During 20 years of operation 207 metric tons of oxide fuel from nuclear power reactors with 19 kg of iodine-129 had been reprocessed in the WAK plant near Karlsruhe In January 1991 the WAK Plant was shut down. During operation iodine releases of the plant as well as the iodine distribution over the liquid and gaseous process streams had been determined Most of the iodine is evolved into the dissolver off-gas in volatile form. The remainder is dispersed over many aqueous, organic and especially gaseous process and waste streams

After shut down of the plant in January 1991, iodine measurements in the off-gas streams have been continued up to now. Whereas the iodine-129 concentration in the dissolver off-gas dropped during six months after shutdown by three orders of magnitude, the iodine concentrations in the vessel ventilation system of the PUREX process and the cell vent system decreased only by a factor of 10 during the same period Iodine-129 releases of the liquid high active waste storage tanks did not decrease distinctly

The removal efficiencies of the silver impregnated iodine filters in the different off-gas streams of the WAK plant depend on the iodine concentration in the off-gas The reason of the observed dependence of the DF on the iodine-129 concentration might be due to the presence of organic iodine compounds which are difficult to remove

I. Introduction

Besides the optimization of the PUREX process particularly by an electrolytic uranium-plutonium separation, an important task for the WAK plant was to demonstrate low iodine releases in view of the project of the German industrial scale reprocessing plant

In 1975 the yearly iodine-129 release limit of the WAK plant via the off-gas was fixed to 240 MBq (equivalent to 37 g iodine-129) By this reason silver impregnated iodine filters had been installed in the dissolver off-gas

Main objective of the iodine management during operation of the WAK plant was to obtain a low residual iodine content in the fuel solution after the end of the dissolution process by evolving most of the iodine into the dissolver off-gas and an almost quantitative iodine removal on silver impregnated solid bed filters in the dissolver off-gas. At the beginning of 1988 silver impregnated solid bed iodine filters entered in operation in two vessel ventilation systems

In the meantime, the licensing authorities had reduced the maximum permissible iodine release of the planned German industrial scale reprocessing plant in Bavaria from 7.4 GBq (200 mCi) to 1.85 GBq per year (50 mCi) for a throughput of 350 tons of uranium from light water reactor fuel (burnup 50,000 MWd/ton U). This value of 1.85 GBq signified that only 0.2 % of the iodine inventory could be released by all off-gas streams of the plant.

After some years of intensive work at the Karlsruhe reprocessing plant WAK in 1989 it was clear that this ambitious aim of 0.2 % release of the iodine inventory could not be demonstrated in the WAK plant. Because of the shortness of time before shut down there was no possibility to install iodine filters in all off-gas lines of the WAK plant. Meanwhile the project of the industrial scale reprocessing plant in Germany had been given up in 1989 after 15 years of intensive development work.

II. Iodine Distribution in the WAK Plant

During fuel dissolution the fission product iodine is present mainly in its volatile elementary form. From the point of view of radio ecology, iodine-129, with a half life period of $1.6*10^7$ years and iodine-131 with a half life period of 8.02 days, are significant. If cooling times are > 1 year, as in the case of commercial reprocessing, practically all of the short life I-131 from uranium fission has decayed.

However, iodine-131 from fission of curium-244 in the fuel is detected and measured in all steps of the PUREX process in the dissolver off-gas, in the vessel ventilation system, and particularly in the vessel ventilation of the storage tanks of the liquid high active waste (Herrmann 1994).

II.1 Residual Iodine Content in the Dissolver Solution

The chemical behavior of iodine in a nitric acid medium is complex. Particularly at low concentrations, iodine behavior is dominated by the redox potential in combination with unavoidable, mostly organic trace impurities in the solution. The species and the concentration of these impurities depend on the suppliers of nitric acid and on processing details. So the behavior of iodine may deviate largely from expected textbook behavior (Henrich 1996, Comor 1992).

The conditions for evolution of iodine into the off-gas have been examined in laboratory, in inactive pilot plant scale, in the hot cell facilities of the Karlsruhe nuclear research center as well as in the WAK reprocessing plant.

Henrich, Grimm and Boukis (1991) demonstrated with a high burnup fuel (50 GWd/T U) from the BIBLIS light water power reactor in laboratory scale dissolution experiments residual iodine contents between 1.1 % (1.2 mg/l) and 2.2 % (2.3 mg/l) of the inventory of the fuel after dissolution of 80 g of UO_2 fuel in 220 ml HNO_3 (7.5 M). The values of 1.2 mg/l and 2.3 mg/l have been obtained with nitric acid of p.a. quality respectively with recycled acid from the WAK plant (Henrich 1991). After filtration of the fuel solution, addition of iodate carrier, subsequent NOx sparging and a second filtration of the fuel solution the residual iodine content decreased below 0.5 % (0.5 mg/l) of the iodine inventory of the fuel. The residual iodine concentration depends strongly on the quality of the nitric acid.

Because of the extraction behavior of the residual iodine in different extractants, Henrich (1991) and Boukis (1991) conclude that the residual iodine must be a mixture of many iodinated organic species with different extractabilities. Henrich (1988) pointed out that the concentration of organic impurities in a pure nitric acid in a ppm range is by two orders of magnitude higher than the aspired residual iodine content in the dissolver solution ($2*10^{-6}$ mol/l). Henrich's interpretation is supported by the results of Lieser (1989).

The WAK plant experiences (>8 hours boiling time, air sparging, addition of carrier iodine during the last 2 hours of dissolution) showed, that it is difficult to reach residual iodine values in the dissolver solution below 1 % of the inventory for a high burnup fuel (35,000 MWd/T U). This value corresponds to an iodine concentration of approximately 1 mg/l.

For dissolution in WAK lower iodine-129 concentrations than 1 % of the iodine inventory in the feed have been reported by Berg (1977). The discrepancy between the earlier WAK values and the recent values of the Karlsruhe research center and of the WAK plant is not connected with the evolving process but with the usual analytic iodine separation and determination procedure which took into account only the inorganic and soluble iodine compounds (Henrich 1996).

Depending on operation conditions in the WAK plant (8 hours boiling time, air sparging), the residual iodine concentrations in the dissolver solution generally were in the range of 1 to 4 mg iodine per liter. It seems that the residual iodine concentration [g/l] is not influenced by the burnup of the processed fuel; the fraction of the residual iodine in [%] is of course higher for the fuel with a low burn-up and with a low total iodine content. Fuel with a low burn-up of 7 to 14 GWd/t U yielded residual iodine contents of 4 % to 12 % (in average 6 %), whereas high burn-up fuel with 30 GWd/t U yielded average residual iodine contents of 2 to 3 % of the inventory of the fuel after the end of the dissolution. In both cases, high burn-up fuel and low burn up fuel, the range of the residual iodine concentration was 1 to 4 mg/l. (Fission product iodine-127 was taken into account with 25 weight % of the iodine-129 inventory).

Important parameters for the evolution of the iodine during the dissolution process are the quantity of water vapor generated during boiling of the dissolver solution (45 m^3/h), the formation of the nitrous oxides (20 m^3/h) and the duration of the dissolution process. For the standard dissolution conditions 8 hours are required. To obtain low residual iodine values in the dissolver solution it is important to have a high quantity of dissolver off-gas passing through the dissolver and the reflux condenser (80 to 120 m^3/h). The addition of natural iodine as carrier and sparging of the dissolver solution with NO_2 during the last hour of the dissolution resulted in an average iodine content of 1 % (about 1 mg/l) of the iodine-129 inventory in the case of a high burnup fuel.

The percentages employed for the following considerations are average values resulting from the analyses of many liquid and many off-gas samples. These values cover the analyzed iodine fractions obtained by fuel with burn-up between 15,000 MWd/t U and 40,000 MWd/t U.

II.2 Iodine Concentration in the Dissolver Off-Gas

In the Karlsruhe reprocessing plant the bulk of the iodine inventory (in average 94 %) is evolved from the dissolver solution and is transported by the dissolver off-gas DOG through a reflux condenser and two subsequent acid scrubbers on two iodine filters in series. These filters contain a silver nitrate impregnated silica material with a grain size of about 1 mm. The iodine concentration in the dissolver off-gas upstream the iodine filters undergoes big variations. Average values during dissolution periods are in the order of 1 to 5 mg/m^3 with peak values up to 100 mg/m^3.

After shut down of the WAK plant the iodine concentrations upstream the iodine filter in the dissolver off-gas dropped from average values of about 2 mg/m^3 in December 1990 to 0.03 mg/m^3 in January-February 1991 and further to 0.001 mg/m^3 at the end of 1991.

II.3 Iodine Depositions in the Sampling Lines of the Dissolver Off-Gas

Iodine depositions in sampling lines have been studied by Glissmeyer and Sehmel (1991). They occur in the sampling lines because of the high surface/volume ratio of the sampling pipes and the relatively low linear velocity of the sampling gas streams. Iodine depositions in the sampling lines can potentially lead to erroneous results of radioiodine measurements and make dubious all short term measurements concerning the removal efficiency of iodine filters or scrubbers. One example may illustrate the problem of iodine depositions:

Iodine sampling in the dissolver off-gas of WAK is performed discontinuously all 4 to 5 dissolutions. At the beginning of a dissolution campaign in WAK after 5 dissolutions of a fuel with a burnup of 14,000 MWd/t U only about 34 % of the iodine inventory of the fuel could be measured in the dissolver off-gas upstream the iodine filters. (This value can lead to the conclusion that the scrubbers upstream the iodine filters had an iodine removal efficiency of 60 %, assuming an iodine evolution of 94 % of the iodine inventory in the dissolver). After 14 dissolutions about 76 %, and after 32 dissolutions about 84 % of the iodine inventory were found on the sampling filters. These delayed iodine concentrations result from iodine depositions formed in the sampling lines at the beginning of a campaign.

The above cited results had been obtained without heating the sampling lines. To overcome the errors due to iodine depositions in non heated sampling lines, long term measurements have to be performed. By heating the whole sampling lines to > 80 °C, it had been demonstrated that iodine depositions can be prevented and that short term measurements of the removal efficiency of the iodine filters yield reliable results.

After the end of a dissolution period iodine concentrations in the dissolver off-gas system drop slowly. Several days are necessary to attain iodine concentrations comparable to the iodine concentrations in the vessel ventilation system of the PUREX process (0.008 mg/m^3).

II.4 Iodine Behavior in the PUREX Solvent Extraction Process

The percentages of iodine in the following considerations are average values resulting from the last five years of operation. They cover the analyzed iodine fractions obtained by fuel with burn-up between 15,000 MWd/t U and 40,000 MWd/t U (see chapter II.1).

The residual iodine species remaining in the fuel solution (in average about 5 % of the iodine inventory of the fuel; about 1 % is fixed on the dissolver residues) are distributed in the subsequent extraction process operations. About 2 % to 3 % of the iodine inventory of the dissolved fuel were found in the organic solvent (20,000 to 40,000 Bq iodine-129/l corresponding to 3 mg/l to 6 mg/l). The rest of about 2 % are spread over the high active waste and different off-gases. The organic iodine compounds in the solvent contribute to the iodine emitted by the vessel vent system of the PUREX process and the vessel vent of the subsequent medium active waste treatment facility. During solvent wash the iodine content in the organic phase does not decrease considerably Only about 0.3 % of the iodine inventory of the fuel was found in the alkaline solvent wash streams.

After shut down of the WAK plant the organic solvent, the organic and aqueous wastes have been transferred to the waste treatment facilities of the Karlsruhe Research Center The iodine releases of this facility had been discussed by Amend (1990).

II.5 Iodine Concentration in the Vessel Ventilation System of the PUREX Process

After 8 hours of dissolution the residual iodine concentration in the dissolver solution is 1 to 4 mg/l The residual iodine is routed to the extraction process In 1990 detailed investigations over different reprocessing periods were carried out during reprocessing of about 9 tons of fuel from nuclear power plants (burnup 5.4 to 30 GWd/t) to determine the distribution of iodine in the PUREX process. From the iodine arriving in the separations process, about 50 % are evolved into the vessel vent system. The average iodine concentration in the vessel vent (270 - 330 m^3/h) is between 0.008 and 0 018 mg/m^3 Maximum values measured over a 14 days period attained about 0.03 mg/m^3 (160 Bq/m^3 Iodine-129).

Immediately after shut down the iodine release via this off-gas dropped from about 10 MBq (1 5 g of iodine-129) per month in December 1990 to 5 MBq per month in January 1991 and reached values of about 0.2 MBq/month (= 30 mg/month) after 10 months

II.6 Iodine in the Vessel Ventilation System of the Medium Active Waste Storage Tanks

The iodine concentrations in this off-gas stream during operation was approximately 0 01 mg/m^3. After shut down this concentration did not drop immediately. One year after shut down the iodine concentration was lower by a factor of 10. No iodine filter was in operation in this off-gas

II.7 Iodine in the Vessel Ventilation System of the Liquid High Active Waste Concentrate (HAWC) Storage Tanks

Two storage tanks contain the high active waste concentrate of 20 years reprocessing history of the WAK plant (about 60 m^3 HAWC).

During the operation period of WAK the iodine concentration measured in this off-gas stream was between 0.002 to 0.006 mg/ m^3 (iodine-129: 10 to 30 Bq/m^3)

After shut down of the plant in January 1991 the monthly amount of iodine-129 evolved by the HAWC has not decreased considerably during five years In average 2 MBq of iodine-129 per month (0.3 g I-129) are evolved Table 1 gives an overview over the iodine-129 evolved.

Year	1991	1992	1993	1994	1995
I-129 evolved [MBq/a]	16.9	16 1	23.7	25.8	26 5

Table 1 Iodine-129 evolution from the liquid high active waste concentrate (HAWC)

The amount of iodine-131 evolved by the HAWC solution in terms of Becquerel is in the same order of magnitude as the amount of Becquerel of iodine 129. Iodine-131 results mainly from the spontaneous fission of Curium-244. Whereas Cm-244 and Cm-246 in the waste solution are the main sources for the generation of iodine-131 by spontaneous fission (Herrmann 1994), the iodine-129 evolved by this off-gas results mainly from the residues of the dissolution processes from 20 years reprocessing, containing some hundred grams of iodine-129.

Up to now the evolution of iodine-129 from these storage tanks show no significant decrease Due to the iodine filter in this vessel vent system the release values are about 10 % of the amount of the iodine evolved by these solutions

II.8 Iodine in the Cell Ventilation System

In the cell vent system of the WAK plant during dissolution periods a fraction of 0.3 % of the iodine-129 inventory of the fuel was measured Iodine monitoring devices in different ventilation systems revealed that the measured iodine (up to 30 mg per day) originated almost exclusively to the shear and dissolver cell The measured iodine concentrations in this off-gas were $3*10^{-5}$ mg/m³ and reached concentrations up to $18*10^{-5}$ mg/m³ during plant operation. Such high release values have been observed exclusively during dissolution periods The high releases of 20 to 30 mg of iodine per day had been measured by two independant monitoring systems over a period of 4 to 6 weeks It can be excluded that the measured iodine was a result of the shearing process itself Leudet and Leseur (1982) demonstrated that during shearing of high burnup fuel from power reactors fission product iodine release was not detectable

Two reasons may be responsible for an iodine leaking out of the dissolver

- A leakage of the dissolver cover seems to be possible at the beginning of dissolution when a high rate of nitric oxides are generated and the reduced pressure of the dissolver off-gas system goes to 0 (related to the pressure in the dissolver cell).
- The reduced pressure cannot be maintained during the opening of the dissolver cover when the fuel is loaded and iodine deposits may come into the cell

After shut down the iodine-129 release values dropped from about one MBq/month in December 1990 to 0.1 MBq/month in November 1991

III. Iodine Removal Devices

III.1 Acid Scrubbers and Caustic Scrubber in the Dissolver Off-Gas

Because of the presence of nitric oxides in the off-gases of a reprocessing plant the use of charcoal is prohibited.

Acid scrubbers: Concerning the two acid scrubbers in series located in the dissolver off-gas system of the WAK plant only 0.5 % to 1 5 % of the iodine inventory of the dissolved fuel had been measured in the nitric acid solution of the two packed columns after each dissolution charge This fact of a low removal efficiency must be seen in connection with the relatively high dissolver off-gas flow rate of the WAK plant of about 100 m³/h.

Caustic scrubber: At the beginning of 1975 during WAK operation it has been tried to remove the iodine evolved from the dissolver by caustic scrubbing. An iodine removal efficiency of 53 % to 71 % could be attained in the dissolver off-gas (Schüttelkopf 1976). Because this iodine removal efficiency was too low, iodine filters with silver impregnated silica entered in operation mid 1975 in the dissolver off-gas. In the vessel ventilation system only 15 % of the total measured iodine could be removed by caustic scrubbing (Herrmann 1990)

III.2 Silver impregnated Iodine Filters in the Dissolver Off-Gas

During dissolution periods the highest removal efficiencies for the two filters in series of 99 5 to 99.9 % related to the iodine concentrations in the off-gas upstream the iodine filter had been measured, the iodine concentrations in the dissolver off-gas varying in average between 1 and 5 mg/m^3. Downstream the two iodine filters in series iodine-129 concentrations of about 0.005 mg/m^3 were observed during dissolution periods.

During outage periods and during the first six months after shut down, iodine concentrations of about 0.01 mg/m^3 (65 Bq/m^3) had been measured upstream the two iodine filters Downstream the iodine filters iodine concentrations of about 0 0007 mg/m^3 were measured The removal efficiency of the two iodine filters in series dropped to 90 %.

One year after shut down the iodine-129 concentrations downstream the two iodine filters dropped to about 0.6 Bq/m^3.

III.3 Silver Impregnated Iodine Filter in the Vessel Off-Gas of the PUREX Process

As shown above the iodine concentration in the vessel off-gas varied between 0.008 and 0 018 mg/m^3 The measured removal efficiency of a prototype filter in a side stream of this off-gas has been 90 to 95 % of the iodine concentration in the off-gas upstream the iodine filter

III.4 Iodine Filter in the Vessel Ventilation System of the High Active Waste Storage

This iodine filter with AC6120/12 % Ag is operating at about 40 °C and has a removal efficiency 90 % to 94 %. The gas flow rate is about 180 m^3/h. The measured iodine contents in the off-gas upstream (evolved) and downstream (released) are shown in table 2

Year	1990	1991	1992	1993	1994	1995
Iodine-129 evolved [MBq/a]	35 0	16.9	16.0	23 7	23 9	26.5
Iodine-129 released [MBq/a]	2 3	0.9	1 5	2.0	1.72	1.4

Table 2 Iodine contents upstream and downstream the iodine filter in the vessel ventilation system of the storage tanks of the liquid high active waste concentrate (HAWC)

IV. Iodine Release of the Reprocessing Plant WAK during Operation and after Shut Down

The iodine release fraction of a reprocessing plant is defined as the ratio of all iodine leaving the plant to the iodine processed in the plant. It is determined by the efficiency of the iodine removal devices.

Most of the iodine released resulted from the vessel ventilation systems. During the considered period the vessel ventilation system had no iodine filters. Although the iodine removal efficiency of the filter in the dissolver off-gas was high (about 99.5 %), the iodine overall release from the plant was in yearly average 1 8 % of the iodine inventory of the fuel during 14 years of reprocessing The highest release fraction in one year was 4.1 % of the iodine processed. This high release fraction resulted from an experimental program with the aim of shortening the dissolution time of 7 dissolution charges from 8 hours to 5, 4 and 3 hours. It must be noted that this experimental program concerned only 7 from 25 dissolution charges in one month

The values of iodine 129 releases during the last year of operation (1990) and the following years after shut down demonstrate clearly a decrease of the iodine-129 concentration by a factor of about 10 in the off-gases.

Table 3 shows the iodine-129 and iodine 131 releases of the WAK Plant from 1990 to 1995

Year	1990 Operation	1991 shut down	1992	1993	1994	1995
Iodine-129 (MBq/a)	91	33	8.7	6.5	4.3	2 9
Iodine-131 (MBq/a)	12	3 7	4.5	4.5	4.1	2.5

Table 3 Iodine release of WAK Plant from 1990 through 1994 (shut-down January 1991)

After shut down most of the iodine releases is originated from the vessel vent system of the medium active waste storage tanks and the high active waste concentrate (HAWC) storage tanks The HAWC evolves in average 25 MBq iodine-129 per year. Since this off-gas stream passes through an silver impregnated iodine filter, the releases are lowered by a factor of about 10.

The iodine 131 emissions after shut down result exclusively from the high active waste concentrate The amount of iodine-131 evolved shows a slight tendency of decrease during the last five years due to the half life period of the nuclide Cm-244 (18 years), generating the iodine-131

During the last year of reprocessing (1990) the release fraction of the WAK plant for iodine-129 was 2.1 % of the iodine-129 inventory processed. From this 2.1 % two thirds originated to the vessel ventilation system of the PUREX process, one fifth to the storage tanks of the medium active waste and one tenth to the cell ventilation system. Only a fraction of 0 028 of the 2 1 % originates to the iodine filtered dissolver off-gas and a fraction of 0.018 to the iodine filtered vessel ventilation system of the liquid high active waste concentrate storage tanks.

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DISCUSSION

SAKURAI: At the WAK reprocessing plant, was the expulsion of iodine from the spent-fuel solution performed by NO_x sparging? And what was the effect?

HERRMANN: It was an experimental program which took a lot of preparation because we must make the demand to the authorities. But we have already made ten dissolutions with additions of I-127 and NO_2. NO_2-sparging and simultaneous addition of iodine-127 to the dissolver resulted in a residual iodine content in the feed solution of 1 mg/l.

JUBIN: I have a question on the high active waste concentrate. Have you had a chance to analyze the iodine content in the HAWC?

HERRMANN: The problem with the iodine-129 analysis was the biggest problem we had because the analytical procedure, by extracting and reextracting the iodine from the high activity solutions did not catch the organic species. And as far as I remember, in the high active waste solutions, we found between 500 and 5,000 B8/l before the concentration step (HAWC). But this was not compatible with the continuous evolution of iodine-129 tanks. (The measurement of iodine-129 in the offgases is reliable because after the HEPA filters, there is no other activity on these sampling filters.) The continuous evolution of I-129 from HAWC results from the solid residues in the HAWC containing iodine.

KNOCH: Iodine depositions can occur also in the main ducts of the offgas.

HERRMANN: In our case the linear velocity in the sampling lines is lower than the gas velocity in the main line. I agree, we cannot exclude depositions in the main pipes.

FUKASAWA: In Table 3 of your manuscript, I -129 release decreased more rapidly than I-131. (I-129: 91 MBq/y ('90) ⇨2.9 ('95); I-131: 12 ('90)⇨2.5 ('95) What is the reason for this phenomenon?

HERRMANN: The rapid decrease of I-129 releases is conspicuous after shutdown of the plant in January, 1991. The I-131 releases after shutdown result from the spontaneous fission of Cm-244 present in the high level liquid waste HAWC.

CLOSING COMMENTS OF SESSION CHAIRMAN

I would like to thank all of the speakers for their effort in attending this conference and for the quality of their presentations. I think that iodine studies continue to be important. In the United States we are moving toward looking at waste. A number of the statements by Dr. Herrmann are relevant to the work that is going on in waste and most certainly in the iodine content of the tanks. As we look at adsorbents we find that they all have potential application when there is a significant quantity of iodine that has to be removed from the waste. Other countries are proceeding with reprocessing and adsorbents can become important in their applications.

In this session we have heard five papers describing very interesting work from around the world. I found the studies concerning the continued release of iodine from the waste tanks at WAK very interesting and in particular the data that indicated the continued generation of iodine 131 from the tanks. While I am not aware of other reports of similar observations, I certainly recognize this as relevant to activities currently underway in the U.S. and warranting further investigation. Clearly this could have impact on the processing of the millions of gallons of waste currently stored within the DOE complex. The first paper of the session provided an update on the research into the behavior of iodine in the dissolver solution. This work continues to shed light on some of the reported variations in the observed iodine evolution from dissolver solutions. The second paper is also a continuation of previously reported work on the silver impregnated alumina iodine sorbents. This paper focused on the impact of NO_x, water vapor, and pre-exposure times. Other off-gas impurities were also investigated. The third paper reported on a fundamental study into the controlling mechanisms of methyl iodide adsorption on silver exchanged mordenite. Micropore diffusion was identified as the rate controlling process for the adsorption of methyl iodide in the long term. The fourth paper looks back over an extensive experience base on iodine removal efficiencies in actual operations. I want to thank the speakers for their effort and interesting research and evaluations.

SESSION 11

FILTERS

Wednesday July 17, 1996
Co-Chairmen: R. Dorman
J. Slawski
J. Dyment

A REVIEW OF DOE HEPA FILTER COMPONENT TEST ACTIVITIES: FY- 1994
J.W. Slawski, J.F. Bresson, and R.C. Scripsick

IN-PLACE HEPA FILTER EFFICIENCY TESTS
W. Bergman, K. Wilson, J. Elliot, and J.W. Slawski

METHOD FOR HEPA FILTER LEAK SCANNING WITH DIFFERENTIATING AEROSOL DETECTOR
B.J. Kovach , E.M. Banks, and W.O. Wikoff

UNCERTAINTY IN IN-PLACE FILTER TEST RESULTS
R.C. Scripsick, R.J. Beckman, and B.V. Mokler

VALIDATION TESTING OF RADIOACTIVE WASTE DRUM FILTER VENTS
L.D. Weber, R.S. Rahimi, and D. Edling

A GENERAL CORRELATION OF MPPS PENETRATION AS A FUNCTION OF FACE VELOCITY WITH THE MODEL 8140 USING THE CERTITEST 8160
N. Lifshutz, and M.E. Pierce

FURTHER DEVELOPMENT OF THE CLEANABLE STEEL HEPA FILTER AND COMPARISON WITH COMPETING TECHNOLOGIES
W. Bergman, K. Wilson, and G. Larsen

THE EFFECT OF MEDIA AREA ON THE DUST HOLDING CAPACITY OF DEEP PLEAT HEPA FILTERS
J. Dyment, and D. Loughborough

POTENTIAL FOR HEPA FILTER DAMAGE FROM WATER SPRAY SYSTEMS IN FILTER PLENUMS
W. Bergman, J.K. Fretthold, and J.W. Slawski

SIMULATION TEST OF AEROSOL GENERATION FROM VESSELS IN THE PRE-TREATMENT SYSTEM OF FUEL REPROCESSING
S. Fujine, K. Kitamura, and T. Kihara

EXTENDED-LIFE NUCLEAR AIR CLEANING FILTERS VIA DYNAMIC EXCLUSION PREFILTERS
S.W. Wright, H.S. Crouch, and J.H. Bond

A REVIEW OF DOE HEPA FILTER COMPONENT TEST ACTIVITIES

FY 1992-FY 1995

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Ronald C. Scripsick[3]

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ABSTRACT

The Department of Energy (DOE) HEPA Filter Test Facilities have continued to operate in a changing political and operational environment. All HEPA filters purchased for installation in DOE nuclear facilities are required to be tested at a DOE Filter Test Facility (FTF) prior to installation, but the program is changing. Due to changes in its primary mission, the numbers of HEPA filters purchased by DOE each year since FY 1991 have been substantially reduced, to the point where one of the FTFs (Hanford) was closed in FY 1995 due to lack of filters to test. During the period FY 1992 - FY 1994, DOE funding was not provided to support the FTF Technical Support Group at the Los Alamos National Laboratory. As a consequence, Round Robin Tests (RRTs), performed twice each year by the FTFs in order to assess constituency of test results among the FTFs, were not performed in FY 1992 and FY 1993. The Annual Reports, summary reports of FTF test activities reports prepared and statistically analyzed by the TSG, were not prepared for fiscal years 1992 - 1995. Technical support provided to the FTFs was minimal. Currently, there is talk of closing a second FTF, and there are ongoing discussions as to whether the DOE will continue to fund operation of one or more of the FTFs.

In FY 1994, DOE Defense Programs commenced funding the TSG. The Round Robin Test Program is again administered by the TSG. RRT data for the years FY 1994 and FY 1995 have been retrieved and entered into the RRT data base; the FY 1994 RRT report has been issued; and the FY 1995 RRT report is in progress. Data from Semi-annual reports prepared by the FTFs have been retrieved, and entered into the FTF data base at LANL. Standards related to HEPA filter test and procurement activities(1-4), which had been written, peer reviewed, and recommended for implementation by DOE (but never "officially" issued) are now scheduled for issuance by the end of CY 1996. Continuation of these activities, however, depends on whether DOE will continue to support the HEPA filter test program.

The history and activities of the FTFs and the Technical Support Group (TSG) at Los Alamos have been reported at previous Air Cleaning Conferences(5-13). Data from the FY 1991 Annual Report of FTF activities was presented at the 22nd DOE/NRC Air Cleaning Conference in 1992(14). Preparation of the Annual Reports was temporarily suspended in 1992. However, all of the FTF Semi-annual report data have been retrieved and entered into the Los Alamos data base. This paper focuses primarily on the results of HEPA filter tests conducted by the DOE FTFs during the period FY 1992 - FY 1995, and the possible effects of the DOE program uncertainties on the quality of HEPA filters procured for installation at the DOE sites.

I. INTRODUCTION

Twice each year the DOE HEPA Filter Test Facilities (FTFs) must prepare a summary report of HEPA filter test activities. Each year, the Technical Support Group (TSG) at the Los Alamos National Laboratory is tasked with compiling the two Semi-annual Reports from the FTFs into an Annual Report. The objective of the annual report is to provide information on the performance and quality of High Efficiency Particulate Air (HEPA) filters being purchased and installed at DOE facilities. Current DOE policy requires that every HEPA filter be tested at one of the FTFs prior to acceptance and installation at a DOE user facility. With the exception of the summary data which appears in Section III, Table 1, below, this report focuses primarily on the period FY 1992 through FY 1995.

II. ORGANIZATION OF THE REPORT

The combined data from tests performed at the DOE FTFs for fiscal years FY 1983 - FY 1995 are presented in Section III A of this report. In Section III-B, summary data for the period FY 1992 - FY 1995 is presented, together with a general discussion of these data. In Sections IV-VII, in order to readily compare the test data with data in previous reports, and to analyze them accordingly, the test data is presented, analyzed and discussed by individual fiscal years. Results of a multi-year trend analysis are presented in Section VIII, and overall summary statements and conclusions regarding the HEPA filter test data appear in Section IX.

III. ANALYSIS OF THE FTF DATA

A. Summary of Overall DOE FTF HEPA Filter Test Activities

Annual reporting of DOE HEPA filter test data commenced in FY 1983. From the program's inception in FY 1983, through FY 1995, the DOE FTFs tested a total of 131,218 filters. The average number of filters tested per year during the period FY 1982-FY 1990 was 12,465. The total number of filters tested during the period FY 1992-FY 1995 was 23,948, an average of just under 6000 filters per year. A significant decrease in numbers of HEPA filters tested each year began in FY 1991, when the total number of filters tested was 7,551, which was a new annual low. The downward trend has continued, such that in FY 1995, only 3,758 filters were tested at the DOE FTFs. Table 1 presents the overall HEPA filter test history for the period FY 1983 - FY 1995.

In FY 1991 and FY 1992, the decrease in filter test activities was attributed primarily to cessation of weapons production activities at the Rocky Flats Plant, resulting in a significant decrease in numbers of HEPA filters procured for installation at Rocky Flats. However, the downward trend continued in the years FY 1993 - FY 1995, reflecting the general curtailment of nuclear activities at several DOE sites. The frequency of HEPA filter changes in facility air handling systems has, in some cases, been sharply reduced, perhaps compounded by the fact that HEPA filters in radioactively contaminated systems at several sites remained in place for extended periods. This latter practice has also caused a decrease in the numbers of HEPA filters procured by DOE sites and tested at the FTFs. In July, 1995, the DOE FTF located at Richland, Washington was closed, due to lack of filters to test. There have been recent discussions within DOE which could result in closing a second FTF, or both of them.

Possible actions which could reverse the downward trend in HEPA filter procurement and testing might include: 1) an increase in treatment operations for radioactive and mixed wastes at several DOE sites; 2) an increase in decontamination and deconstruction activities at DOE nuclear facilities; and 3) a commitment to comply with previously established frequencies for replacing filters in radioactively contaminated air handling systems.

Table 1
Annual Filter Test Results- FY 1983 - FY 1991

Period	N[1]	NIA/%[2]	NAW/%[3]	NR/%[4]
10/82-9/83	10,468[5]	9,811/94	291/2.8	366/3.5
10/83-9/84	12,223[6]	11,657/95	310/2.5	255/2.1
10/84-9/85	13,762[7]	12,141/88	1014/7.4	597/4.3
10/85-9/86	14,500[8]	13,263/91	847/5.8	392/2.7
10/86-9/87	13,656	13,161/96	235/1.7	260/1.9
10/87-9/88	11,822	10,847/92	745/6.3	230/1.9
10/88-9/89	12,538	12,042/96	139/1.1	347/2.8
10/89-9/90	10,750[9]	10,398/97	52/0.5	352/3.3
10/90-9/91	7,551	7,353/97	0/0.0	198/2.6
10/91-9/92	6,221	5,868/94	0/0.0	353/5.7
10/92-9/93	8,683	8,028/92	0/0.0	655/7.5
10/93-9/94	5,286	4,763/90	0/0.0	523/9.9
10/94-9/95	3,758	3,082/82	0/0.0	676/18
TOTALS	131,218	122,414/93	3,633/2.8	5,204/3.9

1. Number of Filters Tested
2. Number Initially Accepted/ %
3. Number Accepted with Waiver/ % (Category Deleted in FY 1991)
4. Number Rejected/ %
5. Does Not Include FY 1983 Data From Oak Ridge FTF
6. Does Not Include Oak Ridge FTF Data for the First Half of FY 1984
7. Disposition of One Filter was Not Given in FTF Reports
   Disposition of 10 Filters was not given in the FTF Reports
8. Per DOE Direction, Two Filters were Reported as Both NAW and NR. The Sum of NIA, NAW and NR Exceeds N by 2.
9. Per DOE Direction, Fifty-Two Filters Were Reported as both NAW and NR. The Sum of NIA, NAW and NR Exceeds N by 52.

B. Summary of DOE HEPA Filter Test Activities: FY 1992 - 1995

Summary HEPA filter test data for the period 1992-1995 appears in Table III-2.

TABLE 2
HEPA FILTER TEST RESULTS FY 1992 - FY 1995

FY	# Rec.	# Acc./%[1]	Rejections			
			Penetration/%[2]	Resistance/%[3]	Other/%[4]	Overall/%[5]
1992	6,221	5,868/94.3	280/4.5	0/0	73/1.2	353/5.7
1993	8,683	8,028/92.4	145/1.7	0/0	510/5.9	655/7.5
1994	5,286	4,763/90.1	103/1.9	2/0.04	418/7.9	523/9.9
1995	3,758	3,082/82.0	68/1.5	479/12.8	129/3.6	676/18.0
TOT.	23,948	21,741/90.8	596/2.5	481/2.0	1130/4.7	2,2079.2

1 Number of Filters Accepted/% Accepted
2 Number of Filters Rejected for High Penetration/ % Rejected
3 Number of Filters Rejected for High Resistance to Airflow/% Rejected
4 Number of Filters Rejected for "Other" reasons/% Rejected
5 Overall Number of Filters Rejected for All Reasons/% Rejected

Of the 23,948 filters tested during the period FY 1992 - FY 1995, 21,741 or 90.8% were initially accepted by the FTFs (NIA), 2,207 or 9.2 % were rejected (NR), and no filters were accepted with waiver or repair (NAW).

The overall rejection rate during the period FY 1992 - FY 1995 was 9.2%, ranging from a low of 5.7% in FY 1992 to a high of 18.0% in FY 1995. These results represent a marked increase over rejection rates for the three previous years, which ranged from 2.6 % to 3.3%, or for the overall period FY 1983 - FY 1991, in which the filters were rejected at a rate of 2.8%.

Review of the test data identified no single cause for the increasing rate of HEPA filter rejection. In FY 1992, high penetration constituted the highest component (4.5%) of the overall rejection rate (5.7%). In both FY 1993 and FY 1994, the highest failure rate was attributed to the general category called "Other" (5.9% and 7.9% respectively). The "Other" category includes but is not limited to: media damage, carrier damage, failure to comply with specifications in purchase orders, physical dimensions which are out of tolerance, and poorly installed or damaged gaskets. Specific details on why filters, or lots of filters, are rejected for "Other" reasons are recorded in the Semi-annual Reports submitted by the FTFs, but have not been specifically broken out in the LANL data base or in the Annual Reports. The specifics for "Other" rejection can be (and were) retrieved, if deemed necessary, from the Semi-annual reports.

In FY 1995, the highest cause for test failure was resistance to airflow (12.8%). More detailed discussion of these failure rates appears in Sections IV-VII of this report.

The category "Accepted with Waiver (NAW)" was abolished in FY 1991, following a revision to the DOE HEPA filter procurement standard(4). From FY 1987 through FY 1990, filters Size 4 and above, which had been initially rejected for high resistance to airflow, were allowed to be tested at decreasing airflow rates until the resistance to airflow across the filter was equal to the applicable limit of 1" w.g.. Therefore, under this provision, <u>every</u> HEPA filter ultimately "passed" the resistance test. The downrated filters were to be installed in air handling systems which would not expose the filters to flow rates in excess of the established downrated test airflows. This technique was not successful; some downrated filters were installed in systems which exposed them to airflows in excess of their downrated airflow values. At an FTF managers meeting in 1990, it was agreed to eliminate both downrating and the "Accepted with Waiver" test category. From that point forward, HEPA filters tested at the DOE FTFs either must either meet the applicable limit of 1" w.g., at rated airflow or be rejected. The DOE Procurement Standard(4) was revised to reflect this change in 1991. Commencing in FY 1992, the category "Accepted with Waiver" is no longer reported.

Strict adherence to the modified test standard for resistance to airflow did not immediately result in higher HEPA filter rejection rates. This was primarily because only one of the FTFs reported tests of HEPA filters Size 7 (1500 cfm) or Size 8 (2000) cfm) during the period FY 1992-FY 1994. Specifically, Rocky Flats reported testing one lot of 24 Size 7 filters in FY 1993, all of which were accepted. However, further review of the circumstances related to this test batch brought forth the information that the filters had been designated as "special" filters, not to be subject to the 1" w.g. test limit for resistance to airflow. None of the filters would have been accepted had the applicable standard for resistance to airflow been applied.

In FY 1995, the Oak Ridge FTF did test one lot of 506 Size 7 (1500 cfm) filters, and a total of 35 Size 8 filters. The Size 8 filters were designated as "special" filters, not subject to the applicable criterion of 1" w.g.. None of the Size 8 filters would have been accepted had the DOE criterion been applied. In fact, none of the Size 8 filters would have been accepted had the criterion of 1.3" w.g. which appears in a once-applicable Military Specification(14), or its successor, (15) been applied, because the measured resistances in all of the tests were either 1.7" w.g., or 1.8" w.g.. The test history of the 506 Size 7 filters is discussed in more detail in Section VII-C of this report.

IV. FY 1992 HEPA FILTER TEST DATA

A. Summary of Test Results by FTF

FY 1992 test results, by individual FTF, appear in Table 3.

Table 3
FY 1992 HEPA Filter Test Results by FTF

FTF	N[1]	NIA[2]/%	NAW[3]/%	NR[4]/%
HANFORD	1,018	1,007/99	0/0.0	11/1.1
OAK RIDGE	3,217	3,056/95	0/0.0	161/5.0
ROCKY FLATS	1,986	1,805/91	0/0.0	181/9.1
TOTALS	6,221	5,868/94	0/0.0	353/5.7

1	**Number of Filters Tested**
2	**Number Initially Accepted/% Accepted**
3	**Number Accepted With Waiver (Now 0)**
4	**Number Rejected for All Reasons/% Rejected**

The overall rejection rate was 5.7%, which is more than twice the overall rejection rate of 2.8% for the period FY 1983-1991 (hereinafter the "Reference Rate"). Review of the results listed in Table 3 indicates a broad range of rejection rates, namely 1.1% at Hanford, 5.0% at Oak Ridge, and 9.1% at Rocky Flats. Review of additional test records indicates a rejection rate of 4.5% due solely to penetration, which by itself is about 1.5 times the "Reference Rate". This subject is further discussed Section IV-D of this report.

In FY 1992, the Oak Ridge FTF tested more filters (52% of the total tested) than the other two FTFs. This was only the second time since the filter test records data base program was initiated in FY 1883 that the Rocky Flats FTF was not the leader in total filters tested

B. Summary of Test Results by Manufacturer

Table 4 presents the overall FY 1992 HEPA filter test data by manufacturer. In FY 1992, Manufacturer # 7 supplied 4,995 of the 6221 (81%) HEPA filters tested by the FTFs; Manufacturer # 3 was second with 663 filters (10.6%); Manufacturer # 4 was third with 240 (3.8%); and Manufacturer # 19 was fourth with 137 (2.2%). The overall rejection rate for Manufacturer # 7 was 2.7%, compared to the overall FY 1992 rejection rate of 5.7%, however high rejection rates for filters supplied by Manufacturer # 3 (13%), Manufacturer # 4 (7.1%) and Manufacturer # 19 3M (75%) served to raise the overall rejection rate to 5.7%.

Table 4
FY 1992 HEPA Filter Test Results by Manufacturer

Manufacturer	N[1]	NIA[2]/%	NAW[3]/%	NR[4]/%
7	4,995	4,860/97	0/0.0	135/2.7
3	663	574/87	0/0.0	89/13
4	240	223/93	0/0.0	17/7.1
19	137	34/25	0/0.0	103/75
29	78	76/97	0/0.0	2/2.6
32	46	43/93	0/0.0	3/6.5
17	24	24/100	0/0.0	0/0.0
21	18	17/94	0/0.0	1/5.6
13	9	9/100	0/0.0	0/0.0
9	4	4/100	0/0.0	0/0.0
16	4	4/100	0/0.0	0/0.0
14	3	0/0.0	0/0.0	3/100
TOTAL	6,221	5,868/94	0/0.0	353/5.7

1 **Number of Filters Tested**
2 **Number Initially Accepted/% Accepted**
3 **Number Accepted With Waiver (Now 0)**
4 **Number Rejected for all Reasons**

C. Summary Discussion - FY 1992

The FY 1992 Semi-annual Report data was analyzed to identify statistically significant differences in HEPA filter test data among the FTFs, or among manufacturers. Statistical analysis was performed by use of an Analysis of Variance technique (ANOVA). When statistical differences are identified, the Semi-annual report data and/or individual test records are further reviewed to determine their cause and practical significance. Statistical analysis of FY 1992 test data identified several significant differences among manufacturers, but not among the FTFs. Chief among them were:

- An extremely low (64.3%) acceptance rate at the Oak Ridge FTF for Size 1 (25 cfm) filters supplied by Manufacturer # 3.

- An extremely low (17.6%) acceptance rate at the Rocky Flats FTF for Size 3 (125 cfm) filters supplied by Manufacturer # 19.

- Acceptance of only six of eleven Size 4 (500 cfm) filters supplied by Manufacturer # 4 at the Oak Ridge FTF.

The statistical analysis described above helped to focus further review on specific filter test data. This review confirmed a higher than usual rejection rate due to high penetration. Review of past test records indicates that although the rejection rates due to high penetration for the period FY 1983 - FY 1991 were typically less than 2.0%, the rejection rate due to high penetration in FY 1992 was 4.5%.

Review of the FY 1992 Semi-annual report data indicates that the high overall rejection rate was due chiefly to filters from four specific shipment lots. All the filters in these lots were rejected for high penetration. Three of the lots were tested by the Rocky Flats FTF; the fourth was tested by Oak Ridge.

Two of the lots tested at Rocky Flats were composed of Size 3 HEPA filters supplied by Manufacturer # 19. In one lot, 61 of 71 filters (85.9%) were rejected for high penetration, in the second lot, 42 of 54 filters

(77.8%) were also rejected for high penetration. This represents an average rejection rate of about 82% for the two lots. In the third lot tested by Rocky Flats, 45 of 242 Size 5 filters (19%) supplied by Manufacturer #7 were rejected for high penetration. In the fourth lot tested by Oak Ridge, 73 of 140 Size 1 HEPA filters (52.1%) supplied by Manufacturer # 3 were rejected for high penetration. The four lots in question accounted for 221 of the 280 (78.9%) filters rejected for penetration in FY 1992.

It is noteworthy that none of the 6,221 HEPA filters tested in FY 1992 failed the test for resistance to airflow. The rejection rate for "Other" causes in FY 1992 was 1.2%.

V. FY 1993 HEPA FILTER TEST DATA

A. Summary of Test Results by FTF

FY 1993 test results, by individual FTF, appear in Table 5.

Table 5
FY 1993 Test Results by FTF

FTF	N	NIA/%	NAW/%	NR/%
HANFORD	903	882/98	0/0.0	21/2.3
OAK RIDGE	3,564	3,330/93	0/0.0	234/6.6
ROCKY FLATS	4,216	3,816/91	0/0.0	400/9.5
TOTALS	8,683	8,028/92	0/0.0	655/7.5

The overall rejection rate for all causes was 7.5%, or about 2.6 times the "Reference Rate". The predominant reason for rejection in the FY 1993 tests was attributed to the "Other" category for which the rejection rate was 5.9%.

B. Summary of Test Results by Manufacturer

Table 6 presents the overall FY 1993 HEPA filter test results by manufacturer.

Manufacturer # 7 supplied 6,980 of the 8,683 HEPA filters (80.4%) tested at the FTFs in FY 1993. Of these, 570 (8.2%) were rejected, nearly three times the "Reference Rate". Manufacturer # 3 supplied 619 (7.1%) of the tested filters. Of these 12 (1.9 %) were rejected. Manufacturer # 32 provided 434 filters (5%), of which 51 (12%) were rejected. Manufacturer # 5 supplied 250 filters (2.9%), of which nine (3.6%) were rejected, and Manufacturer # 4 supplied 158 filters (1.8%) of which four (2.5%) were rejected. The remaining 242 filters (2.8%) were supplied by twelve different vendors, and nine of these (3.7%) were rejected.

Table 6
FY 1993 HEPA Filter Test Results by Manufacturer

Manufacturer	N	NIA/%	NAW/%	NR/%
7	6,980	6,410/92	0/0.0	570/8.2
3	619	607/98	0/0.0	12/1.9
32	434	383/88	0/0.0	51/12
5	250	241/96	0/0.0	9/3.6
4	158	154/97	0/0.0	4/2.5
11	72	72/100	0/0.0	0/0.0
19	60	60/100	0/0.0	0/0.0
10	29	26/90	0/0.0	3/10
23	20	18/90	0/0.0	2/10
21	18	17/94	0/0.0	1/5.6
29	11	11/100	0/0.0	0/0.0
14	9	6/67	0/0.0	3/33
16	8	8/100	0/0.0	0/0.0
33	6	6/100	0/0.0	0/0.0
17	6	6/100	0/0.0	0/0.0
9	2	2/100	0/0.0	0/0.0
25	1	1/100	0/0.0	0/0.0
TOTAL	8,683	8,028/92	0/0.0	655/7.5

C. Summary Discussion - FY 1993

The FY 1993 Semi-annual Report data was analyzed to identify statistical differences among the FTFs or the manufacturers. There were no statistically significant differences among the FTFs, however, there was a statistical difference identified among the manufacturers for Size 5 (1000 cfm) filters. It was determined that the acceptance rates for filters supplied by Manufacturer # 7 were lower than usual especially at Rocky Flats and Oak Ridge.

Further review of the FY 1993 test data indicates that the high rejection rates for the Size 5 filters occurred in the "Other" category, and were primarily related to two shipment lots. The first lot was tested at Rocky Flats. Of a shipment lot of 1,358 filters, 304 (22.4%) were rejected because of media damage. The second lot was tested by the Oak Ridge FTF. Of 930 tested filters, 80 were rejected because of missing extraction clips, 25 for defective fluid seal gaskets, and 1 for frame damage, a total of 106 rejects (11.4%). The overall rejection rate for the year FY 1993 was 7.5%, about 2.7 times the "Reference Rate", of which 5.9% was due to "Other" causes, and 1.7% was due to high penetration. No filters tested in FY 1993 were rejected for high resistance to airflow.

VI. FY 1994 HEPA FILTER TEST DATA

A. Summary of Test Results by FTF

FY 1994 HEPA filter test results by FTF appear in Table 7. The overall rejection rate for filters tested in FY 1994 was just under 10%. This rate is more than three times the "Reference Rate". The highest rejection rate component (8%) was the "Other" category.

Table 7
FY 1994 HEPA Filter Test Results by FTF

FTF	N	NIA/%	NAW/%	NR/%
HANFORD	708	681/96	0/0.0	27/3.8
OAK RIDGE	1,371	1,175/86	0/0.0	196/14
ROCKY FLATS	3,207	2,907/91	0/0.0	300/9.4
TOTALS	5,286	4,763/90	0/0.0	523/9.9

B. Summary of Test Results by Manufacturer

Table 8 presents the overall FY 1994 filter test results by manufacturer.

Table 8
FY 1994 HEPA Filter Test Results by Manufacturer

Manufacturer	N	NIA/%	NAW/%	NR/%
7	3,752	3,616/96	0/0.0	136/3.6
3	937	718/77	0/0.0	219/23
32	313	229/73	0/0.0	84/27
19	111	52/47	0/0.0	59/53
4	54	52/96	0/0.0	2/3.7
29	41	41/100	0/0.0	0/0.0
5	20	0/0.0	0/0.0	20/100
10	20	19/95	0/0.0	1/5.0
23	13	12/92	0/0.0	1/7.7
16	11	11/100	0/0.0	0/0.0
13	9	9/100	0/0.0	0/0.0
21	4	4/100	0/0.0	0/0.0
6	1	0/0.0	0/0.0	1/100
TOTAL	5,286	4,763/90	0/0.0	523/9.9

Of the 5,286 filters tested, Manufacturer # 7 supplied 3,752 (71%); Manufacturer # 3 supplied 937 (17.7%); Manufacturer # 32 supplied 313 (5.9%); Manufacturer # 19 supplied 54 (0.1%); and various other manufacturers supplied 119 filters (2.3%). Of the 3,752 filters supplied by Manufacturer # 7, 136 (3.6%) were rejected. Of the 937 filters supplied by Manufacturer # 3, 219 (23.4%) were rejected. Of the 313 filters supplied by Manufacturer # 32, 84 (26.8%) were rejected. Of the 111 filters supplied by Manufacturer # 19, 59 (53.2%) were rejected. Of the 54 filters supplied by Manufacturer # 4, two (3.4%) were rejected, and of the 119 filters supplied by various other manufacturers, 23 (19.3%) were rejected. Of these, an entire shipment of 20 filters supplied by Manufacturer # 5, was rejected.

C. Summary of Test Results - FY 1994

The FY 1994 test data was analyzed to determine whether there were statistical differences among the FTFs or among the manufacturers. There were strong differences among the FTFs for Size 5 (1000 cfm) filters, and among manufacturers for Size 3 (125 cfm) filters.

The high rejection rates for both Size 3 and Size 5 filters were due primarily to the "Other" category and were related to two specific shipments. At Rocky Flats, an entire shipment of 200 Size 3 filters supplied by Manufacturer #. 3 was rejected. There was no further explanation available from the Rocky Flats FTF regarding the specific problem or problems which led to rejection of the entire batch of filters. At Oak Ridge, 100 filters of a shipment of 126 Size 5 filters (79.4%) supplied by Manufacturer # 7 were rejected because the gaskets had not been installed according to purchase specifications.

The rejection of all thirty-five filters in a lot of Size 6 filters for "Other" reasons is also noteworthy. The filters were supplied by Manufacturer # 33, and tested at Oak Ridge. Further review of the test records indicates that 34 of the filters had splintered frames and/or improperly seated gaskets. The remaining filter was rejected because it was not a "Nuclear Grade" filter. The cause of the splintered frames was not documented, and it is not known whether the filters were damaged during shipping and handling, or simply not properly inspected prior to shipment.

The overall rejection rate for HEPA filters tested in FY 1994 was 9.9%, more than three times the "Reference Rate". The overall rejection rate includes: 1.9% for high penetration, 2.0% for high resistance to airflow, and 7.9% for "Other" reasons. This was the first of the four years in which filters were rejected for high resistance to airflow.

VII. FY 1995 HEPA FILTER TEST DATA

A. Summary of Test Results by FTF

Table 9 presents the overall FY 1995 HEPA filter test data by FTF. 3,758 filters were tested, the lowest test total since LANL initiated the HEPA filter test data base in FY 1983. Of these, 2,471 (65.8%) were tested by Oak Ridge, 1,197 (31.9%) were tested by Rocky Flats, and 90 (2.4%) were tested by Hanford. Of the 2,471 filters tested by Oak Ridge, 62 (12.5%) were rejected; of the 1,197 filters tested by Rocky Flats, 46 (3.8%) were rejected; and of the 90 filters tested by Hanford, nine (10%) were rejected. FY 1995 was the first of the years covered in this report in which a significant number of filters was rejected for high resistance to airflow.

Table 9
FY 1995 HEPA Filter Test Results by FTF

FTF	N	NIA/%	NAW/%	NR/%
HANFORD	90	81/90	0/0.0	9/10
OAK RIDGE	2,471	1,850/75	0/0.0	621/25
ROCKY FLATS	1,197	1,151/96	0/0.0	46/3.8
TOTALS	3,758	3,082/82	0/0.0	676/18

B. Summary of Test Results by Manufacturer

FY 1995 HEPA filter test data by Manufacturer appears in Table 10.

Of the 3,758 filters tested by the FTFs, 2,794 (74.3%) were supplied by Manufacturer # 7; 751 (20%) were supplied by Manufacturer # 3; 56 (14.9%) were supplied by Manufacturer # 33; and 52 (13.8%) were supplied by Manufacturer # 32. Other manufacturers supplied smaller quantities of filters in FY 1995 as follows: Manufacturer # 19supplied 26 filters (0.7%); Manufacturer # 23 supplied 22 filters (0.6%); Manufacturer # 12 supplied 14 filters (0.4%); Manufacturer # 29 supplied 12; Manufacturer # 21 supplied 12; Manufacturer # 25 supplied 8; Manufacturer # 1 supplied 7; Manufacturer # 14 supplied 2; Manufacturer # 4 supplied one; and Manufacturer # 9 supplied one. Of the 3,758 filters tested in FY 1995, 676 (18%) were rejected for all reasons.

Table 10
FY 1995 HEPA Filter Test Results by Manufacturer

Manufacturer	N	NIA/%	NAW/%	NR/%
7	2,794	2,233/80	0/0.0	561/20
3	751	712/95	0/0.0	39/5.2
33	56	39/70	0/0.0	17/30
32	52	37/71	0/0.0	15/29
19	26	12/46	0/0.0	14/54
23	22	10/45	0/0.0	12/55
12	14	14/100	0/0.0	0/0.0
29	12	12/100	0/0.0	0/0.0
21	12	12/100	0/0.0	0/0.0
25	8	0/0.0	0/0.0	8/100
1	7	0/0.0	0/0.0	7/100
14	2	0/0.0	0/0.0	2/100
4	1	1/100	0/0.0	0/0.0
9	1	0/0.0	0/0.0	1/100
TOTALS	3,758	3,082/82	0/0.0	676/18

Of the 2,794 filters supplied by Manufacturer # 7, 561 (20%) were rejected. Of the 751 filters supplied by Manufacturer # 3, 39 (5.2%) were rejected. Of the 56 filters supplied by Manufacturer # 33, 17 (30.4%) were rejected. Of the 52 filters supplied by Manufacturer # 32, 15 (28.8%) were rejected. Of the 26 filters supplied by Manufacturer # 19, 14 (54%) were rejected. Of the 22 filters supplied by Manufacturer # 23, 12 (54.5%) were rejected. All of the eight filters supplied by Manufacturer # 25, the seven filters supplied by Manufacturer # 1, the two filters supplied by Manufacturer # 14, and the single filter supplied by Manufacturer # 9 (a total of 18 filters) were rejected.

C. Summary Discussion - FY 1995

The overall rejection rate for FY 1995 was 18%, more than six times the "Reference Rate", and by far the highest rejection rate encountered in the test program. The FY 1995 Semi-annual report data was analyzed to determine whether there were statistical differences among the FTFs or the manufacturers. Statistically significant differences were identified among the FTFs and the manufacturers for Size 5 (1000 cfm) filters. For Size 7 (1500 cfm) filters, 518 of the 524 Size 7 filters tested in FY 1995 were rejected. The remaining six filters were accepted, but only because they were designated as "special case" filters. All six of these filters also exceeded the criterion for resistance to airflow.

Further review of the actual test data for Size 7 filters confirmed that high resistance to airflow was the largest contributor to the overall FY 1995 rejection rate of 18%; this category accounted for just under 13% of the rejected filters. The rejection rate due to high penetration was 1.8% (about average), and the rejection rate due to "Other" causes was 3.4%, which was higher than noted in previous years. Of a single lot of 506 Size 7 HEPA filters supplied by Manufacturer # 7, 476 were rejected for excessive resistance to airflow. In the same lot, seven additional filters (1.4%) were rejected for high penetration, 18 filters (3.6%) were rejected for defective fluid seals, four filters were rejected for shipping damage and one was "out of square". Thus, the entire lot of 506 filters was rejected.

This manufacturer's lot raises a serious question concerning purchase of HEPA filters at DOE sites in general, and at the Savannah River Site in particular. The purchase order for these filters specified a nominal airflow rating of 1500 cfm, but a limit for resistance to airflow of 1.3" w.g.. Procurement organizations at WSRC apparently do not recognize the applicable limit for resistance to airflow (1" w.g. for filters Size 4 and above) which appears in the DOE HEPA filter procurement standard(4). Instead, WSRC chose to specify the limit of 1.3" w.g. which appears in the former Military Specification, MIL 51068F(14) and the current specification (ASME AG-1 Code, Section FC)(15).

The limit for resistance to airflow which appears in the DOE Standard was carefully considered and approved by consensus. Filter manufacturers were included in the Technical Review Committee which recommended that DOE adopt the standard. The DOE FTFs are directed to apply the DOE limit for resistance to airflow as a basis for HEPA filter acceptance/rejection. The operating contractor, when notified that the filters had been rejected, directed the testing FTF to place rejection labels on the shipping containers, but not on the individual filters (contrary to established policy), and to ship the 476 filters which had been rejected for high resistance to airflow to the contractor site. The request was complied with, under protest from the Oak Ridge FTF, the FTF Coordinator at Los Alamos, and the HEPA Filter Performance Assurance Program Manager at DP-45.

It should be noted that the filters in question are intended for use in the Defense Waste Processing Facility (DWPF), which is designed to process highly radioactive High Level Waste. It is suspected that the rejected filters have or will find their way into the safety class exhaust system(s) of the DWPF.

The statistically significant differences for the Size 5 (1000 cfm) filters, which were identified by the statistical analysis of the FY 1995 test data, did not appear to be traceable to one specific cause. A review of the test data produced the following information:

- Of 206 Size 5 filters supplied by Manufacturer # 3, 171 (83%) were rejected by Oak Ridge because of "Other" reasons. The gaskets did not meet specifications.
- Of 73 Size 5 filters supplied by Manufacturer # 7, six (8.2%) were rejected by Oak Ridge for "Other" reasons, in this case because of general deterioration due to long term storage, a situation not necessarily related to the manufacturing process.
- Of 24 Size 5 filters supplied by Manufacturer # 33, 12 were rejected by Oak Ridge because of "Other" reasons, related to splintering and rough edges of the plywood filter frames.
- The totals for these three batches are: 303 filters received with 189 (62.4%) rejected for "Other" reasons.

VIII. MULTI-YEAR TREND ANALYSIS

A statistical trend analysis of the consolidated Annual Report data for the five year period FY 1991-1995 (a slightly different time frame than that of this report) was performed. Data from these years were combined and then analyzed to identify statistically significant differences between FTFs and manufacturers for each filter size (Sizes 1-8. Following is a summary of the major conclusions from the Trends Analysis:

- There is a strong statistically significant difference among manufacturers for Size 1 (25 cfm) filters. This is caused primarily by the low acceptance rates for filters supplied by Manufacturer #3 (64%) and Manufacturer #4 (51%) by the Oak Ridge FTF. All three FTFs accepted Size 1 HEPA filters supplied by Manufacturer #1 at about the same rate (95-97%).
- There are statistically significant differences between among manufacturers and among FTFs for Size 3 (125 cfm) filters, caused primarily by the low acceptance rates for filters supplied by Manufacturer # 3 (59%) and # 19 (25%) at the Rocky Flats FTF. All three FTFs accepted Size 3 filters supplied by Manufacturer # 7 at about the same rate (98-99%).
- There is a statistically significant difference in acceptance rates for Size 5 (1000 cfm) filters, for the manufacturers and for the FTFs. The Oak Ridge FTF accepted a lesser percentage of filters supplied by Manufacturer #3 (92%) than the other two FTFs. The Oak Ridge FTF also tested far more filters from Manufacturer # 3 (1995) than the other two FTFs combined (253). Oak Ridge accepted a lower percentage of

filters from Manufacturer # 4 (85%) than did Rocky Flats (96%), however, in this instance, Oak Ridge tested only 26 filters from this manufacturer compared to 159 tested by Rocky Flats.

- The acceptance rate for Size 5 filters supplied by Manufacturer # 7 was fairly consistent among the FTFs, with Hanford accepting 99%, and Oak Ridge and Rocky Flats each accepting 95%. However, the 5% rejection rate for filters from Manufacturer # 7 at Oak Ridge and at Rocky Flats is significantly above the overall failure rate for HEPA filters (2.8%) noted during the period FY 1983 - FY 1991.

In order to further examine the history and trends of HEPA filters supplied to DOE in the recent past, Tables 11 - 13 were prepared to present the overall acceptance/rejection history for the three major suppliers of HEPA filters for the period FY 1992 - FY 1995. These three manufacturers supplied 94.9% of the filters tested in FY 1992, 91.5% of the filters tested in FY 1993, 92.3% of the filters tested in FY 1994, and 97% of the filters tested in FY 1995. Manufacturer # 7, with overall filter supply percentages ranging from 71% to 80.4%, is by far the major supplier. Manufacturer #3 supplied from 7.7% to 20% of the filters tested during the period covered by this report, and the third manufacturer, a combination of Manufacturers # 4 and # 33 (one bought the other during the report period), supplied from 2.7% to 3.9%.

Table 11
Overall FY 1992 - FY 1995 Acceptance/Rejection Rates for Manufacturer # 7

Fiscal Year	# Received	Number Accepted/%	Number Rejected/%
1992	4,995	4,860/97.3	135/2.7
1993	6,980	6,410/91.8	570/8.2
1994	3,752	3,616/96.4	136/3.6
1995	2,794	2,233/79.9	561/20.1
TOTALS	18,521	17,119/92.4	1402/7.6

Manufacturer # 7 is by far the largest supplier of HEPA filters to the DOE complex, and, in general, has had the best overall acceptance rate of the major filter suppliers. The 2.7% rejection rate for FY 1992 is similar to the "Reference Rate", and the rejection rate of 3.6% in FY 1994 is marginally (0.8%) higher. However the rejection rates for FY 1993 (8.2%) and FY 1995 (20.1%) further support the conclusion that the quality of HEPA filters supplied to DOE has diminished. In fairness to the manufacturer, it can be argued that the two lots of size 7 filters, in which 518 of 524 filters were rejected due to a disagreement over the applicable criterion for resistance to airflow, should be removed from the FY 1995 statistics, because rejection of these filters is not directly related to the manufacturing process. If this is done, then only 43 of the remaining 2270 filters (1.9%) were rejected. On the other hand, the manufacturers are well aware of the DOE specification for resistance to airflow, and know that the filters they provide do not meet the DOE specifications. It would appear that this issue should be resolved by further review of all the applicable filter performance specifications, leading to technical consensus, such that there is no longer a conflict among the applicable standards.

The decreasing numbers of Manufacturer # 7 filters tested at the DOE FTFs each year during the period covered by this report reflects the diminishing DOE market for HEPA filters.

Table 12
Overall FY 1992 - FY 1995 Acceptance/Rejection Rates for Manufacturer # 3

Fiscal Year	# Received	Number Accepted/%	Number Rejected/%
1992	663	574/86.6	89/13.4
1993	619	607/98.1	12/1.9
1994	937	718/76.6	219/23.4
1995	751	712/94.8	39/5.2
TOTALS	2,970	2,611/87.9	359/12.1

Manufacturer # 3 was the second largest supplier of HEPA filters to the DOE complex during the period FY 1992 - FY 1995. The acceptance rates for Manufacturer # 3 filters have been highly variable, and the overall rejection rate of 12.1% is more than four times the "Reference Rate". Of the 89 filters rejected in FY 1992, 84 were tested and rejected by Oak Ridge. Of the 84 filters rejected at Oak Ridge, 78 were rejected for high penetration. Seventy-three of these were from one lot of 140 25 cfm filters, which was discussed in the summary report section for the year FY 1992. Two hundred of the 219 Manufacturer # 3 filters which were rejected in FY 1994 constituted an entire batch which was rejected at Oak Ridge for "Other" reasons. This situation was earlier discussed in the summary report section for FY 1994. The test data for Manufacturer # 3 filters further support the conclusions that the quality of filters supplied to DOE during FY 1992 - FY 1995 has lessened, and that filter failures tend to occur in batches.

Table 13
Overall FY 1992 - FY 1995 Acceptance/Rejection Rates for Manufacturer # 4-33

Fiscal Year	# Received	Number Accepted/%	Number Rejected/%
1992	240	223/92.9	17/7.1
1993	298	251/84.2	47/15.8
1994	186	114/61.3	72/38.7
1995	103	71/68.9	32/31.1
TOTALS	827	659/79.7	168/20.3

Manufacturer # 4 became Manufacturer # 33 in 1993. This manufacturer combination accounts for the third highest total of filters supplied to DOE in the period FY 1992 - FY 1995. Individual records from the Semi-annual Reports were reviewed, and the combined totals were compiled and appear in Table 14. The combined test history for Manufacturer # 4-33 during the reporting period of FY 1992 - FY 1995 constitutes the highest rejection rate of the major suppliers. Review of the individual test reports again indicates batch, not random type failures, and further demonstrates the general lessening of HEPA filter quality.

IX. SUMMARY AND CONCLUSIONS

This combined Annual Report presents summary results of HEPA filter tests performed by the DOE Filter Test Facilities for the four year period FY 1992 - FY 1995. Test results for each year are discussed separately in specific sections (IV-VII) of the report, including a trend analysis. The test results for each fiscal year were analyzed in order to identify statistical differences, either among the FTFs by manufacturer and filter size, or by manufacturer. In Section VIII, a more general multi-year trend analysis for the four year period is presented.

The FTF program was instituted in the late 1960s and early 1970s when it became apparent that the HEPA filters supplied to the Department of Energy for installation in its nuclear facilities were not always of the high quality required to adequately protect workers, the environment, and the general public from the hazards associated with release of radioactive materials. The FTFs have been instrumental in identifying HEPA filters which do not meet required performance standards and preventing their installation in critical safety systems

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The changing nature of the Department of Energy's overall mission is apparent when the number of HEPA filters procured and tested is reviewed and compared to previous years. Review of the test records indicates a significant decline in the numbers of filters tested during the period addressed in this report. Prior to FY 1991, the numbers of HEPA filters tested each year were on the order of 10,000-14,000 filters. These numbers have declined steadily over the past four years, such that in FY 1995, only about 3,800 filters were tested. In FY 1995, one of the FTFs was closed, due to lack of filters to test. In FY 1996, there have been ongoing discussions concerning the future of the FTFs and the HEPA filter test program, and there have been recommendations to close one or both of the remaining FTFs.

The recent FTF test data verifies that the quality of the HEPA filters supplied to the DOE has diminished substantially. Review of the test data indicates that annual average rejection rates due to all causes, during the period FY 1992 - FY 1995 have increased from two to more than six fold. over the rejection rates observed during the period FY 1983 - FY 1991. Had there been no FTFs, the numbers of substandard filters installed in DOE's nuclear facilities could have increased significantly, leading to an increase in the probability that higher concentrations of radioactive materials could have been released to work stations, the on-site worker populations, or to the public and general environment.

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DISCUSSION

FRANKLIN: We sold a lot more filters to DOE facilities than were evidently tested. Is this a trend?

BRESSON: I think it has to do with whether they are procuring specification HEPA filters and the intended use. I hope that it is not a trend, but I suspect that procurement people at DOE sites are finding ways to get around testing of filters, and having to deal with rejected filters, the latter to avoid delays caused by replacing defective filters. There does not appear to be consistency any more among the DOE sites with respect to procurement activities. In addition, HEPA filters are often purchased for installation in non-nuclear facilities, and these filters do not have to be tested at a DOE FTF.

FRANKLIN: Some of our filters may have been rejected for not meeting specifications, but they met the user's purchase order . In those cases, we didn't even know they were rejected.

BRESSON: The records that I have reviewed indicate that when the filter test facilities perform their tests, they test all the filters the same way, regardless of whether they are specification filters or how they were procured. Consequently, the filter test data remain consistent.

FIRST: I listened to all your problems and now I am going to ask you the question that always gets asked at DOE, "What are the lessons learned here?"

BRESSON: I think the lesson that should have been learned is that air cleanup in nuclear facilities is a very important part of environmental and health protection activities at the sites. There is a move afoot, and I do not know how it is going to come out, within the Department of Energy, to do away with the DOE HEPA filter test facilities, and to rely instead on QA tests, QA inspections, manufacturers' data and in-place testing. To my mind, this would be a much different, less effective, and probably more expensive program than the current component assurance test program in which every filter is tested at the FTFs, and at a reasonable cost. I can not think of a better, more reliable QA program than the current test program, rather than one which relies on tests performed at the beginning of a QPL qualification cycle, followed by vendor inspections. One of the messages in my presentation is that, in recent years, the FTFs have rejected a higher percentage of HEPA filters, for all reasons. Given this fact, it makes little sense to me to back off on the quality test program.

SLAWSKI: I can add something to the discussion. We have a working group at DOE looking at this question explicitly. It looks like we will continue to test every filter. Where we will do it, we do not know at this time. We are considering other things. There are some people that are very emphatic that the QA/QC program should be placed exclusively on the manufacturers. We have considered that. I think we know how we are going to proceed on it but the decision has yet to be made.

GILLES: Over the past 4 years, what percentage of all the filters rejected were rejected due to flaws found visually?

BRESSON: Failures due to visual inspection are a part of the category called "Other" in the summary test data for the years FY 1992 - FY 1995. Failure reasons which are lumped together into the "Other" category include, but are not limited to, carrier damage, media damage, failure to comply with purchase specifications, dimensional problems, and improperly installed gaskets. With the exception of procurement specifications, some or all of these failure modes are detected by visual inspection. Note that

Table 2 of my presentation shows that, for the years FY 1992 - FY 1995, filter failure rates due to "Other" category causes have ranged from about 1% to 8% per year, the average being nearly 5%. A cursory review of individual test records, which provide additional information on the causes for failures recorded in the "Other" category, leads me to conclude that the visual inspection process detects a high percentage of these failures, perhaps as high as 75-80% of them.

IN-PLACE HEPA FILTER PENETRATION TEST*

by

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Abstract

We have demonstrated the feasibility of conducting penetration tests on high efficiency particulate air (HEPA) filters as installed in nuclear ventilation systems. The in-place penetration test, which is designed to yield equivalent penetration measurements as the standard DOP efficiency test, is based on measuring the aerosol penetration of the filter installation as a function of particle size using a portable laser particle counter.(1) This in-place penetration test is compared to the current in-place leak test using light scattering photometers for single HEPA filter installations and for HEPA filter plenums using the shroud method. Test results show the in-place penetration test is more sensitive than the in-place leak test, has a similar operating procedure, but takes longer to conduct. Additional tests are required to confirm that the in-place penetration test yields identical results as the standard dioctyl phthalate (DOP) penetration test for HEPA filters with controlled leaks in the filter and gasket and duct by-pass leaks. Further development of the procedure is also required to reduce the test time before the in-place penetration test is practical.

I. Introduction

Before a HEPA filtration system can be used in a DOE nuclear facility, the ventilation system and the HEPA filters must pass acceptance tests described in ASME N510 or AG1, and the HEPA filter must pass the MIL-STD-282 penetration test. (1-3) The acceptance tests consist of leak tests of ducts and housings, airflow capacity and distribution tests, and air-aerosol mixing uniformity tests. The airflow distribution test is designed to insure that HEPA filters see a uniform air flow, while the air-aerosol mixing test is performed to insure that the concentration of aerosols challenging the filter is uniform. This will insure that representative samples can be obtained before and after the filter for computing the filter penetration.

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*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-ENG.45. The work was supported by DOE's Defense Program Office of Technical and Environmental Support, DP-45.

The HEPA filter penetration test is given in MIL-STD-282.(1) This test requires HEPA filters to have less than 0.03% penetration for 0.3 μm DOP aerosols as measured by a light scattering photometer. The 0.3 μm aerosols were originally selected because they were believed to be the most penetrating aerosols and would yield the most conservative penetration values for the HEPA filters. These aerosols were generated in a very large machine by a controlled condensation of DOP vapor and were thought to be monodisperse.

After the HEPA filter is installed in a certified ductwork, and once a year thereafter, the filter installation must be tested for leaks.(2-4) This in-place leak test is performed to insure that the HEPA filter is properly installed and has not been damaged, that there are no leaks in the mounting frame or between the mounting frame and the housing, and that the system contains no bypassing that would reduce the system penetration. The in-place leak test is not a filter penetration test and can not be used in determining the penetration of HEPA filters. The difference between the two tests is the particle size and the type of aerosol generator used to challenge the filter: the DOP penetration test uses near monodisperse 0.3 μm particles generated by a very large vapor condensation generator, while the in-place test uses heterodisperse 0.7 μm particles generated by small portable air or thermal generators.(2-4) ERDA 76-21 recommends an acceptance criterion of 0.03% maximum penetration for the in-place DOP test.(4)

The HEPA filter leak test was implemented in 1960 in the U.S. to verify that the installed filtration systems did not have leaks.(5) This test represented a second-best choice at that time since it was not possible to conduct in-place penetration tests using the available test equipment. The problem was that the particle measuring instruments at that time could not distinguish between particle sizes, and monodisperse 0.3 μm aerosol generators were not portable. The available light scattering photometers were portable but could not distinguish between different particle sizes. To measure HEPA filter penetration at 0.3 μm diameter, it was necessary to have a monodisperse 0.3 μm diameter generator, which were not portable. The only portable aerosol generators at that time produced heterodisperse aerosols.

Now, a variety of instruments and aerosol generators are commercially available that can be used for measuring in-place filter penetration. Portable particle spectrometers are available that can measure specific particle sizes in heterodisperse aerosols. Portable aerosol generators are also available that can generate monodisperse aerosols. Thus it is now possible to measure in-place HEPA filter penetration at 0.3 μm using portable equipment consisting of either a particle size spectrometer and a heterodisperse aerosol generator or an integrated particle analyzer (e.g. photometer, condenstation nuclei counter) and a monodisperse aerosol generator. We will only address the in-place penetration method using laser spectrometers and heterodisperse aerosols in this paper.

II. Difference Between Penetration, In-Place Leak, and In-Place Penetration Tests

The difference between the results of the penetration and the in-place leak tests can be illustrated with a typical HEPA filter penetration curve shown as a function of particle size in Figure 1. The penetration is a maximum at 0.15µm, decreases rapidly with increasing particle size and is negligible at 0.7 µm for HEPA filters with no leaks. Although the penetration measurement at 0.3 µm is significantly less than the maximum, it still provides a sensitive measurement of the filter penetration. In contrast to the in-tact HEPA filter installation in Figure 1, particle penetration through leaks is independent of particle size. Thus any penetration that is measured at 0.7 µm diameter during the in-place leak test can be attributed to leaks.

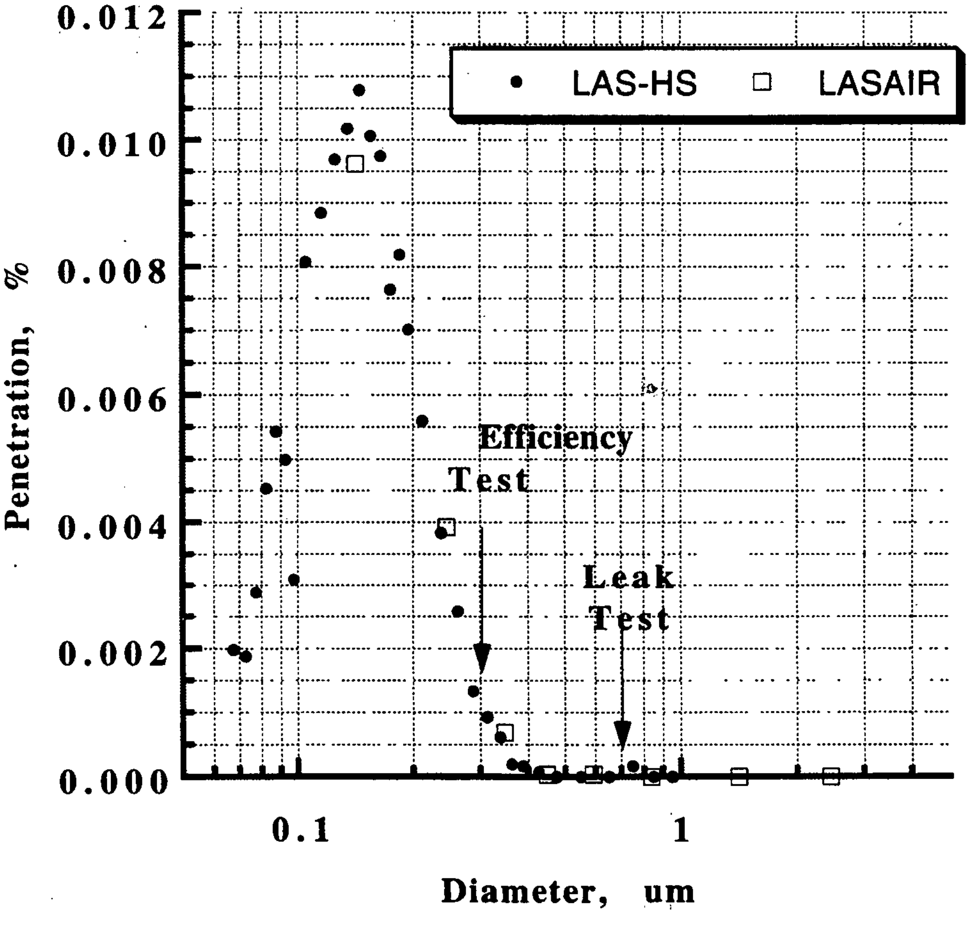


Figure 1. Plot of HEPA filter penetration measurements as a function of particle size for dioctyl sebacate (DOS) aerosols with two different laser spectrometers. Nuclear grade, 1,000 cfm HEPA filter.

Two different laser particle counters (Particle Measurement Systems, Bolder, CO) were used to generate the curve in Figure 1: the LAS-HS laser counter, which measures particles from 0.067 to 0.95 µm diameter and the LASAIR laser counter, which measures particles from 0.14 to 2.4 µm diameter. The diameter measurements are based on the logarithm midpoint of each of the counter channels. A 100:1 diluter (TSI, Minneapolis, MN) was used to dilute the upstream measurements to avoid coincidence counting. The dioctyl sebacate aerosols were generated with a Laskin nozzle aerosol generator (Virtis, Gardiner, NY). Details of the test procedure are described in previous reports.(6,7) The agreement between the two instruments is good.

It is possible to conduct filter penetration tests as described in ASME N-510 and ASME AG-1 using a laser particle counter during in-place filter tests.(2,3) If the laser counter is used for measuring the total number of particles without regard to particle size, then the filter test becomes another leak test. However, if the laser counter is used to discriminate between different particle sizes, such as 0.3 µm, then the laser test becomes an in-place penetration test. Using the laser particle counter also allows the maximum filter penetration, as shown in Figure 1, to be determined with the in-place penetration test. A description of the filter efficiency test using the laser particle counter is given by Bergman and Biermann and by Scripsick et al.(6-8)

The in-place penetration test using the laser particle counter is a measurement of the penetration of the total filtration system. This test incorporates the aerosol penetration from both the HEPA filter and leaks in the filter housing or gaskets. In separate filter penetration and leak tests, the total penetration of the filtration system is determined from the sum of the filter penetration and the leak penetration. In separate penetration and leak tests, once the filter is installed, it is only possible to determine system leaks with the light scattering photometer and assume the filter penetration remains the same. The in-place leak test using the light scattering photometer can only detect a major deterioration in filter penetration.

The increased sensitivity of the laser particle counter allows filter penetration measurements of two stages of HEPA filters for both the leak test and the penetration test. This capability, which is not possible for the standard photometer based leak test, is advantageous because of the reduced testing time and the difficulty in measuring the penetration of individual stages in systems having minimal space between stages. Schuster and Osetck were the first to use a laser particle counter to measure the filter penetration of one-stage and two-stage, size 1 HEPA filters.(9) They found typical DOP penetrations of 0.003% for single stage and 0.000005% for two stage HEPA filters. However measurements of penetration versus particle size were only reported for the single stage HEPA filters.(9)

Ortiz determined the filter leaks in a number of 20,000 cfm two-stage HEPA filter systems.(10) He did not discriminate between particle size, but rather used the total particle count before and after the filters to determine the system leaks. The test was therefore a leak test and not a penetration test. The leak measurements for ten systems varied from 0.0067% to 0.00000009%. The maximum allowable leakage for two stage HEPA filters is 0.000009%. This study was significant not only because the test system was demonstrated under field conditions, but also because it showed the laser particle counter detected filter system failures that were not seen with the standard single stage method described in ASME N510.(2)

Ortiz et al also conducted a round robin test of two-stage HEPA filtration system in which they measured filter penetration as a function of particle size using a laser spectrometer.(11) In this configuration, the filter test was an in-place penetration test. To avoid coincidence counting, the upstream concentration was diluted. The test apparatus and procedure were incorporated into an ASTM test method for evaluating HEPA filters.(12)

The Los Alamos National Laboratory (LANL) uses a laser spectrometer and heterodisperse aerosols as developed by Ortiz and incorporated in the ASTM standard for conducting in-place HEPA filter leak tests in all of their facilities.(10-13) Since the particle measurements are made by adding all of the sizes into a single count, the LANL in-place filter measurements can not be used for determining filter penetration, but rather for leaks. Adding together the particle counts in the different particle size bins destroys the ability to measure filter penetration with heterodisperse aerosols. However, by keeping the particle counts in the different size bins separate, the LANL test procedure for leaks can be converted to a test of filter penetration test.

III. Correlation of In-Place Penetration Test With Standard Penetration Test

In order to claim that an in-place filter penetration test is equivalent to the standard HEPA filter penetration test at 0.3 µm, it is necessary to establish a correlation between the in-place penetration test with the standard penetration test specified in MIL-STD-282.(1) Such a correlation would include penetration measurements on HEPA filters with varying defects in the filter and the gasket as well as by-pass leaks in the ventilation ducting. These correlation tests have not yet been completed. However Scripsick et al conducted tests on 849 new HEPA filters using laser measurements at 0.31 µm and the standard Q-107 measurements at 0.3 µm.(8) The correlation between the laser measurements at 0.31 µm and the Q-107 measurements at 0.3 µm is good, as shown in Figure 2.(8) Note that the correlation becomes worse at smaller penetration values. This is not surprising considering the photometer in the Q-107 measurements is increasingly noisy below 0.01% penetration. We plan to conduct similar correlations using filters with controlled leaks in the media and gaskets and using controlled by-pass leaks in the ducting.

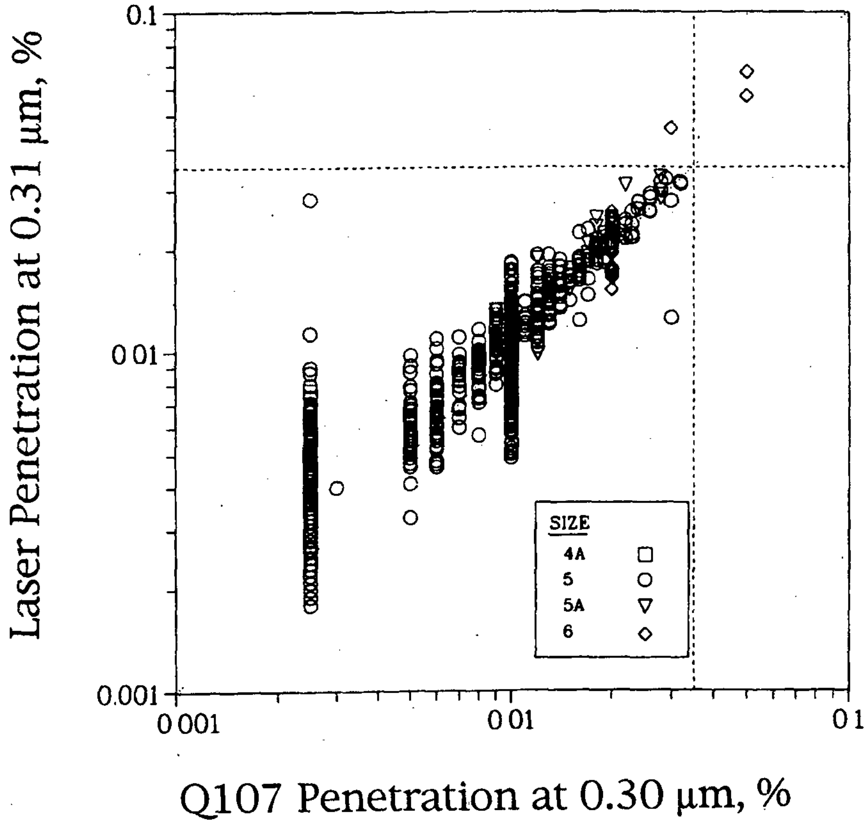


Figure 2. Correlation of HEPA filter penetration between laser spectrometer and Q107 photometer.[8]

For measurements of the maximum filter penetration, it is not necessary to conduct correlation tests with the Q107 tester because it only measures the penetration at 0.3 µm. The Q107 can not be used to determine the maximum filter penetration at 0.15 µm, as seen in Figure 1. In fact, there are no standard reference tests for the maximum filter penetration. The laser spectrometer can be used in a primary test standard for the maximum filter penetration if the particle size range is sufficient to clearly show a maximum as seen in Figure 1.

IV. Correlation of In-Place Penetration Test With Standard Leak Test

We have conducted a series of filter penetration tests on a HEPA filter with an increasing number of pin holes to establish a correlation between the in-place penetration test and the standard leak test. A nuclear grade, 1,000 cfm HEPA filter was used in these correlation tests. Two different laser spectrometers were used to determine the in-place filter penetration as a function of size: the LAS-HS laser counter, which measures particles from 0.067 to 0.95 µm diameter and the LASAIR laser counter, which measures particles from 0.14 to 2.4 µm diameter. A 100:1 diluter (TSI, Minneapolis, MN) was used to dilute the upstream measurements to avoid coincidence counting. The dioctyl sebacate aerosols used in the in-place penetration tests were generated with a Laskin nozzle aerosol generator (Virtis, Gardiner, NY). Filter penetration was determined from the ratio of the downstream concentration divided by the upstream concentration after correcting for the upstream dilution and subtracting background aerosols. Figure 1 shows the penetration of the new HEPA filter as a function of particle size.

The standard leak test was conducted using a TDA-2GN light scattering photometer (ATI, Owings Mills, MD) to obtain aerosol measurements before and after the HEPA filter. A TDA-5B aerosol generator (ATI, Owings Mills, MD) was used to generate the alpha-olefin (Emery 3004) aerosols for the in-place leak tests. Filter leak measurements were made by electronically setting the photometer upstream concentration to 100% and reading the downstream concentration directly. The in-place leak test yielded a leak of 0.01% for the test shown in Figure 1.

Following the initial test on the new HEPA filter, we made a single pinhole in the filter medium using a 0.025 inch diameter needle and repeated the in-place penetration and in-place leak tests. Additional pin holes were then made in the filter, and the filter was retested each time for penetration and leakage. The test results for the in-place penetration measurements are shown in Figure 3 for the filter having 0, 1, 2, and 6 pin holes and in Figure 4 for the filter having 9, 13, 19, 27, and 40 pin holes. The photometer measurements for each of the filter tests are shown in Table 1 along with the designated number of pinholes. Table 1 also shows the filter pressure drop and the penetration measured at 0.15, 0.3, and 0.7 µm diameter. Note that the pressure drop is not affected by the pin holes, whereas the laser penetration and photometer leaks show large increases with increasing number of pin holes.

The agreement between the HS-LAS and the LASAIR laser counters is very good over the overlapping size range as seen in Figures 3 and 4. The HS-LAS and LASAIR data are indicated by the open and closed data points, respectively. Both laser counters also yield the same value at the maximum filter penetration. However, the maximum penetration for the LASAIR occurs in the first size channel (0.1-0.2 µm), which will not allow verification of maximum penetration when the LASAIR instrument is used alone. This is not a serious problem since the maximum penetration occurs at 0.15 µm diameter for filters with and without pin holes. The preferred laser counter should have several measurements between 0.1 and 0.2 µm to verify that the maximum filter penetration is bracketed.

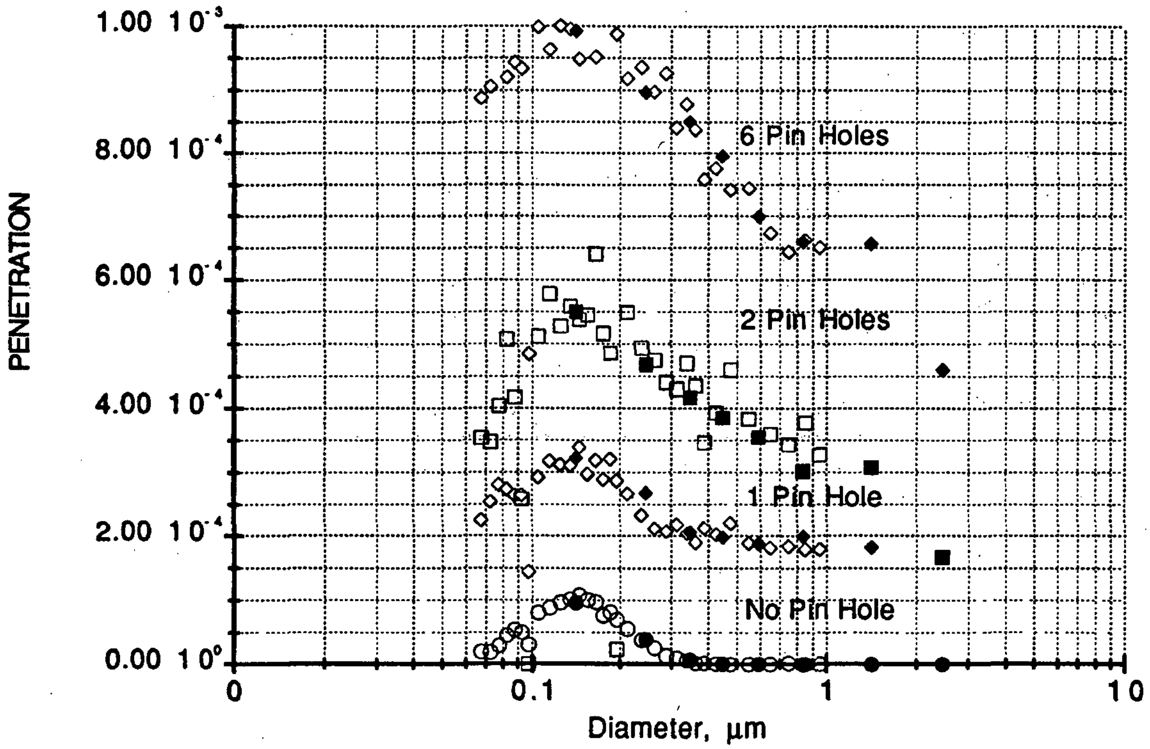


Figure 3. Penetration of DOS aerosols as a function of aerosol diameter for the same HEPA filter having 0, 1, 2, and 6 pin holes produced with a 0.025 inch needle. HS-LAS, open points, LASAIR, closed points.

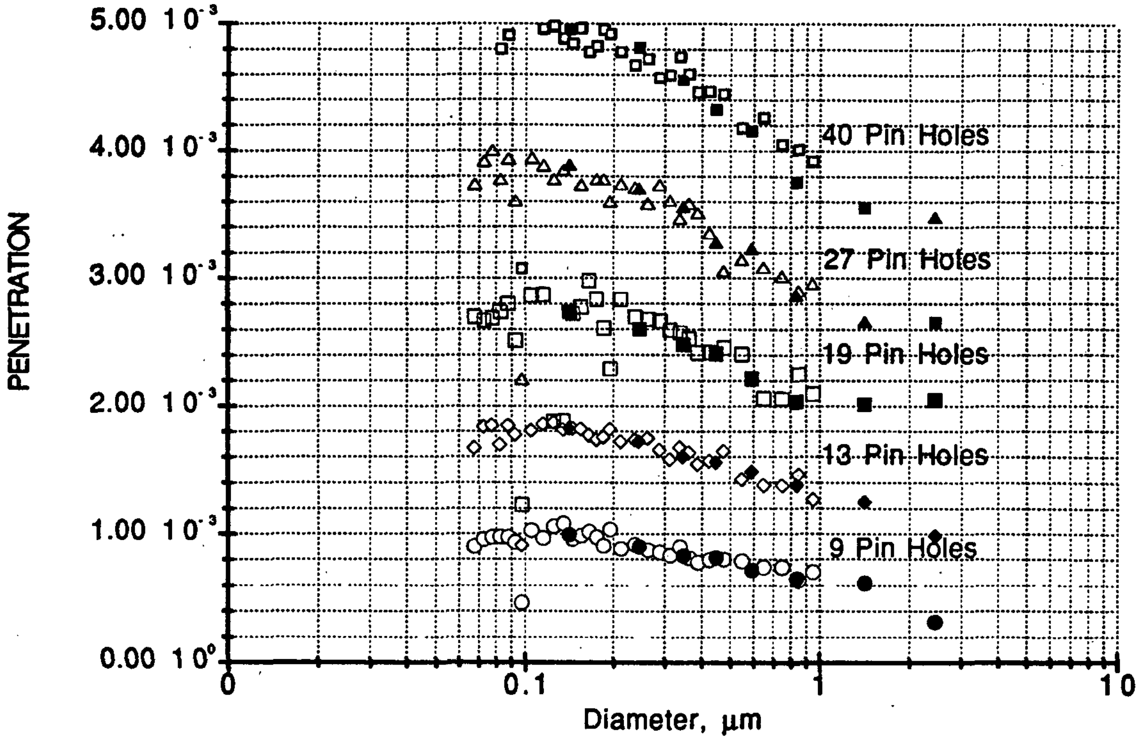


Figure 4. Penetration of DOS aerosols as a function of aerosol diameter for the same HEPA filter having 9, 13, 19, 27, and 40 pin holes produced with a 0.025 inch needle. HS-LAS, open points, LASAIR, closed points.

Table 1. Penetration and leak measurements on a HEPA filter with varying pin holes .

Pin - Holes	ΔP, inches	Laser Penetration at Diameter			Photometer Leak
		0.15 µm	0.3 µm	0.7 µm	
0	1.06	1.5 x 10-4	1.0 x 10-5	1.0 x 10-6	1 x 10-4
1	1.06	3.2 x 10-4	2.2 x 10-4	1.8 x 10-4	2 x 10-4
2	1.06	5.8 x 10-4	4.5 x 10-4	3.5 x 10-4	2 x 10-4
6	1.06	1.00 x 10-3	8.8 x 10-4	6.5 x 10-4	8 x 10-4
9	1.07	1.03 x 10-3	8.8 x 10-4	7.5 x 10-4	9 x 10-4
13	1.07	1.85 x 10-3	1.65 x 10-3	1.40 x 10-3	1.1 x 10-3
19	1.06	2.9 x 10-3	2.6 x 10-3	2.3 x 10-3	1.2 x 10-3
27	1.06	3.8 x 10-3	3.6 x 10-3	3.0 x 10-3	1.3 x 10-3
40	1.06	4.9 x 10-3	4.6 x 10-3	4.1 x 10-3	1.7 x 10-3

We have plotted the threee different penetration measurements versus the photometer measurements from Table 1 in Figure 5 to examine the correlation between the various measurements.

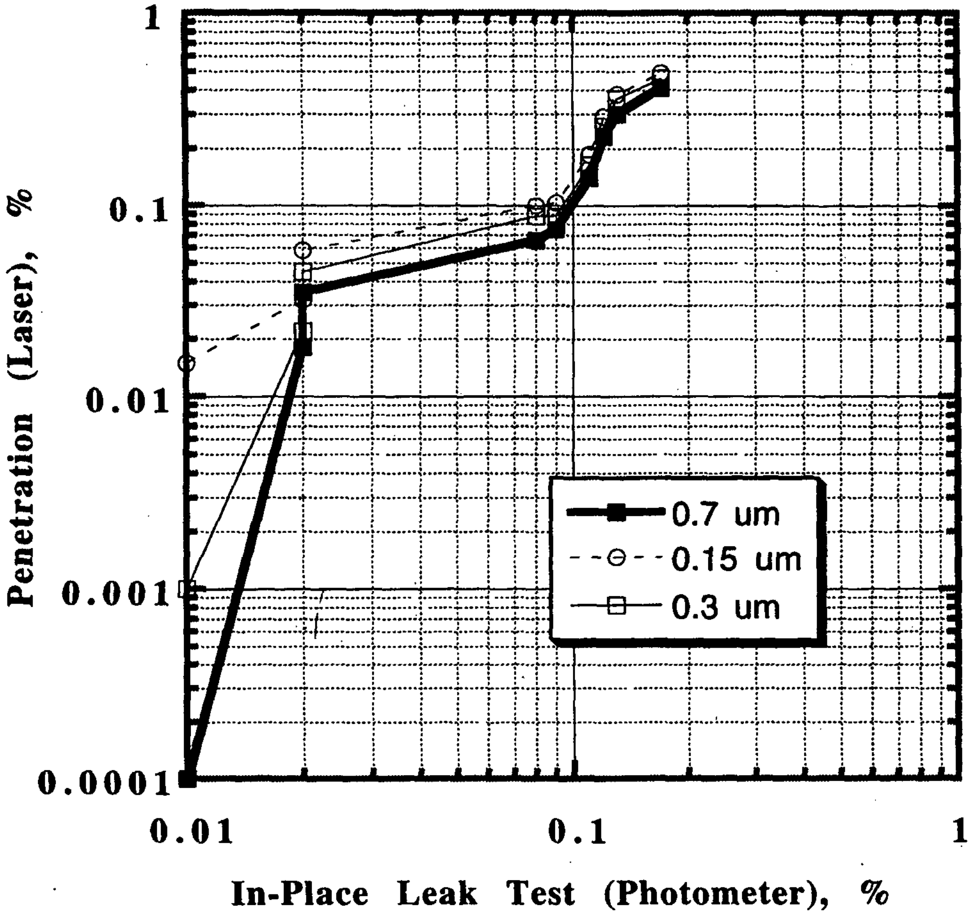


Figure 5. Correlation of laser penetration test with in-place leak test.

In general, there is poor correlation between the photometer leak and the laser penetration measurements, even for the 0.7µm data, which is supposed to represent the average size of the test aerosol in the photometer test. One of the reasons for the poor correlation is the lack of sensitivity of the photometer for penetration measurements less than 0.01%. However, the major reason for the poor correlation between the photometer leak and the laser penetration measurements is due to the fundamental difference between differential and integrated size measurements with heterodisperse aerosols. Bergman and Biermann have shown that large variations in the photometer measurements are possible compared to laser or condensation nuclei counters depending on the degree of aerosol heterodispersion and the extent of filter leaks.(7,14) Figure 5 also shows that the photometer measurements, although still not satisfactory, correlate better with the maximum penetration measurements at 0.15 µm than with the measurements at 0.3 or 0.7 µm. The lack of correlation between the in-place penetration test and the in-place leak test illustrates that the present leak test provides only an approximate measure of the sytem penetration.

V. Field Evaluation of In-Place Penetration and In-Place Leak Tests

We have conducted in-place penetration and leak tests on two typical HEPA filter installations at LLNL, a single HEPA filter system and a two-stage HEPA filter plenum, to evaluate the practicality of the in-place penetration test. The single HEPA filter system located on the roof of a LLNL building is shown in Figure 6 with the HS-LAS laser counter on the HEPA filter, the LASAIR laser counter on the blower, and the TSI aerosol diluter on the floor. The Laskin nozzle aerosol generator, not shown, was placed inside a ventilation hood in one of the building laboratories. After several in-place penetration tests were completed, the standard in-place leak test was performed using a TDA-2GN aerosol photometer (ATI, Owens Mills, MD) and a TDA-4A aerosol generator (ATI, Owens Mills, MD) with Emery 3004. The in-place leak test indicated the HEPA filter system had 0.006% leakage.

Several in-place penetration tests were conducted on the single HEPA filter system to determine the effect of challenge concentration and the repeatability of the test results. The challenge concentration is an important factor in the in-place penetration test because it affects the accuracy of the data and the duration of the test. Higher aerosol concentrations result in shorter and more precise tests but also result in instrument error due to coincidence counting. Counting errors due to coincidence occur at higher concentrations when two or more particles are counted as a single particle. Since filter penetration measurements involve two measurements at significantly different concentrations, one upstream and one downstream of the filter, separate optimizations are required for each measurement. In theory, the challenge concentration is adjusted so the downstream concentration after the filter is just below coincidence counting. The upstream concentration then has to be diluted to avoid coincidence counting. However, since the commercially available diluters have a fixed dilution ratio; e.g. 100:1 for one stage dilution, 10,000:1 for two stages of dilution; the challenge concentration must be adjusted to avoid coincidence in both the upstream (challenge) and downstream measurements.

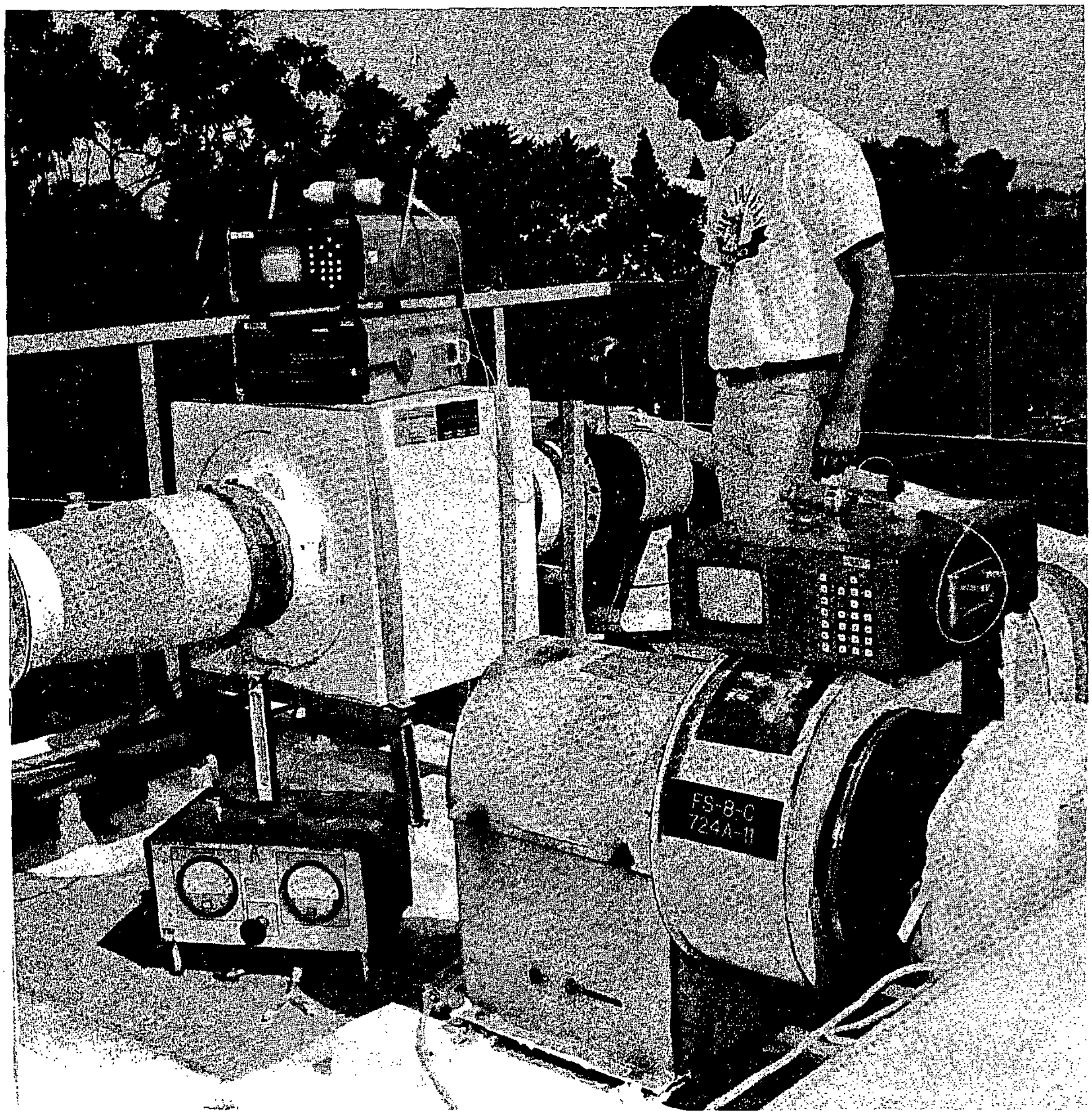


Figure 6. Photograph of the in-place penetration test apparatus on a single HEPA filter system using laser counters. The HS-LAS laser counter is on the HEPA filter, the LASAIR laser counter on the blower, and the TSI aerosol diluter on the floor.

The available dilution ratios did not allow for optimization of the concentration measurements as shown with the following illustration. Figure 7 shows the filter penetration curve derived from measurements using a 100:1 dilution of the upstream (challenge) aerosols for a single HEPA filter system which is similar to the system shown in Figure 6. The filter penetration curve is extremely noisy, even with a 1 minute upstream and a 15 minute downstream sample, because the low downstream aerosol concentration is at the background level. This resulted from reducing the challenge concentration to avoid coincidence counting. Increasing the sampling time did not help in this case because the measurement of background aerosols also increased. Using a 10,000:1 diluter on the upstream sample significantly improved the precision of the data and also reduced the sampling time as seen in Figure 8. The upstream and downstream sample times for that test were 2 and 6 minutes, respectively. An optimized diluter between 1,000:1 and 2,000:1 would reduce the sample time to about 1 minute for each measurement. The optimized diluter and associated calibration procedure must be developed before the in-place penetration method is adopted for routine measurements.

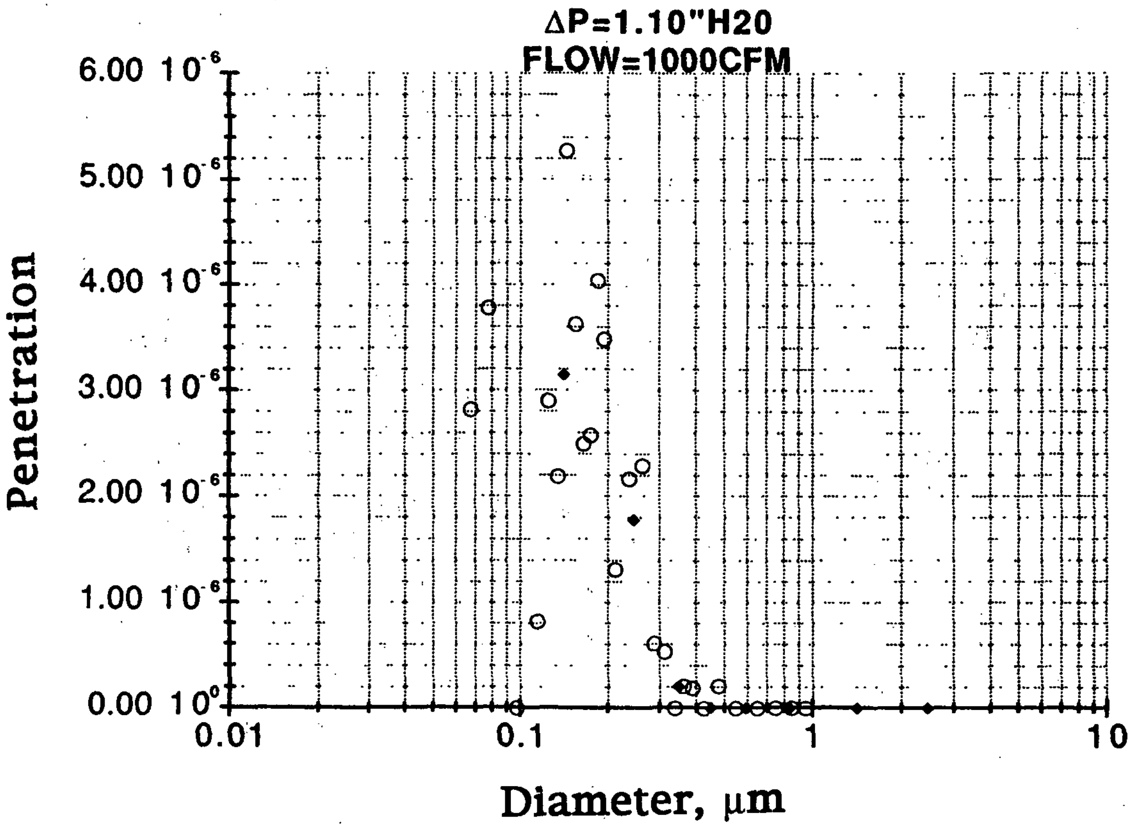


Figure 7. Filter penetration as a function of aerosol diameter for a single HEPA filter system using the in-place penetration measurement with a 100:1 diluter. Open data was generated with HS-LAS, closed data with LASAIR. In-place leak test with a photometer was 6 x 10^{-5}.

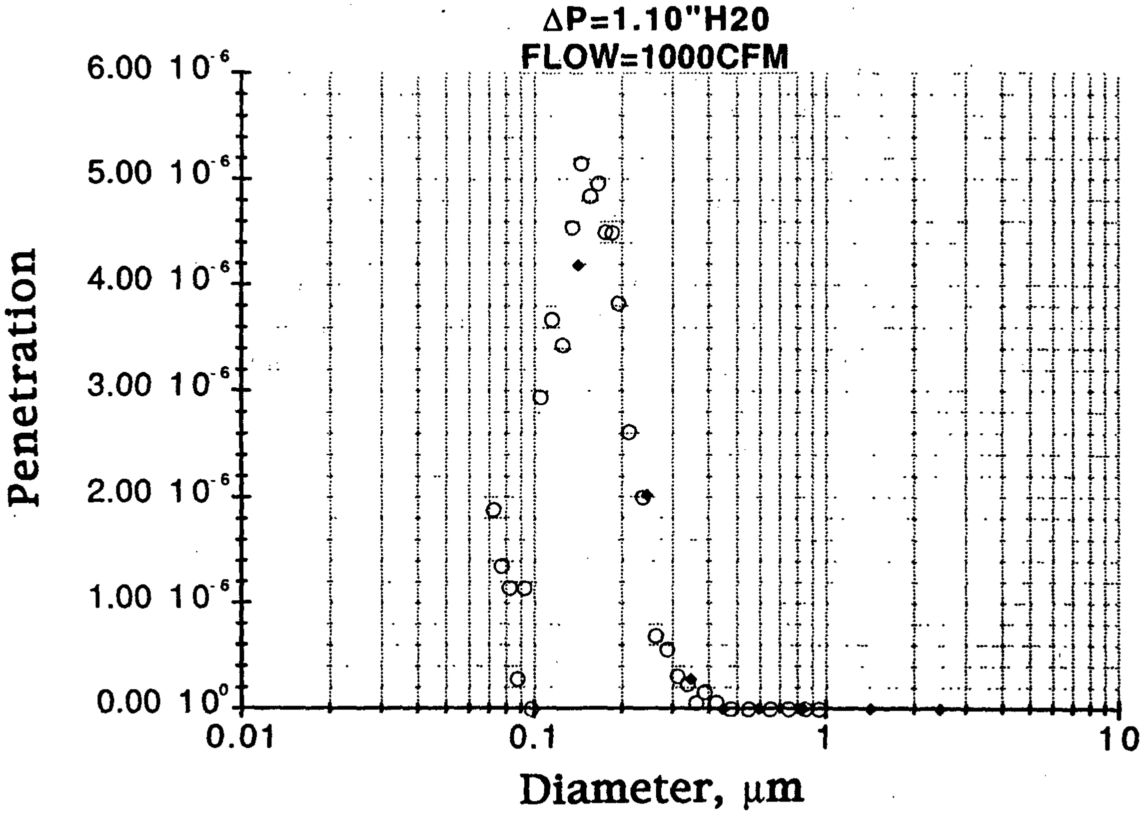


Figure 8. Filter penetration as a function of aerosol diameter for a single HEPA filter system using the in-place penetration measurement with a 1,000:1 diluter. Open data was generated with HS-LAS, closed data with LASAIR. In-place leak test with a photometer was 6 x 10^{-5}.

A detailed comparison of the time requirements for the in-place leak and the in-place penetration test is given in Table 2. The increased time to carry the penetration equipment was due to the additional laser counter, the diluter and pumps and miscellaneous items. After the in-place penetration equipment and procedure is finalized, the time for carrying the equipment will be the same for both in-place tests. The much longer test time for the penetration test can be reduced to be comparable to the leak test once the optimum diluter is developed.

Table 2. Comparison of time requirements for in-place leak and in-place penetration measurements on a single HEPA filter installation.

Task	Leak Test	Penetration Test
Carry equipment to roof	2 min.	10 min.
Set up equipment	2 min.	3 min.
Set up generator	8 min.	8 min.
Test filter	2 min.	12 min.
Total	14 min.	33 min.

We repeated the in-place penetration test two additional times to assess the repeatability of the test. Figure 9 shows the three in-place penetration tests on the single HEPA filter installation are very repeatable.

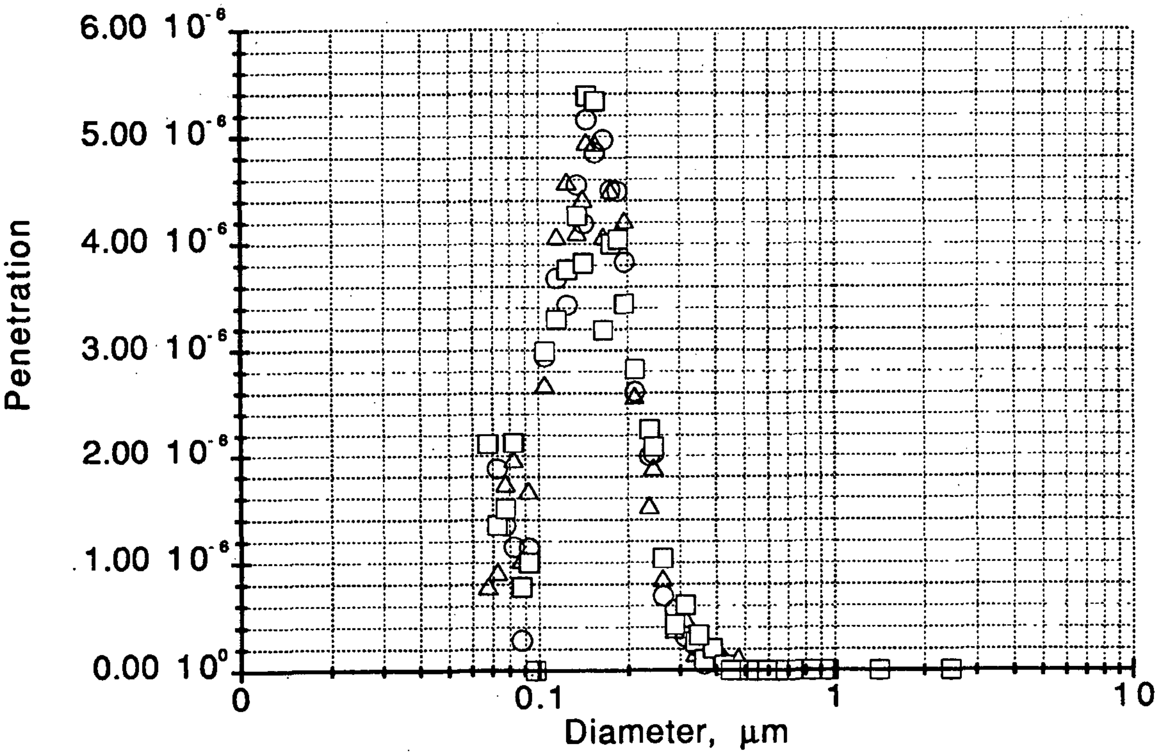
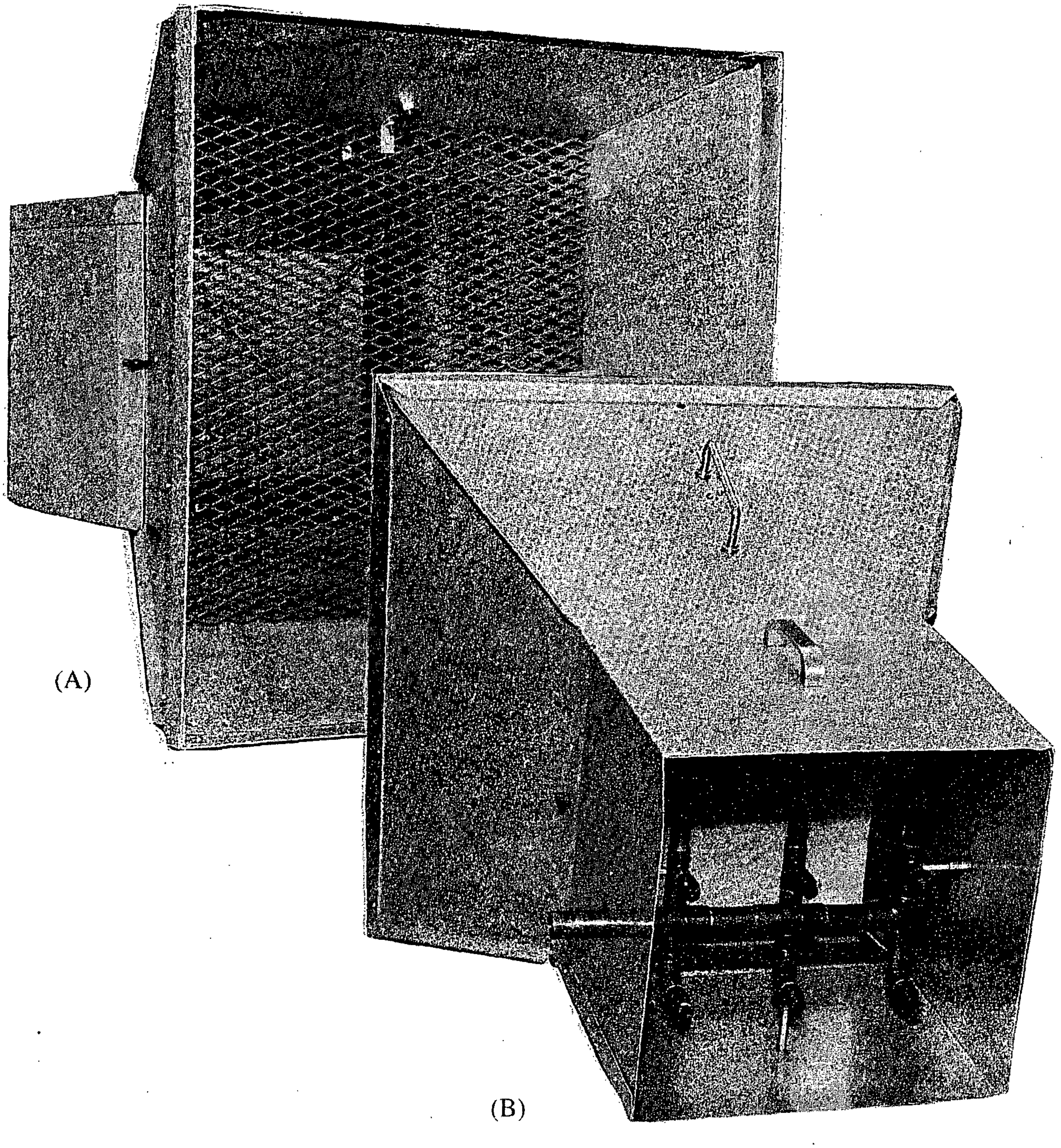


Figure 9. Measurements of the filter penetration obtained with the in-place penetration test apparatus shown in Figure 6 repeated three times.

The second field evaluation of the in-place penetration measurement was in a two-stage HEPA filter plenum using the shroud sampling method. The shroud sampling method allows individual HEPA filters to be leak tested independent of the other HEPA filters in a filter bank. This is done by placing shrouds on the upstream and the downstream side of individual HEPA filters to effectively isolate the HEPA filter from all others in the filter bank. Each shroud is a sheet metal duct that is held against the HEPA filter or frame on one end and has a reduced 1' x 1' section on the other end. The upstream shroud is used for injecting aerosols, and the downstream shroud is used for sampling the downstream aerosols. Figure 10 shows the front (A) and rear (B) sides of the upstream shroud, that is used to expose a HEPA filter to a uniform aerosol concentration. Figure 10 B shows the rear side of the upstream shroud with the 9 point aerosol injection manifold. The aerosols are then mixed by a baffle plate seen in Figure 10 A and B and further dispersed by a screen seen in Figure 10 B. The upstream shroud also has a sample port for sampling the challenge concentration. The downstream shroud, shown in Figure 11, has a 9 point sampling manifold and no internal mixing devices. The filter leak or penetration is obtained by simultaneously placing the upstream and downstream shrouds against the HEPA filter or frame as shown in Figures 12 and 13 respectively.



10. Upstream shroud for exposing individual HEPA filters in a filter plenum to challenge aerosols. (A) shows the front side, (B) shows the rear side.

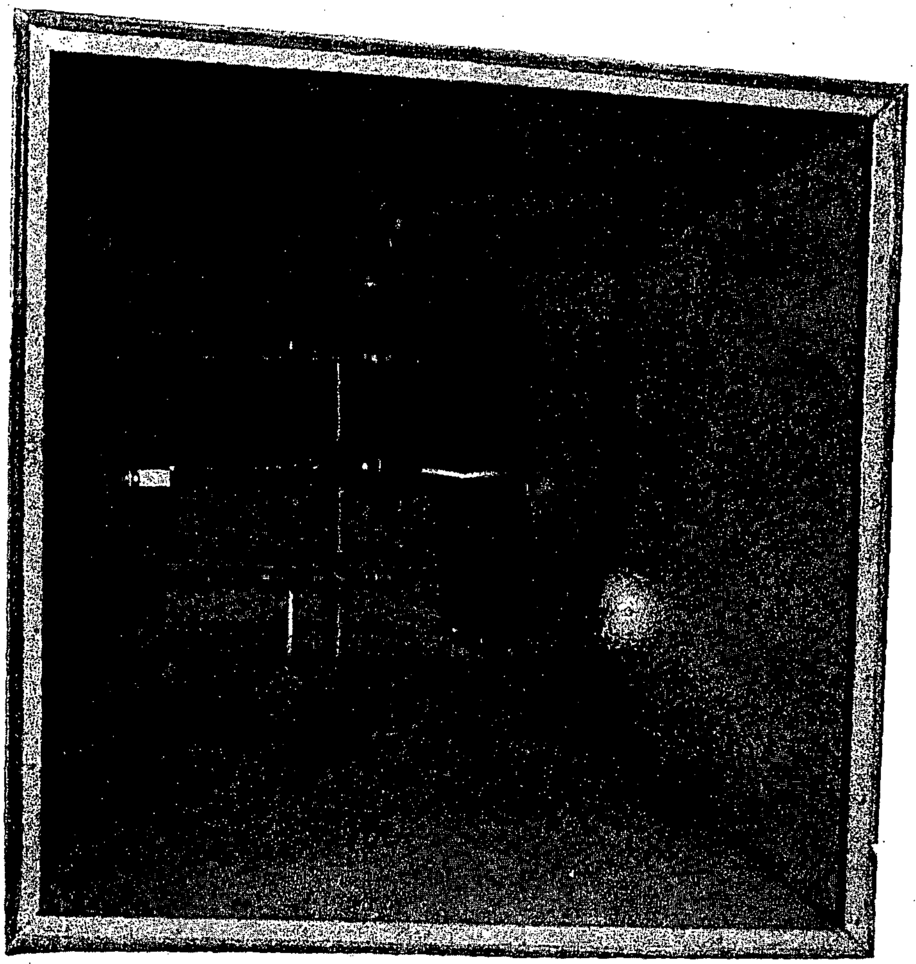


Figure 11. Downstream shroud for sampling filter penetration or leak. Nine point sampling manifold is seen from the inlet side facing the HEPA filter.

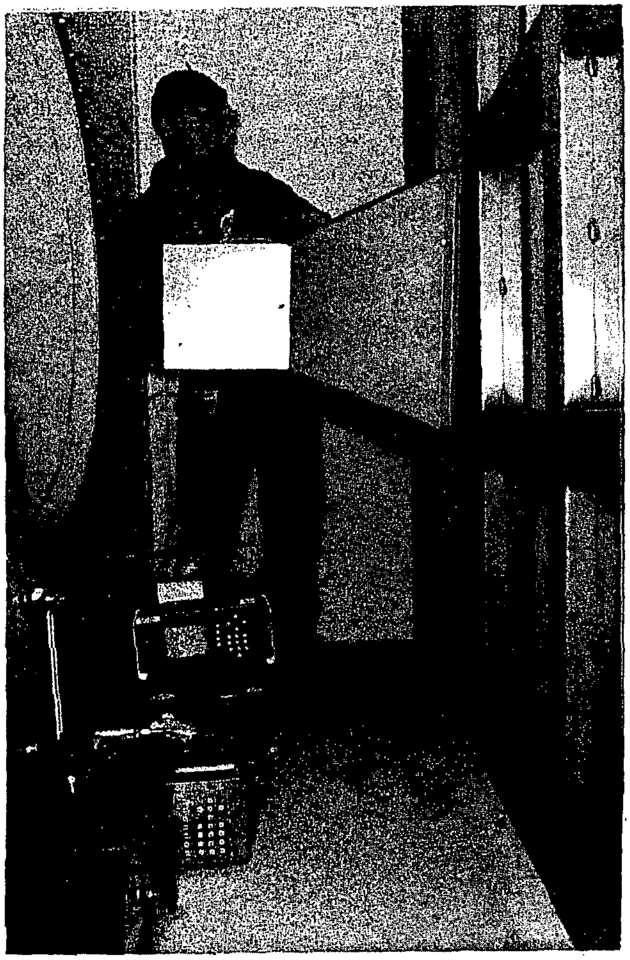


Figure 12. Downstream shroud for sampling aerosol penetration from individual filter. In-place penetration equipment used in this test.

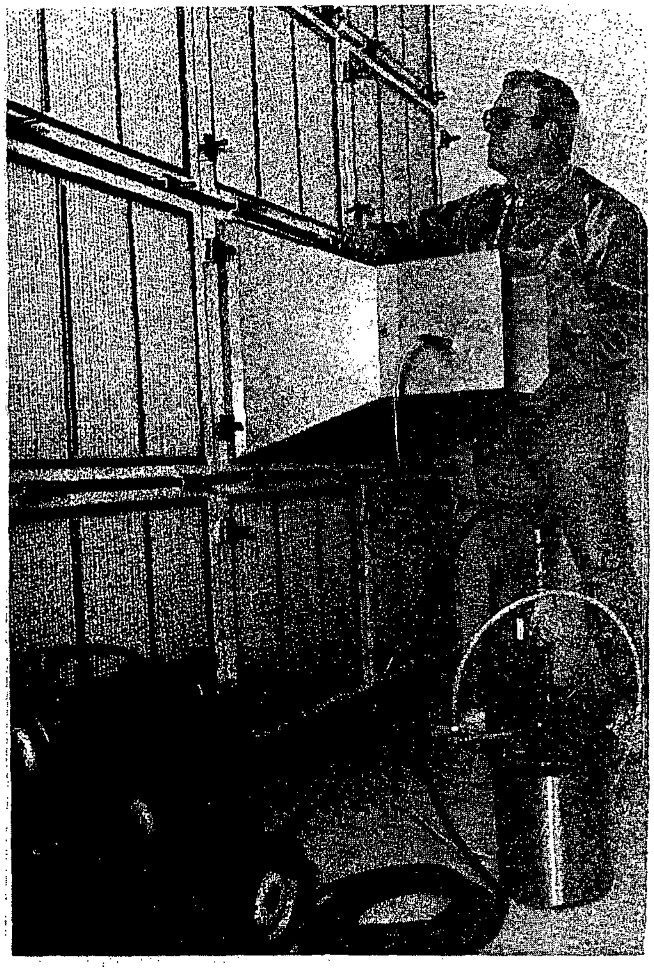


Figure 13. Upstream shroud for generating challenge aerosols. Laskin nozzle aerosol generator used in this test.

The result of the in-place penetration measurement on one filter in the plenum is shown in Figure 14. We were unable to generate the required high concentration of challenge aerosols to use the 10,000:1 diluter because the compressor shown in Figure 13 could not supply sufficient pressure to the Laskin nozzle aerosol generator. As a result, we used the 100:1 diluter with a lower aerosol concentration. This resulted in lower precision and a longer sampling time than would be required with a higher aerosol concentration and a 10,000:1 diluter. The upstream and downstream sample times were 2 and 8 minutes, respectively. The equipment used for the in-place penetration measurement using the shroud method was the same as previously described for the single filter test.

Since the shroud method only measures the penetration or leaks through the filter, and not around gasket leaks, a separate leak test is performed on each filter. This is done by directing a concentrated aerosol challenge around the perimeter of the upstream side of the filter using a long tube. Another person samples the perimeter of the downstream side of the filter using a long probe that is moved in syncronization with the upstream challenge tube. If the downstream leak is greater than 0.03% of the upstream concentration, then the filter is replaced. This traverse leak test is far more conservative than the leak or penetration measurement through the filter because no significant air volume passes through the leak compared to that flowing through the filter. Since the air flow through a gasket leak parth is not known, the traverse leak test is not quantitative, but rather a qualitative test. When using the laser counter in this leak test, the counter output is set to the concentration mode and not the count mode.

The conventional in-place leak test indicated the filter in Figure 14 had a leak of 2 x 10^{-4}. We used a TDA-2EN photometer and a TDA-5B aerosol generator, both from ATI, for the in-place leak test. The test aerosol for the in-place leak test was Emery 3004.

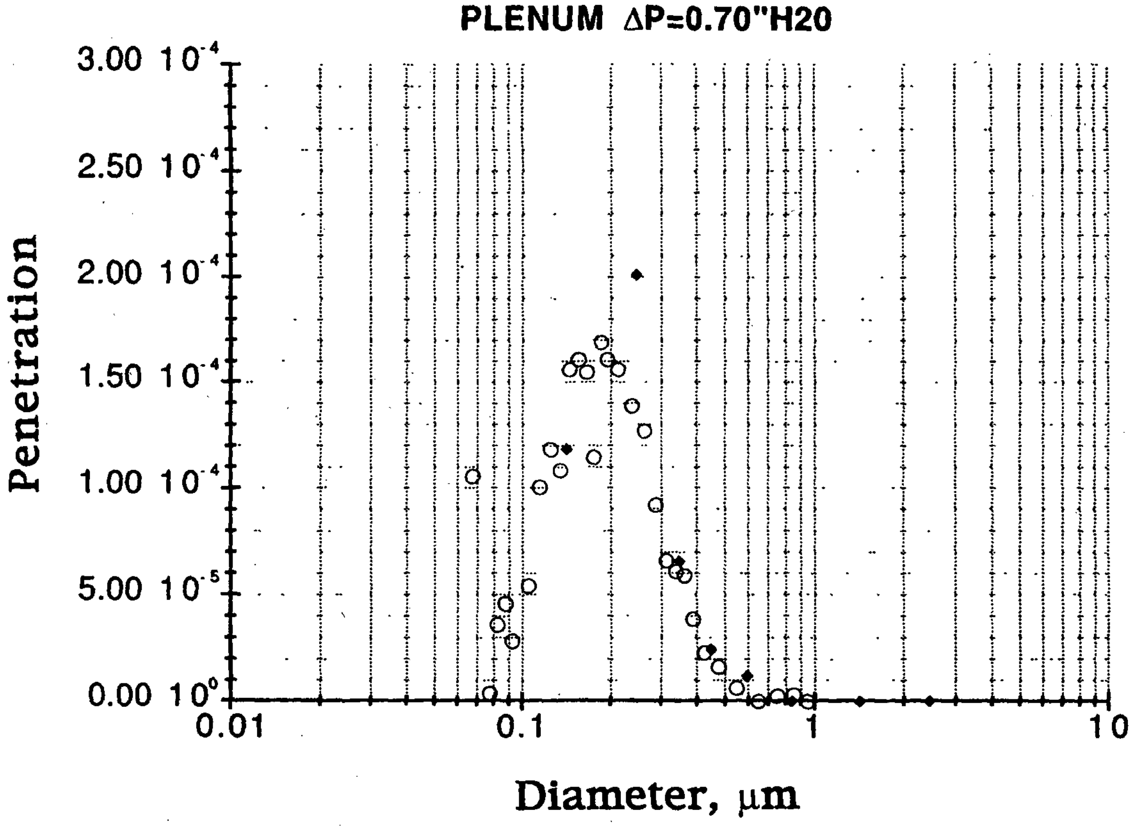


Figure 14. In-place penetration measurement of a HEPA filter in a plenum using the shroud sampling method. Open data obtained with HS-LAS, closed data with LASAIR.

We performed a detailed analysis of the time requirement for the in-place leak and the penetration test using the shroud method and tabulted the results in Table 3. The time requirements for all of the tasks except for the downstream measurements are comparable for the two in-place tests. As noted before, the long downstream sampling times was primarily due to the inability to generate a sufficient concentration. We anticipate that the in-place penetration measurement would not require much more time than the in-place leak test once the experimental test system is optimized.

Table 3. Comparison of time requirements for in-place leak and in-place penetration measurements on a HEPA filter bank using the shroud method.

Task	Leak Test	Penetration Test
Equipment set up	10 min.	15 min.
Equipment warm up	10 min.	10 min.
Upstream meas./filter	(5 min.)	(4 min.)
Upstream bank (16 filters)	80 min.	64 min.
Downstream meas./filter	(0.3 min.)	(10 min.)
Downstream bank(16 filters)	5 min.	160 min.
Tear down	30 min.	30 min.
Total	135 min.	279 min.

VI. Conclusions

We have demonstrated the feasibility of conducting in-place penetration tests on high efficiency particulate air (HEPA) filters as installed in nuclear ventilation systems. The in-place penetration test, which is designed to yield equivalent penetration measurements as the standard DOP penetraton test, is based on measuring the aerosol penetration of the filter installation as a function of particle size using a portable laser particle counter.(1) Additional tests are required to confirm that the in-place penetration test yields identical results as the standard DOP penetration test for HEPA filters with controlled leaks in the filter and gasket and duct by-pass leaks. Further development of the procedure is also required to reduce the test time before the in-place penetration test is practical.

VII. Acknowledgments

We gratefully acknowledge the assistance Mr. Wayne Krause and Mr. Donald Beason in the shroud tests.

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DISCUSSION

FRANKLIN: On the DOP feed of the sampler, was that downstream of the grid? I could not tell where you were sampling the concentration of the DOP feed.

BERGMAN: The upstream sample was measured through a single probe that was inserted through a porthole in the shroud just before the HEPA filter. A single probe is sufficient at this point because the Emory 3009 aerosols were well mixed. The aerosols are injected through a nine-port manifold within a one foot by one foot area. The aerosols then hit a baffle that covers about 70% of the open area and is further mixed by a grid. The sample is then taken after the grid.

KOVACH, B: I have one question . When you tested with the shroud method I understand how you calculated the average leak with the shroud, but how did you add the gasket leakage to the efficiency?

BERGMAN: The shroud method only allows you to measure the average leak if the HEPA filter is mounted on the upstream, dirty side of the frame. In this case, the shroud is placed against the frame on the downstream side. Penetrations through gasket leaks and the filter are measured together as a single measurement. If the HEPA filter is mounted correctly on the downstream, clean side of the frame, it is not possible to quantify the leak through the gasket. The shroud is placed over the HEPA filter and only measures the leak through the filter. Leaks through the gasket are determined in a separate test in which a probe is traversed around the perimeter of the gasket. If the aerosol penetration at any point exceeded 0.03% the filter was removed.

METHOD FOR HEPA FILTER LEAK SCANNING WITH DIFFERENTIATING AEROSOL DETECTOR

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NUCON International, Inc.
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Abstract

While scanning HEPA filters for leaks with "Off the Shelf" aerosol detection equipment, the operator's scanning speed is limited by the time constant and threshold sensitivity of the detector. This is based on detection of the aerosol density, where the maximum signal is achieved when the scanning probe resides over the pinhole longer than several detector time-constants.

Since the differential value of the changing signal can be determined by observing only the first small fraction of the rising signal, using a differentiating amplifier will speed up the locating process. The other advantage of differentiation is that slow signal drift or zero offset will not interfere with the process of locating the leak, since they are not detected.

A scanning hand-probe attachable to any NUCON® Aerosol Detector displaying the combination of both aerosol density and differentiated signal was designed.

Introduction

The scanning of HEPA filters is described in numerous articles and the general conclusion is that the size of the smallest leak detected is the function of the threshold sensitivity, reduced by the photometer response time versus scanning speed of the operator. The explanation is that the bell shaped curve of the aerosol concentration behind the pinhole is the highest in the center of the hole. Consequently, while scanning, the probe should reside over the center of the hole long enough to build up the maximum aerosol concentration in the optical chamber of the photometer. Since this is seldom the case, the conclusion is that with any given photometer there is a compromise between "missing some of the holes or working unnecessary long hours." Instead of such compromising, a mathematical solution of "enhancing" the data by differentiation of the exponential response curve was suggested

The Method of Measuring the Aerosol Density and its Limitations

An isokinetic sampling probe for 100 feet per minute (fpm) face velocity using the 1 CFM pump was designed with an opening of 3" long and 0.5" wide. At a scanning speed of 10 fpm., it passes the pinhole leak in 0.5 sec

The response curve of the aerosol detector to a sudden increase of the aerosol concentration is an exponential function. The time constant of this function is independent of the pulse height. (3) The time constant of the NUCON® aerosol detector used for our experiment on the sensitivity range of 0.1 microgram/ liter is 0.62 sec. The detected pulse, with previously mentioned scanning speed of 0.5 seconds, reached approximately 30% of the maximum value. Scanning over the pinholes where this signal value is equal to the drifts generated by the detectors electrical system and/or drift of the aerosol concentration, no leaks were detected. To improve the threshold sensitivity, the following steps could be taken·

1. Slow the scanning speed
2. Decrease the time constant of the aerosol detector
3. Decrease the electrical drift

As neither of those should significantly improve the threshold sensitivity, the logical approach was to use a differentiating "enhancing" amplifier.

The Differentiating Method: Advantage and Limitations

The differentiating amplifier does not recognize the constant signal value; in our case it is the analog value of the background aerosol concentration combined with the slow electronic drift. The time constant chosen for this amplifier selectively enhances the functions, having the rise time similar to the optical chamber. This approach ensured the recognition of aerosol concentration increase in the optical chamber, while suppressing all other slow drifts signals.

The output signal of this amplifier is displayed on a 99 segment LCD display. The display is electrically preset to 50% value to allow movements in both positive and negative directions. When the scanner approaches the vicinity of the hole, the meter moves first in one direction, returns to zero and, as the probe is moved away from the hole, moves in the other direction. Due to the long sample line, this reading is delayed and the operator has to practice using the hand probe.

The Combination of Measuring the Aerosol Concentration and Differentiated Signal

As a final solution, a double display fast LCD meter was built in a hand-probe with two operational amplifiers. The first meter displays the aerosol concentration transferred from the aerosol detector meter The second meter, adjusted to the 50% value, makes positive and negative movement only during changes of the aerosol concentration. The operator, observing this movement, returns on the same path to locate the hole and read the concentration on the first meter.

Conclusion

Tests performed using a NUCON® aerosol detector with the added differentiating hand-probe confirmed that the time spent scanning for leaks can be decreased by as much as 50-90% of the standard scanning method. The benefit of this is a reduction in the total time spent in radiation fields and confined spaces, and an increase in the total number of filters scanned in any given time.

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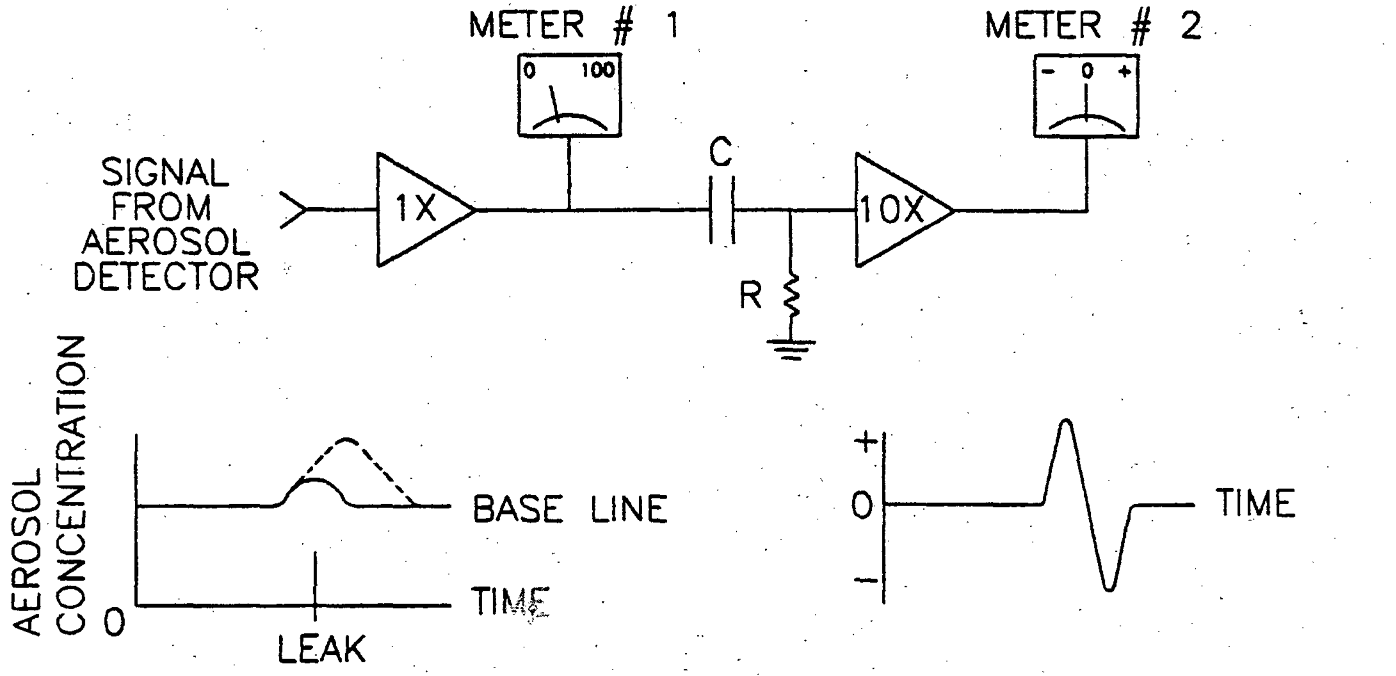

SCANNER SIGNAL WAVEFORM WHILE PASSING OVER A LEAK

DIFFERENTIATED SIGNAL WAVEFORM OF THE SCANNED LEAK

FIGURE 1

DIFFERENTIATING HEPA SCANNER HANDPROPE

DISCUSSION

RICKETTS: You mentioned that if you stay at the location of the leak long enough, after you have found it, that you can make an absolute measurement. Do you have to switch modes, somehow?

KOVACH, B: No, both instruments are on the same probe. You can see the display on both sides. One is a differential display which has the zero in the middle and the other is the number reading, the absolute value.

UNCERTAINTY IN IN-PLACE FILTER TEST RESULTS*

Ronald C. Scripsick[1], Richard J. Beckman[2], and Brian V. Mokler[3]

Abstract

Some benefits of accounting for uncertainty in in-place filter test results are explored. Information the test results provide relative to system performance acceptance limits is evaluated in terms of test result uncertainty. An expression for test result uncertainty is used to estimate uncertainty in in-place filter tests on an example air cleaning system. Modifications to the system test geometry are evaluated in terms of effects on test result uncertainty.

Introduction

In-place tests are performed on high efficiency particulate air (HEPA) filter systems to evaluate system performance. Test results are compared to system performance limits to judge acceptability of system performance relative to requirements of system design that assure health and environmental protection. In the absence test result uncertainty, acceptance limits on test results coincide with limits on system performance (see Figure 1). Uncertainty in test results has the effect of offsetting test result acceptance limits from acceptable system performance limits. Test results below test result acceptance limits provide clear evidence that system performance meets acceptance limits.

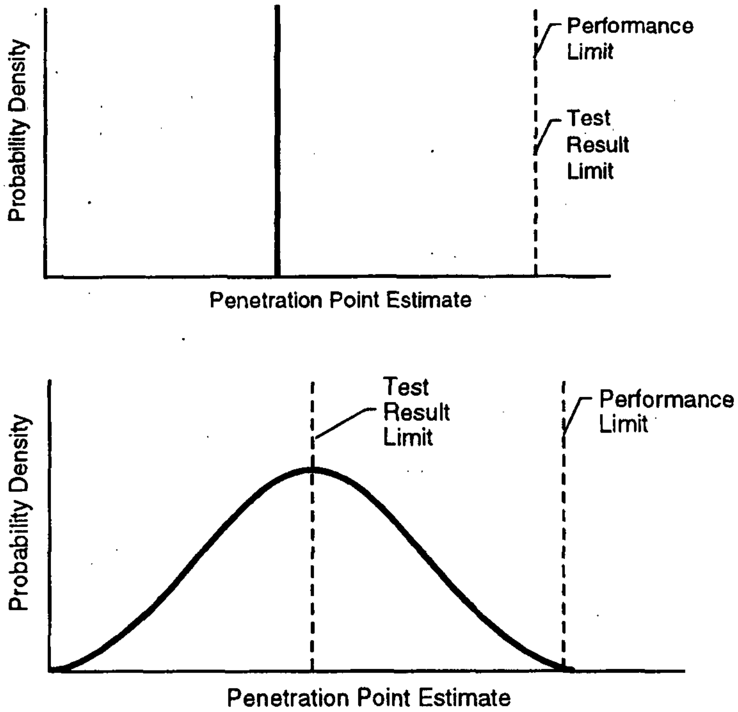

Figure 1 Two plots showing relation between system performance acceptance limit and test result acceptance limit for the case where test result uncertainty is zero and for the case where test result uncertainty is greater than zero.

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*Support for this work comes from the US Department of Energy, the office of Defense Programs (DP-451) and the office of Nuclear Energy (NE-30). The program managers are James Slawski and George Sherwood.

Recently an expression for uncertainty in in-place filter test results for a single HEPA filter bank was developed using error propagation analysis[1]. The expression uses indices of spatial variation of test aerosol concentration, flow velocity, and penetration to estimate test result uncertainty. These indices are referred to as heterogeneities and are defined in terms of relative standard deviations. In this paper, the uncertainty expression is used to evaluate the benefit modifications to test geometry might have in reducing uncertainty of in-place filter tests on a HEPA filter system.

An illustration of the geometry of in-place filter tests is presented in Figure 2. Test aerosol is injected into the ventilation system upstream of the HEPA filter bank at the injection plane. Aerosol concentration is sampled upstream of the filter bank in the challenge plane and downstream of the filter bank in the downstream sample plane. Concentration heterogeneity of the challenge aerosol is reduced by an upstream mixing factor, h_U, between the injection and challenge planes. Heterogeneity of aerosol penetrating the filter banks is reduced by a downstream mixing factor, h_D, between the downstream plane and the downstream sample plane.

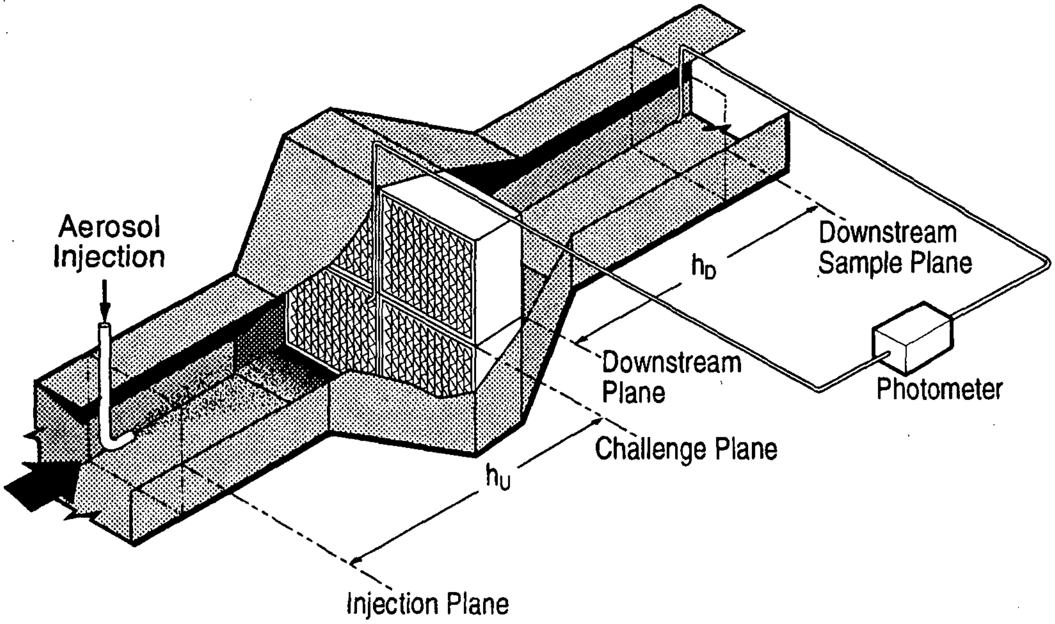

Figure 2 Generalized HEPA filter system showing in-place filter test geometry and mixing factors.

An estimate of aerosol penetration through the bank is given by:

$$\hat{P} = \frac{X_{DS}}{X_{US}} \quad (1),$$

where,

$\hat{P}$ = penetration point estimate,
X_{DS} = the downstream sample concentration, and
X_{US} = the upstream sample concentration.

Error propagation analysis yielded an approximate expression for the uncertainty in $\hat{P}^{1}$:

$$H_{\hat{P}} = \left[\frac{\left(\frac{1}{X_U} - 1\right)}{h_U^2} \left(\frac{1}{h_D^2} + 1 \right) + \frac{\left(\frac{1}{\hat{P}} - 1\right)}{h_D^2} + \frac{H_Q^2}{h_D^2} \right]^{1/2} \qquad (2),$$

where,

$H_{\hat{P}}$ = heterogeneity of the penetration point estimate or estimate of test result uncertainty,

X_U = dimensionless test aerosol challenge concentration, $= \frac{Q_{inj}}{Q}$,

Q_{inj} = volume flow rate of injected test aerosol,

Q = total HEPA filter system volume flow rate, and

H_Q = heterogeneity of the challenge flow velocity.

Analysis and Results

The expression for test result uncertainty (Equation 2) was used to estimate uncertainty in in-place filter tests on an example HEPA filter system. Example system design is based on an existing system at the Mound Facility in Miamisburg, Ohio[2]. A diagram of the example system is shown in Figure 3. The system has two air flow entries immediately upstream of the HEPA filter bank. Test aerosol is injected in the primary entry. There is no aerosol injection in the secondary entry.

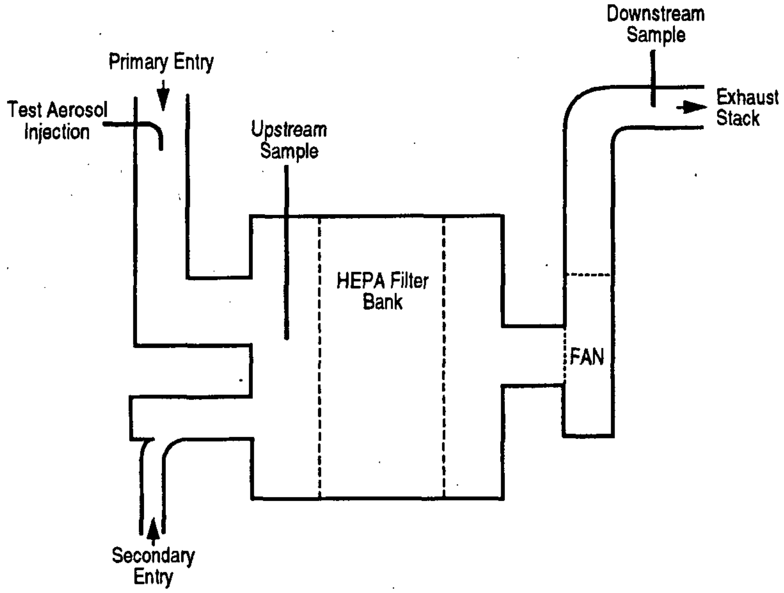

Figure 3 Example exhaust filtration system with two entries. In-place filter testing injection and sampling locations are shown.

For this analysis, Q_{inj} will be 2 cfm and Q will be 30000 cfm; both values are within the range of values observed for nuclear facility HEPA filter systems[2]. Test aerosol is assumed to be well mixed in the primary entry to the filter plenum. However, because no aerosol is injected in the secondary entry, the challenge concentration is almost certainly not the same for all filters. Consequently, h_U for this analysis was estimated to be 150, which is a tenth of the value needed for this system to meet the ASME N510 'air-aerosol mixing uniformity' requirements[3]. Because flow downstream of the filter bank passes through a fan prior to being sampled, h_D is certainly much greater than h_U. For this analysis h_D was estimated to be 1500. The division of the air flow between the two entries is assumed to be balanced such that the system meets ASME N510 'airflow distribution' requirements[3].

Values of test result uncertainty predicted from Equation 2 are shown in Figure 4 for test aerosol injected in the primary entry. At a typical system performance acceptance limit of 0.05% penetration, the predicted uncertainty was 0.82.

One potential method to reduce uncertainty in test results for this system is to inject aerosol into both entries. If aerosol injection rates are adjusted so that the average concentration is the same in both entries, the value of h_U would be increased, thus decreasing the uncertainty estimate. To illustrate this point, the analysis was repeated with test aerosol injection in both entries. This modification was assumed to increase h_U by a factor of five to 750. Uncertainty estimate predictions for this test aerosol injection configuration are shown in Figure 4. At the penetration point estimate of 0.05%, the uncertainty prediction is reduced to 0.17, almost a factor of five less than that for injection in the primary entry only.

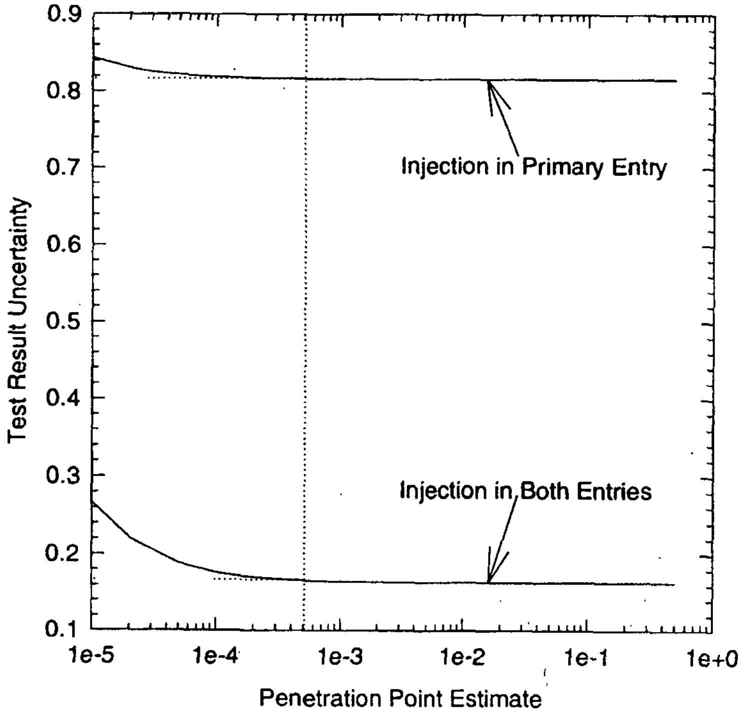

Figure 4 Values of test result uncertainty plotted against the penetration point estimate.

The uncertainty estimates were used to predict test result acceptance limits. The test result limits were determined using an offset below the system performance acceptance limit equal to three times the uncertainty estimate. Results of this analysis for both test aerosol injection configurations are shown in Figure 5. For injection in the primary entry, the test result acceptance limit was approximately 0.014% at the system performance acceptance limit of 0.05% penetration. The analysis indicates that test results below 0.014% provide clear evidence that system penetration is no greater than 0.05%. For test aerosol injection in both entries, this performance is assured by test results of 0.033% or less.

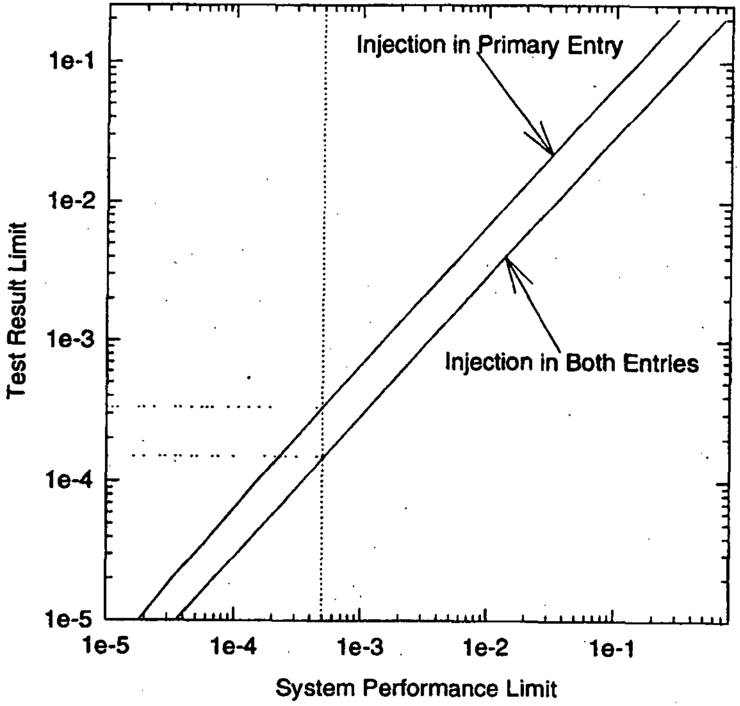

Figure 5 Test result acceptance limit plotted against system performance acceptance limit.

Discussion and Conclusions

The method presented here to account for uncertainty in in-place filter tests provides an objective rationale to judge whether tests results support the conclusion that system performance meets acceptance limits. Test result acceptance limits coincide with system performance acceptance limits only when there is no uncertainty in test results. Uncertainty in test results can be accounted for by offsetting test result acceptance limits below system performance acceptance limits by an increment related to the uncertainty. Here this increment was set equal to three times the test result uncertainty estimate. By this rationale, penetration point estimates below the test result acceptance limit are judged to provide clear evidence that limits on system performance are being met.

In addition to providing a rationale to judge acceptable HEPA filter system performance, test result uncertainty estimates can provide a metric to assess potential benefits of test geometry modifications. In the example described here, the test result acceptance limit could be increased by more than a factor of two through a modification in the test procedure. This metric provides facility managers a means to evaluate whether benefits from such modifications are cost effective. In this example, the facility manager could assess whether the extra cost of injecting test aerosol in both entries is offset by reducing the number of times system performance is rejected. If no test results have been reported in the 0.014% to 0.033% range, then the analysis indicates the modification would not be cost effective. However, if even a few test results are expected in this range, then the modification may be cost effective in delaying such costly system maintenance actions as filter replacement.

The utility of the uncertainty estimates may increase when ventilation system modifications are considered to reduce test result uncertainty. Such modifications can be costly, especially for systems contaminated with hazardous materials. Ventilation system modifications are among those being considered to establish compliance of existing systems with standards that post-date system design and construction. A number DOE nuclear air cleaning systems are in this category. The uncertainty estimates can help identify what system modifications might be needed to reduce overall test result uncertainty to levels that assure performance equivalent to that provided by tests on fully compliant systems. The estimates can also help identify costly modifications that contribute little to establishing this equivalency. Systems that pass these equivalent tests can be reasonably expected to provide levels of health and environmental protection equivalent to that provided by the fully compliant systems.

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DISCUSSION

DAUBER: I am intrigued by this method and I wonder if you have applied it to the testing of adsorbers as well as to HEPA filters and, if so, could you elaborate?

SCRIPSICK: I have not done it and did not think about it until you just asked. I do not see anything right off that would prevent it. I am not as familiar with the requirements of the adsorber test as I am with the in-place filter test. From a statistics point of view, I think that it could be applied.

GRAVES: The view graph you presented showed a two entry system. Why wouldn't you just qualify the system and inject in both places according to N-510 and be done with it?

SCRIPSICK: They have tested that system that way for a number of years. However, there is a cost associated with injecting in both systems but I would opt for injecting in both. The point I was trying to make is that this gives the cost-benefit information that a manager needs to have to justify a decision like that. There will be additional costs in injecting both because the injections are remote from the plenum. You would have to add at least one person to the test team. So there would be some costs, minor ones, I think.

GRAVES: Injecting at a single point, that is not even a test. There is a cost associated with a system that might leak because people get hurt, or contamination spreads, or something like that. But I do not see any guesswork in the one you showed. The single injection is not a test of that system, it is somebody doing an exercise, but it is certainly not a test.

DORMAN: I have some comments on in-place testing but I would not want to say my comments applied to bad testing or to Scripsick's or Bergman's presentations. They are general so I will make them in the chairman's including remarks

VALIDATION TESTING OF RADIOACTIVE WASTE DRUM FILTER VENTS

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ABSTRACT

The minimum requirements for Drum Filter Vents (DFV's) can be met by demonstrating conformance with the Waste Isolation Pilot Plant (WIPP) Trupact II Safety Assessment Report (SAR), and conformance with U.S. Federal shipping regulations 49 CFR 178.350, DOT Spec 7A, for Type A packages.

These together address a number of safety related performance parameters such as hydrogen diffusivity, flow related pressure drop, filtration efficiency and, separately, mechanical stability and the ability to prevent liquid water in-leakage.

In order to make all metal DFV technology (including metallic filter medium) available to DOE sites, Pall launched a product development program to validate an all metal design to meet these requirements. Numerous problems experienced by DOE sites in the past came to light during this development program. They led us to explore enhancements to DFV design and performance testing addressing these difficulties and concerns.

The result is a patented all metal DFV certified to all applicable regulatory requirements, which for the first time solves operational and health safety problems reported by DOE site personnel but not addressed by previous DFV's. The new technology facilitates operations (such as manual, automated and semi-automated drum handling/re-drumming), sampling, on-site storage, and shipping. At the same time, it upgrades filtration efficiency in configurations documented to maintain filter efficiency following mechanical stress.

BACKGROUND

A great number of TRU radioactive waste packages have been generated throughout the DOE weapons complex. Condition of these packages varies widely. In addition, DOE sites continue to produce significant quantities of TRU waste, and will do so for the foreseeable future.

Hydrogen and other gasses are radiolysis products of several materials under alpha particle bombardment within the drums. This can result in flammable/explosive mixtures within the packages and/or their pressurization. The gasses must be vented while maintaining absolute containment integrity, in an environment also subject to fluctuating ambient temperature and weather conditions, and normal handling and transportation.

DOE's objective is to protect the public by consolidating these TRU waste packages in the WIPP underground repository. To meet this objective, DOE plans to ship packages in good condition, properly overpacked, with each container having at least one Drum Filter Vent (DFV), all conforming to regulatory requirements for transport and subsequent final storage.. DFVs are required on all drums and boxes of TRU waste.

Several years ago, the Pall Corporation was asked by waste management personnel at the Idaho National Engineering Laboratory (INEL) to explore design possibilities of an all stainless steel DFV filter as an alternative to those in use, principally relying on a carbonaceous filter medium bonded to its mounting hardware. Availability of a qualified DFV with improved damage resistance was INELs principal objective. Pall's stainless steel filter medium at HEPA grade efficiency had been certified to a number of MIL-F-51079 performance criteria(1). It was an obvious candidate technology for use in these new designs.

DFV RATIONALE

To guide the DFV development process, Pall engineers extensively contacted DOE TRU waste management personnel. During the ensuing site visits and discussions, a number of additional concerns about existing DFV's surfaced:

1. Preliminary testing at INEL indicated that reliable head gas sampling for VOC's could not be achieved through the carbon filter medium. This was investigated by INEL because representative sampling through the filter would significantly simplify the WIPP Waste Acceptance Criteria (WAC) certification process. In order to satisfy this component of the WAC, methods were adopted in certifying waste packages which required destruction/replacement of the carbon based DFV.

2. Questions were raised concerning the effective lifetime of adhesives used in manufacturing the carbon based DFV filter medium. Compounding this concern was the varied temperature, radiation, chemical, and climatic environments to which these TRU waste packages would be exposed, in conjunction with their intended lengthy periods of service.

3. In-leakage of water through DFV's with carbon based filter medium was reported at several DOE sites. At one site, over 4,000 drums were re-processed and de-watered because of concerns arising from up to 14 gallons of water having entered <u>each</u> drum. Mechanism of entry: ambient temperature cycling and associated temperature/pressure variations within TRU waste drums having accumulated water on their covers (e.g. rain, or melted snow).

   This in-leakage and its potential to re-occur was of concern to criticality safety personnel due to water's properties as a neutron moderator.

   Liquid water in-leakage also raised questions of unseen corrosion. This is important as these packages have to be "certified" safe for transport to WIPP

4. There was a desire, common to all of the DOE contractor personnel contacted, to maximize hydrogen diffusivity, minimize pressure drop across the DFV, and to assure HEPA level filter efficiency (≥99.97% for heat-generated monodisperse 0.3um DOP smoke).

   Several sites, including Savannah River, were questioning whether to install more than one DFV per TRU package, in order to increase hydrogen dissipation rates and better prevent build-up to a flammable concentration.

   HEPA level filter efficiency was referred to as the recognized standard for protecting public safety, and a level of performance desirable in DFV's. DFV's are not currently required by WIPP to perform to HEPA level efficiency. However, some DOE site specifications do require HEPA filter efficiency.

5. A very small fraction of existing drums at one DOE site were found with head gasses containing concentrations of HCl significant to stainless steel from a corrosion standpoint. Where encountered, this can be addressed by polymeric and/or higher alloy metallic DFV's. Our survey of DOE sites has not encountered any other drums where HCL would be expected to present a problem.

VALIDATION TESTING

Extensive DOE site survey also revealed current dimensional needs which Pall engineers effectively embodied in an assortment of hardware designs. A variety of these (below) have now been tested in accordance with the requirements, given in Table I, and shown under DOE witness and/or third party witness to meet or exceed them.

Table 1
DFV Validation Test Requirement and their Sources

SOURCE	TEST
Basic Regulatory Requirements	
1. Trupact-II SAR	Hydrogen Diffusivity Pressure Drop vs. Air flow DOP Efficiency
2. 49 CFR 178.350 DOT Spec 7A, Type A	Water Spray Drum Drop Compression Rod Penetration
Functional Requirements Identified Through DOE Site Visits	
3. Liquid Water in-leakage Prevention	
Pall Laboratories	In-leakage prevention limit
4. Representative Head Gas Sampling	
INEL	Hydrogen, methane, and VOC Transport Test (Formal Report recently completed.)

DFV'S SUBJECT TO VALIDATION TESTING

Pall all metal DFV's tested utilize the same filter medium, and comprise stainless steel filter medium and hardware. Models tested are depicted in Figure 1, attached.

DFV #1

The Standard Design (hexagonal body, 3/4 inch thread), intended for newly generated TRU waste packages. It is also employed on boxes and 85-gal drums used to repack or overpack damaged 55-gal TRU drums of retrieved waste. Also available in round body (#5R, Appendix A); choice made based on current equipment, handling fixtures and site procedures and practices.

Note: prior to commercial production this model DFV #1 was designated by its R&D code: "625exxx," where xxx is a three digit serial number. This code appears in this report where applicable.

DFV #2

This design arises from LANL's approach to remotely venting drums being retrieved from landfills on their site. The design mates with LANL equipment that remotely inserts a DFV into the retrieved drums.

DFV #3 & 4

These are INEL designs differing only in thread size, 7/16 inch and 1/2 inch self tapping. They arise from INEL's approach to remote venting of retrieved drums. These DFV's mate with the INEL equipment that inserts the DFV into a retrieved drum.

TEST METHODS AND RESULTS

All tests reported were conducted in compliance with indicated source (Table 1). What follows are functional descriptions of the tests, and test results.

Trupact-II SAR Requirements

Tests of hydrogen diffusivity and airflow resistance at between 1 and 10 psig were performed by an independent test facility, the Westinghouse Science and Technology Center, under contract by Pall Corporation (2). Methods were exactly as previously used in qualifying conventional carbon based DFV's.

Tests of DOP efficiency, and fixed flow rate pressure drop tests were performed under witness and certified by an independent third party, ETL Testing Laboratories, Inc., under contract by Pall Corporation. All DOP tests herein reported were performed using an ATI model Q127 DOP penetrometer, delivering heat-generated monodisperse 0.3um DOP smoke.

1. Hydrogen Diffusivity Test

Results are given in Table 2, below. The minimum acceptance criterion specified by WIPP is 1.90E-06 mole/sec/mole fraction.

Table 2
Diffusion Coefficients and Standard Errors for All Filters

Filter	D' mol/mole%/sec	D' mole/mole%/sec standard error	D' mole/sec/mole fraction	D' mole/sec/mole fraction standard error
625e016	5.13E-08	9.38E-10	5.13E-06	9.38E-08
625e046	5.33E-08	2.01E-09	5.33E-06	2.01E-07
625e010	4.96E-08	1.43E-09	4.96E-06	1.43E-07
Avg 625e's	5.14E-08	1.46E-09	5.14E-06	1.46E-07

2. Pressure Drop vs. Air Flow Test

Results are given in Table 3, below. The minimum specification established by WIPP is one LPM at one psi gauge pressure drop across the DFV (or 200 cc/min at one "H_2O gauge pressure drop; see also Table 5, below).

Table 3
Flows versus Pressure Drop at 1.0 psig

FLOW, SLPM AIR, at ΔP = 1.0 psid

625e016	625e010	625e046
10	11	10

Plots of pressure drop across the filters vs. flow for all filters were prepared from a series of measurements up to 10 psig. These were linear with correlation coefficients greater than 0.99 for each filter. The relationship between flow and pressure drop may also be expressed as the flow coefficient, C_f = flow/pressure drop, where flow is in standard liters per minute air and pressure drop is in psig. Since the graphs were linear, the flow coefficients are the slopes, shown in Table 4:

Table 4
Flow Coefficients for All Filters.

Filter	C_f, slpm air/psig
625e016	14.5
625e010	14.9
625e046	13.5

3. Pressure drop; DOP Efficiency.

The minimum flow capacity established by WIPP at one "H_2O gauge pressure drop across the filter is 200 cc/min. WIPP also specifies that each filter shall exhibit filtering efficiency >99.9% with 0.3 - 0.5 um particles of DOP smoke.

Filter pressure drop and aerosol Penetration were measured at 200cc/min flow of hot-generated 0.3um monodisperse DOP, and certified under third party witness: ETL Testing Laboratories, Inc. The results are given in Table 5, below.

TABLE 5
DOP Penetration and Filter Pressure Drop at Fixed flow Rate

	Filter	Flow Rate		Air ΔP, in. H_2O	% Penetration
Model	Part Number	SCCM	ACCM		
DFV #1	Log 916E #049	200	208	0.55	0.005-0.008
DFV #1	Log 916E #047	200	208	0.55	0.004-0.007
DFV #1	Log 916E #032	200	208	0.60	0.004-0.005
DFV #2	Log 180F #39	200	208	0.80	0.002-0.003
DFV #2	Log 180F #39	200	208	0.80	0.002-0.003
DFV #2	Log 180F #51	200	208	0.75	0.002-0.003
DFV #3	Log 216F #1	200	208	0.75	0.001-0.003
DFV #3	Log 216F #4	200	208	0.75	0 001-0.003
DFV #3	Log 216F #12	200	208	0.75	0.002-0.005
DFV #4	Log 215F #2	200	208	0.75	0.002-0.004
DFV #4	Log 215F #6	200	208	0.80	0.001-0.002
DFV #4	Log 215F #5	200	208	0.65	0.002-0.003

DOT Spec 7A., Type A Requirements

DOP penetration testing is not specified as a DOT Spec 7A performance requirement, however, this was performed as added demonstration of DFV robustness before and after the mechanical tests specified for Type A packages, items 2, 3, and 4, below.

1. Water Spray Test, performed under witness by: INEL personnel, and Edling & Associates, Inc.

The purpose of this test is to demonstrate that "rain" will not adversely affect the containment integrity and that there will not be any in-leakage of liquid water under rainy out-door storage conditions. It probes in-leakage resistance of the filter medium, DFV construction, and seals. Note: Passing this test has no bearing on the ability of the DFV to allow the passage of water in its gaseous or vapor state.

Four DFV's, one each of the four types tested, were installed into a drum lid, 90° from one another. Blotter paper was placed under the DFV inlet (drum contents side of lid) so that should liquid water enter the drum it would be captured by the paper, providing an easily detected, visual indication of even small quantities of liquid in-leakage. The blotting paper was affixed to the inside surface of the lid securely with standard duct tape, and drum assembly then completed. All DFV's and the lid were affixed using applicable torque as specified in the "DOT Spec 7A Evaluation Documents."

Following drum assembly per above, shower heads were used to deliver "rain" uniformly over the drum lid for a period of an hour. Upon completion of the water spray, in further accordance with test requirements, the package was allowed to stand two hours without draining or other disturbance prior to examination for in-leakage or other detrimental effect. At this point, water was standing on the drum lid to its height of overflow. A rain gauge placed on the lid during the shower showed overflow beyond its 5.5" capacity, demonstrating that "rain" had been well beyond the 2" per hour minimum required.

The water was drained off the lid, the lid removed, and the blotting paper thoroughly inspected for evidence of water. To pass this test, there must be no water detectable. Duplicate trials were run, each utilizing different drums and DFV's. Results are given in Table 6, below.

Table 6
Water Spray Test Results

	PASS/FAIL	
DFV MODEL	TEST 1	TEST 2
DFV #1	PASS	PASS
DFV #2	PASS	PASS
DFV #3	PASS	PASS
DFV #4	PASS	PASS

2. Drum Drop Test, performed under witness by: INEL personnel, and Edling & Associates, Inc.

This tests the ability of DFV's and drums to maintain integrity/containment as an assembled unit in the aftermath of a defined free fall.

A new drum was loaded to 950 lb using a gravel (bottom) and sand (top) mixture, as verified by weighing. A layer of 1 - 2" of fluorescein:flour mixture at 1:20 by weight was leveled on top of the sand. The drum was now full. Prior to installation, DFV's were tested for DOP penetration. They were required by Pall to provide efficiency at ≥ 99 97% for heat-generated monodisperse 0.3 μm DOP smoke at flow rate ≥200 sccm, producing $\Delta P \leq$ 1"H_2O. The reason for selecting flow rates in some cases higher than 200 sccm is that the INEL site imposed a condition that DOP efficiency tests of DFV's for their site be run at the flow rate generating 1"H_2O. As this flow rate was higher than 200 sccm, it presented another parameter by which testing was more stringent than required by the Trupact II SAR.

After testing for DOP penetration, four DFV's, one each of the four types tested, were installed into a drum lid, 90° from one another. This lid was then sealed to the weighted drum, such that the closure ring bolt was adjacent to one of the DFV's. The drop test was repeated four times with new drums and DFV's. In each trial, a different DFV model was adjacent to the closure ring bolt.

Once filled and assembled together with the four DFV's, the drum was hoisted upward and suspended from a wire harness such that the central drum axis was at 60° to the floor. In this orientation, the closure ring bolt was at the lowest point, 40" in height from a thick steel plate bolted to the concrete shop floor. A bolt cutter with pneumatic drive was used to cut the central suspension rod of the wire harness to initiate free fall.

To pass this test, there must be "no loss of contents," as determined by a complete absence of fluorescein. A UV lamp was shown with a known sample of the flour· fluorescein mixture to cause fluorescence of the fluorescein. This lamp was used to inspect the weighted drum-DFV assembly before and after each drop. Inspection was conducted on the drum, drum lid and drop platform both directly and by the inspection of wet swipes.

Following this inspection, the DFV's were retested for DOP penetration at 200cc/min, or at ΔP = 1" H_2O where this pressure drop was produced at >200cc/min. Abrupt drum deformation on impact appeared to have caused inlet (drum) side challenge of several DFV's by a visually significant quantity of fluorescein:flour. For this reason the DFV's were reverse-flushed with filtered isopropanol and dried prior to post-drop DOP tests. Even with flushing, some loss of flow capacity generally remained. In one case, a DFV remained completely blocked to flow, despite attempted flushing. The average decrease in flow capacity not counting this DFV was of the order of 15%. The results are given in Table 7, below

Table 7
Drum Drop Test Results

Each drum lid containing four DFV's at 90° separation.

		DOP Efficiency, Pass/Fail at 99.97%	
DFV Model	Drop Pass/Fail	Before Drop	After Drop
DFV #1	PASS	PASS	PASS
DFV #2	PASS	PASS	PASS
DFV #3	PASS	PASS	PASS
DFV #4	PASS	PASS	PASS
DFV #1	PASS	PASS	PASS
DFV #2*	PASS	PASS	PASS
DFV #3	PASS	PASS	PASS
DFV #4	PASS	PASS	PASS
DFV #1	PASS	PASS	PASS
DFV #2	PASS	PASS	PASS
DFV #3*	PASS	PASS	PASS
DFV #4	PASS	PASS	PASS
DFV #1	PASS	PASS	PASS
DFV #2	PASS	PASS	Blocked to flow
DFV #3	PASS	PASS	PASS
DFV #4*	PASS	PASS	PASS

*At closure ring bolt (impact) position.

3. Compression Test, performed under witness by: INEL personnel, and Edling & Associates, Inc.

After testing for DOP penetration, four DFV's, one each of the four types tested, were installed into a drum lid, 90° from one another. The lid was installed on a new drum, maintained empty. A steel plate weighing 5,000lb was placed upon the drum lid for 24 hours. The DFV's were visually inspected and tested again for DOP penetration. The results are shown in Table 8, below. To pass this test, there must be no visually detectable physical distortion of the DFV's.

Before and after Compression test, the DFV's were tested for DOP efficiency at flow rate ≥ 200 sccm, producing $\Delta P \leq 1"H_2O$.

Table 8
Compression Test Results

DFV Model	Compression Pass/Fail	DOP Efficiency, Pass/Fail at 99.97% Before Compression Test	After Compression Test
DFV #1	PASS	PASS	PASS
DFV #2	PASS	PASS	PASS
DFV #3	PASS	PASS	PASS
DFV #4	PASS	PASS	PASS

4. Penetration Test (Dropped Rod), performed under witness by: INEL personnel, and Edling & Associates, Inc.

DFV's were installed on a drum prepared as for the Drum Drop Test, above, and evaluated in the following manner for physical penetration (damage) under the mechanically localized impact of a free falling steel rod.

A steel bar weighing 13.2 pounds was dropped from a height of 40 inches so that it impacted in the center of the "rain hat" of the DFV. This impact point was chosen because it represents the weakest point, as required in the DOT regulations.

In each case only an insignificant dent resulted from impact. Dents ranged from visually undetectable to a maximum depth of approximately 0.060".

To pass the test, there must be no "loss of contents" through the DFV. This was assessed as in the Drum Drop Test, above.

As a test beyond DOT Spec 7a., Type A requirements, DOP efficiency was measured before and after this Penetration Test at a flow rate $\geq$ 200 sccm, producing $\Delta P \leq 1"H_2O$. The results are shown in Table 9, below.

Table 9
Penetration Test Results

DFV Type	Penetration Test (Dropped Rod) Pass/Fail	DOP Efficiency, Pass/Fail at 99.97% Before Rod Drop	After Rod Drop
DFV #1	PASS	PASS	PASS
DFV #2	PASS	PASS	PASS
DFV #3	PASS	PASS	PASS
DFV #4	PASS	PASS	PASS

Liquid Water in-leakage Prevention.

Pall Laboratories: In-leakage prevention limit.

The "rain hats" were removed from the DFV's to be tested, revealing an unobstructed view of the outside surface of the filter medium. The DFV being tested was installed filter throughput direction vertical at the bottom opening of a J-tube, the long leg of which extended upward for ready measurement of hydrostatic head. The J-tube was filled gradually with water to a hydrostatic head of $75"H_2O$. After a 3 minute waiting period, if no liquid flow occurs, hydrostatic head is slowly increased to the first visual penetration. This is a sensitive test because once the liquid water in-leakage pressure is exceeded, flow is maintained and liquid droplet(s) accumulate on the filter medium.

The results are shown in Table 10, below.

Table 10
Liquid Water In-Leakage Prevention Test

DFV Model	No Leakage at 75" H_2O Pass/Fail	No Leakage at 85" H_2O Pass/Fail	Min. Pressure of Initial Flow, "H_2O
DFV #1	PASS	PASS	89*
DFV #2	PASS	PASS	N/A
DFV #3	PASS	PASS	89*
DFV #4	PASS	PASS	N/A

*Witnessed by INEL personnel.

INEL Selective VOC and other Gas transport.

INEL recently tested Pall all metal DFV's on the basis of hydrogen, methane, and VOC transport. A formal report is to be issued, soon. Personal communications indicate the report to confirm the all-metal filters as transparent to the cited compounds, consistent with non-adsorptive properties expected of stainless steel. Testing was performed consistent with requirements of the WIPP Quality Assurance Project Plan (QAPP)

DISCUSSION AND RECOMMENDATIONS

Test results show Pall all-metal DFV's to exceed Trupact II SAR requirements for hydrogen diffusivity, air flow ΔP, and DOP penetration. At the specified flow rate of 200cc/min, per Trupact II DOP test conditions, the all metal filters are at $\Delta P < 1"$ H_2O, and efficiency >99.97% for hot-generated monodisperse 0.3um DOP smoke. These results were documented and submitted to WIPP in October, 1995.

Test results also verify conformance of Pall all metal DFV's to DOT Spec 7A, Type A.

DOP penetration measurements were added before and after the DOT test sequences. Mechanical shocks or other stress to DFV-drum assemblies will affect the rate of radiolysis and other chemical processes within sealed drums by promoting remixture of their contents. The affect will be largely unpredictable, but hydrogen evolution and/or other pressure producing reactions could be accelerated. For this reason, we recommend pre- and post-DOT test DOP/pressure drop measurements in validating DFV designs. The test data support a conclusion that the mechanical stresses specified by DOT Spec 7A produced no breach in filter integrity of the all-metal DFV's.

Liquid water in-leakage prevention results indicate minimum ΔP required to produce water flow is reliably at >85" H_2O. Ideal gas law calculations show a ΔP of 85" H_2O as corresponding to a temperature swing of $123F^0$ in the waste drum environment (drum temperature at 130^0F dropping to $+7^0F$, lid flooded), well beyond that expected by DOE facilities. It is recommended that new DFV designs be certified to such a standard of liquid water in-leakage, as environmentally non-inducible.

INEL has completed testing of VOC transport through Pall all metal DFV's. We understand from personal communications that it validates the all metal DFV's as providing VOC transport representative of head gas concentrations. This will mean that head gas sampling can for the first time be performed through the filter non-destructively, including such sampling to meet WIPP QAPP requirements..

Another result of Pall's ongoing contact with DOE site personnel is further design refinement. We opted to revise the designs and increase the variety of models available that adapt to a tool facilitating easy, non-destructive head gas sampling through the DFV. While performing this design evolution, we also found ways to improve producibility of our all metal DFV's. The updated designs are described in Appendix A, and depicted in Figure 2, both attached. No change in filter medium has been made since the testing herein described and, in some cases, design is so similar that the new models (Appendix A) may prove certified by existing test results. Pall is pleased to perform validation testing of design variants, where required.

CONCLUSIONS

In comprehensive discussion with personnel at DOE sites, we confirmed the regulatory requirements for DFV validation, and further identified practical problems hampering daily site operation and generating additional costs. In the course of testing new DFV designs for certification, we responded both to current regulatory requirements and to the practical needs presented to us for more economic site operation while maintaining public/worker safety.

As a result of this test program, we are pleased to point out that for the first time a rugged, all metal DFV is available to DOE sites which will:

1. Meet all applicable WIPP Trupact II SAR, and U S government DOT requirements.
2. Provide HEPA efficiency and pressure drop at the rated flow
3 Reduce criticality risk by providing a new level of liquid water in-leakage prevention.
4 Enable direct head gas sampling non-destructively through the DFV (INEL testing, to be reported). This is expected to reduce both operating and DFV replacement costs.

ACKNOWLEDGMENT

The authors gratefully acknowledge the DOE and M&O Contractor engineers who contributed their comments and time to this effort, and thank the members of Pall's DFV Team and Support personnel for their many contributions.

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Appendix A
Updated Designs of All Metal DFV's, Comprising Stainless Steel Filter Medium and Hardware

DFV #1H

The Standard Design (hexagonal body), intended for newly generated TRU waste packages. It is also employed on boxes and 85-gal drums used to repack or overpack damaged 55-gal TRU drums of retrieved waste. Also available in round body (#5R, below); choice made based on current equipment, handling fixtures and site procedures and practices.

DFV #2L

This design arises from LANLs approach to remotely venting drums being retrieved from landfills on their site. The design mates with LANL equipment that remotely inserts a DFV into the retrieved drums.

DFV #3R & 4R

These are INEL designs differing only in thread size. They arise from INEL's approach to remotely venting retrieved drums. These DFV's mate with the INEL equipment that inserts the DFV into a retrieved drum.

DFV #5R

This round body design is intended as standard design for newly generated TRU waste packages. It is also used on boxes and 85-gal drums used to repack or overpack damaged 55-gal TRU drums of retrieved waste. Also available in hexagonal body as #1H, referenced above.

The round body designs (suffix "R") mate with a sampling fixture allowing head gas samples to be taken non-destructively through the stainless steel DFV, as often as needed.

Pall's Stainless Steel Drum Filter Vents Subject to Validation Testing

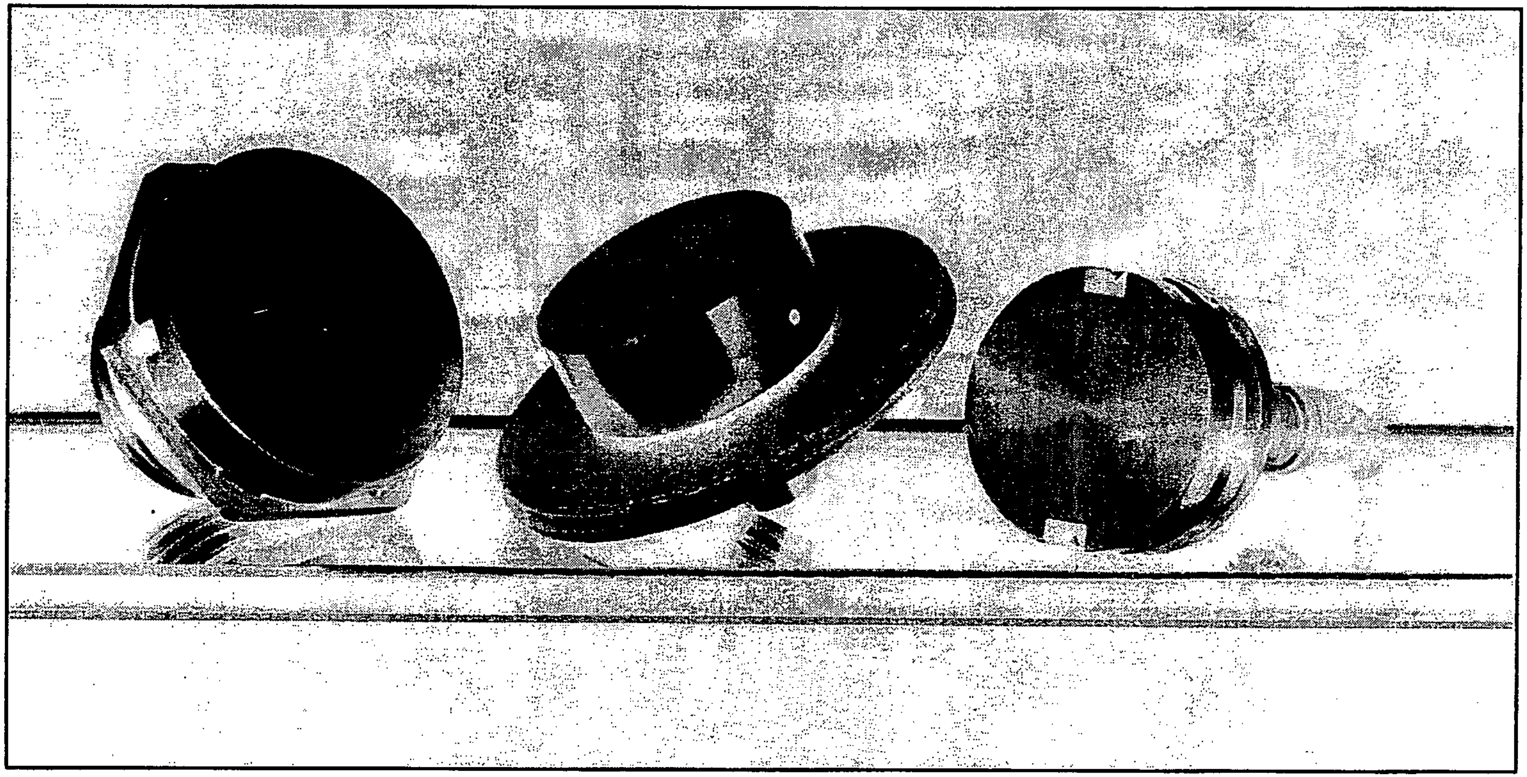
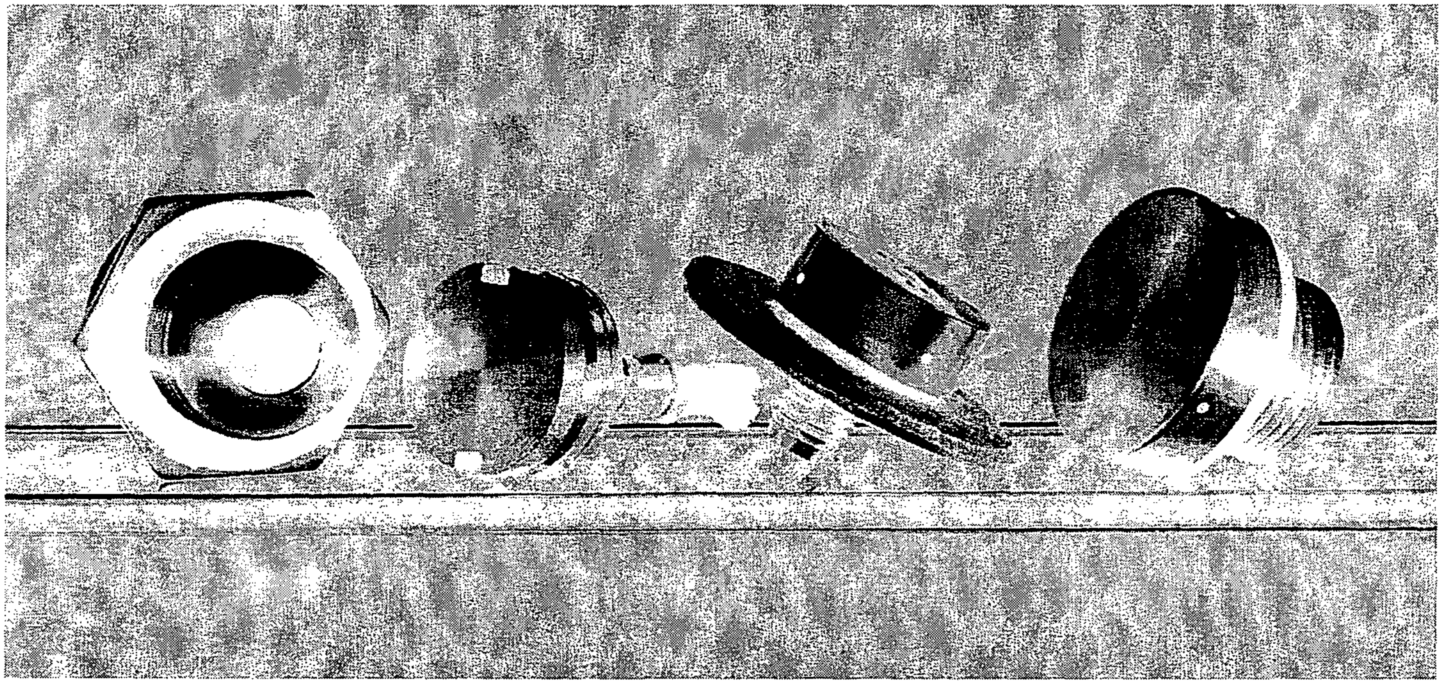


Figure 1

Pall Corporation's Family of All Stainless Steel HEPA Efficiency Drum Filter Vents for DOE Rad Waste Containers



The Pall part numbers are (L to R): DFV #1H, DFV #2L, DFV #3R & 4R, DFV #5R

Figure 2

DISCUSSION

DERDERIAN: Would you discuss the simulant that you use to pressurize the drum contents?

WEBER: The simulant is specified by the DOT and the applicable CFR. It is one part fluorescein to twenty parts cooking flour by weight. The flour serves to dilute the fluorescein because there is plenty there for ultraviolet light to pick up.

DERDERIAN: But it does not pressurize the inside of the drum, is that correct or not?

WEBER: By itself, no, but when you drop the drum from a height the impact momentarily gives you quite a burst of pressure.

SCRIPSICK: Did you look at airborne fluorescein in the test? The test procedure calls for you to look on the floor. It is quite possible the dust hasn't settled yet. If you go back a week later you might find some.

WEBER: That is an interesting thought. The DOT standard used to certify the filter does not address that possibility. The DFV itself is mounted so close to the lid of the drum that you would see evidence of it from inertial impaction if it were to be true. We did not.

SCRIPSICK: On the upstream side? I assume the upstream side of the filter was coated with fluorescein.

WEBER: Yes, very much so. We saw it there and we also saw some increased resistance to flow after the test. You could also look inside to the part of the DFV that faces the contents of the drum and you could see the stuff in there. There were no measurable amounts outside.

SCRIPSICK: One of the things we found was that it is very difficult to seal up pipe threads. I wonder if the tests that you did considered that seal because it would be part of the in-place test.

WEBER: The tests were done in conformance with the existing specifications so what was tested was the assembled unit of the DFV, the drum lid, and the drum. The fact that there was no loss of contents by that test indicates that the pipe joint was not a weak point. That could be an area for additional investigation. The main seal to the drum lid is by a gasket. A lot has to do with the strength that you need to make a seal and not rip the drum lid.

MONROE: Have you done any studies on the plugging rate during normal service of these filter vents?

WEBER: We do not yet have any normal service experience with the filter vents because we have just gotten them certified. That will be a very important parameter to follow. Service does not call for extended periods of flow so I am predicting a very low plugging rate. The primary function of the filter is to dissipate by diffusion and pressure the hydrogen that is generated thermally from radiolysis inside the drum.

CONKLIN: In Washington State, drum vents that are used at Hanford must meet HEPA efficiency requirements according to Washington State regulations.

WEBER: What regulation in particular?

CONKLIN: The Washington State Clean Air Act that requires best available radionuclide control technology.

A GENERAL CORRELATION OF MPPS PENETRATION AS A FUNCTION OF FACE VELOCITY WITH THE MODEL 8140 USING THE CERTITEST 8160

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Abstract

The CertiTest 8160 is a Condensation Nucleus Counter (CNC) based filtration test stand which permits measurement of penetration as a function of particle size. The Model 8140 is also a CNC based filtration test stand which provides a single penetration measurement for a fixed particle distribution aerosol challenge. A study was carried out measuring DOP penetration on a broad range of flat filtration media at various face velocities to compare these two instruments. The tests done on the CertiTest 8160 incorporated a range of particle sizes which encompassed the most penetrating particle size (MPPS).

In this paper we present a correlation between the MPPS penetration as measured by the CertiTest 8160 and the penetration values obtained on the Model 8140. We observed that at the lowest air face velocities of the study the Model 8140 tended to overpredict the MPPS penetration as measured by the CertiTest 8160. We also present a correlation of MPPS penetration with face velocity which may be of use for extrapolation purposes.

1. Introduction

It is a well-known phenomenon that the penetration of aerosol particles through a fibrous filtration medium is a sensitive function of the particle diameter, peaking at the most penetrating particle size (MPPS). Over the years there has been increasing emphasis by both filter element manufacturers and filter media manufacturers on measurement and specification of filter media penetration performance at the MPPS. Two recent documents that have referenced reporting the MPPS and its penetration at application velocity are IES-RP-021(1) and CEN/TC 195(2). While this can readily be carried out using a flat sheet test stand such as the CertiTest 8160, it is a relatively slow, time-consuming process, requiring tests at a number of particle sizes. These tests are not suitable as real time quality control tools in a media manufacturing environment. An alternative is the use of a flat sheet test stand such as the Model 8140 which uses a fixed challenge aerosol having a mean particle size diameter of 0.18 micrometers and geometric standard deviation of 1.6. The test time of the 8140 is a fraction of the test time of the 8160. Thus, the first objective of this study was the comparison of the penetration performance reported by these two test instruments.

The "Holy Grail" of filtration is the simultaneous achievement of lower particle penetrations at lower filter resistance. This has led filter manufacturers to design elements operating at lower air face velocities relative to media area, with greater emphasis on measurement and specification of filter media penetration performance at these low velocities. This is again a challenge to the penetration measuring stands because the low face velocities frequently involve flow rates at the measurement limit of the equipment, and because the particle count rates require longer and longer sample times for statistical confidence. It would be desirable to measure penetration performance at higher face velocities and be able to extrapolate to the lower face velocities of interest. Thus the second objective of this study was the establishment of a correlation between MPPS penetration and face velocity which might be used for such an extrapolation.

2. Experimental

Two different flat sheet test stands were used for this study. The more sophisticated is the TSI CertiTest 8160(3) which is shown schematically in Figure 1. A fine particle aerosol of dioctylphthalate (DOP) is generated by atomization and evaporation of a dilute solution of DOP in isopropyl alcohol. This aerosol then encounters an electrostatic classifier, which permits only a tunable monodisperse aerosol of the desired particle size to proceed to challenge the test media. Samples of aerosol are withdrawn upstream and downstream of the test media and fed to

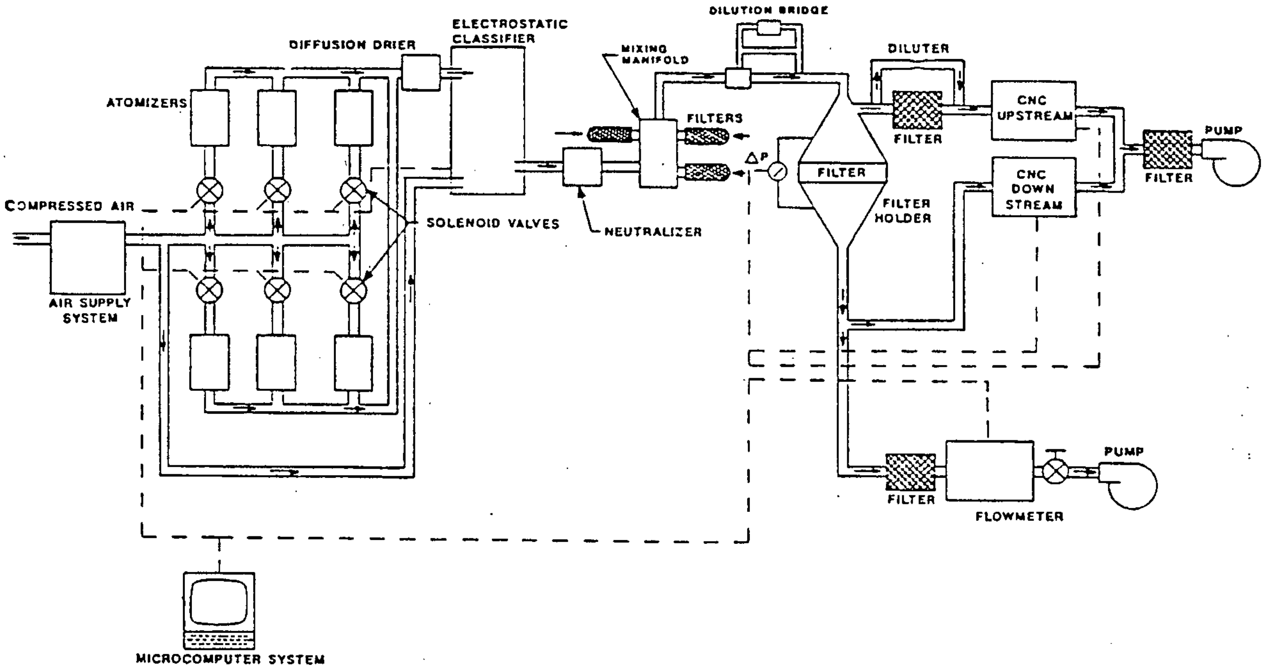


Figure 1.
Schematic of TSI Model 8160 Automated Filter Tester

separate CNC's for determination of the penetration for that particle size. To obtain a full curve of penetration for a range of particle sizes encompassing the maximum penetration, a series of particle sizes is selected and the individual penetration measurements are determined sequentially. With this equipment penetration can be reported to a precision of 10^{-8} percent over a particle size range from 0.015 to 0.40 micrometers at flow rates from 5 to 100 liters per minute.

The less sophisticated test stand is the TSI Model 8140, which is shown schematically in Figure 2(4). This instrument generates a polydisperse aerosol of DOP by atomization. This aerosol then passes through a coarse fibrous prefilter intended to narrow the particle size distribution. The aerosol then proceeds to challenge the test media. Samples of the aerosol are withdrawn upstream and downstream of the test media and fed to CNC's for determination of penetration. With this equipment penetration can be reported to a precision of 10^{-7} percent at flow rates from 15 to 100 liters per minute.

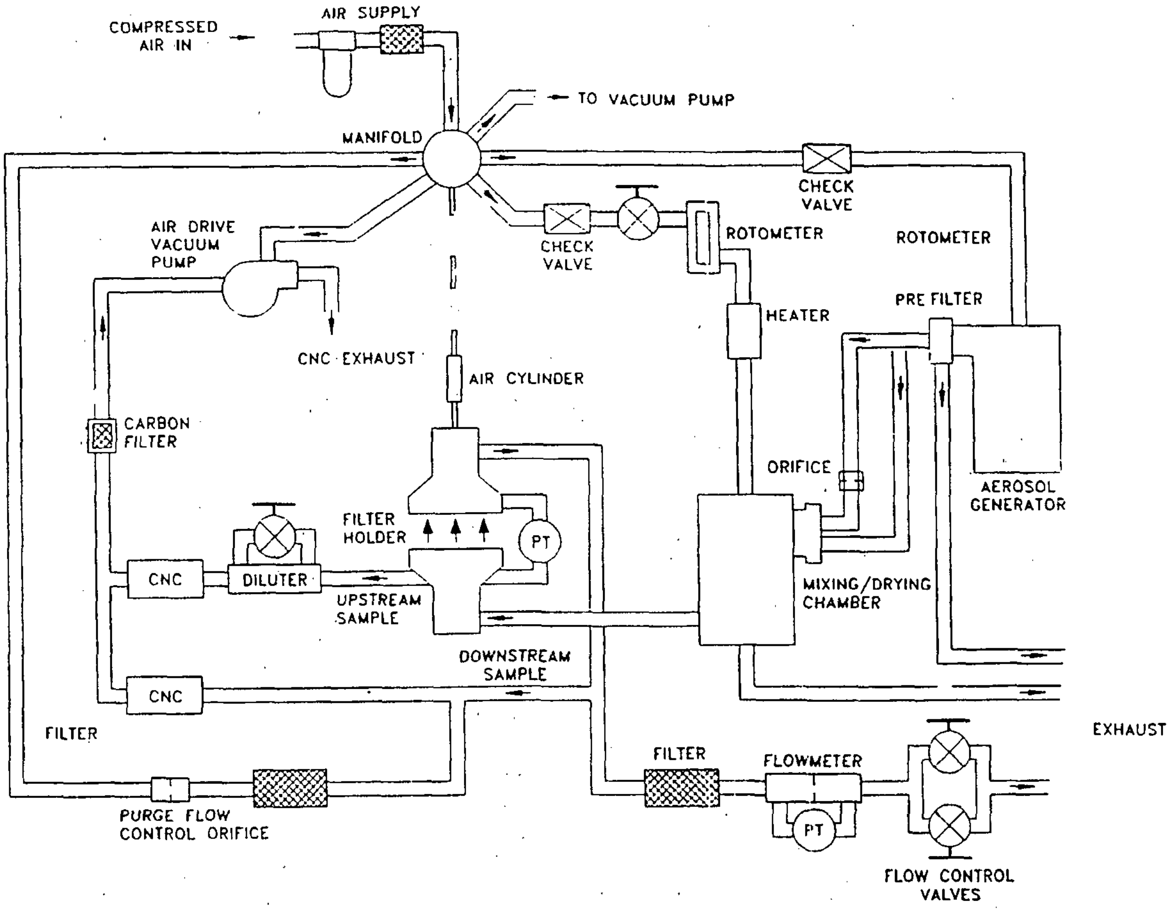


Figure 2.
Schematic of TSI Model 8140 Automated Filter Tester

With both instruments it is necessary to use purge times long enough to guarantee achievement of steady state, and sampling times long enough to provide satisfactory counting statistics. The normal sample area for both instruments is 100 cm^2, but on the 8140 we use a 333 cm^2 sample area for face velocities below 1.8 cm/sec in order to maintain flow rate accuracy.

Multiple samples of ULPA, HEPA, Sub-HEPA, and 95% DOP efficiency media were obtained. These were first tested in the 8160 using face velocities of 1.0, 1.2, 1.8, 2.5, 3.5, and 5.35 cm/sec for 0.075, 0.10, 0.12, 0.15, 0.18, 0.22, 0.26, 0.30, and 0.35 micrometer particle diameters. The same area of each sample was then retested at the same velocities using the 8140 tester Each 8160 data set was subjected to regression analysis to fit the data to the model:

$$\ln(Pen) = A(\ln D)^2 + B(\ln D) + C \qquad (1)$$

Where Pen = Penetration fraction

and D = Particle diameter

The MPPS is then easily determined by setting the derivative equal to zero, so that:

$$\ln(MPPS) = -B/2A \qquad (2)$$

where MPPS = Most penetrating particle size

and substituting back into the model we get:

$$\ln(Pen_{MPPS}) = C-(B^2/4A) \qquad (3)$$

3. Results and Discussion

Figures 3, 4, 5, and 6 are typical 8160 curves for the ULPA, HEPA, Sub-HEPA and 95% DOP efficiency media along with the 8140 results for the same samples. In general the quality of the fit to this simple model is quite good, with an average R^2 value of 0.98 for roughly 72 data sets of six points apiece. Thus the model provides a simple objective way of treating such a data set in order to abstract an MPPS value and a Pen_{MPPS} value.

It is clear from these graphs that the curves are tangent to or just below the 8140 lines shown. It is noted that at the lower test velocities the 8140 values tend to overpredict the 8160 MPPS values by an appreciable percentage. Since the particle size distribution in the 8140 is certainly not monodisperse, one would expect that the 8140 should give penetration values somewhat below the Pen_{MPPS}, but our experimental results do not confirm this. From a media specification point of view, however, the 8140 penetration is a conservative estimate of the MPPS penetration. Areas we suspect to be possible causes for these results are diluter

FIGURE 3
PENETRATION CURVES OF ULPA MEDIA

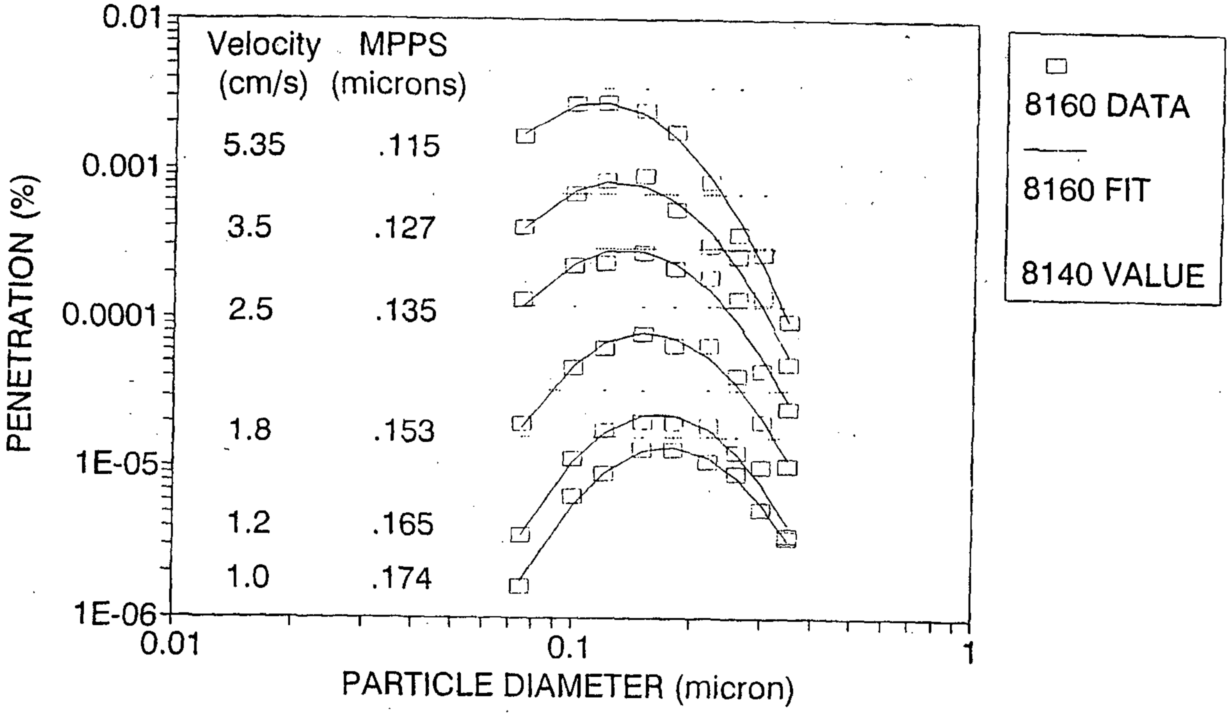


FIGURE 4
PENETRATION CURVES OF HEPA MEDIA

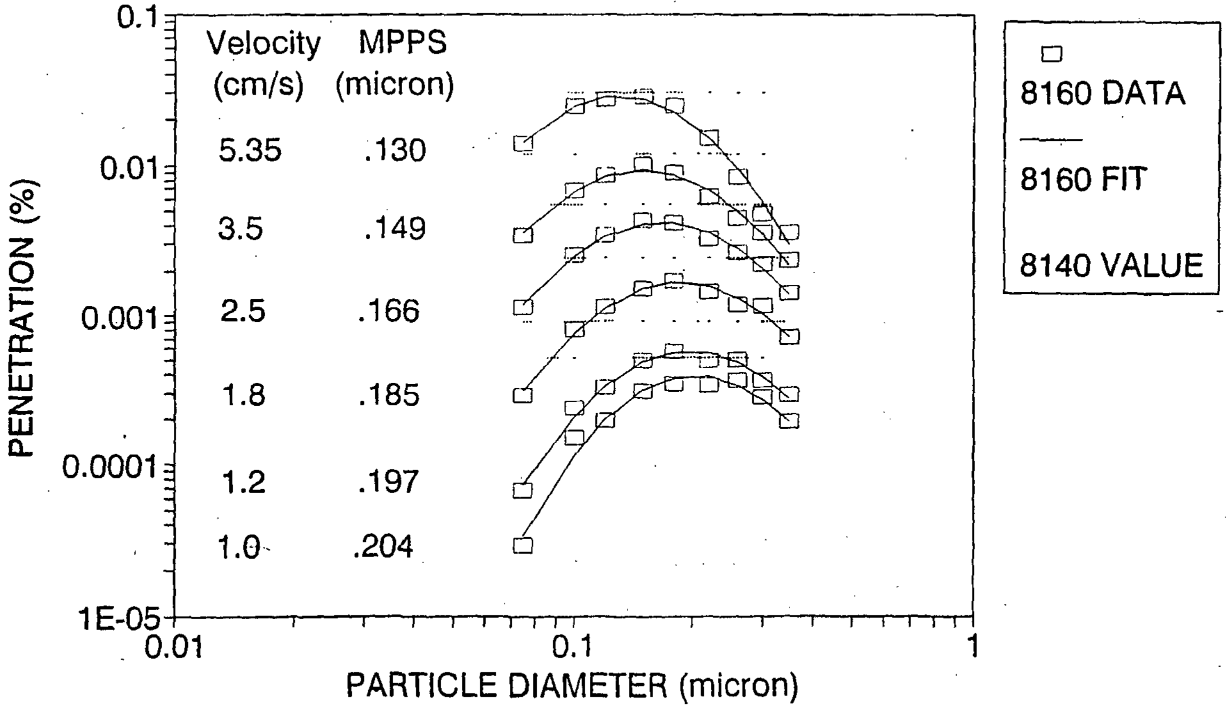


FIGURE 5
PENETRATION CURVES OF SUB-HEPA MEDIA

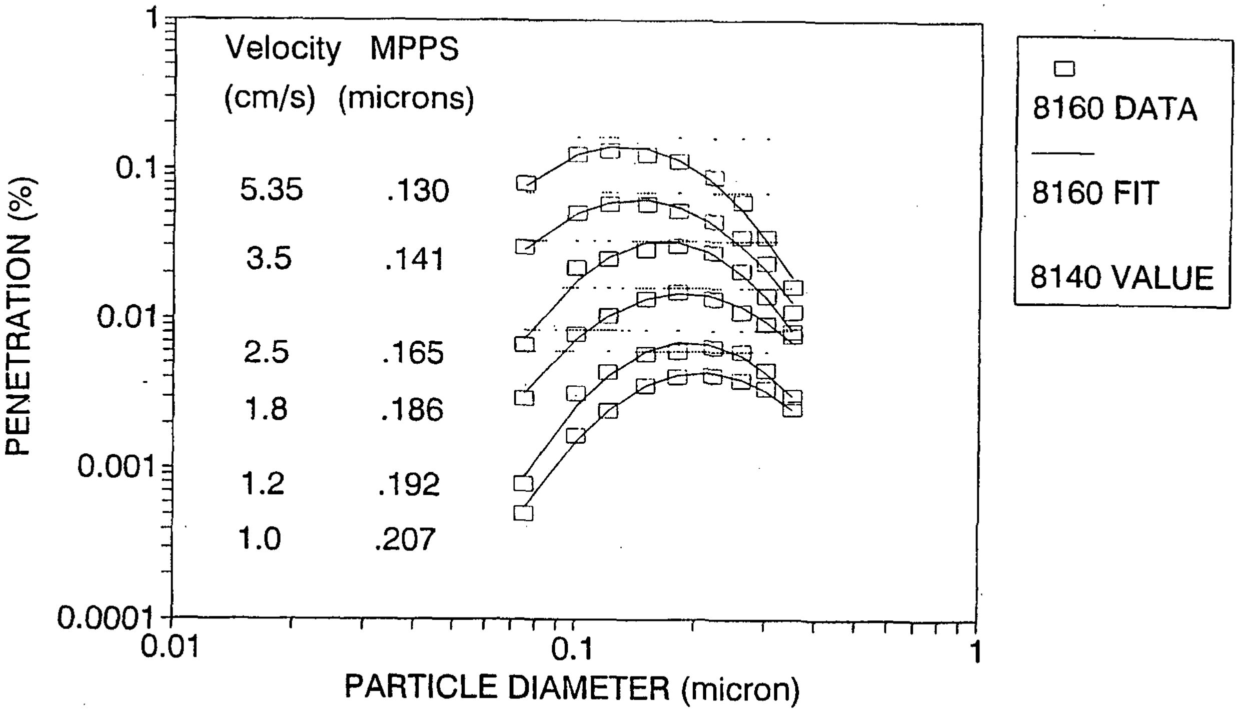
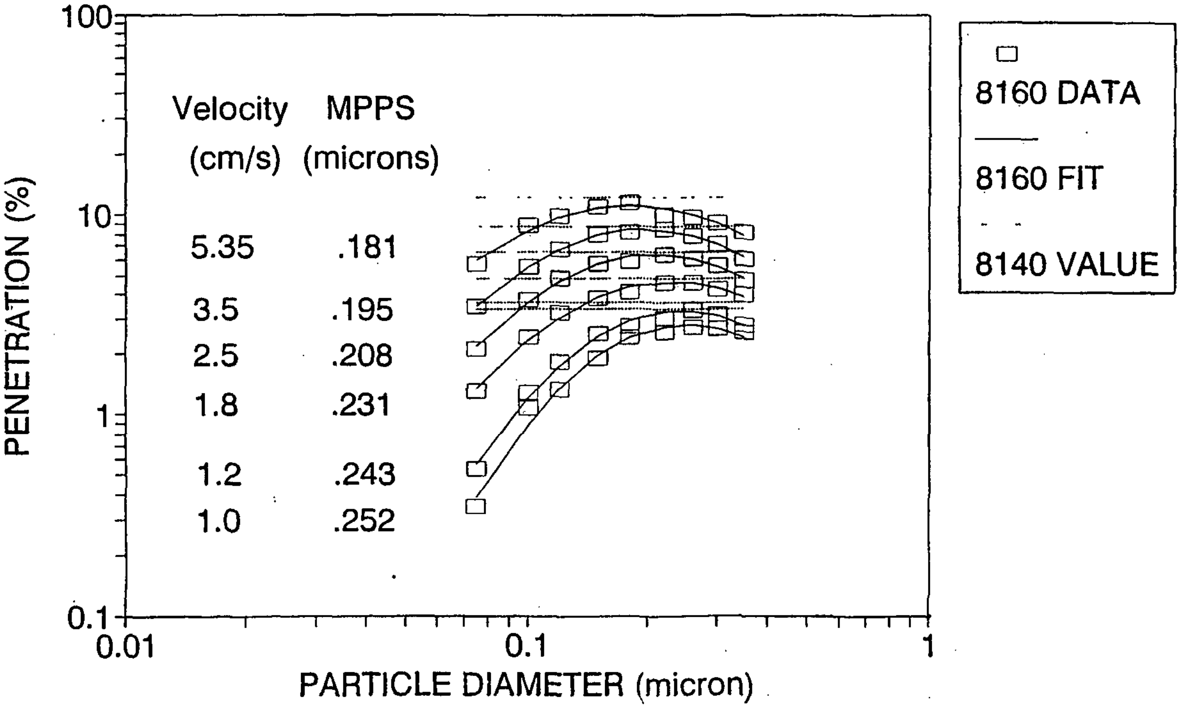


FIGURE 6
PENETRATION CURVES OF 95% DOP MEDIA



differences between the instruments, individual CNC response differences, adequate purge time at low velocity, and flow measurement precision at low velocity.

Figure 7 is a plot of Pen_{8140} values against Pen_{MPPS} values obtained from the fits to the 8160 data. Over seven orders of magnitude the two measures of penetration agree very well.

Since the 8140 gives penetration values that correlate so well with the MPPS penetration, a correlation of 8140 penetration with velocity would be useful. The 8140 data for each sample was fit to the power model for filter media penetration previously presented at this conference(5):

$$\ln Pen = \ln Pen_r (V/V_r)^N \qquad (4)$$

Where Pen = Penetration fraction at face velocity, V

and Pen_r = Penetration fraction on the same sample at the reference velocity, V_r

The R^2 values obtained from these regressions were all above 0.98. Figure 8 is a graph showing the velocity dependence of 8140 penetration for the typical media samples shown earlier. The ULPA, HEPA, and Sub-HEPA curves are parallel having N values equal to -0.24. The 95% DOP media is different, however, having a slope of -0.28.

The determination of the N value for a filter medium or filter media family allows for measurement of penetration at a reference velocity within reasonable operating parameters of the test equipment and estimation of the penetration at the low application velocities which will be encountered.

Conclusions

A comparison of the penetration performance values between the TSI CertiTest 8160 and the TSI Model 8140 has shown that the penetration value obtained from the 8140 correlates very well to the MPPS penetration obtained from the 8160 penetration curve for penetrations spanning several orders of magnitude.

The 8140 penetration is related to face velocity by a power law model. This can be a useful tool for specifying media penetration performance at reasonable test equipment operating parameters.

FIGURE 7
8140 PENETRATION VS MPPS PENETRATION

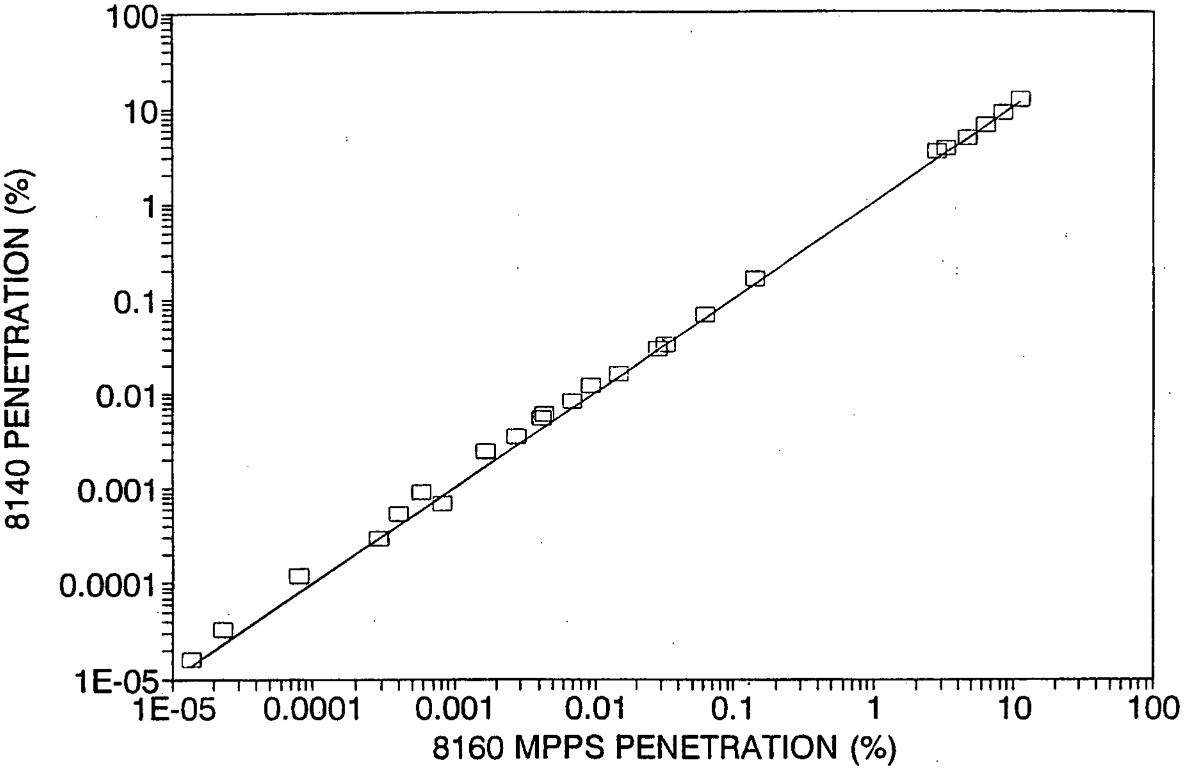
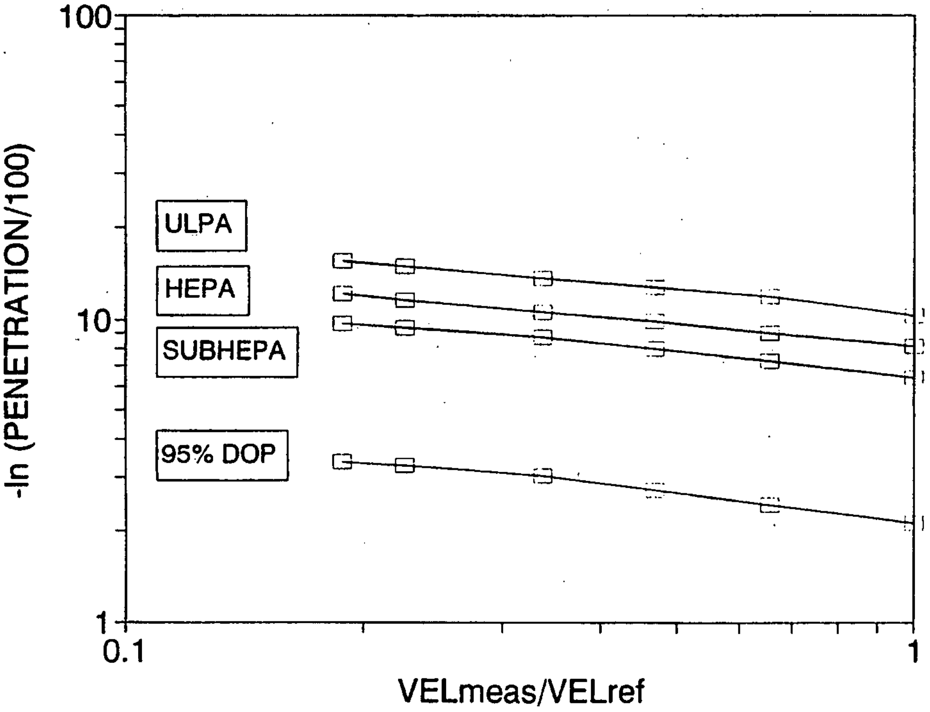


FIGURE 8
EFFECT OF VELOCITY ON PENETRATION



24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

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(4) TSI Incorporated, 500 Cardigan Road, St. Paul, MN, "Model 8140 Automated Filter Tester Operation and Service Manual", 1992.

(5) Pierce, M., Guimond, R., Lifshutz, N. "A General Correlation of DOP Penetration With Face Velocity as a Function of Particle Size Using the FTS-200", CONF-880822, pp. 973-982, Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, Boston, MA (1988).

DISCUSSION

SCRIPSICK: How does the particle size at maximum penetration and the penetration curve compare to theory? Did you look at that? We have seen that theory predicts much greater slope values than measurements on filters.

PIERCE: We have not compared our laboratory flat sheet results to any computer models of what the theoretical penetration would be. As a general comment, we have observed that the theoretical penetration curves tend to have steeper slopes on either side of the most penetrating particle size than test data.

DYMENT: Please comment on the relationship between the MPPS and efficiency of the different media which you chose to use.

PIERCE: Theory dictates that as face velocity is decreased, penetration will increase and the most penetrating particle size will increase. I believe this is because diffusional effects are more pronounced and inertial effects are less pronounced at lower and lower velocities, so that larger particles become more penetrating. Also, it is generally observed that as efficiency between media samples is reduced, effectively increasing the mean fiber diameter within the media samples, the MPPS increases.

FURTHER DEVELOPMENT OF THE CLEANABLE STEEL HEPA FILTER, COST/BENEFIT ANALYSIS, AND COMPARISON WITH COMPETING TECHNOLOGIES*

by

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ABSTRACT

We have made further progress in developing a cleanable steel fiber HEPA filter. We fabricated a pleated cylindrical cartridge using commercially available steel fiber media that is made with 1 µm stainless steel fibers and sintered into a sheet form. Test results at the Department of Energy (DOE) Filter Test Station at Oak Ridge show the prototype filter cartridge has 99.99% efficiency for 0.3 µm dioctyl phthalate (DOP) aerosols and a pressure drop of 1.5 inches. Filter loading and cleaning tests using AC Fine dust showed the filter could be repeatedly cleaned using reverse air pulses. Our analysis of commercially optimized filters suggest that cleanable steel HEPA filters need to be made from steel fibers less than 1 µm, and preferably 0.5 µm, to meet the standard HEPA filter requirements in production units.

We have demonstrated that 0.5 µm steel fibers can be produced using the fiber bundling and drawing process. The 0.5 µm steel fibers are then sintered into small filter samples and tested for efficiency and pressure drop. Test results on the sample showed a penetration of 0.0015 % at 0.3 µm and a pressure drop of 1.15 inches at 6.9 ft/min (3.5 cm/s) velocity. Based on these results, steel fiber media can easily meet the requirements of 0.03 % penetration and 1.0 inch of pressure drop by using less fibers in the media.

A cost analysis of the cleanable steel HEPA filter shows that, although the steel HEPA filter costs much more than the standard glass fiber HEPA filter, it has the potential to be very cost effective because of the high disposal costs of contaminated HEPA filters. We estimate that the steel HEPA filter will save an average of $16,000 over its 30 year life. The additional savings from the clean-up costs resulting from ruptured glass HEPA filters during accidents was not included but makes the steel HEPA filter even more cost effective.

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*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-ENG.45 and is based on the reports cited as references 1 and 2.

We also present the results of our evaluation of competing technologies with metallic and ceramic powder filters, ceramic fiber filters, and reinforced glass fiber filters. In general, the metallic and ceramic powder filters have pressure drops in excess of 25 inches of water for HEPA grade efficiencies and are therefore not viable candidates. The ceramic fiber filters cannot meet the HEPA efficiency because the fiber diameters are too large. The reinforced glass fiber filter is a promising candidate for the cleanable HEPA filter but requires additional development and testing to confirm its potential to be repeatedly cleaned.

This report is based upon material extracted from a DOE technical review of the Mixed Waste Integrated Program and from the final report of a systems analysis of cleanable steel HEPA filters.(1,2)

I. Introduction

Cleanable steel filters have been used for many years by various industries, including the nuclear industry, to provide high efficiency filtration with minimal maintenance. These filters were made from steel powder that was sintered together and formed into a hollow cylinder. Compressed air pulses were directed into the interior of the cylinder to dislodge particle deposits that had formed on the outside of the cylinder. Figure 1 illustrates the basic concept of the cleanable steel filter having multiple filter elements in a single housing, a blow-back gas for cleaning, and a hopper for collecting the particles.

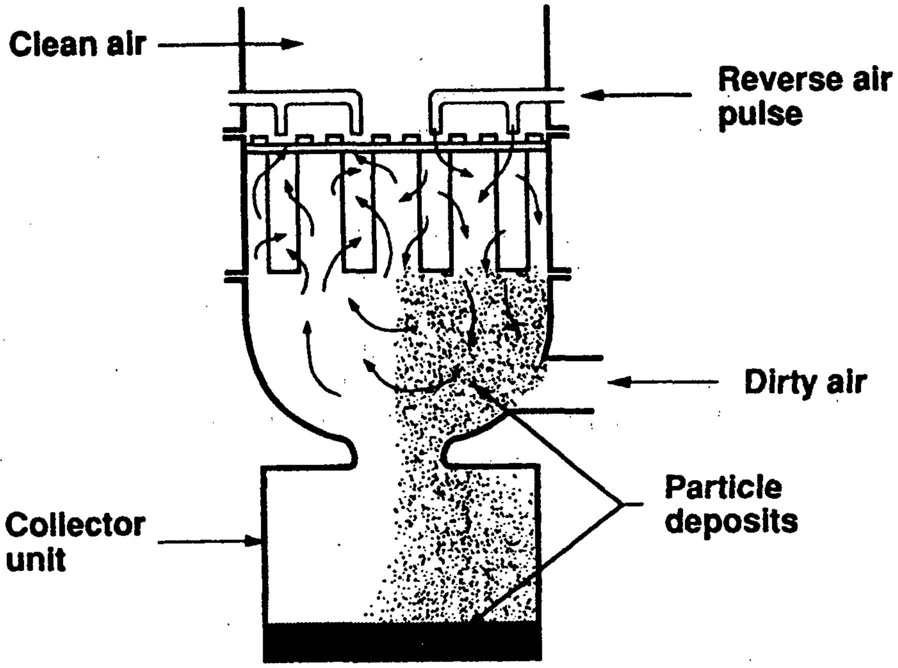

Figure. 1. Typical cleanable filter with multiple cartridges and a blow-back cleaning apparatus.

The cleanable filter shown in Figure 1 is a well established design used with many other filter elements such as cloth bags, ceramic tubes, and polymeric tubes. Design variations include other filter shapes than cylinders such bayonets, stacked plates, hollow panels, etc. All filter elements have an exterior surface for collecting the deposited particles and an interior volume through which the cleaned gas exits and through which a blow-back gas is used to dislodge the deposited particles.

The applications for these filters range from recovery of catalysts in petroleum refineries to off-gas filtration in incinerators. Rocky Flats had used sintered metal filters to remove the suspended particulate from a fluidized bed incinerator that burned transuranic waste contaminated with plutonium.(3) The sintered metal filters were repeatedly cleaned by reverse air pulses. Kirstein et al also showed that sintered metal filters had excellent performance in both removal efficiency and reverse air-pulse cleaning for applications in another incinerator.(4) The filters are robust and require minimal maintenance. Despite the excellent performance of the sintered metal filters, they only had about 60% DOP efficiency when clean and had relatively high pressure drops.(5)

In the early 1980s, researchers in Europe had developed high efficiency air filters using the new filter media from Bekaert that was made from 2 μm steel fibers. Dillmann et al described the use of 2 μm stainless steel fibers to make deep bed filters for use as vent filters in nuclear power reactors.(6,7) The deep bed filters had efficiencies comparable to the glass HEPA filters but were much larger and could not be cleaned. Klein and Goossens showed major improvements in filter efficiency with decreasing diameter of the steel fibers from 12 to 4 μm.(8) However, the efficiencies were far below HEPA grade. They also showed that deposits of methylene blue aerosols could be efficiently cleaned from a cylindrical filter by washing with a water spray.

By the late 1980's, Pall Corp. had developed cylindrical filter elements using steel media having separate layers of sintered steel fibers and sintered steel powder. Randhahn et al described a stainless steel filter from Pall Corp.(9) that had efficiencies comparable to a HEPA filter, but they did not report any pressure drops. The filter consisted of two layers of 5μm fiber media and one layer of fine powder metal. Our tests showed that the filter had a pressure drop of 2.2 psi (61 inches of water) at 13 cfm, which corresponds to 1,000 cfm through a standard size HEPA filter.(10) A variation of the Pall filter with lower pressure drop and lower efficiency was installed as a prefilter in all of the French nuclear power plants.(11)

In 1990 Bergman et al showed that by eliminating the use of steel powder and using the smallest available steel fibers, filters could be made that had the same efficiency as a HEPA filter and a pressure drop only three times as great.(12) Bergman then used this new filter to begin developing a cleanable steel HEPA filter.(13)

Two designs of the cleanable steel HEPA filter have been developed to date: an assembly of multiple cartridges housed in a standard 2' x 2' x 1' frame and multiple cartridges housed in a pressure vessel. We developed the basic design parameters for the steel filter that can be retrofitted into the standard HEPA housing.(14) This filter design consists of 64 individual filter cartridges housed in a standard HEPA filter frame of 2' x 2' x 1'. We were only able to use 150 ft^2 of media in the filter instead of the minimum 200 ft^2 found in glass HEPA filters. This limitation was due to the clindrical cartridge design, that prevented more media from being used. The cleanable steel filter, shown in Figure 2, consists of 64 cartridges assembled into the HEPA filter housing.

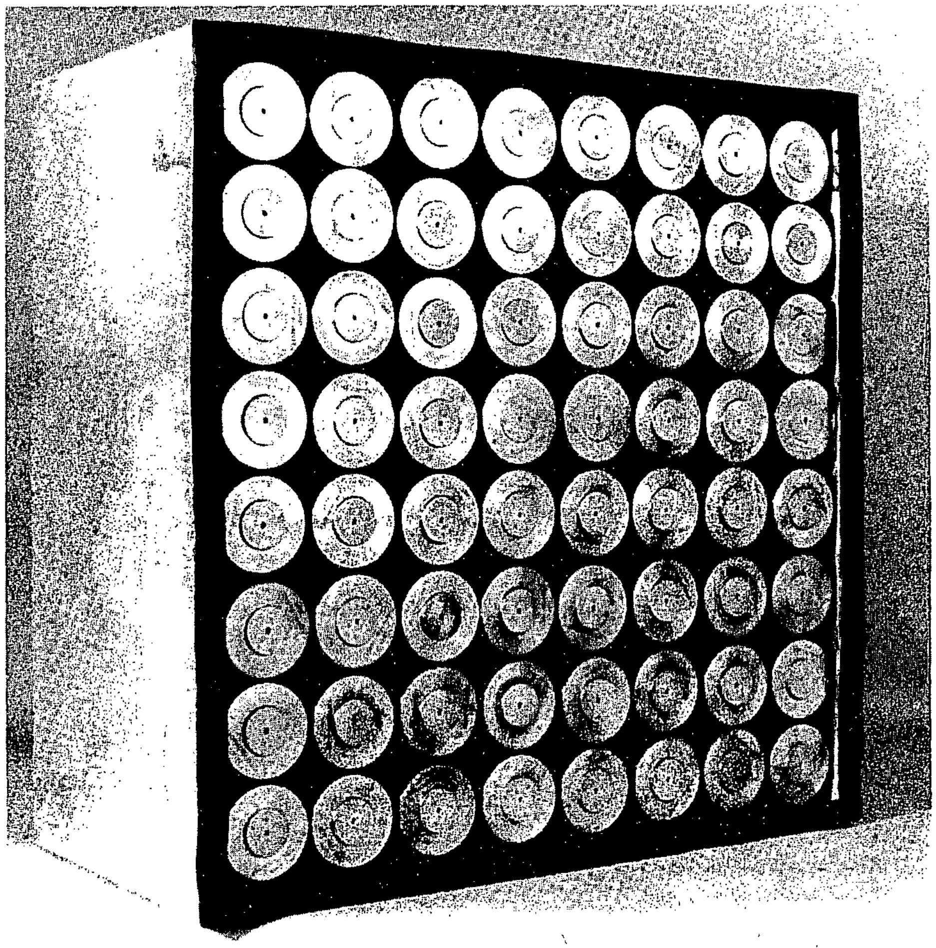

Figure 2 Photograph of the assembled cleanable steel filter using the flat panel design with 64 cartridges

We made two cleanable steel filters like that shown in Figure 2 using filter cartridges from Pall Corporation and Memtec Corporation and evaluated their performance.(14) The filter media used to make the filter cartridges was made from 2 µm steel fibers sinctered into sheets and pleted to increase the surface area. Both filters met the required 0.03 % DOP penetration, but had a pressure drop of 3 inches and weighed over 200 pounds. After a successful laboratory demonstration that the filters could be repeatedly cleaned by reverse air pulses and reused, both filter units were evaluated in the exhust stream of a uranium oxide grit blaster at the Y-12 Plant in Oak Ridge, TN.(15) The field evaluation was not completed because water accumulation in the exhaust system caused excessive pressure drop and interfered with the filter cleaning studies.(15) Since additional funds were not available to dry the wet exhaust, the field evaluation was prematurely terminated.

In addition to the panel filter design shown in Figure 2, the cleanable steel filter can be designed as a pressure vessel for use in applications that do not require retrofitting into existing housings. Pall Corp. has built several units in which multiple cartridges are housed inside a pressure vessel as shown in Figure 3. This is the design that was to be used in the vitrification plant at Hanford.(16,17) The filter in Figure 3 is cleaned using a reverse water flush. Tests by Pall using Arizona road dust show that fully loaded filters can be efficiently cleaned using the water wash.(18,19)

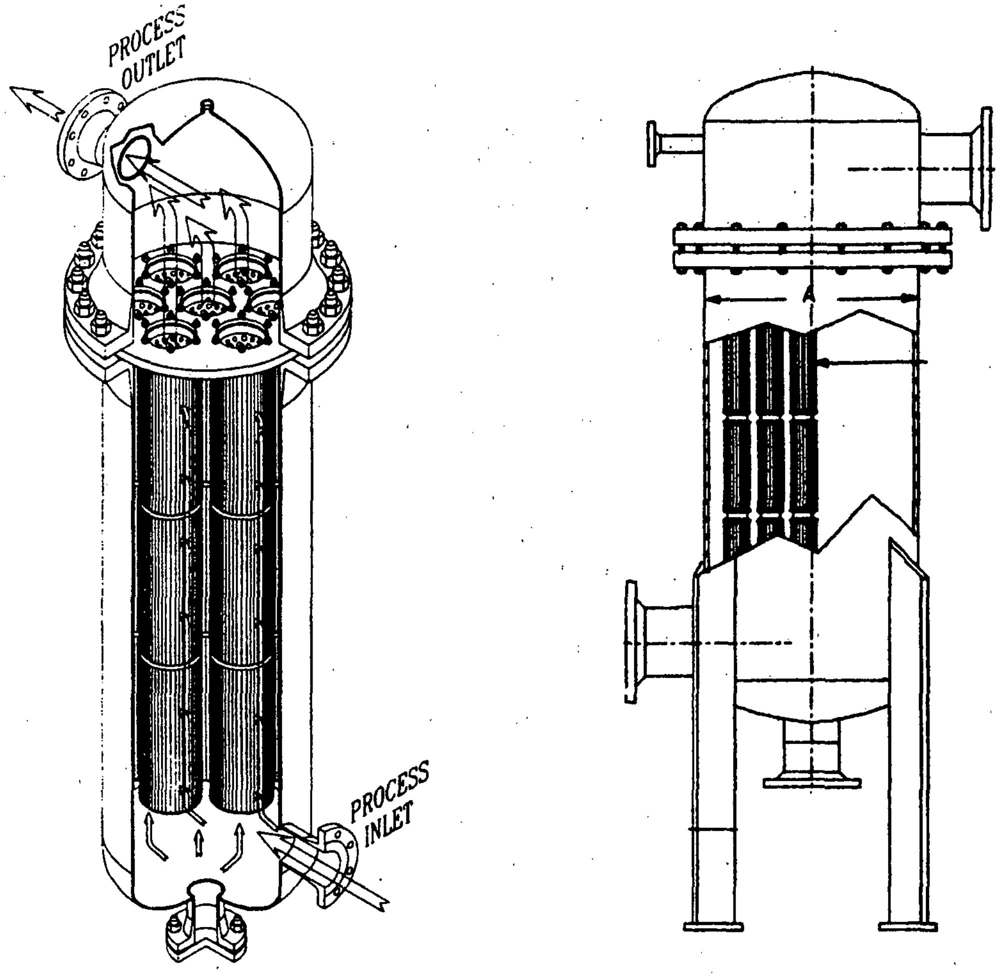

Figure 3. Drawing and schematic of the cleanable steel filter with filter cartridges housed in a pressure vessel.

Neither of the two steel HEPA designs shown in Figures 2 and 3 have been accepted by the nuclear industry as replacement for the glass HEPA filter. The cleanable steel filter shown in Figure 2, which is designed for both new and retrofit applications, has the overall dimensions of a standard glass HEPA filter, but has an unacceptable high pressure drop and weighs too much. Installing more powerful blowers to overcome the high resistance is not acceptable because of the extra cost and the misbalance introduced into existing building and system ventilation systems. In addition, special lifting and positioning equipment would be needed to install and remove the 200 pound filters. In our field demonstration of the cleanable filter, we built a specially designed alignment table and mounted it on a scissors lift in order to install the steel filter.(15) Unfortunately, this type of equipment could not be used in most existing HEPA filtration systems due to space limitations. The high pressure drop, high weight and special lifting equipment are only a problem in existing filtration systems and not in future systems that can be designed to accomodate the special requirements.

The pressure vessel design in Figure 3, which is intended for new filtration systems, also has high pressure drop, high weight and requires special lifting equipment. This design had been selected for use in a waste vitrification plant at Hanford prior to the cancellation of the plant.(16,17) The pressure vessel design was selected over a deep-bed sand filter for that application.(16) The initial cost of the steel HEPA filter was also less than the cost for the deep bed sand filter. However, both the steel HEPA and the sand filters cost far more than the conventional HEPA filter.

Another major reason why steel HEPA filters are not selected over glass HEPA filters in the nuclear industry is their high cost. The current steel HEPA filter shown in Figure 2 costs about $70,000 compared to $300 for the glass HEPA filter.(20) The cost for the pressure vessel design shown in Figure 3 is estimated at $109,000.(20) These costs are for current prototype steel HEPA filters. We have estimated that the cost of the panel filter in Figure 2 could be reduced to $5,000 with further development and with production efficiencies.(14)

Despite the much higher costs for the steel HEPA filters compared to the glass HEPA filters, the high cost of disposing of contaminted HEPA filters made the steel HEPA filters appear economically attractive. Our previous cost analysis shows that a $5,000 steel filter would save $54,000 over its life compared to glass HEPA filters.(14) This cost saving is due to the average cost of $4,450 for handling and disposing of glass HEPA filters.(21) Implicit in the cost estimate was that the glass filter had a 3 year life while the steel HEPA filter had a 45 year life.(14) If the assumptions were significantly in error, then the potential cost savings could disappear. Although no additional data on the assumptions was available since our last estimate, we have performed a sensitivity analysis of the potential cost savings as a function of the assumed input parameters.(2) That analysis, which will be summarized in this report, shows that the cleanable steel HEPA filter is still cost effective under a wide range of assumptions.(2)

In order to overcome the identified deficiencies in peformance and the high cost, further development of the steel HEPA filter is required before it can replace the glass HEPA filter. We will summarize the recent developments of the cleanable steel fiber HEPA filter and compare the performance with competing technologies.

II. Reduction in Pressure Drop Achieved With Smaller Diameter Fibers

The most important parameter that controls the efficiency and pressure drop of fibrous filters is the diameter of the fibers used in the filter medium. To illustrate this point, we have plotted the minimum efficiency and the filter pressure drop in Figure 4 for typical commercial glass fiber filters as a function of the average fiber diameter used in the filter media. The minimum efficiency, pressure drop and fiber diameter for each of the filters identified in Figure 4 represent typical values for each class of filter. The filters are normailized to the same dimensions (2' x 2' x 1') and flow rate (1,000 cfm). As seen in Figure 4, the efficiency increases much faster than the pressure drop with decreasing fiber diameter. Since the filters used to generate the curve in Figure 4 represent typical commercial products, we assume that the filters have been optimized to maximize the efficiency and minimize the pressure drop. Thus filter media with smaller diameter fibers are needed for higher efficiency filters.

Using Figure 4, we can illustrate that reducing the fiber diameter is more effective than alternative approaches such as increasing the amount of fibers or the thickness of the media to obtain filters with the desired efficiency and pressure drop. For a filter medium having a fixed fiber diameter, higher efficiencies are obtained by adding more layers of media. For example two layers of a 95% efficient ASHRAE filter with 1 μm fiber media will yield a filter with a combined efficiency of 99.75% ($E= 1-(1-.95)(1-.95)= 0.9975$). The pressure drop for the combined layers is twice the single layer (0.5 inch), or 1.0 inch. Alternatively, Figure 4 shows that by using a filter media with 0.7 μm diameter fibers, we can reach the same efficiency but only have a pressure drop of 0.7 inches.

We applied the principle of reducing the fiber diameter to improve the performance of the steel filters. The commercially available steel filters shown in Figure 2 meet the HEPA filter efficiency requirement but have a pressure drop of 3 inches of water. In order to reduce the pressure drop to the required 1 inch, the steel fiber media must be made from fibers having diameters about 0.5 μm instead of the present 2.0 μm diameter.

We have fabricated and tested a filter cartridge element using steel media obtained from Tomeogawa Inc. that was made from 1 μm diameter, 316L stainless steel fibers.(1,22,23) An electron micrograph of the sintered media sheet is shown in Figure 5. Tests on the flat sheet are shown in Figure 6 where the penetration is plotted as a function of particle diameter. The face velocity is 3.5 cm/s, which corresponds to the velocity that would be obtained with 150 ft^2 of media in a full scale filter. Figure 6 shows that the 1 µm media has a penetration of 0.004% at 0.3 µm aerosol diameter and a pressure drop of 1.05 inches. Thus, the 1 µm media represents the threshold for achieving HEPA filter performance.

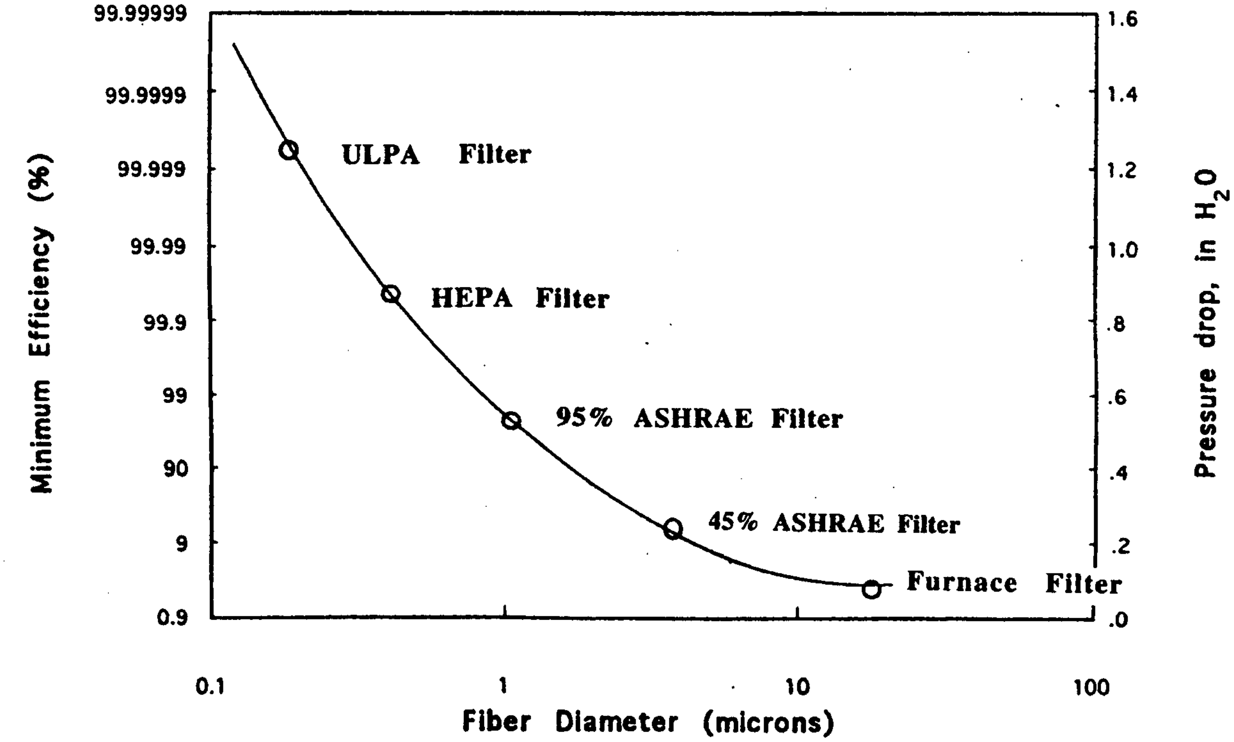

Figure 4. Relationship between the minimum efficiency, pressure drop and fiber diameter in commercial filters.

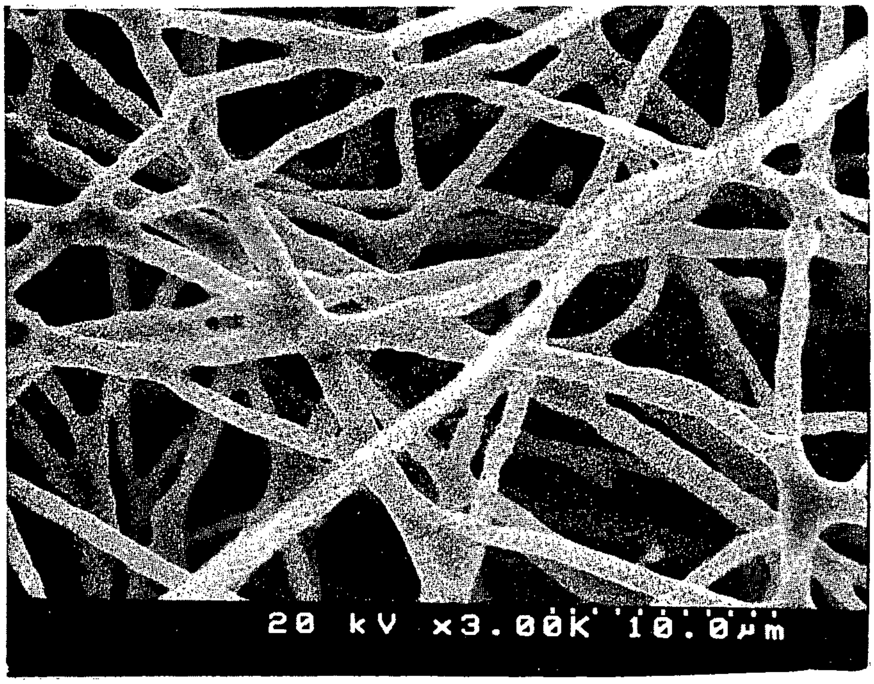

Figure 5. Electron micrograph of Tomeogawa steel fiber media made from 1 µm diameter, 316L stainless steel fibers.[(23)]

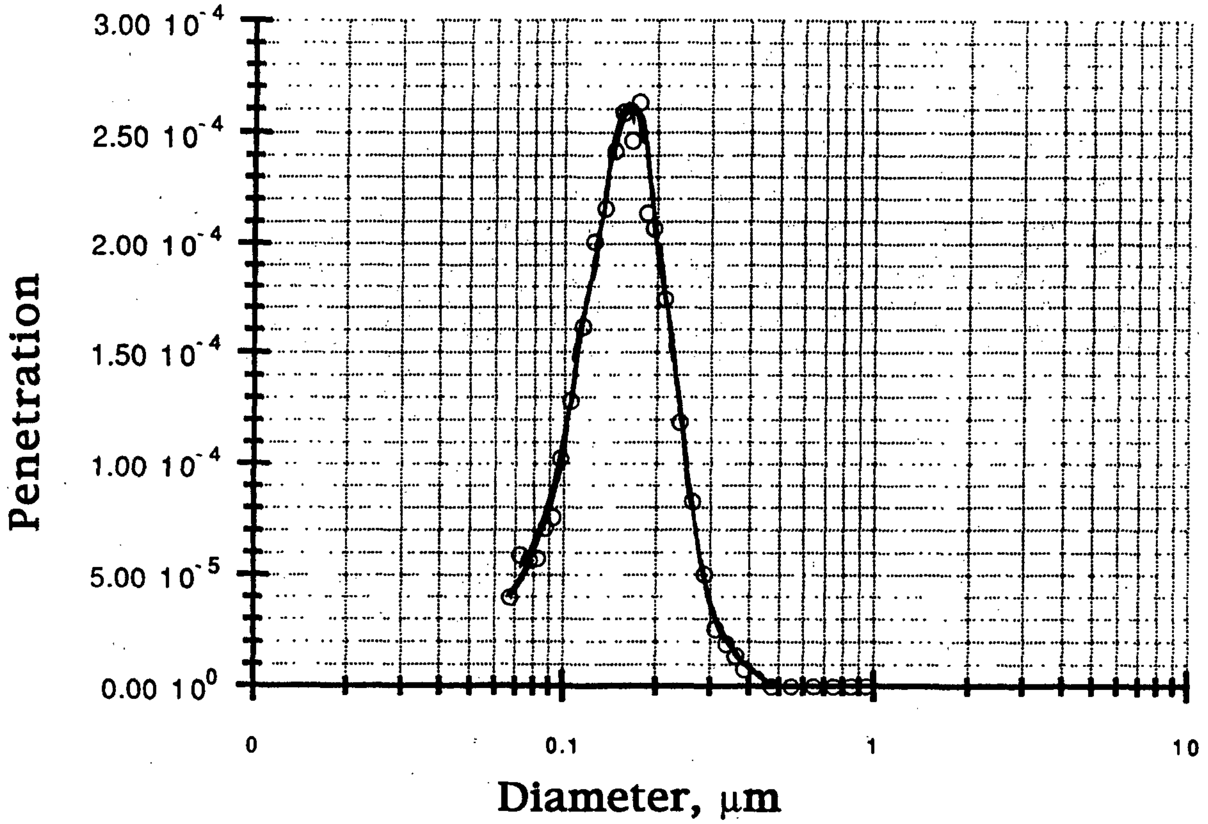

Figure 6. Penetration of DOS aerosols through 1 µm fiber media from Tomeogawa at 3.5 cm/s. Pressure drop was 1.05 inches.

The filter cartridge, shown in Figure 7, was made by sandwiching the media between support screens, pleating the composite layers, welding the composite sheet ends to form a pleated cylinder, and sealing the two, pleated, cylindrical ends in a potting compound. The pleated, cylindrical ends also could have been sealed by brazing to end caps. We used the test method and apparatus described in our previous report to evaluate the filter cartridge at 15.6 cfm to correspond to a full-scale HEPA filter.(14) Figure 8 shows the penetration of dioctyl sebacate (DOS) aerosols as a function of aerosol diameter. Although the penetration at 0.3 µm diameter is satisfactory at 0.002% , the pressure drop is 1.5 inches of water and exceeds the maximum allowable 1 inch. The major reason for the higher pressure drop in the cartridge than in the filter media shown in Figure 6 is the variablitiy in the media properties. The cartridge in Figures 7 and 8 was made from a different media batch having 50% higher pressure drop than the media in Figure 6. This variation was due to the small sample size in the media production and should not occur with larger samples. Thus, we have approached the threshold for achieving a HEPA filter using 1µm media. Steel media having fiber diameters less than 1 µm is needed for making steel HEPA filters with production variability.

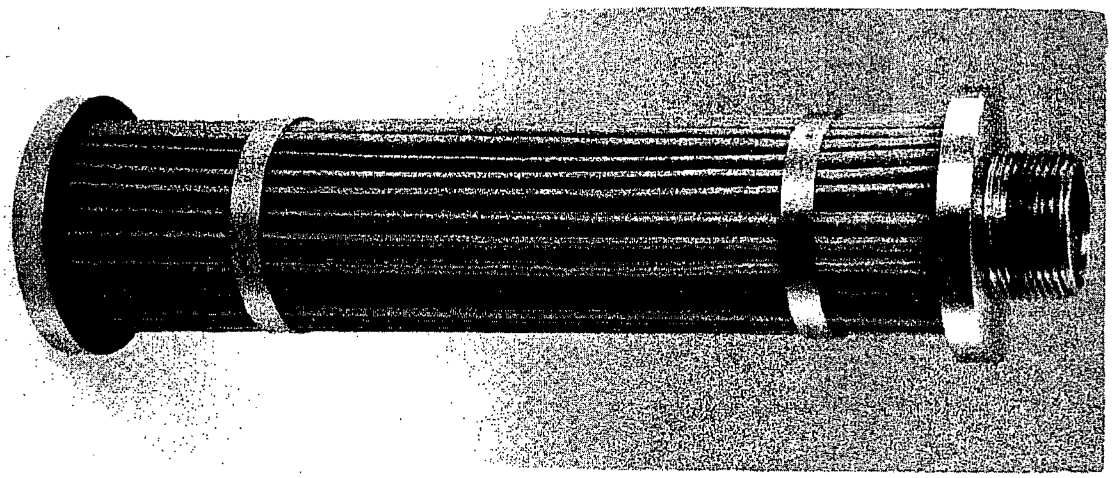

Figure 7. Pleated filter cartridge made from 1 µm steel fiber media.

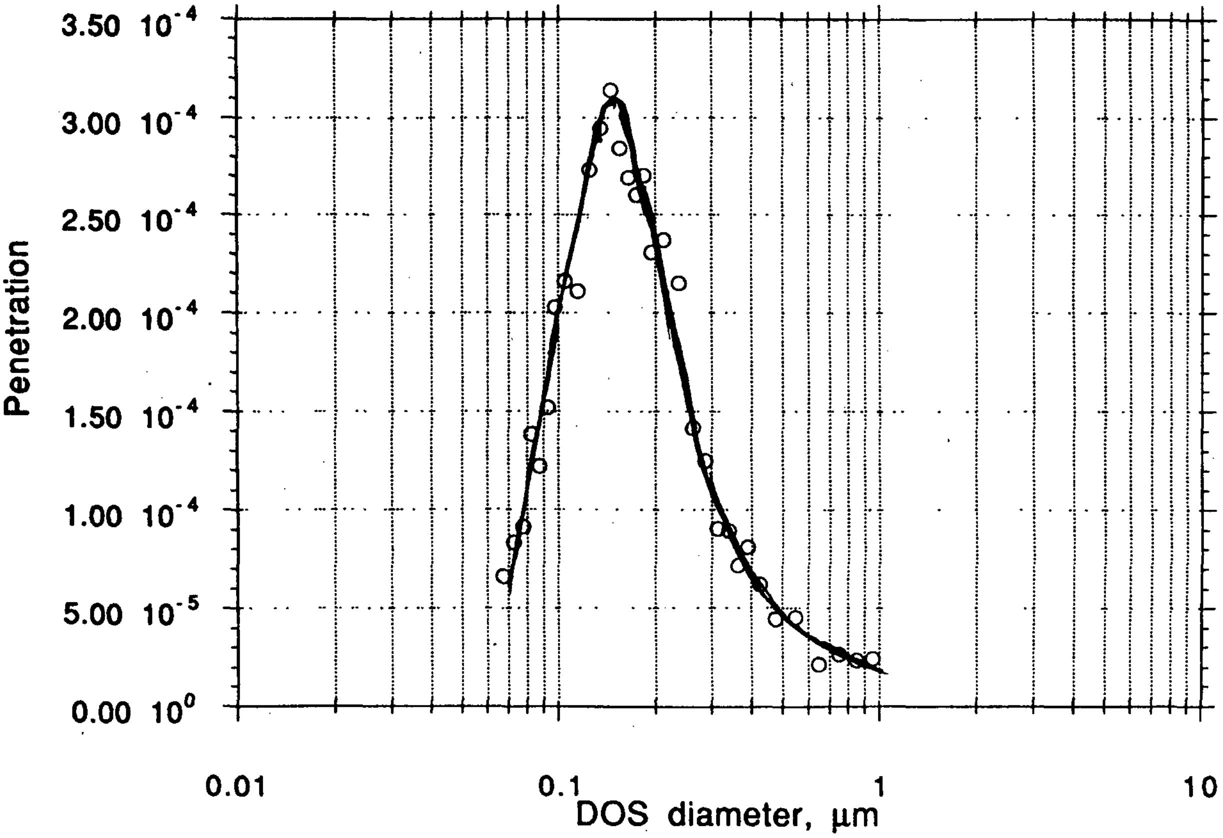

Figure 8. Aerosol penetration through filter cartridge shown in Figure 7 as a function of aerosol diameter. Pressure drop is 1.5 inches at 15.6 cfm flow.

Since the ability to clean and reuse the steel HEPA filter is an important property of the cleanable steel HEPA filter, we conducted a series of filter clogging and cleaning tests on the filter cartridge shown in Figure 7. We used AC Fine dust (Powder Technology Inc, Burnsville, MN) to load the filter and compressed air pulses to remove the particle deposits. The test system is described in our previous publication.(14) Figure 9 shows the results of loading and cleaning the filter cartridge 10 times. The test shows that the filter can be repeatedly cleaned and reused. Note that there is a small increase in the baseline pressure from 1.5 to 2.0 inches up to the fifth cleaning. Beyond that point the residual deposits in the filter remain constant.

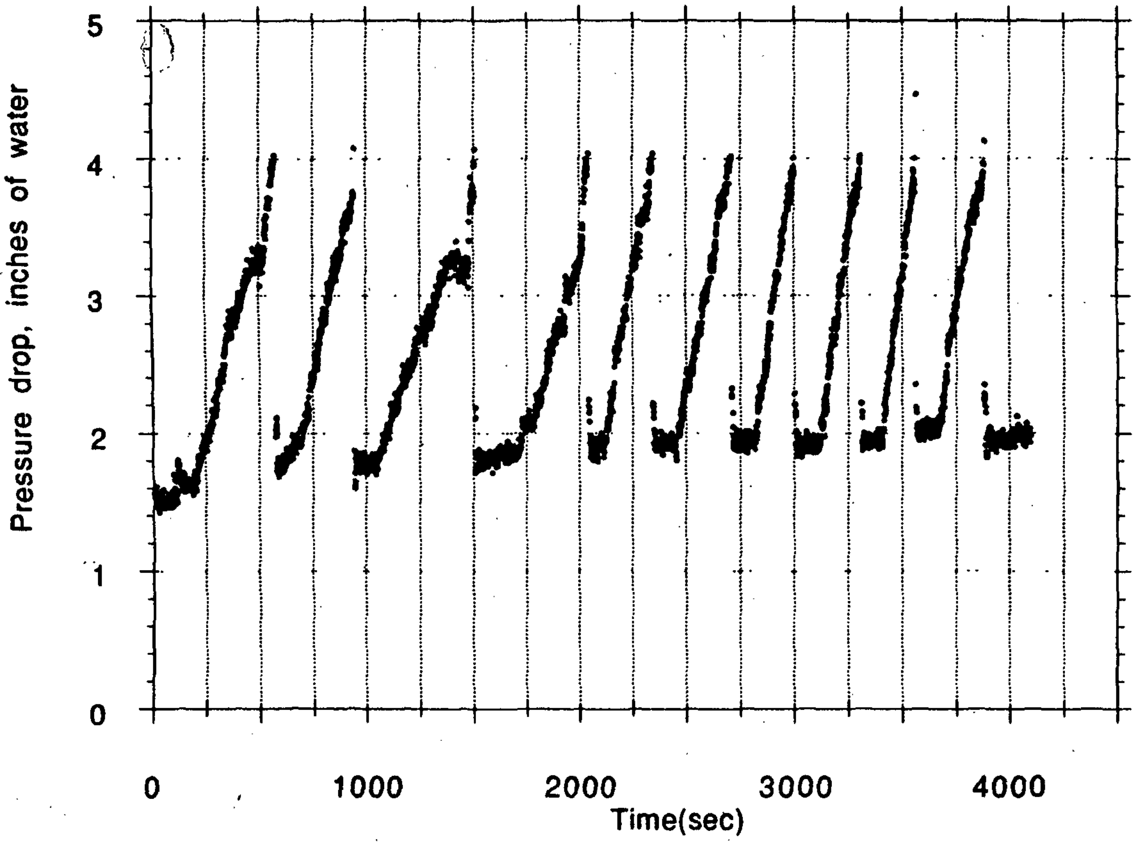

Figure 9. Filter loading and cleaning cycles using AC Fine test dust and compressed air pulses on the filter cartridge in Figure 7.

Since there are no commercial sources that can make 0.5 µm steel fibers, we used fundamental laboratory techniques based on the wire bundling and drawing process to make a small quantity of these steel fibers. The process, which is extremely labor intensive and not suitable for prototype development, involves a series of repetitive steps in which wires are bundled together into a rod and then reduced in diameter by drawing through progressively smaller dies. The starting point is a stainless steel rod that is snugly fitted inside a copper tube. We then reduced the diameter of the rod by swaging until the resulting rod could be drawn through a standard wire drawer for further size reduction. The wire drawing process was periodically interrupted to heat treat the rod to reduce the hardness induced by the drawing process. The reduced wire was then cut into fixed lengths which were then inserted into a new copper tube and the process repeated. Figure 10 shows a rod consisting of a bundle of wires being reduced in diameter through progressively smaller dies. The individual wires have a copper coating from the initial cladding operation to prevent sticking to the other wires. Figure 11 shows a cross section of the rods, starting with the original rod and going through the first, second and nth bundling. When the desired fiber diameter is reached, the copper cladding is dissolved in nitric acid and the fibers dispersed.

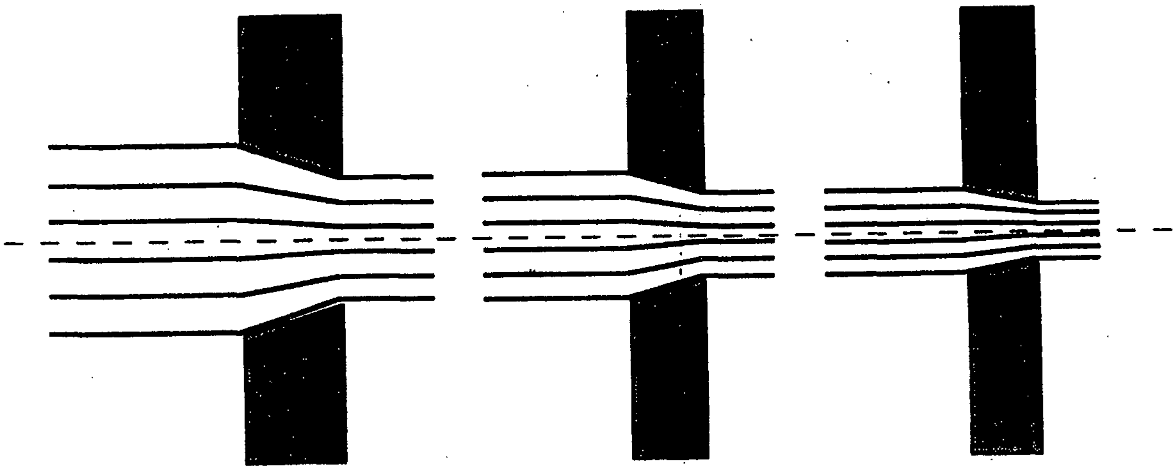

Figure 10. Wire drawing is used to produce smaller diameter steel fibers.

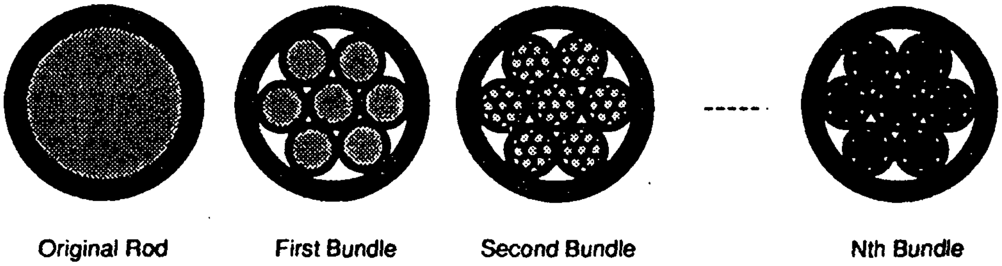

Figure 11. Cross section of steel rods from the original to increasing iterations of bundling and drawing

We then made a small sample of stainless steel fiber media from the 0.5 µm steel fibers using the paper making process followed by sintering.[(1)] Figure 12 shows an electron micrograph of the media. Laboratory tests at 3.5 cm/s face velocity yielded an efficiency of 99.998% for 0.3 µm dioctyl sebacate (DOS) aerosols.

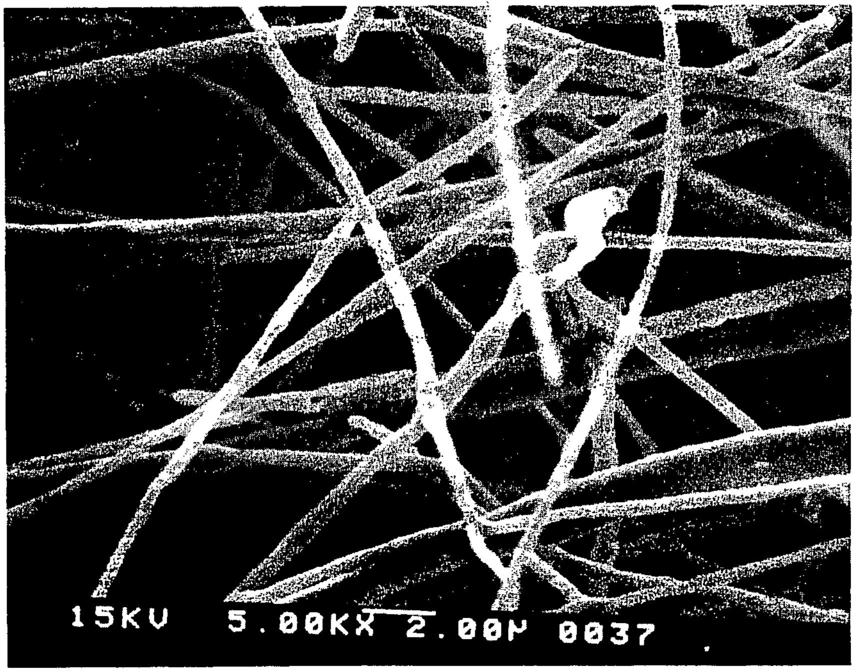

Figure 12. Electron micrograph of the steel fiber media made from 0.5 µm steel fibers.

Figure 13 shows the penetration (1-efficiency) measurement of the media as a function of particle size. The pressure drop was 1.15 inches. The media had a greater quantity of fibers than was needed to achieve the desired efficiency value. We estimate that reducing the quantity of fibers to yield an efficiency of 99.97% will result in a media pressure drop of 0.8 inches. Unfortunately, we did not have sufficient fibers to optimize the media formulation. Nevertheless, our tests have demonstrated that filter media made from 0.5 µm steel fibers will yield the desired HEPA filter performance.

We have shown the feasibility of developing a steel HEPA filter that meets the efficiency and pressure drop requirements for HEPA filters. However, the laboratory bench scale process must be scaled up in order to produce a sufficient quantity of fibers and media to make several prototype HEPA filters. This represents the next step in the development of the cleanable steel HEPA filter.

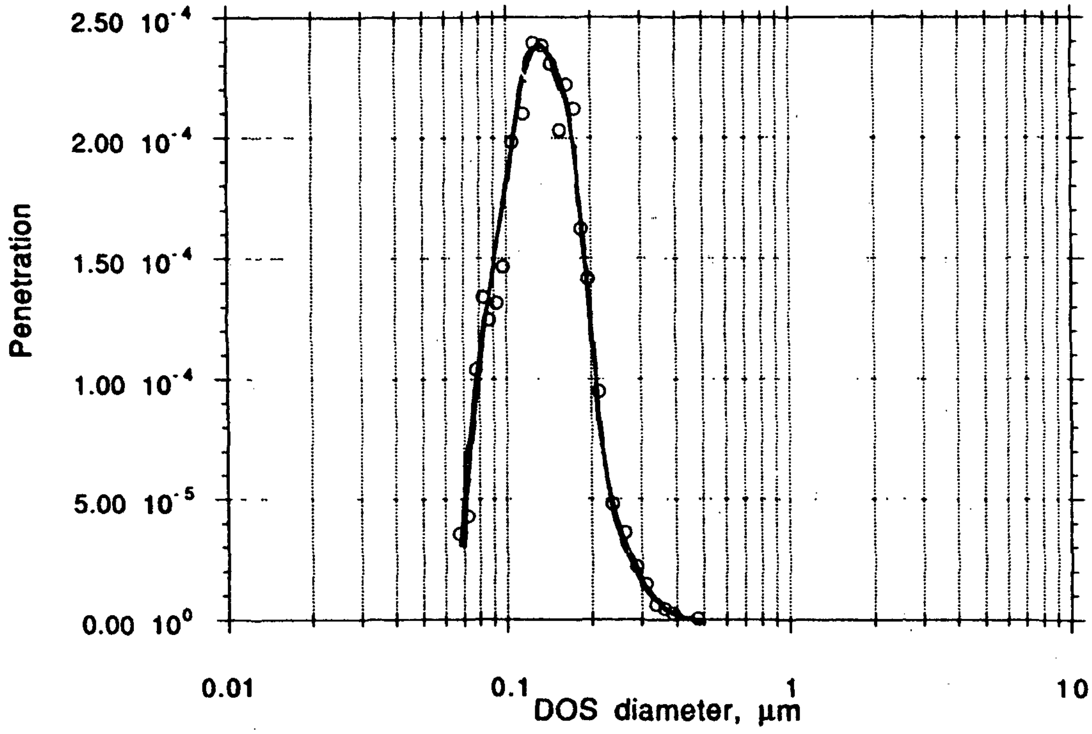

Figure 13. Aerosol penetration measurements at 3.5 cm/s face velocity through steel fiber media shown in Figure 12. Pressure drop was 1.15 inches.

III. Reduction in Weight Achieved by Using Conventional HEPA Design

Since the filter media for the steel HEPA is expected to weigh about 10 pounds for 200 square feet (glass fiber media would weigh 3.3 pounds), most of the weight is due to the support structure. The filter design that consists of multiple pleated cylinders as shown in Figure 2 would require a considerable amount of heavy metallic support elements and end plates on which to attach the cylinders. This design can not be used to fabricate a steel HEPA filter that has a comparable weight to the steel-framed HEPA with glass fiber media. To achieve the weight objective, it will be necessary to use a similar design as used for glass fiber HEPA filters. Figure 14 shows a design using corrugated separators. Since the steel media is much stronger than the glass media, it also is possible to eliminate the separators. Other designs such as the mini-pleat and Dimple Pleat^{TM} design are also possible.(14,24) The assembly of such filters is very similar to that used for the present glass HEPA filters except that organic sealants would be replaced with a brazing compound. Any of a variety of different brazing or welding techniques can be used to seal the pleated media pack into a steel frame. The final weight of the filter is expected to be less than 60 pounds, compared to the 200 pounds for the commercial units.

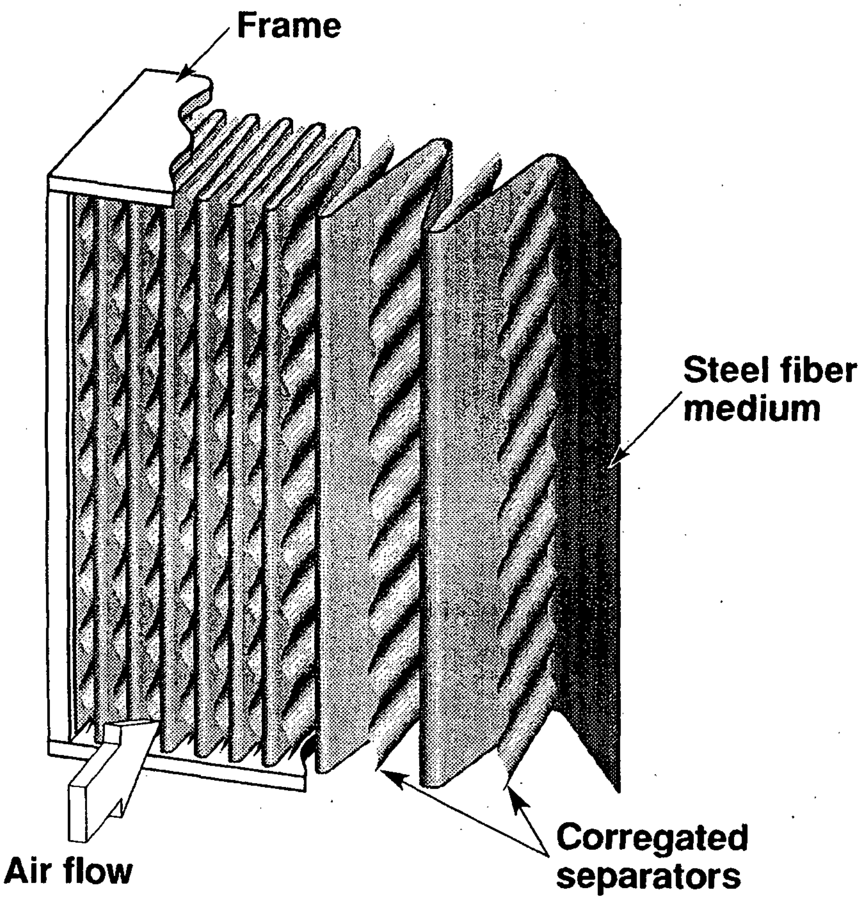

Figure 14 Cleanable steel HEPA filter with the deep pleat and separator configuration.

IV. Sensitivity Analysis Shows Cleanable Steel HEPA Flatters Are Cost Effective

The initial driver that was responsible for the early development work of the filter was the cost saving that resulted from reducing the large waste disposal costs by cleaning the filter and reusing it.(13,14) We found that during the 1987-1990 period, DOE facilities used an average of 11,478 HEPA filters per year and had an annual estimated cost of $55 million.(21) We estimated that replacing all of the glass HEPA filters with steel HEPA filters would reduce the annual costs to $13 million and save $42 million per year.(14)

Since the number of HEPA filters used by DOE facilities have decreased dramatically in recent years and the parameters used in the cost estimates are uncertain, we have performed a sensitivity analysis of the cost parameters to reevaluate the potential cost savings.(2) The annual number of HEPA filters used by DOE facilities dropped from about 12,000 in 1990 to 4,000 in 1995 as a consequence of the end of the Cold War.(2) The other major factors that determine the total cost savings from using cleanable steel HEPA filters are the average filter life for the glass and steel HEPA filters, the initial purchase price for the glass and steel HEPA filters, the installation, test, removal and disposal cost for a glass or steel HEPA filter, and the cost for cleaning the steel HEPA filter.

The average filter life for the glass-paper HEPA was estimated to be 3 years from a study of filter usage during 1977-1979.(21) If we assume that the number of facilities and operations remain constant during this period, then it is possible to estimate the total number of filters in DOE facilities by multiplying the number of filters tested each year by the average life. For the period between 1977-1979, DOE tested an average of 10,352 filters and therefore had 31,055 filters in its facilities.

Once we have the total number of filters, we can estimate the average filter life by dividing the total number of filters by the annual number tested. Assuming the total number of active filters is still about 31,000, we estimate that the average filter life is (31,000/4,000 = 7.8) 7.8 years. This estimate is reasonable based on the filter age data from Lawrence Livermore National Laboratory as of 10/13/94 that is shown in Figure 15. However, the 4,000 annual filters reflect a relatively idle DOE undergoing a major redirection following the end of the Cold War, and a large fraction of DOE operations, such as environmental clean-up , waste processing and weapons manufacturing are not yet in full operation. The number of HEPA filters used is expected to significantly increase with a corresponding decrease in the average HEPA life as DOE begins to process its radioactive waste and decontaminate and decommission its facilities. For our analysis, we will assume the average filter life will fall within the range of 3 years for full production and 7.8 years for primarily idle operation. The average is 5 years. In addition, there is a growing trend for DOE facilities to impose a 5 year life time on glass HEPA filters because of deterioration with age.(25)

The life of the steel HEPA is another uncertain parameter in the potential cost savings from using steel HEPA filters. The life of the cleanable steel HEPA filter, assumed be 45 years in our original cost savings estimate, is probably much less.(14) The 45 year life estimate assumed that the steel HEPA filter would last the life of a typical facility, hence 45 years. However, the life of the steel HEPA depends on the environment to which the filter is exposed. For a relatively clean, non-corrosive environment, this is probably still a good estimate. However, if 304 or 316 stainless steel filters are exposed to a halide salt or acid environment, then the filter will rapidly degrade due to chemical attack. In fact, these filters should not be used in those environments. For applications in corrosive environments, the fibers should be made from Hastelloy or Inconel. Unfortunately, these fibers are only available in diameters greater than 8 μm, which are not suitable for HEPA filters as seen in Figure 4.

In addition to chemical attack on the fibers, the filter life is also determined by the ability to clean the filter. If the filter cannot be effectively cleaned, then the filter life will be shortened. In our cost analysis, we have assumed a life of 30 years. This is based on having a minimum of six cleanings (i.e. six equivalent glass HEPA filters, each having a 5 year life). In our laboratory tests, we were able to repeatedly clean the steel HEPA for an equivalent of 15 glass HEPA filters.(14)

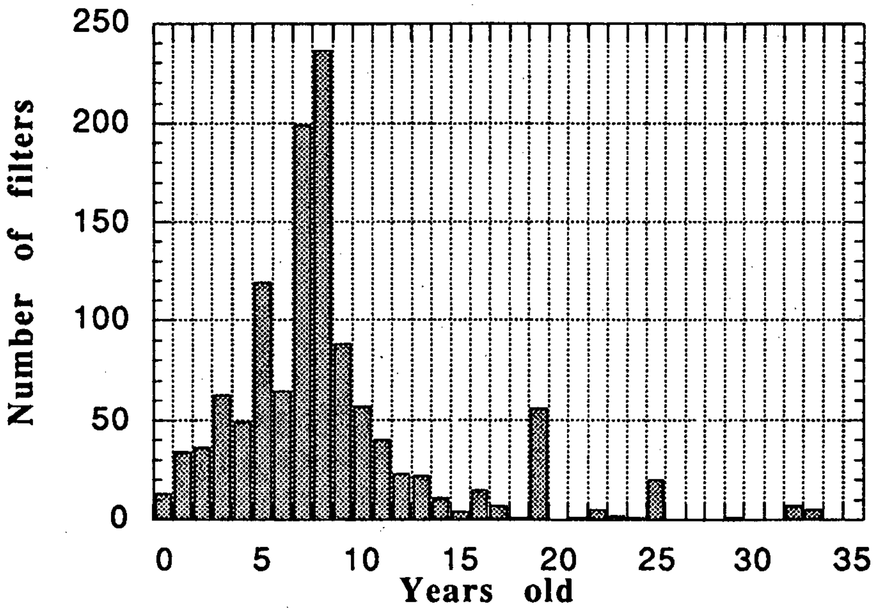

Figure 15. Distribution of HEPA filter age at LLNL as of 10/13/94. The filters are size 5.

Another uncertain parameter in the cost analysis is the final cost of the cleanable steel HEPA filter after it is completely developed and in production. We have assumed that the cost of the steel HEPA filter can be reduced to $5,000 through further development work and with efficiencies in mass production. The present cost of a cleanable steel filter with 3 inches pressure drop and weighing 200 pounds is about $70,000.(20) In contrast a standard glass HEPA filter, which weighs about 40 pounds, costs about $300.

The cost for the installation, test, removal, and disposal was $4,450 as obtained from a survey of life-cycle costs of glass HEPA filters for the period 1987-1990.(21) We assumed that this cost would be the same for both the prototype and the steel HEPA filter. The prototype steel filter would have a slightly higher cost because of its greater weight, but we have ignored that in our analysis.

The final parameter to be considered in our cost analysis is filter cleaning costs. We have assumed reverse pulse air cleaning or filter removal and off-line washing would be the primary cleaning methods. Pall has also developed and successfully tested an on-line water cleaning method for their pressure vessel design.(18,19) We have estimated that each cleaning cycle would cost $500 based on labor costs. The associated capital costs for the cleaning hardware (e.g. blow back tubes) would be lumped into the initial cost for the filter element housing or in the initial cost of the steel HEPA filter.

We have summarized the various costs and parameters for the glass HEPA filter, the commercially available steel filter, and the fully developed cleanable steel HEPA filter in Table 1. We have also computed the total filtration cost for a given HEPA filter installation over 30 years. The total filtration cost for the HEPA filters are given by:

$$C_{GT} = (30/L_{GF})(C_{GF} + C_M) \qquad (1)$$

$$C_{ST} = (30/L_{SF})(C_{SF} + C_M) + N_C(C_C) \qquad (2)$$

where C_{GT} = total filtration cost for glass HEPA in a single installation over 30 years.

C_{ST} = total filtration cost for steel HEPA filter in a single installation over 30 years.

L_{GF} = Life of glass HEPA filter, years

L_{SF} = Life of steel HEPA filter, years

C_{GF} = Initial cost of glass HEPA filter

C_{SF} = Initial cost of steel HEPA filter

C_M = Maintenance cost of installation, test, removal and disposal

C_C = Cleaning cost of filter

N_C = $30/L_{GF}$ = Number of cleanings

Equation 2 incorporates the assumption that the steel HEPA is cleaned prior to disposal at the end of its useful life. The cost of the cleaning system that is required for retrofit applications is included in the cost of the cleanable steel HEPA because it is small compared to the cost of the filter. The cleaning system would either consist of an in-duct reverse air pulse jet or the filter would be removed for off line cleaning in a liquid bath.

Once the costs for glass and steel HEPA filters are determined from Equations 1 and 2 respectively, a variety of other cost figures can be computed such as annual costs per filter location, total and annual cost savings for steel HEPA filters compared to glass HEPA filters, and total DOE filter costs and total savings. We have made these computations in Table 1.

As seen in Table 1, the commercially available steel filter is not cost effective because of the high purchase cost of $70,000 and the few cleaning cycles for applications having an average HEPA life of 5 years. This explains why these filters are not being used in applications where conventional glass HEPA filters are used. The steel HEPA filter becomes more cost effective with increasing cleaning cycles because of the $4,450 in handling and waste disposal costs that are saved with each cleaning. Table 1 also shows that the steel HEPA filter costing $5,000 is very cost effective for the given assumptions. We believe that this cost reduction is achievable with additional development and improvements in production methods.

To assess the sensitivity of the filtration costs and cost savings to variations in the key parameters in Table 1, we used Equations 1 and 2 to determine the total cost as a function of the glass HEPA life (or cleaning frequency), the purchase cost of the steel HEPA filter, and the service life of the steel HEPA. Details of the sensitivity study are presented in our previous report.(2)

Table 1. Comparison of costs and parameters for glass HEPA and cleanable steel HEPA filters.

	Glass-paper HEPA	Stainless steel HEPA	
		Commercial	After Development
Filter element (1000 ft^3/min)	$300	$70,000	$5,000
Installation, test, removal, and disposal	$4,450	$4,450	$4,450
Cleaning	$0	$500/cleaning	$500/cleaning
Average filter life	5 years	30 years	30 years
life costs for one location(30 years)	$28,500	$77,450	$12,450
life savings per location	$0	-$48,950	$16,050
cost per location per year	$950	$2,648	$415
annual savings per location	$0	-$1,698	$535
total DOE cost per year (31,055 filters)	$29.5M	$82.2M	$12.9M
total DOE savings per year (31,055 filters)	$0	-$52.7M	$16.6M

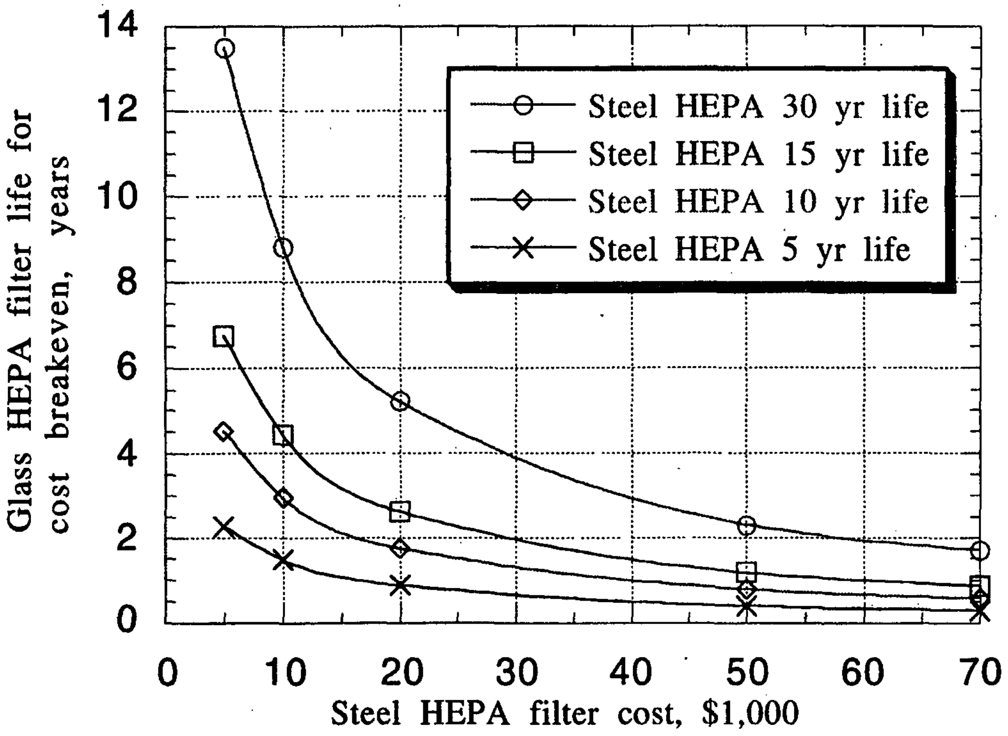

Figure 16 Break-even costs for cleanable steel HEPA filter having different filter lives as a function of purchase cost.

The results of our sensitivity analysis are summarized in Figure 16 which defines the break-even costs as a function of glass HEPA life, steel HEPA cost, and steel HEPA life. Using a cleanable steel HEPA filter will be cost effective for any combination of glass HEPA life and steel HEPA cost that lies below the curve defining a given steel HEPA life. Figure 16 shows that more expensive steel HEPA filters are only cost effective with long steel filter life and short glass HEPA life. Conversely, lower cost steel filters can be cost effective with higher glass HEPA filter lives and lower steel HEPA lives.

In addition to the direct cost savings shown in Table 1, there are additional cost savings due to the increased reliability of the steel HEPA filters. Steel HEPA filters have a much higher reliability than the present glass HEPA filter, which can be damaged or destroyed under a number of operational and accident conditions involving fires, explosions, tornadoes, or water exposure.(26) When the HEPA filters are damaged, radioactive contaminants can escape and cause environmental contamination. The typical consequence of a accidental release is a facility shut down and an environmental clean-up operation, both of which are very expensive.

V. Evaluation of Competing Technologies for Cleanable HEPA Filter

The major competitors of the sintered steel fiber filter are the metal and ceramic sintered powder filters and the reinforced glass fiber HEPA filter. In fact, the early high efficiency metal filters used in nuclear air cleaning applications were sintered steel powder filters.(3-5,9) Currently, both steel and ceramic sintered powder filters are used extensively in high efficiency filtration applications in which the filters are repeatedly cleaned and reused. Most of the applications involve filtering gas and liquid process streams at relatively low flow rates and have high pressure drops across the filters.

We have evaluated sintered metal and ceramic powder filters and concluded that these filters have much higher pressure drops than fibrous filters with the comparable efficiency. Figure 17 illustrates the general structure of a sintered powder filter which consists of several layers of different size powders that are sintered together.(27) The layer having the smallest size particles performs the basic filtration, while the intermediate layers and substrate provide structural support to the filtration layer. In order to minimize the pressure drop, the thickness of the filtration layer is made as small as possible.

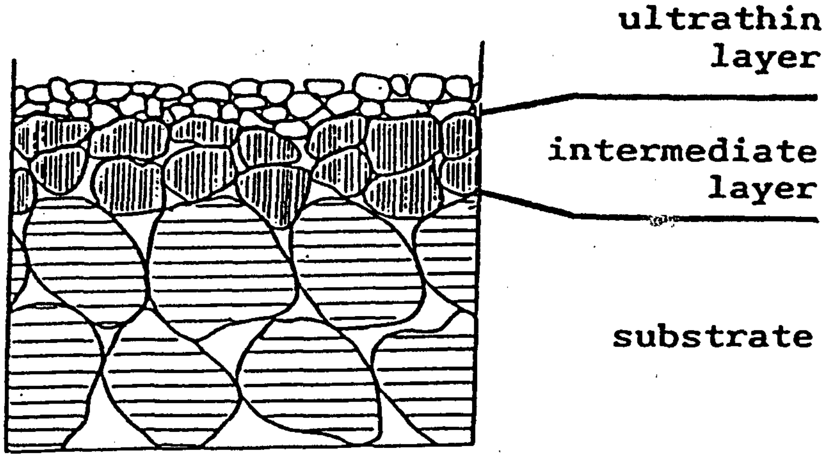

Figure 17. Typical structure of a ceramic powder filter having multiple layers of different size powder.(27)

An example of a typical ceramic powder filter is illustrated in Figure 18 which shows electron micrographs of the cross section of the French KERASEP filter.(28) The substrate layer of 5 μm aluminum and titanium oxide powder and the surface layer of 0.8 μm zirconium or titanium oxide powder are seen in the two photographs. In addition to the filter with a surface layer of sintered 0.8 μm powder, we also obtained KERASEP filters with a surface layer of 1.4 μm powder and one filter having only the substrate with no surface layer. This filter was used by the French Atomic Energy Agency for isotope separation.

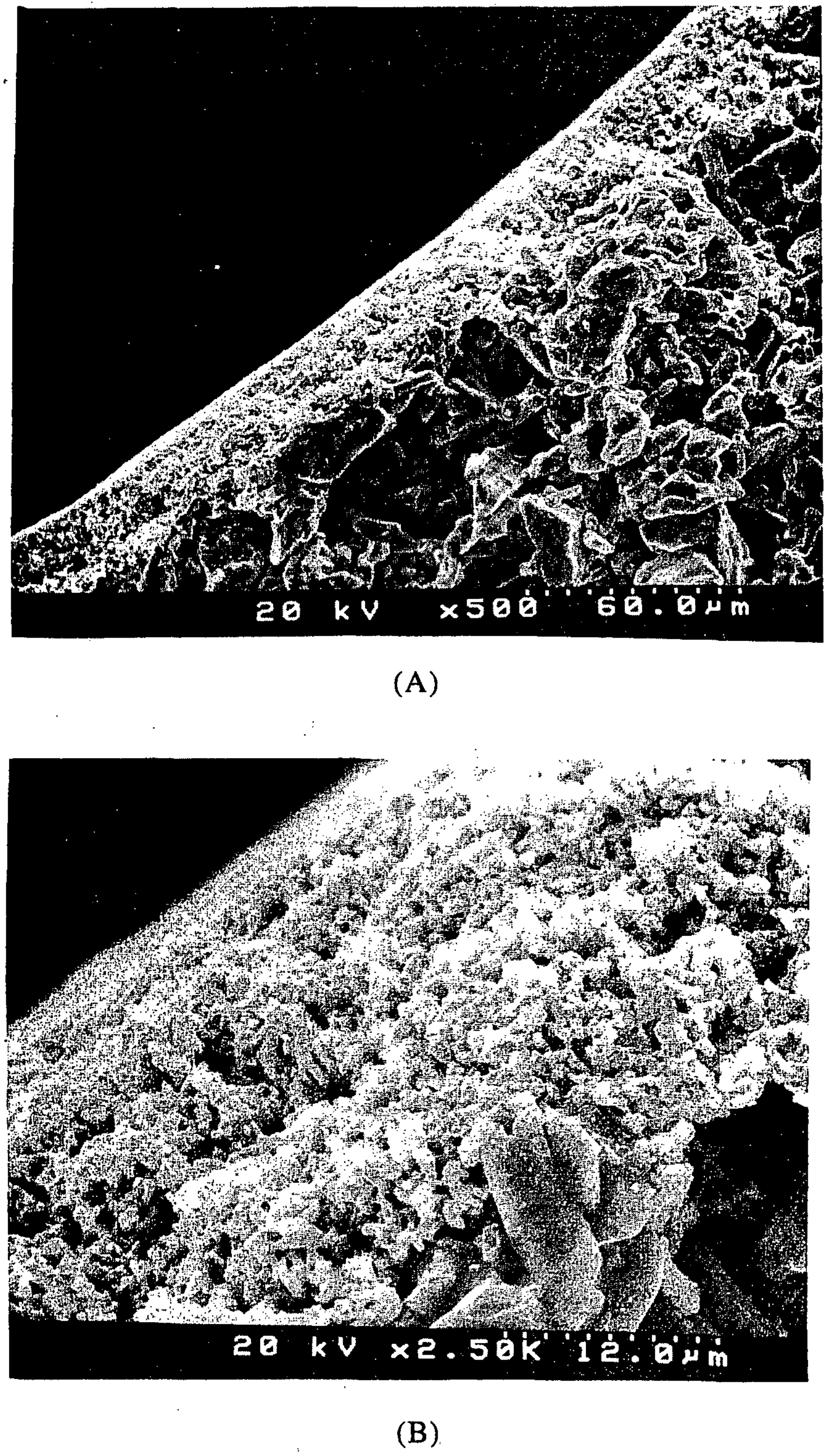

Figure 18. Electron micrographs of the cross section of the KERASEP ceramic powder filter having a surface layer of 0.8 µm powder. B is a magnification of A.