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PANEL SESSION: CODE ON NUCLEAR AIR AND GAS TREATMENT ASME/ANSI AG-1

William H. Miller, Jr. Moderator
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Introduction

Happy Birthday AG-1, you're seven years old now and you're about to experience a significant growth spurt! Yes CONAGT is very close to issuing three major AG-1 code sections as follows:

* Section SA - Ductwork
* Section IA - Instrumentation and Control
* Section TA - Field Testing of Air Treatment Systems

Those of you who recently received your 92 Edition of AG-1 may have noticed that our seven year old is dressed in a new suit - a hot pink cover. Some of you have accused me of selecting this color to better market our youngster but this simply is not true. Our fully empowered ASME staff picked this color and I applaud their choice.

1990 Panel Session

Two years ago I chaired this same panel session and probably bored you with a review of AG-1's history and organization. For those of you who are unfamiliar with AG-1, please consult the 1990 Conference Proceedings for that perspective. Our panel discussion in 1990 centered primarily on our TA and TB field testing Code Sections which we thought would be published by now, but in fact are still running the consensus gauntlet. A comparison review of these documents revealed sufficient inconsistencies to merit a series of spirited Subcommittee meetings and a couple of Main Committee interventions, but all is well now.

1992 Panel Focus

This year we will focus more on the progress we've made in our equipment code section work in the past two years. We'll hear about:

* Changes in our Filter Code Sections
* Revamping of our Ductwork Code Section
* Emergence of a vastly improved I & C Code Section

Then two of our CONAGT members will regale us with tales of actual applications of AG-1. To top this off, our panel will field your questions for the balance of our allotted time.

CONAGT Status

Before we get started with our panel presenters, I'd like to spend a few minutes making observations on CONAGT's health. As a charter member of CONAGT since 1976, I've had the opportunity to observe its ups and downs. I never cease to be amazed by the vigor and vitality of our members who are, in my opinion, the most committed group of code committee members in the world. We purposely hold only two Main Committee meetings a year in order to preserve our sponsor support, but what it really does is free up our members to teach ASME short courses, write white papers, hold Subcommittee and Subgroup meetings, study and vote on a dozen ballots every month, and participate in NACC, ANS, ASHRAE, ASTM, AGS committees and the list goes on. These CONAGT members are little dynamos who merit special recognition by this audience. Let's give all CONAGT members a loud round of applause.

I feel I owe you an update on what CONAGT's accomplished in the last 24 months since I last addressed you. The following are just a few of the most significant accomplishments:

* CONAGT'S first ASME Short Course held in San Diego in conjunction with the 21'st NACC was only the beginning as it has been held, successfully, numerous times since and is being taught later this week on this site. My hat's off to our trainers and course coordinator Dr. Mel First.
* In September 1991, we learned that our three years of correspondence with DOE to gain recognition of AG-1 was fruitful as DOE General Design Criteria 6340.18 was revised to invoke ASME AG-1 for air cleaning devices.
* After learning from our NRC representatives of NRC's assigning a low priority to the revision of R.G. 1.52, CONAGT used its official communications link with NRC via ASME's Vice-President of NCS to lobby for a quicker update. When NRC's official response was negative, I took the matter up with BNCS' NRC rep, Mr. Guy Arlotto. Our understanding is that the R.G. 1.52 is literally racing around NRC now.
* Earlier this year our CONAGT Vice-Chairman Mr. Ray Weidler was selected to fill a BNCS participant position, thereby further strengthening CONAGT'S influence on this prestigious managing board.
* CONAGT'S liaison with ANS, ASHRAE, and our International Air Cleaning brethren continues to improve thanks to CONAGT members who serve our industry through multiple memberships, and Ray Weidler who continually promotes us overseas through frequent updates of the Listing of International Nuclear Air cleaning Codes, Standards,

Regulations and Texts. ASME requested CONAGT to consider rendering assistance to the American Glovebox Society (AGS) who is preparing a Glovebox Standard. We were recently represented at their AGS Board of Directors meeting and treated very well. We continue to explore opportunities for joint work.

* CONAGT has debated for years what the ultimate destiny is for N509 and N510 once the full AG-1 Code is issued. Over the years the periodic maintenance of these standards has consumed a fair amount of CONAGT resources. Based on our most recent discussions it is probable that N510 will not be revised again once the TA Section of AG-1 is issued late this year. N509 is now recognized as an invaluable integrating standard for AG-1 component sections and as such five-year updates should be expected.

DUCTWORK SECTION (SA) IMPROVEMENTS

Cliff Ashton
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Amazing as it may sound, the Ductwork Section of AG-1 is about to be published, assuming that our second BNCS ballot, which was just initiated, is successful. My subgroup's hard work over the past two years in resolving literally hundreds of Main Committee and Board comments is about to be rewarded. Since we're the third group in 15 years to attempt to produce this code section, you must excuse us if we're a mite proud of this accomplishment.

Our Main Committee Chairman refers to the SA section as the "bridge that connects all components" and he has steadfastly refused to appear before the NRC to promote AG-1's adoption until SA is issued. If SA is so important then why has it been so hard to complete you might ask? I suspect it stems from the widely divergent expectations of the various customers of this code section: utilities want something different than contractors who expect something different than consultants who want something different than testing firms. The net result is a somewhat tortuous journey through the consensus process, time and time again. In defense of this process, however, I really believe this code section is a very high quality product which will stand the test of time.

I've been asked to summarize the improvements in the SA section in the past few years and I'll do so briefly as follows;

* gradual transition of ANSI N509 and N510 air cleaning unit requirements into AG-1 code system related consideration of ductwork.
* consideration of air conditioning/cooling function into code requirements.
* revision of code section to remove overly restrictive requirements, allow for plant design flexibility to meet specific design, environmental and related criteria.
* established more flexible guidance in determination of acceptable leakage criteria.
* at the direction of the main committee, removed housings from the scope of SA section due to the decision to dedicate a new section HA to housings.
* clarified interface boundaries.
* clarified load combinations.
* incorporated interface considerations for fire protection and plant security.

* improved the definitions of various design and operating pressure considerations consistent with other AG-1 sections.
* incorporated lessons learned in ductwork field installations into code section requirements.
* added metric units to code section.
* provided non-mandatory guidance related to leakage determination.

Until we get this code section on the street and into a few specifications and installations, we will still be cautiously celebrating the completion of this task.

INSTRUMENT & CONTROLS SECTION (IA) IMPROVEMENTS

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In reading Cliff Ashton's mini-paper, we couldn't help but relate to the sense of accomplishment that he portrays since we too are on the doorstep of publishing a code section in the making for some 15 years. While we're the second, not third group to attempt to complete this job, we too have labored long and hard to reach this milestone. Mothers sometime describe the actual delivery of a newborn as a tremendous relief and now we can relate better to that feeling too. But enough of feelings!

Our list of improvements in the IA code over the past few years reads as follows:

* reformatted the entire document to make it read like a code section and not a specification.
* revamped the definitions section to be consistent with other published code sections and ISA and IEEE standards.
* added an allowable material table to conform to other sections.
* added an appendix to provide guidance in determining the necessary instrumentation for major NACU components.
* updated the reference document section.
* rewrote the IA inspection and testing section to delete motherhood statements and reference correct sections of AG-1.
* clarified the section scope
* added separation requirements for wiring and tubing.
* added specificity to the division of responsibility
* referenced the appropriate ISA standards for setpoint calculation requirements.
* improve the tubing requirements to be compliant with NRC requirements.
* enhanced the documentation requirements of the section

When stated in summary form like this, these improvements may not sound like a whole lot but believe me there was a lot of word crafting involved in producing the IA section which is now being balloted a second time by BNCS. Thank-you!

PANEL SESSION: FILTER SECTIONS OF ASME AG-1, CODE ON NUCLEAR AIR AND GAS TREATMENT

Richard D. Porco
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Introduction

The design, performance, construction, qualification, testing, and quality assurance requirements for nuclear air cleaning components are contained in Division II, Ventilation Air Cleaning and Ventilation Air Conditioning, of ASME AG-1. The filter sections are part of Deviation II, and are complete. Section FG, Mounting Frames is the last to be published and will appear in the Summer, 1992 Addenda. Section FA, Moisture Separators; Section FB, Medium Efficiency Filters; Section FC, HEPA Filters; Section FD, Type II Adsorber Cells; Section FE, Type III Adsorbers; and Section FF, Adsorbent Media are all currently undergoing maintenance and editorial revisions.

Section FA Moisture Separators

Moisture Separators, Section FA, was added to AG-1 in the 1991 Revision. Moisture separators are installed in air cleaning systems to remove entrained water droplets from the air stream that could adversely affect the HEPA filters and carbon adsorbers.

Section FB Medium Efficiency Filters

Medium Efficiency Filters, Section FB, was added to AG-1 in the 1991 Revision. This section applies to extended media, dry type, ASHRAE 52 rated filters with an average atmospheric dust spot efficiency greater than 45%.

Section FC HEPA Filters

The HEPA filter section of AG-1 was added in 1988. Since then we have continued to upgrade and revise this section. This section is currently under a relatively major maintenance and editorial revision mainly to the inspection and testing articles. Although this section has been around for some time, some subtle errors currently exist in the document. For instance, the penetration requirement after the heated air qualification test is in error. Pending CONAGT Main Committee reballot, corrections will be published. Another item of note is that the subcommittee is working on a non-mandatory guide that could include guidelines for the use of laser particle counters for production test efficiency of HEPA filters in lieu of the Q107 pentometer.

Section FD Type II Adsorber Cells
Section FE Type III Adsorbers

Section FD, Type II Adsorbers was added to AG-1 in 1987. Section FE Type III Adsorbers was added in 1989. These sections have also seen maintenance revisions and updates since initial publication. A new adsorber section, Type IV Adsorber Cells, is currently being prepared by the subcommittee. The Type IV Adsorber is a 24" x 24" x 18" deep V-bed cell similar to the old serpentine Type I cell, except the Type IV cell has a 2" thick bed and is nominally rated at 500 CFM. The Type IV Adsorber Cell is predominantly used in Bag-In/Bag-Out housings which are also being addressed in the housing sub-committee. Bag-In/ Bag-Out filter systems are more common at DOE sites, such as Idaho Falls, Idaho and Richland, Wa. The reason for the addition of these items to the code is to be responsive to their needs.

Section FF Adsorption Media

Adsorption Media, Section FF, was added to the code in 1988. This section has also undergone various maintenance revisions. This section contains the detailed requirements for adsorbent media used in nuclear air and gas treatment systems for the removal of radioiodine compounds. Activated impregnated carbon is addressed in this section because it is the primary adsorbent used in the nuclear industry. The subcommittee for this section has also addressed questions and responded with formal code interpretations.

Section FG Mounting Frames

Mounting Frames, Section FG, addresses filter holding frames or racks for moisture separators, prefilters, HEPA filters, and Type II adsorbers. This section will appear in the Summer 1992 Addenda of AG-1.

Conclusion

The filter sections of AG-1 have been completed and have been successfully implemented on commercial nuclear power plants such as YGN 3&4 in Korea and domestic retrofits and upgrades. The AG-1 Code is a working document and, as such, is continually being updated to incorporate new technologies and regulatory requirements. I urge all users of this code to submit questions or suggested changes to ASME. User feedback is the best way to initiate code improvements and to service the needs of the industry.

CODES IN USE

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The actual application of AG-1 has had a variety of responses in the industry. These include the engineer, the client and the vendor. The following highlight several of our experiences.

AG-1 has been incorporated into the Department of Energy Standards and Criteria Guide for Nonreactor Nuclear Facilities. With this, CONAGT has asked and received more input from areas outside the energy production facilities and will monitor the usage of this code at sites such as Savannah River.

Drywell Dampers

In 1986, two control dampers were specified for a drywell cooling unit. The specification included compliance with AG-1. The vendor indicated that he would comply with the technical aspects of the specification but would not comply with AG-1. We believed this to be attributed to the newness of AG-1 and the limited size of the damper specification.

Bubble Tight Dampers-1

In 1988, a specification was written for bubble-tight dampers and appropriate references to AG-1 were made. The engineer involved had some difficulty following AG-1, due primarily to the number of cross-references within the code. The vendor did not take exception to AG-1, and the project proceeded smoothly.

Bubble Tight Dampers-2

In 1991, bubble-tight dampers were specified for another project. The design and construction data included in the Procurement Specification is based on information provided in AG-1. The test procedure/acceptance criteria is also based on the data in AG-1.

AG-1 was not invoked in entirety by name because the client felt that this document, if used in design, would form the baseline document and thereby they may be forced to use it in future mods.

As a result of this decision, the different applicable sections from AG-1 were incorporated into the specification.

After the award, the vendor commented that he could have complied with AG-1 if it had been invoked.

New Nuclear Units

Sargent & Lundy is currently involved in the design and construction of the two newest nuclear units in the world today. The Yonggwang Nuclear Power Plant Units 3 and 4 (YGN) are currently being constructed in South Korea for the Korea Electric Power Corporation. There are PWR units and are approximately 1100 MW each.

The Safety-Related HVAC component specifications include:

- Air Cleaning Units
- Air Handling Units and Fans
- Cubicle Coolers
- Dampers
- Reactor Containment Fan Coolers
- Water Chillers

These specifications were prepared in 1987-88 with appropriate recognition of the initial issue of ASME AG-1 in 1985 as well as company standards. The scope of work, division of responsibility, section of AG-1 were very useful to the design engineer in establishing the requisite specification input parameters and in defining the vendor's responsibility in complying with AG-1.

The evaluation of the specification proposals included the resolution of clarifications and exceptions submitted by the vendors. Throughout this step in the process questions were raised and resolved. However, it is important to note that there were few, if any questions raised with regard to compliance with AG-1. The specification were subsequently awarded to both domestic and Korean vendors.

On the project, the use of AG-1 was positively received by the entire project team. Specifically the code provided

- Good Guidance
- Definition of Scope of Responsibility
- Flexibility in Construction

CONAGT is presently considering a revision to N509-1989. This revision is intended to further endorse AG-1 for component requirements in the design and fabrication process.

In addition, CONAGT is working with the Nuclear Regulatory Commission to include AG-1 in a revision to R.G. 1.52 if/when that guide is reissued.

Both the above items are intended to have AG-1 made accessible to the owners of nuclear facilities, their suppliers and A-E's. This should also alleviate any confusion or hesitance in using AG-1 vs. another standard for materials in Nuclear Air Treatment Systems.

As we all mature in the AG-1 environment, improvements in understanding of the code are occurring steadily. We can use the code with confidence to ensure the quality of specifications and components needed in our industry.

DISCUSSION

VOGAN: I am Chairman of the Air Cleaning Equipment Subcommittee. I have a comment and wish to request additional comments from the panel. I would like to have additional discussion on applications of AG-1. AG-1 is different from other ASME codes issued through ANSI in that it contains rules for designing components, trains, standards for the individual components, and in-service field testing procedures all in one document. I would like additional comments regarding the use of AG-1. The document is unique, it is very useful, and we are interested in its use.

PORCO: I think the real proof of the usefulness of AG-1 will be its application to nuclear plants. We found that AG-1 was applicable to components. Problems were encountered and we still had to use N509 for system design criteria. There are sections that are incomplete in AG-1. Because AG-1 is a component specification, some things have fallen through the cracks. Although they are addressed in N509, I think all the committees are now working to identify the missing sections and to close the gaps.

MILLER: Does that answer your questions, Mr. Vogan, or are you really interested in exploring the field testing aspects more?

VOGAN: AG-1 is a unique document; it is three documents in one. It is a design code, it is a set of standards for components, and it is a field test document. I want to encourage people to use the document for replacement components where they can. If you encounter difficulty with your interpretation of the code, or with interpretations of manufacturers' interpretations, those who build the equipment, bring the problems back to us and perhaps by the next Conference we can make this the best code and standards document that ASME puts out.

MILLER: Maybe this is the right time to mention the process that ASME has for asking questions. If you are having difficulty interrupting a code, you can send a question to ASME and the Committee will give you a response. In the past, our turn around time on responses was not admirable, but we have been trained in quality improvement processes and now we are making responses in short order.

TODD: My question is for Rich Porco, regarding the Filter Section. Will there be any change in the code regarding QPLs on HEPA filters? Currently the code refers to the fact that the QPL is not required when making purchases for power plants.

PORCO: There will be no change in the code for QPL listing. I will say now, as I did earlier, that qualification testing is still being addressed because it is not complete in Section FC. If you conduct qualification testing by MIL-F-51068 and you are a filter manufacturer, you can be listed on the QPL. You don't have to be listed according to the code, but if you have done the testing and want to sell to the military market, I would suggest that you get listed. It is not a requirement.

MILLER: So, it is not a nuclear power plant issue, but it just might be a good business decision.

TODD: It is a good business decision to apply only if the business is there.

PORCO: That is true. If you are going to go through the qualification test for nuclear power plants, the business is there and you have spent the money, whether you are listed or not.

MILLER: How much money is involved in a QPL test? Can anyone help me with that?

PORCO: Depending on the number of filters you are qualifying, it may be $16,000 to $18,000.

TODD: The test cost $20,000, and must be updated every five years.

PORCO: It is supposed to be updated every five years in a Government facility.

TODD: It is supposed to be, that is what it says, but it doesn't quite work out that way.

PORCO: Does anybody remember when the last go-around was, other than this one?

TODD: I think it was around 1978, and then it was updated in 1990.

FRANKLIN: The last time was 1978. They said 5 years, but its been 10 years. DOE sent a letter recently saying that DOE safety-related systems require QPL filters. Some nuclear power plants have this requirement in their Technical Specifications. Today, their safety-related HEPA filters have to be QPL filters. So that takes care of that question.

PORCO: QPL is irrelevant because the qualification testing requirements are identical.

EDWARDS, J: The ambiguity arises in the HEPA filter section of N509, where it says you have to meet all the QPL requirements, but you don't have to be listed. This has caused difficulties. Let me give an example; some HEPA filters were ordered to meet the military standard. They were provided without being on the QPL. As a result, even though the HEPA filter manufacturer was sure he met the requirements of N509, he did not, in fact, meet the requirements of N510-1968. As a result, a Part 21 action was filed against the manufacturer. I am not sure it was totally his fault. I think N509 is very ambiguous in its treatment of HEPA filters. Indeed, I hope that section will be addressed to clarified. HEPA filters are a real problem right now with N509-1989.

MILLER: We were told a few minutes ago that the intention is to reference AG-1 in the N509 revision. That should clear up the conflicts.

EDWARDS: Does AG-1 require QPL listing?

PORCO: AG-1 does not, but it does require a qualification test. N509 calls for a HEPA filter qualification report. Whatever facility was responsible for not certifying that a qualification report was part of the documentation package was at fault.

We can put the fault anywhere we want to but the simplest solution is to require listing on the QPL, and that assures that everybody meets N510-1968 plus later revisions. That addresses the problem adequately. To dance around the issue, in my opinion, is to invite these kinds of ambiguous actions by whatever vendor it may be, and by whatever power utility company it may be. For example, the DOE sites that I am familiar with reference N510-1968 but they do not require listing on the qualified products list. Commercial power plants that cite N510-1968 do require filters from manufactures on the QPL. That is a confusing issue in the industry.

PAUL: The general design document, 64301.A, has been referenced a few times. I have been told that draft document 5480 NNFDC may cancel Division 13 and the special facilities portions of 6430-1A. If AG-1 is to be referenced, it would probably be referenced by 5480 NNFDC,if it gets issued.

MILLER: For those of us who don't recognize those document numbers, can you explain them a little better?

PAUL: Document 6430 contains general design criteria for DOE facilities. If draft 5480 NNFDC gets issued, it will remove Division 13 and all the 99 sections from 64301.A.

MILLER: But AG-1 is referenced in draft 6430 1.B. I don't have the specific chapter number it is in.

PAUL: It is in 1B, in Division 15.

FIRST: I would like to return to the issue of revising N509. The reason I am doing this is because I think it should be explained very clearly and carefully why that document cannot be abandoned. I want to see it spread on the record so that everybody will be able to understand it thoroughly.

OLSON: Right now, N509 is considered to provide the glue that holds together the various component specifications that are included in AG-1. Reviewing the previous issues of N509, I see sections that provide component requirements, and then there are system requirements that pull them all together. The intention of the revision of N509 it to further endorse AG-1 as a component specifications, yet to allow N509 to continue to provide that overview that makes it possible to pull all the sections together into an overall system.

There are a few additional items that need to be addressed. I mentioned earlier that there are a few inconsistencies between N509 and AG-1 that have been addressed through an inquiry. Also, there is an errata section being issued for N509. In addition, there is a change in maximum permissible concentrations related to control room habitability that will be addressed in the appendix to N509. Our intention is to slim down N509 because we will be taking credit in AG-1 for components. But it will maintain all the meat as far as pulling together the various components. At this Air Cleaning Conference two years from now, we expect to provide a paper that will outline more specifically where we are with the change and provide a little better idea of the schedule for issuance.

MILLER: Can you ever envision the day when the AG-1 Code would be so complete that you wouldn't need N509. I mean, is this temporary or is it something that we really have decided needs to go on and on.

OLSON: Right now, I don't ever see N509 going away based on the present scope dictated to CONAGT with respect to AG-1.

MILLER: It is probably important to note here that The American Nuclear Society prepares and maintains nuclear plant systems standards. ANS has a heavy interface role to determine the requirements for the various systems and the components that we design. To me, there is a logical relationship among ANS 59.2 (HVAC system Outside Containment), N509, and AG-1 that may be somewhat permanent. N509 acts as a type of integrator between ANS 59.2 and AG-1. I would have liked to report that the control room habitability standard that ANS decided to embark upon some 5 years ago is further along in completion, but I understand that it is now stagnant. As a result of the CONAGT Main Committee meeting last Friday, I will be taking some action to try to build a fire under that standard again. Many of us in the business feel that the document needs to be completed.

FIRST: I don't think you have explained completely why the material that will remain in N509 cannot be included in AG-1. Again, I am asking the question because I would like to have it very clearly explained.

OLSON: Right now, N509 provides more of a system guideline, whereas the specifics of AG-1 are related to components. There are many integration details and I would like to defer discussion until we have a chance to consider them. The revision process for N509 has only been in the thought process for approximately 4 months. I would like to defer specifics until the next Air Cleaning Conference when we can really lay it out. We may be able to demonstrate at that time which areas have been withdrawn from N509 and deferred to AG-1, and which items of N509 are presently not addressed by AG-1 and will be remaining in this standard for good reasons.

MILLER: This subject was discussed in great detail at a Main Committee meeting during January 1992. The discussion is documented in the notes of that meeting. This panel, as members of the Main Committee, support the decision and will defend it in the future.

EDWARDS: May I suggest that future plants only reference AG-1 in its entirety and not cite N509. Then, N509 can be retired when all of the current plants have been finally decommissioned, because they represent tech specs that are not going to be ratcheted into compliance with AG-1. Is that a reasonable kind of timetable?

PORCO: I think it is a good point, but I am not sure it is a good timetable. There are a lot of plants that do not conform to the latest N509-1989 edition. So, you still have to maintain the prior editions of N509. That is what the Technical Specifications are based on. I think the point of maintaining the N509 document for the current plants is valid.

MYERS: I am not sure who to direct this question to. Obviously, a lot of plants are controlled by Technical Specifications. I wonder what efforts have been made to develop new specifications of a kind that would make it unnecessary to go to the NRC and say, "We don't quite meet this provision". In other words, can it be applied generically. For example, one of the requirements, I believe, states that the plants are to replace carbon after so many hours of operation. We have some plants that currently operate the designated hours but not go at the full system air rate. Normally, you would prorate the service and extend the hours. In other words, are such factors given consideration to make it easier for a plant to operate without violating NRC rules?

PORCO: The Technical Specifications specify the number of hours of operation between carbon testing, but radioiodine testing predicts when you must replace carbon. Replacement is based on test results. Does that answer your question?

OLSON: I think you are asking for a generic endorsement of AG-1 by the NRC. I think we will see that when Reg. Guide 1.52 revisions are completed. Until that time, we are pretty much bound by the current Reg. Guide 1.52 in operating areas. Individual stations must petition NRC for exemptions from Reg. Guide 1.52.

MILLER: The Committee on Air and Gas Treatment has been wrestling for at least two years with a white paper to consolidate practical problems that are being encountered by utilities in dealing with technical specifications and outdated Regulatory Guides and Standards. The white paper will be summarized by Mr. Kovach later in this Conference and after the Conference, I am committed by Main Committee action to send a letter which includes this paper to the ASME Vice-President of Nuclear Codes and Standards. If he agrees, we will send it to the NRC to request that they meet with CONAGT to discuss and lay out solutions to these issues. Will the

new AG-1 code automatically make this problem go away? No. We need to work together with the NRC and the utilities to get all the paper work to hang together. Right, Dr. Bellamy?

BELLAMY: The answer is, yes. Let me say something more along those lines. We have heard that there have been improvements, upgrades, and additional sections of the code issued over the last two years. And we have heard that there will be further additions, upgrades, and improvements on code sections that will be issued in the next two years. I submit, for the sake of argument, that we should not revise Reg. Guide 1.52 until the entire code is fully developed, published, and ready to be used. If I were to put a lot of effort into getting Reg. Guide 1.52 out this year, which I will not be doing, I would be in the same situation you are in. And then we would encounter the same situation two years from now. I invite your response, but I think your last statement that we simply need to work our way together through the paper work is an outstanding offer.

MILLER: I found it interesting that the 5 year period for QPL relisting died in 1978. Reg. Guide 1.52 has stagnated since 1978. The year 1978 must have been a special year for documents to freeze in place. I feel that the sections in the code that are currently available for use, insofar as they pertain to much of the important content of Reg. Guide 1.52, are adequate. There could be an argument made that the improvements made in the SA (Ductwork) Section, (which will be out shortly) would enhance Reg. Guide 1.52 if that document were available so that NRC would be able to reference both sections. There is some give and take there, I don't deny it. If, in fact, the official position of the NRC was that the document would not be revised until AG-1 was complete, we would then know that Reg. Guide 1.52 would never be issued, because a code is really never completed, it is a living document. It goes on, and on, and on. That is why our children will have work to do on codes and standards.

WEIDLER: Since I was gone for a few minutes, someone probably brought it up. Did anybody talk about the life span of N510?

MILLER: N510 will not enter another maintenance revision on the assumption that the TA and TB sections of the code will be sufficient to handle the material that N510 contained. The TA section is close enough to publication so that N510 will not have to be revised. But it will be available. It is still referenced in Technical Specifications. As long as there are copies in circulation, it will still be used. But it just will not be updated. Will the committee answer inquiries on it? Yes.

WEIDLER: The TA section covers surveillance testing and acceptance testing. Since the TA section covers the whole gambit of HVAC, not just filter filtration systems, I wonder if anybody would want to comment on what they think might be the impact to the industry of having all these topics together in one section and covering all the HVAC systems at the plant.

MILLER: Many of the members of the public have not seen the recent drafts of the TA section. Knowing that we are going to have surveillance testing, acceptance testing, and factory testing, all in one code, is that going to mean that there will be practical implementation problems in nuclear power plants or the nuclear facility industry? That is really the question.

VOGAN: I was going to ask a question dealing with the elimination of N510. Since many plant Technical Specifications currently require surveillance testing according to N510, I would envision, based on my knowledge of the current TA, that many plants would want to stay with N510 testing because if you eliminate N510, there is a potential for increased surveillance if you strictly follow the TA section. TA is intended for the future, not necessarily for the past. So, while I have been an advocate of eliminating N510, I think we may want to revisit where TA and N510 are today at another Main Committee meeting to reassess where we are going to go with TA and N510.

Should we keep both documents alive until all Technical Specifications get up to date and reference TA. I feel that there is a potential for an impact in all TA sections and that we will need all those documents for a while.

MILLER: The chairman of the Subcommittee on Testing, who had a lot to do with the TA section, stated that he would be willing to prototype the use of the TA document at his nuclear power plant and that all the lessons that he might learn from that application could be fed back into either improvements in the TA section, or if we revisited the subject, perhaps some improvements in N510, although the Main Committee is on record right now as saying they don't want to revise N510. TA is a document that has been through the consensus process up to the Main Committee level. It is well written, it is not like anything you have seen before, but it definitely has possibilities of increasing some of the surveillance requirements. There is no getting around that. The people in the testing subgroup and subcommittee feel very strongly, based on their experience with real plants, that these requirements are necessary. Time will tell whether or not the utilities, who will read it and have to decided whether to invoke it, will agree. But I think your comment is well put. The other thing that I would like to say is, that at the CONAGT Executive Committee meeting last Saturday, we discussed the subject of a correspondence status with CONAGT. That is not a corresponding member, we can't use the term "member" when we are talking about correspondent. But we want to do what other committees have been doing very quietly; that is, maintain a mailing list of people who are really interested in seeing these code sections and standards when they are in preparation, before they get too far through the approval process. Otherwise, they are forced to make a tough decision whether to intercede in the public review period. The Executive Committee is going to recommend to the Main Committee, and I feel confident that the Main Committee will approve this action, that we will circulate a sign-up list in this group today and start the correspondence mailing list for our future code sections. If you want to receive new and revised draft code sections in the future, we will send them out to you. We will entertain all your comments, but I do not want to impose upon the Committees a responsibility to answer all comments because that takes a lot of work. I don't think the Committees will abuse the situation because they really want your comments, but the preparation of responses is time consuming, very time consuming.

KUMAR: Regarding N510, Technical Specifications, and AG-1, there is a possible solution for this particular problem, as I see it. Since we, at Davis-Besse, referenced N510 in the Technical Specifications, we can evaluate where the differences are between N510 and AG-1 and then with a software program we can take exception to those particular positions that we cannot meet because our unit may or may not have been designed to N509 requirements. Based on that, we could negotiate with NRC for a new date for us to make changes, if needed. As long as we are meeting our present commitment, I don't see any problem in this particular thing. It is a software problem rather than anything else.

MILLER: So that is a vote of confidence. That is the process, there are obstacles but they are not impossible.

EDWARDS, JIM: The question Weidler raised was, "Is TA going to be more difficult to handle than N510 and some other documents?" When I voted on TA, I looked at it from the point of view of a manufacturer who does in-plant factory testing. Although there are some sections I don't agree with, or some specifics I don't agree with, I didn't see any pitfalls as I read through it that are going to cause difficulty. I also read it through from the point of view of a surveillance and test person in the field, with which I have had some experience. I had some parts I disagreed with but I still didn't see any pitfalls that are going make it unworkable. There may be some things that come up later, but I think, all in all, it is going to be easier for those of us who do testing

to have all the requirements and procedures in one place so that we can just refer to one document no matter what kind of testing we are doing.

MILLER: There is definitely additional guidance along the procedural line in the new TA section but it is my understanding that plants will still have to write additional implementing procedures.

EDWARDS, JIM: Yes. It is not an all-inclusive document. I said I disagreed with some of the things in it. For example, as a rule, we do a pressure decay leak test in a 5-minute time interval. The TA section is going to require a minimum of 15 minutes. That is all right as long as it is 15 minutes for everybody.

WILLIAMS: We are involved with the DOE. This may sound like a reiteration of the question the gentleman from Martin Marietta had, but I need clarification. I am not sure whether to ask DOE or CONAGT. The question refers to a special facility situation where there is no wording to legally define the test procedures. DOE cites AG-1 as being the document for compliance. Maybe AG-1 needs to be the document that should be cited for special facility compliance.

PAUL: There are quite a few documents that are referenced in DOE Orders, such as ERDA 76-21, AG-1, N509, and N510. There is a lot of overlap between these documents in terms of requirements and then it becomes a question of which is the higher-tiered document. I don't know if that is precisely your question, but I have a feeling these issues have come up before. ERDA 76-21 is a handbook and should be used as such. It wasn't intended to be a standard. My opinion is that if we replace N509 and N510 with AG-1, AG-1 should be the document that DOE facilities refer to in the future for the requirements for air cleaning systems. And I think ERDA 76-21 should be used for guidance only.

WILLIAMS: We had discussions to determine if N509 and N510 are the documents we should be in compliance with because their titles refer to nuclear power plants, but because we are not a reactor facility (we are what we consider to be a non-reactor special facility) it is not clear. Maybe the AG-1 should state, special nuclear facilities.

PAUL: The scope of AG-1 is for nuclear facilities including nuclear power plants. Where AG-1 may still be slanted in the direction of nuclear power plants, it can be improved. We need feedback from DOE or other industry segments if the requirements are not sufficiently inclusive of all types of nuclear facilities.

MILLER: I want to supplement that. The Board of Nuclear Codes and Standards developed a strategic plan within the last three years. As part of that strategic plan, the Board recognized that it needed to determine which nuclear facilities it wanted to serve in the total quality management arena. We are in the process of preparing a matrix for all of the Committees that the Board supervise, QA, O&M, QME (Qualification of Mechanical Equipment), CONAGT, and the Boiler and Pressure Vessel Committee. The major matrix contains all of the different nuclear facilities and each of the reporting committees is filling in squares in the matrix where it believes there is a client base. There are more people that we should be serving with our codes and standards. The matrix will be the first step in recognizing the broader base of potential customers of our codes and standards.

EDWRDS, JIM: Just to add to what you were saying, we have already recognized that the expansion of AG-1 into special nuclear facilities is a very desirable thing and have taken steps in that direction. For example, Joe Paul's subgroup on housings and Tom Vogan's subgroup on Type IV adsorbers, which are now used in special facilities, are already in development. So we are slightly ahead of the curve in terms of that effort and we are addressing special requirements.

MILLER: Were Type IV adsorbers referred to late last week as alternative lifestyles?

EDWARDS, JIM: Type IV adsorbers are really mainstream lifestyle; everything else is alternative lifestyle, if you go by the numbers of units under construction in the last 5 years.

GHOSH: Different plants are committed to different versions of the standard. I know some plants are committed to the 1980 version and some to 1976. We run into problems with replacements such as a door being warped, or a gasket needs changing. If you think that AG-1 will be used, I don't think it will happen because the plants are never going to change commitments. ANS 59.2 and EPRI documents try to define how you can go back and classify the replacement components. Every effort has been made to qualify individual components of the filtration systems.

PORCO: You have quite a few questions wrapped up in that comment. Let me try to address a few of them. The first one you mentioned is the application of AG-1 in current plants. Indeed, there are plants now that are specifying retrofit units as conforming to AG-1. We are supplying those plants with replacement and upgraded systems. Component replacement is another issue, where you no longer get a direct replacement for some instruments. If you can't get a direct replacement, you must requalify the component before you use it. That is the basis for component qualification and re-qualification.

GHOSH: Commercial dedication, that is the only document that counts. What can we do from the ventilation aspect to make it easier for somebody to make a decision in terms of line replacement components?

PORCO: What we are doing as a company is generating a list of items we have qualified as specific replacements. We do it generically and provide replacements as a service to utilities. After we do a requalification for one plant, we find that there are other plants that can use the requalified item.

OLSON: I don't think I can answer your question, but I would like to provide some information that might help you out and that you can take into consideration. There is a repair and replacement section that is being developed to be included in AG-1. That would not necessarily cover repair and replacement components of N509 specifically. That is a separate standard. You have a very good point and it is something that should be taken into consideration. I want to make sure that you and everyone in the room, is aware that AG-1 will include repair and replacement of components in the code.

MILLER: This R & R section is the equivalent of a B & PV Section XI built into AG-1 and that is something we haven't brought up so you really helped us bring that out. We thank you.

DEMETRIA: Are you going to add to AG-1 new types of filtration units in addition to HEPA filters? Specifically, I am talking about (Mil 5) filters which are coming into the industry rather strong.

MILLER: I think that is an excellent question, especially in light of Wilhelm's comment that closed the morning session. Of the papers this morning, he said, why can't we all get together, decide what these systems should be, and then we don't have to prepare papers on all the differences every two years. I think that kind of paraphrases what he said. I feel the same way when I see all the new materials. A fellow, this morning, showed a piece of interesting-looking metal mesh and said he was going to put it into his containment to capture aerosols so they will not load the sand bed on the roof of his reactor building. At what point do we in the United States codes and standards business take a more pro-active approach to writing codes and standards for

components that are being used around the world successfully, but may not, for marketing reasons, or whatever, be used in this country. It is difficult for the Main Committee of CONAGT to decide to invest many, many volunteer manhours to develop codes or standards for products that aren't being used by the utilities or the manufacturers that are sponsoring the people on the code writing committees.

PORCO: Your point is well taken. The thing to remember is that AG-1 is a consensus document. So you must have people from the utilities, NRC, manufacturing, etc. voting on what goes into them. The debate on performance vs a component specification has been going on for years. I think the biggest fight was over what you would specify as adsorber media. We ended up limiting adsorbents to activated carbon. HEPA filter variations have also been a major decision problem, and we have talked about adding a section on unusual filter sizes and configurations.

VOGAN: In regard to carbon cells, FH is the main lifestyle section. We have Sections FD, FE, and FH that cover the three most common adsorbers. However, the case of other filters is on the agenda but we haven't made much progress. We discussed, but we may not yet have all of the knowledge needed to handle metal filters. We need more information, more help.

One vehicle you could use is to submit your alternative filter as a code change. If you submit all the data, test methods, test results, qualification of materials, we can review them and possibly allow it. The code does not make an attempt to exclude materials as long as they meet all the performance requirements.

MILLER: There is another alternative, join the Committee.

ANON: I was going to suggest a knowledgeable person as a member of the Committee so we can get something going because we have been working with these filters for over three years, almost 4 years now.

MILLER: I think your point is well taken. What I want to add here are some of the comments that were made during the morning session about changes in source terms and the increase in aerosols plus the possibility that with accidents we could have smoldering of organic materials that would greatly increase the particulate content of the aerosol and the loads on our filter systems. We may need new filters. We may not be able to use what we have today.

EDWARDS: A couple of years ago, Pall Corporation wrote a letter asking about stainless-steel filters. What you are suggesting is that rather than Pall writing a letter and asking the Committee what we are going to do about stainless-steel filters, Pall should develop a code case question concerning use of stainless-steel media filters and submit the question to the Main Committee for resolution. Is that correct?

MILLER: I am not sure that the only thing that could move CONAGT is a code case. I think if someone came in with a product with successful applications, and some good solid qualification data, the Committee would have a hard time looking the other way. I would like to say, yes, if you want to do it as a code case then fine, you will get an answer for sure. It won't be an expansive answer because the lawyers at ASME let us say, "Yes," or, "No," and very little else. But we definitely need to get more input so that our code doesn't end up stagnating and not being useful. It has to reflect what people need.

But we are also very aware of the ASME vs Hydro-level case. For those of you who aren't familiar with it, it was a rather significant case in ASME's history because it made a significant payout. A suit was filed against a committee that was dominated by an individual

manufacturer. The committee's actions resulted in forcing a competitor out of business. We are very sensitive about giving people an opportunity to convince us that we should be revising our codes and standards. We are at a point now where we can take on additional work. We are not fighting the same backlog of work that we had before. So, why not get at it? Is anyone in the audience currently using AG-1 to specify equipment or considering using AG-1 to specify equipment? Let's raise hands. Wow, a dozen people in this audience are going to be doing some prototype application of our code; please give us feedback. If you need help, let us know, and we will help you through it.

JACOX: You might want to mention that the Main Committee has honored requests from various vendors to come into the Main Committee and present something they believe is significant but currently excluded by the code.

MILLER: The easiest way to do that is just to call me or contact a member of the Main Committee and tell them that you want to be on the agenda for the upcoming meeting and we will do it. Our secretary is Michael Kozlik at ASME.

BLACKLAW: In Washington, we are introducing new regulations that require BACT, best available radionuclide control technology. As part of that, we referenced AG-1, N509, N510. We look for the most efficient equipment available, which does not necessarily limit the evaluation to standard nuclear-grade equipment. That will bring along things like metal filters and ULPA filters. These technologies, and others, will have to be evaluated. Therefore, any State agencies that use this engineering standard will have to address the same issue.

MILLER: I agree with you and I welcome your attendance here today and your interest in this session. I think it is a good sign that some of the states are interfacing through the Air Cleaning Conference. Perhaps you should also consider coming to one of our twice-a-year CONAGT Main Committee meetings and giving us your input. All the ASME meetings are open meetings to the public, except very small portions of the meeting that deal with personnel items.

PORCO: On the use of ULPA filters, when you evaluate the best available technology, you must also evaluate it for the application. ULPA filters have a higher efficiency but they do not meet the qualification tests that HEPA filters do. The filter medium is different. Although you get higher efficiency on penetration, you don't get the right type of construction nor the strength, nor radiation resistance with an ULPA filter. The question always comes up, "Why aren't we using ULPA filters?" That is the reason.

MILLER: I am going to plead ignorance and probably there is one other person in the audience that doesn't know what an ULPA filter is.

PORCO: ULPA stands for ultra-low penetration air filters. They are used predominantly in the clean room industry and you can get efficiencies up to 99.9995% on 0.3 μm size particles.

MILLER: What resistance?

PORCO: They are customized but usually use face velocities of 70-80 ft per minute for a resistance of 1 in. w.

GRAVES: In the matter of new technologies, CONAGT has a subcommittee on technology. That subcommittee would certainly be willing to listen to anything on new technologies. That is why CONAGT has that subcommittee.

MILLER: Lou Kovach, from NUCON, is the subcommittee chairman of the Technology and Training Subcommittee. That would be a good place to start if you felt intimidated by the Main Committee.

This has really been a good session. I ordinarily would summarize it but I don't think that is needed here. I think I was concerned at some point whether we would have trouble filling two hours, and here we are about an hour and 56 minutes into the session.

SESSION 10

FILTERS AND FILTER PERFORMANCE

Wednesday: August 26, 1992
Co-Chairmen: W. Bergman
W. L. Anderson

OPENING COMMENTS OF SESSION CO-CHAIRMAN BERGMAN

CHALLENGES WITHIN VENTILATION SYSTEMS DURING ACCIDENT SITUATIONS
M. Fronhöfer, M. Neuberger, J.G. Wilhelm

RADIAL FLOW SYSTEMS FOR THE NUCLEAR INDUSTRY
M.L. Davis

BEHAVIOR OF THE LOADED POLYGONAL HEPA FILTER EXPOSED TO WATER DROPLETS CARRIED BY THE OFF-GAS FLOW
K. Jannakos, H. Mock. G. Potgeter, J. Furrer

THE APPLICATION OF HEPA FILTER UNITS IN GAS STREAMS OF HIGH DUST CONCENTRATIONS
H. Leibold, I. Döffert, T. Leiber, M. Fronhöfer, J.G. Wilhelm

PREDICTING MASS LOADING AS A FUNCTION OF PRESSURE DIFFERENCE ACROSS PREFILTER/HEPA FILTER SYSTEMS
V.J. Novick, J.F. Klassen, P.R. Monson, T.A. Long

APPLICATION OF HIGH-EFFICIENCY METAL FIBER FILTERS IN VENTILATION SYSTEMS OF NON-REACTOR NUCLEAR FACILITIES
G. Grewal, Z. Milatović, F.L. Landon, W.M. Harty

DEVELOPMENT AND EVALUATION OF A CLEANABLE HIGH EFFICIENCY STEEL FILTER
W. Bergman, G Larsen, F. Weber, P. Wilson, R. Lopez, G. Valha, J. Conner, J. Garr, K. Williams, A. Biermann, K. Wilson, P. Moore, C. Gellner, D. Rapchun, K. Simon, J. Turley, L. Frye, D. Monroe

DEVELOPMENT AND EVALUATION OF A HEPA FILTER FOR INCREASED STRENGTH AND RESISTANCE TO ELEVATED TEMPERATURE
H. Gilbert, W. Bergman, J.K. Fretthold

CLOSING COMMENTS OF SESSION CO-CHAIRMAN ANDERSON

OPENING COMMENTS OF SESSION CO-CHAIRMAN BERGMAN

Welcome to the session on Filters and Filter Performance. We will have a series of presentations dealing with filter performance under various test conditions, high-strength HEPA filters, and steel high-efficiency filters. The latter two technologies were pioneered in the laboratories of Mr. Wilhelm at KfK, and I would like to acknowledge this pioneering work in my introduction of Mr. Wilhelm.

During the past decade, Mr. Wilhelm and his colleagues have investigated the effect of accident conditions on the performance of HEPA filters. His studies with Dr. Ruedinger and Dr. Ricketts on the effect of moisture and high flow conditions on HEPA filter failures led to an understanding of the failure mechanisms and to the development of a high strength HEPA filter that is presently used in German nuclear power plants. An important finding in their studies is that high moisture exposure on slightly used HEPA filters can result in structural damage, even if a demister is used to protect the HEPA filter. The common U.S. practice of protecting HEPA filters from fires with a water deluge-demister system should be evaluated in light of the German studies.

The paper by Mr. Gilbert on high-strength HEPA filters represents the first study of this topic in the U.S. since the initial German studies reported by Mr. Wilhelm and his colleagues. The high-strength HEPA filter offers a solution to many of the failure modes that occur with standard HEPA filters under off-normal environmental conditions.

CHALLENGES WITHIN VENTILATION SYSTEMS DURING ACCIDENT SITUATIONS

M. Fronhöfer, M. Neuberger, J. G. Wilhelm

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Abstract

A numerical code (LAFIS) is developed which allows accurate modelling of flow transient in air cleaning systems under accident situations. With the support of this code the mechanical loadings on the filter units can be calculated. In addition a new type of High-Strength HEPA filter for accident stresses recently developed at Karlsruhe Nuclear Research Center is tested.

Clean and particle loaded High-Strength HEPA filters in the standard size of 610x610x292 mm were exposed to shock waves producing a peak differential pressure up to 170 kPa (24.6 psi), to evaluate their structural limit. For differential pressures between 80 and 170 kPa the residual particle removal efficiencies were greater than 99,8%. For preloaded filters (TiO_2) no sign of particle release was evident in high-speed video films (400 frames/s) taken during transient conditions.

The results show High-Strength HEPA filters should be employed in air cleaning systems with high risk due to shock waves. Such filters have been implemented as an additional Engineered Safety Feature (ESF) in the air cleaning systems of German nuclear power plants.

I. Introduction and Problem Outline

During the last years there have been cases in which conventional HEPA filters were damaged even in normal operation and the reliable retention of activities was no longer ensured /1, 2/. A number of observations years ago had shown that conventional HEPA filters will tolerate only low mechanical loads without being damaged and suffering a drastic decline in removal efficiency /3/.

For better assessment of the failure risk of HEPA filters and, consequently, the risk of hazardous substances being released into the environment in increased amounts under off-normal operating conditions of a nuclear power plant, the loads arising within ventilation systems due to flow dynamics and thermodynamics must

be known. A number of computer codes have been developed in nuclear technology over the past few years which allow the loads acting on the containment and on the surrounding auxiliary buildings to be modeled /4/.

The structual loads to which HEPA filters may be subjected at their places of installation within ventilation systems are determined by the accident under consideration and by the sequences of accident steps. This situation so far has been covered only by very rough estimates which, in nuclear power plants, indicate the occurrence of high specific radioactivity of the atmosphere, high air humidities, including periods in which the dew point is underrun, elevated temperatures, and high pressure drops /5/. More precise data can be generated only by means of special computer codes which allow the flow dynamics and thermodynamics to be modeled in the complex nuclear ventilation systems, some of which have several hundreds of components.

The importance of the annulus exhaust air filter systems, and their reliable functioning in environmental protection in the vicinity of nuclear power plants, asks to quantify in more detail and enhance, respectively, the existing safety margins of filter plenum at the end of the ventilation systems. For practical purposes, this is tantamount to an improvement in the mechanical stability of HEPA filters and to the development of a computer code LAFIS (LAF Iteration Solver) for transient flow dynamics conditions to model the very complex ventilation systems in nuclear facilities, including the condensation of water vapor.

II. Numerical Code LAFIS for Modelling Accident Loads in Ventilation Systems

A ventilation network is considered a complex combination of a large number of components including straight duct sections, ducts changing direction (elbows), throttles, ducts changing cross section (nozzles and diffusors), "active" components (blower), and duct branches. In addition, randomly defined components may be added which can be described by their flow resistance characteristics and are called "discrete losses" (filters, dampers, heat exchangers, etc.).

In calculating the fluid dynamic and thermodynamic state variables, Kirchhoff's rules known from electrical engineering are employed for the steady-state case. In determining flow variables and state variables, the laws of conservation of mass, momentum and energy are used, thus allowing compressible non-steady state flow processes to be described. A detailed description of the code LAFIS will be published /6/.

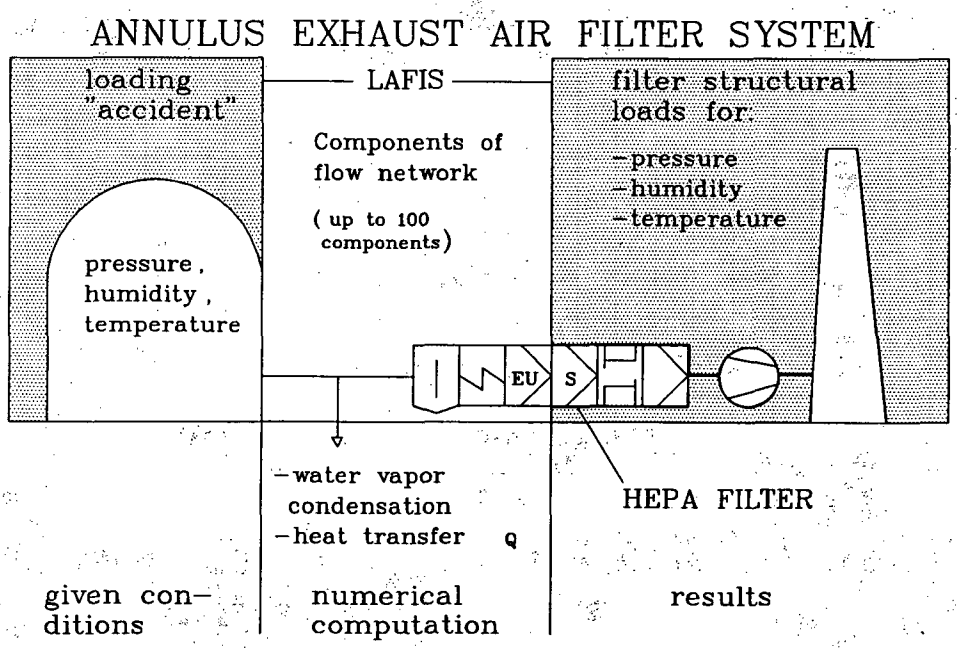

Fig.1: Numerical code LAFIS for modelling pressure and flow transients at filter service locations in ventilation systems.

In the laws of conservation some aspects are mentioned taking into consideration the special characteristics of steady- and non-steady-state flow in ventilation systems. Conservation of Mass: For non-steady state flows, inertia must be taken into account while, in compressible flows, it is the capacitance of large volumes that must be considered. Conservation of Momentum: The law of conservation of momentum describes the pressure loss and the pressure change, respectively, in each component (elbows, cross sectional changes, heaters, coolers, filters, ducts, etc.) as a function of the mass flow through these components /7/. Law of Energy Conservation: If the assumption of constant temperature is dropped, and if condensation phenomena in the ventilation duct is to be included, the energy equation must be used for each individual component. For nonsteady state flows, again the capacitance of large volumes must be taken into account.

The LAFIS (LAF Iteration Solver) ventilation code enables users, for given levels of pressure, temperature, mass flow or humidity as a function of time in a complex ventilation network, to calculate these same quantities at any other position in the ventilation system. There is also a possibility in the LAFIS code to calculate the changes in relative humidity and condensation of water vapor, if any, for each individual component. In this case, the humidity at the ambient nodes is given and its change determined as a function of pressure and temperature in the components.

Code Description

The input part has the function of indicating all geometric data and flow data for each component of the ventilation system and their interconnection at the nodes. All ambient nodes and connecting nodes must be defined. Ambient nodes are connections between the ventilation system and its environment, e.g., the exhaust air stack or the pressure vessel and containment, respectively, etc. The ACRITH program package, based on an improved Newtonian procedure with interval arithmetics, was developed at Karlsruhe University in cooperation with IBM. The output part is used as post-processor for graphic data representation. In this way, the tabulated state variables and flow parameters can be output in a clearcut way both on the screen and by means of a plotter. To represent the results for nonsteady state flows, the pressure, density, temperature, and humidity for a certain node, and the mass flow, volume flow, velocity and Mach number, respectively, for a specific component, are plotted as a function of time.

Shock Propagation in Ventilation Systems

In accidents in nuclear facilities or process installations, explosions or deflagrations may give rise to pressure disturbances (compression waves) which, under certain conditions, may be amplified into shock waves in ventilation ducts. In order to estimate the resultant hazard potential to the ventilation system and the downstream filter sections, shock propagation in ventilation system was studied.

Implementing empirical pressure coefficients, which can be taken either from steady-state flow studies or from handbooks /7/ on ventilation technology, allows wave propagation to be computed in any plant component. The occurrence of secondary shocks as a result of the flow being accelerated to the velocity of sound can also be taken into account. Even more complex ventilation networks can be modeled by combining the components of the plant. In this way, it is possible to extrapolate from familiar relations associated with steady-state flows to nonsteady-state shock wave propagation /8/.

III. High-Strength HEPA Filters under Accident Conditions

The LAFIS program package described above allows, for a given accident at the inlet end of a ventilation system, to describe the loads (temperature, humidity, pressure) expected to arise in the filter at the outlet end of the ventilation system. To protect the environment from the effects of a potential accident, two possibilities are available which, in combination, can result in technically optimum environmental protection. On the one hand, protective devices should be provided for in the design of the ventilation system at specific points in order, e.g., to attenuate pres-

sure waves. On the other hand, the filters installed at the exhaust of the ventilation system should have higher mechanical strength without generating higher pressure drops during normal operation, in order to achieve maximum safety.

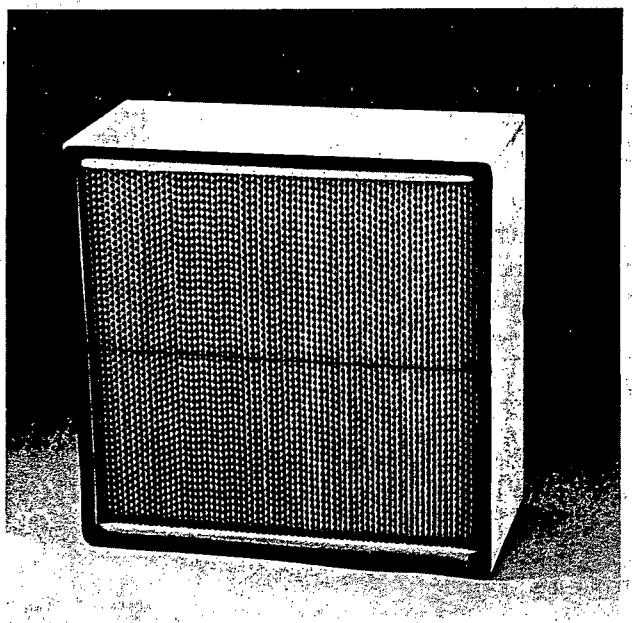

Fig. 2: High-Strength HEPA filter (610x610x292 mm) developed at Karlsruhe Nuclear Research Center (KfK).

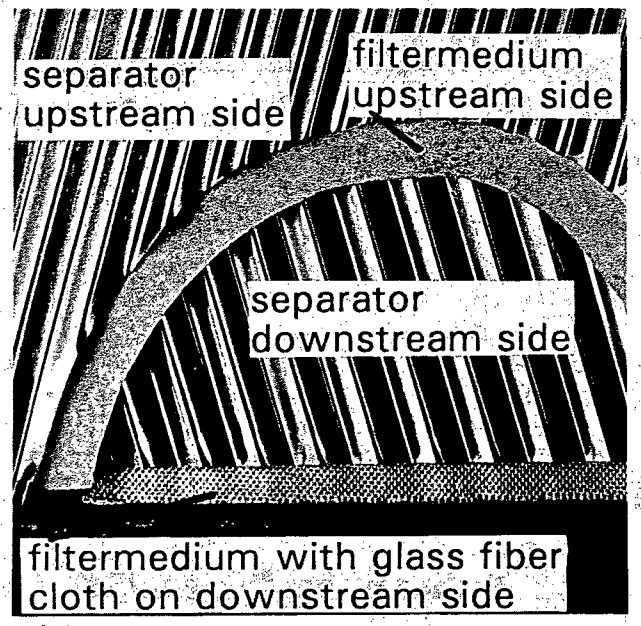

Fig. 3: Construction of High-Strength HEPA filter: aluminium separators with inclined corrugations; filtermedium reinforced with a fiberglass cloth on downstream side.

For almost three decades, commercial HEPA filters have been studied for application in the ventilation systems of nuclear plants. To this day, the mechanic load-bearing capacity of conventional commercial deep pleat and mini-pleat filters has not improved significantly over the initial levels /9, 10/. In the period between 1984 and 1987, High-Strength HEPA filter units have been developed at the Laboratorium für Aerosolphysik und Filtertechnik II, which withstand extreme pressure drops and volume flows. To this day, they have worked satisfactorily in many exhaust filter systems of German nuclear power plants and in critical experimental facilities with high potentials for releases of radioactive and toxic dusts. The filters are available commercially under *license from two German companies and one English company. The operating experience accumulated, and the test results generated, with the newly developed High-Strength HEPA filters will be compared below with conventional HEPA filters.

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* Atex Filter GmbH, Camfil Luftfilter GmbH, Vokes Ltd.

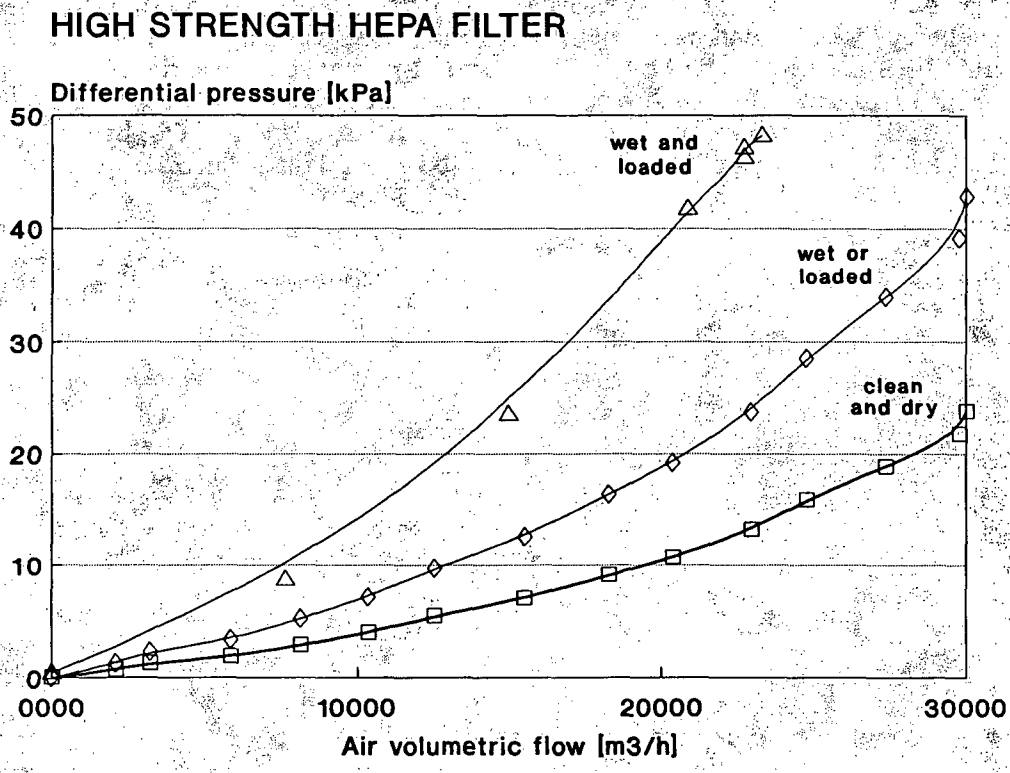

Fig. 4: Flow-resistance curves for High-Strength HEPA filter: 1. clean and dry, 2. wet or loaded, 3. wet and loaded.

Characteristics of High-strength HEPA Filters at High Pressures, High Temperatures, and High Air Relative Humidities

The failure mechanisms of conventional deep pleat and mini-pleat filters were studied in detail in a test facility built 1984, BORA /5, 11, 12/. The conventional deep pleat filter was used as a model for a High-Strength filter (610x610x292 mm). The external characteristics of the High-Strength filter are an increased number of pleats and ribs installed in the middle of the upstream and downstream sides to prevent the frame from ballooning (Fig. 2). The high mechanical strength of the filter is achieved by crossed separators on the upstream and downstream sides (Fig. 3) and a fiberglass cloth reinforced on the downstream side /13/.

High-Strength filters can be subjected to a steady-state flow in the BORA test facility; in this way filters may be tested also under prolonged accident conditions. Figure 4 shows the characteristic curves (pressure versus volume flow) for various filter loads. A new, unloaded, High-Strength HEPA filter can be exposed to a volumetric flow of 30,000 m^3/h (at 30 °C) of air, which gives rise to a pressure drop of 25 kPa across the filter. If the filter unit is loaded or moist, or if a filter is exposed to combined loads and stresses, the pressure drop will rise to more than 50 kPa at a lower volumetric flow. The characteristics of the

blowers in the BORA test facility do not allow higher pressures to be generated at the flows mentioned above. Tests conducted in the BORA facility were raised up to pressure drops of 56 kPa, and none of the High-Strength filters showed any visible damage. After the tests, all filters had removal efficiencies 99.97% for particle sizes of 0.3 μm, which is required for HEPA filters, and were leakfree as measured with the oil plume test according to DIN 24184.

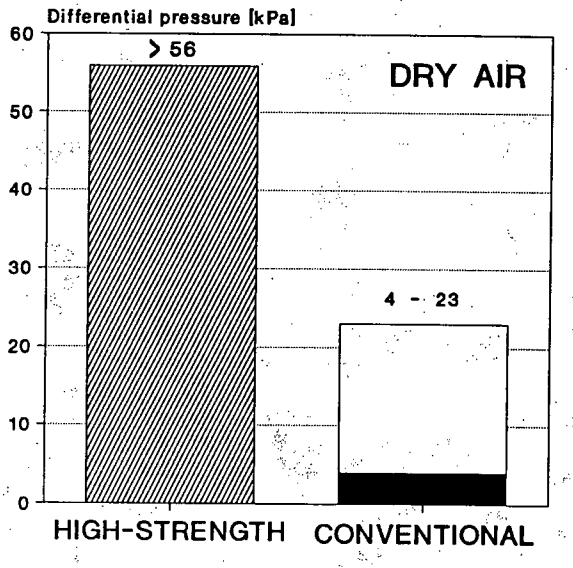

Fig.5: Comparison of structural limits for conventinal HEPA filters in dry air (differential pressure at failure) to those of High-Strength HEPA filters (differential pressure without failure at test rig maximum).

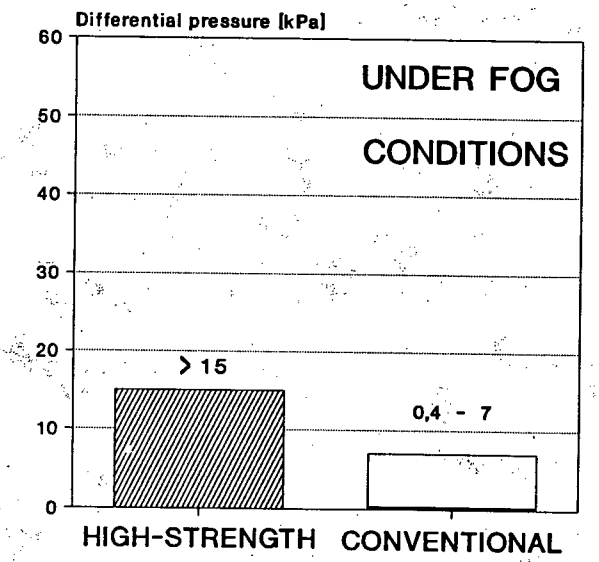

Fig.6: Comparison of structural limits for conventinal HEPA filters under fog conditions (differential pressure at failure) to those of High-Strength HEPA filters (differential pressure without failure at test rig maximum).

The pressure drops achieved without the High-Strength HEPA filters showing any structural failure are compared in Fig. 5 and, for moist air, in Fig. 6 with the structual limits of conventional commercial HEPA filters. The actual failure limit of the new High-Strength HEPA filters was not determined. In conventional filters, the range of failure is indicated, with some filters showing failure already at a pressure drop of 4 kPa in dry air and only 0.4 kPa in moist air.

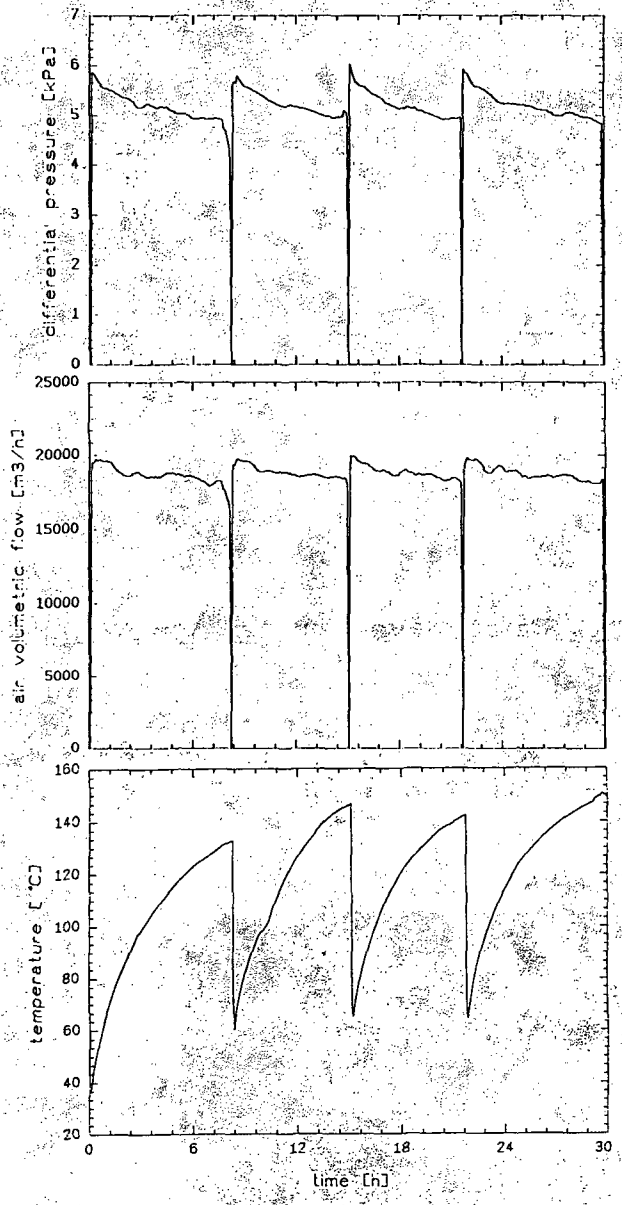

Fig. 7: Test of 30 h duration with High-Strength HEPA filters.

Normal glass fiber paper loses some 85% of its tensile strength (about 50 N/5 cm), if it is moist and pleated at the same time, this is reduced to a tear strength of about 7 N/5 cm specimen width. The glass fiber filter medium reinforced with a glass fiber cloth on the downstream side has a 16 times higher tensile strength of about 800 N/5 cm in the dry state. Even in the wet, pleated state, the tear strength of the reinforced filter medium is about 620 N/5 cm, which is approximately 12 times higher than that of normal filter paper in a dry condition.

In a prolonged experiment, High-Strength HEPA filters were subjected to a volumetric flow of approx. 20,000 m^3/h of air for 30 hours, with the mean pressure drop being 5 kPa (Fig. 7). The High-Strength HEPA filters have been designed to a max. service temperature of 120 °C. After 8 hours of continuous operation without cooling, the air recirculated in the BORA experimental facility was heated to 130 °C. The volumetric flow and the pressure drop prevailing across the filter decreased to lower levels. The facility cooled down to 60 °C over night. The filter was again challenged by an air flow in three additional cycles of 7 hours each, until a temperature limit of 140 °C, which is above the design temperature, had been reached. The High-Strength HEPA filter was not removed from testsection in between and, consequently, was subjected also to thermal cycling. After the end of the test, the filter was free from oil plumes and had a removal efficiency of η = 99.97% required for a HEPA filter (DIN 24184 or equivalent).

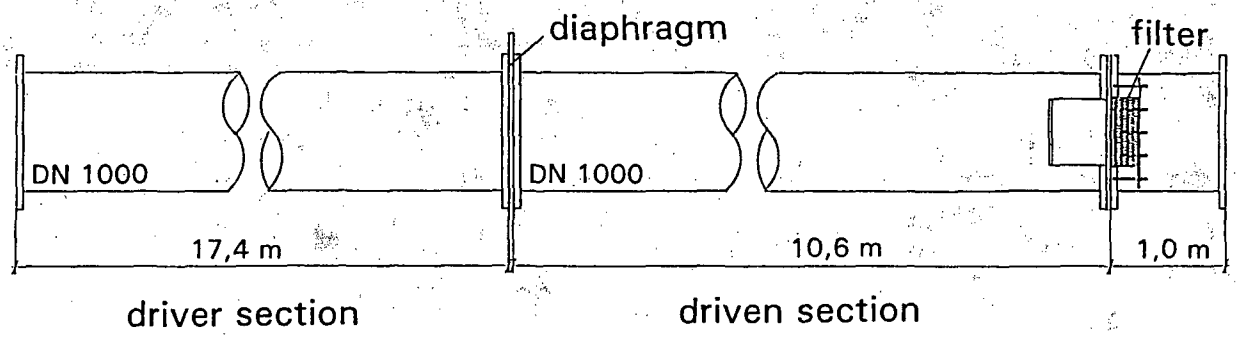

Fig. 8: Schematic of shock tube.

High-Strength HEPA Filters Exposed to Shock Waves up to Δp=170 kPa

In many test facilities, the structural limits of HEPA filters are determined by transient loads. In conventional deep pleated HEPA filters (610x610x292 mm) the structural limit corresponds to the pressure drops of 4-20 kPa as determined in a steady state flow /9, 10/.

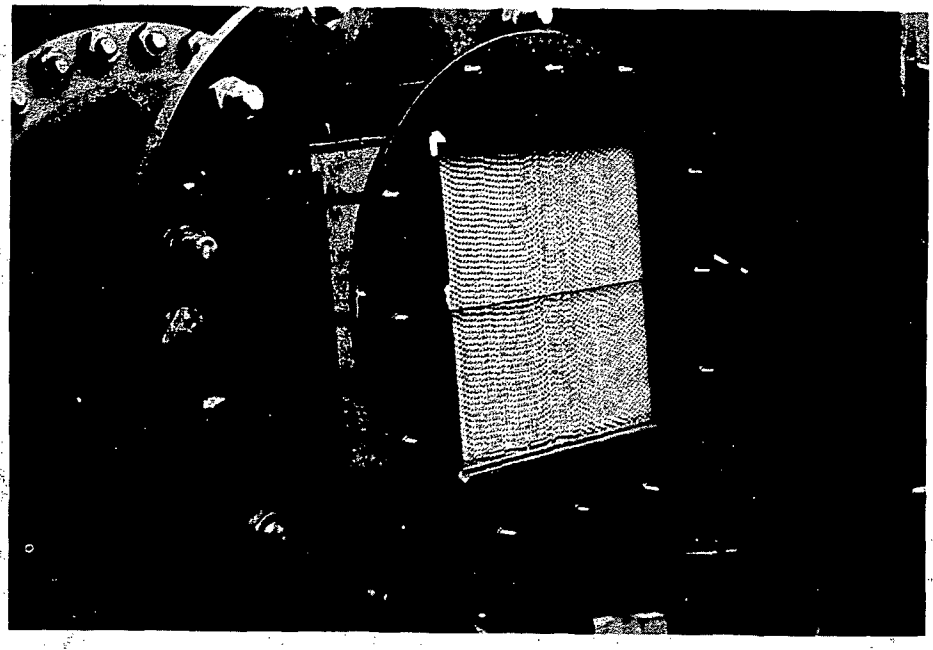

Fig. 9: High-Strength HEPA filter at the end wall of the shock tube.

At the Ernst Mach Institute of the Fraunhofer Society in Germany, a shock tube (Fig. 8) of 1 m diameter and 28 m length was

available for testing High-Strength HEPA filters up to the occurrence of the first visible structural damage. The High-Strength HEPA filters were tested relative to the ambient pressure (Fig. 9); consequently, the maximum possible pressure drop prevailed across the filter. The filters were subjected to shock waves generating maximum peak pressure drops of 30-170 kPa (4.3 psi - 24.2 psi).

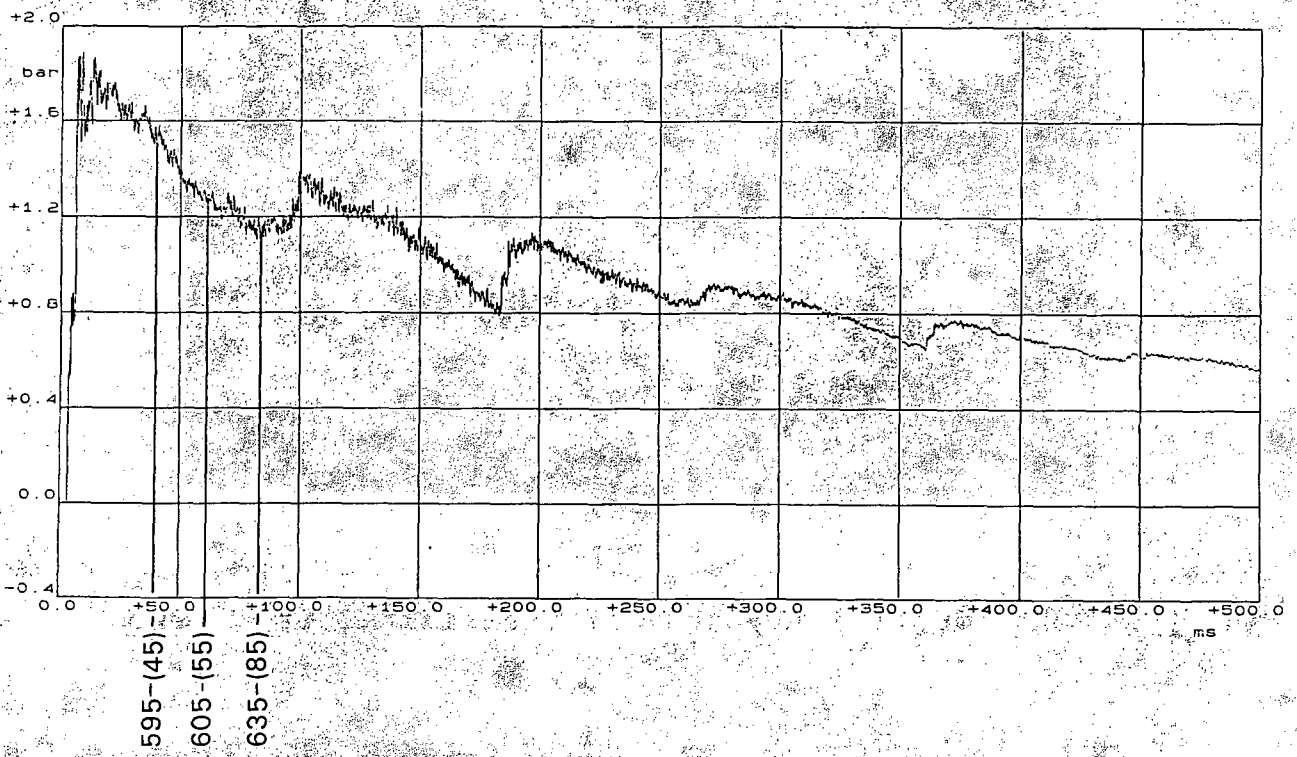

Fig. 10: Pressure transients from HEPA filter test (P_{21} = 1.8, Δp = 170 kPa).

The most spectacular experiment with a maximum pressure drop of 170 kPa (24.2 psi) will be described below. The development of pressure versus time in the experiment as measured directly at the filter is shown in Fig. 10.

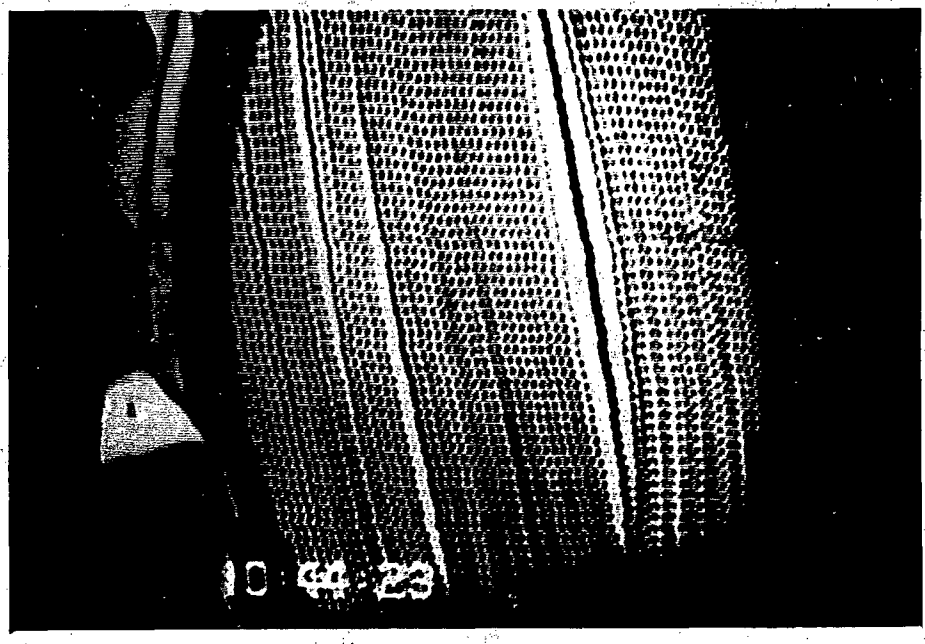

Fig. 11: Behavior of High-Strength HEPA filter under shock wave (P_{21} =1.8, Δp = 170 kPa)

Figure 11 show the decisive picture taken during the test at a pressure drop of 170 kPa (24.2 psi). The time at which the pictures was taken is shown in the diagram in Fig. 10 (635 - (85)). The pictures were recorded by means of a high-speed video camera operating at 400 frames per second. The shock wave starts, hits the filter after some 2.5 ms and is reflected (Fig. 10), thus causing a pressure drop rise across the filter of 170 kPa. After some delay, the filter unit begins to be passed through which, after 40-45 ms, leads to the first ballooning of the filter pleats. Another 12 ms later, the flow continues to increase. The wooden frame expands despite the powerful clamping device. The threaded rod installed in the middle, to prevent the frame from buckling, is ruptured. The filter pack is exposed to pronounced dynamic forces until the weakest spot in the filter pack has been found, at which it can show maximum buckling. The inflated pleats migrate through the filter pack until, after 85 ms, a state has been reached in which the highest flow occurs and the filter thus is subjected to the highest load. After about one second, the approx. 14 m^3 of compressed air in the driver section under a pressure of 240 kPa (35.5 psi), have been discharged through the filter.

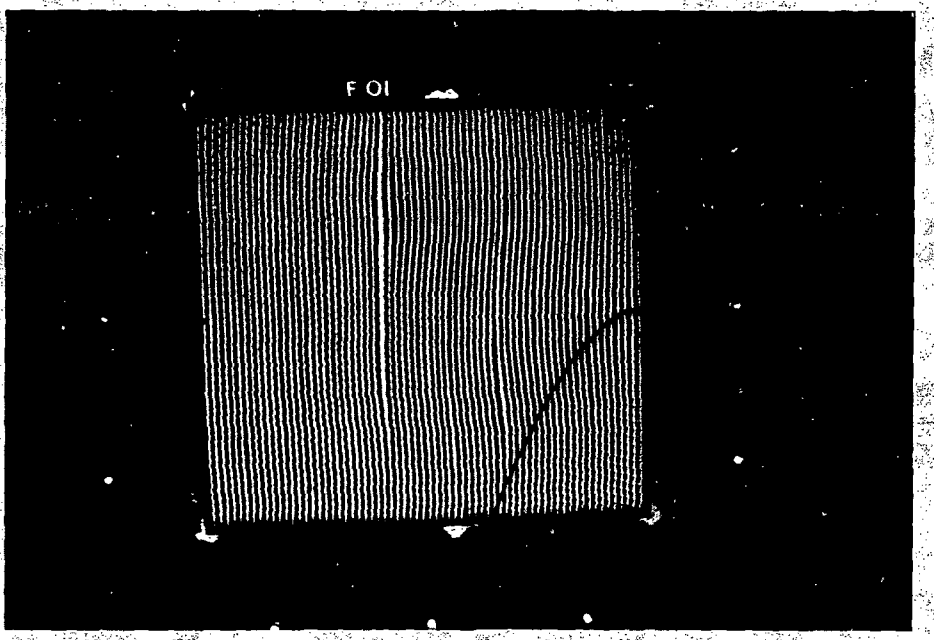

Fig. 12: High-Strength HEPA filter after shock wave exposure (P_{21} =1.8, Δp = 170 kPa).

The High-Strength HEPA filter was inspected for visible damage while still installed in the test facility (Fig. 12). The recognizable defects were dented separators and the ruptured connecting rod. No cracks in the filter paper and in the elastomeric sealant were seen. The fiber glass on the downstream side prevents the filter pleats from breaking up. Where the pleats had expanded, the glass fibers of the glass fiber filtermedium were partly fractured. The filters subsequently were taken through a removal efficiency test with DEHS** at a nominal volume flow of 1700 m^3/h. In line with their loading in the tests, their removal efficiency declined (Fig.13). High-Strength HEPA filters are required to have a removal efficiency at least of η = 99.97%. The filters, which were subjected to a pressure drop of 30 and 40 kPa during the test, did not indicate any decreasing removal efficiency. After a pressure drop load of 75 and 80 kPa, the removal efficiency dropped to η = 99.96%, which barely misses the criteria applied to HEPA filters. But even after a load of 120 kPa, the removal efficiency drops only to η = 99.9% and, at 170 kPa, to η = 99.8%. The oil plume test indicated leakages of individual oil filaments (40 kPa) up to an oil mist covering a larger area (120 kPa and 170 kPa). This is indicative of broken fibers in the fiberglass mat, whose further rupturing is prevented by the supporting structure.

** DEHS: Di- (2-ethylhexyl)-sebacat (DES), particle distribution like DOP

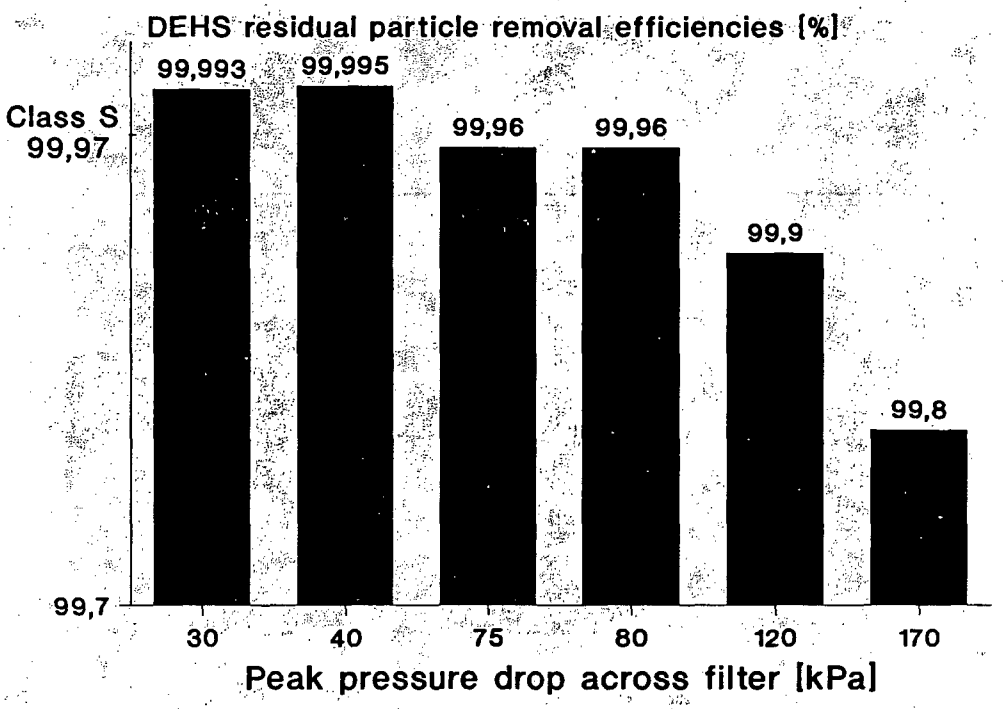

Fig. 13: Comparison of residual DEHS particle collection efficiencies of High-Strength HEPA filters after shock wave pressures across the filter.

The results are significant, as no High-Strength HEPA filter showed total failure even under extreme pressure drops (no cracks in the filter medium or in the elastomeric sealant), and all filters had removal efficiencies afterwards at least of Class R (η > 98%).

Two HEPA filters were exposed to TiO_2 particles (x_{50} = 0.3 μm) applied by a brush dosing unit up to a pressure drop of 1000 Pa. Both filters then were exposed to shock waves, which generated pressure drops of 48 kPa and 90 kPa across the filter. No sizeable dust discharge was observed, but dust migrated into deeper layers of the filter medium. After the test the filters, at nominal volume flow (1700 m^3/h), had pressure drops of 760 Pa (after a load of 48 kPa) and 600 Pa (after 90 kPa) instead of the 1000 Pa they had before the test. Under the more pronounced shock wave impact there was also a more pronounced migration of TiO_2 particles into deeper layers (Fig. 14). Evaluation of the high-speed video film shows a peak-like penetration of dust for a few milliseconds, as has also been determined with DOP droplets /8/. The downstream side of the filter (Fig. 15) was examined under the scanning electron microscope (SEM), but no TiO_2 particles were found to adhere. The removal efficiencies after the tests corresponded to those shown in Fig. 13 for new filters: η = 99.97% at a pressure drop load of 48 kPa (still class S) and η = 99.93% at 90 kPa (Class R).

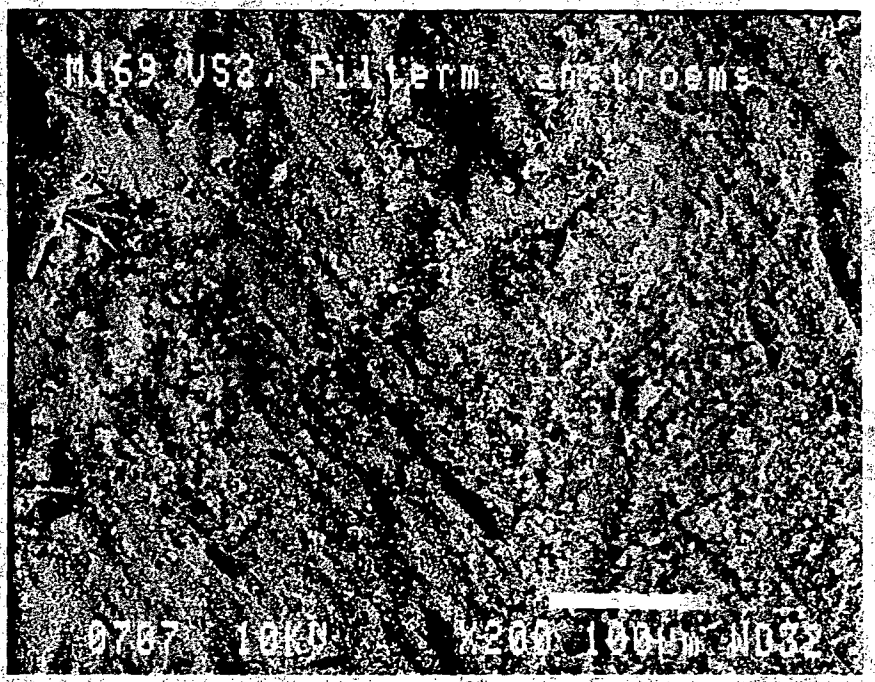

Fig. 14: SEM - photograph of filter medium on the upstream side from TiO_2 loaded High-Strength HEPA filter after shock exposure(P_{21} =1.42, Δp = 90 kPa).

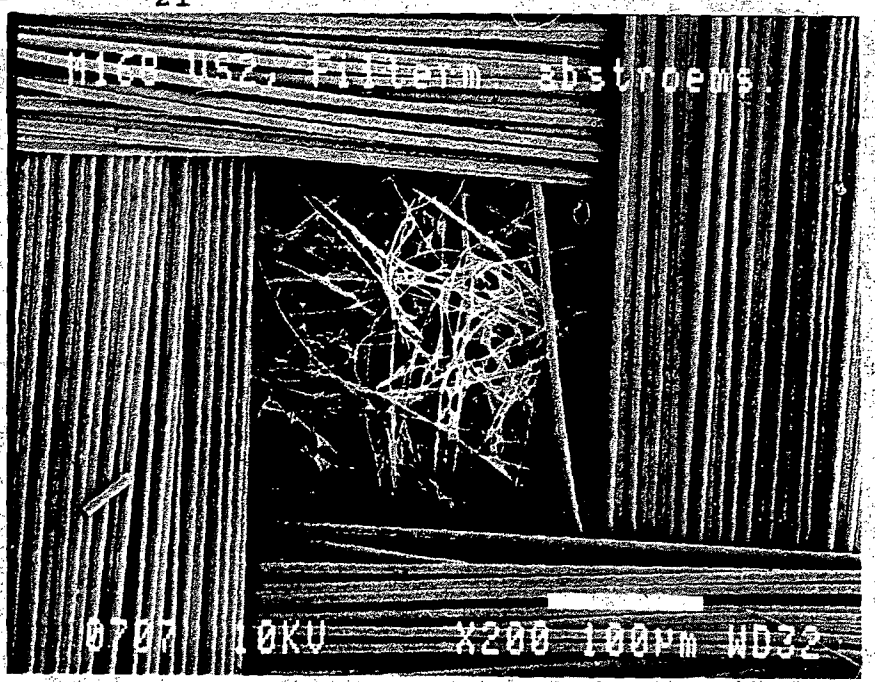

Fig. 15: SEM - photograph of reinforced filtermedium on the downstream side from TiO_2 loaded High-Strength HEPA filter after shock exposure(P_{21} =1.42, Δp = 90 kPa).

IV. Conclusion

With the numerical code LAFIS it is possible to calculate the mechanical loading on filter units at the discharge of exhaust air filter systems with more than one hundred components (e.g. ducts, elbows, duct branches, nozzels and diffusors, blowers and compressors, filters, dampers, heat exchangers, described by their Δp-V characteristic) for a given accident at the inlet end (e.g. containment) of a ventilation system.

All test results obtained with the high-strength HEPA filters, newly developed at the Laboratorium für Aerosolphysik und Filtertechnik II, indicate that it is possible to protect critical test installations with a high hazard potential by the appropriate HEPA filters. In dry air, pressure drops at the filter should not exceed 50 kPa, a level which still leaves a wide safety margin. Under high relative humidity conditions, pressure drops up to 15 kPa have been found to cause no damage and still leave a safety margin. A detailed description of all experiments and results will be given in a report /14/.

The High-Strength HEPA filters have been designed specifically for accident filter systems in German nuclear power plants and can be built in various sizes with the same levels of mechanical strength. This has greatly reduced the hazard of releases of radioactive and toxic dusts, respectively, through exhaust air filter systems. Other areas of application for these filters are ventilation systems in the chemical industry and processing industry with high hazard potentials, and facilities for the extraction of explosible dusts.

V. References

/1/ Carbaugh, E. H.
Survey of HEPA Filter Applications and Experiments at Department of Energy Sites;
PNL - 4020 (Pacific Northwest Laboratory), 1981.

/2/ Czarnecki, J.
Some Experimence with Measurements of Stack Releases and their Correlations with Environmental Measurements;
IRPA - Tagung, Sydney, 10. - 17. April 1988, S. 689 - 692.

/3/ Ricketts, C. I.; Rüdinger, V.; Wilhelm J. G.
HEPA - Filter Response to High Differential Pressures and High Air Velocities;
Proc. 5th International Meeting on Thermal Nuclear Reactor Safty, Karlsruhe 1984, KfK 3880 (1984), Bd. 2, S. 1572.

/4/ Fischer, M. et al.
The Multi Compartment Code WAVCO to Analyse the Behavior of Non-Condensibles During Hypothetical Accidents;
Second Int. Meeting on Nuclear Thermohydraulic, Santa Barbara, Cal.,Jan. 1983.

/5/ OECD/NEA - Report
Air Cleaning in Accident Situations,
Paris, OECD 1984, S.26

/6/ Neuberger, M.
LAFIS - Ein Rechenprogramm zur Bestimmung der strömungs- und thermodaynamischen Belastungen in Lüftungssystemen;
LAF II, PSF - Bericht , Kernforschungszentrum Karlsruhe GmbH, to be published, (1992)

/7/ Idelchik, I. E.
Handbook of Hydraulic Resistance;
Second Edition, Springer Verlag 1986.

/8/ Neuberger, M.
Zur Ausbreitung schwacher Stoßwellen in Lüftungssystemen;
KfK 4920 (1991).

/9/ Billings, C. E. et al.
Blast Effects on Air Cleaning Equipment - Results of Filter Test;
Proc. 4th AEC Air Cleaning Conference, TID Report 7513, p. 279, (1956).

/10/ Cuccuru, A. et al.
Effects of shock Waves on High - Efficiency Filter Units,
EUR 10580 (1986), S. 877

/11/ Rüdinger, V., Arnitz, Th., Ricketts, C. I., Wilhelm J. G.
BORA - A facility for experimental investigations of air cleaning durning accident situations;
CONF 840806, p. 1441 (1985).

/12/ Rüdinger, V., Ricketts, C. I., Wilhelm J. G., Alken, W.
Development of Glass-Fiber HEPA Filters of High Structual Strength on the Basis of the establishment of the Failure Mechanisms;
CONF 860830 (1987).

/13/ Rüdinger, V., Ricketts, C. I., Wilhelm J. G.
High Strength High Efficiency Particulate Air Filters for Nuclear Applications;
Nuclear Technology, Vol. 92. Oct. 1990.

/14/ Fronhöfer, M. et al.
Hochfeste Schwebstoffilter - Typ KfK;
KfK - Bericht, Kernforschungszentrum Karlsruhe GmbH, to be published, (1992).

DISCUSSION

TSAL: Does your LAFIS computer program for non-steady state transient flow analysis include simulations of the control system as well as the HVAC systems? Is the program commercially available or is it a proprietary code of your company.

WILHELM: LAFIS is assigned for simulation of HVAC and control systems. It will be available by KfK as LAF II next year. It is based on the algorithm of the Fortran-ACRITH program package by IBM.

JANNAKOS: Could you tell me what was the size of the filter exposed to the wave shocks, and whether efficiency depends on the size of filters and differential pressure?

WILHELM: The size of the high-strength HEPA filters is that of the standard 610 x 610 x 292 mm HEPA filter. They are also built in larger sizes for some of the reactors. But there is neither an effect on efficiency nor on strength. Filters larger than standard size were not tested. The effect of pressure differential is given in the paper.

BERGMAN: Can you tell us the cost of this filter?

WILHELM: The cost of one of those filters is 650 marks at the moment which in Germany is 2.5 times more than that of the standard HEPA filter. KfK originally didn't want to buy these HEPA filters because they had a higher price but they have extended life and one can put more dust on them. In addition, one saves money for the exchange of the HEPA filters, which is very important. So, a few years ago KfK changed completely to high strength HEPA filters expecting that the total price would be lower for air cleaning. I should like to add one thing. Mr. Leibold will also speak about these HEPA filters being used in conventional plants and recleaned. Some of them have been in service for 18 months up to now.

RADIAL FLOW SYSTEMS FOR THE NUCLEAR INDUSTRY

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Flanders Filters Inc.
Washington, N.C.

Abstract

Handling and disposing of HEPA filters in the nuclear industry is often difficult, dangerous and inefficient. This paper presents containment filtration systems designed to address these problems using round, radial flow filters.

Most filtration systems in use presently use rectangular shaped axial flow filters. The most commonly use size (size 5) is 24" X 24" X 12", delivering 1000 CFM at 1" Water Gage of pressure drop. These filters are made using one of two basic frame materials, wood and metal. Most wood framed models weigh approximately 35 pounds. Most metal models weigh approximately 50 pounds. Changing these filters, especially when they are above floor grade, can be hazardous and difficult simply because of their weight. When bag-in bag-out systems are required, the corners on rectangular filters present a potential for damaging the bags. An equivalent 1000 CFM radial flow filter, with stainless steel end caps and faceguards, weighs approximately 28 pounds, and has no corners to threaten bag integrity. This paper includes a description of a system which uses a waste storage drum as the filter housing, which eliminates entirely the handling of filter inserts and the attendant hazards.

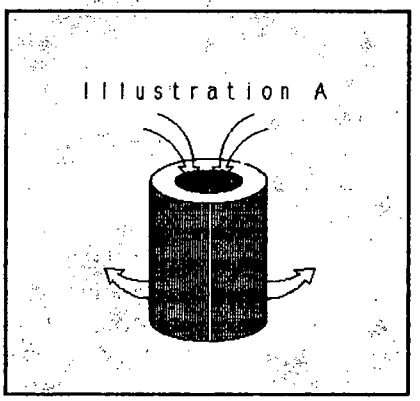
Long term hazardous waste storage is a major problem for the nuclear industry. We believe that radial flow systems present a potential for reducing the volume of this waste. Spent filters which contain radioactive filtrates are often placed in 55 gallon drums for long term storage. In order to get it into a drum, the size 5 filter must first be dismantled or crushed. Either method releases filtrate into the air, necessitating the use of specially designed (and costly) facilities and equipment. We have designed radial flow filters so that they fit into drums with no dismantling or crushing needed. One size is rated at 1500 CFM, and still easily fits into a DOT 55 gallon drum. Usually, one drum holds one size F filter, which means 1000 CFM of spent capacity per drum. The radial flow system allows 1500 CFM per drum with no filter crushing or dismantling. The paper presents designs, configurations, and performance characteristics of filtration systems utilizing radial flow filters. It includes descriptions of methods for performing in-place efficiency testing for multiple filter housings.

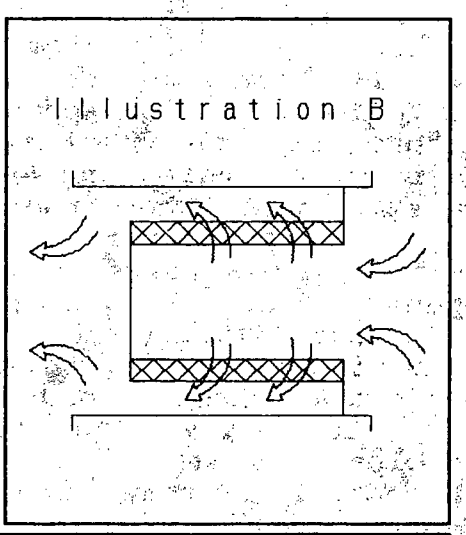
A radial flow filter directs air flow through the filtration medium in a direction which is radial relative to the filter's center axis (Illustration A). Radial flow systems work with the airflow direction either in toward the axis or out away from it. If air flow is directed into the center of the filter and then out through the medium, the filter acts like a canister, helping to maintain control of the filtrate during handling of spent filters. If the housing is designed so that it's inlet is also the filter's

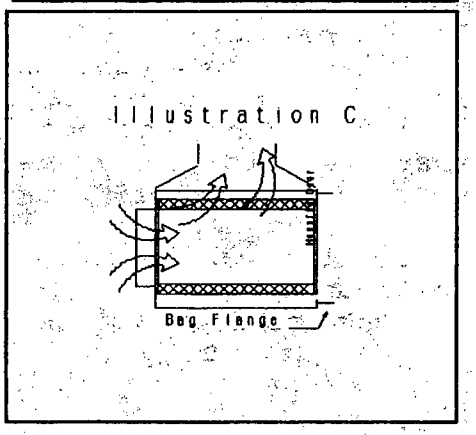
inlet (Illustrations B & C), this keeps the entire housing free from particulate contamination. All of the designs we have been working on utilize this intrinsic safety feature.

The physical size we have concentrated our development on is a 20" outside diameter 32" long cylinder. The obvious rationale for this is that it fits into a DOT 55 gallon drum, with enough room left over for a containment bag. With a 2" deep pack, yielding a 16" inside diameter, this filter has about 346 square feet of available medium. The traditional size 5 aluminum separator design has about 215 square feet. Illustration D shows flow versus pressure drop curves for both of these filters, plus a radial filter of 15" outside diameter and a 20" O.D. filter with a 4" deep pack. This last filter has about 486 square feet of medium. However, the smaller inside diameter (12") which this presents creates a pressure drop penalty. All the air which passes through a radial filter must pass through the orifice created by it's inside diameter. Pushing 2000 CFM through a 12" orifice takes about a .85" pressure drop. For a 16" orifice, the pressure drop is about .32" at 2000 CFM. For this reason the 16" ID filter has a better flow versus pressure drop performance, even though it has less medium surface.

The 15" OD filter contains about 230 square feet of medium. It can fit inside the 20" OD 16" ID filter, thus enabling the storage of about 675 square feet of medium in one drum with no filter deformation required. A relatively simple hydraulic ram compactor could double that. With waste handling and storage costs running as high as $8,000 per drum, this presents a potential for a five-fold reduction in spent filter storage volume and cost, with little or no added handling complication. We believe that this is a compelling reason for considering radial flow designs.





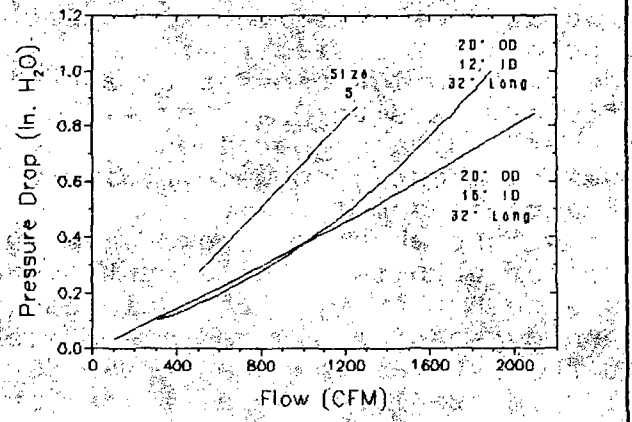


Filter	Square Feet of Medium
Size 5	215
20" OD 16" ID 32" Long	346
20" OD 12" ID 32" Long	486
15" OD 11" ID 31" Long	230

There are two basic housing design schemes suitable for radial filters. One is the traditional side load (Illustration B), with filters inserted into the housing normal to the entering air flow direction. The other is end load (Illustration C), with filters inserted parallel to the entering air flow direction.

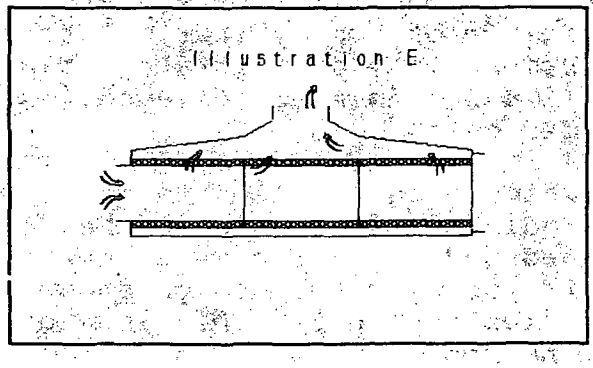
Side load designs have the advantage of allowing vertical stacking of housings. A large bank of filters would present a design very similar to what is used for axial flow systems. In effect, even though the filter itself is radial flow, the housing remains axial flow. Testing has shown that each filter needs a minimum of 2" of clearance in a radial direction to allow enough plenum space for leaving air without imposing a noticeable pressure drop penalty. This means that a housing for a 20" OD filter would have the same 24" inside cross section as a size 5 housing. For a 32" long filter, however, the housing would have to be longer than a size 5 housing. This difference is offset by the increased medium area, which means that a radial design can be smaller in filter count than an axial system of equivalent air handling capacity. If we use a conservative 1500 CFM capacity for the radial filter, and the standard 1000 CFM for the size 5, two radial filters replace 3 axial filters.

Illustration D



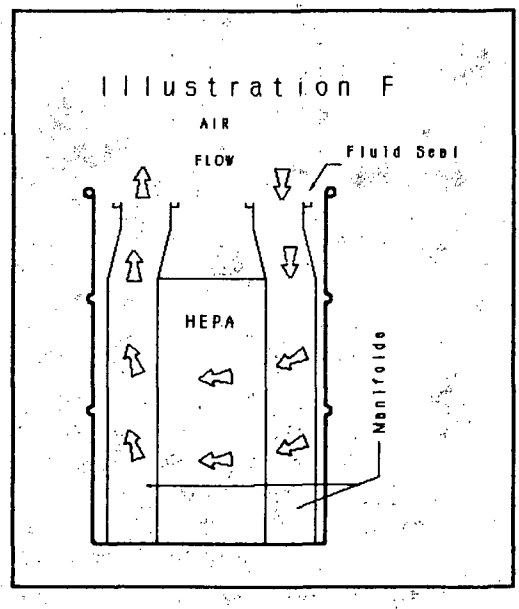
An end load design is especially appropriate where leaving air direction turns 90 degrees from entering direction (Illustration C). Housings can be closely packed in one direction, but a 2 dimensional matrix of them would not be possible. Filters can be mounted end to end, like shells in a shotgun magazine (Illustration E). There is a limit to how many can be strung together in this manner. The filter's inside diameter presents a pressure drop penalty at high velocities, much like a section of duct. More than 3 filters in a line would probably not be practical.

Illustration E

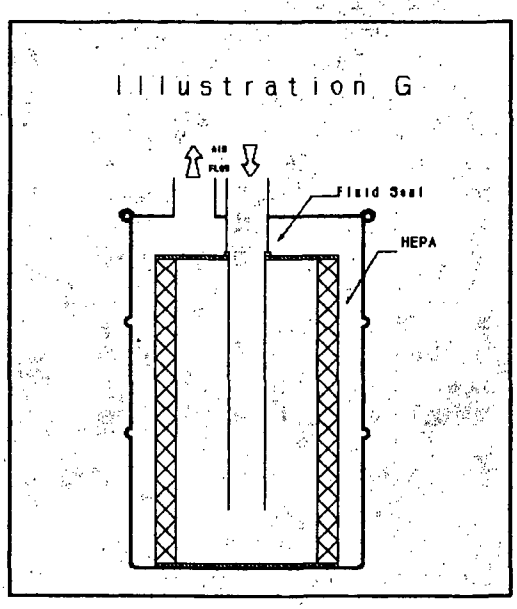


Locking mechanisms for side load housings would be similar to current axial system designs. For end load systems, however, the design can be very uncomplicated. Replaceability is easy to design, and field replacement is simplified. This results in decreased expense and greater reliability. In critical systems, the simplicity and reliability can be high priority considerations.

In-place testing would be accomplished in much the same way as with axial flow filters. In side load systems, in-place test designs can be virtually identical to traditional axial systems. End load systems which have only one filter per housing can be very similar. End load systems with more than one filter per housing, however, present a complication. Since in essence, these filters act like one very long filter, all the filters in a housing dump leaving air into a common plenum. This makes the problem of isolating a leak to an individual filter or filter-to-filter seal very difficult. We have some ideas as to how this could be done, but none have been developed fully as of now.



There are reasons other than waste storage efficiency for considering radial flow filter design. For instance, a radial filter of equivalent capacity weighs less than an axial flow filter. A size 5 filter with a wood frame and face guards on both faces weighs about 35 pounds. With a stainless steel frame and face guards, it weighs about 50 pounds. A radial filter with the same amount of media as a size 5 filter, with stainless steel end caps and stainless steel mesh on both upstream and downstream faces, weighs 28 pounds. The 20" OD 16" ID 32" long radial filter, which delivers over 2000 CFM at 1" pressure drop, weighs about 32 pounds. This weight advantage is important to whomever is loading or changing filters. In bag-in/bag-out systems, the lack of corners on radial filters, along with the lighter weight, is a distinct safety advantage. The lighter, rounded design decreases the likelihood of bag puncture. Also, since the filtrate is trapped in the inside of the cylindrical filter, the probability of filtrate escaping, even if a bag does get damaged, is decreased.

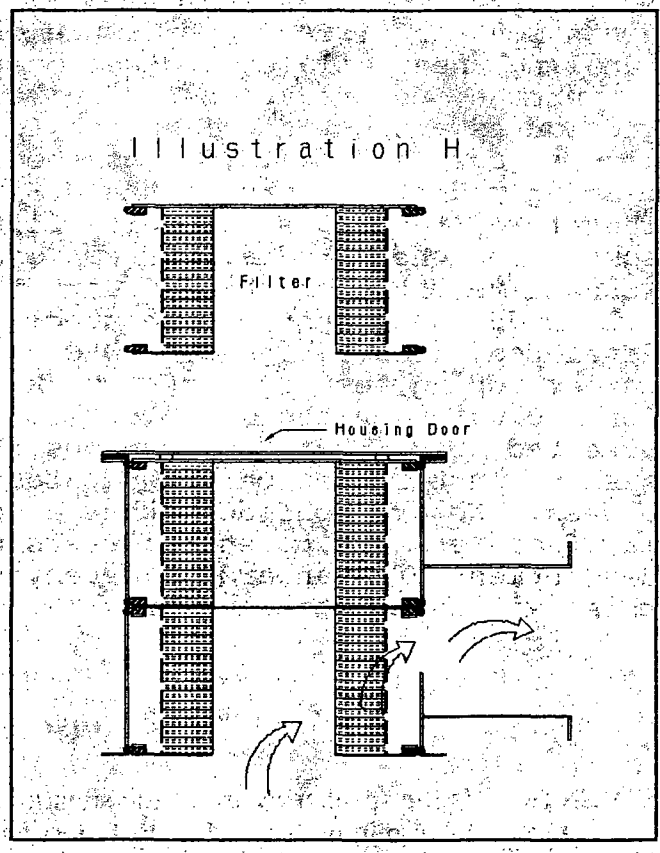


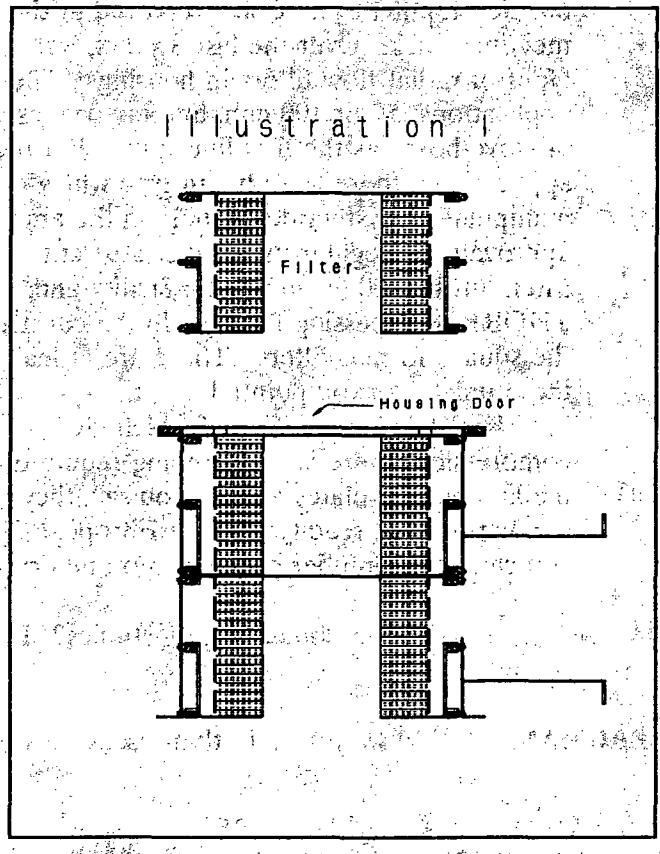
There are some other applications which uniquely lend themselves to radial design. One is the "filter-in-a-drum" idea. We were recently asked to quote on the design shown in illustration F. This is a design incorporating a DOT 55 gallon drum as the filter housing. Note, however, that it still requires a substantial amount of stainless steel fabrication to make the inlet and outlet plenum systems. The filter, a size 4, presents 100 square feet of medium. Compare this with the design in illustration G. This utilizes a radial filter element with 275

square feet of medium. It also eliminates the costly stainless plenum fabrication. When the element is spent, the drum top with the inlet and outlet ducting is removed, and a standard drum top is mounted. The filter is then enclosed in a drum, ready for handling or storage.

Another application which works well with the radial design is what we call the push-through housing. It is a design which is often seen on glove box applications. Illustration H depicts the concept. The spent filter is displaced by pushing a new filter into the housing. The displaced filter is pushed into the glove box, where it is then removed through a bag-out port or otherwise processed. Illustration I shows a modification of the design which prevents bypass from the glove box to the outlet during filter change. This is accomplished by the addition of a third gasket (gasket C). As the filter moves out of the housing, gasket C prevents unfiltered air from entering the outlet after gasket A loses contact with the housing wall. Without gasket C, air could bypass the filter as soon as gasket A loses contact. This feature eliminates the need to provide shutoff dampers or other means of preventing bypass during filter changeout.

We believe that there are some very sound reasons to consider using radial flow filters in the nuclear industry. There is another issue to consider besides mechanical design, however. That issue is the need to comply with regulations. Test specifications to insure quality, safety, and suitability have been in place for axial flow rectangular filters for a long time. Issues like





dimensions, efficiency, pressure drop, resistance to rough handling, heat, flame, and wet overpressure are thoroughly covered by current specifications. Equivalent specifications and test procedures are not now in place for round radial filters. There is also no current provision (no specifications or test equipment) for placing radial filters on the U.S. Qualified Products List. Therefore, there are no radial filters on the list. There may be some cases where radial systems can be used despite this lack, but we believe that for the industry to safely incorporate radial filter designs, appropriate specifications and procedures must be developed. The U.S. Army CRDEC has said that they see no barrier to developing test equipment with which to qualify radial filters for inclusion on the QPL. But for that to happen, they must be directed to do that. This means that you, as users of filtration system, must let it be known through proper channels that there is a need. We are confident that a cooperative effort between manufacturers and potential users will result in the rapid development of standards, thereby assuring the safe application of this exiting new technology.

DISCUSSION

DYMENT: Is the speaker aware of the situation regarding the use of radial flow filters in the U.K.? I can outline it as follows: I must agree with your sentiments that this type of filter has great potential within the nuclear industry. I say that as a user. I can give you a very quick rundown to illustrate what I mean. The position in U.K. on radial flow filters is that our development phase was reported to this Conference by Ron Pratt of UK AEA some few meetings back. Over the last 8 years, we have prepared and improved standards for two main types of radial flow filters in housings. The push-through type, we use for smaller applications, 50 or 100 cfm, and my own establishment has some hundreds of these installed in glove-boxes as the first-line filter. For the larger size applications, e.g., ventilation applications, there is a plug-in type which can be changed by a bagout or a remote manipulation system depending on the application. These units have all received full approvals for regular use in the most critical nuclear applications. At MoD, they are first line filters in the 400 glove box Pu facility and, I believe, they are used exclusively in BNF's THORP reprocessing facility. In the construction of new facilities, they have largely displaced the square format filters. There are at least two manufacturers in U.K. currently producing these units. As you pointed out, there have been advantages in the types which are produced in U.K. They have a lip-seal which gives a virtually hermetic seal without the need for compression, there is no clamping required, they contain minimal material other than the media and end plates and, as you say, they are readily crushable. The largest units of 2,000 cfm capacity fit readily into the European 200 liter waste drum. If you crush them, of course, you can get a number of them into one drum.

DAVIS: Have you done crushing studies? How many of them are you able to put into a drum?

BERGMAN: Could we just hold that discussions until later.

PORCO: The radial filter is very similar to the M56 filters supplied to the military which are tested at Edgewood Arsenal. Are you using Mil Spec. F-51079 media?

DAVIS: Yes.

PORCO: Have you done any qualification testing, such as heated air, moisture, over-pressure, rough handling?

DAVIS: No. As far as I know, there are no test facilities available for doing these tests on filters of this size and shape. There are no specifications in place for testing radial filters. The M56 military filters are not subjected to heated air or wet over-pressure testing at Edgewood. Only pressure drop and efficiency testing have been done.

BEHAVIOR OF THE LOADED POLYGONAL HEPA FILTER EXPOSED TO WATER DROPLETS CARRIED BY THE OFFGAS FLOW

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Abstract

For cleaning of the dissolver offgas from reprocessing plants a HEPA polygonal filter was developed and tested which can be used to filter also exhausts from processes in other facilities. The following tests were carried out in order to obtain information about the behavior of the loaded filter element exposed to water droplets in the offgas stream:

The filter elements were loaded up to 1300 Pa differential pressure with a) alumina powder particulates < 3 µm in size, b) a sorted fine dust fraction taken from dust bags of household vacuum cleaners, and c) salt aerosols and then exposed to water aerosols supplied to the offgas flow upstream of the filter.

Throughout the tests with filter element loading according to a) and b) the filter elements were not damaged. Whereas in the test series with type a) loading the differential pressure remained almost unchanged, it increased at different degrees in the tests with loading according to b), depending on the amount of water aerosols supplied. In the tests involving type c) loading the differential pressure steeply rose at the filter and the filter element was damaged after about 25 minutes at a final differential pressure of approx. 14.5 kPa. With the results from the last test campaign on hand, mechanical testing of the HEPA polygonal filter element was terminated.

A special device was developed, built and put into operation for manufacturing the HEPA polygonal filter element. This device will be briefly described here.

Introduction

The polygonal filter is a pentagonal chamber filter; the filter element is cylinder shaped. The offgas flows from the bottom through a circular cross-section in axial direction into the inner space and then radially to the outside passing through the filter media of the five chambers. The circular cross-section of face flow is much smaller than the face flow surface of the filter medium and dimensioned such that at nominal volume flow rate in the non-loaded state the total pressure drop of the filter element is approximately 300 Pa. The maximum admissible service temperature is 160° C. With the test results available, the mechanical structure of the filter element has been optimized so that the axial strain of the stainless steel filter frame does not exert an influence on the filter medium at service temperatures up to 180° C.

In a first test series the behavior of non-loaded or little loaded filter elements exposed to water droplets was investigated and reported at the 21st DOE/NRC Nuclear Air Cleaning Conference [1]. Mechanical testing of the polygonal filter was continued and has been terminated meanwhile, and the results of a

second test series dealing with the behavior of loaded polygonal filter elements during exposure to water droplets will be reported here.

The second series of tests were carried out in the same test facility as the first test series. The water droplets were generated by means of a two-fluid nozzle. The mean droplet diameter was about 18 µm at 150 mm distance from the nozzle. The diameter of the droplets immediately before they hit the filter paper was not measured.

Filter elements were examined which had been loaded with the following materials:

- alumina powder: grain size ≤ 3 µm,
- sorted fine dust fraction from dust bags of household vacuum cleaners,
- salt aerosols.

The solids and the salt solution ($NaNO_3$ solution) used to generate the salt aerosols were supplied to the intake line of the filter element by means of two-fluid nozzles.

Testing under condition of loading with salt aerosols was the primary goal and necessary because the polygonal filter elements had been developed in the first line for purification of the dissolver offgas arising in fuel element reprocessing plants and as it is envisaged to actually use them in such plants (e.g. JNFS plant). Due to the nitric acid solution present in the dissolver, the dissolver offgas is loaded with salt aerosols.

Experimental

The new filter elements were installed at the test facility in conformity with conditions of operation and loaded up to about 1300 Pa differential pressure at the filter, with solid particulates or salt aerosols supplied at constant volume flow rate. The differential pressure of 1300 Pa was chosen because the filters have to be replaced upon attainment of that value at the latest. After loading the filter elements were dried, if necessary, and exposed to water droplets in the same test facility without any modifications being made. In all experiments with salt aerosols the water was injected at a flow rate of about 5.5 l/h and about 9.2 g/m^3 gas respectively. For the operating condition under consideration of the dissolver offgas this water volume corresponds to approx. 5°C underrating of the dew point which in case of failure of the heater of a dissolver offgas purification system would be quite possible. In the experiments involving alumina powder and dust also smaller amounts of water were injected. It has been outlined in [1] that the differential pressure establishing across the filter during exposure to water droplets is dependent on the amount of water injected. If the amounts of water differ from those chosen for the test, the differential pressure establishing across the filter will be lower (smaller water volume) or higher (larger water volume).

Test Data:

volume flow rate:	600 m^3/h ambient air
face flow surface of the filter:	0.13 m^2 corresponding to 1/5 (one chamber) of the polygonal filter
filter medium surface:	5.4 m^2
intake condition:	room conditions
filter condition:	the tests were performed with new filter elements each

The measurements related to:

- test duration,
- amounts of dust and water,
- residual water downstream of the filter,
- differential pressure across the filter.

It was possible to observe the filter condition at any moment because part of the filter housing was made of Plexiglas.

Results Obtained

In order to be able to attain 1300 Pa differential pressure across the filter, approx. 518 g of powder were needed for loading with alumina powder. The loaded filters were exposed to water droplets supplied at a rate of 2.5 l/h (4.2 g/m^3)for about five hours. The differential pressure across the filter did not rise. At the end of testing no damage had occurred to the filter elements.

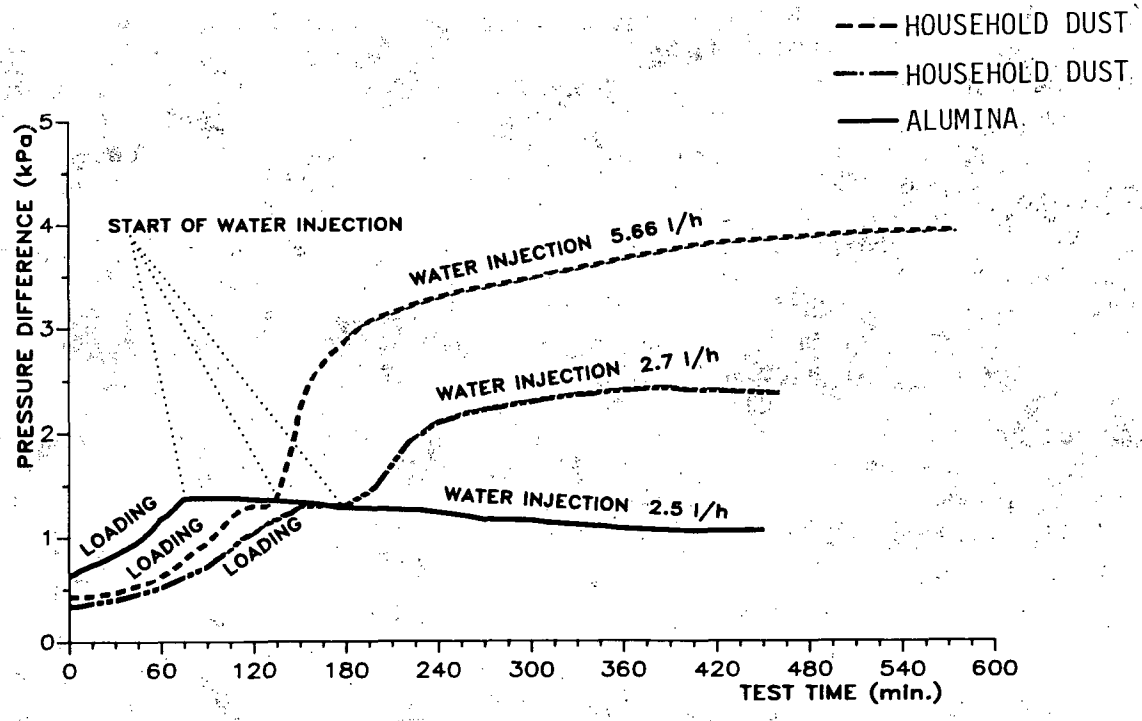

Fig. 1 Pressure differences across polygonal filter during the tests

For loading with the fine dust fraction from household vacuum cleaners 1482 g of dust were needed in order to attain a differential pressure of 1300 Pa across the filter. The subsequent exposures to water droplets supplied at the rates of 9.5 (4.5) g/m^3, were interrupted after about eight (five) hours. During that interval the differential pressure across the filter increased continuously to about 3930 (2450) Pa. At the end of testing the filter elements had not suffered any damage. Figure 1 is a plot of the differential pressure establishing across the filter element during loading and the subsequent exposure to water droplets.

When loading the filters with salt aerosols, $NaNO_3$ was dissolved in water and the solution fed into the intake line of the test facility by means of a two-fluid nozzle. The flow rate of the solution was set at 1.3 l/h so that the water evaporated before it reached the filter surface and only the salt aerosols together with air reached the filter medium. Approx. 980 g of salt ($NaNO_3$) were needed to attain a differential pressure across the filter of 1300 Pa.

During the subsequent exposure to water droplets supplied at a rate of approx. 5.7 l/h (9.5 g/m^3) the differential pressure rose to approx. 14.5 kPa within about 25 min. With this differential pressure tears developed in the filter paper and the differential pressure dropped. As during the last seconds the rise in differential pressure was very steep, it is supposed that the peak value was higher but that it could not be recorded due to attenuation of the plotter. It was observed that at the chosen rate of flow of the salt feed the salt aerosols deposit on the face flow surface of the filter so that the gaps between the spacer and the filter paper close.

With larger aggregate amounts of salt supplied, the filter face flow surface during loading became gradually covered almost completely with salt particulates, which attached to it. Under that condition the air was capable of passing only through a few paper pleats, which expanded. Then the differential pressure across the filter rose steeply until tears developed in the filter paper at the edge of pleating. This happened for approx. 1300 g of salt supply and a differential pressure of approx. 15 kPa in our tests. At this differential pressure the rate of flow dropped from 600 m^3/h to approx. 450 m^3/h (controlling no longer possible) (tests 24 and 25). Figure 2 is a plot of the differential pressure across the filter element during loading and exposure to water droplets. Figure 3 shows tears in the filter paper on the downstream face of the filter element occurring in a test after exposure to water droplets (test 27).

The tests have shown that measures have to be taken in dissolver offgas purification to the effect that the exhaust air temperature upstream of HEPA filters is higher than its dew point temperature and that in case the dew point is underrated (e. g. by failure of the gas heater) the system must be switched over to the non-loaded standby filter system within the following 15 minutes.

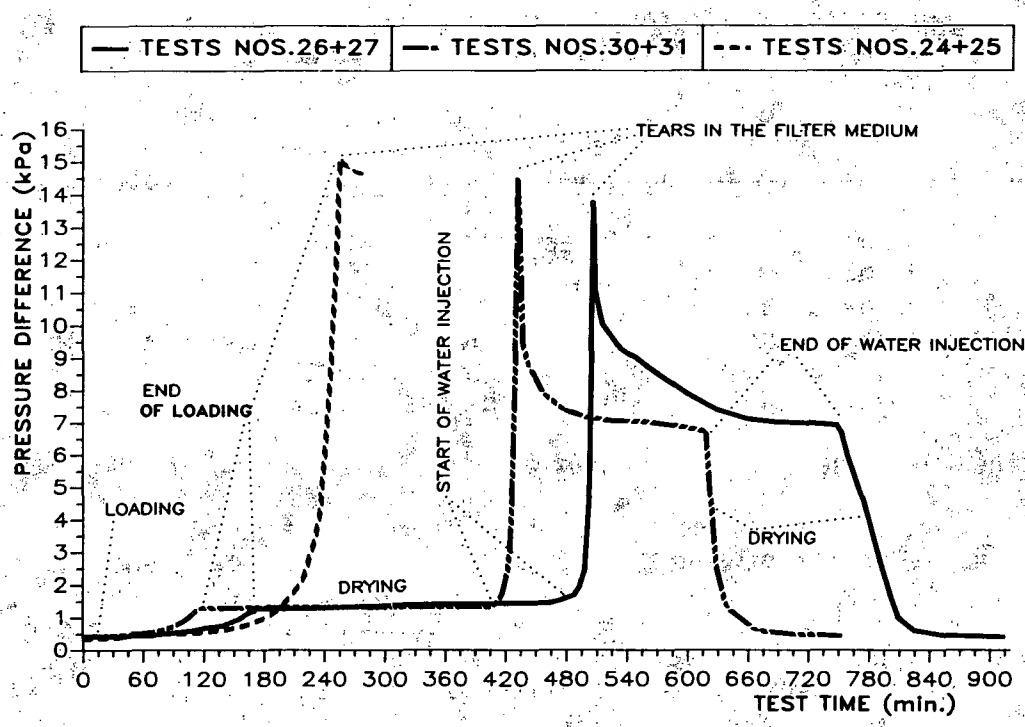

Fig. 2 Pressure differences across $NaNO_3$ loaded polygonal filter during the tests

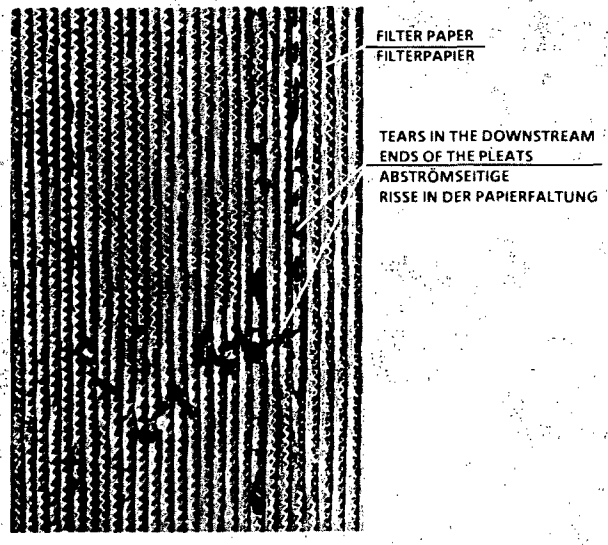

Fig. 3 With $NaNO_3$ loaded polygonal filter element after exposure to water droplets

Manufacture of the Polygonal Filter Element

To manufacture the filter element a device was developed which allows the pleated filter paper equipped with spacers to be arranged as a polygon. This gives in the ready for use version a cylindrical (circular) filter element. Figure 4 shows the filter mounting device during manufacture of a polygonal filter element.

The filter paper arranged as a polygon and secured is taken from the device using a hoisting unit or pullley and placed first into one of the covers on the front side for tight embedding of the filter paper with a sealing compound and then, after drying, into the other cover on the front side. During the same process the grating provided as an external protection of the filter is fastened to the cover by means of the sealing compound.

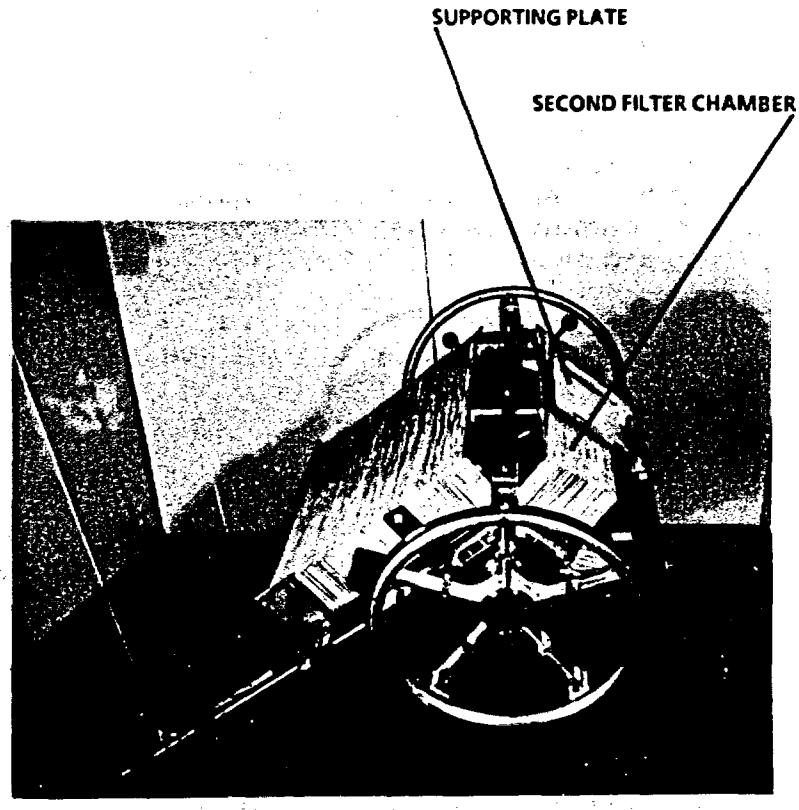

Fig. 4 Filter assembling device, separation of second filter chamber

/1/ Jannakos, K., Potgeter, G., Legner, W., "Behavior of the Polygonal HEPA Filter Exposed to Water Droplets Carried by the Offgas Flow". Proceedings of the 21st DOE/NRC Nuclear Air Cleaning Conference, Vol. 2, 772 (1990).

/2/ Jannakos, K., Potgeter, G., Mock, H., Furrer, J., "Advanced Filters for Nuclear Facilities and Filter Conditioning for Disposal". Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, Vol. 2, 1055 (1988).

THE APPLICATION OF HEPA FILTER UNITS IN GAS STREAMS OF HIGH DUST CONCENTRATIONS

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Abstract

Almost without exception, High Efficiency Particulate Air Filter (HEPA) units are currently employed for cleaning air and gas streams of very low dust concentrations where their high removal efficiencies reliably protect the environment. The high dust concentrations encountered during the modification and decomissioning of nuclear facilities, in the processing of contaminated scrap or in the incineration of radioactive waste have limited the use of HEPA filters to the role of final stage, clean-up filters.

Recleaning HEPA filter units in their service locations offers economic advantages compared with conventional combinations of multiple dust removal devices. Primarily fluid dynamic techniques come into consideration for the nondetrimental recleaning of inherently fragile, glass fiber filter media. This is explained by the relatively low mechanical stress induced during the required high-intensity recleaning processes, in comparison to beating or shaking methods.

Recleaning via low pressure reverse flow will be addressed in detail. The influence of reverse flow intensity and particle size on recleanability was studied in laboratory tests on specimens of HEPA filter media. The minimum required reverse flow intensity was determined on the basis of the residual pressure drop after recleaning. Measurements of local pressures in a single pleat and theoretically calculated flow patterns showed that airflows in conventional deep-pleat pack geometries during reverse flow recleaning are not uniformly distributed. The difference between the air velocities at the pleat inlet and the downstream end can vary by up to a factor of five at typical reverse flow intensities. This decreases the overall effectiveness of particle dislodgement from the filter medium which can result in a shortening of filter unit service life.

Finally, the results of field investigations into the recleanability of deep-pleat filter units during actual service conditions will be presented for three different dust types.

I. Introduction

HEPA filters are used for the highly efficient removal of very fine dusts down into the range of particle sizes < 1 μm in nuclear technology, but also in conventional applications, such as the semiconductor industry, pharmaceutical industry, or in hospitals [1]. However, the compact design and low pressure drop, which are additional advantages of HEPA filters, can be exploited only if the dust concentrations are comparatively low, on the order of a few mg/m^3 or even less. Being accumulation filters without regeneration capability, HEPA filters very soon become uneconomical at high dust contents, because of their short service lives, and should therefore be used only as backup filters [2].

Due to their extremely high removal efficiency, however, HEPA filters should be installed also in those instances where very high dust concentrations up to several g/m^3 arise. Typical applications of this kind are revision and decomissioning of nuclear power plants and other nuclear installations, treatment of contaminated scrap, and incineration of radioactive waste. HEPA filters can be operated economically under these conditions only if they can be cleaned repeatedly while installed, thus ensuring stable filtration [2].

In principle, filters installed can be cleaned by such mechanical procedures as beating or shaking of the filter units [3], or by aerodynamic cleaning techniques, such as low-pressure reverse flow, jet pulsing, or by shock waves. The mechanical procedures have been found to be ineffective. More effective cleaning techniques are required to dislodge the dust from the filter medium and remove it from the filter element.

II. Requirements

Stable operation of HEPA filters over long periods of time in the presence of high dust concentrations raises two basic requirements: The removal efficiency of the filter unit must, at any point in time during the period of operation, attain at least 99.97 % for the DOP test aerosol of 0.3 μm particle size.

Over the entire period of operation, the pressure drop of the filter must not exceed a given maximum level, i.e., filter clogging must be prevented reliably by the recleaning process. Various studies [2, 4, 5, 6] have indicated that very high velocities of up to 40 m/s are required to detach single particles by flow forces; these velocities increase greatly as the particle size decreases. If the dust has been deposited close to the surface as a continuous dust layer, the necessary flow velocities will be much lower, which would advocate surface filtration as a primary mode of operation. Soft cleaning at low reverse flow velocities should be endeavored also because fiberglass filter media are very sensitive mechanically and have only low tensile strengths. When high mechanical loads are applied, the filter medium is likely to be damaged and its removal efficiency reduced. In the light of these considerations, a suitable cleaning technique to be employed is low-pressure reverse flow. During the cleaning process, uniform cleaning of the filter unit over the entire pleating depth of the filter pack must be ensured.

Differences in the effectiveness of cleaning give rise to local differences in the flow conditions during the filtration phase and, ultimately, may cause the filter unit to be clogged.

III. Experimentals

Initially, plane specimens of filter media were subjected to laboratory-scale tests to find out the filtration velocities at which particles of submicron size can be deposited close to the surface. Also under laboratory conditions, the extent to which fiberglass filter media can be recleaned by reverse flow was studied, i.e., the filtration and cleaning conditions under which a constant residual pressure drop can be achieved after cleaning. These activities were supplemented by theoretical and experimental studies of the flow through a filter pleat during recleaning. Filter tests carried out in parallel with practice-related dusts at three different locations provided information about the transferability of laboratory data to specific dust removal problems and produced important findings about the cleanability of deep-pleat filter units.

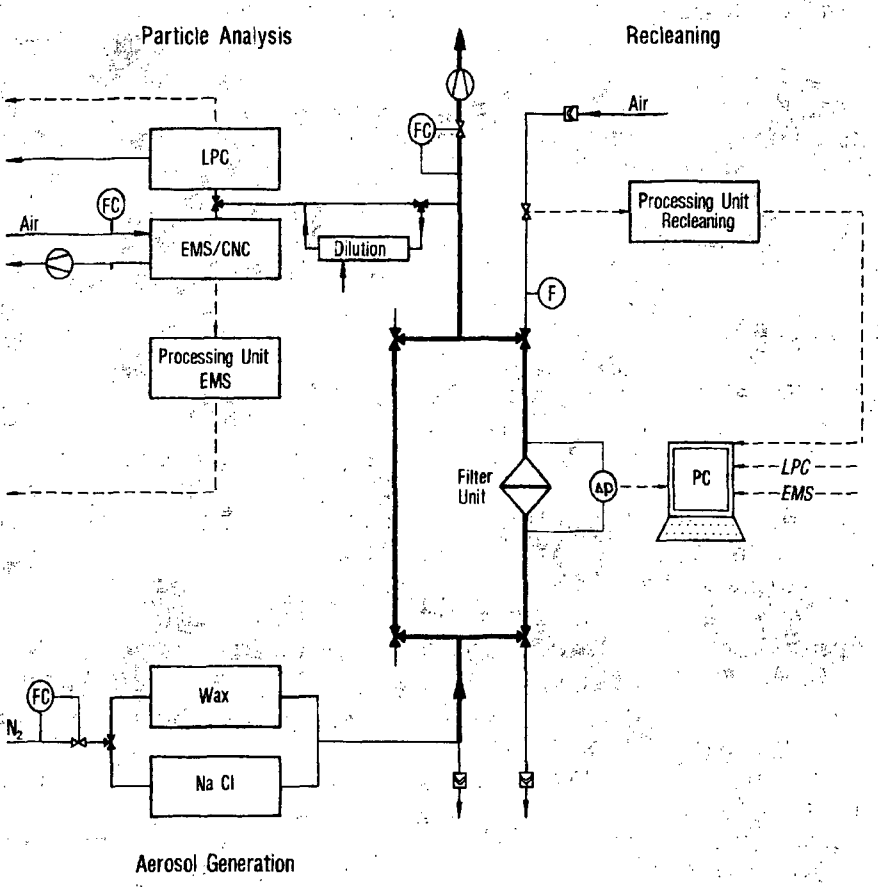

Fig. 1: Laboratory apparatus for studies of the recleanability of HEPA filter media.

The first picture shows the laboratory apparatus used to study the filtration and removal of submicron-size particles from HEPA filter media. At face velocities between 0.5 and 5 cm/s, this apparatus can be loaded with plane filter specimens of 32 mm diameter carrying monodisperse and quasi-monodisperse test aerosols, respectively. In the range of particle diameters of 0.05-1 μm, NaCl aerosol is used which is generated at temperatures between 500 and 700 °C in a Sinclair LaMer generator. The particles are spherical and are made up of amorphous NaCl, since dry nitrogen is used as a carrier gas. For the diameter range of 0.2-2 μm, a condensation aerosol with spherical wax particles is produced also in a Sinclair LaMer generator. The numerical concentrations of both aerosols are on the order of 10^6 particles/cm^3, with excellent constancy in time. The penetration and the pressure drop of the filter medium are measured continuously. For particle diameters > 0.2 μm, a Laser Particle Counter (LPC) is used to determine penetration which allows the particles in the diameter range of 0.12-7.5 μm to be classified in 16 channels. For smaller particles, penetration is determined by means of an Electromobility Spectrometer (EMS) in combination with a Condensation Nuclei Counter (CNC).

The apparatus branches into one duct section containing the test filter and an identical duct used to determine the raw gas concentration.This design of the apparatus allows high resolutions to be achieved in determining penetration. Penetration levels below 10^{-9} can be determined continuously and with absolute reliability. When recleaning the loaded HEPA filter media, reverse flow velocities to a maximum of 2 m/s can be set.

Recleaning was initiated by triggering a solenoid valve above the test filter and may be carried out either at preset time intervals or after a preset filter pressure drop has been reached. To facilitate operation, especially in long-term experiments extending over several days, control and data acquisition are PC based.

The design of the test filter systems for practice-related experiments can be seen from Fig. 2. The filter systems were operated in the bypass mode at a maximum volume flow of 1000 m^3/h. In the filtration phase, the raw gas passes first through the HEPA filter to be recleaned and then into the main air stream through a safety filter and the in-plant blower. Recleaning is performed off-line at a compressed air supply pressure of 3-6 bar by traversing the filter downstream side with a nozzle manifold oriented parallel to the pleats. The individual pleats are consecutively cleaned by exposure to the reverse air flow. The extracted airborne particles fall into the dust hopper. After a programmable sedimentation interval, the filtration cycle begins again.

Upstream of each filter unit, the dust concentration in the raw gas and the particle size distribution and particle shape are determined at specific sampling points. The raw gas concentration was measured gravimetrically, while the particle size distribution was determined by means of cascade impactors and in dust analysis

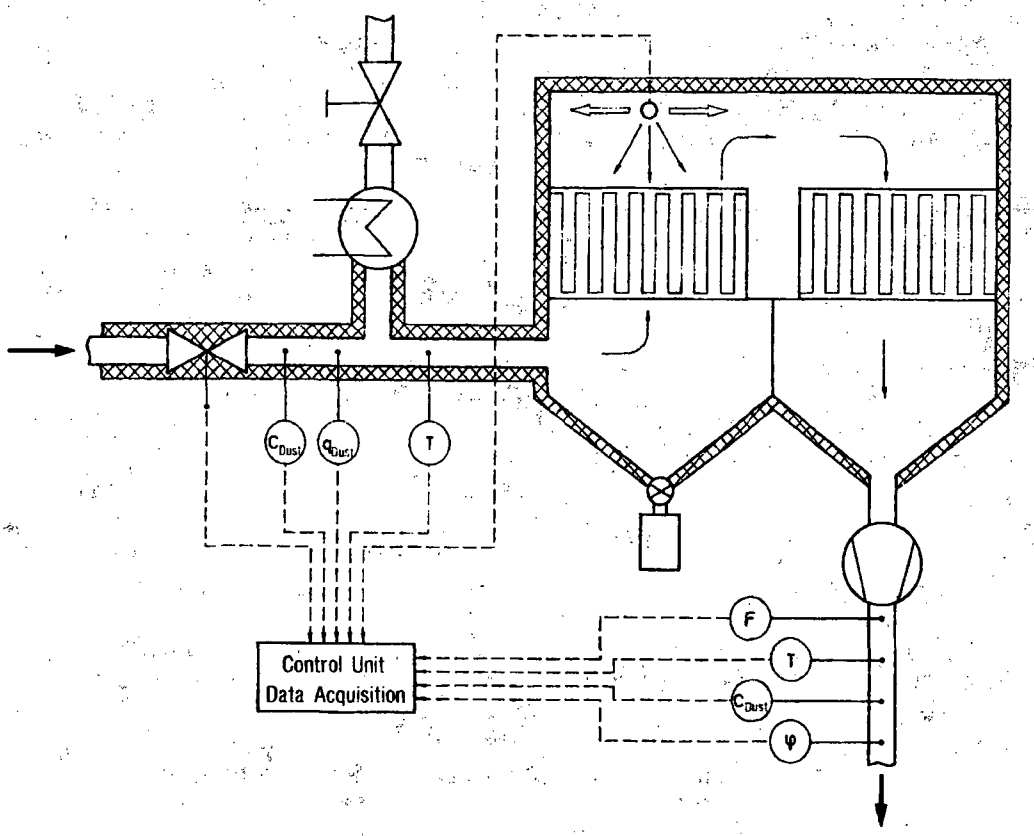

Fig.2: Design of the test filter systems for tests with complete filter units under practical conditions.

performed under the scanning electron microscope. Conditions on the upstream side can be seen from Table 1. On the downstream side, the throughput and the dust content of the clean gas were determined continuously. Concentrations were measured photometrically by dust photometers measuring in the forward direction. The gas temperature was continuously determined on the upstream side and, together with the relative humidity, also after the gas had passed through the filter.

Table 1: Operating conditions at the locations of the test filter systems.

Dust Source	MMD µm	c_{Dust} mg/m³	Temperature °C	rel. Humidity %
Blasting Box	2-8	500-2000	25	65
Ag/Cd Smelter	< 1	< 500	55	30
Rotary Kiln	< 2	< 40	110	70

Control of the test filter unit and continuous data acquisition were automated by means of a personal computer.

IV. Results

To facilitate filter cleaning, the dust collected should be deposited as continuous surface layers. Such dust layers adhering to the surface support filtration and can be detached with less force than the dust penetrating into the filter medium. In dust deposition on the surface of a HEPA filter medium, a linear rise of the pressure drop with the mass of dust is observed. The diagram (Fig. 3) shows that, for particles > 0.4 µm, at a usual face velocity of 5 cm/s, this linear relationship can be observed; the pressure drop rises the faster, the smaller the particles are. For particles < 0.4 µm, there is first depth filtration over a long period of loading, which can be recognized from the progressive development of the pressure drop curve, before the deposition is shifted to the surface of the filter medium.

It is important to note that, in this range of particle sizes, no continuous dust layers can be detected even after long loading periods. Layers are formed only as isles along the fibers, while larger areas in between show little deposition.

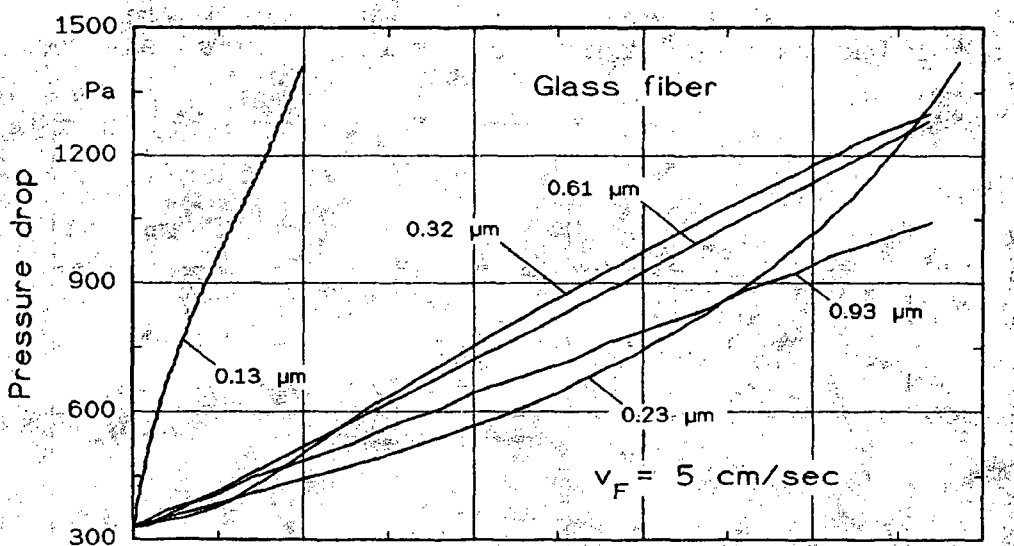

Fig. 3: Pressure drop curve of a HEPA filter medium loaded with monodisperse particles in the submicron range.

The pressure drop immediately after cleaning is the most important quantity in assessing the cleanability of HEPA filter media. This residual pressure drop therefore was used as the main criterion to assess stable filtration/cleaning modes of operation. The residual pressure drop is influenced primarily by the recleaning conditions, as represented by the reverse flow velocity, the development of the recleaning phase over time, and the properties of the adhering dust.

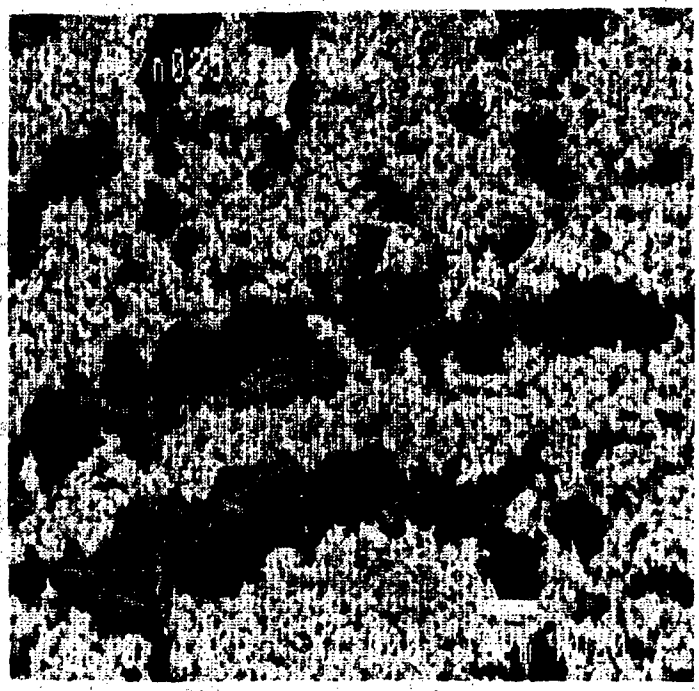

Fig. 4: Insular dust deposits for particles of 0.15 µm in diameter (SEM micrograph).

Figure 5, by way of example, shows the influence of the reverse flow velocity on the residual pressure drop for particles of 0.52 µm diameter for the range of technical interest above 0.4 µm.

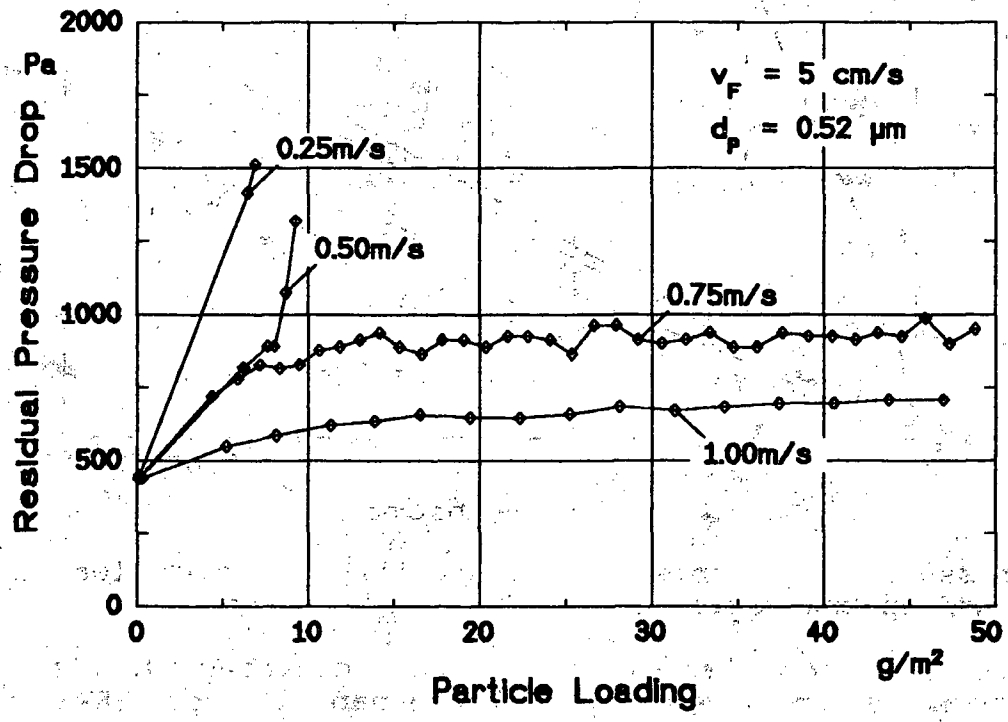

Fig. 5: Development of the residual pressure drop for recleaning 0.52 µm particles at different reverse flow velocities.

Cleaning was initiated whenever a pressure drop of 1500 Pa had been reached. For reverse flow velocities of 0.75 and 1 m/s, the residual pressure drop stabilizes at 710 and 930 Pa, respectively. It is seen that the filter medium becomes clogged very quickly at lower reverse flow velocities, thus making stable filter operation impossible.

For particles in the range of the removal minimum (diameters around 0.2 μm), which initially were deposited inside the filter medium in large numbers, the required minimum reverse flow velocity is 1 m/s. Much smaller particles are still under study.

For the particle range investigated the duration of the recleaning step has been found to have no impact on the recleaning performance of HEPA filter media.

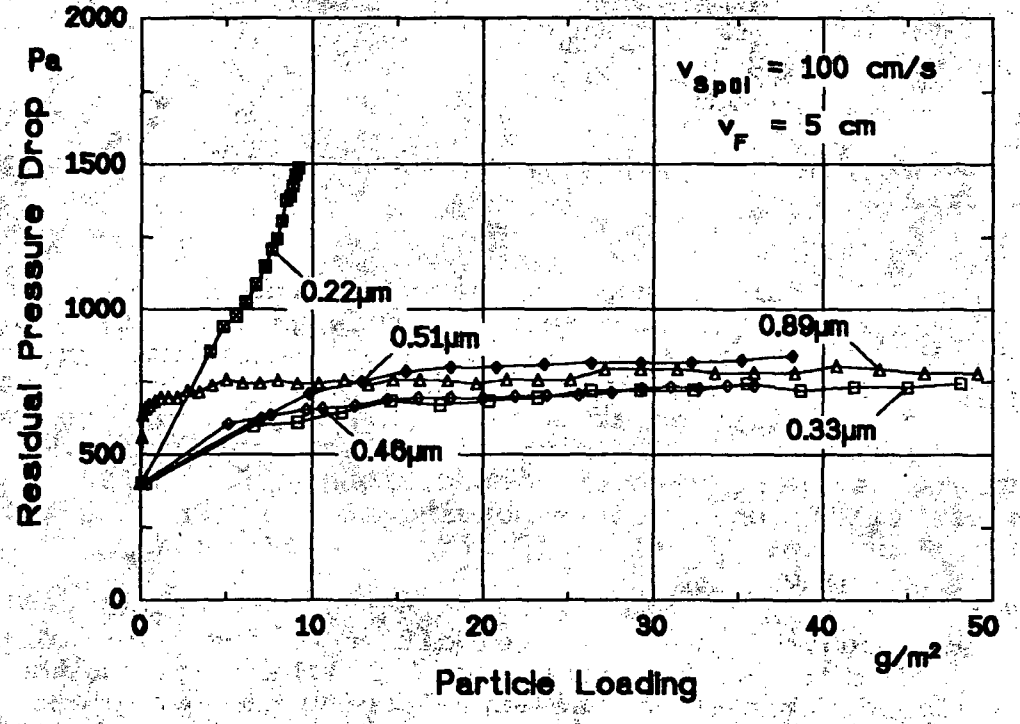

Fig. 6: Residual pressure drop for recleaning particles in the range of 0.22-0.89 μm diameter.

In a deep pleat HEPA filter unit, the filter medium is not directly exposed to the reverse flow during the recleaning process. The air first passes straight into a filter pleat at high velocity and only then is deflected to the filter medium.

Figure 7 illustrates this process. To achieve optimum recleaning, the same reverse flow velocity must be generated at each point within the filter pack, and the air flow through the filter unit must be uniform over the entire pleat depth. If there are local differences in the degree of recleaning achieved, the well cleaned areas will show higher flow velocities in the ensuing filtration phase, thus allowing particles to penetrate to greater depths into the filter medium and aggravating recleaning at these points.

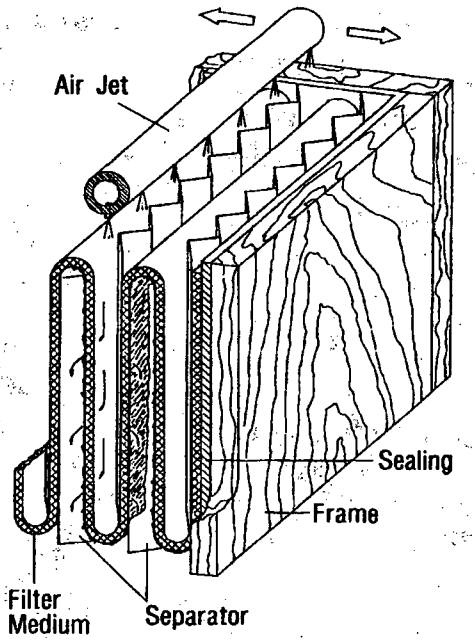

Fig. 7: Recleaning a HEPA filter unit by compressed air (schematic diagram).

Figures 8 and 9 indicate the influence of the air flow into a pleat upon the uniformity of the velocity through the filter medium along the pleat. The results are based on a computation model describing the pressure and velocity conditions in a triangular duct, of the type constituted in a HEPA filter pack by the filter medium and a separator [7].The diagram at the top indicates the situation under the usual filtering conditions, i.e., 1700 m^3/h of volume flow per filter unit, corresponding to a filtration rate of some 2.8 cm/s. Along the whole pleat there is only a minor change in the filtration velocity.

On the other hand, reverse flow velocities on the order of those required for recleaning show significant irregularities in the flow distribution. The diagram shows the actual curve along a pleat for a mean reverse flow velocity of 28 cm/s. There is a significant increase in velocity at the closed end of the pleat, which is particularly pronounced for an unloaded filter medium. It can be seen that the velocity increase diminishes with rising preloading towards the end of the pleat, as the high pressure drop of the loaded filter paper has an equalizing effect. Yet, the difference in velocities between the pleat inlet and the pleat end, at preload up to 2000 Pa, is still more than a factor of 2. Model calculations show that the irregular distribution becomes more pronounced with increasing flow of recleaning air. Excessive flow of recleaning air consequently, merely for flow reasons, may have negative impacts because they give rise to very different cleaning conditions along a pleat, although they would be advantageous from the filtration point of view. In addition, the pleat ends on the downstream side of a filter pack are subjected to unusually high loads at very high recleaning flows, which finally causes the pleat ends to rupture.

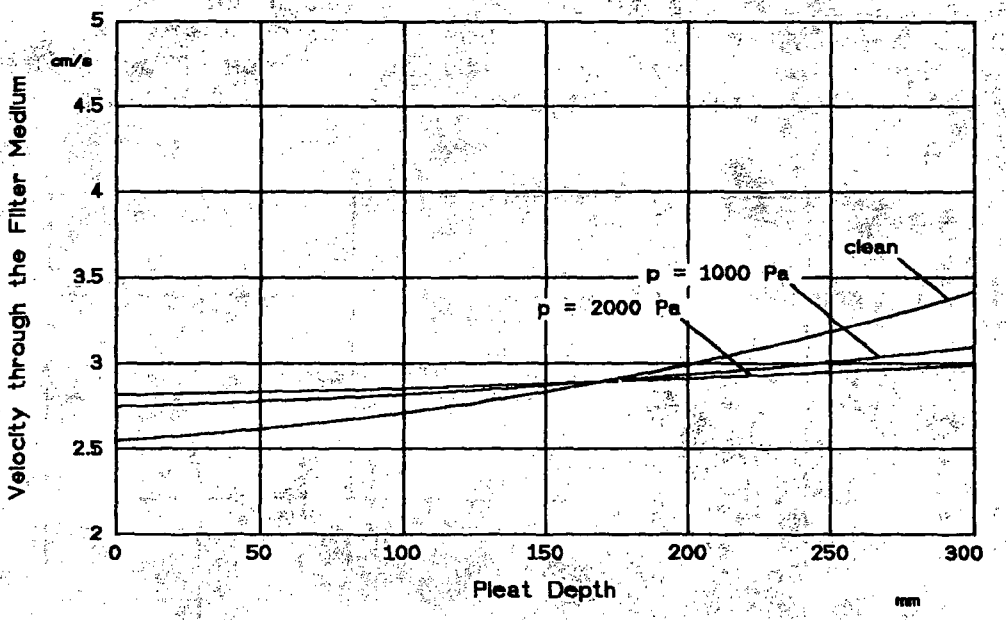

Fig. 8: Velocity through the filter medium along the upstream side of a filter pleat in a HEPA filter unit at design volume flow and various preloads.

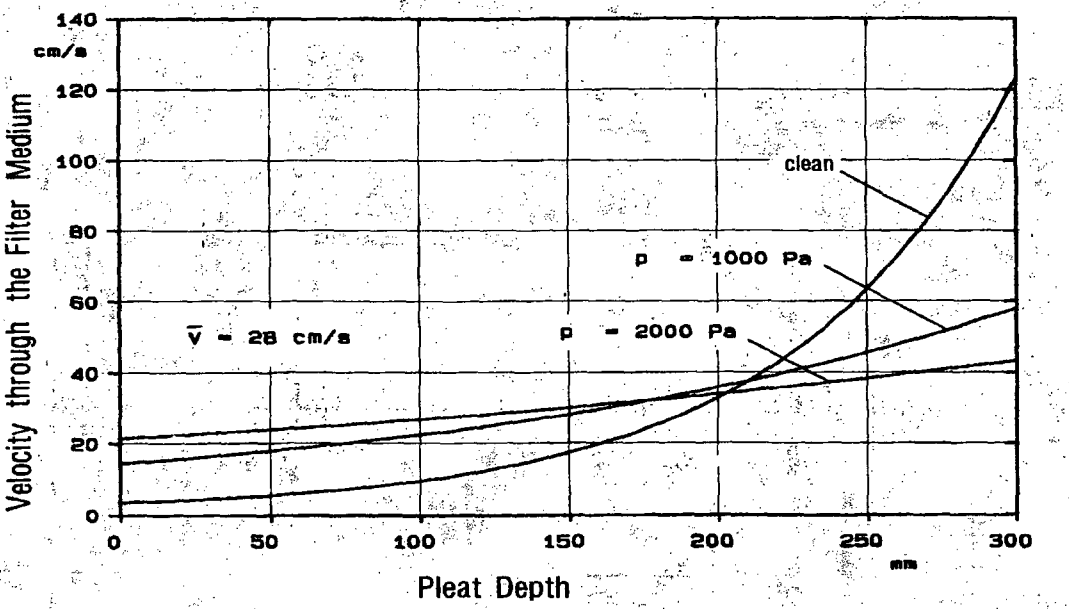

Fig. 9: Reverse flow velocity through the filter medium along the upstream side filter pleat of a HEPA filter unit at various preloads.

Due to the additional influence of pleating upon the local reverse flow velocities of the filter unit, the laboratory findings about the recleanability of filter media cannot readily be extrapolated to conditions in a filter unit. It must also be borne in mind that, in practice, dust normally has a broad distribution of

particle sizes not quite to be compared with the model dusts used. For the three types of dust chosen, which were filtered under practical conditions, recleanability is discussed below as compared to laboratory findings.

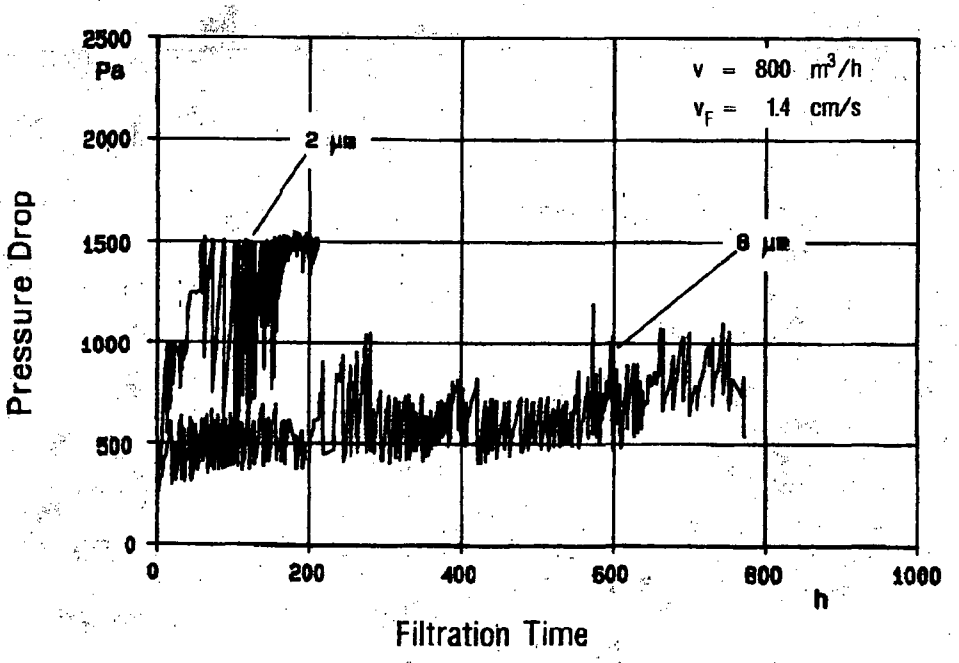

Fig. 10: Pressure drop curve of a HEPA filter for the filtration of fine dusts in a blast cleaning room.

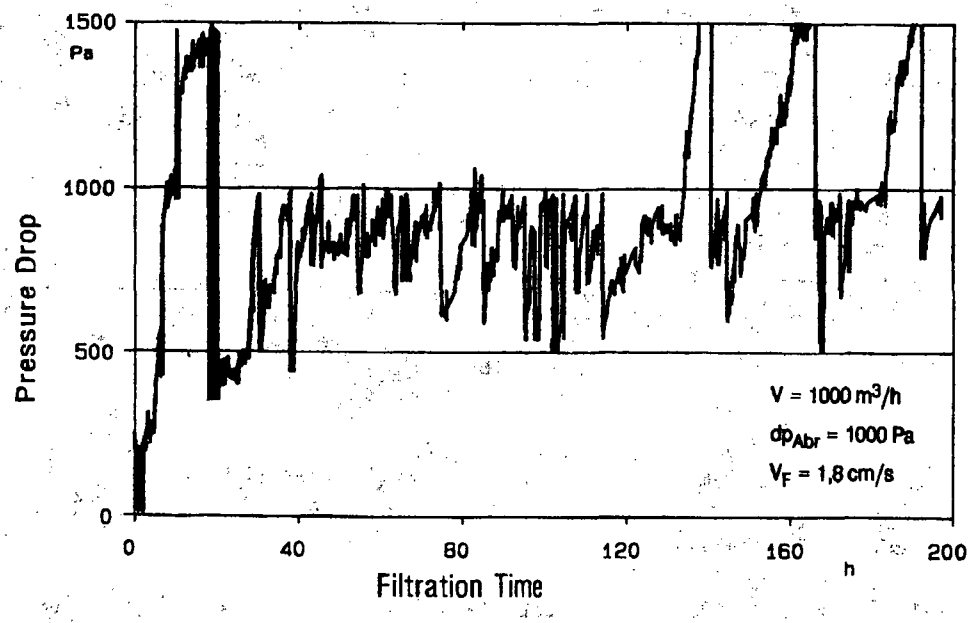

Fig. 11: Pressure drop curve of a HEPA filter for filtering fines in an Ag/Cd smelter.

For dust arising in a blast cleaning room , the curves shown in Fig. 10 were recorded as a function of particle diameters. For the coarser dust fraction, quasi-stable filter operation is possible over for a long period of time, with the residual pressure drop gradually rising to five times its initial level during approximately 800 h. For the finer dust fraction, the filter needs to be replaced after only 200 h. Under the existing conditions no stable filter operation was achievable. It must be taken into account that, in this case, 20% by mass of the dust is in the submicron range and, consequently, relatively difficult to detach from the filter medium.

In the filtration of extremely fine dusts arising in smelters, the curve shown in Fig. 11 is measured for HEPA filter units. Under comparable operating conditions, a maximum residual pressure drop of 800 Pa is observed for this dust. The development is seen to be extremely non-uniform, with pronounced fluctuations in the residual pressure drop probably due to changes in the dust composition as a function of time. Also in this plant, filter service lives of at least 500 h are possible.

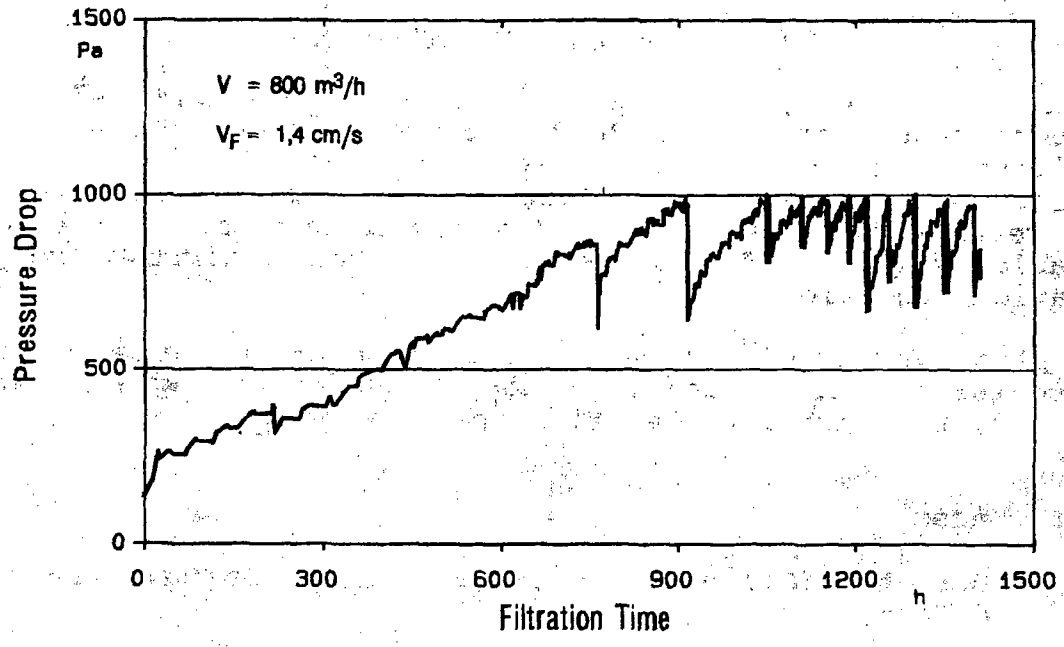

Fig. 12: Pressure drop curve of a HEPA filter for the filtration of cement dust.

Figure 12 shows the filter pressure drop plotted as a function of time under particularly difficult operating conditions. In this case, cement dust with particle diameters mainly in the submicron range was filtered. A special problem was posed by the high relative humidity of 70% at offgas temperatures of 110 °C. Due to the relatively low dust concentration, the pressure drop in the first filtration interval rises in an approximately linear fashion over a period of 750 h. Later, the typical sawtooth curve for the pressure drop of a recleanable filter can be seen. It is obvious that the residual pressure drop after recleaning fluctuates greatly also in this application, not exceeding a maximum residual pressure drop of 800 Pa. Compared to the two applications discussed above, the raw

gas concentration of cement dust is relatively low, as a result of which a total of only 11 recleaning cycles were required up to dismantling of the filter, despite the long period of operation of 1400 h.

In comparing the residual pressure drop, which is approx. 800 Pa in the first three applications with nearly stable filter operation, with the corresponding laboratory levels, one finds the residual pressure drop to be three or four times higher. This is a clear indication of the insufficient overall recleaning efficiency of the filter unit. In addition, it must be taken into account that the narrow filter pleats may become clogged by dust, which has not been removed, which also contributes to an increase in the residual pressure drop. Nevertheless, it is apparent that an approximately stable residual pressure drop can be achieved for HEPA filters in a combined mode of filtration and recleaning over long periods of operation. In particular at high fines contents of up to several g/m^3, this allows HEPA filters to be operated economically without the need for prefilters.

V. Conclusions

The area of application for HEPA filters can be expanded to include cases involving high upstream concentrations of fine particles. Cost-effective operation is only feasible via periodic *in-situ* recleaning of the filter units. Experimental investigations into reverse flow recleaning on a laboratory scale have shown that reliable long-term filter service can be attained under cyclical operation conditions.

Optimization of filter pleat geometries appears to be a prerequisite for attaining the high cleaning-air velocities necessary to improve filter field performance.

References

(1) Dorman, R.G.; Dust control and air cleaning; Pergamon Press; Oxford; 1974.

(2) Leibold, H.; Wilhelm, J.G.; "Entwicklung abreinigbarer Schwebstoffilter - Versuchstechnik und erste Ergebnisse"; Kfk-PEF 80; Vol. 2; p. 773-743; (1991).

(3) Borho, K.; " Mehrstufiges Abscheiden von Stäuben mit Schwebstoffiltersystemen"; Maschinenmarkt; Vol. 90; p. 1266-1269; (1984).

(4) Corn, M. and Silverman, L.; "Removal of solid particles from a solid surface by a turbulent air stream"; Am. Ind. Hyg. Assoc. J.; Vol. 21; p. 337-347; (1961).

(5) Löffler, F.; " Abblasen von an Filterfasern abgeschiedenen Feststoffteilchen"; Verfahrenstechnik: Vol. 6; p. 1-5; (1972).

(6) Medjimarec, V.; Okuyama, K.; Payatakes, A.C.; "Estimation of the drag force acting on particle dendrites"; J. Colloid. Interf. Sci.: Vol. 82; p. 543-559; (1981).

(7) Schlehuber, F.; Neuberger, M.; "HEPAFIL - ein Programm zur Berechnung der Strömungsgrößen am Schwebstoffilter"; KfK 4773; (1990).

DISCUSSION

ANON: Were any measurements made to see if the filter is damaged by the reverse air jet?

LIEBOLD: Yes, we did it on a laboratory scale and in the practice-related filter tests. The laboratory scale penetration was measured during all the filtration cycles. No leakages could be detected. Maximum penetration occurred all the time immediately after the recleaning but it did not exceed the initial penetration of the medium. For the full-scale filter elements, the pleat ends are critical, but by optimizing air pressure, nozzle diameter, and distance between the nozzle manifold and the filter pack, damage of the filter medium can be avoided during filter servicing. We controlled the integrity of the filter units by continuous monitoring with a photometer measuring in the forward direction. These photometers detect dust concentrations down to 0.2 $\mu g/m^3$.

PREDICTING MASS LOADING AS A FUNCTION OF PRESSURE DIFFERENCE ACROSS PREFILTER/HEPA FILTER SYSTEMS

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and
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Aiken, South Carolina

Abstract

In many filtration scenarios, the need to estimate either the maximum mass that can be loaded onto a filter system or the corresponding pressure difference across a system for a known or expected mass loading, is a major concern for efficient design and for realistic risk assessment. Previous work has focused on determining the specific resistance of a filter for an aerosol of particular interest. Few attempts were made to determine the effects of particle density or diameter on the specific aerosol and filter combination that had been tested experimentally.

This work is an attempt to broaden the ability to predict the mass loading and pressure drop by accounting for the aerosol particle size and density effects on the specific resistance using empirical correlations. These correlations, along with measured efficiency characteristics for the particular prefilter, provide a more accurate method at estimating the mass loading and final pressure difference across the prefilter/HEPA filter system. The equations and methodology described also applies to predicting pressure differences based on known or expected mass loadings.

Results show the average difference between the measured and predicted total mass loading was 11.7% with a standard deviation of ±15.7%, indicating that an estimate based on this technique can be expected to be 25% of the measured value due to the error in the correlations and the variation in particle size distribution between tests.

Introduction

The purpose of this work is to develop a methodology for predicting the mass loading and pressure drop effects on a prefilter/ HEPA filter system. The methodology relies on the use of empirical equations for the specific resistance of the aerosol loaded filter as a function of the particle diameter. These correlations relate the pressure difference across a filter to the mass loading on the filter and account for aerosol particle density effects. These predictions are necessary for the efficient design of new filtration systems and for risk assessment studies of existing filter systems. This work specifically addresses the prefilter/HEPA filter Airborne Activity Confinement Systems (AACS) (1), at the Savannah River Site. Other applications include air pollution control in factories, buildings or facilities where large quantities of aerosols may be released and must be contained. The AACS consists of a two-stage prefilter/HEPA filtration system in which the demister/prefilter is designed primarily to remove water droplets, but will also remove any other large aerosol particles, thereby

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reducing the mass loading on the High Efficiency Particulate Air (HEPA) filter and extending the service life of the HEPA filter.

In order to determine the mass loading on the system, it is necessary to establish the efficiency characteristics for the prefilter, the mass loading characteristics of the prefilter measured as a function of pressure difference across the prefilter, and the mass loading characteristics of the HEPA filter as a function of pressure difference across the filter. Furthermore, the efficiency and mass loading characteristics need to be determined as a function of the aerosol particle diameter. A review of the literature revealed that no previous work had been performed to characterize the prefilter material of interest.

The mass loading capacity of the HEPA filter was previously studied [2] [3] [4] [5]. The direction of this research was to develop correlations to allow the prediction of either the final pressure difference across a loaded HEPA filter or the maximum mass that could be loaded onto a filter for a specified pressure difference. The experimental data from Novick, et al [2] [3], for the specific resistance were found to be well correlated with the mass median particle diameter and independent of the particle density.

In order to complete the foundation of information necessary to predict total mass loadings on prefilter/HEPA filter systems, it was necessary to determine the prefilter efficiency and mass loading characteristics. The measured prefilter characteristics combined with the previously determined HEPA filter characteristics allowed the resulting pressure difference across both filters to be predicted as a function of total particle mass for a given particle distribution. These predictions compare favorably to experimental measurements (±25%).

Theory

The total efficiency of a filter can be described by combining the individual theoretical efficiencies due to impaction, interception and diffusion. Theoretical equations exist for each of these mechanisms, but usually semi-empirical equations are used to improve the accuracy of the predicted efficiency. The combined single fiber efficiency is generally determined as the sum of the efficiency of each collection mechanism. Equations for the most important mechanisms, impaction [6], diffusion[6] and interception [7] are given.

$$\eta = \eta_I + \eta_D + \eta_I \qquad (1)$$

where

$$\eta_I = \psi^3 / \{ \psi^3 + (0.77\ \psi^2 + 0.22)\}$$

$$\psi = \rho V d_p^2 C / 18 \mu d_f$$

$$\eta_D = 6\ Sc^{-2/3}\ Re^{-1/2}$$

$$Sc = \mu / \rho D$$

$$Re = V \rho d_f / \mu$$

$$\eta_I = \{1/(2\ Ku)\}\ \{2\ (1+R)\ [\ln\ (1+R)] - (1+R) + [1/(1+R)]\}$$

$$Ku = \alpha_f - [(\ln \alpha_f) / 2] - (3/4) - (\alpha_f^2 / 4)$$

The theoretical collection efficiency of the filter (E) is then determined from the following equation given by Hinds [7].

$$E = 1 - e^{-(f \eta)} \quad (2)$$

where $f = 4 \alpha h / \pi d_f (1 - \alpha_f)$

h = depth of filter material = 5.08 cm (2 in)

These theoretical efficiency equations hold for both solid particles as well as liquid particles providing the particle sticking coefficient is unity.

A simple model describing the total pressure increase across a filter due to solid particle mass loading can be written as the sum of the pressure increase across the clean filter plus the pressure increase across the filter cake due to particle loading. (8)

$$\Delta P = \Delta P_0 + \Delta P_c \quad (3)$$

This simple model is appropriate for HEPA filters because their high collection efficiency causes a particle cake to rapidly form on the surface of the filter. From D'Arcy's law, ΔP_0 can be written in terms of the gas media velocity times a constant and the gas media velocity times the mass loading per unit filter area times another constant. The first constant, K1, depends upon the physical characteristics of the filter media such as the fiber diameter, filter porosity and thickness. The other constant, K_2, is identified as the specific resistance of loading material on the filter and depends primarily upon the particle diameter.

$$\Delta P_0 = K_1 V \quad (4a)$$

$$\Delta P_c = K_2 V M / A \quad (4b)$$

K_2 can be experimentally correlated with parameters that are known or easily estimated so that accurate predictions can be made for the pressure increase across a given filter as a function of mass loading. (4) (5) (9)

For a low efficiency filter, like a woven fiber prefilter, a particle cake never covers the entire surface of the prefilter. Most of the particles are removed inside the layers of the prefilter. As mass is collected on the prefilter, the specific resistance changes due to the particles becoming trapped inside the filter. The specific resistance, therefore, becomes a function of the particle mass per unit area being collected in the filter. A simple model can be postulated similar to that in Equation 4b,

$$\Delta P = (K_{1P} + K_{2P} M/A) V \quad (5)$$

where the subscript P denotes prefilter.

Mathematically, this equation is the same as Equation 3. As in the case of the HEPA filter model, an empirical correlation can be made that relates K_P to the particle diameter of the challenge aerosol.

For liquid aerosol mass lengths, models that predict the pressure difference across a filter are very sensitive to the geometry of the filter. These models differ from the solid mass loading models because as liquid aerosol is collected on the filter, an equilibrium develops between mass collected and

mass removed by drainage. Therefore, the total liquid mass collected no longer contributes to the pressure difference across the prefilter, once the equilibrium value has been attained.

$$\Delta P_{we} / \Delta P_0 = A_1 [(d_f / \alpha_f h)^{0.561} (A t \cos\theta / Q \mu)^{0.477}] \quad (6)$$

Equation 6 relates the equilibrium pressure difference to the physical characteristics of the filter [10]. In general, the contact angle of the droplet with respect to the fiber is usually unknown. In addition, for the Savannah River prefilter, the effective fiber diameter is an uncertain quantity due to the stranded nature of the woven fibers.

Experimental

Particle collection efficiencies for the prefilter were tested using Savannah River Site prefilter material. The prefilter is formed from individual teflon fibers with nominal diameters of 0.02 mm. The individual fibers are bundled into strands with resulting diameters ranging between 0.78 mm and 1.3 mm. The strands are woven into a mesh-like structure with the addition of fine stainless steel wire. The prefilter mat contains 24 layers (12 double layers) of this material which is compressed to a thickness of two inches with a stainless steel frame. Many of the fibers have been broken from the strands and protrude at various angles from the strands.

For both the efficiency and the mass loading tests, the prefilter material was cut to a 10.2 cm x 12.7 cm (4 in. x 5 in.) rectangle and stacked together in a metal holder designed to hold the 12 double layers of material. This arrangement was designed to maintain the prefilter mat thickness of 2 inches. A metal frame covered the edges of the prefilter mat in the holder, leaving a rectangular face area of 7.6 cm x 10.2 cm (3 in. x 4 in.).

In the AACS, standard prefilter size is 0.6 m x 0.6 m (2 ft x 2 ft) with an effective filtration area of 56.8 cm x 56.8 cm or 3210 cm^2. The nominal total flow rate through the AACS is about 100,000 to 120,000 cfm. The flow is distributed through 5 sets of compartments, each with 20 prefilter assemblies and 32 HEPA filters. The lower AACS flow would result in a flow rate of at least 1000 cfm through each prefilter assembly. Therefore, the resulting gas velocity through the prefilter in the AACS can be calculated to be approximately 150 cm/sec. For the laboratory scale filter with an effective area of 77.4 cm^2 (12 in^2), the volumetric flowrate through the test assembly should be at least 24.6 cfm to simulate the AACS.

A HEPA filter with an effective filtration area (not cross sectional area) of 3855.5 cm^2 (4.15 ft^2) was used in the test system downstream of the 77.4 cm^2 prefilter. The volumetric gas flowrate was controlled at 25 cfm resulting in a HEPA media velocity of 3 cm/s. The filtration velocities through each test filter are the same as those through the AACS filters.

Tests were conducted to establish efficiency characteristics for the prefilter and to measure mass loading characteristics as a function of pressure difference across the prefilter in order to develop a methodology for predicting the mass loading and pressure drop effects on a prefilter/HEPA filter system. To determine filtration efficiency of the prefilter for both solid and liquid particles, various nebulizing methods were used. A TSI Model 3075/3076 Constant Output Atomizer (COA) was used with a TSI Model 3071 Electrostatic Classifier (EC) to produce both solid and liquid particles with Mass Median Aerodynamic Diameters (MMAD's) less than 0.5 μm. Sodium chloride was chosen as the

material for the small solid particles, and fluorescein was used as a tracer in solutions of ethylene glycol, diethylene glycol and dioctyl phthalate which were chosen for the small liquid particles. To generate solid and liquid particles greater than 1.5 μm a TSI Model 3450 Vibrating Orifice Generator (VOG) was used. A sodium hydroxide and water solution with fluorescein was used to produce the solid particles, and the same solutions as listed above were again used to produce the liquid particles. A 3-jet Collison Nebulizer was used with a TSI Model 3072 Evaporation/Condensation Aerosol Conditioner (E/C) to generate liquid particles in the range between 0.5 micrometers and 2.5 μm. Solutions of ethylene glycol, diethylene glycol and dioctyl phthalate with fluorescein tracer were again used to produce these liquid particles.

In tests utilizing sodium chloride particles, efficiencies were determined by counting particles with two Condensation Nucleus Counters (CNC), one sampling in the upstream flow of the aerosol and the other sampling in the downstream flow of the prefilter. Upstream and downstream particle counts were taken simultaneously for one minute. Several readings were taken to assure reproducibility and averaged to improve statistical accuracy. The downstream particle count was divided by the upstream particle count to determine the percent penetration of particles through the prefilter. The efficiency ratio was determined by subtracting the percent penetration from 100%.

In tests utilizing fluorescein as a tracer, the prefilter was rinsed in a sodium hydroxide/purified water solution following the test. The rinse solution was analyzed with the Model 111 Turner Fluorometer. The intensity of the light re-emitted by a sample exposed to a constant ultraviolet light source is directly proportional to the concentration of fluorescein in the solution. These fluorometric readings were multiplied by the amount of the rinse solution to obtain an equivalent mass. At least three rinses of each filter were made until the fluorometric reading was less than 10 times the background reading. The rinse results from each filter were summed to give separate equivalent mass results for the prefilter and the HEPA filter. The efficiency is the ratio of the equivalent mass on the prefilter to the total equivalent mass on the prefilter plus the HEPA filter.

Experimental measurements of the filtration efficiency as a function of particle diameter for both solid and liquid particles at a filtration velocity of 152 cm/s, are shown in Figure 1. Also shown in Figure 1 is a calculation of the expected theoretical efficiency based on Equations 1 and 2. The differences are primarily attributed to the non-uniform distribution of fibers in the prefilter due to its stranded construction.

The mass loading characteristics were determined as a function of pressure difference across the prefilter with respect to particle size and composition of the aerosol. The prefilter mass loading tests were done at a flow velocity of 152 cm/s. Pressure changes were monitored across the prefilter and across the HEPA filter. The clean prefilter and HEPA filter were initially weighed and placed into the test system. The filters were loaded with challenge aerosols until a desired total pressure difference across both filters was achieved. When the given target pressure difference was reached, both filters were carefully removed from the system and weighed again. The change in mass was used to determine the mass loading per unit filter area.

For liquid aerosol mass loading tests, the prefilter and HEPA filter were weighed when the first target ΔP was reached. The drainage of liquid from the prefilter was also collected and weighed as part of the mass collected on the prefilter. The filters were carefully replaced into the system and the test continued until the next ΔP was reached. This procedure was repeated until the final target ΔP was reached.

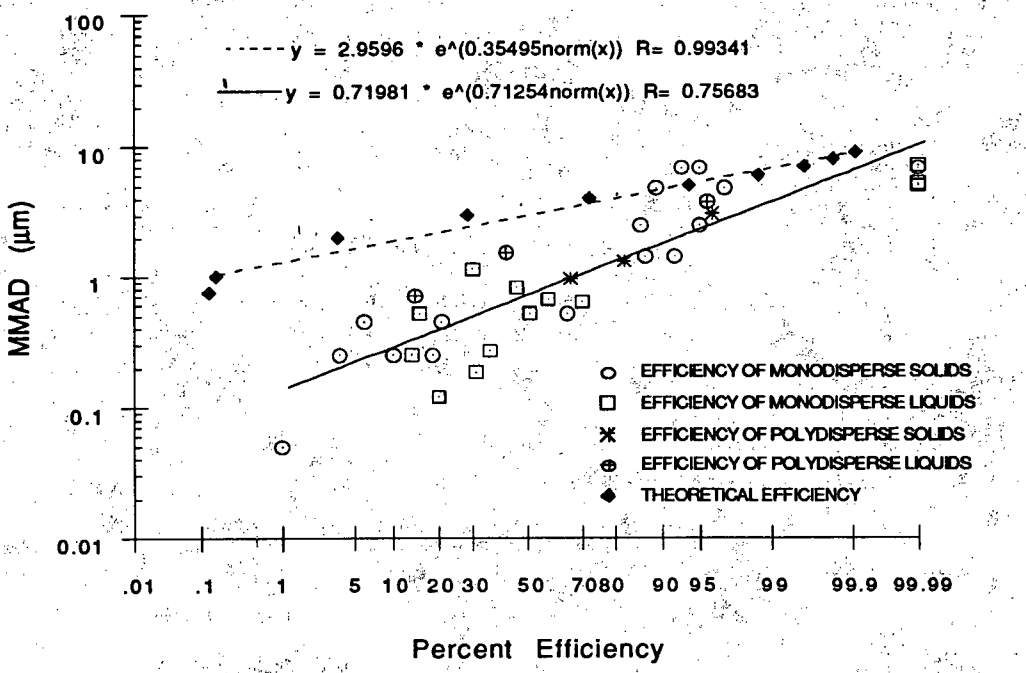

FIGURE 1 Theoretical and experimental collection efficiency curves for particles for the prefilter material at a face velocity of 152 cm/s. Experimental particle diameters are both solid and liquid particles.

In contrast to the liquid tests, the solid particles mass loading tests each had to be started from ΔP_0, removed and weighed at the target ΔP, and new filters used for the next target ΔP. This procedure was required due to the change in particle cake structure of solid particles caused by handling the prefilters.

Three different aerosol generators were used to generate the three sizes of liquid particles. A BGI Inc. 6-jet Collison Atomizer was used to atomize a solution of 50% dioctyl phthalate (DOP) and 50% isopropyl alcohol generating particles with an MMAD of approximately 1.5 µm. To generate particles with an MMAD less than 1.5 µm, an evaporation-condensation aerosol generator was used in conjunction with a TSI Constant Output Atomizer (COA). The third liquid generation technique used three Bennett ultrasonic nebulizers to generate an aerosol with an MMAD greater than 1.5 µm. A graph of the mass loading versus the net pressure change for liquid particles is shown in Figure 2. Note that there is no change in ΔP with mass loading within the limits of the resolution of the pressure transducers.

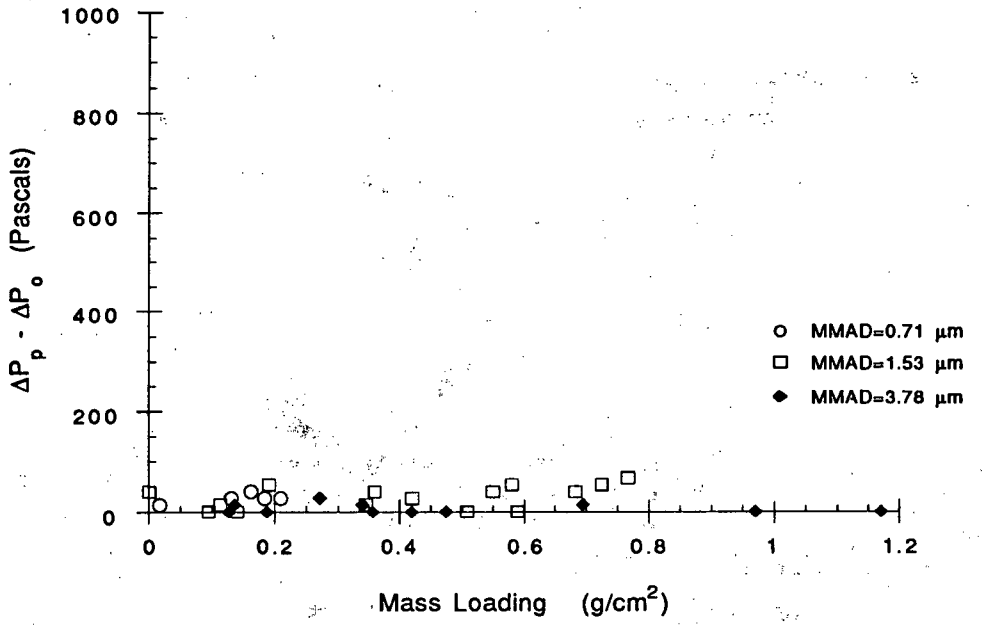

FIGURE 2 Mass loading -vs- net pressure change for liquid particles on the prefilter material at a face velocity of 152 cm/s. Three particle sizes were studied, each MMAD being the average of tests done for that specific size. Two liquid solutions were used, di-ethylene glycol and dioctyl phthalate.

Three distributions of solid particles were dispersed using a BGI Model WDF-II Wright Dust Feeder. Aluminum oxide powder was chosen to produce the solid particle aerosol. The output aerosol particle size is solely dependent on the size of the powder used down to a limit of about 0.1 µm. Figure 3 shows a graph of the mass loading versus the net pressure change for solid particles.

The specific resistance of the prefilter was determined from data obtained in the mass loading tests for solid particles. This was done by dividing the slope of each curve on the graph in Figure 3 by the filtration velocity. This data is plotted against the mass median particle diameter (MMD) and shown in Figure 4. The data was analyzed with a linear least squares curve fit resulting in the correlation,

$$\Delta P_P = \Delta P_0 + [4.427 + (0.0001103 / d_P)] \, V \, M / A \qquad (7)$$

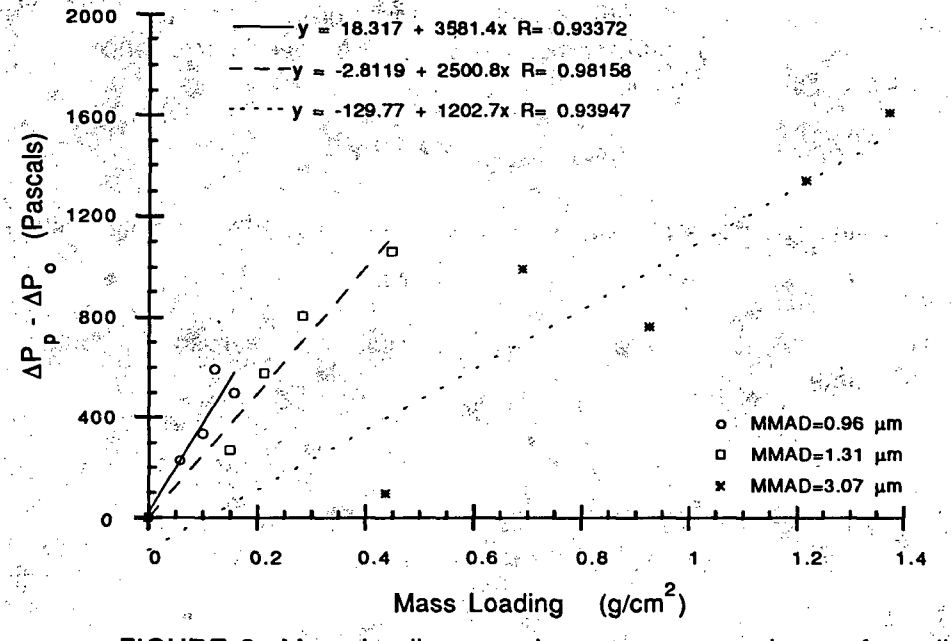

FIGURE 3 Mass loading -vs- the net pressure change for solid particles on the prefilter material at a face velocity of 152 cm/s. Three particles sizes of aluminum oxide powder were studied, each MMAD being the average of tests done for that specific size.

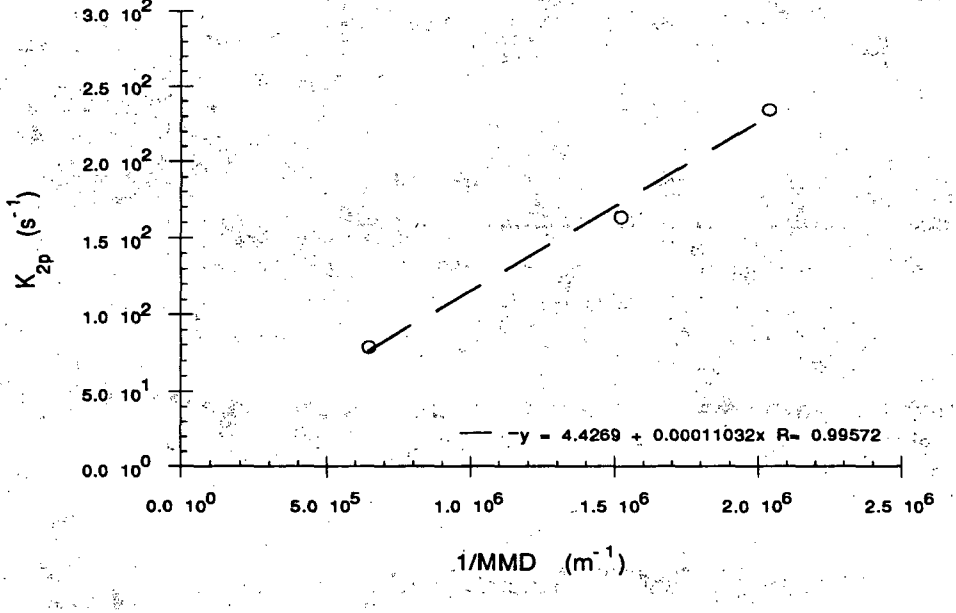

FIGURE 4 The specific resistance of aluminum oxide filter cakes plotted as a function of the inverse of the MMAD for the prefilter material.

The MMD was chosen to describe the aerosol introduction, to be consistent with the HEPA filter correlation. This correlation will be used with the prefilter efficiency characterization to calculate the total predicted mass loading on a prefilter/HEPA filter system. To complete this calculation, the particles that penetrate the prefilter are loaded onto the HEPA filter and must be considered. Figure 5 presents the data that was used to previously determine the correlation for the specific resistance as a function of particle diameter for HEPA filters. (2) (3) (9)

$$\Delta P_H = \Delta P_0 + [-1.586 \times 10^5 + (0.9494 / d_P)] \, V \, M / A \qquad (8)$$

where the subscript H denotes HEPA filter and d_P is the MMD required to determine the specific resistance (K_2) of the HEPA filter .

This correlation allows the ΔP to be calculated for a given mass loading of an aerosol distribution with a known mass median particle diameter.

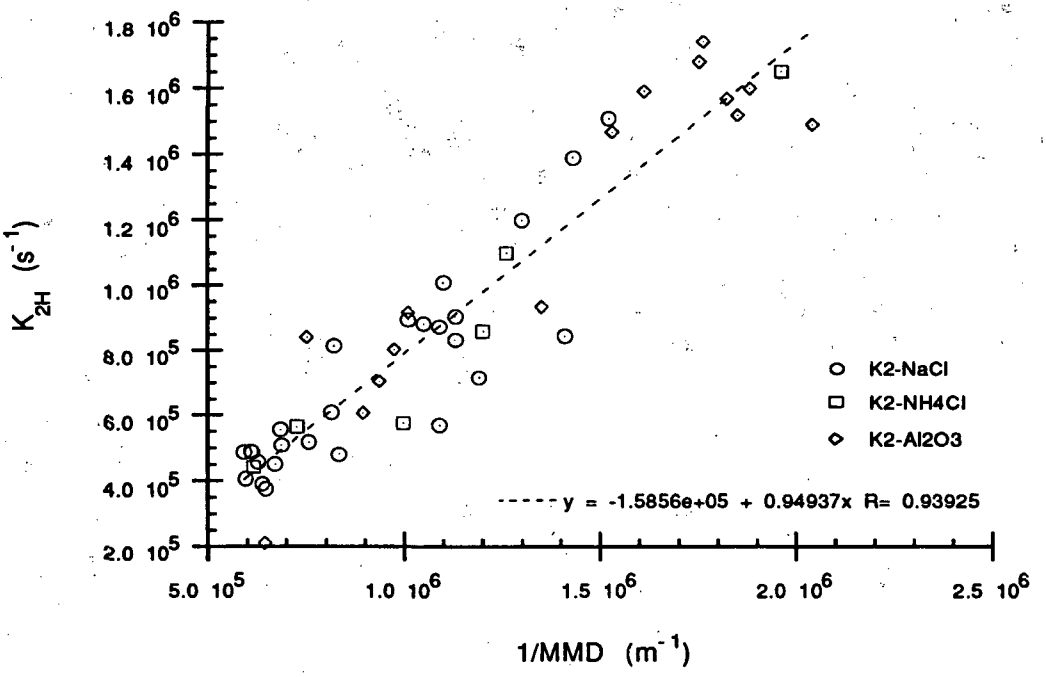

FIGURE 5 The specific resistance of sodium chloride, ammonium chloride and aluminum oxide filter cakes on the HEPA filter media plotted as a function of the inverse of the MMAD.

Predicting Loading on Prefilter/HEPA Filter Systems

The mass loading on a prefilter/HEPA filter system can be predicted by empirical correlations for the prefilter efficiency, prefilter mass loading and HEPA filter mass loading. These correlations provide an accurate method of estimating the mass loading and final pressure difference across the

prefilter/HEPA filter system. Separate expressions were developed for liquid and solid particles because of the difference in the structure of the accumulated particles on the filters.

Solid Particles

In order to model the behavior of the total aerosol mass collected on a system for a given pressure drop as a function of particle diameter, three fundamental equations are necessary. These equations will then be combined with the correlations developed experimentally. The total pressure difference in the prefilter/HEPA filter system can be expressed as

$$\Delta P_{SYSTEM} = \Delta P_H + \Delta P_P + (\Delta P_0)_H + (\Delta P_0)_P \quad (9)$$

The efficiency of the prefilter can be expressed in terms of mass loading,

$$E = M_P / M_P + M_H \quad (10)$$

And the specific resistance of either filter can be expressed,

$$K_2 = (\Delta P - \Delta P_0)\, A / V\, M \quad (11)$$

From Figures 4 and 5 in the previous section, the specific resistance, K_2, can be correlated with the mass median aerosol diameter challenge in the prefilter and HEPA filter.

$$K_{2H} = -1.586 \times 10^5 + 0.9494 / MMD_H \quad (12)$$

$$K_{2P} = 4.427 + 0.0001103 / MMD_P \quad (13)$$

In this series of equations, the surface area, A, of the prefilter and HEPA filter are both known quantities. The velocity, V, through the prefilter and HEPA filter are parameters initially set for the system. The initial ΔP across the prefilter and HEPA filters are both measurable quantities based on the velocity. The final or design limit ΔP of the system is an assumed value based on the system that is being studied. The mass collected on the HEPA filter, M_H and the mass collected on the prefilter, M_P are both unknown quantities. The ΔP across the prefilter and the ΔP across the HEPA filter are also unknown quantities. The efficiency of the prefilter is a quantity established from the prefilter efficiency characteristics tests. The mass median diameter, MMD_P, of particles collected on the prefilter is a known value based on the measured or assumed aerosol distribution challenging the system. However, the particle size distribution, MMD_H, for the particles collected on the HEPA filter is an unknown quantity.

The key to solving the system of equations is to determine the MMD of the aerosol distribution reaching the HEPA filter. The first step is to divide the known or assumed initial aerosol distribution into segments. In this work, the initial aerosol distribution was assumed to be the average of the measured Mass Median Aerodynamic Diameters (MMAD's) for each distribution tested, and the geometric standard deviation was assumed to be 2.0. The reason the measured distributions were not used to generate the calculated values of mass loading and pressure difference was to provide an indication of the magnitude of the error that might be expected using this methodology in a predictive

manner using reasonable initial assumptions. The segments of the initial distribution can be arbitrarily chosen. For our calculations, the mid points of each segment were based on the cut points (ECD's) of a cascade impactor. Once the midpoint of each segment is determined, the penetration efficiency of the particles in that segment can be determined from the efficiency curve of the prefilter. The penetrating aerosol distribution is determined by multiplying the efficiency by the quantity of aerosol in each segment. In this case, the mass of aerosol was used to define the distribution since the mass loading is the ultimate quantity of interest. Once the distribution of the aerosol that penetrates the prefilter, and therefore challenges the HEPA filter, is determined, the mass median diameter (MMD_H) of the distribution can be calculated. The MMD_H is then used to determine K_{2H} from Equation 12. The specific resistance of the prefilter (K_{2P}) is determined for Equation 13 by calculating the MMD of the initial aerosol distribution from the known or assumed MMAD, by dividing the MMAD by the square root of the particle density.

Knowledge of the specific resistances reduces the problem to a set of four equations and four unknowns. The equations to be solved are (8), (9) and (10), where Equation (10) is written once for the HEPA filter and again for the prefilter. The four unknowns are the mass collected in the HEPA, M_H, the mass collected on the prefilter, M_p, the final ΔP of the HEPA, ΔP_H, and the final ΔP of the prefilter, ΔP_P. A comparison between the actual mass collected on the HEPA filters in the laboratory experiments, and the mass that was calculated from the methodology presented above, is given in Table 1. The average of the absolute value of the differences between the calculated and measured masses is 11.7%.

Table 2 compares the calculated pressure increases and the measured pressure increases on the filters used in these experiments. The average difference for the prefilter pressure increase is 12.9% and the corresponding average difference for the HEPA filter pressure increase is 20.6%.

Calculations predicting the mass loading capabilities of the AACS are based on the following initial conditions and assumptions.

Total ΔP of System:	ΔP_{System} = 1750 Pa
Initial ΔP across HEPA filter:	$\Delta(P_0)_H$ = 228.2 Pa
Initial ΔP across Prefilter:	$\Delta(P_0)_P$ = 187.9 Pa
Surface area of HEPA filter:	A_H = 2229.7 m^2
Surface area of Prefilter:	A_P = 32.12 m^2
Velocity through HEPA filter:	V_H = 0.0254 m/s
Velocity through Prefilter:	V_P = 1.76 m/s

The predicted total mass of solid particles collected by the system with a given total pressure drop of 1750 Pa, as a function of the MMAD is shown in Figure 6.

Figure 7 compares the predicted total mass of solid particles that are expected to be collected by the AACS when calculated using the above methodology to extrapolated experimental test data. The experimental data was scaled by the AACS/experimental filter area ratios to obtain the extrapolated AACS values.

Table 1. Measured vs. calculated mass loadings on the prefilters and HEPA filters used in the laboratory tests

Initial MMAD (μm)	Initial MMD (μm)	Penetrating MMD (μm)	Calc. Prefilter Efficiency	Calc. Prefilter Mass (g)	Calc. HEPA Mass (g)	Calc. Total Mass (g)	Meas. HEPA Mass (g)	Meas. Prefilter Mass (g)	Total Meas. Mass (g)	Calc. vs. Meas. Total Mass Diff (%)
3.34	1.69	0.71	0.98	33.87	0.55	34.42	0.65	33.85	34.50	- 0.2
3.16	1.60	0.71	0.98	66.30	1.27	67.57	4.95	71.60	76.55	-11.7
3.13	1.58	0.71	0.98	72.63	1.46	74.09	1.75	53.35	55.10	34.5
3.13	1.58	0.71	0.98	121.40	2.44	123.84	6.25	106.35	112.60	10.0
2.65	1.34	0.71	0.97	79.37	2.49	79.37	2.40	94.20	96.60	-17.8
1.38	0.70	0.41	0.85	11.70	2.05	13.75	2.60	11.50	14.10	- 2.5
1.35	0.68	0.41	0.84	31.22	5.78	37.00	6.90	34.60	41.50	-10.8
1.21	0.61	0.41	0.81	20.00	4.67	24.68	4.65	21.90	26.55	- 7.1
1.21	0.61	0.41	0.81	13.32	3.11	16.43	3.60	16.35	19.95	-17.6
0.99	0.50	0.33	0.74	4.50	1.62	6.11	1.95	4.45	6.40	- 4.5
1.00	0.51	0.33	0.74	7.92	2.80	10.72	3.35	7.75	11.10	- 3.5
0.83	0.42	0.33	0.66	12.02	6.22	18.24	7.25	12.10	19.35	- 5.7
1.02	0.52	0.33	0.75	14.15	4.83	18.99	5.65	9.40	15.05	26.2
							|Difference| Average			11.7
							Standard Deviation			15.7

Table 2. Measured vs. calculated pressure increases across the prefilter and HEPA filter used in the laboratory tests

Initial MMAD (μm)	Total System ΔP (Pa)	Measured $\Delta P_H - \Delta P_0$ on HEPA (Pa)	Measured $\Delta P_P - \Delta P_0$ on Prefilter (Pa)	Calculated $\Delta P_H - \Delta P_0$ on HEPA (Pa)	Calculated $\Delta P_P - \Delta P_0$ on Prefilter (Pa)	HEPA Difference (%)	Prefilter Difference (%)
3.34	930	93	492	51	463	-45.6	- 5.8
3.16	1488	359	757	117	955	-67.5	26.2
3.13	1606	146	983	134	1056	- 8.1	7.4
3.13	2405	385	1595	224	1765	-41.7	10.6
2.65	1953	173	1329	229	1308	32.4	- 1.6
1.38	1134	306	266	345	373	12.8	40.1
1.35	2405	944	1050	972	1016	3.0	- 3.2
1.21	1927	718	797	786	725	9.5	- 9.1
1.21	1422	425	571	524	482	23.2	-15.5
0.99	957	332	226	343	198	3.2	-12.3
1.00	1355	625	332	593	346	- 5.1	4.1
0.83	2365	1488	492	1319	630	-11.4	28.1
1.02	2047	1076	585	1025	606	- 4.7	3.6
					| Difference | Average	20.6	12.9
					Standard Deviation	28.4	16.8

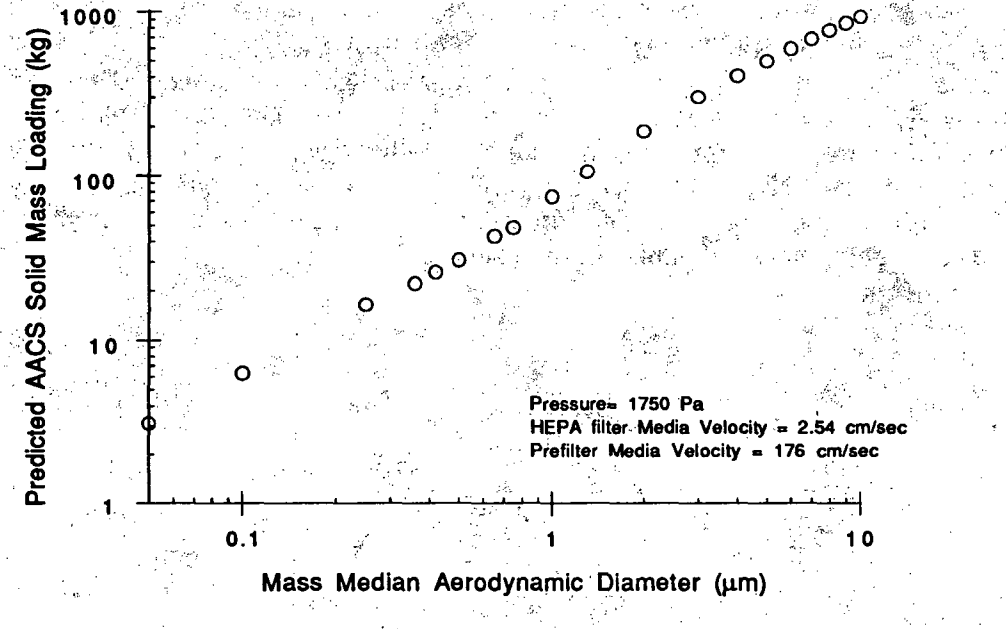

FIGURE 6 Predicted AACS mass loading for solid particles as a function of particle size.

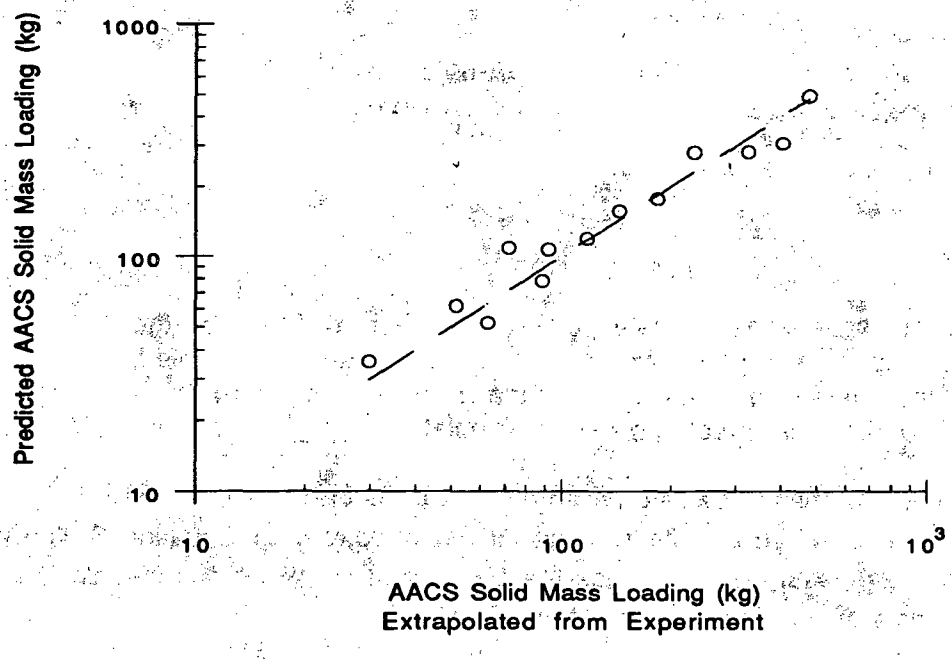

FIGURE 7 Comparison between the maximum solid aerosol mass loading predicted for the AACS determined by calculation and by extrapolation of the experimental results scaled by the respective AACS/Experimental filtration area ratios. The dashed line represents perfect agreement.

Liquid Particles

A similar type of strategy can be developed for predicting the liquid mass loaded onto a system. However, in the liquid model an equation cannot be written for K_2 because no cake is formed. Instead, a graph of net pressure change versus the liquid mass loading on the HEPA filter, Figure 8, was used to determine an average mass loading for a liquid at a given ΔP regardless of the particle diameter. The assumption is that the liquid particles will coalesce and coat the fibers with a liquid film after attaining a critical volume. Therefore, the first order relationship between mass loading and ΔP should not be a function of droplet size. Note that since the prefilter drains excess liquid mass away from the prefilter fibers, the equilibrium pressure difference across the prefilter is a constant. Therefore, the HEPA filter always determines the limit of the system ΔP.

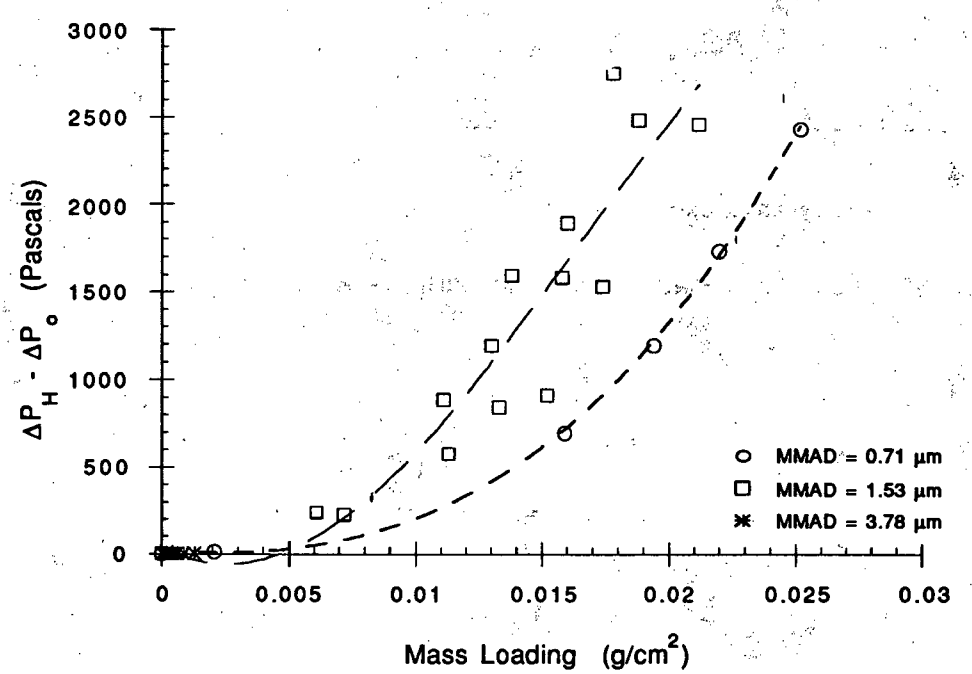

FIGURE 8 Mass loading -vs- net pressure change for liquid particles on the HEPA filter media at a face velocity of 3 cm/s. Three particle sizes were studied, each MMAD being the average of tests done for that specific size. Two liquid solutions were used, di-ethylene glycol and dioctyl phthalate.

In addition, $\Delta P_P - (\Delta P_o)_P$ is assumed to be zero based on the results presented in Figure 2. This results in only two unknowns, ΔP_H which can now be calculated directly from Equation 8 with a known target pressure and initial pressure drops across the filters, and M_P which can be calculated directly from Equation 9 after determining the efficiency from Figure 1.

Using the AACS parameters as an example, the average mass loading per unit area of the HEPA filter, for a pressure difference of 1550 Pa, is determined to be 0.018 grams/sq cm. Since the total area of the HEPA filter media in the system is 22,297,000 sq cm, the amount of mass the HEPA

filters in the system could collect is 401 kg. This amount of liquid mass depends only on the total HEPA filter filtration area and the design ΔP limit. The prefilter will remove mass in relation to its efficiency. For example, for a particle distribution with an MMAD of 1 micrometer, the prefilter efficiency is 0.68, as determined from Figure 1. Therefore, for a design limit system pressure difference of 1750 Pa across the prefilters and HEPA filters, the total mass of 1 μm aerosol that could be collected on the system is 1253 kg. The predicted total mass of liquid particles collected by the AACS with a given total pressure drop of 1750 Pa, as a function of the MMAD is shown in Figure 9. No comparison is made between the measured and predicted liquid mass loadings due to the number of common parameters.

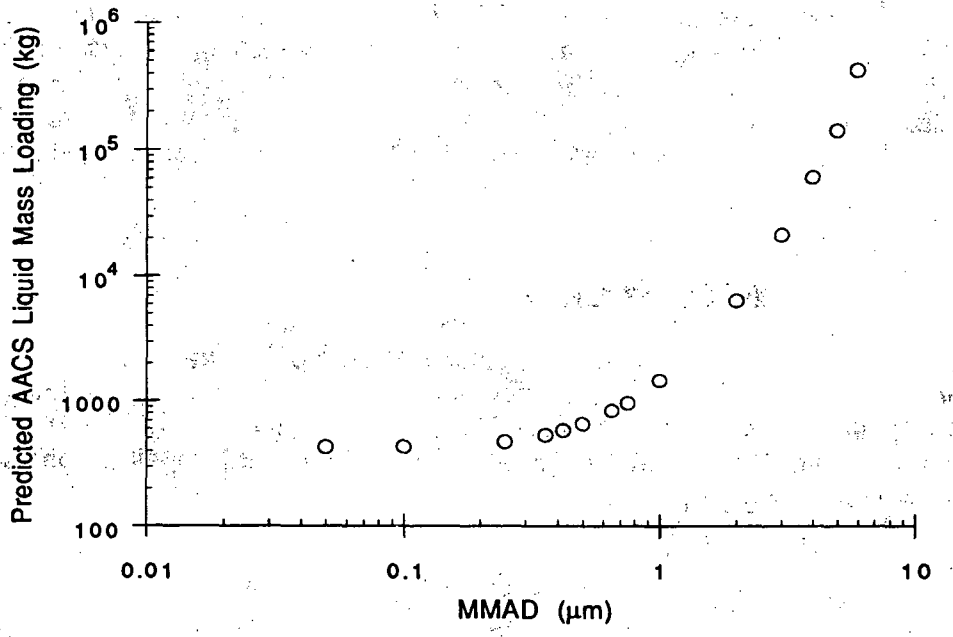

FIGURE 9 Predicted AACS mass loading as a function of liquid particle size based on experimental data from efficiency and mass loading tests for a total pressure difference of 1750 Pa, prefilter velocity of 152 cm/s and a HEPA velocity of 3 cm/s.

Conclusions

As expected, this method of predicting the total mass of solid particles collected by a prefilter/HEPA filter system shows that the small particle region the system mass is limited by the specific resistance of the HEPA filter. As the particle diameter increases, the specific resistance of the prefilter becomes the dominating factor. Comparisons between the predictive model for solid particles with scaled aluminum oxide experiments results in the average of the absolute value of the difference between the mass predicted from calculations and the mass measured from the experimental data of 11.7%, with a standard deviation of ±15.7%.

Although this is not a completely independent comparison because of the experimental data used to

determine K_2 for the prefilter, the remaining parameters are independent and lead to the conclusion that relatively accurate predictions of system mass loading can be made as a function of postulated particle diameter and density.

The predicted liquid mass loading on a system as a function of MMAD indicates that the higher mass loading in the small particle region is dominated by the HEPA filter. As the particle diameter is increased, the prefilter efficiency increases but the total ΔP is still controlled solely by the HEPA. Eventually very little aerosol reaches the HEPA filter so the total mass collected by the system becomes limited only by the capacity of the prefilter drain or trap.

The methodology presented in this paper allows predictions of pressure increases resulting from loading aerosols on a prefilter/ HEPA filter system as a function of particle size. The accuracy of these predictions is generally better than 25% which is significantly better than other methods of estimation. These results represent the boundary cases of mass loading on a system for pure solid aerosols and pure liquid aerosols, but do not necessarily represent the limits of mass loading for a mixed solid and liquid aerosol.

Acknowledgements

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References

1. Hyder, M.L., "The severe accident analysis program for the Savannah River nuclear production reactors," Nuclear Safety, Vol. 32, No. 4, pp. 502-510 (1991).

2. Novick, V. J., Abrahamson, C. A., and Richardson, W. B., "Relationship between the pressure drop across the Savannah River Site's HEPA filter material and aerosol mass loading," WSRC-RP-90-779 (1990).

3. Novick, V. J., Higgins, P. J., Dierkschiede, B., Abrahamson, C., Richardson, W. B., Monson, P.R. and Ellison, P.E., "Efficiency and mass loading characteristics of a typical HEPA filter media material," 21st DOE Nuclear Air Cleaning Conference (1990).

4. Bergman, W., Taylor, R. D., Miller, H. H., Biermann, A. H., Hebard, H. D., da Roza, R. A., Lum, B. Y., "Enhanced filtration program at LLNL. A progress report," 15th DOE Nuclear Air Cleaning Conference, CONF-780819, Boston (1978).

5. Gunn, C. A. and Eaton, D. M., "HEPA filter performance comparative study," 14th ERDA Air Cleaning Conference, CONF 760822 (1976).

6. Strauss, W., Industrial Gas Cleaning, Pergamon Press, Oxford, 1975.

7. Hinds, W. C., Aerosol Technology - Properties, Behavior, and Measurement of Airborne Particles, John Wiley & Sons, Inc., New York, 1982.

8. Wakeman, R.J., Progress in Filtration and Separation, Elsevier, Amsterdam, 1986.

9. Novick, V. J., Monson, P. R. and Ellison, P. E., "The effect of solid particle mass loading on the pressure drop of HEPA filters," Journal of Aerosol Science, Vol. 23, No.6, pp. 657-665 (1992).

10. Liew, T. P. and Conder, J. R., Journal of Aerosol Science, Vol 16, No. 6, pp. 497-509 (1985).

Nomenclature

A	=	surface area of the filter
A_1	=	Liew and Condor correlation coefficient
C	=	slip correction factor
D	=	diffusion coefficient
d_f	=	fiber diameter
d_p	=	diameter of particle
E	=	filtration efficiency
h	=	depth of filter material
K_1	=	constant depending on filter parameters
K_2	=	specific resistance of the cake
Ku	=	Kuwabara hydrodynamic factor
M	=	mass collected on filter
ΔP	=	total pressure difference
ΔP_c	=	pressure difference due to particle cake on filter
ΔP_0	=	pressure difference across clean filter
ΔP_{we}	=	equilibrium pressure difference across the wet filter
Q	=	volumetric gas flowrate
R	=	d_p/d_f
Re	=	Reynolds number
Sc	=	Schmidt number
t	=	surface tension of the liquid
V	=	velocity
α_f	=	filter solidity, or packing (volume) density
η	=	single fiber efficiency
η_I	=	single fiber efficiency due to impaction
η_d	=	single fiber efficiency due to diffusion
η_I	=	single fiber efficiency due to interception
μ	=	gas viscosity
ρ	=	particle density
$\varnothing$	=	contact angle of a droplet with respect to the fiber's surface
ψ	=	Stokes number

DISCUSSION

DYMENT: I am talking about solid particles, not liquid particles. Did you find that the particle size distributions of the particles which penetrate through the prefilter vary as a function of time? I think it has been reported in the past that certain filters do change their efficiency characteristics as they begin to load with particles. There is often a need to make a decision as to whether there is an economic benefit in the use of a prefilter in conjunction with a HEPA filter. Does your work enable you to conclude that there is an economic advantage in using prefilters in conjunction with HEPA filters, and if so, roughly speaking, what efficiency of prefilters should one aim to use.

NOVICK: 1) Prefilter efficiencies were measured for clean prefilters. One measurement was performed on a loaded prefilter. The resulting efficiency did not differ significantly from the clean prefilter. This may be attributed to the fact that the HEPA prefilter system studied in these tests were terminated before reaching a total delta P of 8 in. of H^20 due to the AACS limitations at Savannah River. These particle loading levels did not obscure the basic structure of the prefilter. Therefore, the efficiency remained essentially unchanged. Obviously, at some point in time (i.e., mass loading) the efficiency would be affected.

2) The focus of this work was on the environmental benefit of maintaining the integrity of the AACS under severe accident conditions, rather then focusing on the economics of when to use a prefilter. However, this work can be used as input to an economic analysis for a specific application. For example, in applications where micron-sized droplets are required to be filtered, this work clearly shows the advantage of adding a prefilter.

KOVACH: You started out the paper by stating that this work was done to either verify the utility of your installation or give you design data for modification of the Savannah River confinement filter system. What is your conclusion, are you going to change it and if, yes, how are you going to use these data in relation to the original intention of the project?

KLASSEN: The intention was to study the system, it wasn't necessarily to change it. The scope of this project didn't involve recommendations for change. The results were turned over to Savannah River and then it became their decision whether or not to make changes.

HYDER: Just a comment on this last question. The purpose of the study was to develop data for computer modeling of the AACS system. The results were useful for that purpose.

APPLICATION of HIGH EFFICIENCY METAL FIBER FILTERS in VENTILATION SYSTEMS of NON-REACTOR NUCLEAR FACILITIES

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Abstract

Sand filters, Deep Bed Glass Fiber filters, and remotely replaceable High Efficiency Particulate Air filters have been successfully used for filtration of exhaust air from highly contaminated exhaust air streams. However, none of these technologies satisfy all requirements of an optimum filtration system design. The basic requirements of a nuclear filtration system are a high decontamination factor, low pressure drop, long operating life, sturdiness during normal operation, ability to withstand Design Basis Accidents, minimize generation of waste, minimum maintenance, high radiation resistance, ease of decontamination and decommissioning, and low life cycle cost. High Efficiency Metal Fiber filters are a new technology and provide a suitable alternative to the currently used nuclear air filtration technologies. This article investigates the advantages and disadvantages of the current air filtration technologies and compares them with those of the High Efficiency Metal Fiber filters. High Efficiency Metal Fiber filters system design considerations for non-reactor nuclear facilities are also discussed in this article. The design considerations include, but are not limited to, physical configuration, space requirements, pressure drop, decontamination factors, dust holding capacity, in-place cleanability, cleaning procedures, in-place testing, and other support equipment.

I. Introduction

Nuclear facilities are designed to minimize their impact on the environment. All exhaust air from these facilities is filtered to minimize the release of radioactivity to the environment. The nuclear air cleaning filters have minimum efficiency requirement of 99.97% for 0.3 micrometer size particles. Nuclear grade High Efficiency Particulate Air (HEPA) filters provide this efficiency and have been used satisfactorily in nuclear air cleaning applications. HEPA filters are fragile and can fail due to overpressurization caused by high concentration of water droplets or dust in the air. HEPA filters are disposable type and must be replaced periodically. HEPA filter failure is always a concern in severe service applications, such as offgas cleaning, exhaust air

filtration from highly contaminated process enclosures, and safety related facility exhaust systems. HEPA filters exposed to high radioactivity, severe acids, and moisture are protected by scrubbers, High Efficiency Mist Eliminators, and heaters to assure that moisture accumulation on the filters will not cause overpressurization and failure. Multiple HEPA filter banks are provided in series and in parallel for reliability and safety. HEPA filters in high radioactivity service are designed for remote maintenance to reduce operating personnel radiation exposure. Highly radioactive HEPA filters are difficult to dispose of. Sand filters and Deep Bed Glass Fiber (DBGF) filters have been used as alternatives to HEPA filters for severe applications in the U.S. Department of Energy (DOE) nuclear facilities for many years. They are described in detail in the Nuclear Air Cleaning Handbook[1] and the proceedings of the DOE/NRC Nuclear Air Cleaning Conferences. The sand filters and the DBGF filters are non-replaceable types and are designed to last the life of the facility. Their design is empirical and performance is difficult to predict in advance. The sand filters and the DBGF filters are normally designed for a target efficiency of 99.95%, but the efficiency is difficult to test reliably due to their large size. The sand filters provide excellent protection from explosions and fire because of the enormous mass of sand, but are difficult to qualify for Design Basis Earthquake (DBE). The decontamination and decommissioning requirements for the sand filters and DBGF filters have not been defined, and no suitable methods of decontamination and decommissioning have been demonstrated.

Owens Corning Fiberglass type 115K was found to be the most suitable media for the DBGF filters[1]. No DBGF filters have been constructed in recent years and this media is not commercially available.

High Efficiency Metal Fiber (HEMF) filters have many desirable characteristics of HEPA filters, sand filters, and DBGF filters. They have high efficiency of HEPA filters, and the permanence and ruggedness of the sand filters and the DBGF filters. HEMF filters would not be damaged by large amounts of moisture droplets, heavy dust, and burning embers in the air stream. HEMF filters are non-replaceable type and are cleaned in-place using water, nitric acid or other chemical solutions compatible with the process application. The resulting liquid waste is treated by the facility radioactive liquid waste treatment system. HEMF filters are constructed of stainless steel and they can be DBE qualified. Presently, the capital cost of the HEMF filter systems is competitive with other filter systems (i.e., remotely replaceable HEPA filters, sand filter, etc.) for filtration of high radioactivity, high temperature, and high moisture content gas streams. The operating, maintenance and disposal cost of HEMF filters will be lower than that of HEPA filters, sand filters and DBGF filters.

The HEMF filter media is relatively new to the industry,

having been commercially available in the U.S. A. for only about past six years. HEMF filters have been successfully used in Europe for high efficiency filtration of gases in the chemical and food industries. These filters have the following potential gas cleaning applications in the nuclear industry:

1. Highly radioactive off-gas systems.
2. Air exhaust from highly contaminated processing cells.
3. Vent filters for radioactive waste storage tanks.
4. Exhaust from Plutonium processing glove boxes.
5. Incinerator off-gas.

HEMF filters are manufactured by Pall Trinity Micro Corporation, Cortland, N.Y.

II. HEMF Construction

All welded stainless steel construction of the HEMF filters

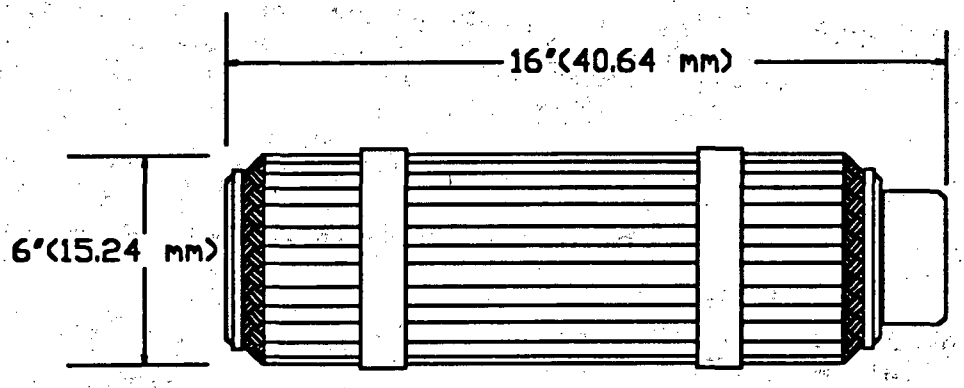

Figure 1 - High Efficiency Metal Fiber Filter Module

provides high mechanical strength, integrity, and corrosion resistance. A large number of very fine 316L stainless steel fibers are sintered at their points of contact to produce a uniform strong multilayered filter media. The sintering process strengthens the filter media and fixes the pore size. The filter media is pleated into cylindrical modules as shown in Figure 1. The cylindrical modules are welded together to produce long tubes. These tubes are welded to a tube sheet and installed in a cylindrical vessel to make a filter unit as shown in Figure 2.

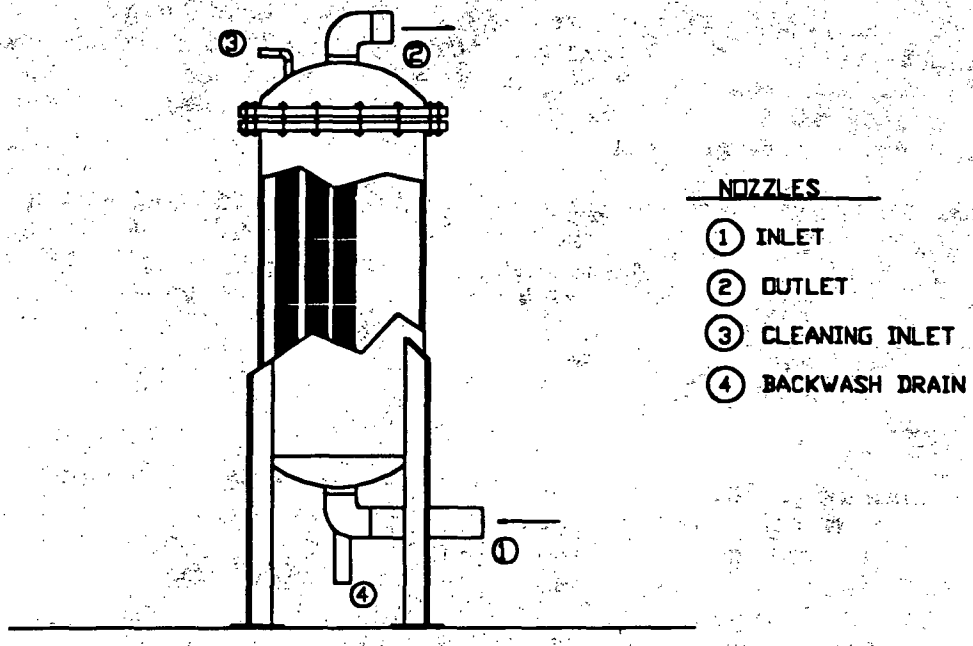

Figure 2 - High Efficiency Metal Fiber Filter Unit

III. Filter Performance

A. Pressure Drop

Pressure drop is an important filter performance parameter. The system power requirement and energy consumption depend on the filter pressure drop. The HEMF filter's high void volume and small pore size give it a combination of high efficiency and low pressure drop. The HEMF filter clean pressure drop can be designed to meet system pressure drop requirements by optimizing the filter media surface area.

B. Dust Holding Capacity

The dust holding capacity parameter of a filter relates the pressure drop increase at constant airflow to the weight of contaminants being captured by the filter. The expected frequency of filter replacement or cleaning is estimated from:

1. Concentration of contaminants (i.e. weight/unit volume) in the gas stream
2. Filter replacement or cleaning pressure drop

The desired filter pressure drop and dirt holding capacity of HEMF filter units are achieved for a specific application by optimizing the filter media surface area, the unit geometry and construction of the upstream, downstream, and filter medium drainage layers.

C. Temperature

The nuclear air cleaning systems can experience high temperature air streams during upset or accident conditions. HEPA filters can be damaged by high temperature airstreams due to deterioration of the filter media binders, unless protected with cool down sprays and mist eliminators.

The HEMF filters contain no synthetic bonding materials and can be subjected to high temperature airstream without any damage to the filter media integrity. According to the HEMF filter manufacturer, these filters can operate continuously at 750°F (400°C), and for 10 minutes at 1000°F (538°C) without any loss of efficiency and the media integrity.

D. Moisture

The nuclear exhaust air filters can be exposed to high concentrations of moisture during upset and accident conditions. HEMF filters are not weakened by condensed moisture on the media like HEPA filters and can be subjected to high pressure differential without media blow-through. HEPA filters are protected from moisture condensation on the media by mist eliminators and, if needed, with heaters. The air flow in the sand filters is upwards through the media and condensed moisture drains back prior to carryover through the media. The HEMF filter test data presented in the literature indicate no degradation in filter efficiencies when exposed to high moisture air streams[2]. However, if exposure to moisture saturates the media, the contaminants may pass through by wicking and/or a dissolution process. The prolonged exposure of HEMF filters to moisture combined with acids may corrode the metal fibers and make cleaning of the media difficult. The HEMF media should be water washed and dried as soon as possible following a high moisture upset to avoid corrosion of the fibers by absorption of acidic species from the gas stream by the water phase and to prevent water-induced migration of contaminants through the media. HEMF filters should be operated dry to assure high filtration efficiency.

E. Filter Efficiency

A HEMF filter module was tested by the U.S. DOE Filter Testing Facility at Oak Ridge, Tennessee and has exhibited an efficiency exceeding 99.97% for 0.3 micrometer DOP particles. Since HEMF and HEPA filter media consist of micrometer size fibers, both filter media are presumed to have similar filtration mechanisms. According to the manufacturer, a single stage of HEMF filters can be designed to provide equivalent filtration efficiency of at least two stages of HEPA filters.

F. Corrosion

Corrosion of the HEMF filter media is possible due to

prolonged localized condensation of acids in the gas stream or if correct cleaning procedures are not followed. The HEMF manufacturing process includes the use of high purity materials and annealing in a dry hydrogen atmosphere after welding to improve corrosion resistance. According to the manufacturer, the HEMF filter elements are now under corrosion test at the U.S. DOE Idaho Chemical Processing Plant, Idaho Falls. The knowledge of the HEMF filter corrosion rate is important and so far no corrosion test data on the stainless steel HEMF filters has been published.

IV. Design Considerations

A. Physical orientation

The following design is based on a 120,000 cubic feet per minute (203,880 m^3/h) exhaust air capacity system of a high level radioactive waste processing facility. Ten HEMF filter units of 12,000 cfm (20,400 m^3/h) capacity each are required in this application.

The HEMF filter units in this application will become highly radioactive during operation and are located in shielded concrete cell. The exhaust air filtration concept using HEMF filters is shown in Figure 3. The exhaust air from the hot cells enters the HEMF filter units at the bottom as shown in Figure 2, distributes amongst the filter module tubes, and flows through the media from

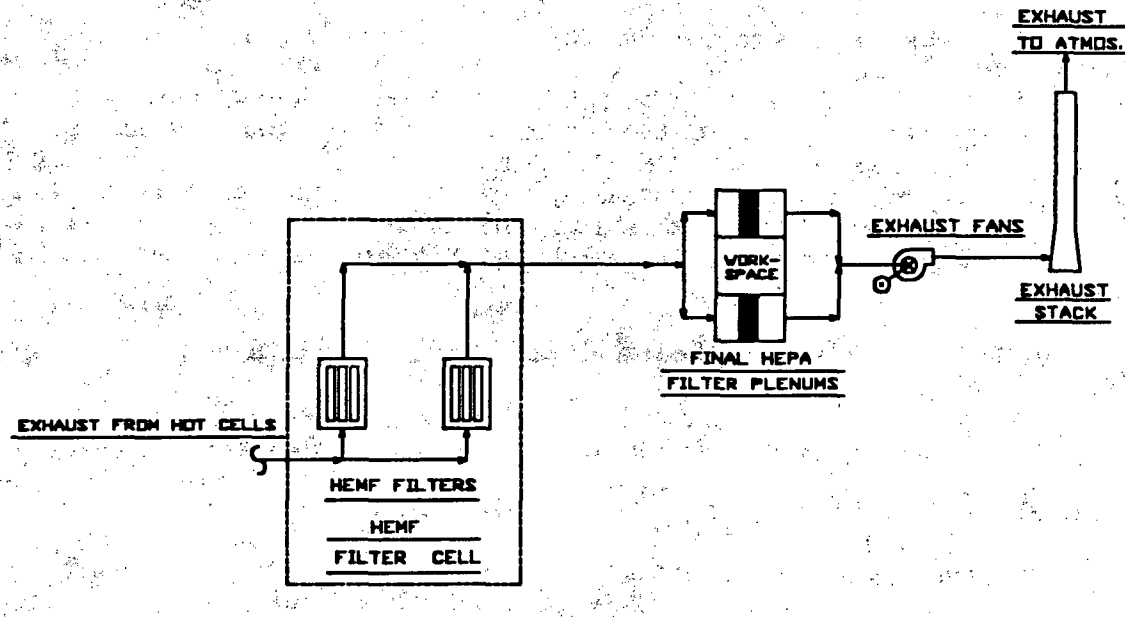

Figure 3 - Exhaust Air Filtration Using HEMF Filters

the outside in. Rising through the tubesheets, the filtered air leaves the housing through the outlet duct at the top of the filter units. From the HEMF filter units, the exhaust air passes through final HEPA filter plenums, and is exhausted through a stack by exhaust fans. The high particulate removal efficiency of the upstream HEMF filters will result in very slow dust loading of the HEPA filters. The final HEPA filters prevent release of any contaminants from the HEMF filters either due to wetting of the media or after cleanup procedure.

A 12,000 cfm (20,400 m^3/h) HEMF filter unit is a vertical cylindrical vessel of approximately 54" (138cm) diameter by 112" (285cm) overall height. Approximately 30 feet (9.2m) clear space is required in the filter cell to accommodate the filter units, isolation valves, and inlet and outlet ductwork. The top head of the vessel is flanged and is removable. The in-place cleanup procedure of the HEMF filters do not require removal of the top head. A tube sheet mounted between the top head flanges supports the internal module tubes, and separates the upstream and downstream compartments of the housing. The use of all welded components eliminates the need for the gaskets and sealants.

The support equipment required for in-place cleaning of the filter units is a cleaning liquid storage tank, pumps, liquid waste collection tanks, compressed air tank, drying air fan and associated air heater. In-place cleaning equipment including controls, and valve operators, are located outside the filter cell. All cleaning operations are performed without requiring personnel entry into the filter cell.

B. Maintenance

HEMF filter systems in nuclear air cleaning applications are designed to be cleaned in-place due to high radiation hazards. The preliminary estimates show that these filters would require cleaning every two to three years in hot cell exhaust air filtration applications. The cleaning interval can be extended by HEPA filtering the hot cell supply air and by increasing the filter surface area. Standby filtration units are provided to maintain continuous operation of the exhaust system during the cleaning operation.

A schematic piping diagram for in-place cleaning of a filter unit is shown in Figure 4.

The following are the basic steps in cleaning of the filter unit:

1. Isolate the filter unit by closing inlet and outlet air valves (V1 and V2).
2. Open the demineralized water supply valve (V6) and vent valve (V3), allow the vessel to be filled with water to the overflow then close the water supply valve, and the vent valve. Allow the filter to soak.

3. Open pressurizing air valve (V4 & V7) and let the air pressure to build up to 80 psi (550 kPa).

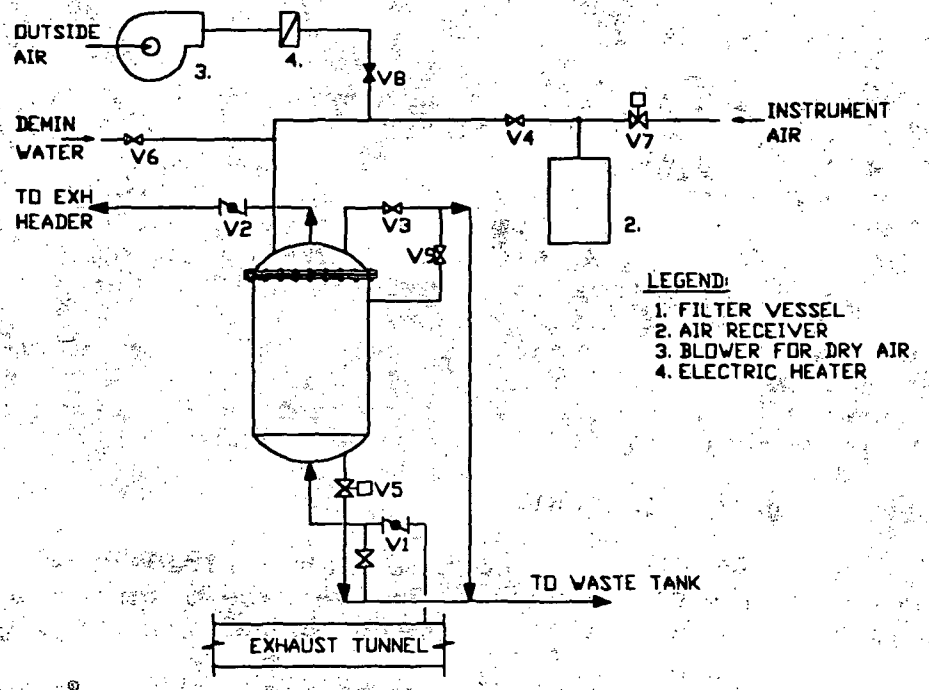

Figure 4 - Piping Diagram for Cleaning an HEMF Filter

4. Open drain valve (V5) and drain the vessel. Flush the vessel with water with approximately 1-3 gallons (4-11 liters) per filter module.
5. Drain all water.
6. Open drying air supply valve (V8) and supply hot air at a rate of approximately 1000 cfm (1700 m^3/h). A dewpoint sensor in the exit air stream indicates when the filter unit is dry.
7. Close water drain valve (V5) and hot drying air supply valve (V8). Open the air inlet and outlet isolation valves (V1 and V2) to return the filter unit into service.

This cleaning procedure using demineralized water for soaking and backflushing of the HEMF filter unit is expected to be 85% to 95% effective by the manufacturer. The effectiveness of filter cleaning is directly related to filter application, the off-gas composition, and the filter design. Chemical agents, such as nitric acid, can be used to enhance cleaning efficiencies by partially dissolving particulate trapped in the media. HEMF filters have potential to last the life of the facility in this type of application.

To date there has not been any in-place cleaning experience of this size HEMF filter unit in nuclear applications. Therefore, it is prudent to withhold final judgement on the effectiveness of in-place cleaning of the HEMF filter units until the filter design is

tested in a simulated off-gas stream application.

C. In-place Testing

Nuclear air cleaning filters are required to be tested in-place periodically. The HEMF filter units will be tested for efficiency prior to shipment and after installation. These filters will also be tested after each cleaning cycle to assure that they continue to meet the efficiency requirements. The design and procedures for in-place DOP testing of HEPA filter housings are described in ASME Standards N509 and N510. The guide lines of these ASME Standards and experience of the testing personnel will be used to develop design features and methods for in-place DOP testing of the HEMF filter units. The in-place testing of the filter units will be done remotely to prevent radiation exposure to the testing personnel.

D. Instrumentation and Controls

Most instrumentation and controls associated with the HEMF filter unit, in-place DOP testing, and in-place cleaning equipment will be located outside the filter cell in the operating gallery.

The following are typical instrumentation and controls associated with the HEMF filter units:

1. Operators of the air isolation valves upstream and downstream of the filter unit.
2. Water supply isolation valves
3. Compressed air isolation valves
4. Valve limit switches
5. Air flow indication through the filter unit
6. Pressure differential indication across the filter unit
7. Negative pressure differential between the filter unit and atmosphere during the cleaning cycle
8. Dew point measurements downstream of the filter unit during the drying cycle

Additional instrumentation and controls may be required to satisfy unique application requirements.

E. Decontamination and Disposal

The HEMF filter units can be decontaminated and disposed of using conventional techniques applicable to other Stainless Steel vessels in hot cells. Remotely operated equipment will be used to disconnect the entire unit from the ductwork and piping, and to open the filter housing to remove the filter module assembly. The empty filter housing and the filter module tube assembly will be thoroughly decontaminated using standard decontamination procedures for contaminated equipment. The decontaminated filter units will be removed and shipped to a radioactive waste burial site.

V. Operational Readiness

A. Testing for Nuclear Applications

The HEMF filters have not been used for nuclear air cleaning in the U.S.A. Demonstration testing is in progress of a 1,000 cfm, HEMF filter unit at the U.S. DOE Y12 Plant at Oak Ridge, Tennessee and a 300 cfm HEMF filter unit for the Hanford Waste Vitrification Plant melter off-gas system at Richland, Washington. The manufacturer has a number of non-nuclear gas cleaning applications to demonstrate that the HEMF filter module assembly performance and efficiency can be reliably scaled up from the performance of a single filter module.

B. Compatibility of Materials with Process Applications

The fully welded 316L Stainless Steel construction of the HEMF filter media, modules, and housings should be suitable for most nuclear air cleaning.

C. Vulnerability to accidents and Upsets

Fire

HEMF filters are made entirely of Stainless Steel and contain no flammable components. They are inherently resistant to high temperatures and over-pressurization. Although the finely divided filter media will not resist direct flame impingement, the media would not be destroyed by burning embers. The filters would get loaded with soot and other products of combustion and would experience high pressure differential. The manufacturer has indicated that HEMF filters can operate continuously at 125 psi (860 kPa) differential pressure and 750° F (400° C), and for 10 minutes at 1000° F (535° C).

Seismic

All the welded construction Stainless Steel of the HEMF filter modules and pressure vessel type construction of the filter unit assembly results in high mechanical strength. None of the HEMF filter units have been so far seismically qualified, but because of their rugged construction HEMF filters should be able to meet all DBE seismic requirements.

Operational Upsets

The impingement of water-saturated process gas and/or liquid droplets is a credible operating upset that would affect the HEMF filter units. Other credible accident scenarios may involve a sudden upset that can produce a large cloud of particulate in the air stream. Such operational upsets would lead to rapid plugging and overpressurization of the filters. The HEMF filter elements

can resist high overpressure credibly produced by the exhaust fans.

VI. Conclusion

HEMF filters have the following advantages over HEPA filters, sand filters, and DBGF filters:

1. Filtration Efficiency in excess of 99.97 percent for 0.3 μm particles.
2. Higher resistance to overpressurization due to moisture loading than HEPA filters.
3. Can be DBE qualified in contrast to sand filters.
4. Lower operation and maintenance cost compared to HEPA filters.
5. Lower decontamination and decommissioning cost compared to HEPA filters, sand filters, and DBGF filters.

The ability to clean HEMF filters in-place repeatedly without loss of efficiency is an important parameter for their application in the nuclear industry. To date there has not been any in-place cleaning experience of HEMF filters in nuclear applications. However, several tests on these filters are currently in progress at U.S. DOE facilities.

VII References

1. C.A. Burchsted, A.B. Fuller, and J.E. Kahn, Nuclear Air Cleaning Handbook (ERDA 76-21), Second Edition, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

2. H. Randahn, B. Gotlinsky, S. Tousi, "The Development of All Metal Filters for Use in the Nuclear Industry", Proceedings of the 20th DOE/NRC Nuclear Conference, NUREG/CP-0098-Vol.2.

DISCUSSION

PORCO: There are no test data in your paper. Do you have test data available for the dust loading, holding capacity, moisture, over-pressure, etc.

MILATOVIC: The paper concentrated mainly on the application of High Efficiency Metal Fiber Filters. However, a test of dust holding capacity and filter efficiency of a Pall HEMF filter was performed per ASHRAE Standard 52-76, by the Air Filter Testing Laboratories, Inc. (AFTL), Crestwood, KY.

PORCO: On the cleaning of the filter, were you able to come back to the initial clean pressure drop?

MILATOVIC: There is no in-place cleaning experience for this size HEMF filter in nuclear application. Based on experience in pharmaceutical and food industries, a cleaning effectiveness of 85% to 95%, over several successive cycles, is achievable. However, filter cleaning in these industries is not done in-place. The filters are usually sent to the manufacturer for cleaning.

PARKER, WAYNE: Have you prepared any type of life cycle cost analysis to compare these filters with any other type of HEPA filter arrangements?

MILATOVIC: There were no life cycle cost analysis prepared for this paper. However, life cycle cost analysis was prepared for the project where HEMF filters are being considered. The data relating to this project are of proprietary nature and cannot be disclosed.

DEVELOPMENT AND EVALUATION OF A CLEANABLE HIGH EFFICIENCY STEEL FILTER*

by

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ABSTRACT

We have developed a high efficiency steel filter that can be cleaned in-situ by reverse air pulses. The filter consists of 64 pleated cylindrical filter elements packaged into a 610x610x292 mm (24x24x11.5 in.) aluminum frame and has 13.5 m^2 (145 square feet) of filter area. The filter media consists of a sintered steel fiber mat using 2 μm diameter fibers. We conducted an optimization study for filter efficiency and pressure drop to determine the filter design parameters of pleat width, pleat depth, outside diameter of the cylinder, and the total number of cylinders. Several prototype cylinders were then built and evaluated in terms of filter cleaning by reverse air pulses. The results of these studies were used to build the high efficiency steel filter.

We evaluated the prototype filter for efficiency and cleanability. The DOP filter certification test[1] showed the filter has a passing efficiency of 99.99% but a failing pressure drop of 0.80 kPa (3.2 in w.g.) at 1,700 m^3/hr (1,000 cfm). Since we were not able to achieve a pressure drop less than 0.25 kPa (1 inch w.g.), the steel filter does not meet all the criteria for a HEPA filter.[2] Filter loading and cleaning tests using AC Fine dust showed the filter could be

*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. The work was supported by DOE's Office of Technology Development, EM-50.

repeatedly cleaned by reverse air pulses.

The next phase of the prototype evaluation consisted of installing the unit and support housing in the exhaust duct work of a uranium grit blaster for a field evaluation at the Y-12 Plant in Oak Ridge, TN. The grit blaster is used to clean the surface of uranium parts and generates a cloud of UO_2 aerosols. We used a 1,700 m^3/hr (1,000 cfm) slip stream from the 10,200 m^3/hr (6,000 cfm) exhaust system.

I. Introduction

This study is a continuation of our investigation on using high efficiency steel filters for nuclear air cleaning that was reported at the 21st DOE/NRC Nuclear Air Cleaning Conference.[3] The motivation for that study was to improve the reliability of the present glass fiber HEPA filter. The present glass HEPA filter is subject to structural damage when the filter is exposed to high air flows, shock waves, high temperatures, high humidities, and heavy particle deposits. Replacing the structurally weak glass fiber medium with a stainless steel medium overcomes these failure modes. The focus of our previous work was on improving the reliability of high efficiency air filters. This was also the motivation of Dillmann et al[4-6], Klein et al[7] and Randhahn et al[8] who had previously conducted investigations of high efficiency steel filters.

Although improved filter reliability is still an important driving force, our present research is focused on cleanable steel filters to reduce the cost of filtration. Air filtration in the nuclear industry is based primarily on disposable HEPA filters. The cost to replace these filters and dispose of the used filters is estimated to be $55 million per year for Department of Energy (DOE) facilities. [9] Moore et al[9] estimate that $50 million of the $55 million annual cost is due to waste handling. By developing a cleanable steel HEPA filter, we believe that a large fraction of the waste disposal costs can be saved.

Cleanable air filtration systems are used extensively in the non-nuclear industry. For example, bag house filters and electrostatic precipitators have proven to be a cost effective means for cleaning exhaust emissions from factories. However these air cleaning systems do not have the required HEPA filter efficiency, nor the reliability for use in nuclear exhaust cleaning. Our study is an initial effort to develop cleanable steel HEPA filters for use in the nuclear industry.

II. Cost Analysis

Moore et al[9] have completed a survey of HEPA filtration costs in the U.S. DOE facilities. They found that DOE facilities use an average of 11,500 HEPA filters per year. The average purchase, handling and disposal cost per HEPA filter is $4,750. DOE therefore spends $55 million per year for HEPA filters.

We used the life-cycle cost of the standard glass-paper HEPA filter to compare with the estimated life cycle cost of the steel HEPA filter as shown in Table 1. We assumed that after several years of development the cost of the steel HEPA filter, not including the cleaning system, will drop to $5,000 (the present cost is $50,000). We also assumed that the maintenance and disposal for both filters will be $4,450 and that the steel HEPA filter can be cleaned repeatedly to yield an effective life of 15 times the life of a glass HEPA filter prior to disposal. The cleaning cost for the steel HEPA filter is assumed to be $400 for the life of an equivalent glass HEPA filter, plus an initial cost of $1,500 to retrofit the cleaning system hardware into the filter housing. The total cleaning cost for the life of the steel filter is $7,500. Using these figures, we estimate the total annual cost to DOE is $55M for the glass-paper HEPA filter and $13M for the cleanable steel HEPA filter, a savings of $42M.

Table 1. Comparison of life-cycle costs for glass-paper and stainless steel cleanable HEPA filters.

	Glass-paper HEPA	Stainless steel HEPA
Filter element (1000 ft^3/min)	$300	$5,000[a]
Installation, test, removal, and disposal	$4,450	$4,450
Cleaning	---	$7,500 (15 x HEPA life)
Annual number of filters used by DOE facilities	11,500	767
Total annual costs	$55M	$13M

[a]Estimated cost for one steel HEPA filter after additional development. Current cost is $50,000 per filter.

III. Conceptual Design of a Cleanable Steel HEPA Filter

Our design of a cleanable steel HEPA filter follows the same design that has been used for many years in industrial applications, including a few applications in the nuclear industry. Schurr[10] described a cleanable sintered metal filter for use in hot off-gas systems from radioactive waste calciners. Kirstein et al[11] evaluated the use of cleanable sintered metal filters for filtering the exhaust from incinerators burning radioactive wastes. These cleanable stainless steel filters were used as prefilters to extend the life of HEPA filters. These filters were made from sintered powder metal and were formed into smooth tubes. They had high pressure drops [over 2 kPa (8 inches w.g.) at 2 cm/s (4 feet per minute) air velocity] and low efficiencies (about 65%) when clean. The pressure drop and efficiency increased as particle deposits formed on the filter. Our previous study[3] demonstrated that these sintered-powder filters had higher pressure drops and lower efficiencies than sintered fiber filters.

The design concept of a cleanable steel HEPA filter that we selected is illustrated in Figures 1 and 2. The filter consists of multiple filter cartridge elements connected together as shown in Figure 1. Each filter cartridge is a closed cylinder with pleated filter media. Dirty air enters the exterior of the cartridge element where the suspended particles are removed. Clean air then passes through the hollow interior and exits on the clean air side of the filter. As the dirty air is cleaned, particle deposits form on the surface of the filter and cause the pressure drop to increase. After the filter reaches a preset pressure drop, a reverse air pulse blows back through several of the filter elements to dislodge the particle deposits, which are then collected in a hopper or barrel as shown in Figure 2. In this configuration it is possible to clean a few of the filter elements while still filtering dirty air in the remaining elements. A fraction of the particle deposits that are blown off the cartridges being cleaned will be redeposited on neighboring cylinders that are operating in the filtration mode. Incomplete cartridge cleaning and redeposited dirt limit the reverse air pulse to only partial cleaning of the filter.

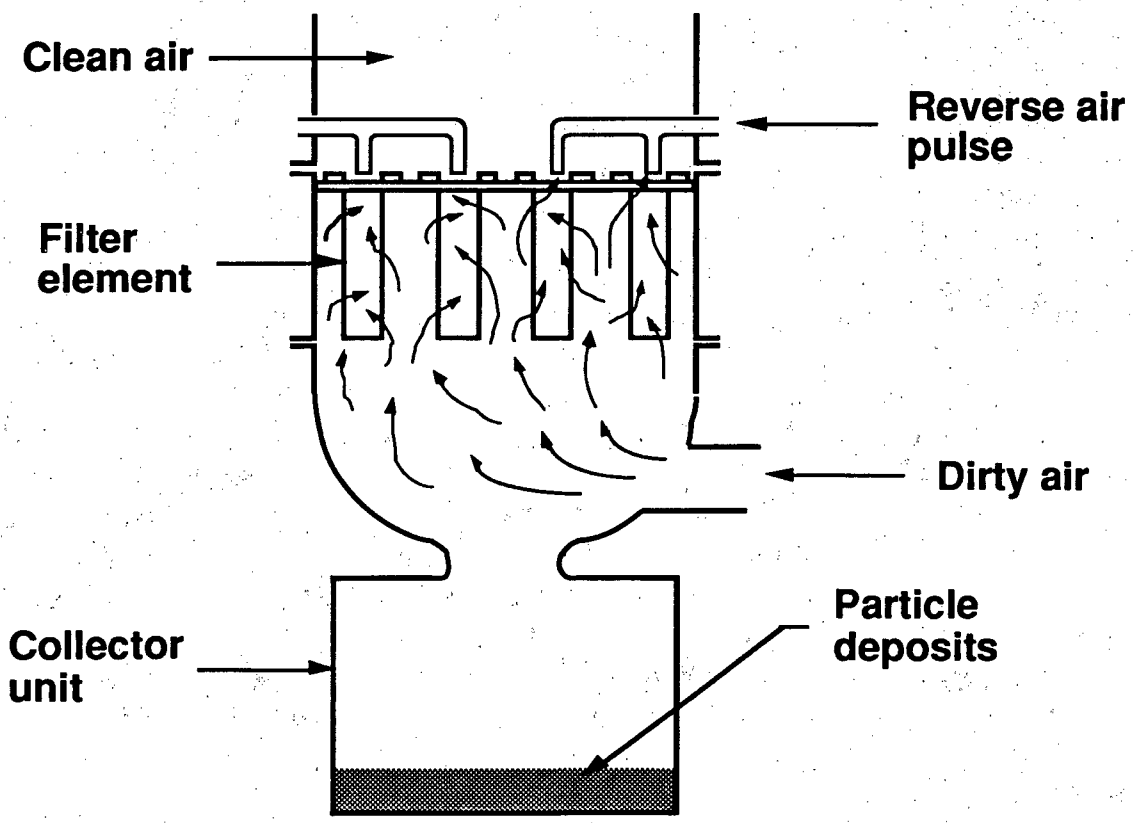

Figure 1 Filtration cycle for steel HEPA filter.

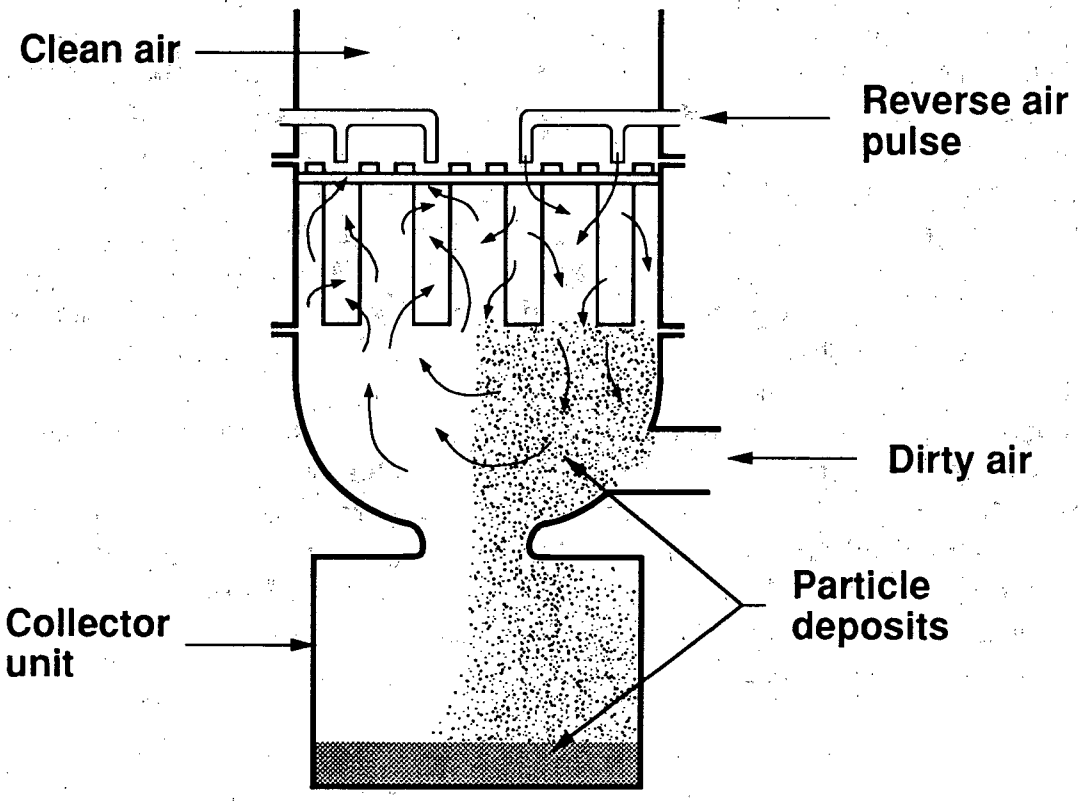

Figure 2 Cleaning cycle for steel HEPA filter.

Other filter cleaning methods can also be used in place of the reverse air pulse illustrated in Figure 2. It is possible to use liquid sprays to clean the filters. The selection of the solvent (eg. acid, base detergents, etc.) or sequence of solvents (eg. cleaning and rinsing solvents) would depend on the particular application. If liquids are used for cleaning, then a liquid handling system would be required to collect the contaminated liquid and recycle it for re-use. For extremely difficult cleaning, the filter can also be removed from the housing and washed in the appropriate liquid.

The final design concept that we incorporated into the cleanable steel HEPA filter was to package the multiple filter cartridges into the standard HEPA dimensions of 610x610x292 mm (24x24x11.5 in.). This choice of multiple filter cartridges housed in the standard HEPA frame represents the unique feature of our design. It is also possible to fabricate a steel HEPA filter using the standard HEPA designs, eg. deep pleat, mini pleat, etc., by substituting the glass fiber medium with the steel fiber medium.

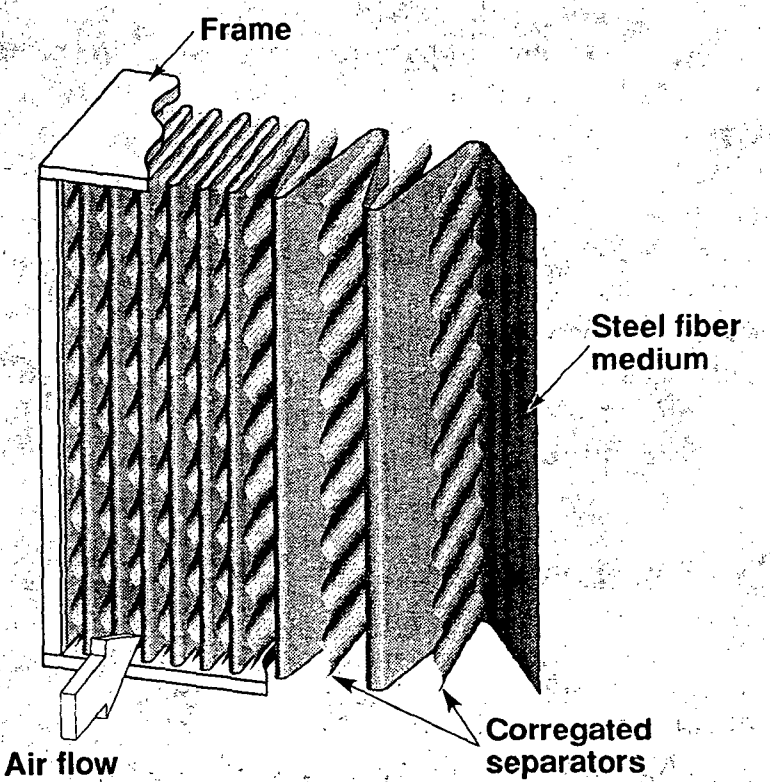

Figure 3 Cleanable steel HEPA filter in the deep pleat configuration.

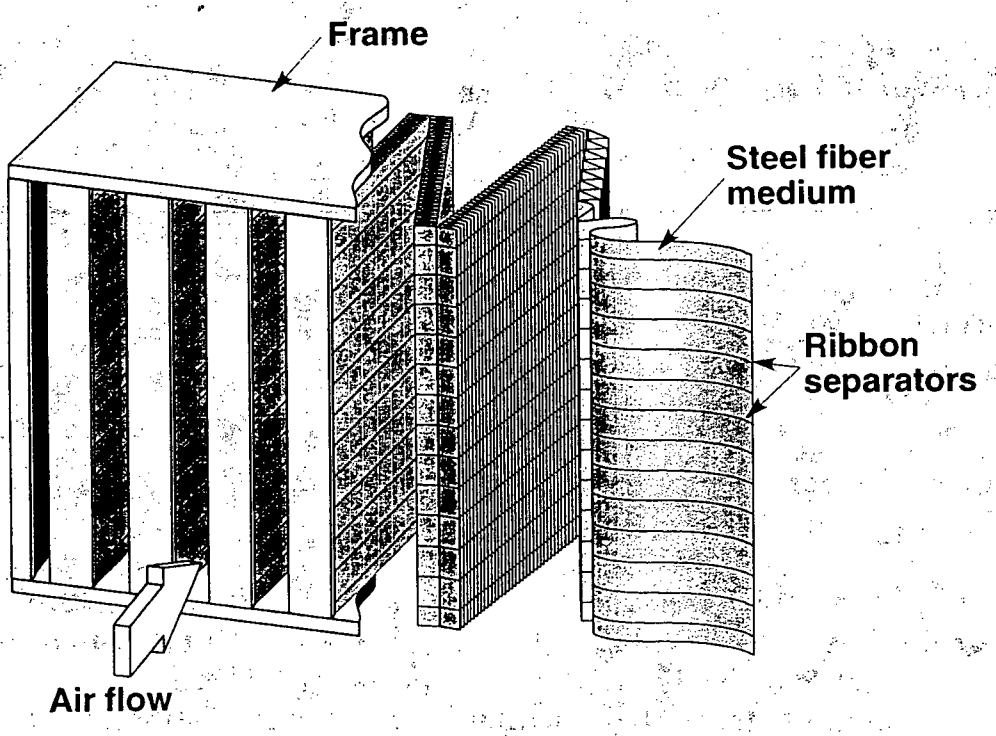

Figure 4 Cleanable steel HEPA in the mini-pleat configuration.

Figure 3 illustrates the fabrication of a cleanable steel HEPA using the standard deep pleat design with corrugated separators. Other deep pleat designs without separators are also possible.[12] The minipleat design is illustrated in Figure 4.

We selected the pleated cartridge design because it is the standard design for metal filters in the filter industry and would be the easiest to commercialize. We also believe the pleated cartridge filter with shallow pleats would be easier to clean by reverse air pulses than the deep pleated or mini pleat filter because the particle deposits would be easier to dislodge in the shallow pleats. Of course, if the filter is removed from the housing, it is possible to remove deposits from any filter design with the proper selection of cleaning agents.

IV. Optimization of the Cleanable Steel Filter

We optimized the pleated cartridge design through a combination of experiments and theoretical analysis. Pleating the media in a cartridge maximizes the surface area contained within the filter box. Our objective was to have a filter that met the efficiency requirement of a HEPA filter (99.97% for 0.3 μm DOP aerosols) and

Figure 5. Cross section of the Pall Steel fiber medium used in our study.

also have the lowest possible pressure drop. We already knew from our previous studies[3] that the steel fiber media we had developed with industry had the same efficiency as the glass fiber HEPA media, but with three times the pressure drop. Figure 5 shows a cross section of the Pall filter medium that was used in our study.

We developed a mathematical model that showed variations of pleat depth, pleat width, cylinder diameter, number of cylinders and the total filter area. Our preliminary analysis showed that for the available filter media, we could only package 13.9 m^2 (150 ft^2) into the standard HEPA frame. In contrast, a standard glass fiber HEPA filter uses over 18.6 m^2 (200 ft^2) of media.

We then used our mathematical model (Figure 6) to show all possible variations of pleat depth, pleat width, and number of pleats to yield 13.9 m^2 (150 ft^2) of area. Using that model, we selected three different combinations of the three parameters as indicated by A, B, and C in Figure 6 for fabricating experimental filters. Another important factor in the optimization was the number of cartridges to be used in the prototype filter; fewer cartridges would simplify the cleaning process. Figure 7 shows the number of cartridges as a function of pleat width and pleat depth and the three combinations of parameters used in Figure 6. We fabricated three different filter cartridges using the specifications given by A, B, and C. Figure 8 shows cartridge A.

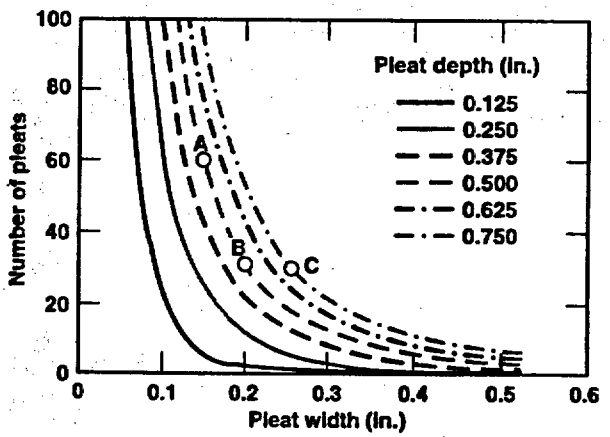

Figure 6 Possible combinations of pleat depth, pleat width, and number of pleats to yield 13.9 m^2 (150 ft^2) of area. We selected the combinations indicated by A, B, and C for fabricating three different filter cartridges.

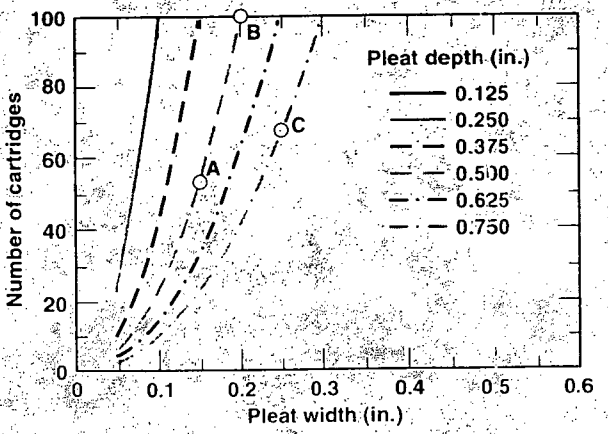

Figure 7 Calculation of number of cartridges to be used in the prototype filter, based on the parameters chosen from Figure 6.

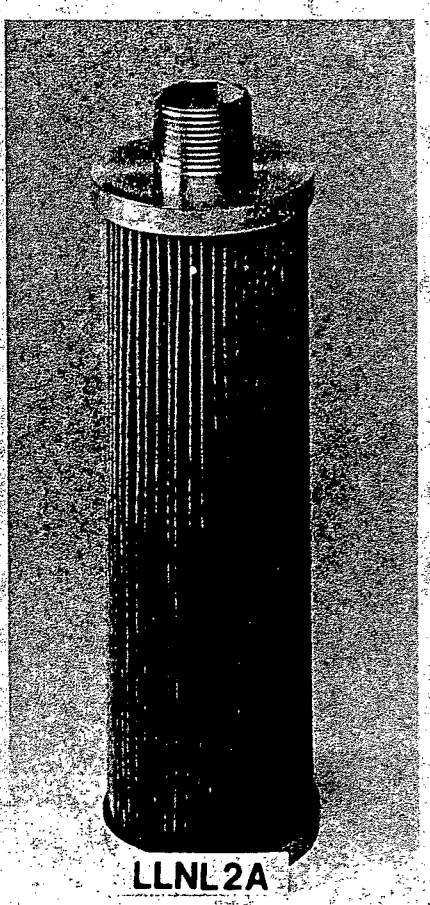

Figure 8 Filter cartridge A.

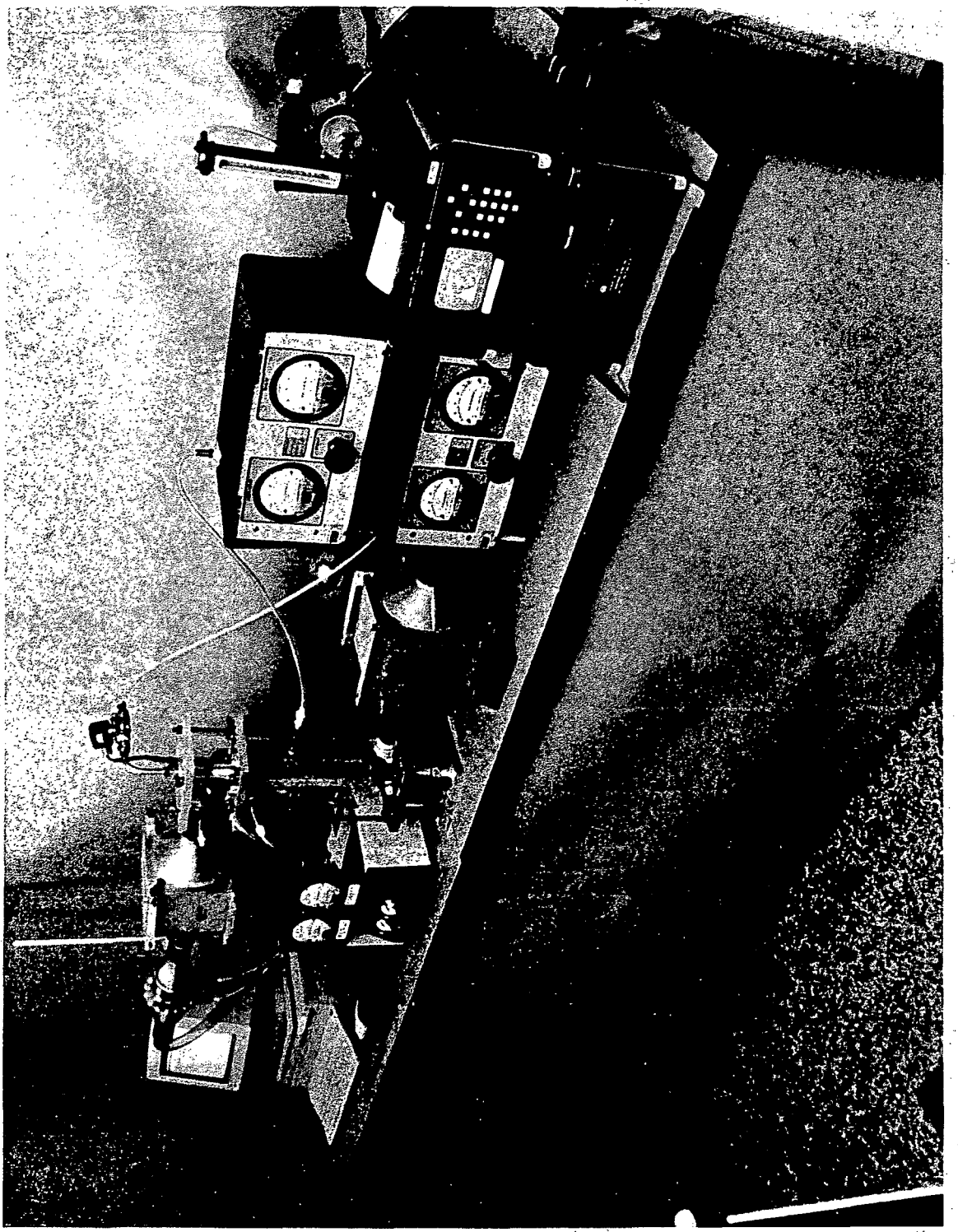

Figure 9 Test apparatus for studying filter efficiency and cleaning.

We tested the three filter cartridges for efficiency and cleaning using the test apparatus shown in Figure 9. We used a laser particle counter, model HS LAS-32, from Particle Measuring Systems (PMS) for the filter efficiency measurements. Details of the filter efficiency test were described in our previous report[3]. The cartridges were cleaned by applying a reverse air pulse on the filter to dislodge the particle deposits. Pleat geometry seemed to have minimal effect on the efficiency of the cartridges; all three had efficiencies of about 99.97%. However, pleat depth had a definite impact on the ability to clean the cartridge; the one with the deepest pleat (1.9 cm, 0.75 in.) had a higher relative pressure drop after loading and cleaning, and also had a faster loading rate than either of the other two cartridges. It is possible that the poor results obtained with the filter cartridge having the deepest pleat were partly due to the individual pleats being blinded because they were not properly spaced apart. We did not use a support screen in our model filters as is the common practice in industry. However, even if the additional wire screen would keep the media pleats from touching, the screens would be touching and make filter cleaning more difficult than wider spaced pleats. Optimizing the filter design with respect to filter cleaning will require more work than was possible in this study.

Using the data generated for the three filter cartridges and the curves in Figure 6, we calculated specifications that would give the desired efficiency and pressure drop, and also have the minimum number of cartridges to yield 13.9 m^2 (150 ft^2). These specifications [pleat depth = 1.27 cm (0.5 in.), pleat width = 0.64 cm (0.25 in.), and 32 pleats] were given to Pall Corp. and Memtec Corp., who built prototype cartridges for testing. With these cartridge specifications, the cleanable steel filter would has array of 64 cartridges.

V. Filter Cartridge Performance

We conducted filter efficiency and cleaning tests on the prototype cartridges. The efficiency test consisted of measuring the particle concentration as a function of size using the PMS laser shown in Figure 9. We used dioctyl sebacate (DOS) aerosols generated by a Laskin nozzle in our efficiency tests so that direct comparisons could be made with the official DOP certification test.[1] A close-up of the filter test housing is shown in Figure 10. The filter test housing consists of three chambers: a lower chamber that functions as a hopper to collect particle deposits, a middle chamber that houses the filter cartridge and an upper chamber that has the reverse air pulse system. Challenge air enters into the lower part of the middle

chamber, passes through the filter cartridge into the upper chamber and then leaves through an exit port shown in the upper left of Figure 10. Sampling probes for the filter efficiency measurements can be seen in the middle and upper chambers. The differential pressure probes are also shown near the plate separating the upper and middle chambers.

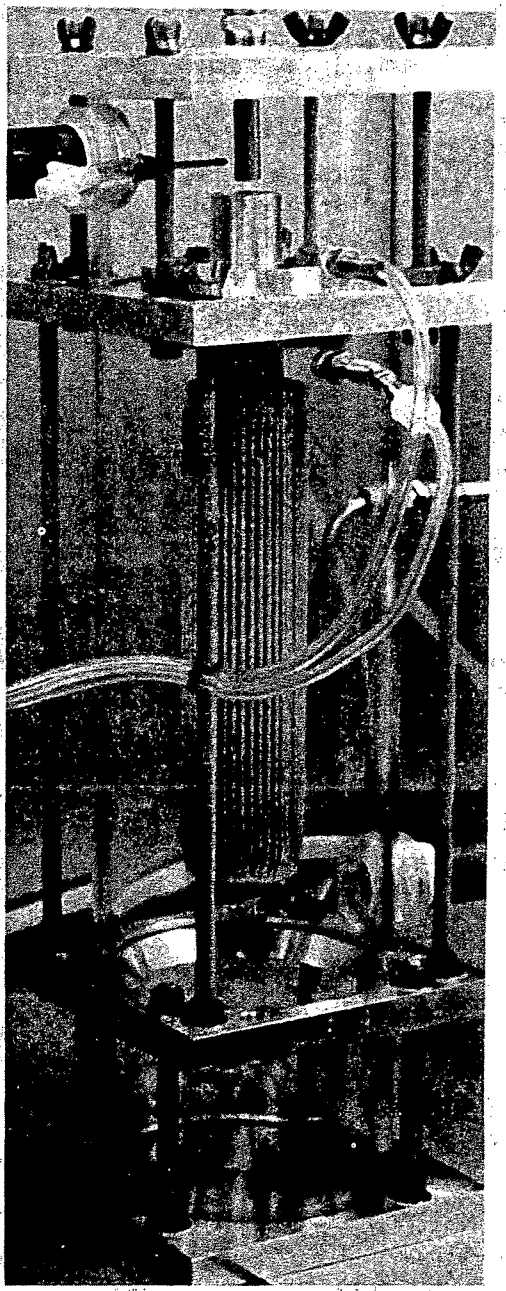

Figure 10 Filter test housing used for efficiency and cleaning tests.

Figure 11 shows the results of our efficiency measurements on one of the 64 Pall filter cartridges tested at 26.5 m^3/hr (15.6 cfm).

This flow rate corresponds to the fraction of the total flow at 1,700 m^3/hr (1,000 cfm) through one of the 64 filter cartridges. The maximum penetration at 0.17 µm diameter is 0.05%. However, at 0.3 µm diameter the penetration is only 0.01%. The remaining Pall filter cartridges gave similar results. Since the DOP certification test allows a penetration up to 0.03%, the steel filter will easily pass the test. Unfortunately the pressure drop at 0.82 kPa (3.3 inches w.g.) is too high to qualify the steel filter as a HEPA filter according to MIL-F-51068.(2) The Memtec filter cartridges were also tested and gave similar results. Further development is required to reduce the pressure drop.

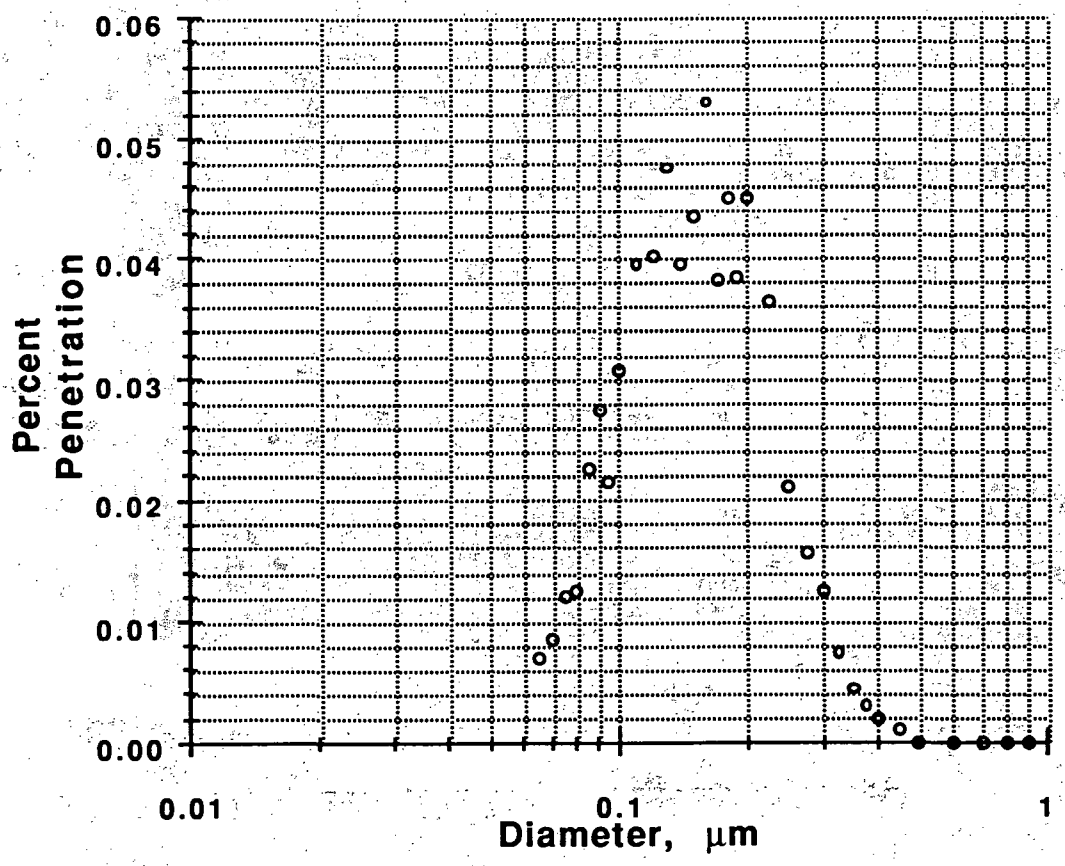

Figure 11 Penetration of DOS aerosols as a function of particle size through Pall filter cartridge. ΔP = 0.82 kPa (3.3 in. w.g.) at 26.5 m^3/hr (15.6 cfm).

For the filter cleaning tests, we set up a reverse air pulse system consisting of a dust generator for accelerated filter plugging,

a single cartridge housing, and a solenoid-actuated reverse air pulse. The experimental apparatus is shown in Figures 9 and 10. We used AC Fine dust in our filter cleaning tests, since it represents a similar, although more severe, challenge compared to the uranium oxide dust measured in the Y-12 Plant. The filter cleaning test consists of loading the cartridge with dust until the pressure drop across the cartridge reaches 1.7 kPa (7 in. of water). At that point, the pressure solenoid valve is automatically opened and the air pulse blows off the particle deposits. In separate tests, we determined that the optimum cleaning pulse is 0.6 seconds at 276 kPa (40 psig).

The results from a sequence of 19 filter clogging and cleaning cycles are shown in Figure 12. The breaks in the clogging and cleaning cycles occurred when the aerosol generator was depleted. We estimate that about three glass HEPA filters would be clogged during a similar particle challenge. Since the glass HEPA filters cannot be cleaned, the corresponding test with glass HEPA filters would require about three filter replacements. We have conducted up to 100 filter clogging and cleaning cycles on a single steel cartridge, which corresponds to an equivalent service life of about 15 glass HEPA filters.

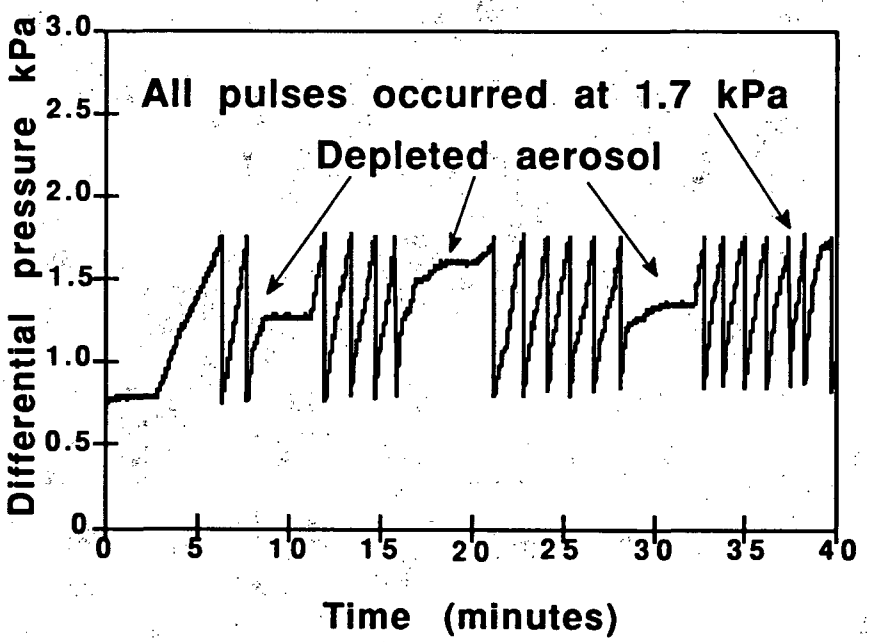

Figure 12 Results from a sequence of 19 clogging and cleaning cycles using one steel filter cartridge from Pall. About three glass filters would be needed for similar challenge.

IV. Fabrication and Evaluation of Cleanable Steel Filter

Fabrication

After verifying the performance of the Pall and Memtec filter cartridges, we completed the design and fabrication of the cleanable steel filter. Figure 13 shows one of the filter cartridges from Pall Inc. and Memtec Inc.. Note the threaded end on the filter cartridges. The individual filter cartridges are threaded into an end plate of a 610x610x292 mm (24x24x11.5 in.) housing. Figure 14 is a photograph of the assembled cleanable steel filter contains 64 Memtec cartridges. The weight of the fully assembled filter containing the Pall and Memtec cartridges were 102 kg (225 pounds) and 95 kg (210 pounds) respectively. Figure 15 shows a close up of a second steel filter containing Pall cartridges.

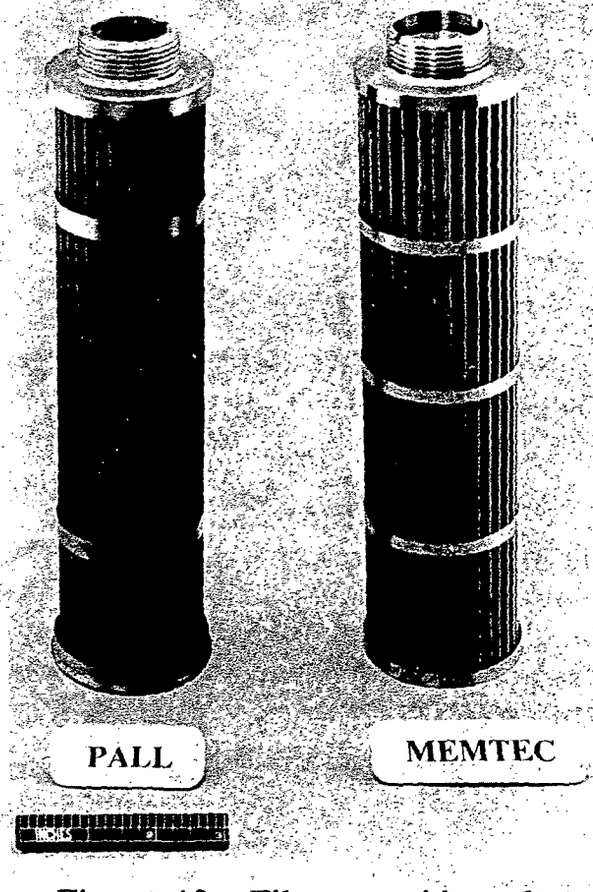

Figure 13 Filter cartridges from Pall and Memtec

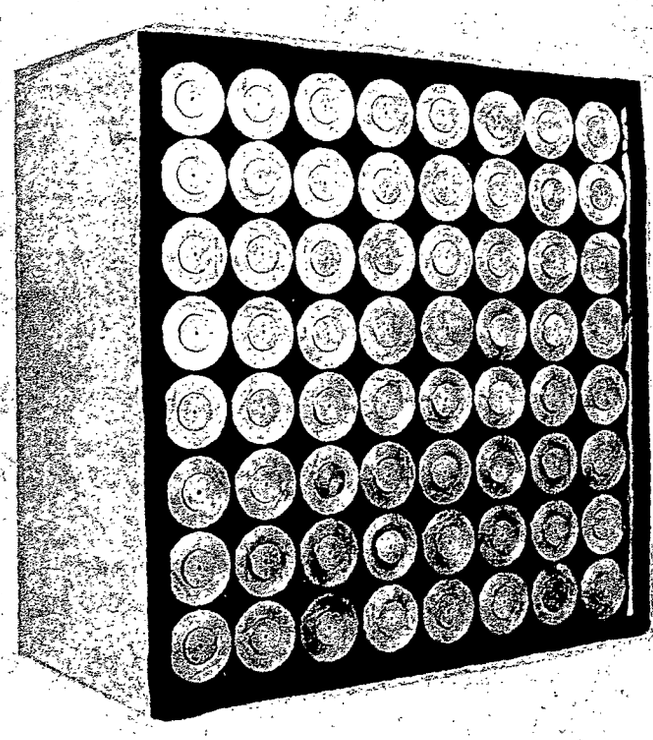

Figure 14 Photograph of the assembled cleanable steel filter with 64 Memtec cartridges.

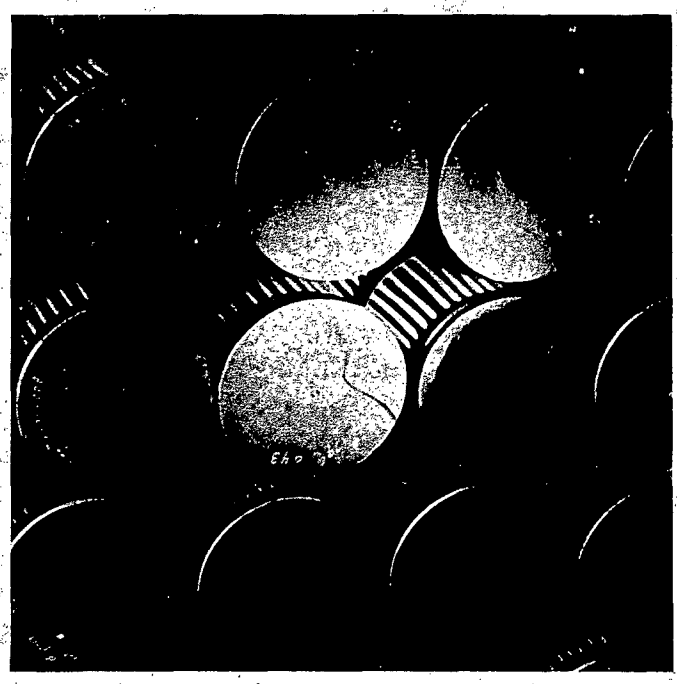

Figure 15 Close up of the filter cartridges from Pall Corp. in the assembled filter.

Penetration Measurements

We installed the filter in our 1,700 m^3/hr (1,000 cfm) test duct as shown in Figure 16 and measured the penetration with DOS aerosols, using the same laser particle counter used in our cartridge tests. To generate sufficient DOS challenge in the 1,700 m^3/hr (1,000 cfm) test duct, we used an aerosol generator having six Laskin nozzles (Phoenix Precision). Figure 17 shows the percent penetration of DOS as a function of particle diameter for the steel filter with Pall cartridges. The filter has a maximum penetration of 0.115% at 0.17 µm diameter but still meets the requirement of less than 0.03% penetration at 0.3 µm diameter as required by the DOP certification test.(1) As we noted previously, the pressure drop at 0.77 kPa (3.1 inches w.g.) is too high to qualify the cleanable steel filter as a HEPA filter according to MIL-F51068.(2)

The penetration measurements for the cleanable steel filter using Memtec cartridges is shown in Figure 18. The penetration is 0.046% at 0.17 µm diameter and 0.01% at 0.3 µm diameter and therefore meets the requirements of MIL-F-51068.(2) However the pressure drop is too high at 0.77 kPa (3.1 inches of water) to qualify as a HEPA filter.

Figure 16 Installation of cleanable steel filter in 1,700 m^3/hr (1,000 cfm) test duct.

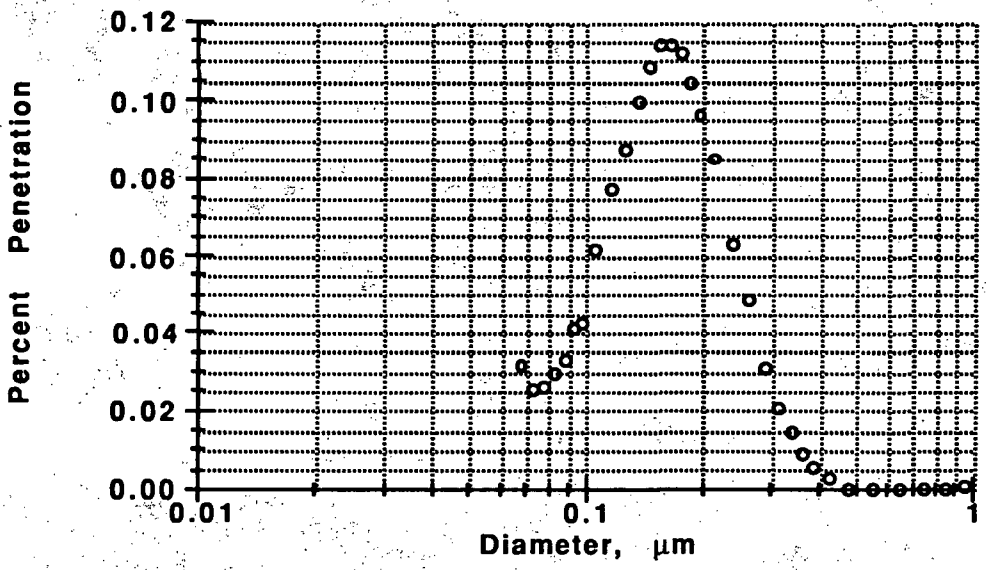

Figure 17 Penetration of DOS aerosols as a function of particle diameter through a cleanable steel filter using Pall cartridges. ΔP = 0.77 kPa (3.1 in. w.g.) at 1,700 m^3/hr (1,000 cfm).

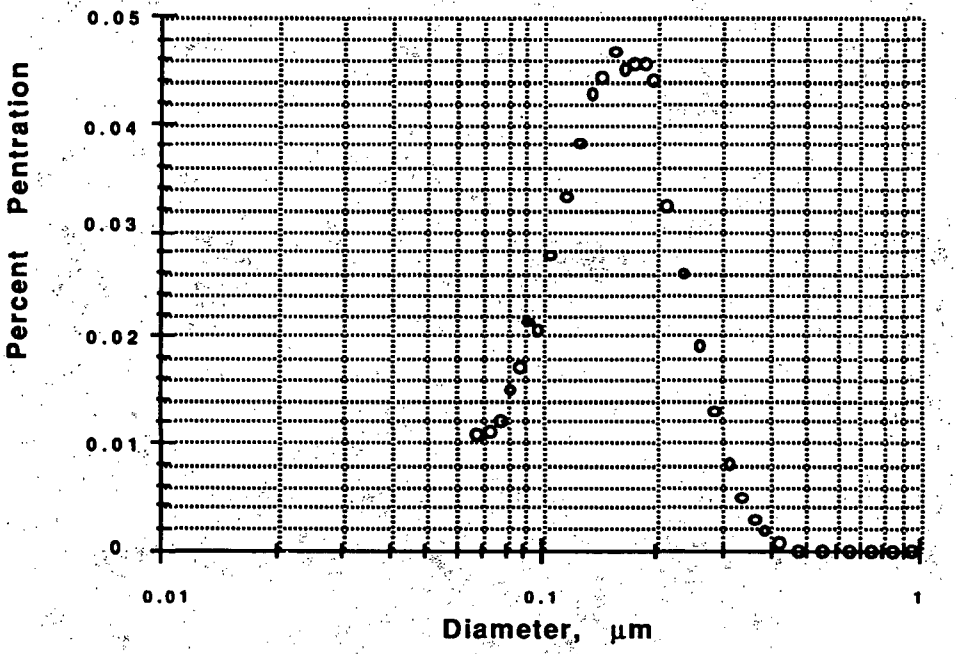

Figure 18 Penetration of DOS aerosols as a function of particle diameter through a cleanable steel filter using Memtec cartridges. ΔP = 0.77 kPa (3.1 in. w.g.) at 1,700 m^3/hr (1,000 cfm).

We also had the two steel filters tested using the official DOP HEPA certification test.[1] The filters were tested at the DOE filter certification laboratory in Oak Ridge, TN. Test results show the DOP penetration was 0.01% for both the filter with Pall cartridges and the filter with Memtec cartridges when tested at 1,700 m^3/hr (1,000 cfm). The corresponding pressure drops were 0.80 kPa (3.2 inches w.g.) for the Pall filter and 0.72 kPa (2.9 inches at w.g.) for the Memtec filter.

Cleanability Tests

After establishing the filter efficiency, we ran a series of tests to establish the cleanability of the filter. These tests were similar to the small scale tests described previously for the individual filter cartridges. However to evaluate the cleanability of the entire filter consisting of 64 cartridges, we used a filter housing and blower assembly that we designed and built for use in our field demonstration at the Y-12 Plant in Oak Ridge, TN.

The filter housing and blower assembly, shown in Figure 19, is an independent filtration system for demonstrating the performance of the cleanable steel filter. The housing assembly was designed to meet seismic and mechanical safety standards. A photograph of the assembly is shown in Figure 20. The housing assembly will pull exhaust from the uranium grit blaster at the Y-12 Plant through the entrance pipe shown on the right side of the figures. The radioactively contaminated exhaust will then be passed through filters, first through the cleanable steel filter and then through a conventional glass filter, before exiting through the exhaust pipe at the top of the housing assembly. The clean exhaust is then passed through a variable speed blower and discharged into an existing baghouse filter at the Y-12 Plant. Figure 21 shows the steel filter, being inserted into the housing with the aid of a support table. Since the steel filter weighs about 100 kg (220 pounds), it is not possible to manually install the filter as is done with standard HEPA filters. However with further development, we estimate that the weight can be reduced to 41 kg (90 pounds) and allow manual installation of the filter.

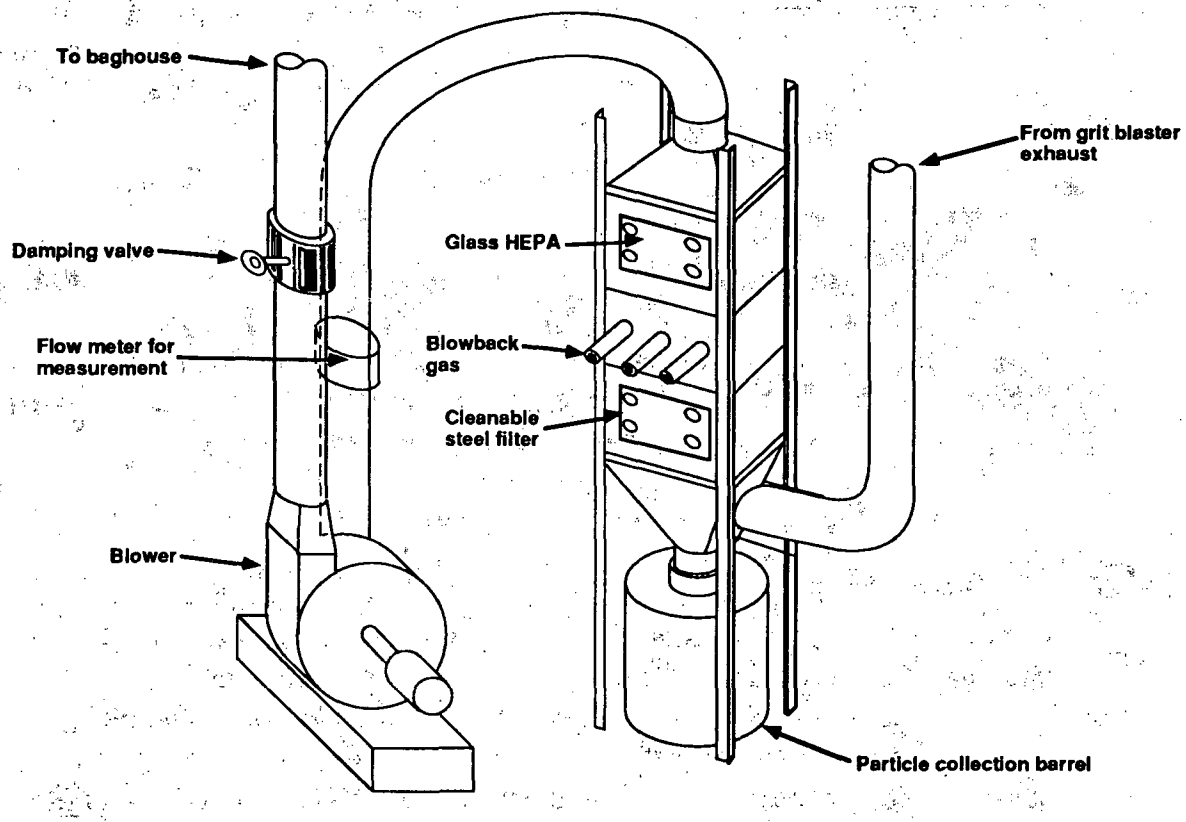

Figure 19 Design of the filter housing and blower assembly for a field test at the Y-12 Plant.

The filter-cleaning system is mounted inside the filter housing assembly between the steel filter and the glass HEPA filter. This cleaning system consists of 64 individual nozzles and solenoids to generate reverse air pulses for each of the filter cartridges. We initially evaluated various manifold combinations (primarily four- and eight-nozzle configurations), but none proved satisfactory. The filter-cleaning tests on the single cartridge tester shown in Figure 10 were not successful using the manifold configurations, apparently due to poor flow distribution and lack of an adequate shock wave. Because of time constraints, we abandoned the manifold design and used a separate air pulse line for each of the 64 cartridge filters. This system is overly complex, expensive and prone to failures. An efficient filter cleaning system is another area for further development.

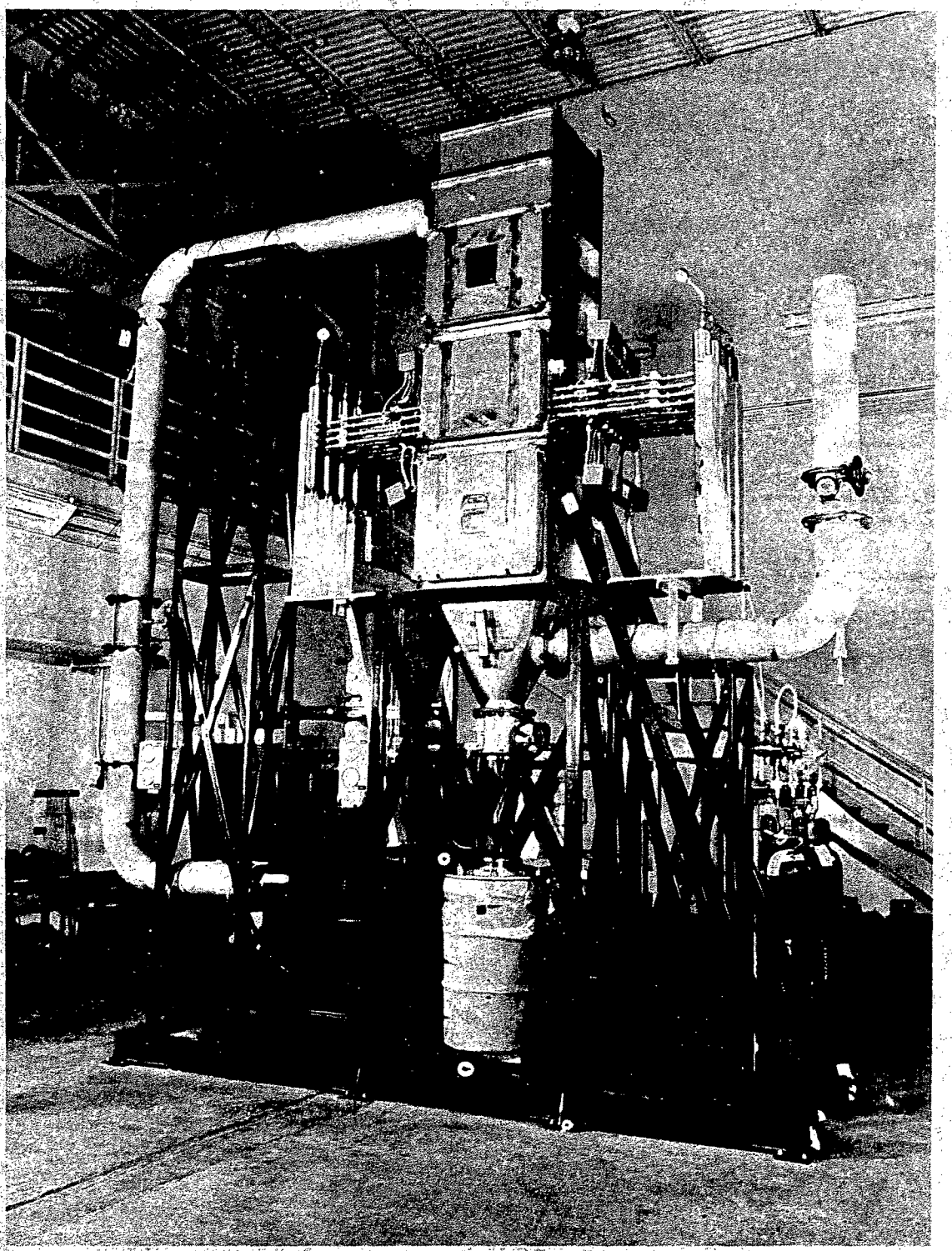

Figure 20 Photograph of the filter housing and blower assembly.

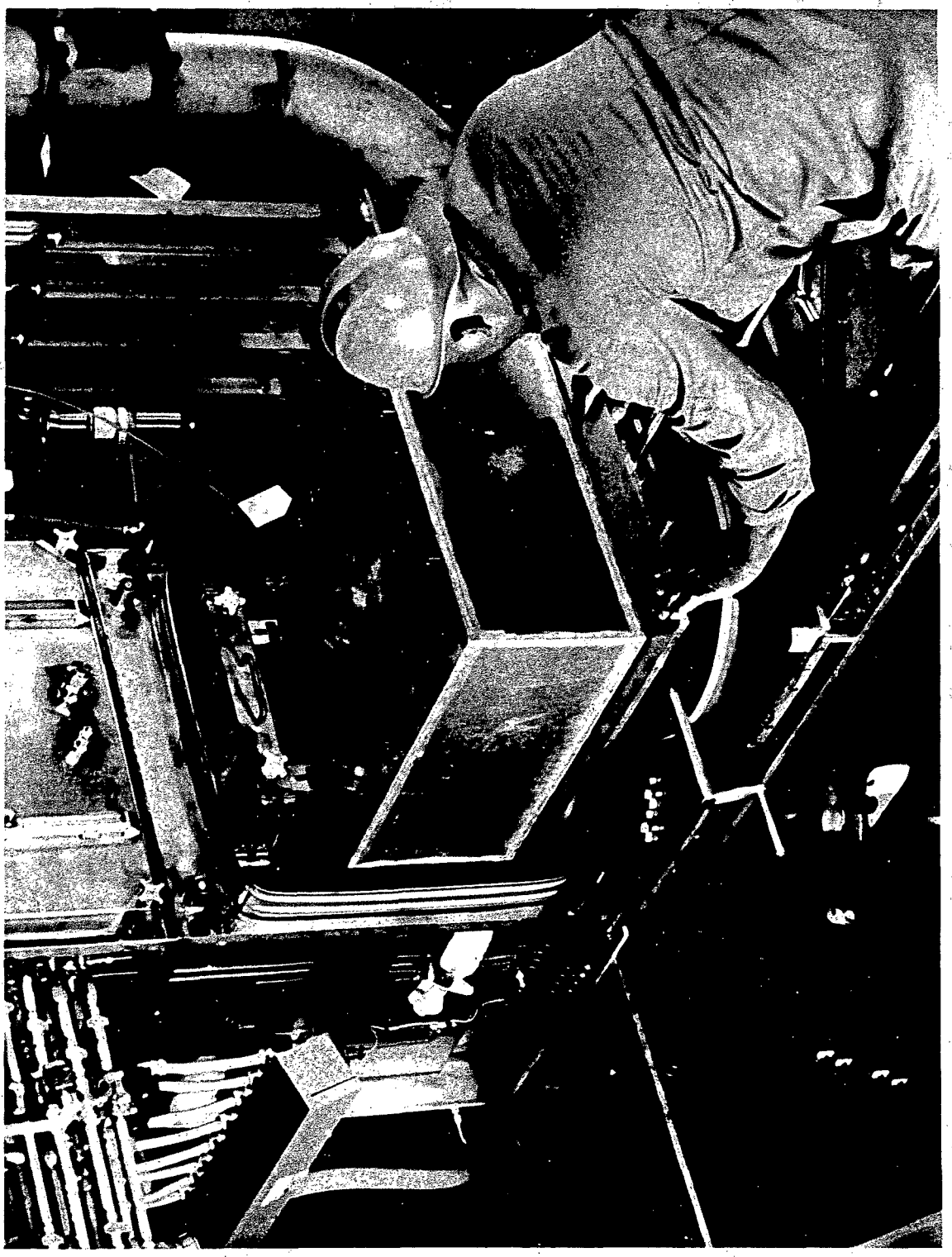

Figure 21 Cleanable steel filter being inserted into filter housing.

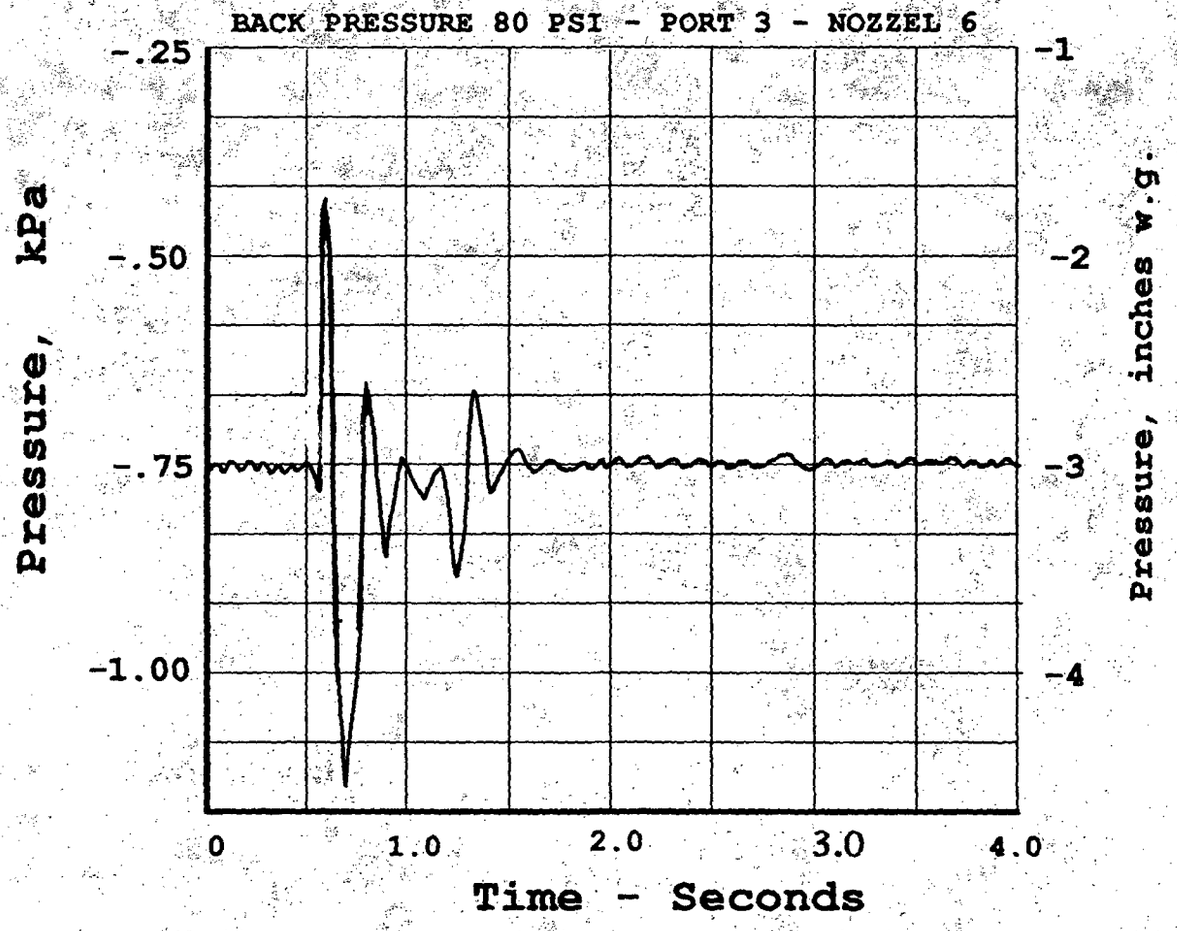

Figure 22 Transient pressure measurements inside filter housing during reverse air pulse.

We then conducted filter cleaning tests that consisted of a series of filter clogging and cleaning cycles. We used AC Fine dust (Powder Technology Inc.) in these tests as was done previously with the individual cartridges. The results of our cleaning tests are shown in Figure 23. Note that the filter pressure drop after each cleaning is only reduced to 1.4 kPa (5.5 inches w.g.). This increased pressure drop (compared to the clean filter) shows that we are not able to remove all of the particle deposits during a cleaning cycle as was done in our single cartridge tests. The deposits that remain on the filter cartridge after pulse cleaning is due to the lower cleaning efficiency of the air pulses in the multi cylinder unit and due to the redeposition of particles blown off one cartridge onto another cartridge. Figure 24 shows that the steel filter has a significant particle deposit that remains after this pulse cleaning. The fiiter cleaning system requires further development.

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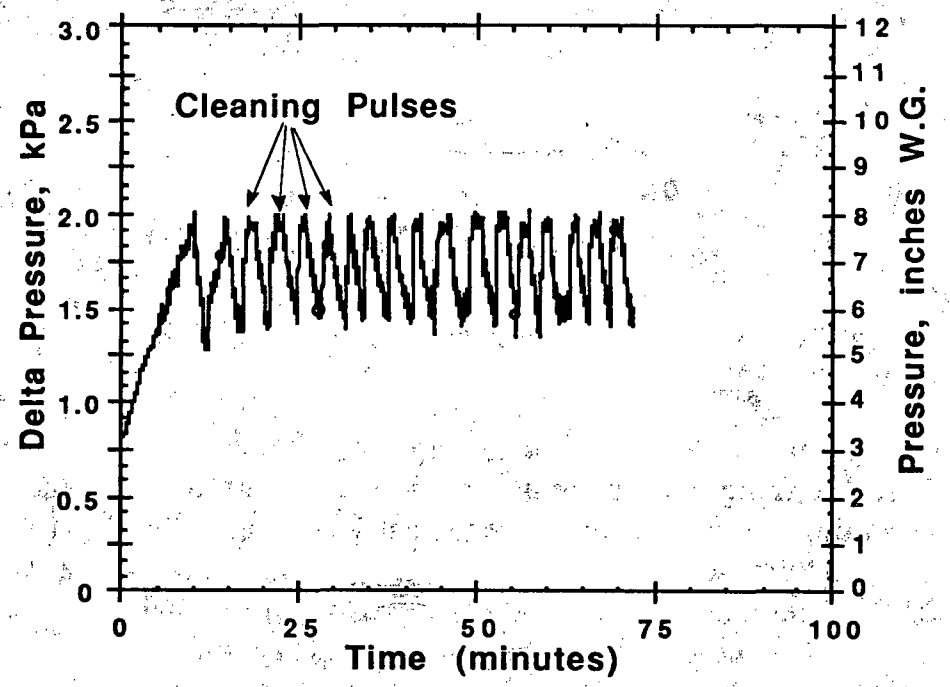

Figure 23 Filter clogging and cleaning cycles for steel filter.

After completing these clogging and cleaning tests, we ran a filter clogging test using a standard glass HEPA filter in the same filter housing. Comparing the two test results show that the 18 cleaning cycles in Figure 23 corresponded to an equivalent clogging of three glass HEPA filters. These test results gave us confidence that the steel filter could easily provide an equivalent life of 15 standard glass HEPA filters.

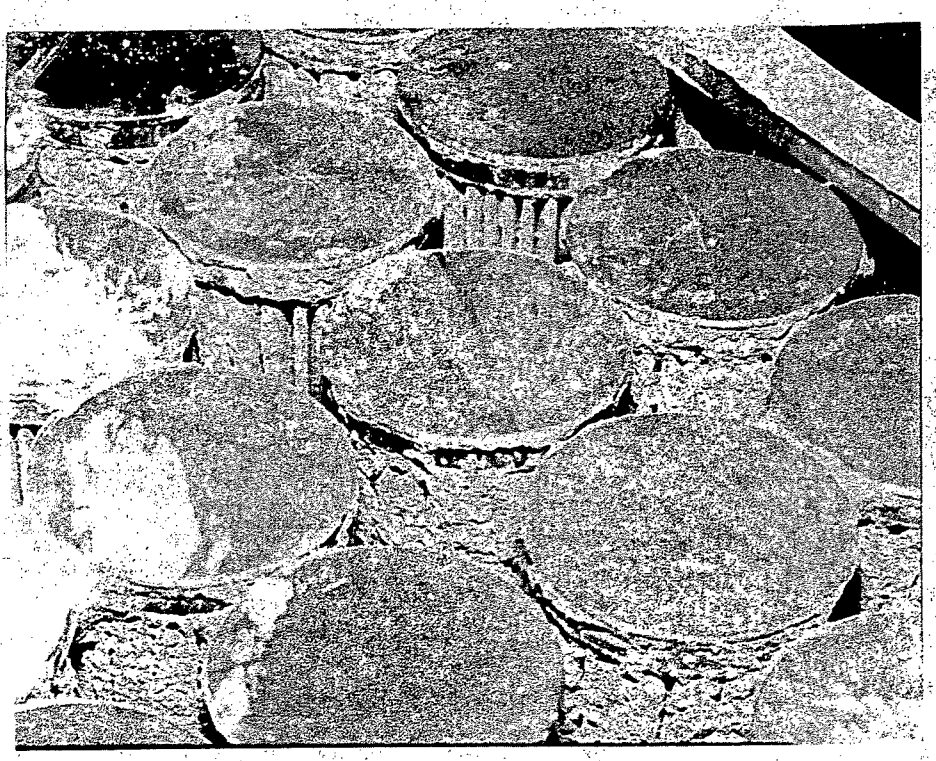

Figure 24 Photograph of steel filter after 18 clogging and cleaning cycles.

VII. Y-12 Demonstration

After completing the evaluation tests at LLNL, we disassembled the filter housing and blower assembly and shipped the unit to the Y-12 plant in Oak Ridge, TN for installation in the exhaust of a uranium grit blaster. This is a facility where the surface of uranium parts are cleaned by blasting with a grit. Design and safety engineers had made extensive preparations for the installation for approximately one year prior to shipping the unit: the filtration hardware and operating system were reviewed, a concrete pad was built to support the filter housing and blower assembly, and auxiliary ducting was cut into the existing exhaust system. The existing filtration systems consisted of a bag house prefilter followed by a bank of six, single-stage HEPA filters to accommodate the 10,200 m^3/hr (6,000 cfm) exhaust. A 1,700 m^3/hr (1,000 cfm) slip stream is extracted from the exhaust of the grit blaster, routed through the cleanable steel filter housing and exhausted back into the bag house filter.

Measurements of the particle emissions show that the average size of the uranium oxide particles is approximately 50 μm. This is much larger than our AC Fine dust, which had an average size of

approximately 8 μm. Given that we have already proven we can load and clean the smaller test particles, we are confident that we will be able to load and clean the much larger particles at the Y-12 Plant. We currently have tests under way to determine the performance of the cleanable steel filter in this application.

VIII. Conclusion

We have developed a cleanable steel filter that has 0.01% DOP penetration and a pressure drop of 0.72-0.80 kPa (2.9 - 3.2 inches w.g.) at 1,700 m^3/hr (1,000 cfm). Although the steel filter cannot meet the pressure requirement for a HEPA filter specified in MIL-F-51068, it can be used in place of HEPA filters for applications not sensitive to the higher pressure drop. Further research and development is needed to reduce the pressure drop and optimize the filter design and the cleaning system. The fact the filter can be repeatedly cleaned and reused will result in significant cost savings.

IX Acknowledgement

This work was supported by DOE's Office of Technology Development, EM-50.

X References

(1) U.S. Military Standard MIL-STD-282, Filter Units Protective Clothing, Gas-Mask Components and Related Products: Performance Test Methods.

(2) U.S. Military Standard MIL-F-51068, Filters, Particulate (High-Efficiency Fire Resistant)

(3) Bergman, W., Conner, J. Larsen, G., Lopez R., Turner, C., Valha, G., Violet, C., and Williams, K. "High efficiency steel filters for nuclear air cleaning" Proceeding of the 21st DOE/NRC Nuclear Air Cleaning Conference NUREG/CP-01116, CONF-900813, Superintendent of Documents, U.S. Govt. Printing Office, Washington, D.C., pp 733-761, 1991.

(4) Dillmann, H.G., and Pasler, H. "Experimental investigation of aerosol filtration with deep bed fiber filters" in Proceedings of the 17th DOE Nuclear Air Cleaning Conference, CONF-820833, NTIS, Springfield, VA, pp 1160-1174, 1983.

(5) Dillman, H.G., and Pasler, H. "A filter concept to control airborne particulate releases due to severe reactor accidents and implementation using stainless-steel fiber filters" in Proceedings of the 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, NTIS, Springfield, VA, CONF-840806, pp 1417-1428, 1985.

(6) Dillmann, H.G., Bier, W., Linder, G., and Schubert, K., "Measurements of removal efficiencies performed on powder metal and fiber metal cartridges to be used in uranium enrichment facilities and glovebox exhaust ducts" in Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference, NTIS, Springfield, VA, CONF-860820, NUREG/CP-0086, pp 392-407, 1987.

(7) Klein, M. and Goossens, W.R. A. "Aerosol filtration with metallic fibrous filters" in Proceedings of the 17th DOE Nuclear Air Cleaning Conference, NTIS, Springfield, VA, CONF-820833, pp 504-522, 1983.

(8) Randhahn, H., Gotlinsky, B., and Tousi, S., "The development of all metal filters for use in the nuclear industry" in Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, NTIS, Springfield, VA, CONF-880822, NUREG/CP-0098, pp 726-748, 1989.

(9) Moore, P., Bergman, W., and Gilbert, H., "Survey of life cycle costs of glass paper HEPA filters" in Proceedings of the 22nd DOE/NRC Nuclear Air Cleaning Conference, Denver, CO, Aug. 24-27, 1992.

(10) Schurr, G.A. " Cleanable sintered metal filters in hot off-gas systems" in Proceedings of the 16th DOE Nuclear Air Cleaning Conference, NTIS, Springfield, VA, CONF-801038. pp 708-718, 1981.

(11) Kirstein, B.E., Paplawsky, W.J., Pence, D.T., and Hedahl, T.G., "High efficiency particulate removal with sintered metal filters" in Proceedings of the 17th DOE Nuclear Air Cleaning Conference, , NTIS, Springfield, VA, CONF-801038, pp 719-744, 1981.

(12) Flanders Filters Catalog showing separatorless filters like the Dimple Pleat™ and Super-Flow™ HEPA filters. Bulletins 812 and 871.

DISCUSSION

DILLMANN: Do you find any effect on the loading capacity and recleanability as a function of the aerosol concentration? High aerosol concentrations can quickly build up a filter cake. Do you have experience in this matter?

BERGMAN: If the high concentration does not result in particle coagulation, I would not expect to see a concentration effect on filter cake removal. However, if the particle concentration is so high that you have particle coagulation, the resulting particle size would increase and deposit more on the surface, which is easier to clean. Unfortunately, I have not conducted any experiments to verify those comments.

PORCO: Do you have a concern about reentrainment of submicrometer particles after you pulse them off? Would they stay in the air stream and then redeposit on the filter?

BERGMAN: The amount of redisposition of reentrained particles depends on the design of the system. The blowback system we used causes large chunks of the particle deposit to fall off while the small particles become suspended in the airstream and redeposit on a neighboring filter element. A blowback cleaning system having reversed air flow through the entire filter does not have the reentrainment problem, but requires off-line cleaning.

MYERS: I know these filters are to be used for HEPA applications in offgas systems and the like. Has there been any work to study or investigate their capabilities to withstand hydrogen explosions or detonations?

BERGMAN: The pleated cylindrical filter cartridges in our paper may possibly survive a hydrogen gas explosion, but we do not know since no high pressure tests have been conducted. The media, with no additional structural support, would collapse under high pressures. However, there is an interior steel core that would prevent total collapse if the thickness of the core is sufficient. Depending on the resulting pressure, the pleats may also collapse. I am not aware of any applications like that. At the 21st Nuclear Air Cleaning Conference, I presented results for the same medium in a different filter configuration for use as a vent for applications having potential pressure surges. We exposed the filter to a differential pressure of 1,000 PSI and then measured the filter efficiency. We saw no loss of efficiency at a penetration of 15^{-8}. When the medium has a strong structural support, all of the forces are put on the support and not the medium. The flat, unpleated, filter medium in our previous study was supported by a very strong inner cylinder that provided this support. I doubt that the multiple cylinder filter presented today could survive anything close to that.

GREENE: In addition to the reverse pressure pulse to clean the fibers, have you considered alternative techniques such as ultrasonic vibrations that might be more effective for reverse pulsing?

BERGMAN: Ultrasonic cleaning in air would probably not be very effective, but if the filter is immersed in liquid, ultrasonics could prove beneficial. There is a large variety of liquid cleaning techniques that could be used, such as reverse sprays, reverse liquid flow with and without detergents. However, a careful analysis has to be made for each application so that you don't generate excessive radioactive waste that reduces the cost savings from reusing the filter.

MCGALLIAN: I see that there was a cost analysis done; did it include handling equipment, since these units weight 200 lbs apiece?

BERGMAN: Our cost analysis did not include special handling equipment for the 200 pound steel filter that is described in our report. The data in the cost analysis applies to a steel HEPA filter after several more years of development effort. I have assumed that the final steel HEPA filter will weight less than 90 pounds, not 200 pounds, and therefore assumed that no special handling equipment would be needed. The steel HEPA filter will, presumably, be in the facility for the life of the facility, which we assumed is equivalent to about 15 HEPA filters. The current filter design does not involve the filter being removed from the housing during this period. If you have to remove the filter from the housing each time you clean it, that dramatically changes the cost analysis. We have not done that kind of analysis. Every new application requires its own experimental verification and demonstration for any new technology.

MCGALLIAN: Has an evaluation of critically problems been approached?

BERGMAN: Our preliminary study shows that we cannot put any more than 500 grams of PU in the filter without having it go critical. The present filter cannot be used in applications where this critical mass can accumulate. You will have to do something to both the filter design and the material to avoid this critically potential.

MCGALLIAN: Basically, this application is for new applications instead of those replacing existing filtration systems.

BERGMAN: No, that is not our intent. Our intent is to use the steel filter for both new applications and for existing facilities. If the filters are retrofitted into existing facilities, there will have to be some modifications, depending on what kind of cleaning is envisioned. If you want in-situ cleaning, you will have to modify the ducting and housing to provide a means for filter cleaning and removal of deposits. For new facilities, you could provide for these needs from the start. Moreover, for a new facility, you are not locked into a 2' x 2' x 1' frame, as pointed out by the previous speaker. You can use an optimum design. I don't believe the standard filter frame will be the most optimum design.

LEIBOLD: You optimized the filter pleats for initial pressure drop and efficiency. I think it would be much better to optimize pleats for the condition of recleaning. I expect that the narrow pleats will clog irreversibly.

BERGMAN: I believe you are correct; optimization should be done with respect to filter cleaning. We have not completed this study. Although the theoretical optimization was done for the initial efficiency and pressure drop, as shown in Figures 4 and 5, we did conduct three experiments on optimizing the filter design for filter cleaning. We built three different filter cartridges having different pleat widths and different pleat heights, and the results are shown in Figures 5 and 6 as A, B, and C. We found that filter C with the most narrow pleats had the worst cleaning performance. This poor performance is likely due to the closely spaced pleats that are in contact. But you are absolutely right; if we had a mathematical understanding of filter cleaning, it would be far better to optimize for cleaning than to optimize for efficiency and pressure drop.

KAHN: It appears that there should be a life cycle energy cost in your Table I cost estimates. You are talking about a 3.5 in. w. clean resistance vs 1 in. w. for the standard HEPA filter. This is a penalty. Is that right?

BERGMAN: That is correct. At the present time there will be an energy penalty. As I said, this study is a preliminary effort. Table I represents the estimated cost comparisons for a stainless steel HEPA filter that has the same pressure drop as a standard glass paper filter. There would, therefore, be no cost penalty relative to the glass HEPA. The steel filter presented in our paper has a much higher pressure drop and would therefore, have a significant energy penalty. Table I does not refer to the present filter but rather to the filter after several years of further development. The prototype that we presented today is only in the early development stage.

DEVELOPMENT AND EVALUATION OF A HEPA FILTER FOR INCREASED STRENGTH AND RESISTANCE TO ELEVATED TEMPERATURE*

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Abstract

We have completed a preliminary study of an improved HEPA filter for increased strength and resistance to elevated temperature to improve the reliability of the standard deep pleated HEPA filter under accident conditions. The improvements to the HEPA filter consist of a silicone rubber sealant and a new HEPA medium reinforced with a glass cloth. Three prototype filters were built and evaluated for temperature and pressure resistance and resistance to rough handling. The temperature resistance test consisted of exposing the HEPA filter to 1,000 scfm (1,700 m^3/hr) at 700°F (371°C) for five minutes. The pressure resistance test consisted of exposing the HEPA filter to a differential pressure of 10 in. w.g. (2.5 kPa) using a water saturated air flow at 95°F (35°C). For the rough handling test, we used a vibrating machine designated the Q110. DOP filter efficiency tests were performed before and after each of the environmental tests. In addition to following the standard practice of using a separate new filter for each environmental test, we also subjected the same filter to the elevated temperature test followed by the pressure resistance test. The efficiency test results show that the improved HEPA filter is significantly better than the standard HEPA filter. Further studies are recommended to evaluate the improved HEPA filter and to assess its performance under more severe accident conditions.

I Introduction

Previous studies have shown that the standard glass fiber HEPA filter may be structurally damaged under accident conditions that may occur in nuclear facilities[1-10]. These studies have shown that the HEPA filter may be damaged when it is exposed to high values of

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temperature, moisture, smoke loadings, air flows, and pressure drops. The moisture weakens the strength of the filter medium and also restricts the air flow which causes an increased pressure drop. The smoke loadings from fires also restricts the air flow. due to the deposits. If the blower in the ventilation system has sufficient power to overcome the increased filter air resistance, then it is possible to structurally damage the filter medium and even blow out the entire medium from the HEPA frame.

The earliest environmental tests on HEPA filters were developed by the U.S. Army and specified in MIL-F-51068[11]. This standard describes a heated air test in which HEPA filters are exposed to an air flow at 700°F (371°C) for five minutes. It also describes a pressure resistance test in which a filter is exposed to a sufficient flow of humid air to produce a pressure drop of 10 in. w.g. for one hour. Another test method in the standard is the rough handling test in which the HEPA filter is vibrated. These tests comprise a portion of the tests that are required for HEPA filters to be used in U.S. Department of Energy facilities. Although these tests were adequate to address many environmental challenges for U.S. Army applications, they were not sufficient to evaluate the variety and severity of accident conditions postulated in nuclear accidents.

To investigate the performance of HEPA filters under simulated accident conditions, special test facilities were built in the U.S. and Europe. Los Alamos National Laboratory built a test facility at the New Mexico State University to study the effects of pressure shocks and tornados on HEPA filters. [1] A fire test facility was built at Lawrence Livermore National Laboratory to study the effects of fire and smoke on the ventilation system and HEPA filters.[2] The KFK institute in Germany built separate test facilities for high humidity and for high air flow studies.[3,4,9,10] The Atomic Energy Authority in England built a high temperature filter facility to measure filter efficiency under hot dynamic conditions.[5,6] The French CEA also built a similar high temperature facility for studying HEPA filters.[7] Except for the high temperature facilities, the other test facilities cannot measure the filter efficiency under the test conditions. The practice is to expose the filter to the desired environmental condition and then measure the filter efficiency in a separate test.

Previous researchers have shown that the reliability of the HEPA filter can be significantly improved by replacing components of the filter with stronger and/or more temperature resistant materials. Pratt [6] described a HEPA filter using a glass cloth reinforced filter medium from Lydall Inc. along with an unspecified high temperature sealant to

seal the medium into the filter case. The filter was able to survive an exposure to 932°F (500°C) air flow with no observable damage. No efficiency measurements were reported. Ruedinger et al [9,10] also described high strength HEPA filters made with the reinforced HEPA paper from Lydall Inc.. They also described pleat separators made with inclined corrugations, that also improved the filter strength. They did not report any efficiency measurements. Ruedinger et al[10] reported that the German nuclear power plants are now using the higher strength HEPA filters.

The present study represents a preliminary effort to develop a HEPA filter with improved reliability to withstand accident conditions in U.S. nuclear facilities. This work represents a continuation of the previous work by Ruedinger[9-10] and Pratt[6] in developing a more robust HEPA filter. Like these previous researchers, we also used the glass cloth reinforced HEPA media from Lydall Inc. to make our prototype HEPA filter. In addition we used RTV silicone rubber for the sealant to seal the HEPA media into the frame for greater temperature resistance.

We had several prototype filters built and evaluated them against standard HEPA filters at the Rocky Flats Plant Filter Test Laboratory. This laboratory has existing test facilities for conducting heated air tests, pressure resistance tests and rough handling tests as specified in MIL-F-0051068[11]. Although more severe tests would be a better representation of potential accident conditions, there are no U.S. facilities comparable to those in Europe for high temperature and moisture exposure. Nevertheless, we felt that the available test facilities at Rocky Flats would still provide a relative comparison of the performance between the prototype and standard HEPA filter.

II Prototype HEPA Specification

The specifications for the prototype HEPA filter are given in Table 1. The elements of the specification affecting frame, gasket, separators, and test performance are not unique. The requirements conform to Military Specification MIL-F-51068.[11] The variation by which temperature resistance and strength were sought was centered on the filter medium and the sealant. The filter medium was a water-repellent treated medium of glass fibers, corresponding to the Military Specification MIL-F-51079[12], but supplemented with a single scrim of glass monofilament. The monofilament measured 6.5 um in diameter and had a mesh size of 42 by 31 filaments to the inch. The filter was positioned for test with the scrim on the downstream face.

The conventional media to frame sealant for HEPA filters that is currently marketed is a polyurethane material containing a fire retardant. A room-temperature vulcanizing silicone rubber was chosen instead for this design. Although RTV silicone rubber is a more expensive material, its selection to provide additional temperature resistance for a specialized application was a logical choice.

Table 1. Specification of Prototype Filter

Dimensions	24 x 24 x 11.5 inches, excluding gasket.
Frame	304 or 409 Stainless Steel. Four frame members to be preformed with double flanges, joints coated with sealant identified below before closing and closed with four bolts, nuts, and cut lock washers.
Medium	Lydair 3255-LW1.
Separators alloy	3003-H19, 1145-H19, or 5052-H39 Aluminum of 0.0015 inch minimum thickness.
Sealant	Room Temperature Vulcanizing Silicone Rubber, Dow Corning 116.
Gasket	Oil-Resistant Expanded Cellular Rubber, ASTM D1056 SCE-43 or -44, 3/4 inch of width and 1/4 inch of thickness.
Test Performance	Penetration not to exceed 0.03% when tested at air flows of 1,000 and 200 SCFM with a Q107 DOP Penetrometer. Resistance to air flow of 1,000 SCFM not to exceed 1.0 inch, water gauge.

Filters were fabricated to the design specified. Each was visually examined and tested for dioctyl phthalate (DOP) penetration at the DOE Filter Test Facility, Rocky Flats Plant, Golden, Colorado, and each conformed to the specification imposed on the manufacturer. These figures were maintained as a base so that penetration of a filter after testing could be used to assess degradation of the unit.

III Filter Evaluation

The test filters were subjected to one or two of three different tests: heated air test, pressure resistance test, and rough handling test.

Heated Air Test

Apparatus for the heated air test is shown in the sketch of Figure 1. It consists of a duct containing a blower, a natural gas manifold, adjustable vanes, and a movable exhaust duct that serves as a chuck to hold the filter in the path of the heated air. The Rocky Flats heated air apparatus generates an air flow of 1,000 standard cubic feet of air per minute (SCFM) (1,700 m^3/hr) which is heated to 700°F (371°C). The rig incorporates a number of improvements in design from the original model at the Edgewood Area of Aberdeen Proving Ground, Maryland, and the Underwriters Laboratories apparatus located at Northbrook, Illinois. The test method is described in Underwriters Laboratories Standard UL 586.[3]

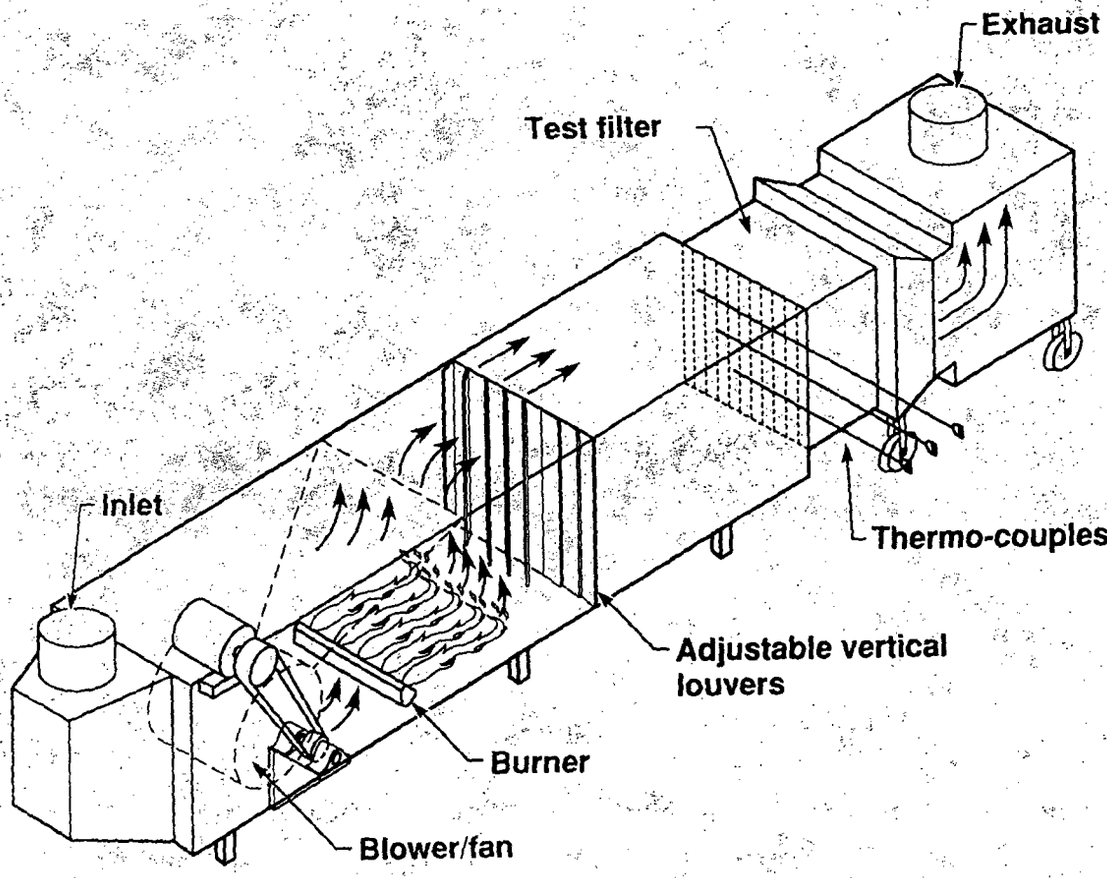

Figure 1 Heated Air Test Apparatus

One of the prototype filters was placed in the holding chuck of the heated air rig, shown in Figure 2. The blower was started and the air temperature was brought to 700 ±50°F (371 ±28°C), at which point the five-minute test began. Following this period of exposure, the gas flame was discontinued, and continued air flow cooled the apparatus to 80-100 degrees to permit removal of the filter.

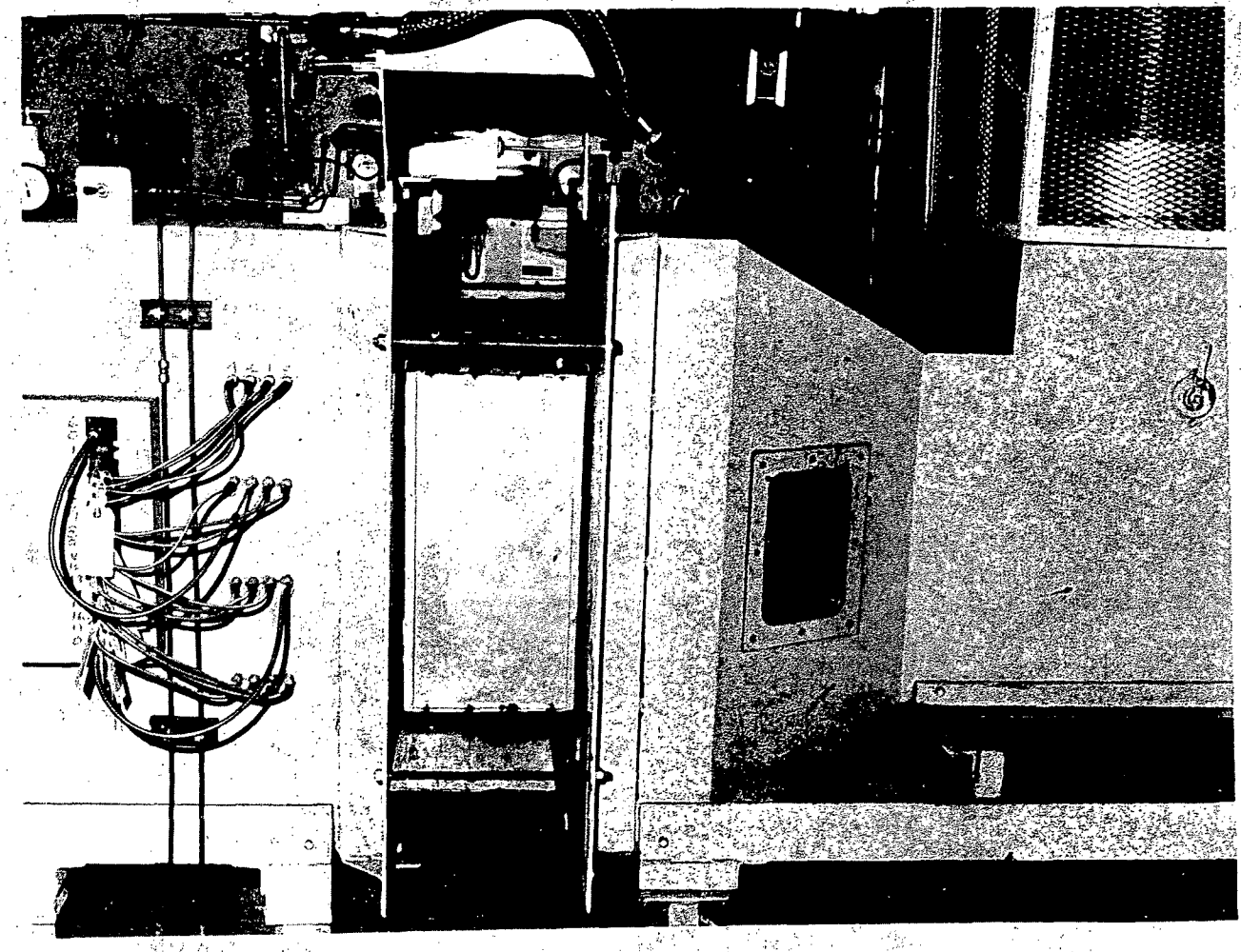

Figure 2 Filter Holding Chuck

Inspection of the prototype unit following the heated air test identified only one change. A few pleats of medium and separators deflected in the center of the pack and near the lower edge of the frame. This is shown in Figure 3. The change is attributed to expansion

of the metal frame under the heat of the test and subsequent contraction after cooling. Pratt and Green[5] observed tears along the pleats when a high temperature sealant was used to join the filter pack to a metal frame. Ensinger et al[15] had observed similar kinking of the filter pleats, but no tears, when the conventional HEPA media was glued to a steel frame with silicone adhesive.

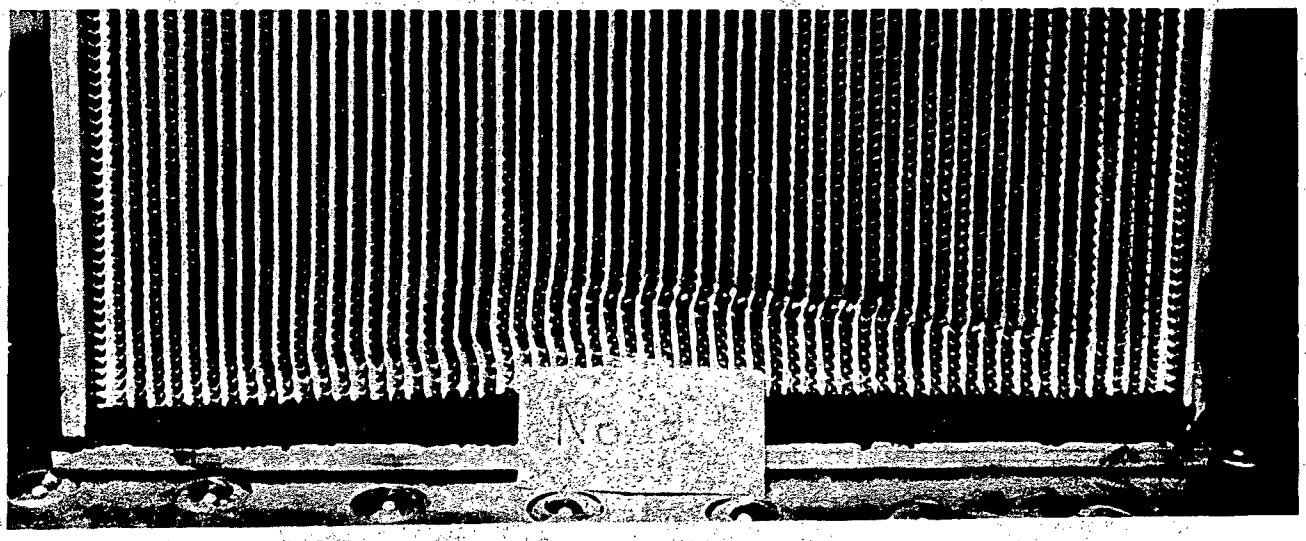

Figure 3 Deflected Medium and Separators

A standard HEPA filter fabricated with a wood frame and polyurethane as the sealant was designated as a control and subjected to the same test procedure. Following the testing, both units were measured for penetration with the Q107 DOP Penetrometer. Results of this stage of testing are given in Table 2.

Table 2 Results of Heated Air Test

	Percent Penetration	
	Before	After
Filter Unit A	0.010	0.070
Control	0.016	0.500

These two filters together with another of the prototype units were placed in an environmental chamber for 24 hours, Figure 4, where the relative humidity was controlled at 95%, ±5%, and the temperature was held at 95 ±5°F (35 ±3°C). Test filters are preconditioned in preparation for the pressure resistance test.

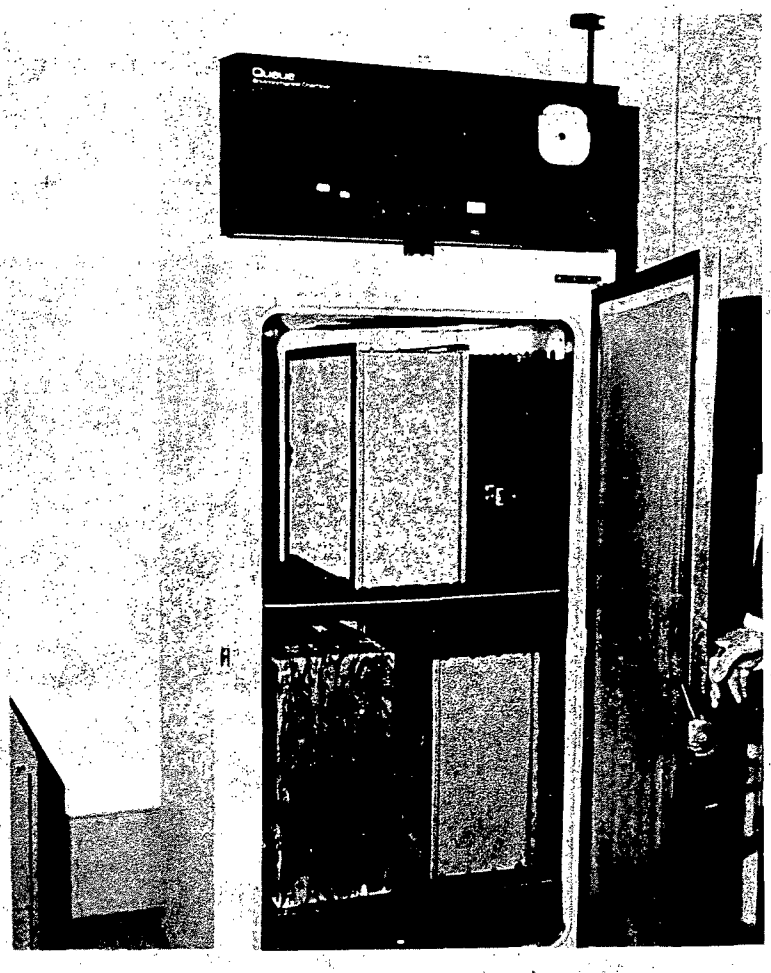

Figure 4 Environmental Chamber

Pressure Resistance Test

The pressure resistance test apparatus is an elongated elliptical chamber through which air and moisture are recirculated to a test filter. An overhead view of the Q160 pressure resistance apparatus at Rocky Flats Plant is shown in Figure 5. A filter that is positioned for testing as viewed through the access door opening is shown in Figure 6. Refer to the the simplified sketch shown in Figure 7 to better understand the test procedure. The blower is started together with the introduction of steam, condensing to water droplets, and the volume of air is increased to maintain a resistance of 10 inches water gauge (2.5 kPa) across the filter. Water droplets are generated at a rate of one pound ±1/4 pound (114 g) per 1,000 cubic feet (1,700 m^3) of air. At 10 inches (2.5 kPa) of pressure drop the air flow, combined with the moisture, measures between 7,000 to 8,000 cfm (11,900 - 13,600 m^3/hr) . This pressure is maintained on the filter for a minimum of one hour.

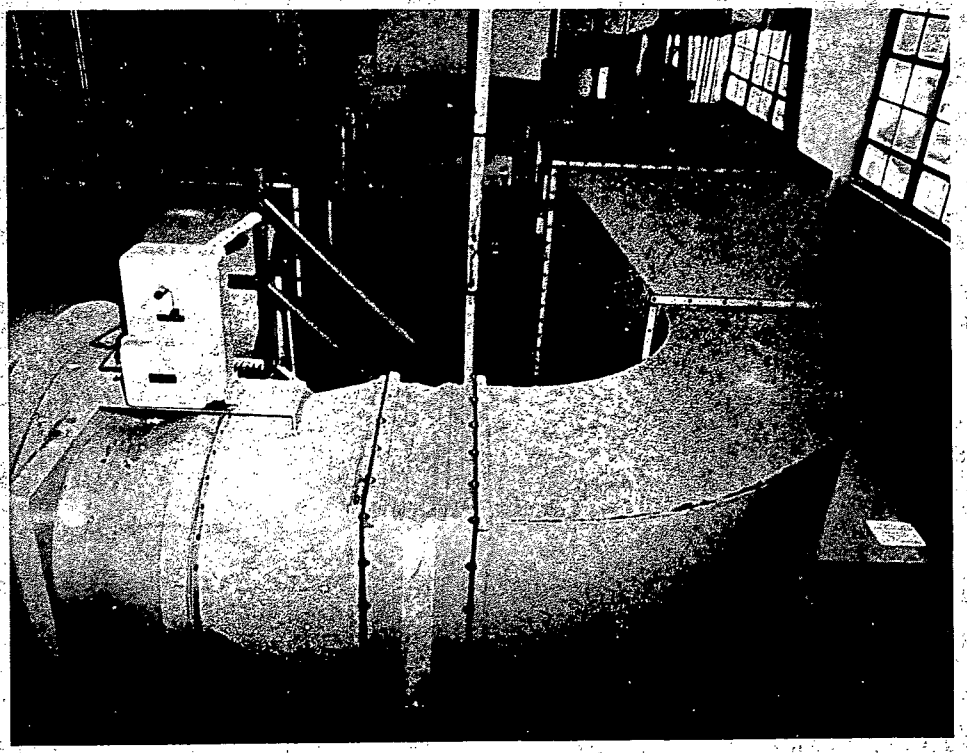

Figure 5 Pressure Resistance Apparatus

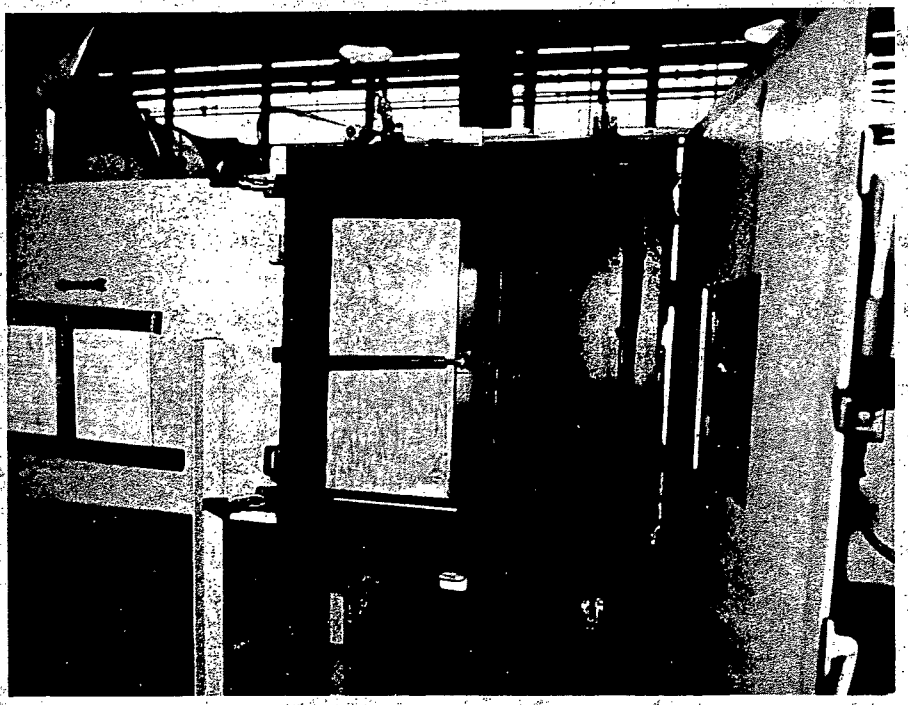

Figure 6 Test Filter with Access Door Open

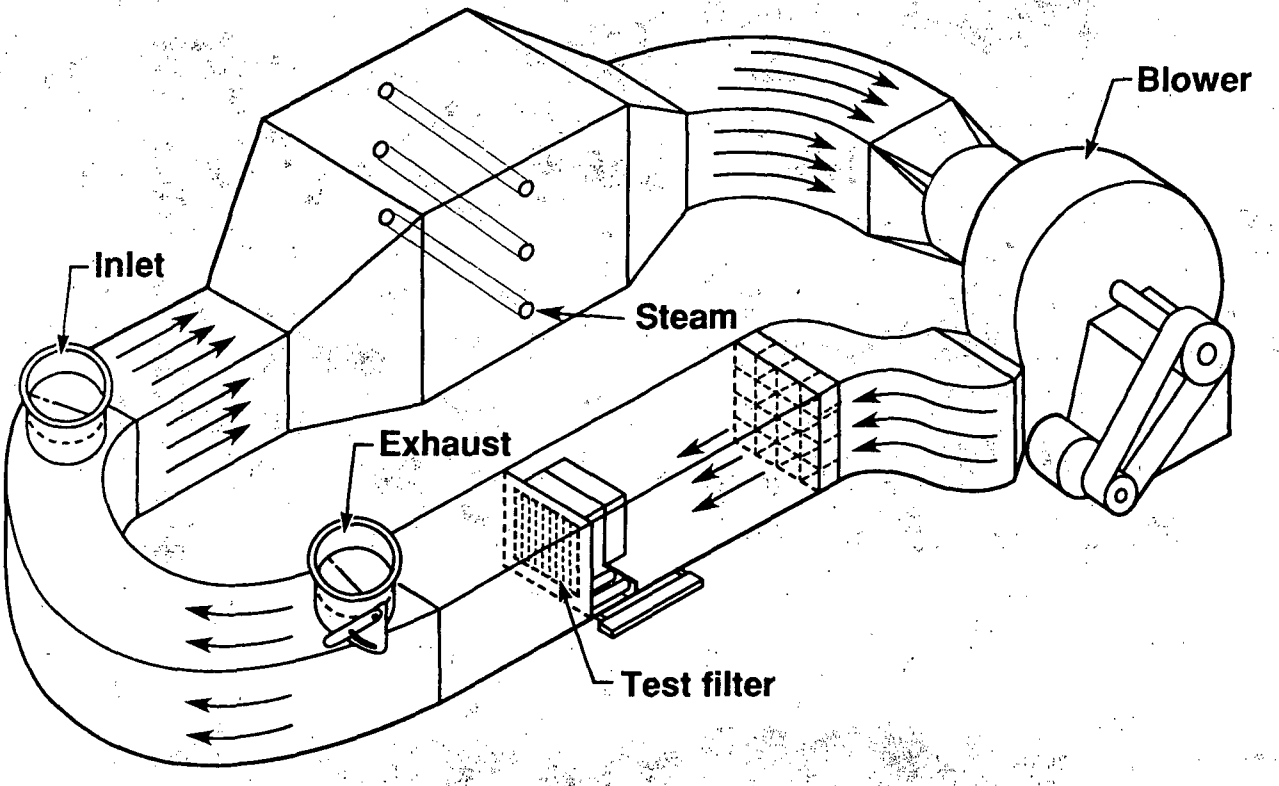

Figure 7 Diagram of the Pressure Resistance Apparatus

Although the practice at the Edgewood Area of Aberdeen Proving Ground is to measure penetration of the filter promptly after its test, the procedure at Rocky Flats is to terminate water droplets and continue the air briefly to remove detectable water and let the filter stand over night before measuring its penetration. The Rocky Flats modification assumes that any perforations of the filter from the pressure resistance test will be detected where otherwise they might be bridged and occluded by residual moisture.

The three filters which had been preconditioned for 24 hours were tested with the Q160 pressure resistance equipment. Results are shown in Table 3.

Table 3 Results of Heated Air and Pressure Resistance Tests

	Percent Penetration		
	Before Testing	After Heated Air	After Pressure Resistance
Filter Unit A	0.010	0.070	0.070
Control Filter	0.016	0.500	1.000
Filter Unit B	0.005	---	0.006

Filter Unit A changed from an initial penetration of 0.01% to 0.07% after the heated air test, which is better than expected, and showed no additional increase after exposure to a 10-inch (2.5 kPa) pressure drop of air and water for an hour. In contrast, the control filter increased from 0.016 to 0.5% after the heated air test and additionally to 1.0% after the pressure test. Figure 8 shows the severe charring of the urathane sealant on the upstream side of the filter. The charring was equally severe on the the downstream side. Two vertical linear cracks in one pleat are visible in the center of the downstream face, Figure 9. These cracks appeared after the combined exposure of heated air and pressure resistance. A second prototype filter, unit B, was subjected to a one hour pressure resistance test and showed only a slight increase in penetration from 0.005% to 0.006%. Comparing the penetration of filter unit B to unit A shows that the heated air test is more damaging to the HEPA filter than the pressure resistance test.

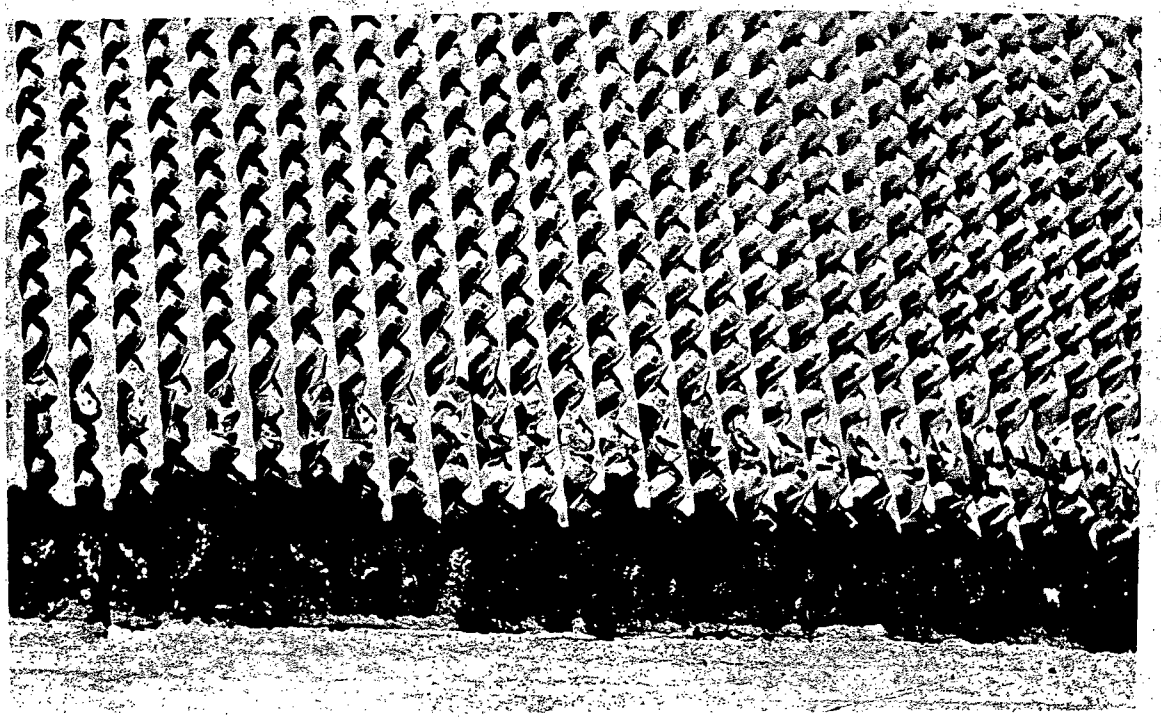

Figure 8 Upstream Face of Control Filter

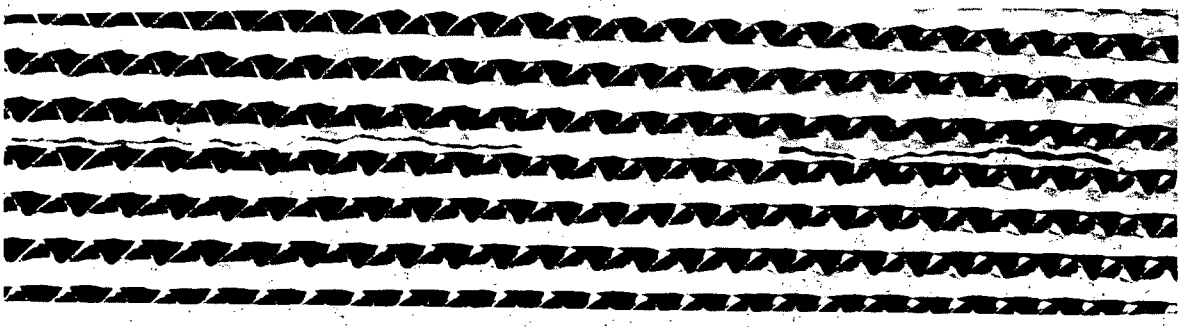

Figure 9 Cracked Pleats on Downstream Face

The maximum allowed penetration of a filter after exposure to heated air is 3.0% according to MIL-F-51068 although any excess beyond 1.0% after this test is a rare occurrence. The performance of the control filter therefore was within the allowable increase of penetration. The ruptured pleat following the pressure resistance test was not expected, however. All of the filters met the current test requirements.

Rough Handling Test

The rough handling test has been used for many years and the test procedure is described in the 1956 issue of MIL-STD-282.[4] The equipment in essence is a vibrating machine designated the Q110 and is designed to simulate transportation vibrations. It provides a platform, to which the filter is attached, and it mechanically moves the bed 200 cycles per minute at an amplitude of 3/4 inch. A view of one of the two cams that lifts and drops the platform is shown in Figure 10.

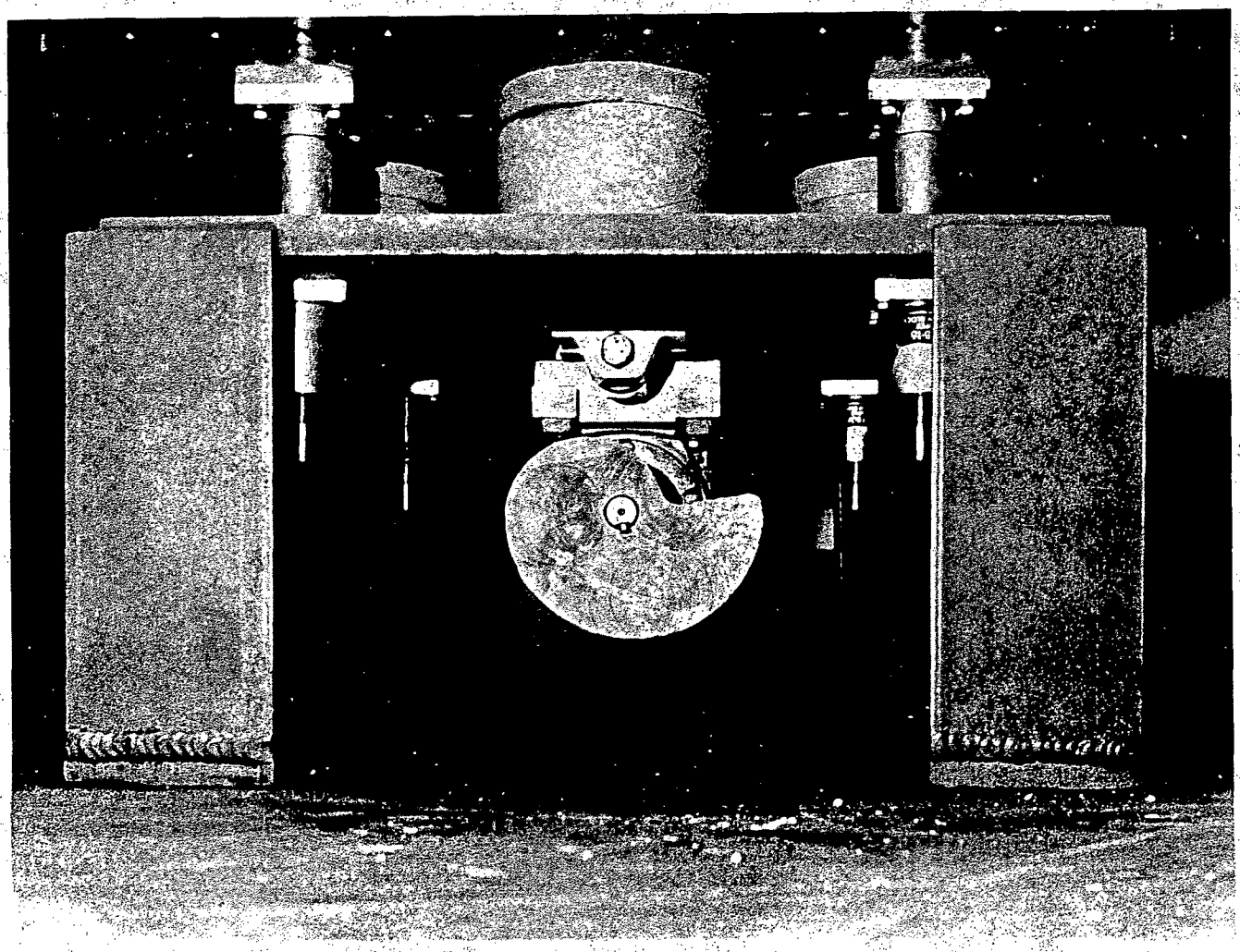

Figure 10 Cam for Lift/Drop Platform on Rough Handling Apparatus

The normal test procedure is to remove the filter from its shipping carton and strap it to the Q110 Vibrating Machine for test. Sixteen years of quality assurance testing at Rocky Flats dictated that transportation of the filter induced more mechanical damage than any other cause. Therefore the test procedure for rough handling was modified to test the filter within its shipping carton. Frequency of 200 cycles per minute and amplitude of 3/4 inch were unchanged. Damage is determined by any increase of DOP penetration above the penetration recorded upon initial test following receipt of the filter. The original procedure to test the uncartoned filter element removed from its shipping carton required two long threaded studs to which a bar was bolted across the filter. The modified test procedure employs four such studs positioned on four sides of the filter packaged in its shipping carton. A plate is bolted to the four studs to hold the filter enclosed in its shipping carton to the platform. The studs and plate are shown in Figure 11. Figure 12 depicts the enclosed filter ready for testing.

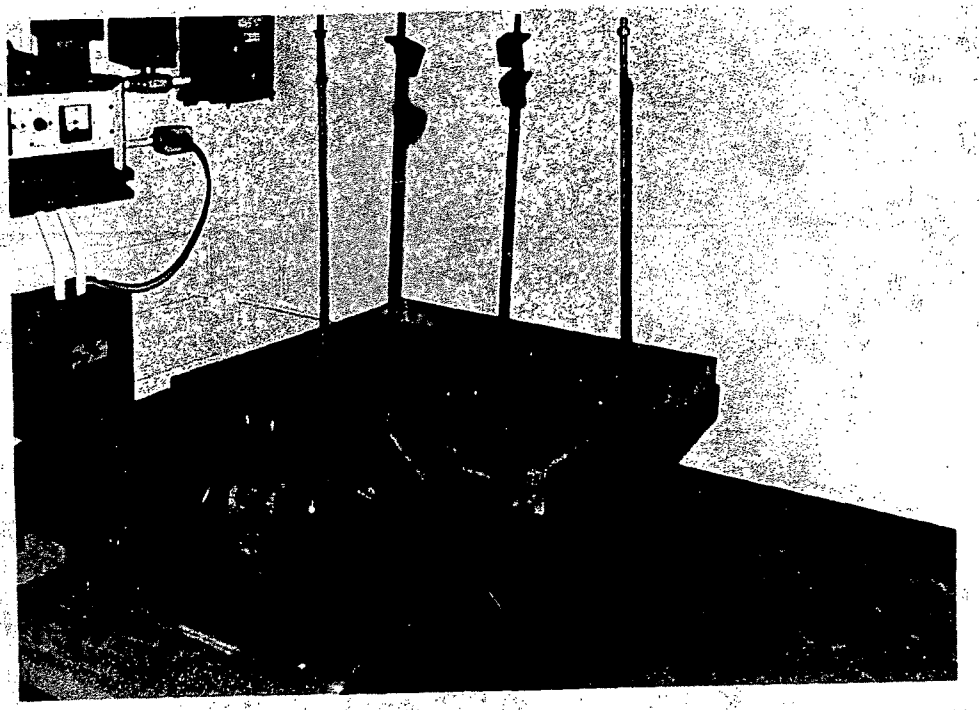

Figure 11 Rough Handling Test Apparatus

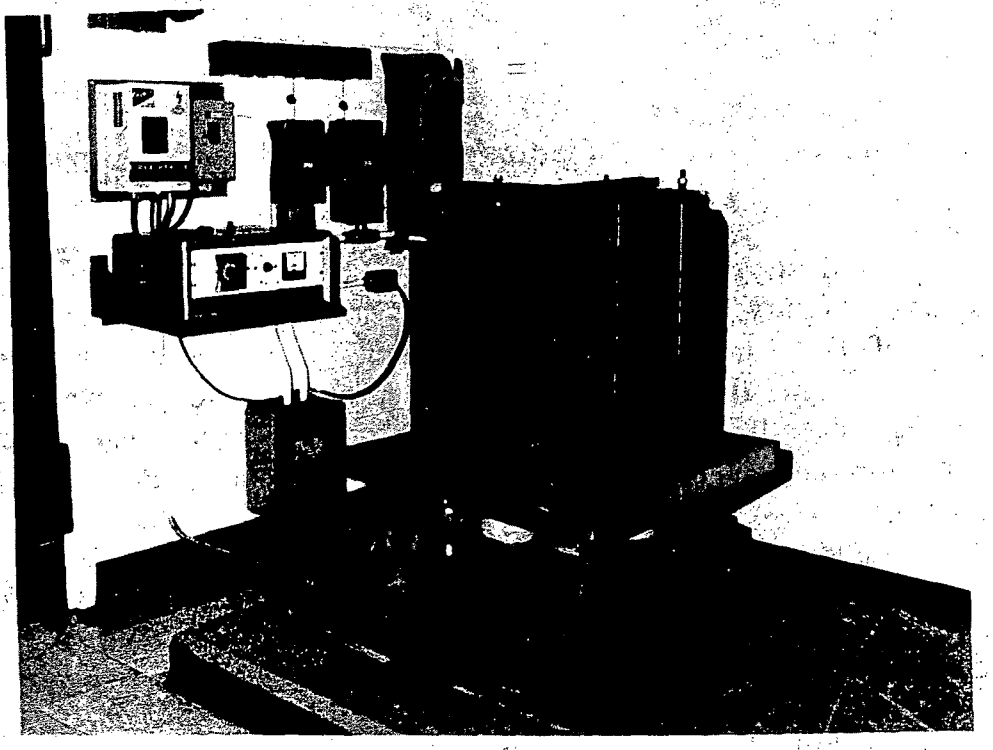

Figure 12 Enclosed Filter Ready for Testing

One of the prototype filters, enclosed in its carton, was bolted to the platform of the Q110 Vibrating Machine, and the test apparatus was operated for the 15 minutes stipulated for the test. Penetration of the filter before and after testing is given in Table 4.

Table 4 Results of Rough Handling Test

	Percent Penetration	
	Before	After
Filter Unit C	0.006	0.006

Penetration through Filter Unit C was unchanged after the rough handling test.

IV. Conclusion

All of the tests described above are termed destructive tests. They are intended to evaluate the fire resistance, strength, and reliability of the design of a HEPA filter. Many HEPA filters, of both conventional and novel design, have withstood these tests at the Edgewood Area of Aberdeen Proving Ground. This is required for identification on the Qualified Products List (QPL) of the Department of Defense. In addition, many models of HEPA filters have successfully undergone the heated air test of UL 586 in order to bear the "UL" label. Although these tests were adequate to address many environmental challenges for Army applications, they are not sufficient to evaluate the variety and severity of accident conditions postulated in nuclear accidents. We have nevertheless used these tests because of their availability and the fact that they can provide a relative comparison between prototype and standard HEPA filters.

This study differs from most previous investigations of HEPA filters under accident conditions in that the same test filter was subjected to more than one environmental test. The previous practice was to subject a filter to only one destructive test. In our study, we evaluated the prototype and standard HEPA filters in a test sequence consisting of a heated air test followed by a pressure resistance test. Ruedinger et al[10] had previously reported that they used a test sequence consisting of elevated temperature in still air, pressure resistance in high air flow, and humid air resistance to qualify filters for use in nuclear reactors.

The results from our preliminary study show that the prototype filter can withstand exposures to heated air and higher pressure significantly better than the standard HEPA filter. The scrim backed

medium and the silicone rubber seals are considered the most significant contributors to the improved performance of the prototype, and the design might be given serious consideration for use in applications subjected to a harsh environment and to design basis accidents in nuclear facilities. We recommend that further studies be conducted to assess the filter's performance under more severe accident conditions.

V. Acknowledgment

The authors acknowledge the cooperation of the Technical Papers Division of Lydall, Inc., in this project.

References

1. Gregory, W.S., Andrae, R.W., Duerre, D.H., Horak, H.L., Smith, P.R, Ricketts, C.I., and Gill, W. "Air cleaning systems analysis and HEPA filter response to simulated tornado loadings" Proceedings of the 15th DOE Nuclear Air Cleaning Conference, CONF-780819, NTIS, Springfield, VA, pp. 694-706 (1979).

2. Alvared, N., Beason, D., Bergman, W., Ford, H., and Lipska, A. "Fire protection countermeasures for containment ventilation systems", Proceedings of the 16th DOE Nuclear Air Cleaning Conference, NTIS, Springfield, VA, pp.1213-1276 (1981).

3. Ruedinger, V., Ricketts, C.I., Wilhelm, J.G. "Limits of HEPA filter application under high humidity conditions" Proceedings of the 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, CONF -840806, NTIS, Springfield, VA, pp. 1058-1084 (1985).

4. Ricketts, C.I., Ruedinger, V., Wilhelm, J.G., "HEPA filter behavior under high humidity airflows" Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0086, CONF-860820, Superintendent of Cocuments, U.S. Govt. Printing Office, Washington, DC, pp. 319-352 (1987).

5. Pratt, R.P., and Green, B.L., "Performance testing of HEPA filters under hot dynamic conditions" Proceedings of the 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, CONF - 840806, NTIS, Springfield, VA, pp. 1107-1127 (1985).

6. Pratt, R.P. "The performance of filters under hot dynamic conditions" Gaseous Effluent Treatment in Nuclear Installations, G.

Fraser and F. Luykx, editors, Graham & Trotman, Luxembourg, pp. 824-836 (1986).

7. Briand, A., Laborde, J.C., and Mulcey, P., "Limits of HEPA filters operation under high temperature conditions" Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0086, CONF-860820, Superintendent of Cocuments, U.S. Govt. Printing Office, Washington, DC, pp. 890-904 (1987).

8. Johnson, J.S., Beason, D.G., Smith, P.R., and Gregory, W.S., "The effect of age on the structural integrity of HEPA filters" Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0098, CONF-880822, Superintendent of Documents, U. S. Government Printing Office, Washington, DC, pp. 366-381 (1989).

9. Ruedinger, V., Ricketts, C.I., Wilhelm, J.G., and Alken, W. "Development of glass-fiber HEPA filters of high structural strength on the basis of the establishment of the failure mechanisms", Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Congerence, NUREG/CP-0086, CONF-860820, Superintendent of Cocuments, U.S. Govt. Printing Office, Washington, DC, pp. 947-966 (1987).

10. Ruedinger, V., Ricketts, C. I., and Wilhelm, J. G., "The realization of commercial high strength HEPA filters," Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0098, CONF-880822, Superintendent of Documents, U. S. Government Printing Office, Washington, pp 917-942 (1989).

11. Filter, Particulate, High-Efficiency, Fire Resistant, Military Specification MIL-F-0051068, Commander, U. S. Army Armament, Munitions and Chemical Command, ATTN: DRSMC-CLW-E/A, Aberdeen Proving Ground, MD 21010-5423.

12. Filter Medium, Fire-Resistant, High-Efficiency, Military Specification MIL-F-0051079, Commander, U.S. Army Armament, Munitions and Chemical Command, supra.

13. High Efficiency Particulate Air Filter Units, Standard for Safety UL 586, Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062. Also identified as ANSI B132.1, American National Standards Institute, 1430 Broadway, New York, NY 10018.

14. Filter Units, Protective Clothing, Gas-Mask Components and Related Products Performance-Test Methods, Method 105.9, Military

Standard MIL-STD-282, Commanding Officer, Frankford Arsenal, Navy Department, ATTN: SMUFA-N1100, Philadelphia, PA 19137.

15. Ensinger, U., Ruedinger, U., and Wilhelm, J."Efficiency of HEPA filters at elevated temperatures: Investigations with the TiO_2 test method" Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, p334 (1989).

CLOSING COMMENTS OF SESSION CO-CHAIRMAN ANDERSON

This session has concentrated on filter unit design and evaluation with several papers exploring advanced filtration devices for special requirements.

Dr. Wilhelm from Karlsruhe addressed the problem of the effects and challenges within ventilation systems during accident conditions and presented current status of potential solutions. Two papers addressed the need for devices that could be used for specific operating conditions. Mr. Davis, from Flanders Filters, proposed the use of radial flow units in a variety of system configurations to facilitate handling, changing, and disposal of filters used by the nuclear industry. Mr. Gilbert presented a Livermore development of an improved HEPA filter of increased strength and resistance to elevated temperatures. Confirmation of enhanced performance was achieved experimentally and unit reliability under accident conditions is to be expected.

Two papers explored the behavior of filter units during unusual off-gas conditions. Mr. Jannakos, from Karlsruhe, studied the effect of water droplets on filter performance while Mr. Leibold reported high dust concentrations on the life and performance of HEPA systems.

Two papers provided an update on the use of metal fibers as an alternative for nuclear air filtration technologies. Mr. Milatovic, from Fluor Daniel, described a 1,000 cfm unit currently involved in demonstration testing at Oak Ridge. Dr. Bergman, from Livermore, outlined a similar unit that has been system tested in his laboratory. Although filtration efficiencies equal to current requirements can be achieved, excessive pressure drop, cost, and weight will prevent these units from being a drop-in replacement.

Mr. Klassen, from Argonne, described a computer-directed program for prediction of filter mass loading as a function of pressure drop across a prefilter/HEPA system. Preliminary verification data were included in the presentation.

This concludes this mornings session. We thank the authors for their interesting presentations and you, the audience, for participating.

SESSION 11

ADSORBER TESTING AND ADSORBER PERFORMANCE

Wednesday: August 26, 1992
Co-Chairmen: J. L. Kovach
Li Qi-dong

A SIMPLIFIED TEST PROCEDURE FOR DETERMINING THE EFFECTIVENESS OF ADSORBENTS FOR THE REMOVAL OF METHYL IODIDE
D.W. Underhill

PARAMETRIC STUDIES OF RADIOACTIVE IODINE, HYDROGEN IODIDE AND METHYL IODIDE REMOVAL
J.L. Kovach

TESTING OF ADSORBENTS USED IN NUCLEAR POWER PLANT AIR CLEANING SYSTEMS USING THE "NEW" STANDARDS
W.P. Freeman

EXPERIENCE WITH ONTARIO HYDRO'S IN PLACE CARBON FILTER TESTING
J. Holtorp, A. Guest, K. Parker, T. Jarv. C. Brain

REPLACEMENT TRACER AGENT FOR THE IN-PLACE LEAK TESTING OF ADSORBERS IN NATS
J.R. Pearson, K.M. Fleming, J.R. Hunt, P.L. Lagus

A SIMPLIFIED TEST PROCEDURE FOR DETERMINING THE EFFECTIVENESS OF ADSORBENTS FOR THE REMOVAL OF METHYL IODIDE

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Abstract

ASTM Test Procedure D3803 measures the ability of nuclear-grade carbon to remove methyl iodide from a stream of humidified air. This test, unlike all the other procedures developed by ASTM Committee D28, has evolved to become extremely complex. The intricacy of this test as well as the great difficulty in obtaining inter-laboratory agreement, creates doubt as to the actual meaning of the results. Here a far simpler test system is described in which thermodynamic principles are used to maintain a constant, reproducible test procedure. This paper describes a system implementing these elements, its cost to build, and the factors affecting its accuracy.

I. Introduction

A "standard" test system for determining the ability of nuclear-grade carbon to adsorb methyl iodide is described in ASTM Standard Test Method D3803.[1] However test systems built to meet these ASTM specifications have given results which differ widely, depending on the laboratory in which the measurements were made. One review of an earlier version of this test procedure states:[2]

> "The NRC is interested in developing a test method to evaluate a carbon's ability to adsorb iodine and methyl iodide. As a result, they have sponsored a program to evaluate D3803. Results from the second round robin series were presented to D28.04 by Chris Scarpellino of EG&G, Idaho.
>
> "According to Scarpellino, the results of methyl iodide adsorption tests by various laboratories varied by two orders of magnitude. Factors that contribute to the variance between laboratories include:
>
> * Problems with test equipment calibration.
> * Problems associated with measurement of relative humidity above 90%, and maintaining constant relative humidity.
> * Flow Measurement difficulties.
>
> "Other potential problem areas with the test method were discussed. McKee indicated moisture condensation in the pores at high relative humidity may be a problem. Physical-chemical effects other than adsorption may occur (Deitz, McKee) at high relative humidity. The effect of oven moisture measurement on impregnated carbons was also discussed."

Later in the same report, Scarpellino cites problem areas found through his contact with other test laboratories. Problems cited include:

> "It is difficult to avoid the conclusion that the measurement of relative humidity, and possibly flow, is inadequate in some or all of the test facilities. The control [of] these factors may be quite adequate, since the intralaboratory variances were quite small.
>
> "The test setups need to be examined for systematic errors, such as using a pressure for calculation that is actually measured at a different point in the system. The interlaboratory comparison had already revealed some such errors, and these had been corrected, or corrections were in progress.
>
> "Modern flow and RH measurement devices, particularly those involving electronics, are marvelous in speed of response and possibly sensitivity and accuracy - but they may lack a bit in stability. Classic methods, such as wet

bulb/dry bulb measurement and orifice meters, often give more reliable data; one can tell if a rotameter ball is stuck.

"At high humidities, one must guard against the creation of droplets; these must be filtered out of the system.

After considering the above information, ASTM Committee D28 concluded that:

"Based on the results to date, the Committee believes D3803 must be modified. No action will be taken by [ASTM Committee] D28.04 until the NRC sponsored program is completed."

The large number of problem areas cited above, along with the absence of any specific program to understand the root source of errors in the methyl iodide penetration test, indicates that both the NRC and ASTM Committee D28 are far from developing an adequate test system. The most important indication of how much needs to be done is that there is no "gold standard" by which interlaboratory differences may be explained. Thus it would appear that any two numbers, even were they to differ by two orders of magnitude, are equally "correct". Thus at this time, those who are trying to develop a standard test procedure for determining methyl iodide retention, do not even know what the results from such a test should be.

What is needed is a reproducible test procedure, based on simple thermodynamic principles, that defines precisely and exactly the test parameters. The principles behind such a test system are described next.

II. Basic Concepts

The two simplifying principles used in the design of this system are:

1. If the test apparatus is sufficiently small and operated isothermally, then the entire system can be contained in a well-stirred, temperature controlled water bath. Because of the very high heat capacity of water, in a well circulated water bath, temperature control within $\pm 0.^{\circ}C$ is not difficult to maintain. Such systems are not only highly precise in their temperature control, but also inexpensive. If the system is based on thermodynamic equilibria, then temperature control is simplified enormously, as it is no longer necessary to build a system in which temperature differences are tightly controlled. We will use the saline concentration of the water in the bath to control the relative humidity in the system. This procedure is highly stable - for example, for the equilibrium relative humidity to be in error by 2.5% (*i.e.* going from a 95% RH to a 97.5% RH), the saline concentration must be in error by 50%.

2. The tagged methyl iodide can be injected with precision as its water solution using an infusion pump. With this scheme, it is no longer necessary to synthesize a pressurized air/methyl iodide mixture, and then monitor its input using a rotameter controlled air infusion system. This system also eliminates the interaction of the methyl iodide with the walls of the gas cylinder and associated plumbing.

III. The Basic System

Figure 1 lays out a test system built to incorporate these concepts. Note that it is simple to hold constant the predetermined the test parameters in this system because:

* The test temperature is controlled by the temperature of a single water bath.
* The relative humidity is controlled by the salt concentration.
* The contact time is controlled by the ratio of the volume of adsorbent to the minute volume of humidified air.
* A simple and precise procedure for injecting methyl iodide is used.

The operation of this system is as follows. Air passes into the opening shown on the left hand side of the drawing, being drawn by the air pump, "P2", at the opposite end of the system. The indrawn air first passes upward through bed "A", which is packed with berl saddles. In this bed it comes into close contact with sodium

chloride solution drawn from the temperature regulated bath surrounding it, through small holes at the top of the bed, at a rate of about 1 lpm. The berl saddles in the bed give the large surface area necessary to permit equilibrium to be established between the gaseous and liquid phases flowing countercurrently to each other.

The number of transfer units required for 99.9% equilibrium with the vapor pressure of water in the saline solution (assuming presaturation to within 10% of the desired value) is ln(100) = 4.6. If it is further assumed that the HETU is 6 cm., then the minimum tower height is 30 cm., a height that will easily fit into a moderately sized bath.

Although not critical to the design of the system, the degree of air-saline water contact (conveniently described in terms of the number of transfer units) can be established by passing air containing tracer amounts of tritiated water through the tower and determining the fraction of the tritium that is removed. The natural logarithm of the ratio of the input concentration to the output concentration of tritium would be equal to the number of transfer units.

Saline solution is drawn off the bottom of bed "A" by a sump pump, "P1", and passed back into the water bath. In order to prevent flooding, the flow through pump, "P1", is set at a rate sightly higher than the expected flow of saline solution. The entrainment of a small amount of air by the pump, "P1", indicates that this pump is operating at a sufficient flow to prevent flooding of bed "A".

For operation at 30°C, the concentration of sodium chloride in the bath's water is maintained at a molality of 1.378, which is the concentration required to establish an equilibrium water vapor pressure equivalent to a RH of 95% over the saline solution at 30°C.[3,4] The salt concentration in the brine is monitored by a hydrometer and makeup water is added as required to maintain the molality.

The air from bed "A" is drawn through the bed "B", containing the carbon to be tested, by the pump, "P2", which in turn is controlled by a mass flow meter at the effluent end of the bed. The diagram also shows a second adsorption bed, needed to prevent any effluent ^{131}I from escaping from the system. All parameters except the air flow rate are governed by thermal or chemical equilibria that are easy to maintain. The air flow rate is the one parameter that requires critical monitoring. This is because the contact time is a dynamic rather than an equilibrium property and thus there is no way to establish this factor, as all the other factors were, by a known thermodynamic equilibrium.

By adding a trace of a dye (*e.g.* fluorescein) to the sodium chloride solution, one can, by wiping the joints after disassembling the apparatus, locate any water leaks. Actually in this system, unlike the test system described in ASTM D3803, small water leaks should have no effect, for introducing a small amount of extraneous sodium chloride solution for which the water vapor pressure is the same as that of the air passing over it, will have no effect on the humidity of the air passing over it.

Thus with this test apparatus, one can determine in a straightforward manner how these test variables effect carbon performance, and thereby obtain the necessary data for accident analyses. In contrast, the current ASTM procedure requires a preheater, humidifier, condenser, and a reheat canister all contained within a temperature regulated system. The allowable temperature tolerance in the ASTM procedure is ±0.2°C. Assuming that condenser is high by 0.2°C and that the beds are low by the same amount, then the RH at which the beds will be tested will be 97.3%. As it is well established that bed performance falls rapidly as a RH of 100% is approached, the severe interlaboratory disagreement found with this procedure seems readily understandable.

Although the system described here is for operation at 30°C, the parameters can be easily modified for operation at other temperatures. For example, with NaCl, a molality of 1.374 would be used to generate a 95% RH at 80°C. This slow drift in the desired saline concentration with temperature reduces any possible confounding effects of temperature and salt concentration.

Alternatively, lithium chloride (LiCl) may be used to reduce the vapor pressure of water, as excellent data on the equilibrium of water vapor pressures above LiCl solutions are available.[5,6] For a 95% RH at 30°C and 80°C, respectively, LiCl molalities of 1.195 and 1.238 would be used. The Appendix gives a BASIC program that uses a 25 parameter quintic equation developed earlier for the vapor pressure of water in equilibrium with 1.0-18.5*m* LiCl at temperatures from 25°C to 100°C. This program is included with this text because if the reader is not familiar with the thermodynamic terminology used by Gibbard, programming his lengthy equations is certain to be very time consuming.

IV. The Methyl Iodide Infusion System

In the system described here, the methyl iodide is dissolved in water and infused by a syringe pump into a midget impinger from which it is desorbed from a steam of air into the test system. This system has the advantages of being highly accurate - using a microsyringe, a precise amount of method iodide can be dissolved in an equally precise volume of water, and an infusion pump used to deliver a metered volume of the solution to be passed into the test system. Infusion pumps that will perform this service with a very high accuracy are readily available. This procedure avoids the problems in setting up concentrations of methyl iodide in compressed air, with wall adsorption of methyl iodide, and with accurately metering the compressed air containing the methyl iodide. Because in the procedure described here, the rate limiting step is the infusion of dissolved methyl iodide, the key to accuracy is knowing the concentration of methyl iodide dissolved in the water and the rate of infusion. The methodology proposed here, which is considerably refashioned from that described in ASTM 3803, was used earlier in the testing of impregnated charcoal for the removal of methyl iodide.[7] Although the results are not presented here, this water phase injection procedure was simple to use, accurate in its delivery of methyl iodide, and inexpensive to build and operate.

We next discuss the design parameters for this infusion system. Glew and Moelwyn-Hughes[8,9] recommend the following equation for calculating the solubility of methyl iodide in water:

$$\log_{10}(C_{sat}) = -110.278 + 37.621 \log_{10}(T) + 4823/T \qquad (1)$$

where C_{sat} is in moles/liter and T is in °K.

This equation gives a solubility of 1.40 gms of methyl iodide in 100 grams of water at 30°C. If it is assumed that 1.4 m^3 of air will pass through the test beds over an one hour injection period, then at a methyl concentration of 1.75 mg/l, the required weight of methyl iodide for the test is 2.51 mg. This amount of methyl iodide could be dissolved in 0.18 ml of water.

How long does it take to establish equilibrium between the influent and effluent methyl iodide in the midget impinger? The equilibrium time, t, required for establishment of a 95% equilibrium between the rates of infused and effluent methyl iodide is:

$$t = 3VK/q \qquad (2)$$

where V is the volume of water, K is the water-air partition coefficient (at 30°C), and q is the flow of air, ml/min.

The water-air partition coefficient (at 30°C) for ethyl iodide in the impinger, is required in order to use Eq. 2. Hasty recommends the following equation for the partition coefficient of methyl iodide between air and water:[9,10]

$$\log_{10}(K) = -4.82 + 1597/T \qquad (3)$$

where K is the water-air partition coefficient (dimensionless). At 30°C, K = 2.8.

Assume that the test is run with an initial 5 ml of water in the midget impinger and that the 2.51 mg. of methyl iodide is contained in 1 ml of water, which is infused into the impinger over the hour of the test. Further assume that a stream of air is passing through the bubbler at a rate of 50 ml/min. With these values, the equilibrium time, t, is ≈1 minute. If this short equilibrium period should be thought to cause any difficulty, then the effluent from the impinger can be vented around the test bed for one minute before starting the test.

Methyl iodide slowly hydrolyzes in water. Moelwyn-Hughes gives a value of 1.73×10^{-7} sec^{-1} as the first order rate constant for the hydrolysis of methyl iodide in water at 30°C.[9,11] At this rate, 16 hours would be required to hydrolyze 1% of the methyl iodide in an aqueous solution. The effect of hydrolysis can be reduced to an altogether unmeasurable level by storing the aqueous solution in a refrigerator, and adding a few copper beads to the impinger to scavenge any iodide that is formed.

V. Additional Considerations

In the test as described here, all but one factor - the flow of air through the test beds - is controlled by equilibrium. There is no possible way to remove this last time dependent factor, as the test itself is not a static measurement, but rather a measurement of the dynamic uptake of methyl iodide, with a rate constant described in terms of inverse seconds. This reliance on equilibrium - rather than temperature differences - results in a formidable decrease in the error expected in practice. Another advantage of the system described here is that in relying on thermodynamically basic factors, the results obtained should be more meaningful.

Finally the cost of the system is really quite low. Below are listed the major expenses that would be incurred in setting up the system.

Infusion Pump	$900
Water Bath	$300
Temperature Regulator	$500
Stirrer	$100
Air mover	$900
Sump Pump	$500
Mass Flowmeters for air measurement	$1,500
Glassware	$1,000
Total	$5,700

Appendix

Basic Program to Calculate the Molality of a Lithium Chloride Solution giving a Desired Relative Humidity at a Known Temperature.

```
10 'Basic Calculations:
20 D(1,4) = 9.947194E-02
30 D(2,4) = 8.226815E-03
40 D(3,4) = 2.238653E-04
50 D(4,4) = -7.046113E-05
60 D(5,4) = 1.982918E-06
70 D(1,0) = 53.28557
80 D(2,0) = 31.26828
90 D(3,0) = -3.094298
100 D(4,0) = .2368127
110 D(5,0) = -7.457059E-03
```

```
120 D(1,1) = 1.764393
130 D(2,1) = -.3632635
140 D(3,1) = .0633694
150 D(4,1) = -4.792288E-03
160 D(5,1) = 1.201533E-04
170 D(1,2) = -.0194551
180 D(2,2) = 5.074271E-03
190 D(3,2) = 8.763426E-04
200 D(4,2) = -1.314343E-04
210 D(5,2) = 4.82115E-06
220 D(1,3) = 9.83248E-04
230 D(2,3) = -5.225767E-04
240 D(3,3) = 2.689426E-05
250 D(4,3) = 1.467403E-06
260 D(5,3) = -1.252579E-07
270 TS = 298.16'K
280 A = 1.5
290 INPUT "What are the desired temperature in degrees centigrade and relative
humidity";T,RH
300 TAU = T +273.16 - TS
310 FOR J= 1 TO 5
320 DCOEF(J) = D(J,4) - .2516103*(-(-D(J,0) + TS*D(J,1) -TS^2*D(J,2)/2 +
TS^3*D(J,3)/6)*TAU/TS^2/(1+TAU/TS) + (D(J,1) - TS*D(J,2) +
TS^2*D(J,3)/2)*LOG(1+TAU/TS) + (D(J,2) - TS*D(J,3))*TAU/2 +
D(J,3)*(2*TS*TAU + TAU^2)/12)
330 PRINT DCOEF(J)
340 NEXT
350 S = 1.17284 - 6202.357*TAU/TS^2/(1 + TAU/TS) + 54.42507*LOG(1 +
TAU/TS) - .161993*TAU + 8.596094E-05*(2*TS*TAU + TAU^2)
355 DELTI = 1
360 PRINT "S =";S: Print "Molality   Error"
370 I=DELTI+I
380 'I is the ionic strength measured in moles of solute per kilogram of solvent
390 X = A*I^.5
400 Z = (1 + X - 1/(1 + X) - 2*LOG(1 + X))/X^2
410 'PRINT "X =";X;" and Z =";Z
420 M=I
430 DM=0
440 FOR J = 1 TO 5
450 DM = DM+DCOEF(J)*M^J
460 NEXT
470 PHI = 1 - S*Z/A + DM
480 DIFFER = PHI+55.51*LOG(RH/100)/I
490 PRINT USING "#.####### ###.###";I/2, DIFFER/2'   NOTE: factor of 2 between
molality and ionic strength.  Molality is printed.
500 IF DIFFER >0 THEN I=I-DELTI: DELTI=DELTI/2:
510 IF DELTI < .000001 THEN STOP ELSE GOTO 370
```

References

1. Standard Test Method for Nuclear Grade Activated Carbon, Test Designation D-3803, American Society for Testing and Materials, Philadelphia, PA
2. ASTM Committee D-28: Minutes of the Fall Meeting, Nov 5-6, 1986, Bal Harbour, Fla.
3. Gibbard, H.F., Ph.D. Thesis, Massachusetts Institute of Technology, 1967.
4. Gibbard, H.F., Jr., and Scatchard, G.: Vapor-liquid equilibria of synthetic seawater solutions from 25-100°C *J. Chem. Eng. Data* 17:498-501 (1972)
5. Gibbard, H.F., Jr., Scatchard, G.: Liquid vapor equilibrium of aqueous lithium chloride, from 25 to 100°C and from 1.0 to 18.5 molal, and related properties *J. Chem. Eng. Data* 18:293-8 (1973)
6. Klimenko, A.P., Mogil'nyi, V.I., and Kryukov, V.A. Vapor pressure diagrams of aqueous calcium and lithium solutions, *Chim. Ind, Genie Chim,* 103:591-3 (1970)
7. Underhill, D.W. Unpublished data.
8. Glew, D.N., and Moelwyn-Hughes, E.A.: Chemical statics of methyl halides in water, *Discuss. Faraday Soc.,* 15:150-161 (1953)
9. Parsly. L.F.: Chemical and physical properties of methyl iodide and its occurrences under reactor accident conditions, ORNL NSIC 82. (1971) Available from the National Technical Information Center, Springfield, VA.
10. Hasty, R.A., Partition coefficient of methyl iodide between vapor and water, *Can, J. Chem*, 46:163-4 (1968)
11. Moelwyn-Hughes, E.A.: The kinetics of hydrolysis, *Proc. Roy. Soc (London)* A-222:386-396 (1953)

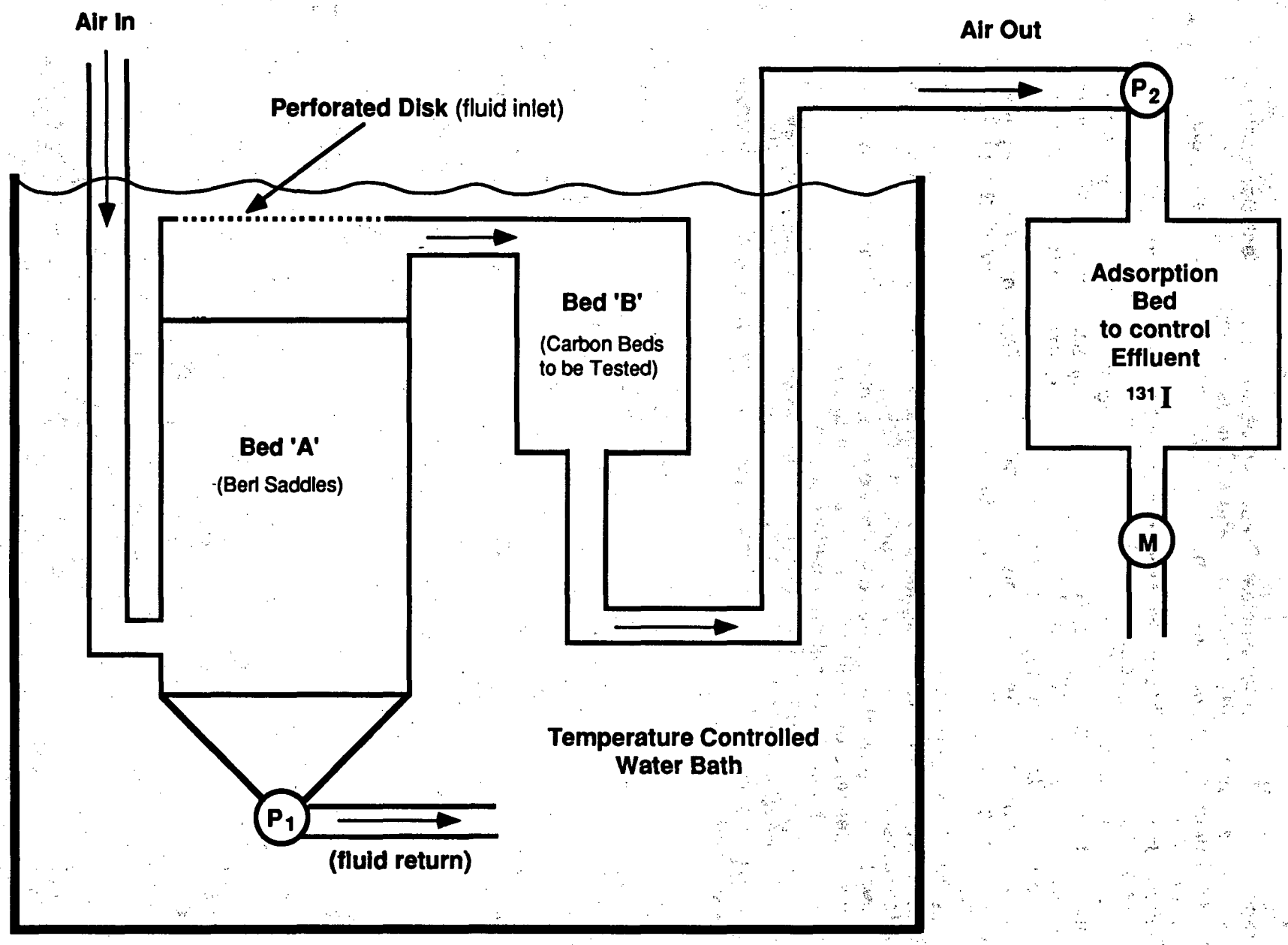

Figure 1: Proposed Test System for Retention of Methyl Iodide

DISCUSSION

FIRST: I don't think that citing that round-robin result buttresses your argument at all, because the whole purpose of the round-robin was to find out if the then standard was adequate. The round-robin did exactly what it was supposed to do. It showed that the description of the test was inadequate and that is why it underwent further study.

UNDERHILL: I think I can say that I can agree with that.

KOVACH: In that particular test loop, I have not seen anything other than so-called calculated verification of any of the parameters that are required for the test; for example, the precision of the temperature regulation or verification of humidity. We all believe that we are good engineers and we use engineering parameters, but, at the same time, these good folks who are called the Nuclear Regulatory Commission require us to verify these values; that we maintain the humidity and we maintain the temperature in a way to generate results that are based on thermodynamic principles. In the test loop that you described, I have not seen any of the verification instrumentation that shows that the parameters that you expect from handbooks, in fact, are being maintained in the system.

UNDERHILL: All I can say is, if you take a simpler test system and you try to verify it, you are better off than trying to verify the accuracy of the complex test system. I am just trying to strip the measurement of methyl iodide penetration down to its basics. This is just a proposal for that.

KOVACH: One additional comment to assist you in this endeavor. The old National Bureau of Standards has a booklet out on humidity measurement which has about 30 or 40 pages of humidity vs salt solution measurements and values reported. You may find that there is something that was cross-checked and verified under various conditions. Not that I want to take away anything from a PhD thesis.

PARAMETRIC STUDIES OF RADIOACTIVE IODINE, HYDROGEN IODIDE AND METHYL IODIDE REMOVAL

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Abstract

The recent evaluation of iodine fission product forms indicates that overall iodine concentration in the gaseous form would be significantly lower than currently assumed in US licensing documents and that the gaseous iodine forms would be elemental iodine, hydrogen iodide, and organic iodides. The removal mechanism of elemental iodine on carbon base adsorbents is primarily by physical adsorption, the removal of hydrogen iodide is by physical adsorption, chemical reaction and isotope exchange, while the organic iodides, best represented by methyl iodide, are removed by isotope exchange.

The methyl iodide removal efficiency of impregnated activated carbons is a complex process, which is influenced by the properties of the base adsorbent, the type of the impregnant and by the process conditions. A systematic study was performed evaluating the individual and combined effects of base carbon particle size impregnant type, temperature, superficial gas velocity, humidity, contact time and bed depth.

Parametric studies were also performed to confirm the removal mechanism of hydrogen iodide by currently used adsorbent types. The data generated permits selection of process conditions which permit the engineering design of radioiodine removal systems. The data indicates that current US regulation frozen designs are not necessarily the optimum conditions and further improvements can be made in the control of radioiodine releases.

Material and Methodology

All adsorbents were coconut shell based. The starting base carbon met the current U.S. quality requirements, i.e. 60% carbontetrachloride activity (CTC) and the particle size distribution required by ASME AG-1 Section FF.

Where special impregnation was used the process was from water solution and the impregnant quantities are indicated, where a standard commercial product i.e. NUCON® NUSORB® KITEG II which contains KI, tertiary amine, pH control and fire retardant impregnants it is from normal production samples.

The basic procedure utilized was the ASTM D3803 (1989) method, where deviation from the specific conditions was required to perform the test, the procedures and required control tolerances of the ASTM D3803 (1989) method were used.

$H^{131}I$ was prepared by isotope exchange between $^{131}I_2$ and $H^{127}I$ with removal of the excess $^{131}I_2$ after the isotope exchange took place.

Particle Size Effects on $CH_3{}^{131}I$ Removal

The 8x16 mesh base carbon was impregnated by 2.0 wt. % KI and 2.0 wt% KI and 2.0 wt. % tertiary amine (TEDA) solution and screened into five fractions. Each of the fractions was tested according to the ASTM D3803 procedure at 30°C and 95% RH.

The $CH_3{}^{131}I$ penetration data for each of the two impregnant types are shown on Tables 1 & 2 and the results are plotted on Figure 1.

In all cases, the coimpregnated carbons show significantly lower $CH_3{}^{131}I$ penetration than the solely KI impregnated carbons. Test beds were segmented into 2.0 inch (5.0 cm) and 4.0 inch (10 cm) depths for the 80 FPM tests and a single 2.0 inch (5.0 cm) deep bed was used for the 40 FPM test bed. In all cases, for both impregnated types at equal residence time (i.e. 0.25 seconds for 40 FPM - 2.0 inch and 80 FPM - 4 inch deep beds) the penetration was significantly lower at the high velocity, 80 FPM conditions than at 40 FPM. In all cases, for both impregnants the $CH_3{}^{131}I$ penetration decreased with decreasing particle size. Both of the two observations indicate that diffusion is a rate controlling step in the $CH_3{}^{131}I$ removal mechanism. Although there are differences in the mechanism between the single KI and the KI-TEDA coimpregnated carbons. This difference indicates that the KI and TEDA are deposited in different parts of the pore structure and the isotope exchange rate also affects the removal process. The main removal mechanism even for TEDA impregnants is the isotope exchange because the excess non-radioactive $CH_3{}^{127}I$ reacts with the TEDA first and then the $CH_3{}^{131}I$ - $CH_3{}^{127}I$ exchange can take place. The data also shows the difficulty in comparing adsorbents for $CH_3{}^{131}I$ removal when the particle size of the adsorbents is not identical.

The obtained results also show that the use of the K-factor for comparing adsorbents is not satisfactory when identical residence times and different carrier gas velocities are used, while it gives similar values at the same velocity different residence times, when the particles size is carefully controlled and the carrier gas velocity is in the 80 FPM (40 cm/sec) range.

Velocity Effects on $CH_3{}^{131}I$ Removal

Tests were performed using the ASTM D3803 (1989) test method and tolerances on 1.0 inch (2.5 cm), 2.0 inch (5.0 cm) and 4.0 inch (10.0 cm) bed depths at 20, 30, 40, 60 and 80 FPM carrier gas velocities. The adsorbent used were samples from commercial NUSORB KITEG II adsorbent. The data are shown on Table 3 and Figure 2. While the penetration is in inverse proportion to velocity for all three bed depths the diffusion control is clearly shown by comparing as an example the values at equal (0.25 sec) residence time at

20 FPM	1.0 inch bed depth
40 FPM	2.0 inch bed depth
80 FPM	4.0 inch bed depth

which clearly show that at equal residence but time higher velocity conditions the penetration as an example is more than an order of magnitude less at 80 FPM than at 20 FPM.

The data also show that at 60 FPM and above the rate controlling mechanism changes from that controlling below that velocity (for the standard particle size distribution adsorbent). The K values are comparable for velocities at and above 60 FPM regardless of residence time while below 60 FPM velocity the K values decrease with increasing bed depth.

Therefore, where the pressure drop consideration is not relevant a significantly smaller size air cleaning system can be designed operating with deeper beds at higher velocities. Considering the floor space costs for nuclear facilities this means significant cost savings, but such better performance, as an example, 4.0 inch deep bed at 80 FPM with the commensurate 0.25 second residence time, is not considered by current U.S. regulations and designs. The other clear indication is that equal residence time does not mean equal $CH_3{}^{131}I$ penetration.

Temperature Effects on $CH_3{}^{131}I$ Removal

Tests were performed using the ASTM D3803 (1989) test method and tolerances at 25, 30, 40, 60 and 80°C on 1.0 inch (2.5 cm), 2.0 inch (5.0 cm) and 4.0 inch (10.0 cm) bed depths on commercial NUSORB KITEG II adsorbent.

The data are shown on Table 4 and Figure 3.

The increased temperature is expected to increase both diffusion and isotope exchange rates and improve the $CH_3{}^{131}I$ removal within the temperature range tested. The performance improvement is much more significant on shallow adsorbent beds (1.0 inch) than for 2.0 inch and deeper beds, however, under all conditions the performance improved with increasing temperature.

It is important to point out that while 1.0 inch beds are rarely used in nuclear air treatment systems they are very commonly used in sampling cartridges monitoring iodine releases. Unfortunately, there were no detailed parametric studies performed to determine use variables on these cartridges, however, data presented here can be an indication of their performance.

As reported elsewhere in this conference, the temperature effects are more significant when testing used adsorbents than for new adsorbents.

Humidity Effects on $CH_3{}^{131}I$ Removal

Tests were performed using the ASTM D3803 (1989) test method and tolerances at 70, 80, 85, 90 and 95% RH on 1.0 inch (2.5 cm) 2 inch (5.0 cm) and 4.0 inch (10.0 cm) bed depths on commercial NUSORB KITEG II adsorbent.

The data are shown on Table 5 and Figure 4.

The detrimental effect of water coadsorption on $CH_3{}^{131}I$ removal is a well known fact and has been demonstrated in the past. However, the data shows that %RH variation is more significant for bed depths shallower than 4.0 inch deep at equal residence times.

For most systems the currently selected U.S. test condition of 95% RH is a conservative test for new adsorbent evaluation.

Screening Tests for $H^{131}I$ Removal

Tests were performed using the ASTM D3803 (1989) method and tolerances under three selected conditions on commercial NUSORB KITEG II adsorbent.

The data are shown on Table 6.

Under all conditions tested the penetration of $H^{131}I$ was higher than that of $CH_3{}^{131}I$. Therefore, if the current source time study indication of $H^{131}I$ presence is validated the $CH_3{}^{131}I$ test for adsorbents may not be conservative.

Conclusions and Recommendations

Most parametric studies reported in the past[1,2] were performed under different test conditions or covered only part of the parameters affecting the $CH_3{}^{131}I$ removal process[3]. The results generated indicate that for engineering design of nuclear air treatment systems and their current U.S. regulations[4,5] is not based on the best available performance conditions for the adsorbents currently available.

The assumption that $CH_3{}^{131}I$ penetration is the most conservative test for characterizing adsorbents is not shown by the results of $H^{131}I$ penetration.

Particularly where energy requirement is not critical it is more advantageous to use deeper beds at higher carrier gas velocity than currently practiced in the U.S.

References

1. Kovach, J. L. "Iodine Fission Product Mass Transfer in Adsorbent Media", 13th AEC Air Cleaning Conference CONF740807, pg. 736.

2. Deuber, H & Gerlach, K "Parametric Investigations on the Retention of Methyl Iodide by a KI Impregnated Activated Carbon", (KfK Karlsruhe) Reports KfK 3594 (1983) KfK 3594 (1984) and Nuclear Safety Vol 26. No. 2 pp 157-169 (1985).

3. Scarpellino, C.D. et al. "Technical Evaluation Report of Testing Procedures for Activated Carbon Adsorbers in Ventilation Filter Assemblies in Nuclear Power Plants", EG&G Idaho Report EGG-CS-7131 (1985) and Final Technical Evaluation Report for NRC/INEL Activated Carbon Testing Program EGG-CS-7653 (1987).

4. USNRC Regulatory Guide 1.52.

5. USNRC Regulatory Guide 1.140.

TABLE 1

PARAMETRIC STUDY OF PARTICLE SIZE EFFECTS

ON $CH_3{}^{131}I$ PENETRATION AT 30°C, 95% RH

Impregnant: KI

Base Carbon: Coconut

US Sieve Mesh	Particle Size mm	0.25 sec. Residence Time 40 FPM (20 cm/sec) velocity 2.0 inch (50 mm) bed depth		0.125 sec. Residence Time 80 FPM (40 cm/sec) velocity 2.0 inch (50 mm) bed depth		0.25 sec. Residence Time 80 FPM (40 cm/sec) velocity 4.0 inch (100 mm) bed depth	
		Penetration %	K Value	Penetration %	K Value	Penetration %	K Value
8X10	2.38 - 2.00	3.900	5.64	11.18	7.61	1.745	7.03
10X12	2.00 - 1.68	1.980	6.81	10.27	7.91	0.901	8.18
12X14	1.68 - 1.41	1.370	7.45	5.84	9.87	0.360	9.77
14X16	1.41 - 1.19	0.626	8.81	3.31	11.84	0.128	11.57
16X18	1.19 - 1.00	0.272	10.26	2.39	12.97	0.059	12.92

$$K = \frac{\text{Log} \dfrac{100}{\% \text{ Penetration}}}{\text{Residence Time}}$$

Test Method: ASTM D3803 (1989)

TABLE 2

PARAMETRIC STUDY OF PARTICLE SIZE EFFECTS

ON $CH_3{}^{131}I$ PENETRATION AT 30°C, 95% RH

Impregnant: KI-Amine

Base Carbon: Coconut

US Sieve Mesh	Particle Size mm	0.25 sec. Residence Time 40 FPM (20 cm/sec) velocity 2.0 inch (50 mm) bed depth		0.125 sec. Residence Time 80 FPM (40 cm/sec) velocity 2.0 inch (50 mm) bed depth		0.25 sec. Residence Time 80 FPM (40 cm/sec) velocity 4.0 inch (100 mm) bed depth	
		Penetration %	K Value	Penetration %	K Value	Penetration %	K Value
8X10	2.38 - 2.00	1.020	7.96	5.690	9.96	0.504	9.19
10X12	2.00 - 1.68	0.380	9.68	3.960	11.22	0.165	11.13
12X14	1.68 - 1.41	0.152	11.27	1.310	15.06	0.033	13.93
14X16	1.41 - 1.19	0.057	12.98	0.930	16.25	0.009	16.18
16X18	1.19 - 1.00	0.032	13.98	0.690	17.29	0.002	18.80

$$K = \frac{\text{Log}\dfrac{100}{\%\ \text{Penetration}}}{\text{Residence Time}}$$

Test Method: ASTM D3803 (1989)

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TABLE 3

PARAMETRIC STUDY OF VELOCITY EFFECTS

ON $CH_3{}^{131}I$ PENETRATION AT 30°C, 95% RH

Adsorbent: NUSORB KITEG II

Velocity		1.0 inch (2.5 cm) Test Bed			2.0 inch (5.7 cm) Test Bed			4.0 inch (10.0 cm) Test Bed		
FPM	CM/SEC	Penetration %	Residence Time Sec.	K Value	Penetration %	Residence Time Sec.	K Value	Penetration %	Residence Time Sec.	K Value
20	10	0.93	0.250	8.13	0.0596	0.500	6.45	0.0013	1.000	4.88
30	15	2.65	0.166	9.48	0.166	0.333	8.35	0.0030	0.666	6.79
40	20	4.80	0.125	10.55	0.291	0.250	10.14	0.0093	0.500	8.06
60	30	10.03	0.084	11.88	1.13	0.166	11.73	0.0190	0.333	11.17
80	40	17.1	0.063	12.18	2.70	0.125	12.55	0.0740	0.25	12.52

$$K = \frac{\text{Log} \dfrac{100}{\% \text{ Penetration}}}{\text{Residence Time}}$$

Test Method: ASTM D3803 (1989) except Velocity

TABLE 4

PARAMETRIC STUDY OF TEMPERATURE EFFECTS

ON $CH_3{}^{131}I$ PENETRATION AT 95% RH, 40 FPM

Adsorbent: NUSORB KITEG II

	1.0 inch (2.5 cm) Test Bed 0.125 Sec. Residence Time		2.0 inch (5.0 cm) Test Bed 0.25 Sec. Residence Time		4.0 inch (10.0 cm) Test Bed 0.5 Sec. Residence Time	
Temperature, °C	Penetration %	K Value	Penetration %	K Value	Penetration %	K Value
25	5.62	10.00	0.304	10.06	0.0105	7.95
30	4.80	10.55	0.291	10.14	0.0093	8.06
40	3.34	11.81	0.131	11.53	0.0065	8.37
60	2.55	12.75	0.125	11.61	0.0046	8.67
80	0.95	16.18	0.105	11.91	0.0043	8.73

$$K = \frac{\text{Log} \dfrac{100}{\% \text{ Penetration}}}{\text{Residence Time}}$$

Test Method: ASTM D3803 (1989) except Temperature

TABLE 5

PARAMETRIC STUDY OF HUMIDITY EFFECTS ON $CH_3{}^{131}I$ PENETRATION AT 30°C, 40 FPM

Adsorbent: NUSORB KITEG II

Relative Humidity %	1.0 inch (2.5 cm) Test Bed 0.125 Sec. Residence Time		2.0 inch (5.0 cm) Test Bed 0.25 Sec. Residence Time		4.0 inch (10.0 cm) Test Bed 0.5 Sec. Residence Time	
	Penetration %	K Value	Penetration %	K Value	Penetration %	K Value
70	0.747	16.96	0.027	14.27	0.0016	9.59
80	1.70	14.08	0.048	13.27	0.0022	9.32
85	2.18	13.28	0.107	11.88	0.0043	8.73
90	3.05	12.16	0.192	10.86	0.0067	8.35
95	4.80	10.56	0.291	10.14	0.0093	8.06

$$K = \frac{\text{Log} \dfrac{100}{\% \text{ Penetration}}}{\text{Residence Time}}$$

Test Method: ASTM D3803 (1989) except %RH

TABLE 6

PARAMETRIC STUDY ON $H^{131}I$

PENETRATION THRU KI-AMINE IMPREGNATED CARBON

Impregnant: NUSORB KITEG II

Base Carbon: Coconut

Temperature °C	RH %	Velocity FPM	1.0 inch (2.5 cm) Bed Depth		2.0 inch (5.0 cm) Bed Depth	
			Penetration %	K Value	Penetration %	K Value
30	95	40	6.7	9.4	1.25	7.6
30	95	80	16.3	12.6	3.7	11.5
30	70	40	2.7	12.5	0.9	8.2

$$K = \frac{\text{Log}\dfrac{100}{\%\ \text{Penetration}}}{\text{Residence Time}}$$

Test Method: ASTM D3803 (1989) except $H^{131}I$ challenge

FIGURE 1

PARAMETRIC STUDY OF PARTICLE SIZE EFFECTS ON $CH_3{}^{131}I$ PENETRATION AT 30°C, 95% RH

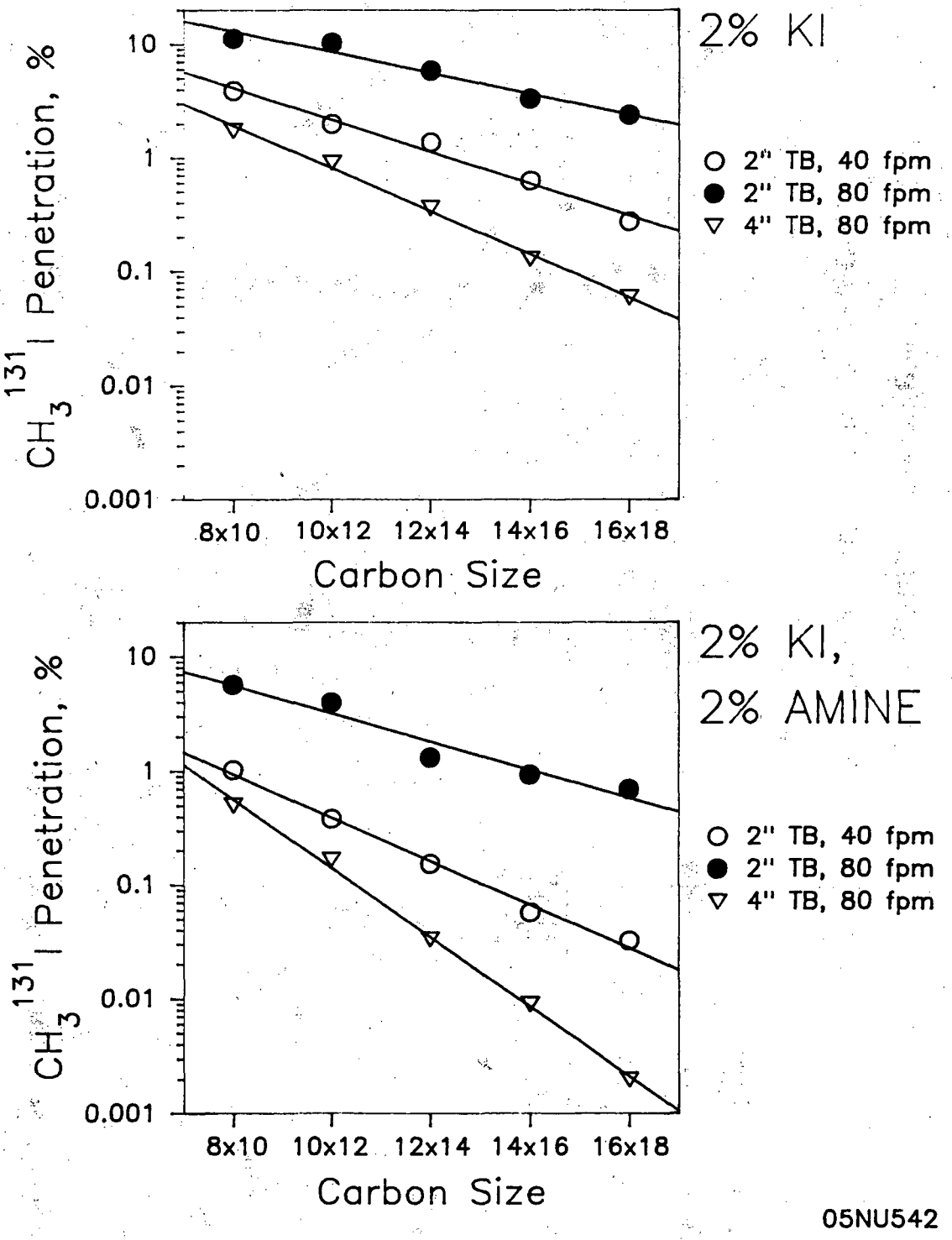


FIGURE 2

PARAMETRIC STUDY OF VELOCITY EFFECTS ON $CH_3{}^{131}I$ PENETRATION AT 30°C, 95% RH

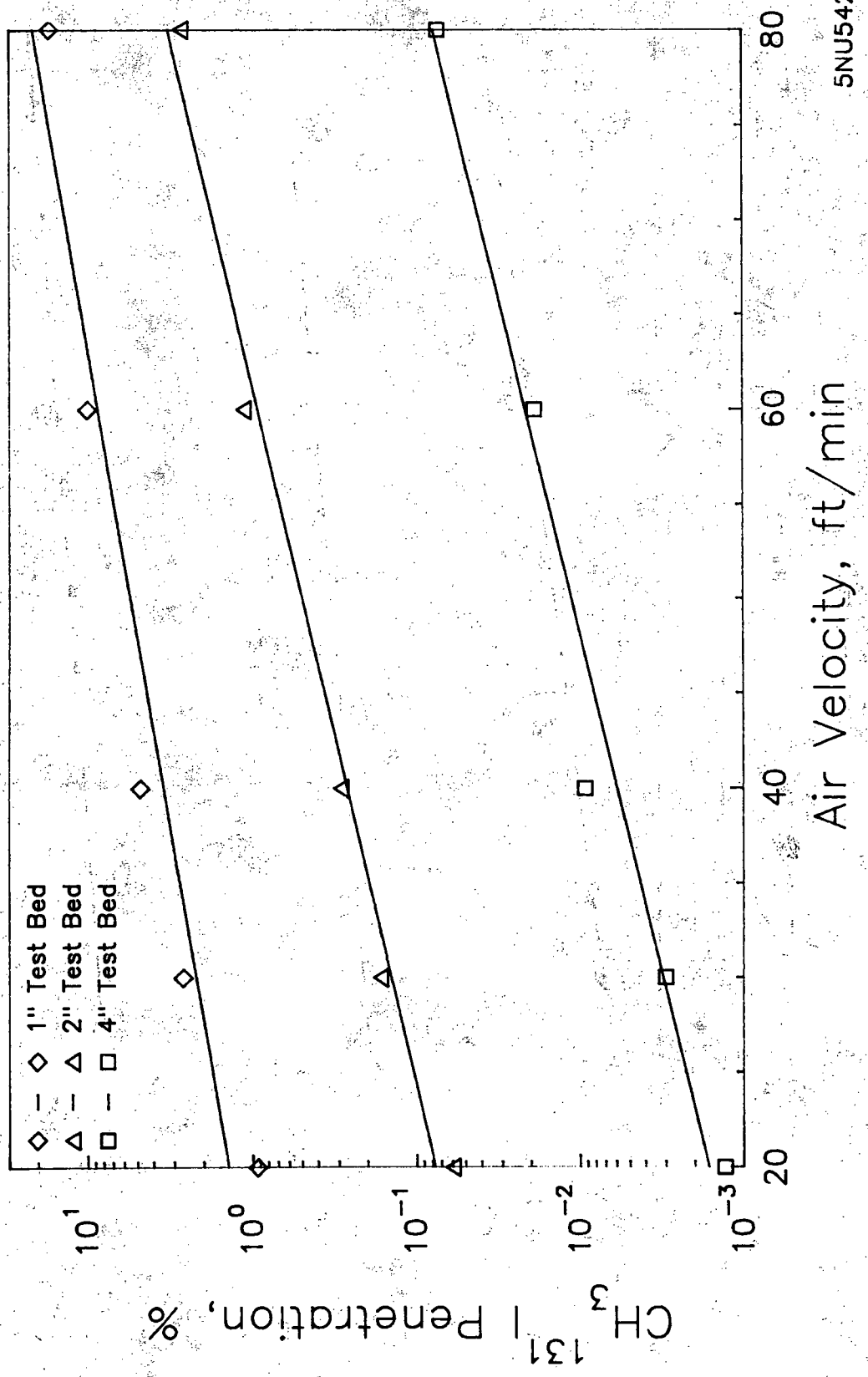


FIGURE 3

PARAMETRIC STUDY OF TEMPERATURE EFFECTS ON $CH_3{}^{131}I$ PENETRATION AT 95%, 40 FPM

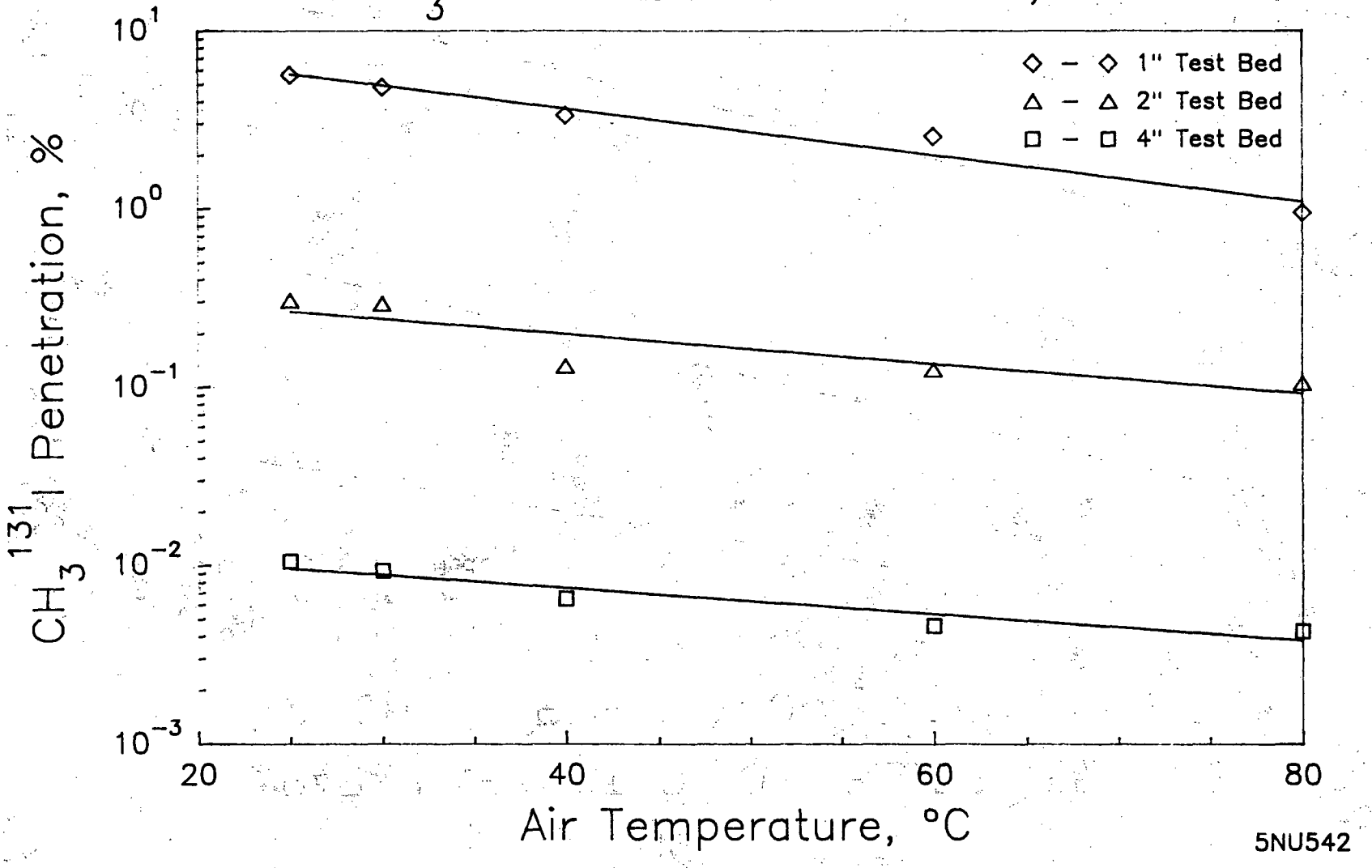
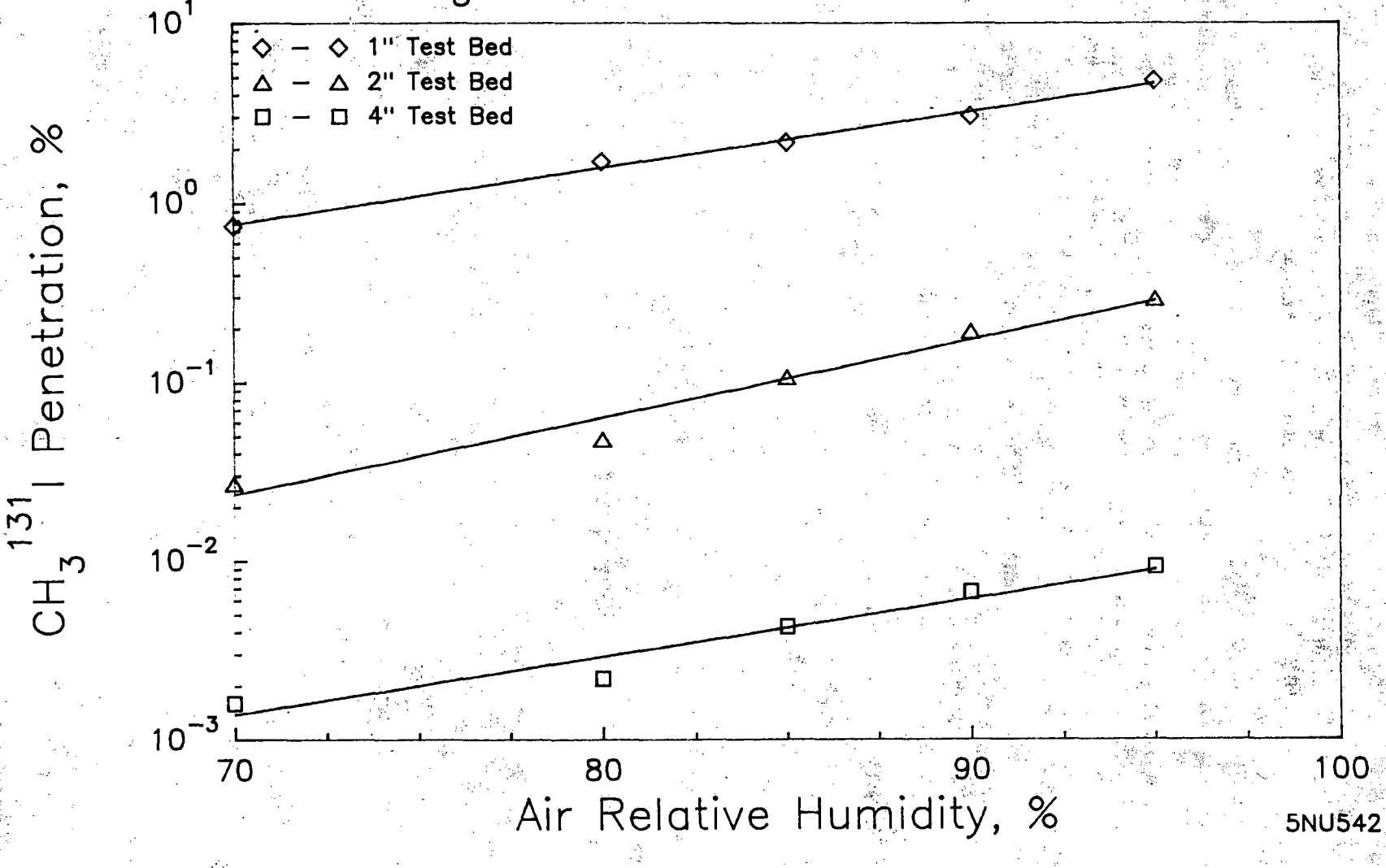


FIGURE 4

PARAMETRIC STUDY OF HUMIDITY EFFECTS ON $CH_3^{131}I$ PENETRATION AT 30°C, 40 FPM



DISCUSSION

SCHOLTEN: You said, with smaller grain size and higher velocity, you get better performance, but you also get a higher delta P. Have you also looked at the correlation between performance and delta P? I think it might be the same. So, you can use a large grain size and make a deeper bed or you can get the same results by taking a shallower bed with smaller sizes.

KOVACH: That is correct. One reason why we ran the particle size effects is that very often people are comparing carbons without determining the particle size distribution of these adsorbents. It just demonstrates that it is extremely difficult to correlate results without knowing in great detail what the particle size distribution of the adsorbent is. I am not proposing that we go to finer particle size and deeper beds. I am saying that the option exists to do either, particularly for non-safety systems, because in nuclear power plants, electricity is not that expensive. They can tolerate the higher pressure drop for systems that don't have to operate off the diesels. I know that pressure drop represents a cost, but, generally, space is even more expensive. If you can put in a smaller air cleaning system that has 80 ft/min velocity in a 4 in. deep bed, and you now have HEPA filters and prefilters available which can handle 2,000 cfm in the 24 x 24 in. size, I think the cost that you save by having a smaller air cleaning system will more than pay for the slightly higher electricity cost right at the generation site.

SCHOLTEN: Also a choice.

TESTING OF ADSORBENTS USED IN NUCLEAR POWER PLANT AIR CLEANING SYSTEMS USING THE "NEW" STANDARDS

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Abstract

Ever since the publication of the NRC Information Notice No. 87-32: "Deficiencies in the Testing of Nuclear-Grade Activated Charcoal," nuclear power facilities in the U. S. have struggled in their efforts to "... review the information for applicability to their facilities and consider action, if appropriate ..." as stated in the notice. Despite the fact that the notice also states that no "specific action" is required, the encouragement of resident NRC inspectors at some nuclear power facilities has prompted a variety of responses ranging from no change at all in testing requirements to contemplated changes in plant technical specifications.

This confusion is a result of a couple factors. The first and foremost factor is the lack of a current revision to NRC Regulatory Guide 1.52. This is the basic document used in nuclear power plant technical specifications for the testing of engineered-safety feature (ESF) post accident air cleaning systems and is considered to be significantly outdated and in error in many technical areas. The second factor is the standards that have been written since the last revision of Reg. Guid 1.52 (Revision 2, 1978) which include two revisions of ANSI N509 and N510 (1980 and 1989) two revisions of RDT M16-1T (now NE M16-1T), two versions of ASTM D3803 (1979 and 1989), two versions of ASTM D4069 (1981 and 1990) and three versions of an ASME code AG-1 (1985, 1988 and 1991). These standards were ostensibly promulgated in an effort to eliminate the inconsistencies and ambiguities of the regulatory guide. However, few of the standards and codes listed above are commensurate with each other and, thus, present a nearly insolvable maze to the HVAC engineer asked to upgrade his adsorbent testing requirements following the "new" standards.

Accordingly, this paper describes our experience with a number of nuclear power facilities in their efforts to meet the requirements of the new standards for testing adsorbents from nuclear power plant air cleaning systems. Additionally, the existing standards are discussed in light of the current state of the art for adsorbent testing of adsorbent media from nuclear air treatment systems. Test results are presented showing the impact of "new" test requirements on acceptance criteria when compared to the "old" test requirements and recommendations are offered for solution of this testing problem in the future.

Introduction

Ever since the publication of the NRC Information Notice No. 87-32: "Deficiencies in the Testing of Nuclear Grade Activated Charcoal",[1] nuclear power facilities in the U.S. have struggled in the efforts to "... review the information for applicability to their facilities and consider action, if appropriate..." as stated in the notice. The information notice itself adds to the confusion that exists regarding acceptable testing standards when it states that "ASTM Standard D-3803-1979 was developed to specify the requirements for testing charcoal and was accepted by the NRC (Regulatory Guide 1.52, 1979)." There is no Regulatory Guide 1.52, 1979. Thus it comes as no surprise that the responses to this information notice have been many and various. The primary factor contributing to this confusion is a lack of a current Revision for NRC Regulatory Guide 1.52.

Regulatory Guide 1.52 (Revision 2, 1978)[2]

This is the basic document used in nuclear power plant technical specifications for the testing of engineered-safety-feature (ESF) post accident air cleaning systems and is considered to be significantly outdated and in error in many technical areas. Although few of the power plants that we provide testing services for use this document literally anymore, it is still referenced in practically all purchase orders as a requirement. However, even in its original sense, the document is confusing because of the paper trail that must be followed. As an example, shown in Table 1 is a reproduction of Table 2 from Reg. Guide 1.52 Rev. 2 which is the guide for how to test used activated carbon samples and the decontamination efficiencies that can be claimed based on the test results. Let's say we have a carbon sample removed from a stand-by gas treatment system that has no humidity control. First, the only place that tells one how often to test the carbon is a footnote in the table. Next, there's no category that specifically covers the sample (i.e. air filtration system outside containment with no humidity control). So we have to run the test at a humidity different than 70%, but what humidity should be used and what methyl iodide penetration should we look for? We turn to test 5.b. of Table 5-1 of ANSI N509-76[3] for help. Shown in Table 2 is a reproduction of Table 5-1 from ANSI N509-1976. We can assume from this table that 95% relative humidity should be used but we still do not have an acceptance criterion for the result (since that table is for new carbons). We turn to RDT-M16-IT par. 4.5.3 for guidance on performing the test (with pre- and post-loading sweep medium at 25°C).

Which RDT-M16-IT do they mean though? By process of elimination, RDT M16-IT October 1973[4] is chosen. Paragraph 4.5.3 in turn references 4.5.1 which gives a rudimentary method. There is only one utility that we provide testing services for that demands the 25°C equilibration, 80°C loading and 25°C post sweep called out by literally following this maze. Even then we still don't know what an acceptable result would be. It soon became apparent to anyone trying to use the Reg. Guide 1.52 Rev. 2 that it was confusing and subject to different interpretations at best. This lead to a proliferation of newer standards, the first which was RDT M16-IT December 1977[5].

RDT Standards

The December 1977 version of the RDT M16-IT standard was a major step forward for testing of nuclear grade adsorbents for a couple of reasons. First, it was an attempt to put all of the testing requirements into one document. And secondly, its appendix C "Standard Method for Radioiodine Testing of Nuclear Grade Gas-Phase Adsorbent" provided a prescriptive method that hopefully could be followed to obtain reproducible test results on nuclear grade adsorbents. The technical and performance requirements for adsorbents in this standard formed the basis and, in fact, are identical to those in ANSI-N509-1980 (except the RDT standard calls the 30°C 95% R.H. a qualification test and the ANSI standard calls it a batch test). The method for radioiodine testing became the basis for and is nearly identical to ASTM D3803-79, "Test Methods for Radioiodine Testing of Nuclear-Grade Gas-Phase Adsorbents."[5] This standard does a good job of describing and specifying the requirements for virgin adsorbents, but does not address the test of used (surveillance) samples. The later version of this standard, NE M16-IT October 1981[6] (now under the auspices of the DOE) changes little from the 1977 standard except to incorporate the ASTM D3803-79 test methods by reference. These standards are not often specified by commercial power plants when requesting adsorbent testing.

ASTM D3803

Originally issued in 1979, these methods are identical to the methods in the 1977 RDT standard. The same five tests are specified (methyl iodide at 30° and 95% relative humidity, 80°C and 95% relative humidity, 130°C and 95% relative humidity, elemental iodine test at 30°C and 95% relative humidity and an elemental iodine retention test at 180°C. This method does prescribe testing for used carbon samples for the 30°C, 80°C and 130°C tests by eliminating the equilibration period where the carbon is exposed to humid air. The issuance of ASTM D3803-86 was not a revision of the standard test methods but just a reapproval of the existing 1979 methods. The revision D3803-89 will be discussed later.

ASTM D4069-81

ASTM D4069[7] provides specifications for physical properties and performance requirements for virgin impregnation carbons used for radioiodine control. The specifications for the 1981 version are identical to N509-1980. The 1986 version has no changes from the 1981 version, while the 1990 revision reflects the changes made in D3803-89. Little use has been made of this specification in the industry.

ANSI N509 and N510

In response to changes in test methodology, ANSI N509 was revised and issued as ANSI N509-80. It's companion standard, ANSI N510-1975, "Testing of Nuclear Air-Cleaning Systems was also revised and issued as ANSI N510-1980[9]. N509-80's performance requirements and physical properties for new activated carbon (shown as Table 3 here) are the same as the RDT standard. It defers to ASTM D3803 for test methodology for radioiodine tests and it makes a batch test out of the 30°C, 95% relative humidity methyl iodide test and makes a lot or qualification test out of the 80°C, 95% relative humidity methyl iodide test. The ANSI N509-1980 standard does an excellent job of describing and specifying virgin adsorbents for radioiodine control, but, other than discussing how to sample installed adsorbers, no guidance for testing used adsorbents is given. The companion N510-1980 does mention that tests to samples withdrawn from adsorbers should be performed. It defers testing procedures to ASTM D3803 and test conditions to plant technical specifications.

The newest versions of N509 and N510, 1989 are really stop gap standards since CONAGT (ASME Committee on Nuclear Air and Gas Treatment) intends on replacing these standards with ASME AG-1, "Code On Nuclear Air and Gas Treatment"[9]. Thus, testing of adsorbents is deferred to AG-1-1988, Section FF for new adsorbents and plant technical specification for used adsorbents for N509-89. N510-89 is somewhat different. It does provide some guidance for when to test used carbon samples (before each leak test, after 720 hours of operation), what tests to perform (ASTM D3803-79) and what acceptance criteria to use (owner's specifications).

AG-1 Code

ASME AG-1-1985 "Code on Nuclear Air and Gas Treatment" section FF, Adsorbent Media, "provides minimum requirements for the performance, design, acceptance testing, and quality assurance for adsorbent media used in air and gas cleaning systems in nuclear facilities." It accomplishes this by specifying ASTM D3803-79 as the test method, and acceptance criteria for each test (identical to N509-80 and ASTM D4069). No guidance is given for testing used (surveillance) samples of carbon (defers to technical specifications). The 1988 revision of AG-1 as well as the 1991 revision of AG-1 are identical to the 1985 version.

ASTM D3803-1989

The NRC move to have systems outside containment tested at 30°C in the early 80's[10], created quite a stir in the industry where systems outside containment had been tested at 80°C and 95% or 70% relative humidity (depending on whether or not the system had relative humidity control). Where a 1% penetration had been the acceptance criterion for used carbon samples, plants were faced with testing at 30°C and 95% relative humidity where 3% penetration was allowed for new carbons. When the results of testing at 30°C for used carbons started circulating around the industry and when large difference in results were noticed, CONAGT decided to conduct an interlaboratory comparison of ASTM D3803-79 Method A (30°C, 95% relative humidity, methyl iodide test on new carbon). When vastly different results were obtained from testing the same carbon, the NRC contracted with the Idaho National Engineering Laboratory to investigate the problem. The result of this program published as EGG-CS-7653, "Final Technical Evaluation Report for the NRC/INEL Activated Carbon Testing Program"[11] included as an appendix a draft revision of ASTM D3803. As a result of the interlaboratory comparison following this draft revision, a validated revision of ASTM D3803 was published as D3803-89 containing only the 30°C, 95% relative humidity methyl iodide test for both new and used carbons. As a caveat to tests required at other conditions (a problem which has been brought to the attention of CONAGT[12]), annex A5 was added to give additional guidance.

Plant Technical Specifications
Problem with Testing Adsorbents

Shown in Table 4 are a sampling of typical testing requirements for "tech. spec." systems at a number of plants we service. As can be readily seen in the table, a variety or conditions are used to test the same kind of system. The problem of trying to change testing is seen when say a Palo Verde would like to change to the 30°C test of ASTM D3803-89 for their control room. The 99% efficiency that they are currently using implies an assigned decontamination efficiency of no more than 95% for their accident analysis. If they used the 30°C test and 95% efficiency, they would be allowed no more than 90% credit in the accident analysis and could thus violate their technical specifications. Other plants have had to deal with this issue and so we will use them as examples and hopefully provide some guidance for other plants that desire to upgrade their adsorbent testing to current standards.

Solutions and Recommendations

In Table 5 are presented some solutions to the problem of testing using the new standards. Perhaps the easiest solution is to take exception to the temperature requirement of 80°C for Reg. Guide 1.52, Rev. 2 and use 30°C as the Braidwood plant has done. In the case of the Calvert Cliffs plant, they have developed a program to look at the results of testing their in-place carbon using different conditions. Results of these tests are shown in Table 5 and indicate that an acceptable test at one condition does not mean that an acceptable result will be obtained using a different condition.

Two extremely important things were learned during the INEL/NRC interlaboratory comparison. First, the 30°C, 95% relative humidity, methyl iodide test is the most sensitive test for assessing the performance of new and used carbons. Secondly, the efficiencies claimed for used carbon tested at 80°C according to the Reg. Guide are not realistic when compared to results obtained at 30°C. Also presented in Table 5 are recommendations for testing new and used carbon for radioiodine control. For new carbons we recommend the 30°C and 95% relative humidity methyl iodide test and a 180°C elemental iodine retention test with the acceptance criteria the same as AG-1. If additional tests are required to satisfy technical specifications, we recommend using the procedure of ASTM D3803-89 and the conditions and acceptance criteria of the technical specifications. For used carbon testing inside containment the method of ASTM-3803-89 is recommended using conditions of 80°C and either 70% or 95% relative humidity depending on whether the system has humidity control or not (this test would be identical to the D3803-79 method B test). The same holds true for used carbons outside containment except 30°C and 70% or 95% relative humidity is used. Suggested acceptance criteria have also been offered. The 99% efficiency suggested for the 80°/70% relative humidity test is the same that has been in use for 1.52, Rev. 2. Where the other efficiencies would cause a no violation of technical specifications, perhaps two tests can be performed (as several plants have done). One test can be performed to satisfy technical specifications, while the D3803-89 test can be performed to judge the condition of the carbon. Unfortunately, without a revision to the Regulatory Guide, this may be the best we can do in the interim.

References

1. NRC Information Notice No. 87-32: "Deficiencies in the Testing of Nuclear Grade Activated Charcoal"; United States Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, DC 20555, July 10, 1987.

2. USNRC Regulatory Guide 1.52, Revision 2, March 1978; "Design, Testing and Maintenance Criteria for Post Accident Engineered-Safety Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants"; USNRC, Washington, DC 20555.

3. American National Standard ANSI/ASME N509-1976, 1980, 1989; "Nuclear Power Plant Air Cleaning Units and Components", American Society of Mechanical Engineers, 345 East 47th Street, NY 10017.

4. RDT M-16-1T, "Gas-Phase Adsorbents for Trapping Radioactive Iodine and Iodine Compounds, January 1971, June 1972, October 1973, December 1977, USAEC, Division of Reactor Research and Development, Now USDOE, Office of Scientific and Technical Information, Oak Ridge, TN 37831.

5. ASTM D3803-79, 86, 89; "Standard Test Methods for Radioiodine Testing of Nuclear-Grade Gas-Phase Adsorbents", ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

6. NE M16-1T, "Gas Phase Adsorbents for Trapping Radioactive Iodine and Iodine Compounds," October 1981, USDOE, Nuclear Energy Programs. Oak Ridge, TN 37830.

7. ASTM D4069-81-86-90; "Standard Specification for Impregnated Activated Carbon Used to Remove Gaseous Radioiodines from Gas Streams", ASTM, 1916 Race Street, Philadelphia, PA 19103.

8. American National Standard ANSI/ASME N510-1975, 1980, 1989; "Testing of Nuclear Air-Cleaning Systems," American Society of Mechanical Engineers; 345 East 47th Street, New York, NY 10017.

9. ASME AG-1-1985, 1988, 1991; "Code on Nuclear Air and Gas Treatment," American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

10. Letter from William Gamill, NRC Chief of Effluent Treatment Systems Branch, to Fred Leckie, NCS, September 24, 1981.

11. Scarpellino, C.D. and Sill, C.W.; "Final Technical Evaluation Report for the NRC/INEL Activated Carbon Testing Program," EGG-CS-7653 April 1987, Idaho Falls, Idaho 83415.

12. ASME/CONAGT; "White Paper on Methyl Iodide Testing," 9 March 1992, Draft 6.

Table 1
From Regulatory Guide 1.52, Rev. 2 1978
Laboratory Tests For Activated Carbon

Activated Carbon[a] Bed Depth[b]	Assigned Activated Carbon Decontamination Efficiencies		Laboratory Tests for Representative Sample[c]
2 inches. Air filtration system designed to operate inside primary containment.	Elemental iodine Organic iodide	90% 30%	Per Test 5.c[d] for a methyl iodide penetration of less than 10%.
2 inches. Air filtration system designed to operate outside the primary containment and relative humidity is controlled to 70%.	Elemental iodine Organic iodide	95% 95%	Per Test 5.b[d] at a relative humidity of 70% for a methyl iodide penetration of less than 1%.
4 inches or greater. Air filtration system designed to operate outside the primary containment and relative humidity is controlled to 70%.	Elemental iodine Organic iodide	99% 99%	Per Test 5.b[d] at a relative humidity of 70% for a methyl iodide penetration of less than 0.175%.

[a] The activated carbon, when new, should meet the specifications of regulatory position C.3.i of this guide.
[b] Multiple beds, e.g., two 2-inch beds in series, should be treated as a single bed of aggregate depth.
[c] See regulatory position C.6.b for definition of representative sample. Testing should be performed (1) initially, (2) at least once per 18 months thereafter for systems maintained in a standby status or after 720 hours of system operation, and (3) following painting, fire, or chemical release in any ventilation zone communicating with the system.
[d] See Table 5-1 of ANSI N509-1976 (Ref. 1).

Table 2
From ANSI-N509-1976
Summary Table of New Activated Carbon Physical Properties Batch Tests
to be Performed on Finished Adsorbents

	Test	Acceptable Test Method	Acceptable Results	
1.	Particle Size Distribution	ASTM D2862	Retained on #6 ASTM E11 Retained on #8 ASTM E11 Maximum Through #8, retained on #12 Through #12, retained on #16 Through #16, ASTM E11 Through #18, ASTM E11	Sieve: 0.0% Sieve: 5.0% Sieve: 40% to 60% Sieve: 40% to 60% Sieve: 5.0% max Sieve: 1.0% max
2.	Hardness Number	RDT M16-1T, Appendix C	95 minimum	
3.	Ignition Temperature	RDT M16-1T, Appendix C	330°C minimum at 100 fpm	
4.	Activity	CCL4 Activity, RDT M16-1T, Appendix C	60 minimum	Base
5.	Radioiodine Removal Efficiency			
	a. Methyl Iodide, 25°C and 95% Relative Humidity	RDT M16-1T, par, 4.5.3, except 95% relative humidity air is required.	99%	
	b. Methyl Iodide, 80°C and 95% Relative Humidity	RDT M16-1T, par. 4.5.3, except 80°C and 95% relative humidity air is required for test (pre- and post-loading sweep medium is 25°C)	99%	
	c. Methyl Iodide in Containment	RDT M16-1T, par. 4.5.4, except duration is 2 hours at 3.7 atm. pressure.	98%	
	d. Elemental Iodine Retention	Savannah River Laboratory	99.9% loading 99% loading plus elution	
6.	Bulk Density	ASTM D2854	0.38 gm/ml minimum	
7.	Impregnant Content	State Procedure	State type (not to exceed 5% by weight)	

Table 3
From ANSI N509-1980
Performance Requirements and Physical Properties of (Unused) Activated Carbon

Test	Test Method	Acceptance Value
Performance Requirements		
Molecular Iodine, 30°C, 95% RH[1]		0.1% penetration, maximum
Molecular Iodine, 180°C	ASTM D3803	99.5% retentivity, minimum
Methyl Iodine, 30°C, 95% RH		3% penetration, maximum
Methyl Iodide, 80°C, 95% RH[1]		1% penetration, maximum
Methyl Iodide, 130°C, 95% RH[2]		2% penetration, maximum
Physical Properties		
Particle Size Distribution	ASTM D2862 using 8 x 16 U.S. Mesh	Retained on #6 Sieve: 0.1% maximum Retained on #8 Sieve: 5.0% maximum Through #8, on #12 Sieve: 60% maximum Through #12, on #16 Sieve: 40% maximum Through #16 Sieve: 5.0% maximum Through #18 Sieve: 1.0% maximum
Ball Pan Hardness	ASTM D3802	92 minimum
C Cl_4 Activity (on base)	ASTM D3467	60 minimum
Apparent Density	ASTM D2854	0.38 g/cm^3 minimum
Ash Content (on base)	ASTM D2866	state value
Ignition Temperature	ASTM D3466	330°C minimum
Moisture Content	ASTM D2867	state value
pH of Water Extract	ASTM D3838	state value

NOTES:

[1] Tests shall be performed only for qualification purposes.
[2] Test shall be performed only for qualification purposes on activated carbon to be installed in primary containment cleanup system.

Table 4
Plant Technical Specification

Plant	System	Test Method	Test Conditions	Acceptance Criterion
Palo Verde	Control Room	D3803-79B	80°C/70% R.H.	99.0%
	Fuel/Aux. Bldg.		80°C/70% R.H.	99.0%
	H_2 Purge		80°C/70% R.H.	99.0%
Prairie Island	Control Room	D3803-89	30°C/70% R.H.	95.0%
		1.52, Rev. 2	130°C/95% R.H.	92.0%
	Aux. Bldg.	D3803-89	30°C/70% R.H.	95.0%
		1.52, Rev. 2	130°C/95% R.H.	92.0%
	Shield Bldg.	D3803-89	30°C/95% R.H.	95.0%
		1.52, Rev. 2	130°C/95% R.H.	92.0%
	Spent Fuel Pool	D3803-89	30°C/70% R.H.	95.0%
		1.52, Rev. 2	130°C/95% R.H.	92.0%
Vogtle	All	INEL Protocol	30°C/70% R.H. 4" Test Bed	Various
Ginna	Control Room	N510-75	51.7°C/95% R.H.	90%
	Spent Fuel	N510-75	65.6°C/95% R.H.	90%
	Post Accident	N510-75	141.1°C/95% R.H.	90%
	All Others	N510-75	51.7°C/95% R.H.	90%
SONGS	Control Room U1	3803-79	30°C/70% R.H.	90%
	Control Room U2 & U3 Air Clean-up	1.52, Rev. 2	80°C/70% R.H.	99%
	Control Room U2 & U3 Emergency Vent	1.52, Rev. 2	80°C/95% R.H.	90%

Table 5
Solutions to Testing with New Standards

Plant	System	Test Method	Test Conditions	Acceptance Criterion
Braidwood	Fuel Handling	1.52, Rev. 2	30°C/95% R.H.	90%
	Control Room	1.52, Rev. 2	30°C/70% R.H.	99%
Calvert Cliffs	Control Room	1.52, Rev. 2	30°C/95% R.H.	Result: 93.56%
			30°C/70% R.H.	Result: 99.50%
			130°C/95% R.H.	Result: 99.83%
	ECCS Pump Room	1.52, Rev. 2	30°C/95% R.H.	Result: 58.80%
	Spent Fuel Pool	1.52, Rev. 2	30°C/95% R.H.	Result: 99.45% (new carbon)
Recommendations:	New Carbon	ASTM D3803-89	30°C/95% R.H.	97%
		ASTM D3803-86	180°C I_2 Retention	99.5%
	Any Tech. Spec. Item Not covered	Use procedure of ASTM D3803-89	Tech. Spec.	Tech. Spec.
	Used Carbon			
	Systems inside containment with humidity control	ASTM D3803-89	80°C/70% R.H.	99%
	Systems outside containment with humidity control	ASTM D3803-89	30°C/70% R.H.	95%
	Systems inside containment without humidity control	ASTM D3803-89	80°C/95% R.H.	97%
	Systems outside containment without humidity control	ASTM D3803-89	30°C/95% R.H.	92%

DISCUSSION

FREEMAN: Should your chart of recommendations have the acceptance criteria on the expected or credited efficiency of the system rather than just giving acceptance criteria?

KOVACH: I think NUCON could establish them for a lot less money than the NRC, but I don't think we are the ones to set them.

HAYES: Just a comment with respect to the criteria you have proposed for used carbon. I would say that for inside containment (and in most cases we are talking ESF systems there) it is really not applicable any more. When Revision 0 of Reg. Guide 1.52 was issued, the NRC was at the stage where sprays were not utilized nor considered as part of the fission product removal system. The major concern and emphasis, both in terms of charcoal (RDT-161T) testing and with respect to Reg. Guide 1.52, was for systems within containment. However, very early in the design cycle, containment sprays began to replace in-containment filtration systems such that today there are only 3 or 4 plants that have safety-grade charcoal systems within containment. So, I would say, unless you need an incontainment system to mitigate the consequences of, say, a fuel handling accident inside containment, you wouldn't have to address that particular item. If you did, I would say that the worse conditions are at a much lower temperature than either 80°C or 130°C. So, my recommendation would be that you should do the 30° C test for all charcoal.

The other question was; "What will be the credited accident efficiency associated with the acceptance criteria?" Depending upon the safety factor currently used by the NRC, i.e. whether you have relative humidity control, you may have a charcoal that will be credited an adsorber efficiency of only 50%. There are not a whole lot of facilities that could utilize an adsorber efficiency of 50% in their accident evaluation and still maintain their design basis doses within the NRC's acceptance criteria.

I will defer the rest of that discussion until our panel tomorrow, when we will explain the correlation between acceptance criteria for the laboratory test, the accident evaluation by the utility, and then by the NRC.

EXPERIENCE WITH ONTARIO HYDRO'S IN PLACE CARBON FILTER TESTING

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Abstract

It is now 5 years since Ontario Hydro's first use of freon to test for both integrity and carbon quality in Nuclear Generating Station carbon ventilation filters. The method has since been refined and the equipment modified and the test has now become routine. Alongside the freon test, a 24 hour methyliodide desorption test is also routinely performed on the worst (most desorbing) filters as indicated by the freon test. The method uses non-active methyliodide injection and neutron activation analysis of dual carbon sampling beds. A chemical means of iodine analysis to replace the neutron activation analysis is being pioneered to streamline the process and render it fully field applicable. So far, the method is still developmental but field testing is hoped for during 1992. In the interim, to complement the freon testing, some TEDA impregnant analysis of carbon grab samples has been carried out. Data on apparent TEDA loss from Emergency (standby) filters over a 3 year period will be presented.

I - Introduction

Ontario Hydro currently operates 18 large CANDU nuclear units with 2 more scheduled to come on stream within a year, which will give an installed capacity of approximately 12.4 GWe. Two older units have been shut down and are being decommissioned. From the earlier to the most recent nuclear generating stations, ventilation system flow rates have risen from a few thousand cfm to over 100,000 cfm (50,000 cfm per filter) for a given system (Figure 1). This has naturally created some challenges in the area of filter testing.

Development of the Freon Test

Freon-11 was first used at Ontario Hydro to test for carbon filter bypass leakage in 1987, replacing an earlier bypass leakage test which used continuous injection of inactive methyliodide and portable gas-chromatographic grab sampling. This earlier test was time-dependent and consequently unable to distinguish between bypass leakage and rapid breakthrough of the test agent. In addition, it was not suited to the higher flow systems.

Based on work performed by Taylor of the British CEGB[1] and the NUCON company of Columbus, Ohio, USA, it was decided to try using the desorption profile of the freon pulse injected in the bypass leakage test to give an indication of the carbon quality. Early results of this work were reported at the 1988 Air Cleaning Conference[2]. However, it was realised at the same time that a freon desorption profile could, at best, only indicate physical characteristics of the carbon and that some measure of overall performance was needed (Figure 2). This overall performance is defined in the Ontario Hydro safety analysis as follows: methyliodide desorption shall not exceed 1% of the filter loading per 24 hour period for normal operation filters (mainly 100 mm bed depths with some 50 mm) and 0.01% per 24 hours for emergency filters (200 mm bed depths).

Replacement of the Laboratory Test

The previously used ASTM D3803 laboratory test was not able to validate this safety analysis assumption. Also, as reported at the 1988 Conference[2], an Ontario Hydro Research Project found considerable variation in airflow through various parts of the carbon bed from a commercial filter, as well as between the filter and the test canisters used to provide the D3803 sample. This led to serious questions about the sample representivity. Finally, the criticism following the international interlaboratory comparison testing caused the D3803 to be discontinued at Ontario Hydro, and the laboratory that performed the test was permanently diverted to other uses.

However, as Victor Deitz mentioned in a previous air cleaning conference, in a similar way to how the memory of TEDA that has apparently disappeared from carbon lingers on in terms of its MeI trapping ability[3], so the memory of the D3803 lingered on, at least in our regulators' minds. The test is now performed again on used emergency filter carbon by Chalk River Nuclear Laboratories, Atomic Energy of Canada Limited. Some data from these tests are presented later in this paper.

In-Place Methyliodide Desorption Test

In order to provide a more direct measure of the safety analysis criteria referred to above, an in-place 24 hour desorption test using non-active MeI was developed. A 24 hour sample of filter outlet air is drawn through carbon sampling beds for subsequent neutron activation analysis (Figure 3). The test was described and very preliminary results reported in the 1988 Air Cleaning Conference[2]. Further results are reported in this paper.

II - Freon Test

The basic method of performing the freon bypass/desorption test at Ontario Hydro has not changed since we first described it at the 1988 Air Cleaning Conference. A pulse of freon is injected into the ventilation flow well upstream of the filter and the concentrations measured up and downstream of the filter. The upstream detector is then switched from the ppm to the ppb range and the equipment left running for a minimum of 20 minutes to observe the desorption profile (Figure 4). However, with the experience of using the test over the last 5 years, a number of changes have been made to the test procedure and to the NUCON test equipment used to perform it. They are as follows:

(1) What was referred as a FEDI (Freon Eleven Desorption Index) in 1988 is now called a CQI or Carbon Quality Index, although the three components of the desorption profile used to calculate it are essentially the same. They are:

   (a) Elapsed time before desorption starts to occur (time to breakthrough).

   (b) Maximum instantaneous desorption observed divided by the elapsed time.

   (c) Maximum rate of increase of desorption.

   The three factors are normalized for inlet concentration and summed in units of inverse time to give the CQI.

(2) A field check of the downstream freon detectors using a 250 ppb freon standard and of the upstream detectors using a 10 or 20 ppm standard is carried out prior to each filter bank test.

(3) The injection pulse has been shortened to 15 s. This measure was adopted to help clarify the distinction between bypass leakage and rapid desorption that was sometimes apparent from our 50 mm carbon beds that have been in service for some time (Table 1). This necessitated removal of the mixing chambers from the detectors used for the filter outlet measurement. The calibration with the standard gases similarly uses 15 s pulses.

(4) Plans to correct the CQI for different relative humidities, specially significant for RH values greater than about 50% which tend to reduce the freon hold-up time, proved to be overly ambitious. It became apparent that corrections would have to be developed for almost every variation of carbon condition and bed thickness (Table 2), leading to a very complex set of curves with limited applicability. Instead, the simpler approach of testing in the Spring and Fall to moderate relative humidity effects and changes was adopted.

(5) Instead of trying to develop the freon desorption test into a precise and definitive measure of the carbon effectiveness, replacing the ASTM D3803, it is now used as a "predictive indicator" of carbon filter performance, as well as for trending analysis. Positive indications arising from the freon desorption test are followed up by the more expensive and labour-intensive 24 hour MeI desorption test alluded to earlier. This dual approach appears to have been working generally satisfactorily and some comparative data are presented in Table 3.

A CQI calculated to be between zero (no observable desorption for the duration of the test, usually 20 minutes) and unity is taken to indicate acceptable quality carbon for the 100 mm filter beds, by far the most common bed thicknesses in use at Ontario Hydro. A CQI greater than unity will call into consideration the filter's history of test results and the relative humidity prevailing at the time of the test and may trigger a MeI desorption test. It has been found that a CQI of unity is a very conservative limit, even at low relative humidities. A 100 mm bed of carbon in near new condition shows no evidence of desorption for the duration of the test. Carbon of the same bed thickness in service for several years in the bypassed mode also appears to show no desorption.

For the 200 mm beds, which are a component of the emergency filters, the CQI limit was set at 0.1 instead of 1 (Figure 5). However, in practice, no significant desorption has been observed and none would be tolerated. Any significant desorption would result in a carbon change with a follow-up investigation.

50 mm beds, which exist at only one station, and have been in service for a considerable period now, frequently exhibit rapid breakthrough of the freon, sometimes almost indistinguishable from bypass leakage. It is these filters that currently pose the biggest challenge to our freon desorption test.

The freon test does, of course, only indicate the physical condition of the carbon. To avoid having to take carbon samples routinely from filters for TEDA analysis, with all the associated problems of representivity, we are accumulating data in an attempt to demonstrate that in-service weathering of carbon leads to physical deterioration (ie, poisoning) at a rate equal to or faster than the loss of TEDA. As reported in the 1988 Air Cleaning Conference[4], Ontario Hydro buys only 5% TEDA impregnated carbon, and all new supplies are QA checked prior to acceptance. Therefore, starting with approximately 5% TEDA, physical deterioration should be the dominating factor. Some data are presented in Table 4.

III - Methyliodide (MeI) Desorption Test

The 24 hour MeI desorption test has also been modified since we first described it in the 1988 Conference. Instead of using the 1 inch thick "off-the-shelf" impregnated carbon cartridges as sampling beds, we have now developed an integral probe and sampling bed holder that is inserted into the filter or the ductwork as appropriate. This allows the pump to be left at a convenient location and eliminates losses on long lengths of sample lines (Figure 6).

The sampling bed holder contains two beds of TEDA impregnated low background iodine carbon arranged in series and separated by a screen. These beds have been sized so that they fit in their entirety into the capsule inserted into the reactor for the neutron activation analysis, thereby avoiding having to attempt to obtain representative subsamples from the sampling beds for analysis. The purpose of having the second sampling bed is to pick up any desorption from the first bed. Table 5 shows desorptions that have been found for the sampling beds at similar flow rates over the same time periods but with different carbon mesh size.

The sensitivity of the test is limited by the availability of carbon that has low background iodine as well as being low in other elements that have a tendency to interfere with the neutron activation analysis of iodine, including Sodium, Manganese, Aluminum, Vanadium, Potassium, and Titanium. We have managed to find carbons with background iodine levels less than 1 ppm which we impregnate with TEDA in house. We have found it is important with this method to submit blank TEDA impregnated samples rather than unimpregnated blanks along with the used sampling beds for activation analysis. This is because on one occasion it was discovered that the impregnation caused the background iodine levels to jump dramatically. The reason was never fully identified although contaminated TEDA was the suspected cause.

Our procedures now call for a filter inlet sample to be collected in addition to the outlet sample. This acts as a check that the expected amount of MeI actually challenged the filter. Although the methyliodide is introduced into the ventilation flow over a period of only a few minutes, the inlet sample pump is left running for the full 24 hours, to duplicate the conditions of the filter outlet sample as far as possible. This information could be useful, for example, with respect to collection bed desorption.

MeI Desorption at Pickering Nuclear Generating Station

This technique helped explain some very perplexing results that arose from tests of the Irradiated Fuel Bay filter at our Pickering Nuclear Generating Station. This single filter is a component of the system that ventilates the air space above the water in which used fuel and such items as adjuster and cobalt rods are stored.

For the first two MeI desorption tests, conducted in the fall of 1988 and 1989, only the filter outlet was sampled. No iodines (above background levels) were detected despite the fact that the filter was known, from previous D3803 tests, freon desorption results, and length of service, to be in poor condition. When the procedure was amended to include filter inlet sampling, no iodine was found there either during tests in late 1990, despite the fact that the injection port and inlet and outlet sampling locations were those used successfully in the freon and DOP tests. Similarly, the probe and sampling beds were those used successfully at other locations. New cylinders of MeI were ordered and the tests repeated in May 1991. The results were the same; no MeI above background was collected upstream or downstream of the filter.

The fuel bay ventilation system at Pickering the same as the other stations with one exception, being the first of our commercial nuclear stations, the system was considerably smaller with only a single filter housing instead of the more common bank of four filters sharing a common inlet as at our other stations. Because of the much lower flow rate, smaller gas cylinders, from the same supplier, were used. Subsequent investigation disclosed that these smaller cylinders were made of aluminum instead of the usual steel, and that a black residue had been reported inside returned cylinders. From this information, it was theorised the MeI may have reacted with the aluminum to form an aluminum iodate compound. New steel cylinders have been ordered and the test is due to be repeated this fall.

IV - Alternate Testing Strategies

Despite the improvements and some encouraging test results from the 24 hour MeI desorption test, it still suffers from a number of drawbacks (Figure 7). These include:

(1) Handling of heavy cylinder and pumps.

(2) Difficulty of obtaining reliable supplies of low background iodine carbon.

(3) Long lead time to obtain neutron activation results.

(4) Possible future loss of local reactor facilities to perform the neutron activation analysis.

(5) Somewhat inadequate detection limit.

(6) Expense; each filter requires 4 samples for neutron activation analysis, not including blanks. A typical bank of 4 filters may require up to 20 samples.

(7) Having to load up the filters with larger than desirable quantities of MeI for each test to obtain the required sensitivity.

To overcome these problems, in conjunction with our Research Division, we have been searching for a chemical method to replace the neutron activation analysis. The first method we investigated consisted of collecting the filter outlet sample by passing the air through various proprietary reusable organic vapour collection tubes. These are marketed as part of a temperature-programmable injection system for gas-chromatographs using thermal desorption. After considerable work, the method had to be abandoned. The collection tubes, made of glass, proved not rugged enough for field use and frequently resulted in breakage. When attempting the thermal desorption process into the gas-chromatograph, it would either prove almost impossible to desorb the MeI off the sample tubes or else other organic compounds would desorb off at the same time, seriously interfering with the gas-chromatographic analysis.

The second method is still under development. Air samples are collected over a 24 hour period in stainless steel canisters whose interior walls have been electropolished by a method commonly referred to as the Summa process. This avoids the need for any collection media other than the containers themselves (Figure 8).

The 24 hour integrated air samples are returned to the laboratory for capillary gas chromatographic analysis. In order to achieve the necessary MeI detection level, the sample is first passed via a heated nickel line to a cryogenic separation trap (-150° C) where the volatile components such as oxygen and nitrogen can be vented off leaving the trace components frozen. The first cryo trap is then heated and the sample passed into a second cryo trap which retains the sample as a tight plug prior to injection onto the capillary columns. To achieve injection, the second trap is heated to 160° C over a short period of time.

Currently, flame ionisation detectors are being used, giving a detection limit of 4 ng for MeI in pure air. However, a different setup using an electron capture detector on a separate gas chromatographic system has been used to demonstrate a detection limit of 3 pg for MeI under ideal conditions.

The stability of MeI sample storage in the properly pre-treated Summa canisters has been demonstrated over as long as a 3 month period. The largest size holds 32 L, and starting with an evacuated canister, a 60 L sample of air could be obtained at the rated canister pressure of 20 psi. For field sampling, a flow controlled sampling rate could be maintained over the 24 hour period, or alternatively, some form of intermittent sampling regimen may be more suitable.

It remains to be determined to what extent moisture and normal station airborne contaminants interfere with the detection level. However, if the system proves successful, a portable field version may be developed in order to give immediate results.

V - Experience with Emergency Filters

Each of the operating CANDU stations in Ontario has a system known as an Emergency Filtered Air Discharge System or EFADS. This is a poised standby system to be operated only following a large LOCA. It is connected to the negative pressure containment system and contains duplicated demisters, heaters, particulate and 8 inch carbon bed filters. Its function is to provide for a long-term controlled and filtered venting pathway from containment, including the vacuum building, to compensate for pressure rise due to in-leakage. Obviously, the condition of the carbon beds in these filters is of critical importance, as they form the final barrier to the environment. they are subject to the very stringent requirement of no more than 0.01% desorption of methyliodide per 24 hours.

Leak testing with freon has been relatively straightforward and problem-free with only the occasional test failure (> 0.05%), contributed to by loose test canisters or fittings, which have now been removed and permanently blanked off from all the EFADS filters. However, testing the 24 hour methyliodide desorption rate has not been possible (other than attempting to infer it from the ASTM D3803) due to the inability to achieve a detection limit applicable to such a restrictive desorption figure. Even in the laboratory setting, this could be extremely problematic for the D3803, and would additionally involve the question of the representativeness of the grab sample. However, regulatory pressure was increasing to demonstrate that the systems, including the filters, could meet very stringent reliability criteria.

Published data and information presented at earlier Nuclear Air Cleaning Conferences have indicated that although TEDA desorption could become significant over the long term, weathering and poisoning are likely to be of greater significance (5,6). All new carbon purchases are QA tested, as mentioned earlier in this paper, and any that do not meet specification, including TEDA impregnant content, are rejected. The carbon is multiple grab sampled upon placement into the EFADS filter to check for aging deterioration while in storage (Table 6).

Knowing the initial TEDA content and the fact that the filters are operated only for testing for the equivalent of a few hours per week, we have made the argument that the dominant process of deterioration of carbon efficiency will be a physical one. This obviates the need for routinely opening up the system (thereby contributing to its unavailability) to take grab samples for TEDA analysis.

The routine freon leakage tests are performed every 6 months, together with the 20 minute desorption profile check. If any indications were to arise from the freon desorption (none ever have), the carbon would be changed immediately and investigations conducted on the removed carbon to determine the cause. However, assuming no indications do arise (excluding bypass leakage), we have committed to changing the carbon after 3 years in service, assuming acceptable test results in the interim (Figure 9). The removed carbon is sampled and analyzed for remaining TEDA impregnant content (it is our belief that it is only on purchase, filling, and removal that representative grab sampling can be conducted on carbon due to the good mixing opportunities afforded).

The above strategy was broadly acceptable to our regulators, who made an additional request that we have performed ASTM D3803 MeI laboratory tests on the removed carbon. This have been done on several filters and the results are included in Table 6.

VI - Anticipated Future Developments

The supply and use of freon-11, even in small quantities, is becoming restricted and we are committed to its eventual phase-out. Although there is a variety of environmentally acceptable test agents that could be used with the existing Nucon detectors to perform a bypass leakage test, the number suited to a desorption test is obviously more limited. The hold-up time on reasonable quality carbon must be long enough to avoid any overlap with bypass leakage yet still short enough so as not to unduly prolong the test (Figure 10). Other undesirable characteristics such as high melting points (R-112), carbon bleed-through at low moisture levels (R-12), low detection sensitivity (R-113) are also considerations.

Materials under consideration for investigation include other CFCs, HCFC-123, 22, etc, Sulfur Hexafluoride and non-active methyliodide. In the event methyliodide proved feasible as a leakage test agent, it may prove possible to combine it with either a short-term or a 24 hour desorption test. This could also help avoid the criticism that the freon desorption test is insensitive to the TEDA impregnant level. MeI is also less sensitive to moisture levels but has the drawback of being considerably less easy to handle as well as permanently using up part of the filter.

Investigation of selected test agents will be performed on a recently completed low-flow test rig at our Research Laboratories, known as the Aerosol Research Facility or ARF (Figure 11). This consists of a 34 ft long, 2 ft square, fully instrumented, variable flow-rate, stainless steel tunnel. Test sections are engineered to hold HEPA filters or straight carbon test beds of 1 inch and 2 inch thicknesses. The "single pass" tunnel also has mixing orifices, turbulence reducers and upstream and downstream sampling sections. At the low flows required for carbon filter work (20 cm/s), relative humidities close to 100% can be obtained by means of water spray atomizers.

So far we have only had the opportunity to perform DOP detector response tests on the ARF. We shortly hope to begin tests on carbon beds with different test agents at varying relative humidities, to compare their desorption characteristics to freon 11.

VII - Conclusions

(1) The dual approach of using the in-place freon, and where indicated, the 24 hour MeI desorption tests to assess carbon quality, represents a satisfactory compromise between test simplicity, expense, and effectiveness.

(2) Attempting to apply a correction factor to freon desorption results for varying RH does not appear to be practical unless dealing with a small number of beds of a uniform quality carbon.

(3) We have shown that for carbon in the standby mode, physical deterioration occurs at a faster rate than loss of chemisorption capability, and therefore, becomes the determining factor in assessing carbon performance. This may allow the freon desorption test to give a reliable overall assessment of carbon performance.

REFERENCES

(1) Non-Active In-Situ Freon Leak Test for Charcoal Filter Installations. S.J. Taylor. CEGB, Manchester, UK, May 1984. NWR/SSD/84/0065/N.

(2) In-Situ Testing of Carbon Filters at Ontario Hydro's Nuclear Generating Stations. A. Guest, J. Holtorp. 20th DOE Nuclear Air Cleaning Conference.

(3) Pre-Accident Weathering of Impregnated Carbons for Iodine Removal. V. Deitz. 16th DOE Nuclear Air Cleaning Conference.

(4) Chemical Analysis of New and Used 5% TEDA-Impregnated Carbon. A. Guest, J. Holtorp. 20th DOE Nuclear Air Cleaning Conference.

(5) Desorption of TEDA from Impregnated Charcoals. G. Wood. 16th DOE Nuclear Air Cleaning Conference.

(6) Desorption of TEDA from Impregnated Respirator and Adsorber Charcoals. American Industrial Hygiene Association, 1984.

TABLE 1

An apparent connection between Carbon Quality Index (CQI) and Bypass Leakage obtained for 2" beds in need of replacement. The results were obtained using a 30s injection of Freon 11, subsequently shortened to 15s.

CQI	Bypass Leakage (%)
17.6	1.4
5.7	1.2
5.0	1.2
4.5	0.7
4.0	0.2
3.1	0.2

TABLE 3

Comparison between the Carbon Quality Index (CQI) and the 24-hr Methyliodide Desorption Test Results for various 2" and 4" beds. Relative Humidities (RH) are included for completeness.

	CQI (RH%)	24-hr MeI Desorption
2" BEDS	0.8 (51)	0.7
	1.0 (51)	2.8
	>1.0 (51)*	2.2
	>1.0 (33)*	6.0
	>>1.0 (51)*	3.0 (1.5% over first 20 min)
	>>1.0 (21)*	16
	>>1.0 (??)*	20
4" BEDS	<0.1 (24)	<0.1
	<0.1 (19)	<0.1
	0.1 (19)	0.1
	0.2 (22)	0.1
	0.2 (22)	0.2
	0.3 (22)	<0.4*
	0.3 (18)	0.7
	0.4 (34)	<0.4*
	3** (45)	<0.4*

* Minimum Detectable Level for the test.
** High bypass leakage made precise calculation of a CQI problematic.

TABLE 2

The effect of relative humidity on the Carbon Quality Index (CQI). obtained for various beds at different times.

	CQI	Relative Humidity (%)
a) 2" BEDS	0.1	21
	0.1	20
	0.2	24
	0.2	21
	0.3	20
	0.3	34
	0.4	36
	0.4	10
	0.6	36
	0.7	34
	0.8	34
	0.8	36
	0.9	24
	> 1*	53
b) 4" BEDS	<0.1	41
	<0.1	19
	<0.1	40
	0.1	18
	0.1	23
	0.1	22
	0.2	22
	0.4	45
	0.5	46
	0.8	45
	2.1	48
	2.2	52
	2.4	53
	3.7	59
	> 1*	47
	>>1*	58
	>>1*	69
c) 8" BEDS	<0.1	30
	<0.1	18
	<0.1	16
	<0.1	42
	0.1	41
	0.2	44

* Various factors such as extremely rapid desorption of the freon, substantial bypass leakage, made calculation of an exact CQI problematic.

TABLE 4a

TEDA and ASTM D3803 Test Results compared with Carbon Quality Indices for various carbons.

TEST DATE	TEDA (duplicated) %	CQI (RH%)	ASTM D3803 2" Efficiency (%)
Normally Bypassed 4" Fuel Bay Bed:			
OCT 88 (old carbon- 6 years in service)	N/A	>>1	62.2 (1" - 38.7)
MAY 89 (new carbon	3.9; 3.9	0.4 (49)	>99.9
JULY 90	2.9; 3.0	1.1 (52)	N/A
JULY 91	2.5; 2.6	0.6 (51)	99.89
Continuously Operated 4" Reactor Building Bed:			
OCT 88 (old carbon- 6 years in service)	N/A	>>10*	34.2 (1" - 18.4)
MAY 89 (new carbon	3.9; 3.9	0.2 (25)	>99.9
JULY 90	1.5; 1.5	1.3 (36)	N/A
JULY 91	0.9; 0.9	1.8 (25)	74.0

* Reading off-scale high.

TABLE 4b

Carbon Quality Index and ASTM D3803 Test Results of Carbon in Service 7 - 8 yr.

ASTM D3803 Efficiency - (%)				CQI (RH%)
1/3*	mid	2/3*	Average	
82	64	81	76	56 (33)
95	72	98	88	82 (62)

* Grab samples for the ASTM D3803 were taken from one-third, middle and two-thirds the distance from one side of the filter.

TABLE 5

Methyliodide Sampling Bed Desorption

(ug MeI per g Carbon)

Sampling Bed US Mesh Size	Filter Inlet Sampling Beds		Filter Outlet Sampling Beds		Blank
	Front Bed	Back Bed	Front Bed	Back Bed	
COURSE					
6-14	578	186	2	0.86	< 1*
6-14	232	539	1.2	1.7	0.76
6-14	4070	54	<15*	<15*	<15*
6-14	4500	19	<15*	<15*	<15*
FINE					
50-200	1715	<25	350	<25	<25
50-200	6260	27	990	<25	<25

* Background Iodine Levels

Notes: Sampling bed face velocity is approximately 40 times that of the main filter bed.

TABLE 6

Apparent TEDA loss and impact on performance as measured by the ASTM D3803 for an emergency standby filter carbon manufactured in 1985.

FILTER 1 (8" bed)	TEDA	TKN*	ASTM D3803 2" Efficiency - (%)
Installed (1988)	3.8; 3.9	4.0	99.37
After 3 yr (1991)	2.7; 2.8	---	99.97; 99.95; 99.97; 99.96
FILTER 2 (8" bed)			
Installed (1988)	3.8; 3.9	4.0	99.37
After 3 yr (1991)	3.8; 3.9	---	99.98; 99.95; 100; 99.96
FILTER 3 (8" bed - same carbon)			
New (1985)	3.5; 3.3	3.9	99.37
3yr service(1991)	2.6; 2.3	4.6; 5.0	99.89; 99.93; 99.91; 99.86

* TEDA number derived from the Total Kjeldahl Nitrogen Test.

Increase in Carbon Inventory & Ventilation Flow Rates Over Time

Station	Irradiated Fuel Bay Ventilation Flow cfm	Station Inventory of TEDA Carbon kg
Pickering-A (1972)	12 000	2 000
Pickering-B	16 000	5 030
Bruce-A	60 000	13 140
Bruce-B	70 000	20 444
Darlington (1992)	100 000	77 400

FIGURE 1

Testing Practices Currently Employed at Ontario Hydro

Testing For:	Type of Test	
Bypass Leakage	Freon	In-Place
Carbon Physical Condition	Freon Desorption	in-Place
Carbon Effectiveness	24-hr MeI Desorption (max. 1% per 24 hrs, 0.01% for emergency filters)	In-Place
Carbon 'Efficiency'	ASTM D3803 (not directly applicable to O-H safety analyses)	Laboratory*

* Now used only for emergency filters at Ontario Hydro

FIGURE 2

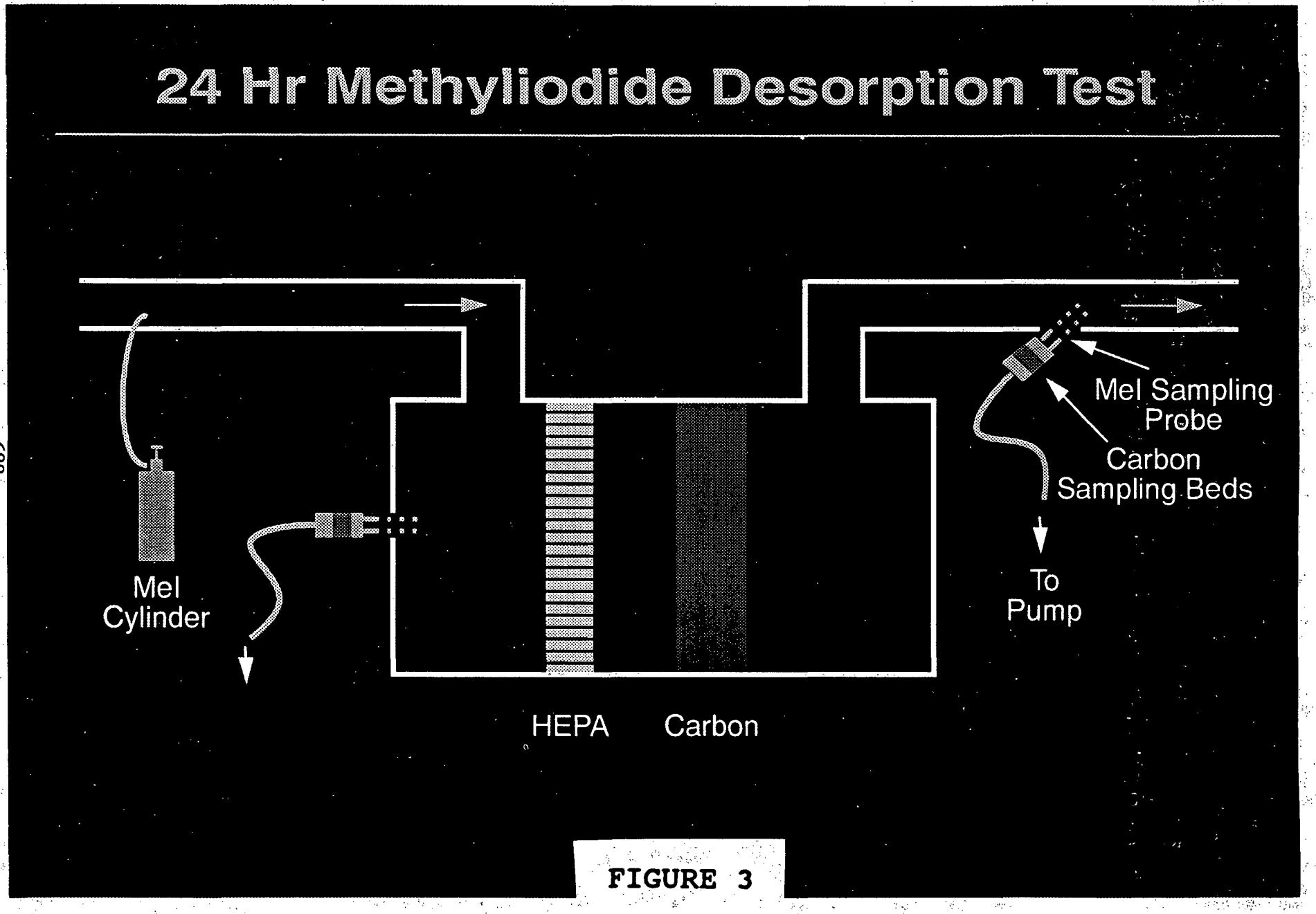
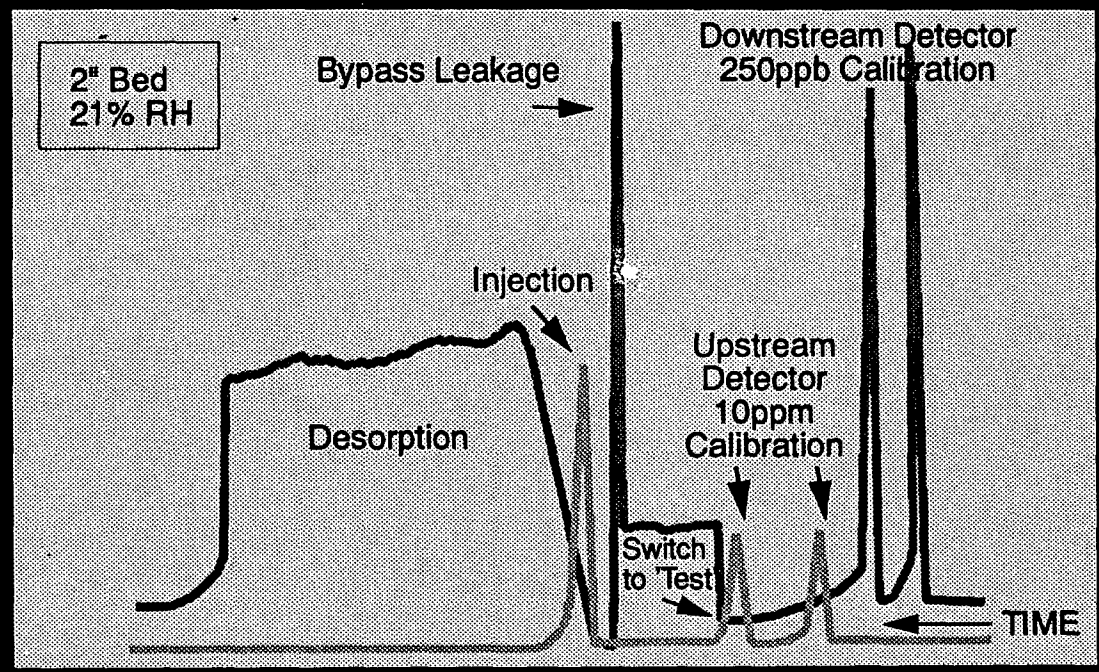

24 Hr Methyliodide Desorption Test
Mel Cylinder
Mel Sampling Probe
Carbon Sampling Beds
To Pump
HEPA
Carbon

FIGURE 3

Freon Bypass/Desorption Profile



Carbon Quality Index (CQI)

1. Time from Injection to Breakthrough
2. Maximum Instantaneous Desorption
3. Maximum Rate of Increase in Desorption

FIGURE 4

Freon Bypass/Desorption Profile

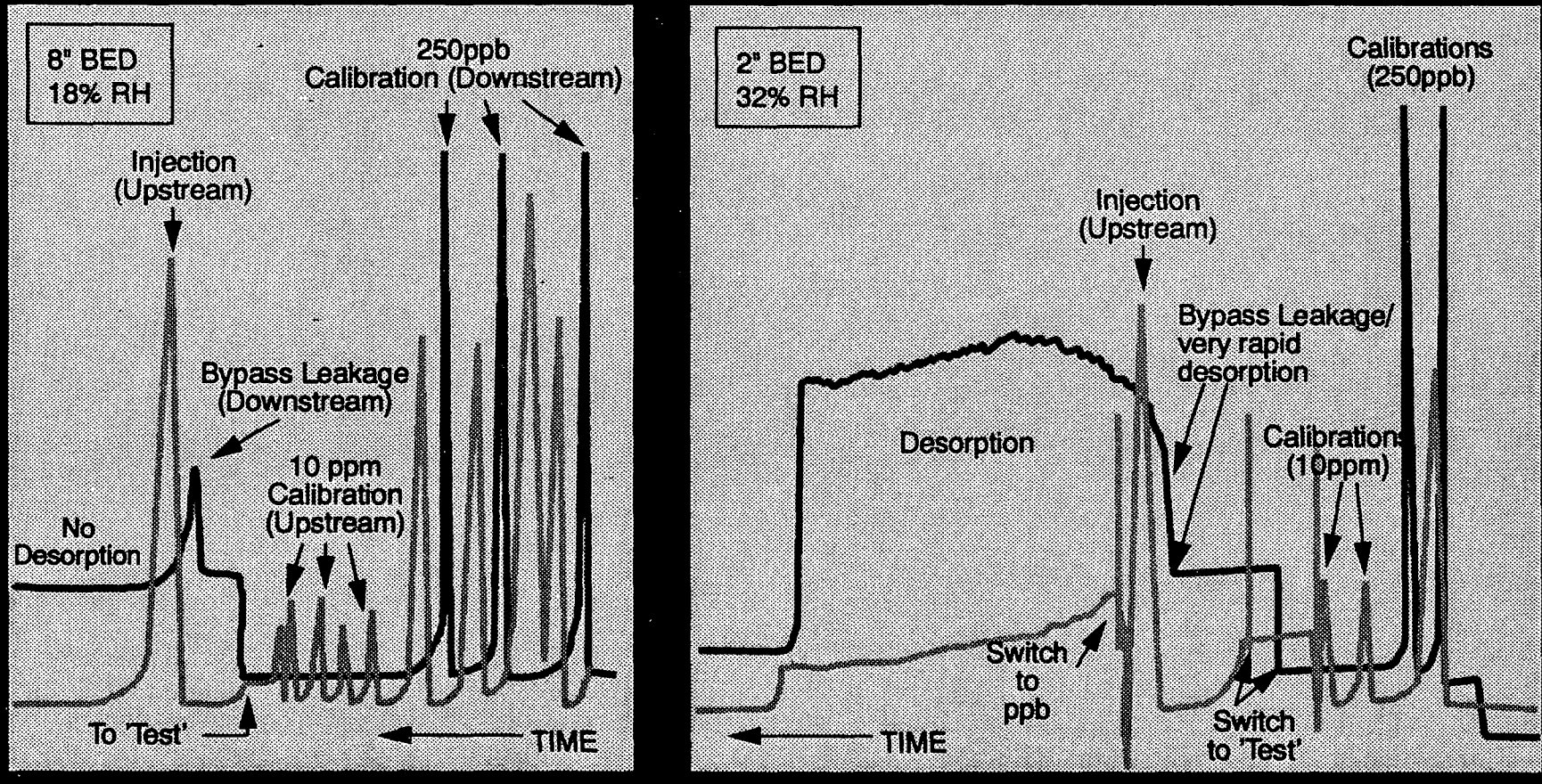


FIGURE 5

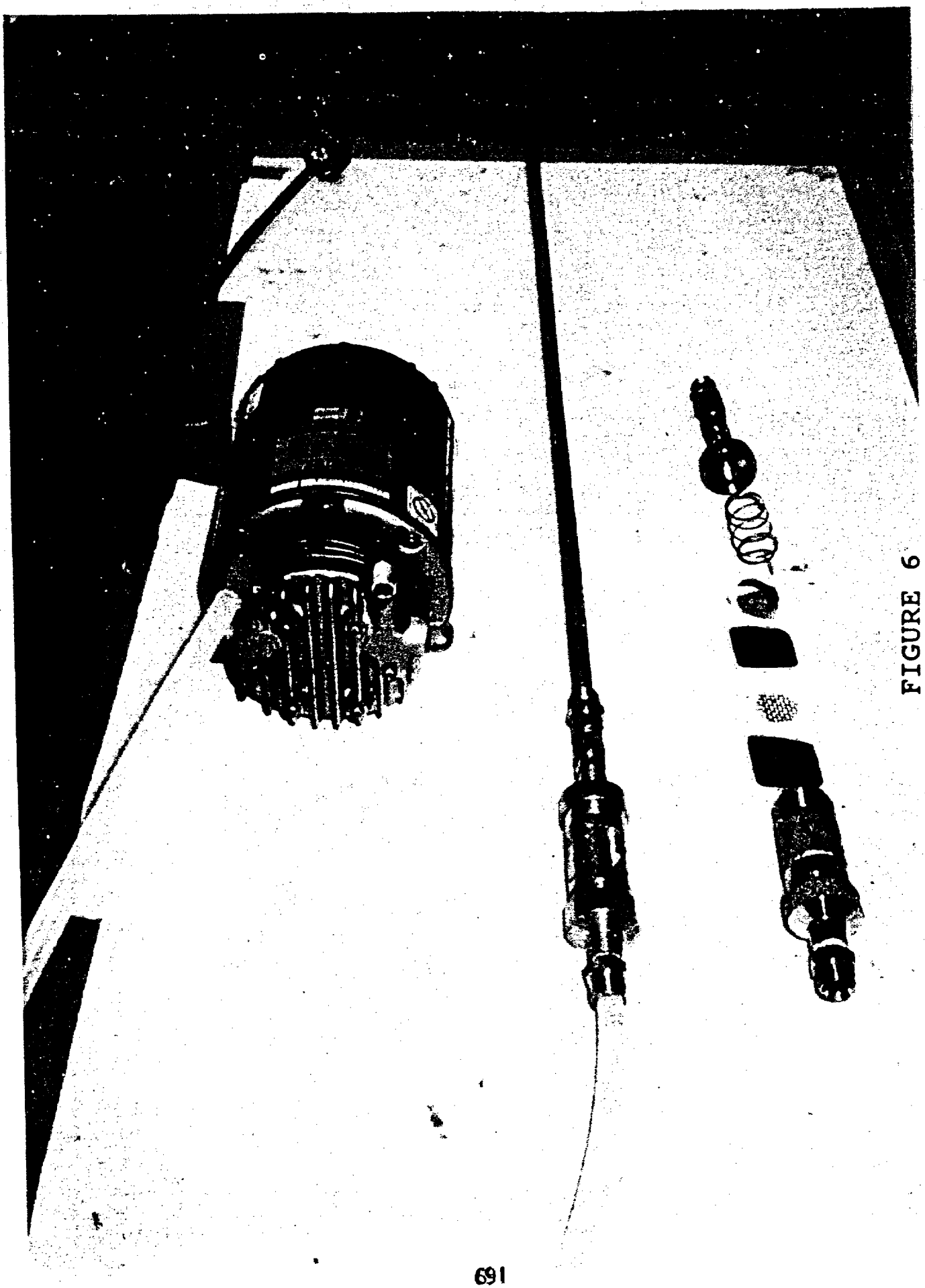


FIGURE 6

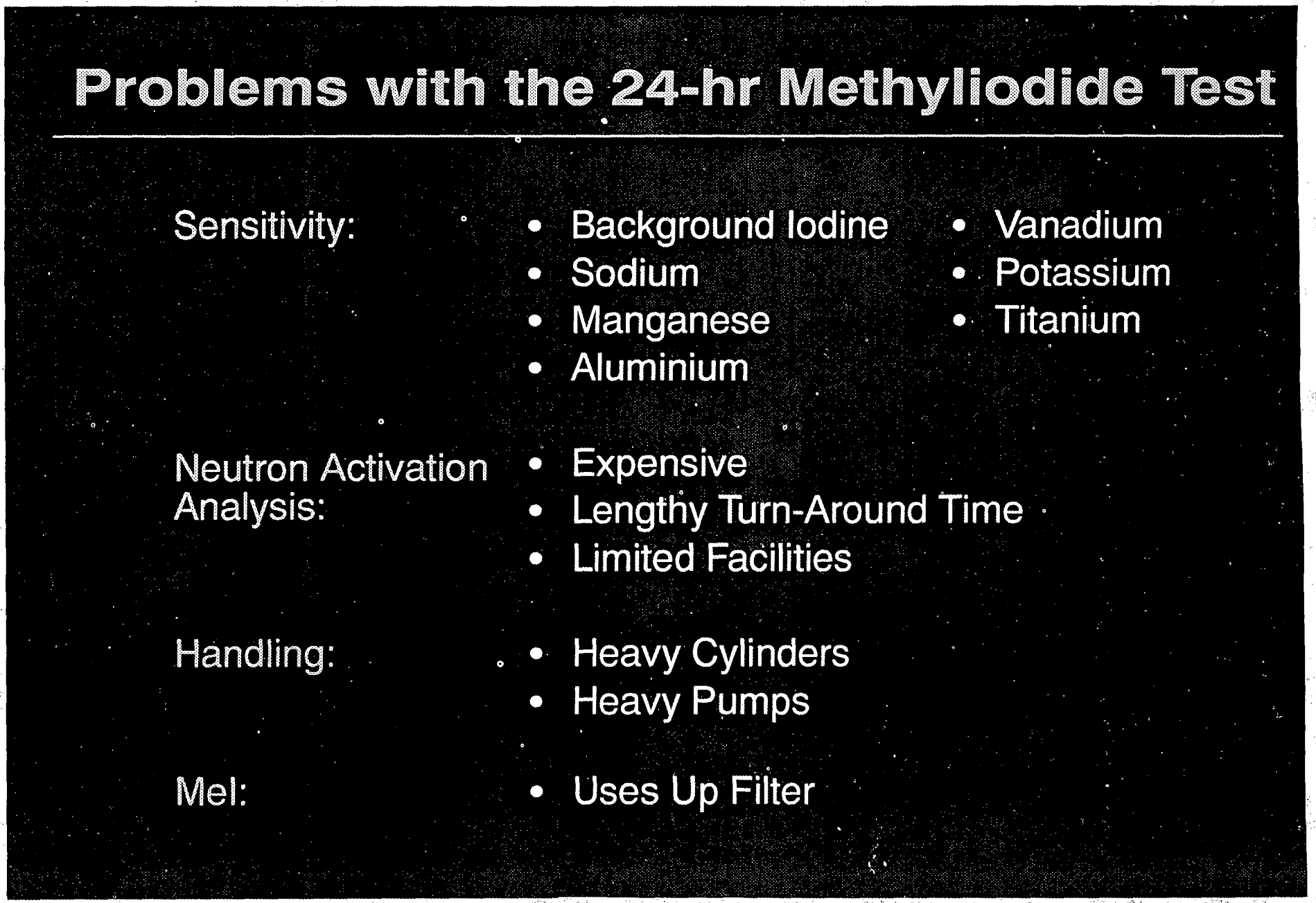

Problems with the 24-hr Methyliodide Test
Sensitivity:
• Background Iodine
• Sodium
• Manganese
• Aluminium
• Vanadium
• Potassium
• Titanium
Neutron Activation Analysis:
• Expensive
• Lengthy Turn-Around Time
• Limited Facilities
Handling:
• Heavy Cylinders
• Heavy Pumps
Mel:
• Uses Up Filter

FIGURE 7

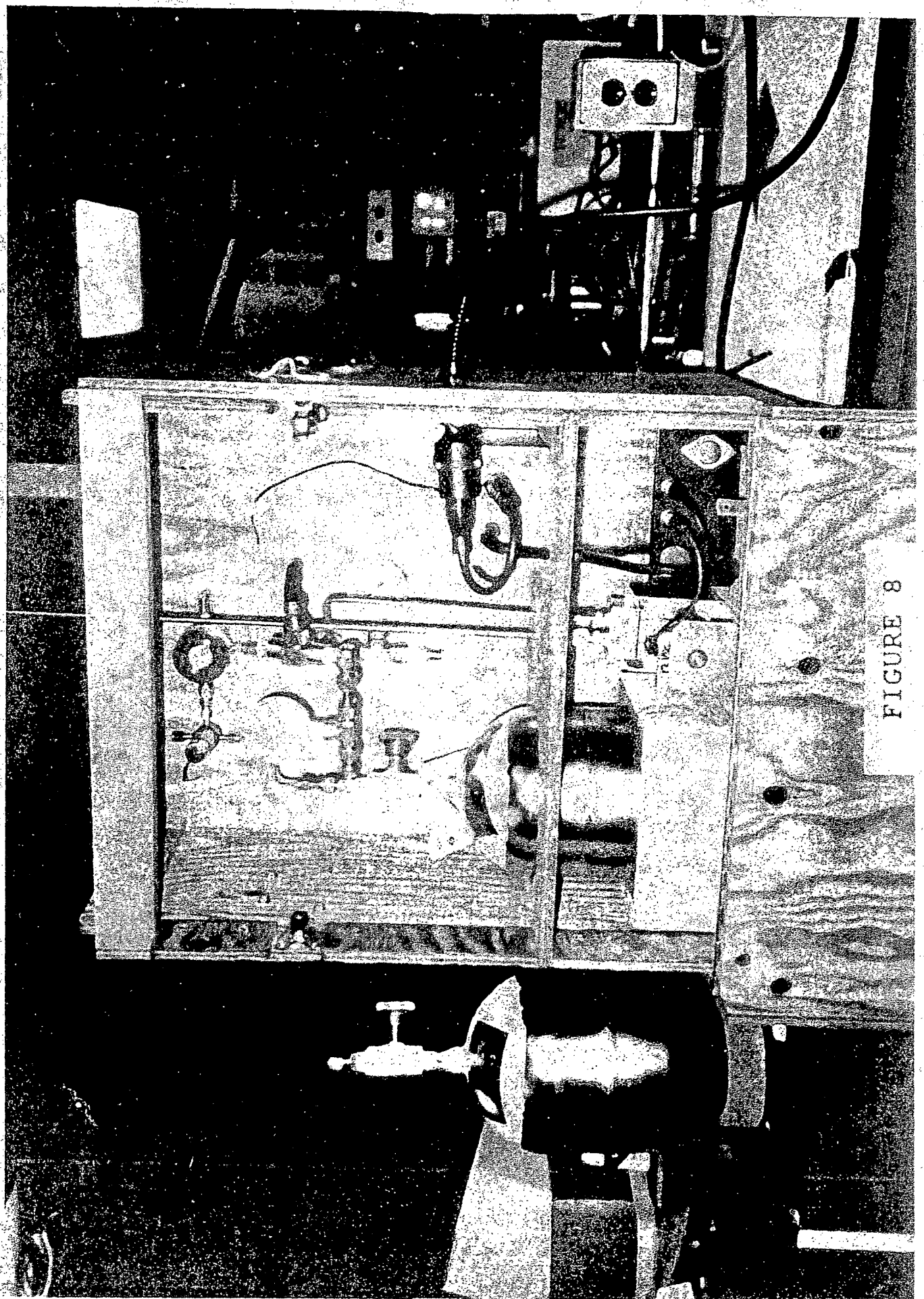


FIGURE 8

Emergency Filter Testing

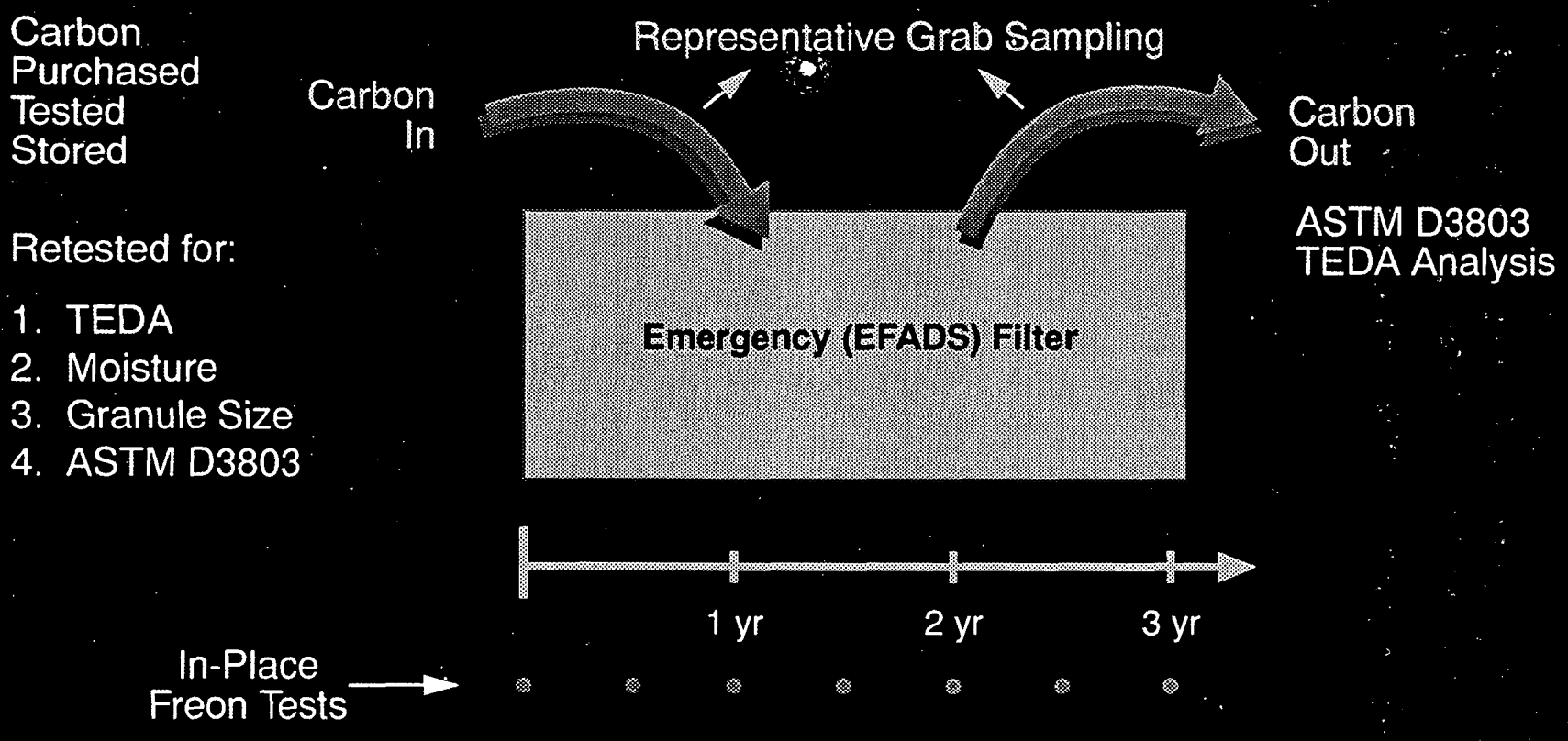


FIGURE 9

Alternatives to Freon 11 for Filter Testing

- Other Freons
- Various HFCs
- HCFCs (including HCFC 123)
- Sulfur Hexaflouride (SF6)
- Methyliodide (non-active)

1. Hold-up time on 2" beds of poor quality carbon: ≥1min
2. Hold-up time on 4" beds of poor quality carbon: <30min
3. Relatively insensitive to RH below ≈50%
4. Gaseous at ambient temperatures
5. Highly Desirable Features:
   - Easy to handle/non-toxic
   - Easy to detect

FIGURE 10

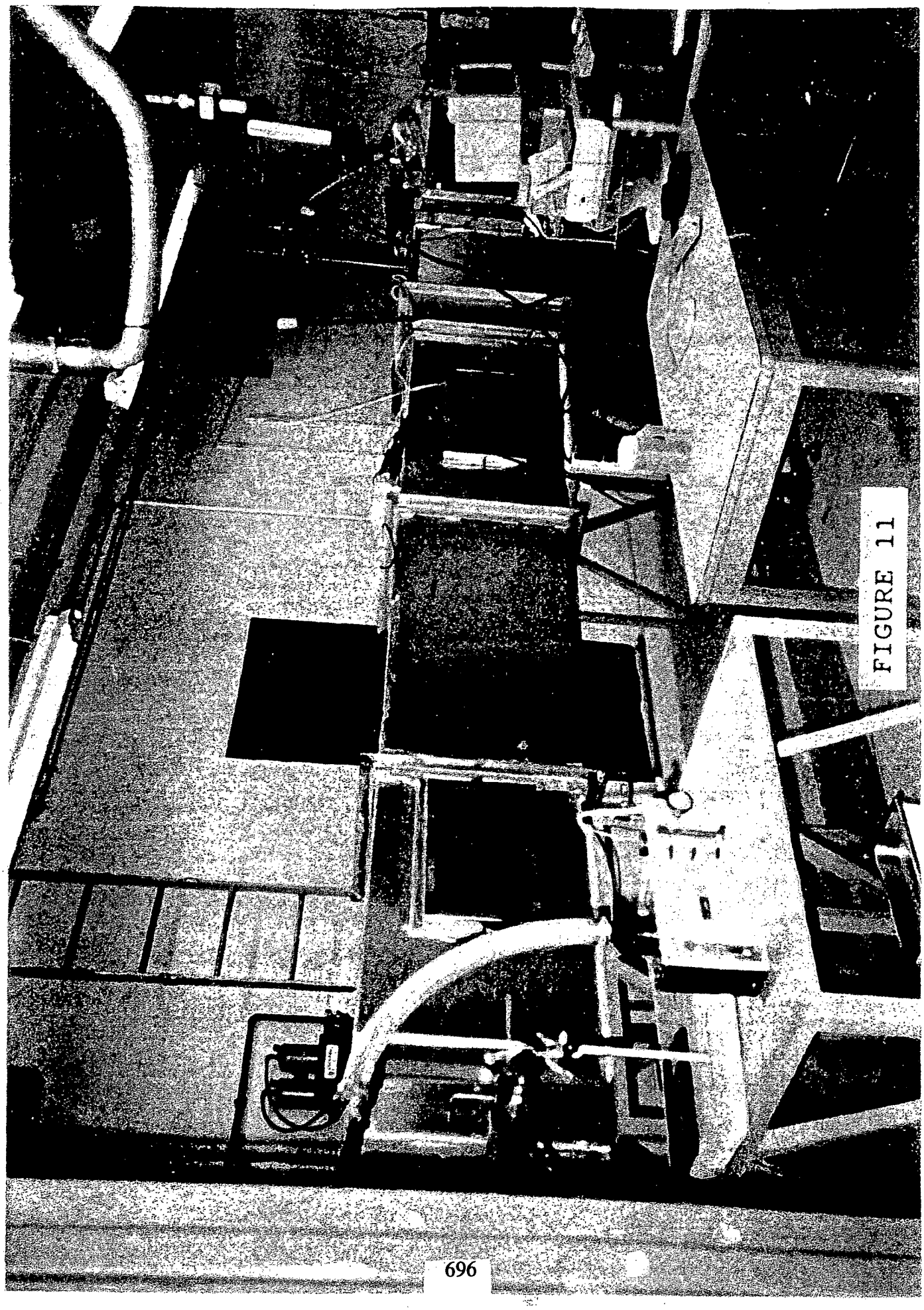


FIGURE 11

DISCUSSION

HUNT: On the Freon desorption profiles, I noticed that bypass leakage was indicated. It preceded the upstream Freon-11 injection peak. I wonder if you could explain that?

HOLTORP: That is a very good point. It appears to precede it, but it actually doesn't come before. In fact, it comes at the same time. The way it is done is, the two pins on the chart recorder are simply offset by about a minute, just for clearance, and that is why it appears that the by-pass leakage comes before the injection.

HUNT: So, they are detected at the same time, it is just a matter of the recorder setting.

REPLACEMENT TRACER AGENTS FOR THE IN-PLACE LEAK TESTING OF ADSORBERS IN NATS

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ABSTRACT

Refrigerant-11 and refrigerant-112 (R-11 and R-112) are currently the tracer agents recognized by ANSI/ASME N510[1] and U.S.N.R.C. Regulatory Guide 1.52[2] for the in-place leak testing of nuclear air and gas treatment systems (NATS). These agents are chlorofluorocarbons and are associated with the destruction of the ozone layer in the upper atmosphere. Federal law mandates that these materials be phased out of use by the year 2000, so suitable replacements must be found. Any replacement material must meet certain selection criteria including favorable adsorption on in-service nuclear carbons, relatively short adsorber retention, detectability in minute concentrations, ease of generation at low concentrations, ease of discrimination from other background compounds, and non- interference with the adsorption of radioiodine by nuclear grade activated carbon. Replacement tracer agents must also be non-toxic, non-flammable, and should not be commonly found in the plant environment.

Perfluorocarbons, based on field and laboratory trials, are ideally suited as substitutes for R-11 and R-112. Perfluorocarbons are environmentally benign and are easily detected by traditional electron capture chromatography. PFCs are easily handled in liquid form at room temperature and can be generated at low concentrations for in-place adsorber leak testing. Certain perfluorocarbons may be substituted for R-11 and R-112 with little or no modification to commercially available testing equipment.

INTRODUCTION

Our work on the search for a new tracer agent began over a year ago when it became clear that the use of current test gases would not be permitted under new EPA regulations. Because the family of chemicals known as the perfluorocarbons are known for their low toxicity and chemical inertness, our work in finding

replacement gases was focused in their direction. The process of establishing a new tracer to be used for testing nuclear adsorber banks is a complex and time consuming problem requiring both regulatory changes and a technical development program. We proceeded on the premise that a tracer gas should be found which offers at least comparable and preferably better in-place leak testing characteristics than the currently used materials.

SELECTION CRITERIA

The following selection criteria were considered in evaluating candidate materials:

1. Toxicity
2. Effect on radioiodine efficiency of nuclear grade activated carbon
3. Detectability
4. Compatibility with current commercially available test instrumentation
5. Unique usage
6. Ozone depletion potential
7. Chemical reactivity
8. Retention on carbon
9. Commercial availability
10. Equivalency of adsorber leak test results

INITIAL SCREENING

The following materials (Table-1) were considered as potential replacements for R-11 or R-112:

TABLE-1

REPLACEMENT MATERIAL	POTENTIALLY REPLACES
Perfluorodimethylcyclobutane (PDCB)	R-11
Perfluoromethylcyclohexane (PMCH)	R-112
Perfluoropentane (PFP)	R-11
Perfluoromethylcyclopentane (PMCP)	R-11
Dichlorotrifluoroethane (HCFC-123)	R-11

Of the four perfluorocarbons initially selected, perfluoropentane was eliminated from further consideration because:

1. PFP has poor sensitivity relative to other perfluorocarbons and refrigerant-11. The estimated lower level of detectability (LLD) was 10 ppb when measured by electron capture gas chromatography.

2. The commercially available product has very low purity. Analysis of the product showed that it was composed of three distinct components, probably isomers, complicating further evaluation.

Dichlorotrifluoroethane (HCFC-123), a recommended refrigerant replacement for industrial chillers, was also eliminated because:

1. HCFC-123 has a TLV of 10 ppm for an 8 hour day. Manufacturers' reference MSDS recommends the use of respirators when working environments may exceed the 10 ppm limit. Additionally, personal monitoring is suggested when using this chemical.

2. HCFC-123 has an ozone depletion potential of 0.02. Since future use of this chemical in industry will require ozone depletion factors of zero, HCFC-123 is considered a temporary replacement.

3. Any material considered as a tracer gas replacement for R-11 should not be a chemical that is commonly used in the industrial environment. Since HCFC-123 is a recommended replacement for large commercial chillers, high background contamination levels are likely to be found in the test environment.

A thorough evaluation of PDCB was conducted using each of the criteria specified in selection criteria of this paper. PMCP and PMCH were also studied on a more limited basis. The evaluation of PMCP and PMCH is still ongoing, but some of the initial data has been included in this paper. The following are the results of these evaluations.

TOXICITY

Perfluorocarbons have been known for many years to be biologically benign[3,4]. Perfluorodimethylcyclobutane has been used in the development of artificial blood substitutes. PDCB, PMCP and PMCH have been used in ventilation testing for almost ten years. Hence, the adoption of one or more of these perfluorocarbons as an in-place leak test agent should pose no health-related problems for field test personnel.

EFFECT ON THE RADIOIODINE EFFICIENCY OF NUCLEAR GRADE ACTIVATED CARBON

Tests were conducted at NCS Corporation to determine the effect PDCB might have on nuclear grade activated carbon. NCS has in-house radioiodine facilities permitting nuclear adsorbents to be evaluated for small differences in results between similar samples. NCS test chambers have the capacity to test two samples at the same time. Samples of test adsorbents are contained in the test chamber simultaneously, with all test parameters except flowrate maintained at common conditions. Temperature, humidity, pressure, adsorbate loading, and iodine^{131} content are identical for each test sample. This allows small differences between the tested samples to be determined by minimizing scatter due to differences in test apparatus.

Samples evaluated for PDCB influence were split into two portions. One half was placed in a glass bottle. One per cent (1%) by weight of PDCB was added to the bottle containing the test carbon, and the bottle was tightly capped. After thorough mixing, the sample was allowed to stand a minimum of 24 hours. The other half of the sample was used for the reference measurement of radioiodine efficiency with no PDCB added. One percent (1%) loading of PDCB is the

equivalent of 200 field tests with the inlet concentration maintained at 1 ppm for a duration of 10 minutes and with the assumption that no desorption occurs between tests.

After the addition of the PDCB to the carbon, radioiodine efficiency measurements were made on each sample. In all cases, both the sample with PDCB and the sample containing no PDCB were tested at the same time in the same test chamber. Any significant difference in the measured radioiodine performance could be attributed to the presence of PDCB on the test carbon.

All radioiodine testing was conducted according to methodology specified by ASTM D3803-1989[5] using CH_3I^{131} except that temperature, pre-equilibration period, and relative humidity were varied as indicated. Tests without a pre-equilibration period (thermal), normally considered to be less severe, were also performed so that the adsorbed PDCB would be present on the carbon when the methyl iodide contacted the adsorbent.

The following are radioiodine efficiency results (Table-2) for both new and used carbon samples at various testing conditions.

TABLE-2

RADIOIODINE TESTING RESULTS

CARBON SAMPLE TYPE	TEMPERATURE DEGREES CENTIGRADE	RELATIVE HUMIDITY %	PRE-EQUILIBRATION PERIOD	METHYL IODIDE % EFFICIENCY NO PDCB	METHYL IODIDE % EFFICIENCY 1% PDCB
NEW	30	95%	18 HOURS	99.48%	99.51%
NEW	30	95%	18 HOURS	99.74%	99.73%
NEW	30	95%	16 HOURS	97.88%	97.91%
USED	30	95%	18 HOURS	88.63%	88.57%
USED	30	95%	18 HOURS	98.14%	98.23%
NEW	30	70%	18 HOURS	99.99%	99.99%
USED	30	70%	THERMAL	99.78%	99.78%
USED	30	70%	THERMAL	96.70%	96.79%
USED	51.7	95%	THERMAL	99.98%	99.97%
USED	65.6	70%	16 HOURS	99.99%	99.99%
USED	80	95%	THERMAL	99.11%	99.08%
NEW	80	95%	THERMAL	99.99%	99.99%
NEW	130	95%	2 HOURS	99.90%	99.88%
USED	130	95%	THERMAL	99.89%	99.88%
USED	130	95%	THERMAL	97.55%	97.48%

The results in Table-2 show differences in the radioiodine efficiency performance are within the precision and bias values stated in ASTM D3803-1989,

Standard Test Method for Nuclear-Grade Activated Carbon and INEL EGG-CS-7643[6]. PDCB appears to have no effect on the iodine removal efficiency of nuclear grade activated carbon when the carbon is exposed to many times more test agent than would be required for a standard ANSI/ASME-N510 adsorber bank leak test. Because the PDCB has no measurable effect on nuclear adsorbents, perhaps the Reg. Guide 1.52, Rev. 2 requirement of operating plant adsorber systems for a specified time following leak testing could be eliminated, if PDCB is adopted as a leak test agent.

DETECTABILITY and COMPATIBILITY

ANSI/ASME N510 requires that field test equipment be capable of detecting test agents in the presence of other background contaminants. The presence of halocarbon gases other than R-11 and R-112 in the plant air requires that the equipment must be able to detect and identify as well as measure the relative test agent concentrations. The oldest version of ANSI/ASME N510-1975[7] requires that the inlet concentration be limited to 20 ppm. Newer ANSI/ASME standards have relaxed this requirement allowing the use of less sensitive instrumentation. These standards put no maximum limits on the inlet concentration which allows any concentration to be used. This practice is wasteful and costly and accelerates the destruction of the protective ozone layer.

Perfluorodimethylcycyobutane (PDCB) is easily detected when analyzed by traditional electron capture gas chromatography. Gas chromatography, as it is used in field testing, is a technique used to separate, identify, and measure a gas phase component in both the upstream and the downstream air flowing through an adsorber bank satisfying the requirements of ANSI/ASME N510.

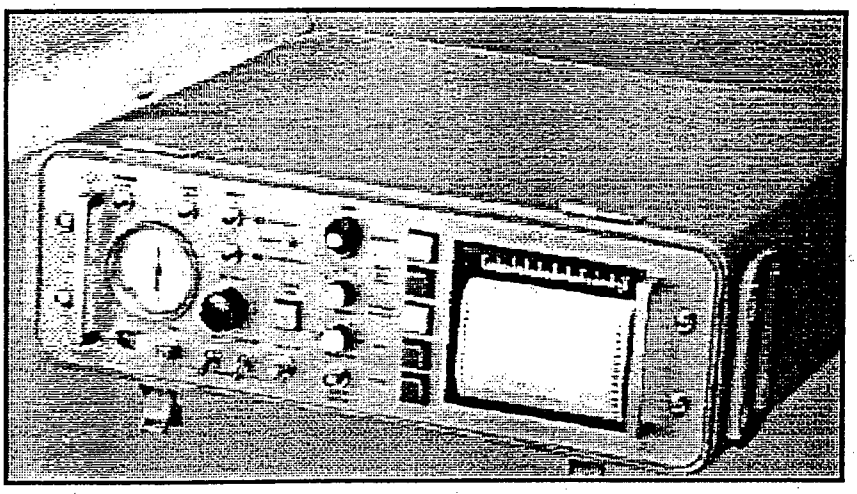
An NCS Corporation Model LMP-10 halocarbon analyzer (Figure-1) was used for detectability testing. The LMP-10 is a portable, self-contained, field-rugged, electron capture detector equipped gas chromatograph. The LMP-10 is designed for the specific task of filter testing, and is able to analyze refrigerant-11 only, with no interferences from other halocarbons. (R-12, R-22, R-114, R-13B1, R-113, trichloroethane, etc.) The selection of a replacement test gas should require little or no change in the gas chromatography, thus allowing interchangeable use of test agents with existing field instruments. PDCB has a similar column retention time as that of R-11, satisfying this requirement.

R-11 is detected at less than 15 parts per trillion (ppt) under laboratory conditions. When using an NCS Model LMP-10, PDCB concentrations of 40 ppt are easily detected in the field. The use of low concentrations of test gas is possible due to the high detection sensitivity for PDCB and the lack of common PDCB

background since PDCB will not be encountered in high concentrations in the field environment.

Figure-1

NCS Corporation Model LMP-10



Sensitivities for PDCB, PMCP, and R-11 are displayed in Table-3. As indicated, the laboratory sensitivity for PDCB using an NCS Corporation Model LMP-10 is approximately 11 ppt. Typical chromatograms illustrating the sensitivity to PDCB, PMCP, and R-11 are shown in Figure-2. Field sensitivity should fall in the 30 ppt range. Because of the superior sensitivity of the electron capture detector to perfluorocarbons and R-11, inlet concentrations of 1 ppm or less may be successfully used for the testing of nuclear adsorber systems. This reduction of the inlet test agent concentration in itself will have a positive impact on our environment regardless of the tracer gas that is ultimately selected.

TABLE-3

DETECTOR SENSITIVITIES

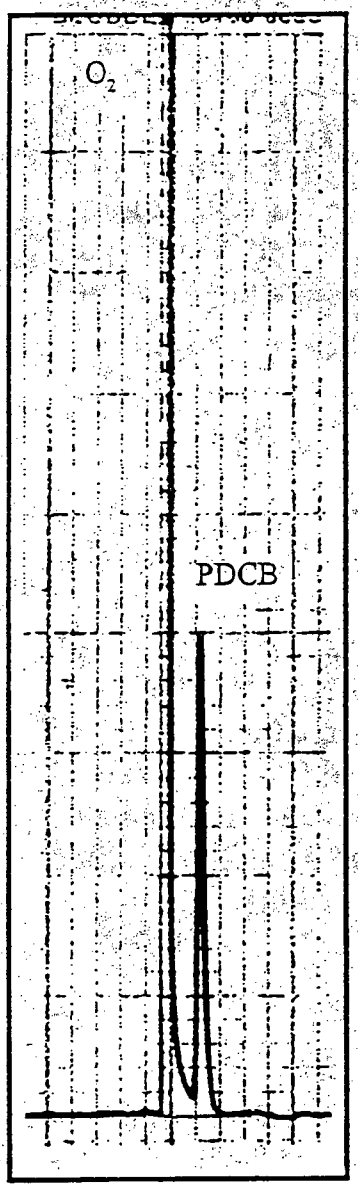
(Parts per Trillion)

TRACER AGENT	LABORATORY SENSITIVITY	FIELD SENSITIVITY
R-11	12 PPT	36 PPT
PDCB	11 PPT	33 PPT
PMCP	1.3 PPT	3.9 PPT

FIGURE-2

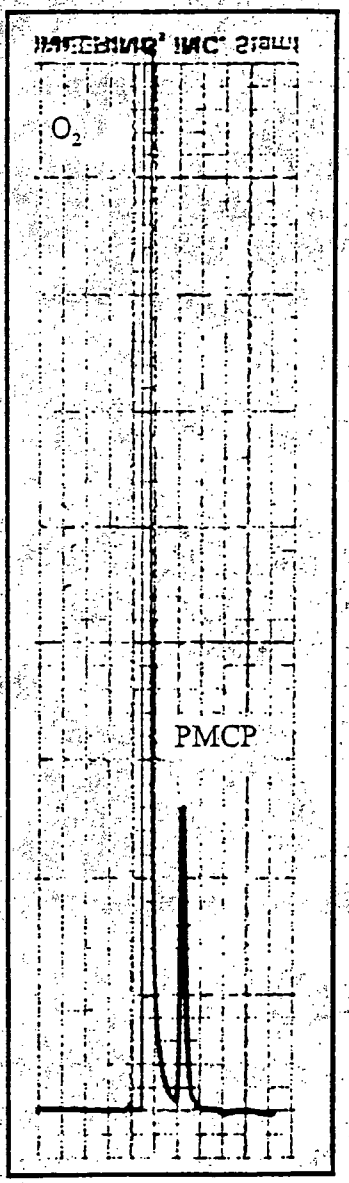
DETECTABILITY OF VARIOUS TRACER GASES

PDCB



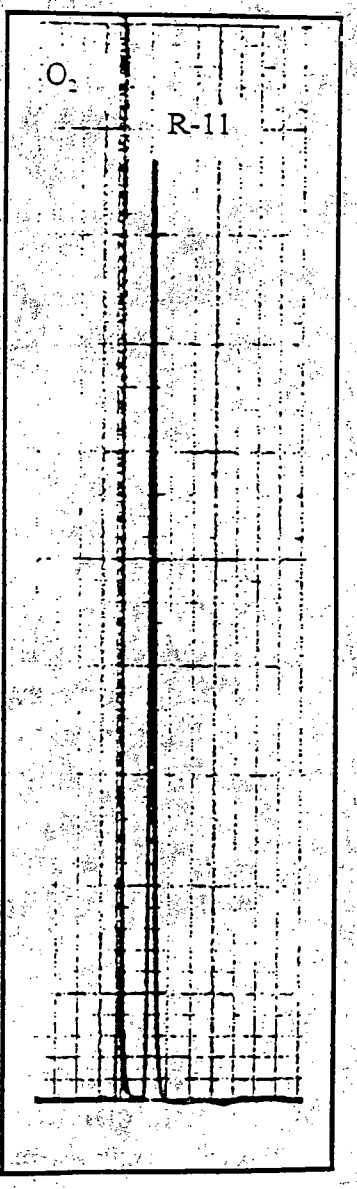
4550 PPT

PMCP



355 PPT

R-11



10600 PPT

All charts recorded on attenuation X10 using an NCS Corporation Model LMP-10 Halocarbon Monitor.

UNIQUE USAGE

A new test agent to replace refrigerant-11 and R-112 should be unique in the industrial work place. R-11 has many uses in a typical nuclear plant including its use as a test agent in NATS testing. R-11 is used in industrial chillers and in degreasing and cleaning operations.

When large amounts of a chemical are routinely used in a nuclear plant, high concentrations will accumulate within the plant's interior. These high backgrounds often create ambiguous results for performing tests per ANSI/ASME-N510 with non-chromatographic instrumentation. The selection of a prospective test agent is compromised if the same material is used throughout a nuclear plant for other operations. PDCB has no known industrial uses so that any PDCB backgrounds encountered in nuclear ventilation adsorber testing would only be the result of prior testing operations. The adoption of PDCB as an in-place filter test agent would make adsorber testing easier for testing personnel who now commonly encounter high R-11 backgrounds.

OZONE DEPLETION POTENTIAL

Any new material selected as a test gas to replace R-11 and R-112 should exhibit zero ozone depletion potential. The desire to mitigate the reduction of ozone in the Earth's upper atmosphere is the primary driving force behind the move to replace chlorofluorocarbons as a test agents in nuclear air cleaning systems. The selection of a gas without zero ozone depletion potential could only be considered an interim action, with future replacement required. Perfluorocarbons such as PDCB are fully fluorinated materials having a zero ozone depletion potential because they do not contain chlorine or bromine atoms that have been associated with the destruction of the ozone layer. Thus the selection of a perfluorocarbon such as PDCB could be considered a permanent replacement for R-11.

CHEMICAL REACTIVITY

The perfluorocarbon family of chemicals are virtually inert. Because PDCB is a fully fluorinated compound, it is unlikely that any undesirable chemical reactions with either the base carbon or its impregnates can occur. PDCB has been used as a tracer gas in building ventilation studies for many years with no known incompatibilities of any kind [8,9,10].

RETENTION ON CARBON

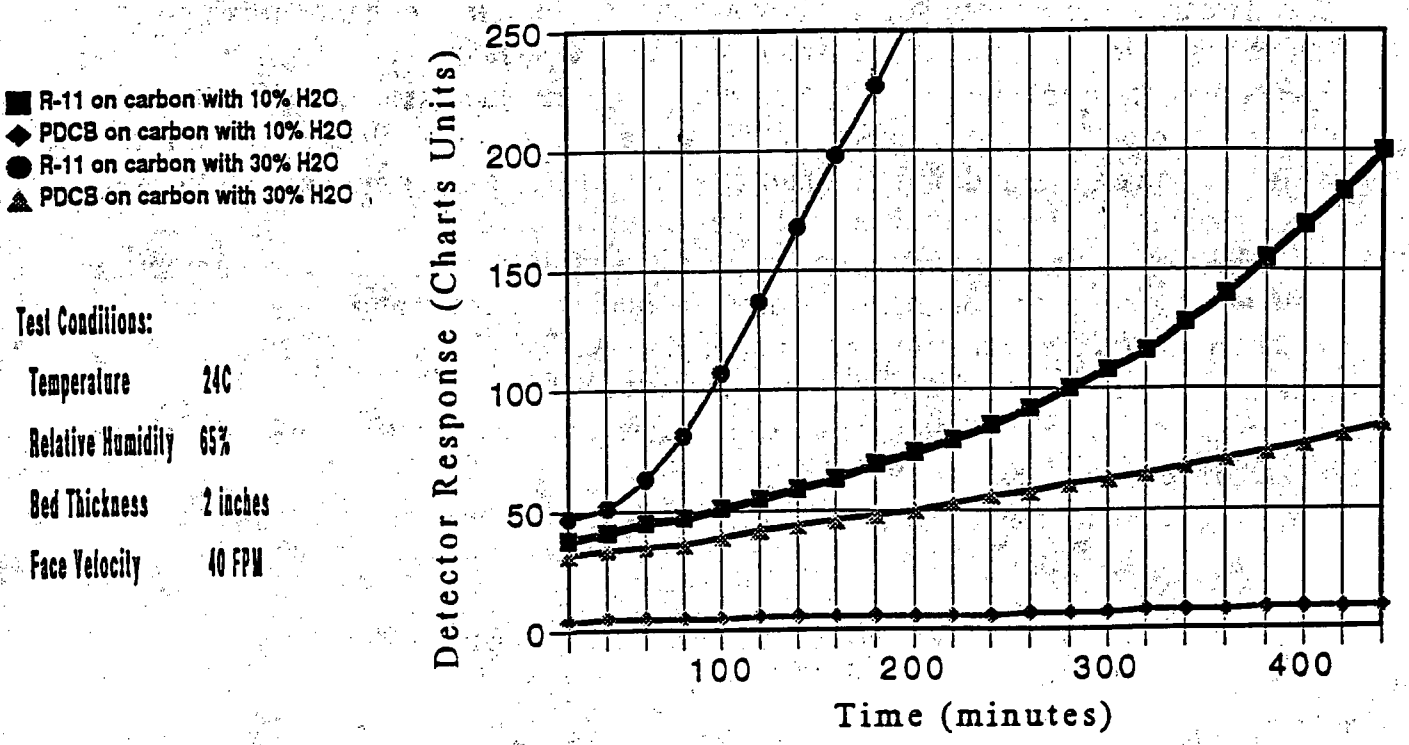
Rapid desorption of refrigerant-11 from nuclear grade carbon has been a problem for field testing personnel for many years. Adsorber systems in the nuclear plant environment collect various volatile organic compounds from sources such as paints and cleaning agents. Eventually, the carbon banks adsorb sufficient amounts of these pollutants so that R-11 adsorptive properties are reduced. Additionally, the carbon beds are at an adsorption equilibrium with the moisture content in the air. As humidities approach saturation (100%), the moisture content in the carbon bed may reach 50% by weight. With organic materials and moisture collecting in the carbon, very little internal surface area is available for the adsorption of the R-11.

Tests were performed on samples of carbon having moisture contents of 10% and 30% by weight to compare R-11 and PDCB retention characteristics. Constant concentrations of PDCB and R-11 were run simultaneously through the carbon. The inlet and outlet concentrations of both test agents were monitored over time to determine desorption profiles for each test agent (See Figure-3). PDCB is retained longer than R-11 on both high and low moisture content carbons.

Longer retention of PDCB on the carbon should facilitate the testing of nuclear adsorber banks, allowing increased testing time prior to desorption of the tracer.

DESORPTION OF PDCB & R-11 FROM CARBON

Figure-3



COMMERCIAL AVAILABILITY

Perfluorodimethylcyclobutane (PDCB) is available commercially. The cost of the chemical is approximately $90/lb. (1992 prices). The higher cost of PDCB at present is due to the limited commercial demand for it. Costs will fall if demand for the product increases. To bring costs in line with present ANSI/ASME-N510 R-11 test costs, one possible solution is to reduce the PDCB injection concentration by a factor of ten. This can be accomplished without compromising the overall ANSI/ASME-N510 sensitivity due to the high detectability of PDCB by electron capture gas chromatography. The cost of using PDCB at a 1 ppm inlet concentration for a duration of 10 minutes is $0.70/1000 CFM tested versus $0.26/1000 CFM for R-11 when using an inlet concentration of 10 ppm. The cost of R-11 will rise steadily as the government implements taxes on refrigerants to discourage the use of chlorofluorocarbons.

EQUIVALENCY OF ADSORBER LEAK TEST RESULTS

Adsorber leak tests were performed using PDCB and R-11. A small filtration system consisting of a HEPA filter and a 2" carbon adsorber incorporating a fixed mechanical leak was used for the testing evaluation. The system flow rate was 40 fpm which gives a residence time of 0.25 seconds.

An NCS Model LMP-10 was connected to the test fixture with the upstream sample probe located just upstream of the carbon adsorber bed, and the downstream sample probe located downstream of the fan to enhance mixing of the tracer with air. Because of the small size of the system, generation of the test agents was accomplished by evaporation from a container with an orifice that was placed upstream of the adsorber in the system inlet tube. While this injection method allowed the addition of small amounts of test gas, some variability in the delivery concentration was noted due to evaporative cooling.

The testing was performed on new carbon with various moisture contents as well as degraded carbon removed from a nuclear plant that had a radioiodine penetration of 26% when tested according to ASTM D3803-1989. Additionally, this carbon had a high relative moisture content (29%).

Results of this testing are illustrated in Table-4 and demonstrate the equivalency of PDCB as a replacement for R-11.

TABLE-4

RESULTS OF LEAK TESTING USING PDCB AND R-11
% MECHANICAL LEAK

SAMPLE	PDCB	R-11
NEW CARBON (<5.0% H_2O)	0.23%	0.20%
NEW CARBON (<5.0% H_2O)	0.22%	0.21%
DEGRADED CARBON	0.21%	0.21%
CARBON WITH 10% H_2O	0.24%	0.26%
CARBON WITH 30% H_2O	0.22%	0.21%

Our evaluation of perfluoromethylcyclopentane (PMCP) is underway. While no data other than detector sensitivity (see table-3) is supplied in this paper, PMCP also exhibits the desirable properties of PDCB. PMCP has a boiling point of 45 degrees Centigrade versus 41 degrees for PDCB. With its lower level of detectability (3.9 ppt), PMCP is an additional candidate for the replacement of refrigerant-11 in the testing of nuclear air and gas treatment systems.

Work is also proceeding on perfluorocyclohexane (PCMH) as a replacement for refrigerant-112. PMCH has boiling temperature of 76 degrees Centigrade and should be more retentive in the carbon of the adsorber banks. This perfluorocarbon may have application in situations where an adsorber bank being tested has a very high moisture content, high organic solvent loading, or has short residence time normally found in Type 1 nuclear filters with one inch thick carbon beds.

SUMMARY

The use of the perfluorocarbon family of chemicals appears warranted in the testing of nuclear air and gas treatment systems. PDCB meets all the selection criteria established for the replacement of refrigerant-11 in the testing of NATS. The material has low toxicity, has no apparent effect on nuclear grade activated carbon, is extremely detectable, and yields leak rates comparable to those measured using R-11. With its zero depletion potential, the use of PDCB should not damage the Earth's protective ozone layer. Because PDCB exhibits longer retention time on carbon than R-11, the in-place testing of nuclear adsorber systems should be a simpler process. Although PDCB seems to be an ideal substitute for R-11, more research is required. Our work is continuing on perfluorodimethylcyclobutane replacement for CFCs in the in-place testing of NATS. We are also testing the effectiveness of other perfluorocarbons such as the

highly detectable PMCP and the heavier PMCH. Before any of the perfluorocarbons can be adopted as a new test agent for the testing of NATS, a consensus is needed in both the standards committees and regulatory agencies of our industry.

REFERENCES

1. ANSI/ASME 1989. ANSI/ASME N510-1989, "Testing of Nuclear Air Cleaning Systems", American National Standard/American Society of Mechanical Engineers.

2. Regulatory Guide 1.52, "Design, Testing and Maintenance Criteria for Post Accident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants", U. S. Nuclear Regulatory Commission, Washington D. C.

3. Mortelman, K.E. and N. Marks, "Invitro Micro Biological Mutagenicity Assays of Perfluoro-1,2-Dimethylcyclobutane", Final Report, SRI International, LSC-8044 1979.

4. Huntingdon, "Acute Toxicity Test for the Flutec PP Fluids", Huntingdon Research Center, Huntingdon, England, April, 1970.

5. ASTM 1989. ASTM D3803-1989, "Standard Test Method for Nuclear-Grade Activated Carbon, American Society for Testing and Materials, Philadelphia, PA.

6. Scarpellino, C. D. and Sill, C. W.; April 1987, "Final Technical Evaluation Report for the NRC/INEL Activated Carbon Testing Program", EGG-CS-7643, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

7. ANSI N510-1975. ANSI N510-1975, Testing of Nuclear Air Cleaning Systems", American National Standard/American Society of Mechanical Engineers.

8. Lagus P.L.; Kluge V.; Woods P.; Pearson J.R. "Tracer Gas Testing within the Palo Verde Nuclear Generating Station Unit 3 Auxiliary Building", 20th DOE/NRC Nuclear Air Cleaning Conference, August 1988.

9. Dietz, R. N., Goodrich, R. W., Cote, E. A., and Wieser, R. F., "Detailed Description and Performance of a Passive Perfluorocarbon Tracer System for Building Ventilation and Air Exchange Measurements," *Measured Air Leakage of 14 Buildings. ASTM STP 904,* H. R. Trechsel and P. L. Lagus, Eds., American Society for Testing and Materials, Philadelphia, 1986, pp. 203-264.

10.Dietz, R. N., and Cote, E. A., "Air Infiltration Measurement in a Home Using a Convenient Perfluorocarbon Tracer Technique," *Environment International,* Vol. 8, No. 1-6, 1982, pp.419-433.

DISCUSSION

KOVACH: I have some questions relating to the desorption curve. I think in ANSI N-510 we started out with R-112. The reason we stopped using it was because it had very similar desorption properties to those you are showing for your new proposed material. I think the reason we decided to use R-11 is because it desorbes fast enough to make it possible to find a leak when you had one. When you had no leak, it was better because it came out faster.

PEARSON: Normally, you don't keep running the material into the filter once you have identified a leak; you stop and see if you can identify the problem. When you are using PDCB, of course, you are able to go back and test it several times before desorption occurs at such a level that you need to give it some time to desorb.

KOVACH: I think the previous speaker showed that you can find a leak in about 20 seconds.

PEARSON: That is possible, but this makes that type of testing unnecessary.

KOVACH: I think that type of testing makes this type of testing unnecessary.

PEARSON: I don't agree with that. I think this test gives you much more data to look at. We are talking about running it for, perhaps, 10 minutes. We feel that this is much more valuable then a simple 20 second or 5 second pulse.

KOVACH: Do you think the mechanical leak will increase over the 10 minutes, or that it will change?

PEARSON: No, it doesn't change in 10 minutes, but I think the more time and more data you have to look at, the more precise you can be with your measurements.

KOVACH: Have you used anything else beside your own instrument?

PEARSON: As a matter of fact, the manufacturers of PDCB use regular laboratory-grade and other types of detectors, other than our own instrument. It is very, very sensitive. In fact, there are probably thousands of electron capture gas chromatographs in use throughout the United States.

KOVACH: What is the volume you are sampling?

PEARSON: We use a 1 cc sampling loop.

KOVACH: You are extrapolating from a 1 cc sample to parts per trillion levels coming out of air cleaning systems?

PEARSON: That is true, that is absolutely true. Anyone that understands gas chromatography knows that this is not a problem.

JACOX: I believe if you read all of the current laws relating to ozone depletion, you will see that R-11 is being banned as a refrigerant, but there are many exceptions for other uses. It will be a number of years, perhaps never, before it will be banned for this specific use. When it is no longer produced in large quantities for a refrigerant, the price will skyrocket. The price may be more of a driving force than an actual ban.

PEARSON: That is absolutely true. It is going to be banned as a refrigerant and manufacturers are going to quite making it. It is going to become very scarce and expensive. I don't think we are setting a good example by continuing to use refrigerant-11 if there is something available that might work better.

SESSION 11A

INVITED SPEAKER

Wednesday: August 26, 1992
Chairman: L. Stirling

OPENING COMMENTS OF SESSION CHAIRMAN STIRLING

DOE WASTE MANAGEMENT PROGRAM - CURRENT AND FUTURE
Joseph A. Coleman

OPENING COMMENTS OF SESSION CHAIRMAN STIRLING

I am pleased to introduce the speaker for this afternoon's session on Wastes. Dr. Joseph Coleman is eminently qualified to speak on the topic. He has received degrees from the University of Rhode Island, Berkeley, and the University of Washington in chemical and nuclear sciences. He has worked in the field of radiation effects on materials and microelectronic technology at the Bell Telephone Laboratories. He directed programs dealing with civilian nuclear waste management issues. He has also worked on solidification of high-level wastes stored at the former spent nuclear fuel reprocessing plant at West Valley. Presently, he is responsible for various cross-cutting technical issues related to the management of DOE wastes.

DOE WASTE MANAGEMENT PROGRAM-CURRENT AND FUTURE

Joseph A. Coleman
Office of Environmental Restoration and Waste Management
U.S. Department of Energy

Abstract

The back end of the nuclear fuel cycle, as well as many operations in the Department of Energy, involve management of radioactive and hazardous waste and spent nuclear fuel. Described herein is the Department's Waste Management Program - where we are and where we're going - and general information about the Program for managing and disposing of waste that will illustrate the importance of air cleaning and treatment in assuring protection of the public and our environment.

The Office of Environmental Restoration and Waste Management

In 1989, the Department of Energy (DOE) committed to a 30-year goal of compliance and cleanup of its nuclear sites. That is, by the year 2019, DOE would clean up the 1989 inventory of inactive sites and facilities and, on a much faster track, bring its nuclear-related sites and facilities into compliance with applicable Federal, State, and local laws and regulations. Before the creation of the Office of Environmental Restoration and Waste Management (EM), no single DOE focal point existed for such activities. Programs responsible for these activities were spread among three principal organizational elements--Defense Programs, Nuclear Energy, and Energy Research. The absence of a consolidated management approach reflected the relative priority for nuclear waste-related compliance and cleanup and impacted DOE's response to increasingly numerous and strict environmental requirements.

In that same year, the Secretary of Energy announced a resetting of priorities in DOE to reflect environmental compliance and cleanup as more heavily weighted than nuclear materials and weapons production. To implement the Secretary's vision of environmental stewardship, EM was created to consolidate DOE-wide responsibility for compliance and cleanup and waste management (Figure 1). The existence of EM also assures that a top level of management will coordinate these activities within DOE's new culture of accountability in the areas of environment, safety, and health.

EM Structure and Responsibilities

EM consists of three programmatic offices and two support offices. Figure 2 shows EM's position within DOE.

The Office of Waste Management (OWM) has program responsibility for waste management at all DOE sites. Principal waste management functions include the treatment, storage, and disposal of several types of waste: high-level radioactive waste; transuranic radioactive waste, low-level radioactive waste; chemically hazardous waste; mixed waste made up of radioactive waste combined with hazardous waste; and sanitary waste. Waste minimization efforts for all DOE activities are also coordinated from this Office.

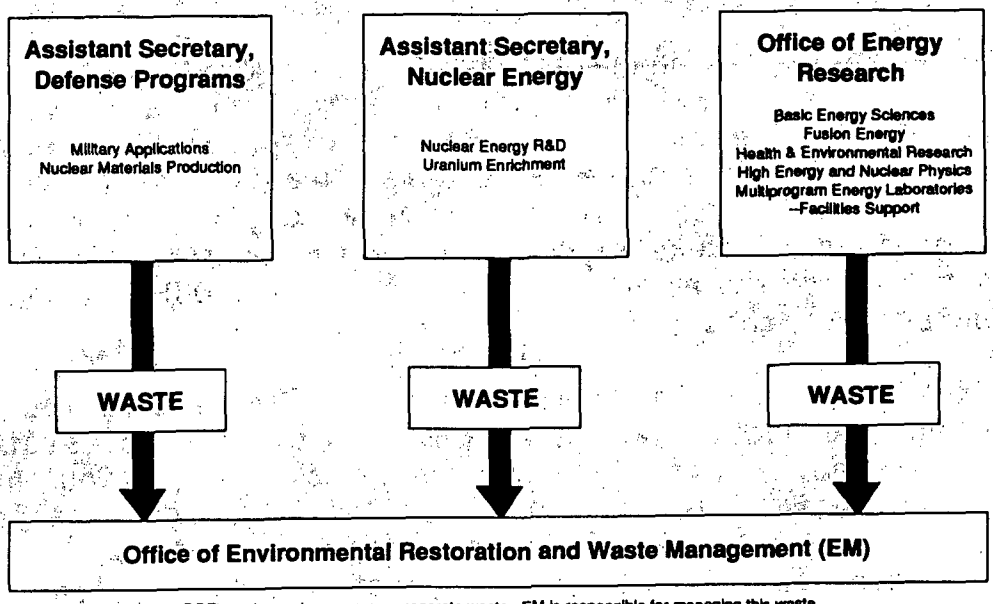
The Office of Environmental Restoration (OER) manages the cleanup of hazardous and radioactive waste at some 110 sites in 32 states, and several sites off-shore. Principal environmental restoration functions include site remedial action and facility decontamination and decommissioning (D&D). Remedial action comprises all aspects of the assessment and cleanup of known and suspect inactive release sites. D&D is concerned with the safe caretaking of surplus nuclear facilities and their decontamination and entombment, or dismantling and removal. The waste produced from environmental restoration activities falls under the management responsibility of OWM.

The Office of Technology Development (OTD) has the responsibility to develop technologies to resolve major technical issues and satisfy emerging requirements for Environmental Restoration and Waste Management Programs. These technologies support efforts to minimize the toxicity and volume of waste; manage unavoidable waste more efficiently and safely; monitor and reduce the release of effluents; achieve cost-effective and safer remediation of sites and facilities; and achieve environmentally acceptable, permanent disposal of waste within regulatory guidelines. OTD is currently supporting work in the areas of off-gas monitoring and treatment, and filter development, topics that have been discussed earlier in this conference.

OWM Manages The Following Categories of Waste.

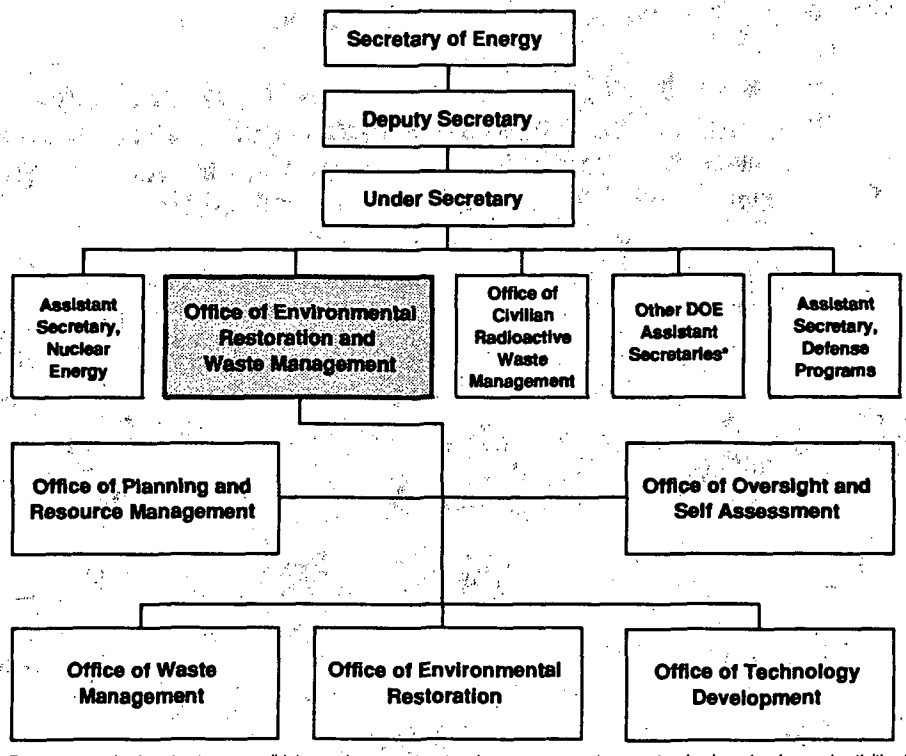
High-Level Waste (HLW) is highly radioactive waste material resulting from the reprocessing of spent nuclear fuel. It includes liquid waste produced directly in reprocessing and solid waste derived from the liquid. Some HLW contains elements that decay very slowly and remain radioactive for thousands of years. Most HLW must be handle by remote control from behind protective shielding. Spent nuclear fuel (SNF) permanently discharged from DOE reactors and civilian nuclear power plants is managed much the same as HLW for storage and disposal.

Management of Waste from Past and Current DOE Nuclear Programs Has Been Consolidated.



DOE's major nuclear programs generate waste. EM is responsible for managing this waste.

Figure 1



The new organization structure consolidates environmental restoration, waste operations, and technology development activities in support of the 30-year compliance and cleanup goal.

* These include the Assistant Secretaries for: Fossil Energy; Conservation and Renewable Energy; Environment, Safety, and Health.

Figure 2

Transuranic Waste (TRUW) is mostly LLW contaminated with alpha-particle-emitting isotopes which have decay rates and concentrations exceeding certain specified levels. It is produced during reactor fuel assembly, nuclear weapons fabrication, and fuel reprocessing operations. It contains man-made elements with atomic numbers greater than 92, thus the name trans (or beyond) uranic (uranium). TRUW decays slowly and requires long-term isolation from the environment. Protective clothing, equipment, and tools may be contaminated with TRU radionuclides. Approximately 2% of TRUW must be handled remotely.

Low-Level Waste (LLW) is radioactive waste that is not high-level waste, transuranic waste, spent nuclear fuel, or byproduct material (e.g., uranium mill-tailings). It is generated in a variety of operations including uranium enrichment processes, reactor operations, isotope production, medical diagnostic procedures, and research and development projects. It is typically contaminated with small amounts of radioactivity dispersed in large amounts of material. LLW is usually rags, papers, filters, tools, equipment, and discarded protective clothing contaminated with radionuclides. Approximately 3% of LLW requires a limited amount of shielding during handling and transportation activities.

Hazardous Waste is waste that exhibits toxic, corrosive, reactive, or ignitable characteristics that can affect human health and/or damage the environment. Hazardous waste includes chemicals, such as chlorinated and nonchlorinated hydrocarbons, explosives, gasoline, diesel fuel, asbestos, acid, organic solvents, metals, and pesticides. As in private industry, DOE must comply with strict Federal, State, and local environmental regulations in treating and disposing of hazardous waste.

Mixed Waste is waste which exhibits both radioactive and hazardous characteristics. Treatment standards and disposal facilities are being developed for mixed waste to satisfy requirements for both the hazardous components regulated by EPA and the radioactive components regulated under the Atomic Energy Act.

Sanitary Waste is waste that is not categorized as radioactive or hazardous. This waste is normally acceptable for disposal in sanitary landfills. Sanitary waste includes liquids which are treated in sewage treatment plants. New EPA requirements have recently been issued which will require lining of the landfills, off-gas/air monitoring and collection and monitoring of ground run-off.

Waste Management

Waste management embraces ongoing DOE-wide activities whose purpose is to characterize, package, transport, treat, store and dispose of DOE waste in an environmentally sound and cost-effective manner. Achieving these goals yields two benefits. It protects people and the environment today and in the future and helps avoid the creation of additional waste sites.

The scope of waste management includes the stored or "legacy" waste from past operations, new waste produced by DOE's defense and civilian programs, and future waste expected from programs with significantly changed missions. This includes constructing and operating treatment, storage and disposal facilities and sites, establishing necessary policy and guidance for waste operations and performing the related integrated and long-range planning. Waste management sites are shown in Figure 3.

Waste Minimization

In addition to managing waste materials on a daily basis, another primary mission of OWM is to provide policy and guidance and coordinate an effective DOE-wide waste minimization program that achieves significant reductions in the volume and toxicity of DOE wastes. Waste minimization programs are underway at all DOE sites and facilities to assist the waste generators with detailed planning and implementation.

Although often perceived as reduction in waste volume and concentration, true waste minimization must be seen as avoidance of the future generation of waste. Waste minimization is becoming one of the highest priority initiatives within the Department. Waste minimization technology is the most interdisciplinary of the waste management tools, affecting all present and proposed DOE operations. Establishing a waste minimization program requires cultural as well as technical changes throughout the DOE complex.

The objective of our waste minimization program is to achieve a significant, near-term reduction in manufacturing waste generation using material substitution, process alteration, new production hardware, and recycling. A comprehensive waste minimization program contributes to decreases in waste treatment, storage, and disposal costs and lower health risks to workers and the public. Technical approaches are being sought to (1) reduce the number of production operations required; (2) increase the use of nonhazardous chemicals and chemicals that produce waste compatible with the environment; (3) increase the use of recyclable chemicals and materials; and (4) design new products, processes, and facilities or redesign existing ones to

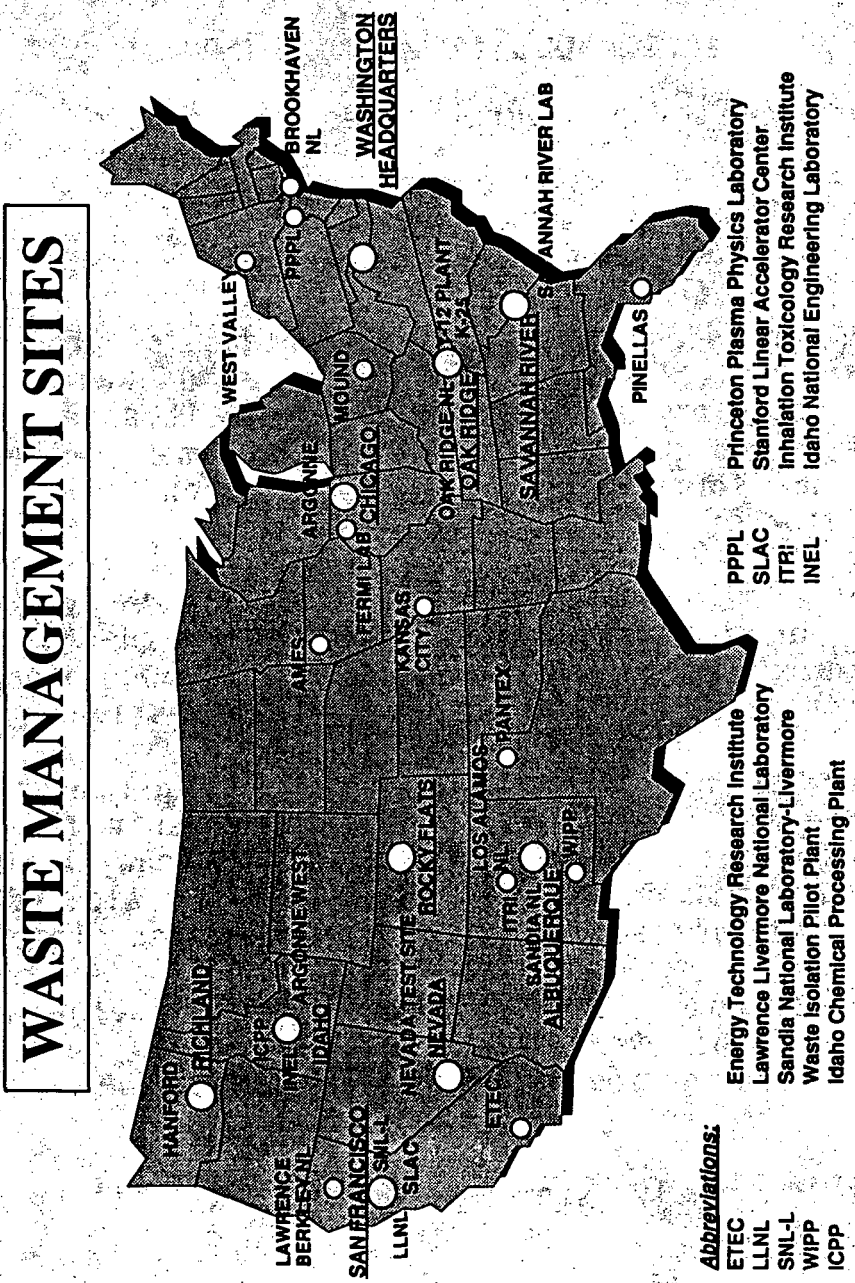

WASTE MANAGEMENT SITES
BROOKHAVEN NL
WASHINGTON HEADQUARTERS
PPPL
WEST VALLEY
ANNAH RIVER LAB
PINELLAS
MOUND
ARGONNE
CHICAGO
FERMI LAB
OAK RIDGE
K-25
X-12 PLANT
SAVANNAH RIVER
AMES
KANSAS CITY
PANTEX
HANFORD
RICHLAND
ICPP
INEL
ARGONNE WEST
IDAHO
ROCKY FLATS
LOS ALAMOS
LAWRENCE BERKELEY NL
SAN FRANCISCO
SNL-L
LLNL
SLAC
NEVADA TEST SITE
NEVADA
ETEC
SANDIA NL
ALBUQUERQUE
WIPP
ITRI
PPPL Princeton Plasma Physics Laboratory
SLAC Stanford Linear Accelerator Center
ITRI Inhalation Toxicology Research Institute
INEL Idaho National Engineering Laboratory
Abbreviations:
ETEC Energy Technology Research Institute
LLNL Lawrence Livermore National Laboratory
SNL-L Sandia National Laboratory-Livermore
WIPP Waste Isolation Pilot Plant
ICPP Idaho Chemical Processing Plant

Figure 3

generate less waste. Some criteria to determine a successful technology include equivalent or improved processing yield, reduced quantities of scrap, reduced waste processing of byproducts, reduced use of hazardous chemicals, positive return on investment, and no loss of product quality.

Treatment, Storage and Disposal

Reference has been made several times to treatment, storage, and disposal.

Treatment

Treatment includes the methods, techniques or processes designed to change the physical or chemical character of waste to reduce the volume or toxicity of the material and make it safer and easier to handle, store, and dispose. Selection of treatment methods depends on the quantity and form of the waste material and the conditions, or requirements, for storage and disposal.

In general, liquid waste is treated by incineration, vitrification, or other thermal processes and non-thermal stabilization (e.g., grouting); solid waste can be reduced through processes such as compaction, incineration, melting, and acid digestion.

Waste processing or vitrification plants take high-level liquid waste or sludge and convert it to a waste form suitable for permanent disposal in a geologic repository. Liquid waste can also be solidified by oxidation and removing moisture (calcining). Calcined material and sludge can be immobilized by mixing it with molten glass particles.

Treatment or conditioning of spent nuclear fuel to meet disposal requirements will be evaluated in the next few years; methods are likely to be varied in view of the many different fuel types in the DOE inventory.

TRUW is currently stored pending availability of disposal capacity.

The principle LLW treatment methods are volume reduction (e.g., compaction, incineration) and solidification.

DOE's near-term strategy is to use commercial facilities to treat and dispose of hazardous waste as it is generated.

For mixed waste, a number of thermal treatment and non-thermal stabilization (e.g., cement) facilities exist or are in the planning, construction, or startup phase. A few mixed waste treatment standards have been established; for example, standards exist for mixed waste containing mercury, lead, powdered zirconium, and high-level radioactive waste.

Storage

Storage is the retrievable retention of waste pending disposal, an interim measure. OWM strategy includes elimination of the backlog of stored waste and reducing the generation of new waste. Before it is solidified, high-level radioactive waste is stored in liquid form in carbon-steel tanks encased in concrete. These tanks have capacities ranging from 500,000 to about 1,000,000 gallons and most provide two separate tanks with a space between them for detecting and cleaning up potential leaks. HLW is also stored as calcined material in stainless steel containers. The main storage sites for DOE HLW are Hanford, Savannah River, and Idaho. On the basis of volume, Hanford has approximately twice the amount of the others combined. Storage of SNF is either dry or wet (e.g., water, sodium) in shielded cells or basins.

A large amount of DOE's present inventory of TRUW (75%) has been disposed in near-surface sites. New TRUW is no longer buried but stored in containers and stacked on asphalt or concrete pads. Current strategy is to upgrade and maintain safe storage at the generator sites and assure that storage complies with RCRA requirements.

Storage of DOE LLW is normally on a temporary basis; the acceptability for disposal of most LLW eliminates the need for long-term storage. LLW will continue to be disposed of using proven or improved surface or near-surface techniques at selected DOE locations. The LLW is characterized to make sure it does not contain hazardous material and stored for the short term awaiting transportation, treatment, or disposal on-site. Small LLW generators will ship to the major DOE sites.

Hazardous waste is stored in permitted DOE facilities pending shipment to treatment and disposal sites. Compliance with land disposal restrictions (LDR's) ensures that hazardous waste is stored and disposed according to specific regulatory provisions in preparation for treatment.

Mixed waste is stored pending treatment and disposal. DOE has over 280 storage units located at 33 sites that store LLMW. Those units include container storage, aboveground tanks, underground storage tanks, waste piles, and surface impoundments. Overall management of

LLMW is complicated by the fact that RCRA regulations impose not only land disposal restrictions but also restrict the length of time that untreated mixed waste may be stored.

Disposal

Disposal is the permanent emplacement of waste in a way that assures its isolation from the human environment for the foreseeable future with no intent of retrieval. OWM determines the technologies and processes to prepare DOE waste for permanent disposal. Facilities are being designed, built, and tested so processing and disposal of stored waste can proceed aggressively.

HLW and SNF are expected to be disposed in a Federal repository, the first of which is proposed to begin operations after the year 2000. In 1987, the U.S. Congress designated Yucca Mountain, near the Nevada Test Site, as the site to be studied by DOE for possible development as a repository. Yucca Mountain offers an extremely dry location, a very deep water table (1,700 feet), and a solid rock formation known as "welded tuff" (a dense form of compacted volcanic ash).

A facility for disposal of TRUW from defense operations has been completed near Carlsbad, New Mexico. Operation of the Waste Isolation Pilot Plant (WIPP) is pending legislation to transfer the land from the Department of the Interior to DOE and completion of test demonstrations. Examination and processing facilities at various DOE sites will certify that TRUW shipments meet the criteria for disposal at WIPP.

LLW is generally disposed by shallow land burial in trenches. New technologies, stabilization techniques, and site monitoring systems are being evaluated to ensure safety and protection of the environment. There are presently six major DOE sites that dispose of LLW either generated on-site or received from smaller DOE generator sites.

DOE currently disposes of hazardous waste in permitted commercial facilities.

Other Waste Management Functions

There are other key waste management functions involved in dealing with DOE waste: packaging, transportation, and characterization. These are self-descriptive to a large degree. While important they are mainly supportive of the big three: treatment, storage and disposal. One of the most widely expressed technology needs by waste management operators in the field is for ways to better characterize the waste

that they receive from generators. A great deal of effort is underway in DOE to develop improved capabilities for waste characterization.

Waste Type Status

A summary of waste management strategies for the various DOE waste types is provided below (Figure 4).

MAJOR EM WASTE CATEGORIES

- **High-Level Waste* (HLW)**
- **Transuranic Waste* (TRU)**
- **Low-Level Waste* (LLW)**
- **Low-Level Mixed Waste* (LLMW)**
- **Hazardous Waste (HAZW)**
- **Sanitary Waste (SANW)**

* RADIOACTIVE

Figure 4

High-Level Waste

The main DOE storage sites for some 400,000 cubic meters of HLW are at Hanford (64%), Savannah River (33%), and Idaho (3%). The strategy for HLW is to upgrade the existing storage tanks and maintain safe storage, and begin treatment to convert it to a form suitable for permanent disposal in a deep geologic repository.

Within DOE, EM is responsible for treatment of the HLW and the Office of Civilian Radioactive Waste Management is responsible for disposal under the Nuclear Waste Policy Act as amended. Similar arrangements apply to SNF. EM's involvement in the management of SNF is a fairly recent development as DOE has determined that reprocessing is no longer needed to recover material for defense-related needs.

Transuranic Waste

Most of DOE's TRUW is buried or stored at four DOE sites, Hanford, Idaho, Los Alamos and Savannah River, with the majority located at Hanford and Idaho. Approximately 75% of the total amount is buried.

The DOE strategy is to make sure the material is stored safely at the generation sites in compliance with AEA and RCRA requirements until the WIPP test phase is completed.

Low-Level Waste

The Department has disposed on the order of 2.7 million cubic meters of LLW at six major sites within the complex with the largest percentages located at Savannah River (22%), Hanford (21%), Oak Ridge (10%) and the Nevada Test Site (15%). The DOE strategy with LLW is to characterize it to make sure it does not contain hazardous material, and treat it if necessary for disposal on-site or for short term storage if the waste is to be shipped to another DOE site for disposal. As a matter of policy, the smaller DOE LLW generators ship to the major sites for disposal.

Hazardous Waste

Currently, DOE has limited on-site hazardous waste management capabilities, depending heavily on commercial hazardous waste management facilities for the treatment and disposal of DOE-generated hazardous waste. It is estimated that between calendar years 1984-1991, DOE generated over 100,000 cubic meters of hazardous waste. During this time frame the Kansas City Plant generated 57% of the waste.

One of the recent issues facing OWM is the hazardous waste shipping moratorium imposed in 1991. The moratorium prohibits shipment of hazardous wastes to commercial hazardous waste management vendors pending review and approval of shipping procedures by Headquarters.

Low-Level Mixed Waste

Regulatory provisions based on the RCRA and the AEA have complicated LLMW management at DOE. RCRA prohibits the land disposal of specified hazardous wastes according to a phased schedule unless either the wastes are treated to specified treatment standards or other requirements, or a demonstration is made to the EPA that "there will be no migration of hazardous constituents from the disposal unit for as long as the wastes remain hazardous." RCRA also prohibits the long-term storage of RCRA-regulated hazardous wastes.

Inventories reported as of March 1992 identify some 750 LLMW streams from 37 DOE sites, with wastes stored at all but three of these sites. Continued generation is anticipated for some 380 of these waste

streams at 33 generator sites. Reliable estimates for LLMW generated from environmental restoration activities have not been identified and are not included in this compilation of waste streams. About 75% percent of the LLMW is at three DOE sites, Idaho, Oak Ridge and Hanford.

Sanitary Waste

DOE facilities and sites generate both liquid and solid sanitary waste. EM has focused primarily on management of solid sanitary waste. The EM program includes complying with new EPA requirements recently issued.

Summary

The scope and complexity of the Department's Waste Management Program described in this paper should make clear the tie between the Program and the subject matter of this conference. For example, capability for monitoring and control of effluents is particularly important for waste treatment operations and facilities. Reactor and fuel cycle facilities need to be designed and operated with the view of minimizing waste produced and assisting in the eventual decommissioning of the facilities. The sharing of information and technology in conference such as this is important to the nation's initiatives in the waste management area.

DISCUSSION

FIRST: Where do you see the need for new gas cleaning technology in this program? Is the need in place, or is a major research and development program specifically related to waste disposal needs now required? As you are well aware, the codes and standards for nuclear air and gas cleaning have been developed for the civilian nuclear power plant industry. They are now being forced-fitted into the rather different requirements of the program which you have just described so well. The second question is, will the current codes and standards be adequate for the very different requirements that you have described?

COLEMAN: Much of the development of our new facilities that will treat many waste streams that are quite unique in the Department of Energy have only begun to be funded and put into place. Many of these facilities also have attached to them a technology development component or, I would call it, a technology adaptation component. To my knowledge, we have not participated in the standards area very much in the past; we should do more in the future. The transition that these programs have been going through in the last three years has caused people in our program to believe they did not have sufficient time nor resources for this participation. If we are going to adapt the standards that have been developed for the commercial sector for the Department's somewhat unique challenges, we are going to have to participate much more. I hope you will hear much more about that in future Conferences.

McGALLIAN: There is a program at present, called waste minimization, residue elimination, which partially addresses Dr. First's question. They are going into a design concept to eliminate residue and encourage waste minimization at Rocky Flats. That is going to require a large research effort into air treatment at Rocky Flats. In fact, I have been recently questioned about the waste minimization and waste residue project at Rocky Flats. Is it going to continue under the budget of the waste program or will it go under the environmental management? What do you see?

COLEMAN: I am not directly involved in this subject, but it is my understanding that at the present time there is consideration being given to the transfer of the Rocky Flats Plant from Defense Program to the Environmental Restoration and Waste Management Program. I am not familiar with all the details. My understanding is that the Rocky Flats Plant is not going to be put into operation again. The suitability of transferring it to our offices for the cleanup and disposal of the waste, including how we manage the residues, is clearly an open question. There is a great deal of work going on in that transition plan, as you perhaps are aware. I expect that sometime this Fall the transition is likely to take place.

McGALLIAN: The transition plan went to DOE Headquarters. My next question is, does the program for the Rocky Flats transition period fall under a Transition Program Department, and is that a separate department?

COLEMAN: It is a separate office that has been established under the Environmental Restoration and Waste Management Program called Facilities Transition. I am not sure how long the Rocky Flats Plant will stay in the transition group before it is split up between the cleanup program and our program in waste management. If you call me at Headquarters, I will try to get an answer for you. The estimate is that there may be, over the next decade, some 1,000 different facilities that will have to be transferred from Defense Programs to our program for cleanup and waste management.

RICE: Our work is governed by DOE-6430-1A, now becoming 1B, which has been in draft form for quite some time. It also refers to AG-1 and DOE NEF3-45 now in a revised form, but not currently in use in its present form. What I want to know is, when are these documents going to be put on the street for actual use?

COLEMAN: I can't answer that question. Maybe I will throw that one to Larry.

STIRLING: I am afraid I cannot help you either. I am not familiar with that particular one.

COLEMAN: Larry, is there a Standards Office in Environment that deals with this?

STIRLING: If you will see me afterwards I will make sure that somebody responses to your question, will get some guidance for you.

WEBER: Just as a point of information, I understand that the revised NEF standards are presently in the hands of Jim Leonard of Defense Programs.

SESSION 12

PANEL SESSION: PROPOSED SOURCE TERM REVISIONS - POTENTIAL IMPACT ON FUTURE NUCLEAR AIR CLEANING REQUIREMENTS

Wednesday: August 26, 1992
Moderator: R. R. Weidler

Panel Members: L. Soffer
H.E. Vanpelt
J.L. Kovach
M.L. Hyder
B. Schwartz

OPENING COMMENTS OF PANEL MODERATOR WEIDLER

INTRODUCTORY REMARKS
L. Soffer

A UTILITY PERSPECTIVE ON NEW SOURCE TERMS
H.E. Vanpelt

NOTES ON THE DRAFT NUREG REPORT ACCIDENT SOURCE TERMS FOR LIGHT-WATER NUCLEAR POWER PLANTS
J.L. Kovach

PROPOSED SOURCE TERM REVISIONS - POTENTIAL IMPACT ON FUTURE NUCLEAR AIR CLEANING REQUIREMENTS, APPLICATION TO DOE PRODUCTION REACTOR OPERATION
M.L. Hyder

REVISED ACCIDENT SOURCE TERMS AND CONTROL ROOM HABITABILITY
G.P. Lahti, R.S. Hubner, W.J. Johnson, B.C. Schwartz

PANEL DISCUSSION

CLOSING COMMENTS OF PANEL MEMBER SOFFER

EFFECT OF FILTERING AT CONTAINMENT VENTING ON THE CONSEQUENCES FOR THE ENVIRONMENT
L.C. Scholten, E.L.M.J. van Wonderen, J. van der Steen

OPENING COMMENTS OF PANEL MODERATOR WEIDLER

We have an interesting and important topic for this panel session - Proposed Source Term Revisions and their Potential Impact on Future Nuclear Air Cleaning Requirements.

I am Ray Weidler of Duke Power Company. I work in the Engineering area of McGuire Nuclear Station in Charlotte, NC and I am also Vice-Chair of the ASME Committee on Nuclear Air and Gas Treatment. I will chair this panel session. My Co-Chair is Leonard Soffer of the US NRC and he will be providing summary remarks at the conclusion of today's session.

We will be hearing five (5) completely different perspectives this afternoon on revised source term implications for nuclear air cleaning from a most distinguished panel:
Mr. Leonard Soffer of the USNRC
Mr. Harry Vanpelt of Duke Power Company
Dr. Lou Kovach of NUCON
Dr. Lee Hyder of Westinghouse-Savannah River
and,
Mr. Barry Schwartz of Sargent and Lundy.

Each panelist will deliver a brief paper on their perspective of the revised source terms and then we will open the session to the audience for questions.

PANEL ON PROPOSED SOURCE TERM REVISIONS AND POTENTIAL IMPACT ON FUTURE NUCLEAR AIR CLEANING REQUIREMENTS

Introductory remarks of
Leonard Soffer
US Nuclear Regulatory Commission

The NRC's proposed revised reactor accident source term and some implications for nuclear air cleaning requirements was presented yesterday at this conference.

This source term is intended for licensing of future light water reactors, and will be implemented via a future revision to 10 CFR Part 50 to incorporate improved source term and other severe accident insights. It is not expected that this source term will be applied in siting future reactors, since a proposed change to 10 CFR Part 100 is expected to eliminate the use of dose calculations for assessing site suitability. Rather, the revised source term is expected to be used in evaluating the capability of the plant to deal with accidents. The revised source term will not be imposed upon existing plants, however they may voluntarily propose to use it. Such applications will be reviewed by the NRC. A more realistic understanding of fission products release into containment must also be combined with a realistic treatment of fission product removal and retention both by engineered safety features as well as by natural removal mechanisms. This area is also part of the NRC's effort to provide a revised understanding of accident source terms and is continuing at this time.

Potential impacts of the revised source term on nuclear air cleaning requirements arise from (1) revised insights on iodine chemical form, (2) the presence of other nuclides, in addition to iodine and the noble gases, (3) revised timing and duration of fission product releases, and (4) the release of non-radioactive aerosols.

Although detailed analyses have not be done at this time, major changes in nuclear air cleaning requirements are not envisioned as a result of the revised accident source term. It is important to recognize that present fission product removal and air cleaning systems, when evaluated realistically, can provide a high degree of mitigation and can be effective against many types of nuclides, whether in aerosol or elemental form. The concept of what constitutes an air cleaning system should be broadened to include other plant systems, as well. In-containment sources of water, for example, can reduce the loading on present filter systems and the combination can provide an enhanced capability to deal with large quantities of aerosols.

One unresolved question is the need for charcoal and elemental iodine retention in filter applications where the pH is controlled. Present filter systems are effective for aerosols as well as elemental iodine. It may be prudent to retain some capability to deal with elemental iodine; however, it may not be necessary to have filters with an elemental iodine removal efficiency as high as present designs. The potential benefits and impacts of reduced charcoal testing and surveillance requirements, assuming pH control, could provide useful insights in resolving this question and deserve further study.

A Utility Perspective on New Source Terms

Harry E Vanpelt

Duke Power Co
McGuire Nuclear Station
Huntersville, NC

The Utility industry may benefit from the revision of accident source terms used for licensing accident analysis provided procedures and requirements are modified to recognize the changes incorporated in the revised source terms.

The design requirements and operating procedures of accident mitigation systems may be tied more directly to response to radiological release concerns. Operation of containment spray and chemistry control may be better linked to radiological release concerns along with plant integrity. This will more directly tie public health and safety benefits to accident mitigation actions. Design and operation requirements of current systems are slanted to respond to very unlikely radiological conditions. Less emphasis will be necessary on immediate availability of HVAC cleanup systems. More concern for long term operation of accident mitigation systems such as annulus ventilation, and control room ventilation will result if new source terms are adopted. The testing requirements associated with these systems may be redirected to focus on their ability to respond to a continuing release of activity from the fuel and not on rapid response to the initial accident signals. The necessary maintenance of systems will be simplified since compensatory measures may be more readily taken which allow maintenance service while maintaining availability of the system components. Chemistry Requirements will be tied more closely to radiological release concerns. Sump Ph is guided primarily by hydrogen generation and metal corrosion concerns at present. Consideration of Ph in limiting Iodine release to the containment atmosphere will further emphasize proper control on this important parameter throughout severe accident response operations.

The importance of carbon filter systems is lessened when considering new source terms. The HEPA filters will now be of primary importance in determining filter effectiveness. This may allow the requirements for carbon bed efficiency to be relaxed to ease testing and maintenance problems. Testing requirements may be adjusted to reflect the concern for particulate removal primarily and for elemental and organic iodine removal at a lesser extent.

The utility industry will directly benefit from revised source terms if the revised accident analysis provides additional margin for optimization of core design for more fuel burnup and better fuel utilization during operation. The source term effect on post accident equipment qualification must also be considered. It is

not clear that the revised source term will result in less conservative post accident dose rates to equipment in all cases.

Adoption of the new source terms by utilities will hinge primarily on the benefits in design requirements and operational improvements gained as a result new terms. If little change in actual operation and testing is seen as a result of the use of the revised source term it is not likely that utilities will see the need to adopt the Nureg. It appears that there are several potential safety and operational benefits associated with the use of new source terms but it will take the cooperation of regulators, component manufacturers and plant owners to properly realize these benefits. Efforts need to begin to relicense plants to take advantage of these benefits.

NOTES ON THE DRAFT NUREG REPORT ACCIDENT SOURCE TERMS FOR LIGHT-WATER NUCLEAR POWER PLANTS

J. L. Kovach
NUCON International, Inc.

The major air cleaning related accident source term changes in the NRC draft report relates to the chemical form of iodine in the containment. While the Regulatory Guides 1.3 and 1.4 assumptions of 91% elemental, 5% particulate and 4% organic forms were known for a long time to be unrealistic, the proposed assumptions of 2.85% elemental 97% particulate and 0.15% organic distribution is also questionable.

Unfortunately, it became typical of the source term studies to use data from carefully controlled laboratory experiments with pure chemicals and extrapolate by computers for a large system such as an LWR containment. However, as those who had seen the TMI-2 containment after the accident well realize, the water on the bottom of the containment was anything but deionized water.

While there is generic agreement that the great majority of the iodine in most accident sequences would by in particulate form - mainly as cesium iodide - the value of 0.15% for organic is questionable. To start with, the data from the TMI-2 analysis indicates only 1/3 of the iodine in elemental form and analysis of the adsorbents used (in the fuel handling building and auxiliary building air cleaning units), which were used in the early stages of accident indicated that the great majority of the removed and released ^{131}I form was organic and not elemental.

There is a large amount of organic material in the containment which is available for reaction with any iodine (whether elemental I_2 or HI). Additionally, recent data indicates that a very extensive reaction can take place between small aerosol particles and gaseous compounds.

While this reaction can have the benefit of additional scrubbing of all gaseous species which have relatively large molecular weight, it can also result in organic iodide generation by reaction between suspended aerosol particles and the low molecular weight organic compounds to result in organic iodides.

Both I_2 and HI are good reactants with various organic compounds to generate a family of organic iodides. An interesting experiment to remember is a South African study when a seemingly iodine concentration effect was observed on the removal efficiency of unimpregnated activated carbon. At high entry concentrations 99+ % removal efficiency was noticed, however, as the elemental iodine challenge concentration was decreased the unimpregnated carbon efficiency drastically decreased. When an impregnated carbon was substituted the apparent concentration effect disappeared. Further investigation showed that there was a constant organic compound concentration in the challenge air stream and as the total ^{131}I concentration decreased a larger and larger fraction was converted to organic iodides causing the apparent concentration effect with unimpregnated carbons which do not remove organic iodides.

There is no assurance that the tellurium iodine precursor will also be in a location where cesium is available for reaction with the iodine daughter products before reaction with organic compounds takes place.

While there may be little argument with the 97% aerosol form, particularly with containment sprays operating, it would be more realistic to state that the non-particulates will be in a family of unknown chemical forms, a majority of which could be organic.

The currently used impregnated carbons exhibit excellent elemental iodine, good methyl iodide (but in shallow beds not all organic iodide form) removal and fairly good efficiency for HI removal (at least those that are not acidic carbons) therefore, little or no technology change is required for currently used adsorbents.

The major change in the family of challenges facing nuclear air treatment systems is the very significant increase in the mass and type of particulate matter, most of which would be various forms of hygroscopic alkali cesium salts. Many of the currently used prefilters, moisture separators are not capable of protecting the HEPA filters from the large mass of aerosol and the philosophy of using "dust" filters as prefilters and non-stainless steel moisture separators needs to change. Where stainless steel knit moisture separators are used as a first component the structural and chemical integrity probably will be adequate. However, where structurally inadequate prefilters and glass fiber moisture separators are used as first components off-design performance and very fast deterioration can be expected.

Unfortunately, in the past and currently the least attention is being paid to these important components. Regardless of the test frequency and regulation on the downstream HEPA and impregnated carbon components, the air cleaning system will not work if prefilters and/or glass fiber moisture separators fail.

The nuclear air cleaning industry (including specifiers, suppliers and regulators) will have to review the adequacy of all components of both air cleaning systems and currently "prefilter protected" fan coolers to ensure that perceived non-critical components will not cause system failures.

There is an editorial comment also regarding the NRC current draft, indicating iodine fractions to two decimal points is presumptuous and does not reflect provable reliable knowledge on full size systems. Our knowledge and the variability of accident sequences does not permit the indication of such certainty.

Proposed Source Term Revisions- Potential Impact on Future Nuclear Air Cleaning Requirements

Application to DOE Production Reactor Operation

M. L. Hyder, Westinghouse Savannah River Company, Aiken, S. C.

Production reactors at the Savannah River Site (SRS), including the K Reactor now operating, are very different from commercial power reactors. They are heavy water cooled and moderated, and are operated below the boiling point. SRS fuel assemblies consist of long nested tubes made from aluminum-uranium alloy, clad in aluminum. (Figure 1)

SRS reactors were designed more than forty years ago, before the concept of a containment had been developed. Protection against radioactive releases is provided by the reactor confinement system, shown schematically in Figure 2. This system incorporates moisture separators, particulate filters, and carbon beds for iodine retention. It is always on line during reactor operation. All effluent air from the reactor building is passed through this air cleaning system to remove iodine and particulate radioactivity. Upgrades now in progress will bring this system into conformance with current air cleaning standards, while retaining the same types of air cleaning components. This system has been extensively described in a sequence of papers presented to this conference over the last thirty years.

It has been clear to us for a long time that the radioactive source term resulting from an accident in this reactor might be considerably different from that of commercial LWR's. Some of the differences in the design and operation of the reactors are shown in Figure 3. There are also differences between the K reactor building and typical LWR containment buildings, and the K reactor has the advantage of being centered in a very large site. The K reactor fuel will melt and relocate at temperatures that are very low compared to the corresponding processes in zircaloy-clad oxide fuels. The aluminum cladding and much of the fuel are molten at 660°C. Experimental measurements of the release of fission product isotopes from melting U/Al fuel have recently been summarized by Rusi Taleyarkhan at Oak Ridge.(1) Some important results are:

- Very little radioactivity is released below the melting point;
- Noble gases, iodine, considerable cesium, and some tellurium are released quickly upon melting;
- Unless some mechanism makes possible heating the fuel to much higher temperatures, other isotopes are of little concern.

After the development of the "TID" source term years ago, it was frequently used in the analysis of potential accidents at Savannah River. This was an easy approach, but more recently we have attempted to develop a spectrum of SRS-specific source terms that could be justified from the characteristics of the Savannah River reactors. This has been done, for example, in our probabilistic risk assessment (PRA). Figure 4 shows how the set of source terms for this PRA was derived.

Our new source terms do not have a big effect on the expected response of the air cleaning equipment in our confinement system. It was designed to retain very large releases of fission products. So long as the accident does not produce so much fine particulate as to overwhelm the filters, we expect the confinement system to retain 99% or more of particulates and iodine. (It will retain none of the noble gases or tritium.) The biggest difference in the new source terms is that substantial amounts of released iodine may be in particulate form, and will be retained on the HEPA filters rather than on carbon. This should hot be a problem for the operation of the system nor its effectiveness.

Perhaps the most important feature of the new NRC source term to us is that it is now reactor specific. One size no longer fits all. This provides an additional justification, if one were needed, for doing source term and confinement system analyses based on our best understanding of accident phenomena in our reactors: fission product releases, the effects of fission product release barriers, and the operation of engineered safety systems. As we have already been moving in this direction, this is very satisfying.

We would suggest that the new NRC guidance might include reactor- and site-specific policy wording. As we have found the local terrain and meteorology to be important in developing source terms, we would suggest that such site characteristics might well be incorporated into siting rulemaking.

Reference

1. R. P. Taleyarkhan, "Analysis and Modeling of Fission Product Release from Heated Uranium-Aluminum Plate-Type Reactor Fuels", presented at the International Topical Meeting on the Safety, Status, and Future of Non-Commercial Reactors and Irradiation Facilities, Boise, Idaho, Sept. 30-Oct. 4, 1990.

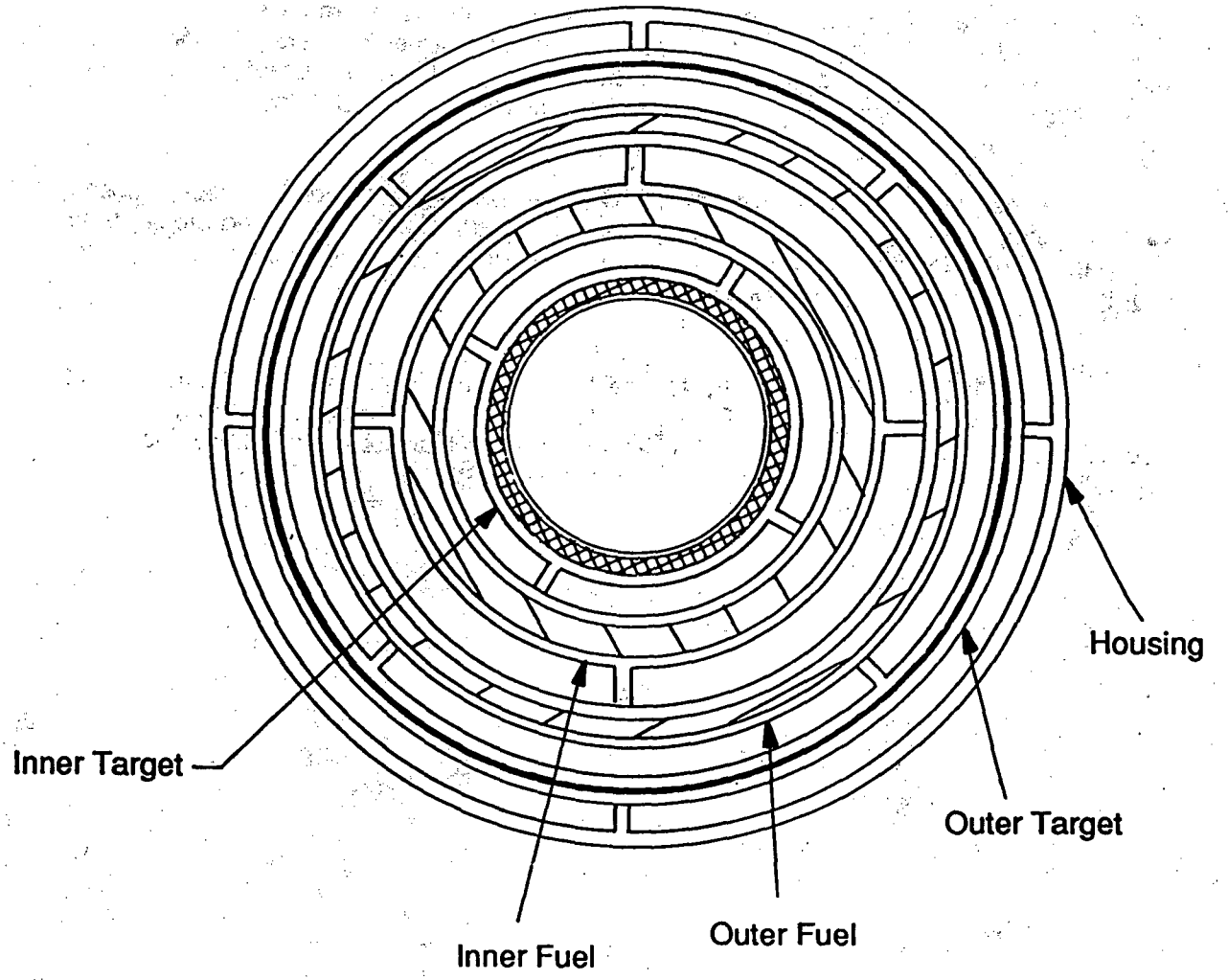
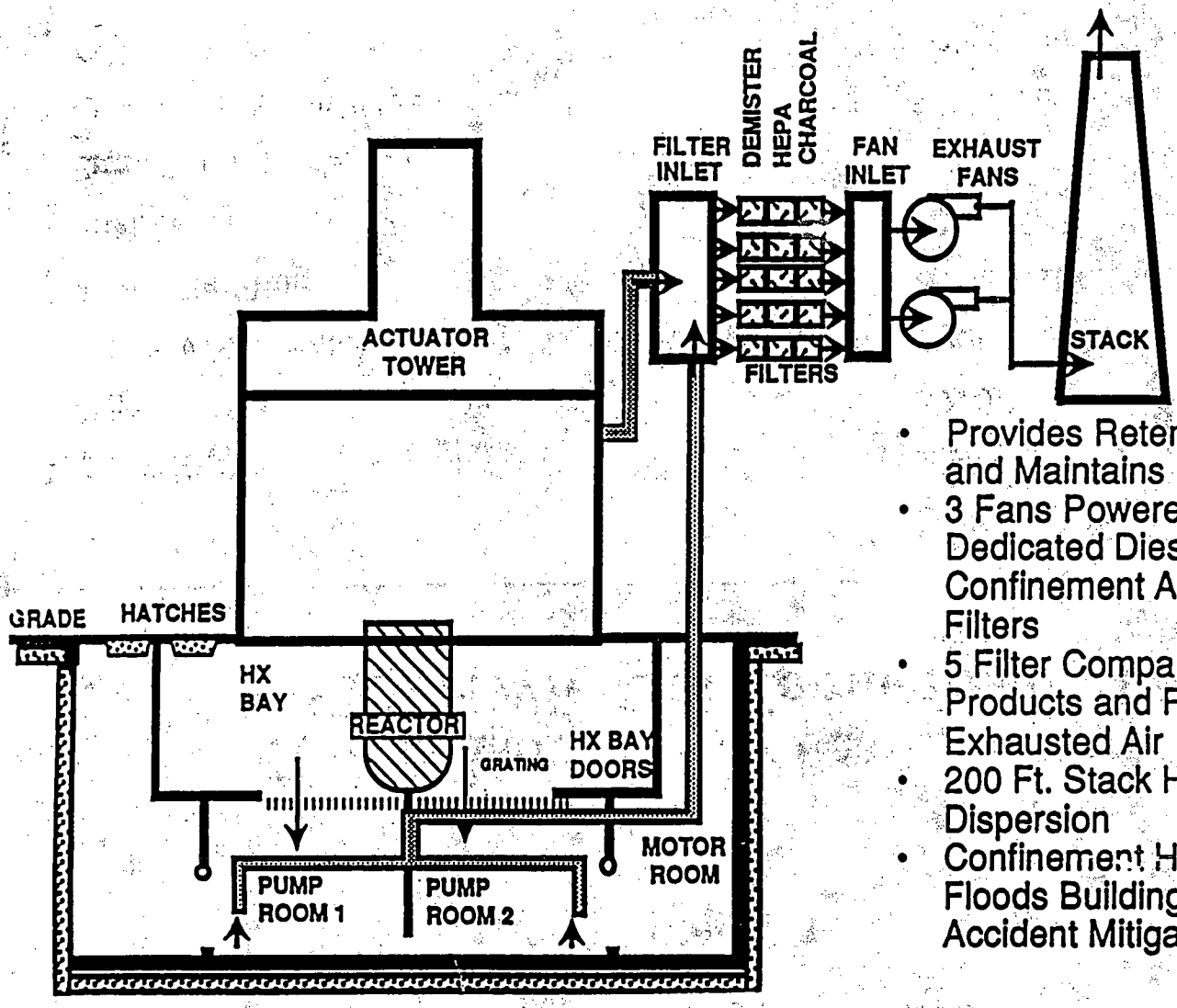


Figure 1. Typical Savannah River Fuel Assembly (Cross Section)

Figure 2

Reactor Building Barrier Airborne Activity Confinement System



- Provides Retention Of Fission Products and Maintains Integrity Of Confinement.
- 3 Fans Powered By Normal AC With Dedicated Diesel Backup Ensures Confinement Airflow Exhausted Through Filters
- 5 Filter Compartments Remove Fission Products and Particulates From Exhausted Air
- 200 Ft. Stack Height Enhances Dispersion
- Confinement Heat Removal System Floods Building Floor For Severe Accident Mitigation

Figure 3

Comparison of Key Features Between SRS HWR And Commercial PWR

Parameter	SRS K Reactor	PWR
Power (MWth)	≤ 720	3293
Primary/Secondary Cooling	D2O / H2O	H2O / H2O
Fuel - Cladding	U/Al - Al Alloy	UO_2 - Zircaloy
Fuel Centerline to Surface Temp. (deg C)	~80	590 - 288
Operating Pressure (psi)	5 (Blanket gas) 220 (@ Primary Water System Pumps)	2250
Reactor Spray System	Unbuffered	Buffered
Outer Fission Product Boundary	Confinement System	Containment

Figure 4

SRS PRA & Severe Accident Programs Have Led To NUREG-1150 Basis Source Term

- Accounts For Fuel & Cladding Behavior During Severe Accidents
- Includes Tritium In Source Term
- Defines Frequency-Magnitude Spectra Of Fission Product Release From SRS K Reactor During Severe Accident Scenarios
- Phases Are Markedly Different From Revised Source Term:

Revised Source Term

Commercial LWR	SRS K Reactor
Coolant Activity Release	Early Vessel Release
Gap Activity Release	Debris Heat-Up
Early In-Vessel Release	Vessel Failure
Ex-Vessel Release	Core-Concrete Interaction
Late In-Vessel Release	Delayed Release

- PRA Analysis "Walks" Scenario Through Release Phases, Applies Decontamination Factors And Determines Environmental Release

REVISED ACCIDENT SOURCE TERMS AND CONTROL ROOM HABITABILITY

Mini paper presented as part of
PANEL SESSION: PROPOSED SOURCE TERM REVISIONS -
POTENTIAL IMPACT ON FUTURE NUCLEAR AIR CLEANING REQUIREMENTS

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Abstract

In April 1992, the NRC staff presented to the Commissioners the draft NUREG "Revised Accident Source Terms for Light-Water Nuclear Power Plants." This document is the culmination of more than ten years of NRC-sponsored research and represents the first change in the NRC's position on source terms since TID-14844 was issued in 1962. The purpose of this paper is to investigate the impact of the revised source terms on the current approach to analyzing control room habitability as required by 10 CFR 50. Sample calculations are presented that identify aspects of the model requiring clarification before the implementation of the revised source terms.

I. Introduction

This year, 1992, marks the 50th anniversary of the first sustained nuclear reaction in the pile at the University of Chicago's Stagg Field. This year also marks the 30th anniversary of the publication TID-14844.[1] Since its inception, TID-14844 has served as the design basis source term for radiological assessments supporting the licensing of nuclear power plants in the U.S. The conservative TID-14844 model assumes that 100% of the noble gases and 50% of the iodines are instantaneously released to the containment and are available for leakage to the environment. TID-14844 is formally embodied in the U.S. Nuclear Regulatory Commission's (NRC) "Rules and Regulations," Title 10 of the Code of Federal Regulations,[2] in Parts 100 (siting) and 50 (review of control room habitability). TID-14844 is also embodied in a host of NRC Regulatory Guides and NUREG reports that address offsite consequences of releases of radioactivity and other postaccident radiological concerns.

The accident at Three Mile Island Unit 2 (TMI-2) in March 1979 spawned many NRC- and industry-funded efforts to better quantify accident scenarios, accompanying source terms, and their radiological consequences. Although the TMI-2 event itself demonstrated that an accident scenario does not cause instantaneous release of radioactivity to the containment as postulated by TID-14844, the industry was mandated to continue all licensing-related radiological assessments using the TID-14844 model.

On April 20, 1992, the NRC staff presented to the NRC Commissioners the draft of "Revised Accident Source Terms for Light-Water Nuclear Power Plants." This effort is documented in SECY-92-127[3] and provides us with the first official source term position of the NRC. The revised

source term will affect many aspects of nuclear power plant design and operation, including offsite doses, emergency planning, equipment qualification and engineered safety feature (ESF) equipment operation. The purpose of this paper is limited to a review of the changes embodied in the revised accident source terms and an investigation of the effect of these changes on the evaluation of control room habitability. In addition, we will look at the impact of the revised accident source terms on the current habitability model to identify areas requiring additional clarification.

II. The Revised Accident Source Terms

Although the revised accident source terms described in SECY-92-127 are still subject to modification, two fundamental changes are immediately evident. First, rather than using the instantaneous release of the TID-14844 model, the revised source terms have a more realistically timed release over the various stages of the accident scenario - coolant release, gap release, and subsequent core melt. This has an immediate impact on the timing of containment isolation, and the actuation and operation of ESF equipment. Second, SECY-92-127 acknowledges that most of the iodine released from the core is in the form of cesium iodide (CsI) and remains in solution, provided the postaccident pH of the containment sump water is greater than seven. This part of the model will affect the presently required containment spray systems, ESF iodine removal (charcoal) systems, and control room habitability systems. A summary of the PWR version of these source terms are given in Table 1. The TID-14844 source terms are also included in Table 1 for comparison.

Table 1 LOCA source terms - fractions of core inventory released to containment.

	TID-14844	SECY-92-127 (PWR releases)			
		Gap Release	Early In-Vessel	Ex-Vessel	Late In-Vessel
Duration, Hr	0	.5	1.3	2.	10.
Noble Gases	1.	.05	.95	0	0
Iodine	.5	.05	.35	.29	.07
Cesium	.01	.05	.25	.39	.06
Tellurium	.01	0	.15	.29	.025
Strontium	.01	0	.03	.12	0
Barium	.01	0	.04	.10	0
Ruthenium	.01	0	.008	.004	0
Cerium	.01	0	.01	.02	0
Lanthanum	.01	0	.002	.015	0

The instantaneous source terms in TID-14844, which represented the best information available in 1962, provided the basis for a deterministic method to estimate the bounding impact of a loss-of-coolant accident (LOCA). This deterministic approach modeled fission product transport and provided the means for plant designs and operating conditions to be rapidly and consistently evaluated for their impact on accident consequences. The revised source terms are derived from detailed, probabilistic studies of current plant designs and represent the best available information today. A revised deterministic method for analyzing a LOCA will have to be developed, however, to incorporate the time-dependent source term into the fission product transport models used to produce upper bound estimates of the accident consequences. Although transport models are still under investigation, SECY-92-127 implies the basic approach in use today will continue to be applicable when the revised source terms are applied.

III. The Control Room Habitability Model

The design basis accident for control room habitability is normally the loss-of-coolant accident. The assumptions used for determining the release from a PWR containment following this accident are described in Regulatory Guide 1.4[4], which is based on TID-14844. Regulatory Guide 1.4 specifies that 25% of the core inventory of iodine and 100% of the noble gases are immediately available for leakage from the containment. This is the same as TID-14844 with the additional assumption that half of the iodine plates out on interior containment surfaces. Regulatory Guide 1.4 also specifies that 91% of the iodine is elemental, 5% particulate, and 4% organic.

Additional guidance on modeling the effect of containment sprays is provided in Standard Review Plan (SRP) 6.5.2[5]. Credit can be taken for the removal of elemental iodine by sprays and plateout until a maximum decontamination factor of 200 is reached. Credit may also be taken for removal of particulates by the spray, but removal of organic iodines is generally not allowed without additional justification.

The effectiveness of the control room habitability system is normally evaluated using the procedure from the famous Murphy-Campe paper[6]. This paper provides the methodology needed to model the transport of the source terms to the control room, the effect of HVAC systems, and the calculation of the dose to the control room operators.

To demonstrate the impact of the new source terms, a PWR control room of Murphy-Campe type A design (isolation with filtered pressurization) was analyzed using the current methodology. This analysis considered a control room with substantial unfiltered inleakage, which resulted in a marginally acceptable habitability system. Because of the small margin, any degradation of the HVAC system could result in a shutdown of the plant. A summary of the data used in the analysis is provided in Table 2.

The same design was then analyzed using the revised accident source terms. Because of the lack of guidance on the in-containment transport for the new source terms, the present calculation assumed that the 5% elemental fraction was airborne as soon as it was released and was subjected to removal by containment spray and plateout. The remaining activity stayed in solution. A decontamination factor of 200 for the

Table 2 Control room habitability system design parameters.

Parameter Description	Value
Containment Building	
Volume	2.75×10^6 ft^3
Leak Rate	
0-1 day	0.1% per day
1-30 day	0.05% per day
Spray Removal Rates	
Elemental I	20 per hr
Particulate I	10 per hr*
Organic I	0.07 per hr
Elemental I Plateout Rate	2.4 per hr
Atmospheric Dispersion (Chi/Q)	
0 - 8 hr	3.5×10^{-3} sec/m^3
8 -24 hr	2.0×10^{-3} sec/m^3
1 - 4 day	1.3×10^{-3} sec/m^3
4 - 30 day	5.7×10^{-4} sec/m^3
Control Room	
Volume	1.2×10^5 ft^3
HVAC Makeup Rate	1600 cfm
Makeup Filter Efficiency	99%
Unfiltered Inleakage Rate	140 cfm

*Particulate removal rate is reduced to 1 per hr after a decontamination factor of 50 is reached.

spray system was implemented by defining it as the ratio of the amount of elemental iodine in the liquid to the amount of elemental iodine in the containment atmosphere. This allowed credit to be taken for spray removal throughout the phased release as long as the spray system was operating.

The results of the two control room analyses are shown in Table 3. The control room thyroid dose calculated using the revised accident source term and continuous spray operation is substantially below the value calculated using the current model. The primary reason for the large difference in the thyroid dose is a combination of a smaller airborne fraction (5% compared with 25%) and the treatment of all the iodine as elemental. Doses calculated based on Regulatory Guide 1.4 and Murphy-Campe are dominated by the organic iodines that are relatively unaffected by the containment sprays. The whole body and beta skin doses, which are primarily caused by noble gas activity, are slightly

smaller for the revised source terms. This is because of the smaller amount of activity available for release early in the accident, when the meteorological and containment leakage conditions are the worst and when relatively short-lived nuclides are available for leakage.

Table 3 Comparison of control room doses based on TID-14844 and the revised source terms.

Source Term Model*	Thyroid Dose, rem	Whole Body Dose, rem	Beta Skin Dose, rem
TID-14844	28.8	0.3	4.1
SECY-92-127	1.5	0.3	3.5
GDC-19 Dose Limits	30	5	30

*Based on the parameters in Table 2 and continuous operation of the spray system during the accident.

IV. New Issues in Control Room Habitability

The phased release affects several aspects of the current model, including removal mechanisms for gaseous species of iodine in containment, the behavior of aerosols, and the timing of worst case dose parameters such as atmospheric dispersion (Chi/Q) and control room occupancy factors. In addition, the commitment for availability of ESF systems may have to change to accommodate the revised source terms.

To illustrate one aspect, note that the results presented in Table 3 are based on continuous operation of the spray system over the entire (11.8-hour) release period. Typically, spray systems are designed to actuate automatically, to inject into containment liquid stored in an external tank and, when the tank is empty, to recirculate water from the containment sump to the spray header. The injection phase of containment spray is typically less than one hour, and the SRP 6.5.2 acceptance criterion for the operating period of the spray is only two hours. As shown in Table 4, if the spray period is reduced to two hours after the start of the injection phase, the thyroid dose rises to 56 rem, which exceeds the regulatory limit. If the spray is shut off at the end of the injection phase (1 hour), the thyroid dose rises to more than 100 rem. Clearly, an alternative method for modeling the iodine transport is required if the commitment for operating the spray system is not to be extended to many hours or days.

One alternative is to assume that plateout of the elemental iodine occurs regardless of whether the spray system is operating. This seems reasonable since plateout is a bulk transfer process, and the containment walls will remain wet regardless of the operating condition of the spray system. Using a continuous plateout rate and spray shutoff at the end of the injection phase results in a thyroid dose of 2 rem (Table 4), still considerably less than the dose resulting from the SRP 6.5.2 model.

Table 4 Effect of containment spray operating period on control room doses (revised source terms).

Containment Spray Operating Period	Thyroid Dose, rem	Whole Body Dose, rem	Beta Skin Dose, rem
Continuous Spray	1.5	0.3	3.5
2-Hour Spray	56.2	0.3	3.5
Injection Only	105.5	0.3	3.5
2-Hour Spray, Continuous Plateout	2.0	0.3	3.5
GDC-19 Dose Limits	30	5	30

V. Summary

This paper has demonstrated the integration of the revised source terms into the traditional, deterministic approach to analyzing control room habitability. A sample calculation indicates a phased release and a small elemental iodine fraction can substantially reduce the calculated dose to the control room operators. However, the calculated doses are very sensitive to assumptions concerning ESF operation and removal mechanisms for fission products. New assumptions concerning fission product transport need to be identified and incorporated into a control room habitability model that will be a worthy successor to Murphy-Campe.

VI. References

1. DiNunno, J. J., Baker, R. E., Anderson, F. D., and Waterfield, R.L., "Calculation of Distance Factors for Power and Test Reactor Sites," U.S. Atomic Energy Commission, TID-14844, March 1962.

2. U.S. Nuclear Regulatory Commission, "Rules and Regulations," Title 10 - Chapter 1, Code of Federal Regulations.

3. USNRC, Memo from James M. Taylor to the Commissioners, "Revised Accident Source Terms for Light-Water Nuclear Power Plants," SECY-92-127, April 10, 1992. (Also, draft NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants.")

4. USNRC, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors," Regulatory Guide 1.4, Revision 2, June 1974.

5. USNRC Standard Review Plan, Section 6.5.2, "Containment Spray as a Fission Product Cleanup System," NUREG-0800, Rev. 2, December 1988.

6. Murphy, K. G. and Campe, K. M., "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19," 13th AEC Air Cleaning Conference, August 1974.

DISCUSSION

SOFFER: I would like to make a rebuttal to several points raise by my esteemed colleague, Mr. Kovach. First of all, you stated that the primary impact of the source term is on a revised iodine chemical form. While that is important, it is by no means the only one. You kind of contradicted yourself when, later in your remarks, you pointed out the increased aerosol loading on particulate filters and what effect this might have.

A second quarrel that I have is that, you have stated that the NRC has quoted the organic iodine content to two decimal places, 2.85% for particulate and 0.15%, I believe you said, for organic. Unfortunately, you are confusing the EPRI proposed source term with the NRC proposed source term. We have not stated elemental iodine or organic iodine in those precise terms. What we stated is that the chemical form of iodine entering containment would be 95% cesium iodide and the remaining 5% would be either in elemental or HI form.

We have also acknowledged that organic iodide would be formed as a result of any elemental iodine that is generated in the containment.

KOVACH: SECY 92-127, Table 10, enclosure 2, which is part of the document, cites 2.85% elemental and 0.15 organic.

SOFFER: That is the EPRI evolutionary ALWR, licensing source term.

KOVACH: This is an actual enclosure to the second listing.

SOFFER: That is not the NRC source term. There may be confusion but that is not what we stated. That is what EPRI has proposed. We are not accepting it and we haven't stated it quite that way.

HAYES: I would like the panel to consider the evaluation as we have it now in TID-14844, to be really very simplistic. You immediately assume that the TID source term is released into the containment. The ESF ventilation systems operate on that source term, and then we calculate both the offsite consequences to the population and to the maximum individual. We also calculate control room operator doses. With the new source term, in many cases, we may be very accident specific in terms of scenario. So, it is very important when a particular part of the accident scenario occurs, such as core concrete interactions and when sprays operate. I wish the panel would comment on how they believe these uncertainties would effect a) their calculations, and b) determining operability. The reason I raise this is because of the information presented by Mr. Schwartz. It appears that, depending upon what type of assumptions you make, you can get an extreme range of doses in the control room, from 1 to 100 rem to the thyroid. It appears to be very important to be able to define the scenario. The question is, are we going to infringe both upon the NRC staff and upon the licensee in terms of defining these scenarios. In terms of operability, as many of you who operate power plants know, there is a continual question when certain equipment comes down. In other words, whether or not we continue to operate. Once again, we get into a situation where we have to make sure that we have defined the various scenarios associated with the operability or degradation of a particular piece of equipment.

VANPELT: My first thought is operability because that is the area we have dealt with in more of a crises mode. I understand your concern that there is a spectrum of accidents whereas we had one set of rules to follow as we went through all of them with particular reference to duration of release. Certainly, your exclusionary boundary dose, will be your limiting dose, but if you pick

scenarios that have most of your release in two hours, you are certainly benefitting yourself a whole lot, but not necessarily being safe. As we see operability and things like that, we would probably be running the spectrum of accidents specific to the equipment in question and trying to assure that in all cases it would be okay. As far as taking equipment out of service, as I understand it, the initial time period before there is a core melt is a big concern because the release prior to that could, potentially, occur without a lot of the equipment that we couldn't be without after core melt began. So, we would like to take advantage of that period for doing maintenance and getting leeway to have systems in maintenance.

SCHWARTZ: As a preparer of calculations to be reviewed by the Commission, I see this as a first step. As it evolves into guidance, there will be documents equivalent to a standard review plan or a guidance document that will describe calculational methodologies that are acceptable for the industry to use for EAB-LPZ and control room calculations to make sure we operate under the same ground rules as preparers and regulators and users of this type of information.

SOFFER: Mr. Schwartz said that he saw this as the first step and that there was a need for additional guidance. I would say that is probably correct. Mr. Schwartz's analysis showed that control room doses, for example, were quite sensitive to the performance of engineered safety features and removal mechanisms. One of the things that we are continuing to work on (and we hope to have additional information in the final source term document) is a better discussion of fission product removal mechanisms. We are presently working with contractor assistance to evaluate things like sprays, suppression pools, and water depths overlying molten core debris to try to get some more realistic understanding of what impact they would have in fission product removal. Obviously, they will make a significant difference in actual doses. There are a couple of points of clarification. I think we are still operating under an old mentality. We are not going to be calculating exclusion area doses and doses at the LPZ anymore. If the proposed revisions to the reactor siting criteria come along as we expect, the exclusion area will be determined without a dose calculation. There will still be a need for dose calculations in areas like equipment qualification and control room habitability. They will be, of course, dependent not only upon the source term, but on the removal mechanisms that the plant will have.

PORCO: Dr. Kovach, you mentioned changes to prefiltration, and one of the things you suggested is using the moisture separator as a prefilter. I think the ASHRAE efficiency for the moisture separator is about 35%. Aren't you concerned about the dust holding capacity of the filter? What changes would you foresee for the other ASHRAE filters; in other words, what changes in prefilters would you expect to see? Keep in mind that ASHRAE filters have glass media like the HEPAs.

KOVACH: To answer both this question and an earlier one concerning how a change in iodine concentration will affect the challenge in particulates, I am concerned about the source term with a change in iodine forms. That doesn't create an extra challenge for existing air cleaning systems because we are already handling much higher levels of assumed organic forms of iodine based on the existing source term. The best way that I can describe the problem I have is to give you an example involving so-called prefilters. In some cases, people have containment coolers with prefilters ahead of them to protect the containment cooler from the dust associated with normal operation. The prefilters probably do it very well. However, when the accident we are now proposing occurs with a very high coating of a hygroscope aerosol on the prefilters, most likely the coating will either block flow or blow into the coils of the cooling system. These prefilters are not going to perform the way we expect them to. Therefore, I think we have to look at both the structure and loading capability of prefilters to see how much mass they can hold under these hygroscopic conditions. Will they fail or not? Currently, we don't have a test requirement, a

surveillance test, or anything similar for prefilters or some of the less structurally sound moisture separators. I am not talking about the Savannah River type unit that is probably one of the best moisture separators, we have. I am talking about some of the less strong units. I think we have put these prefilters and moisture separators into systems with the idea that they will protect the HEPA filter and the adsorber from droplets and dust. I think we have to reexamine that idea because for very large challenges, the first item in the filter system will be these same prefilters and moisture separators.

HYDER: I just want to mention in this context, that there was a paper this morning by Klassen and Novick on the performance of one type of moisture separator used as a prefilter and the combined performance of moisture separators ahead of HEPA filters.

KUMAR: Mr. Schwartz, regarding your calculations of the cumulative 30-day dose to control room operators, are they made with or without the ESF operating?

SCHWARTZ: They are 30-day doses for containments containing a leak. They are 30-day dose numbers calculated for various combinations of spray and plateout scenarios.

KUMAR: Is the control room emergency ventilation system operating during all that time?

SCHWARTZ: Yes, it is operating at 1600 cfm makeup air with 140 cfm unfiltered in-leakage.

KUMAR: That means the result will depend upon the particular plant, because we restrict intake quite a bit.

WEIDLER: Mr. Scholten would you care to present a perspective on the source term issue from the European viewpoint?

CLOSING COMMENTS OF PANEL MEMBER SOFFER

We heard from a number of speakers; Mr. Vanpelt provided a utility perspective and indicated that the new source term provided a significant number of potential opportunities to look at accidents in a more realistic way and that our present systems were, he felt, slanted towards an unrealistic view of accidents. The new source term provides an opportunity for improved maintenance. He felt that the emphasis was shifting towards HEPA filters and away from charcoal filters. However, he also indicated that there was a potential for questions regarding equipment qualification, especially in a post-accident liquids and post-accident shielding environment, and that there were many practical aspects that needed to be explored to begin to take advantage of this source term insight.

Mr. Kovach then provided some remarks and questions concerning iodine chemical form. He felt that the specification of iodine chemistry to two significant figures was unrealistic. He also felt that there was the potential for large generation of organic compounds and that the specification of iodine chemistry in a pure environment was completely unrealistic considering the large and diverse number of chemical reactions that could and will take place in containment in a post-accident environment.

Mr. Hyder then discussed the new source term in relation to severe accident research that is presently underway at the K reactor in Savannah River. He indicated that there was a revised analysis of severe accidents that was being performed for the K reactor. As a result of this and as a result of EPA studies, they have developed new source terms for the K reactor and he was pleased that the NRC had developed source terms by proceeding along the same type of methodology, same approach.

Mr. Schwartz from Sargent and Lundy then looked at a potential application of new source terms with regard to control room habitability and indicated that the new source terms appeared to reduce thyroid doses significantly. However he indicated a number of factors that seemed to be quite important such as the effect of spray duration and that the doses that resulted were very sensitive to removal mechanisms.

There was then a discussion period. A number of the points that were brought up were a rebuttal by Mr. Soffer saying that the specification by NRC of iodine chemistry to two significant figures was not correct, but that these were part of an EPRI proposed formulation. There were discussions about how one would use equipment operability in regard to this kind of a source term. Others indicated that they saw this as a first step and that implementing guidance was required to be followed. It was pointed out that additional work on removal mechanisms was taking place.

Mr. Kovach pointed out, for example, that in regard to those installations using containment fan coolers the prefilters and moisture separators were likely to undergo a severe challenge from the particulate loading. This was an area that needed considerable examination.

Finally, there was a discussion from Mr. Scholten from the European Community who talked about efforts underway in Holland with regard to containment venting and the effects that filtering would have upon reducing the source term associated with this.

KOVACH: Reviewing the basis of the source term, it appears that the principal investigators who were involved in the various studies only considered organic iodide formation from elemental iodine. They did not consider organic iodide formation from cesium iodide. I think that this probably accounts for significant differences in the theories that people are willing to accept.

SOFFER: It is true that the investigators that were working on this, primarily at Oak Ridge, regarded the formation of organic iodide to be principally from elemental iodine. That is true, and I think that is a worthwhile comment.

EFFECT OF FILTERING AT CONTAINMENT VENTING ON THE CONSEQUENCES FOR THE ENVIRONMENT

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Abstract

Containment venting is considered in many countries as an option to avoid an uncontrolled release of radioactivity due to containment rupture in the case of a severe reactor accident. The source term is reduced by filtering the vented gases and so the consequences are mitigated further.

In this study the benefits of filtering are assessed by calculating the consequences of a release with and without a filter. The results show that with a filtered release the consequences for the environment remain below the intervention levels applied in the Netherlands, except those for land contamination with iodine.

I. Introduction

The Dutch Nuclear Inspectorate has asked the nuclear power plants to consider the installation of a filtered containment venting system (FCVS) to mitigate the consequences of an uncontrollable core-melt accident. The objective is:
" releases, if they cannot be avoided, to be limited in such a way that short-term countermeasures for the population will not be necessary and no extensive nor long-term contamination of land or surface water will arise."
This objective will be achieved if:

- the potential 24-hour dose to an individual is less than:
  - effective dose: 5 mSv
  - thyroid dose: 50 mSv
- surface contamination is less than:

I-total	5 kBq/m2
Cs-137	2.8 MBq/m2
Cs-134	4.4 MBq/m2
Sr-90	4.7 MBq/m2
Pu-total	2.8 GBq/m2

The consequences were calculated with the European ACA-code COSYMA[1,2]

II. Source term

The consequences were calculated for the environment of the Borssele NPP. This is a PWR of 450 MWe of a German design which has been in operation since 1973. To calculate the consequences of a scenario with a filtered release, a relevant source term has to be considered. At the moment a level-2 PSA for the Borssele NPP was not available, so an appropriate source term has to be established. Some

American risk analyses on comparable reactor types were used to choose a source term. [3,4,5,6] To calculate the benefits of venting, only those accident scenarios need to be considered for which venting is an option to mitigate the accident. In about 90% of the accident scenarios described venting is not necessary, since they do not lead to containment rupture. From the remainder the S3C scenario for the Seabrook plant was considered relevant for the purpose of this study. By filtering during the venting the source term is reduced. This leads to a source term according to table 1.

Table 1 Representative source term*

	no filter	with filter**
Xe - Kr	1	1
I	5.10^{-3} ***	3.10^{-4}
Cs - Rb	5.10^{-3}	5.10^{-6}
Te - Sb	3.10^{-2}	3.10^{-5}
Ba - Sr	5.10^{-4}	5.10^{-7}
metals	5.10^{-4}	5.10^{-7}
La - act.	5.10^{-5}	5.10^{-8}

* in fractions of core content

** decontamination factors DF= 1 for noble gases
DF= 10^3 for aerosols
DF= 10 for I_2
DF= 1 for CH_3I

*** 38% elemantary (I_2)
2% organic (CH_3I)
60% aerosol-bound

The decontamination factors given in Table 1 are a factor 10 lower than specified for the filter (except for the noble gases). This leads to conservatism in the consequence calculations. Furthermore an indication of the sensitivity of the results to filter efficiency is obtained.

The source term from Table 1 is reasonably comparable with the source term from the risk analysis by GRS for the Biblis-B plant.[7] Apart from the power the Bilblis-B plant is of the same design as the Borssele plant.

The partition of iodine release in elemental, organic and aerosol bound fractions is quite uncertain. Proposed figures for the US has been given by Soffer at this conference.[8] Figures for European countries are given in Table 2, which is taken from an international comparison exercise.[9] There is hardly any consensus. Therefore an extra sensivity analysis is performed for this point.

Table 2 Assumptions of the partition of released iodine in several member states [9]

	B	F	I	E	GB
molecular	0.91	0.9	0.495	0.91	0.000
organic	0.04	0.1	0.010	0.04	0.002
aerosol	0.05	0.0	0.495	0.05	0.998

III. COSYMA code

For the evaluation of the doses and ground contaminations in the environment, the probabilistic consequence assessment code COSYMA is used. This code was developed for the European Commission by KfK (Germany) and NRPB (UK). For the dispersion parameters σ_y and σ_z figures from the Dutch National Model [10] were used. Hourly data of weather conditions from 1982 and 1983 obtained at a nearby weather station were used as meteorological input. Stratified sampling will assure a well distributed selection of weather sequences out of the total spectrum of conditions, including extremes. For more details of the Code, see references 1 and 2.

IV. Results

Effective dose

Figure 1 presents the 95-percentile for the individual effective committed dose for exposure during the first 24 hour after the release as a function of distance. No countermeasures are taken into account. With the use of a filter a dose of 5 mSv, the postulated low intervention level for sheltering, will only be exceeded at distances shorter than 1 km. There are no people living within such a short distance. In extreme weather conditions the doses may be higher.

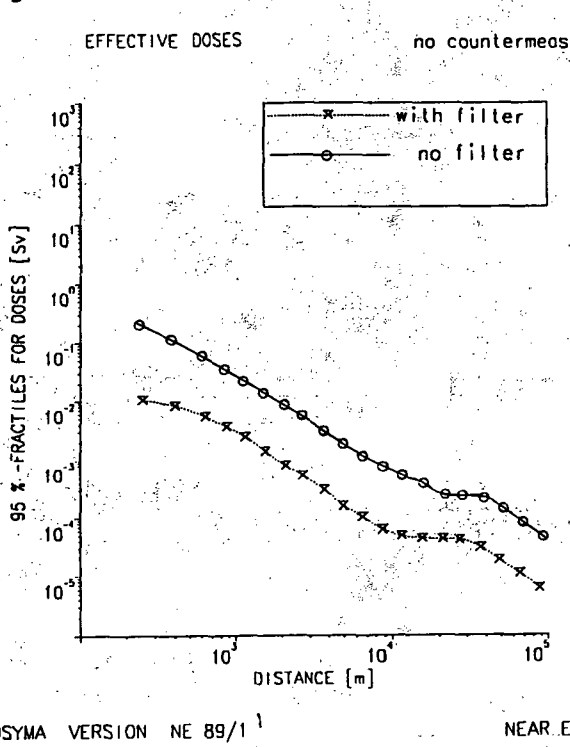

Figure 1 95%-fractiles for effective doses as function of distance from the plant

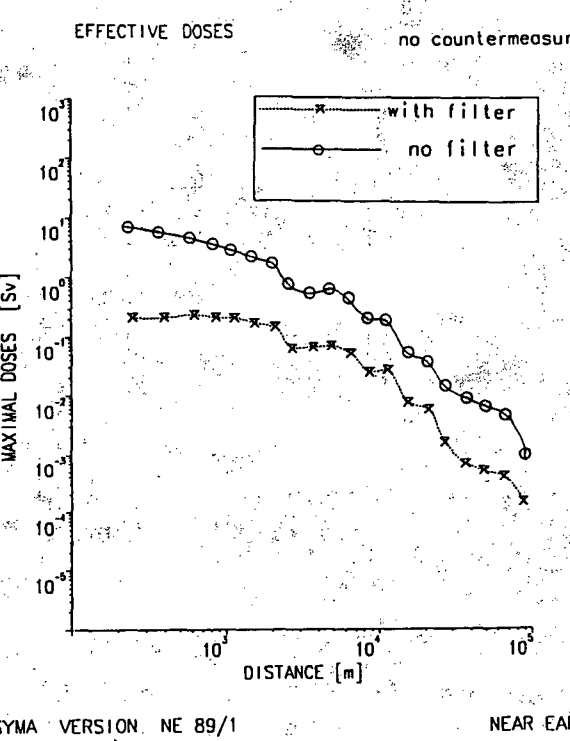

Figure 2 Maximum for effective doses as function of distance from the plant

Figure 2 shows the maximal expected doses under these circumstances. Without a filter the dose may increase to several sievert, a dose giving rise to severe non-stochastic injuries. With a filter, the dose will be at maximum 0.2 Sv at distances < 2 km; this is still a high dose, but it entails no risk of acute injuries. However, if the accident occurs, the probability of such a severe weather condition is lower than 10^{-4}.

Ground contamination

The CCFD for contamination without filtering for longer living, nuclides is given in Figure 3. The contaminated areas are quite small or absent in the case of Pu. If the release is filtered, no contamination levels will be exceeded at all.

In Figure 4 the CCFD for ground contamination with I-131 is given for release with and without filter. Despite the filter, still a substantial area is contaminated with I-131 above the intervention level for grazing. However, with the short half-life time of 8.05 days of I-131, the contamination vanishes within a few months.

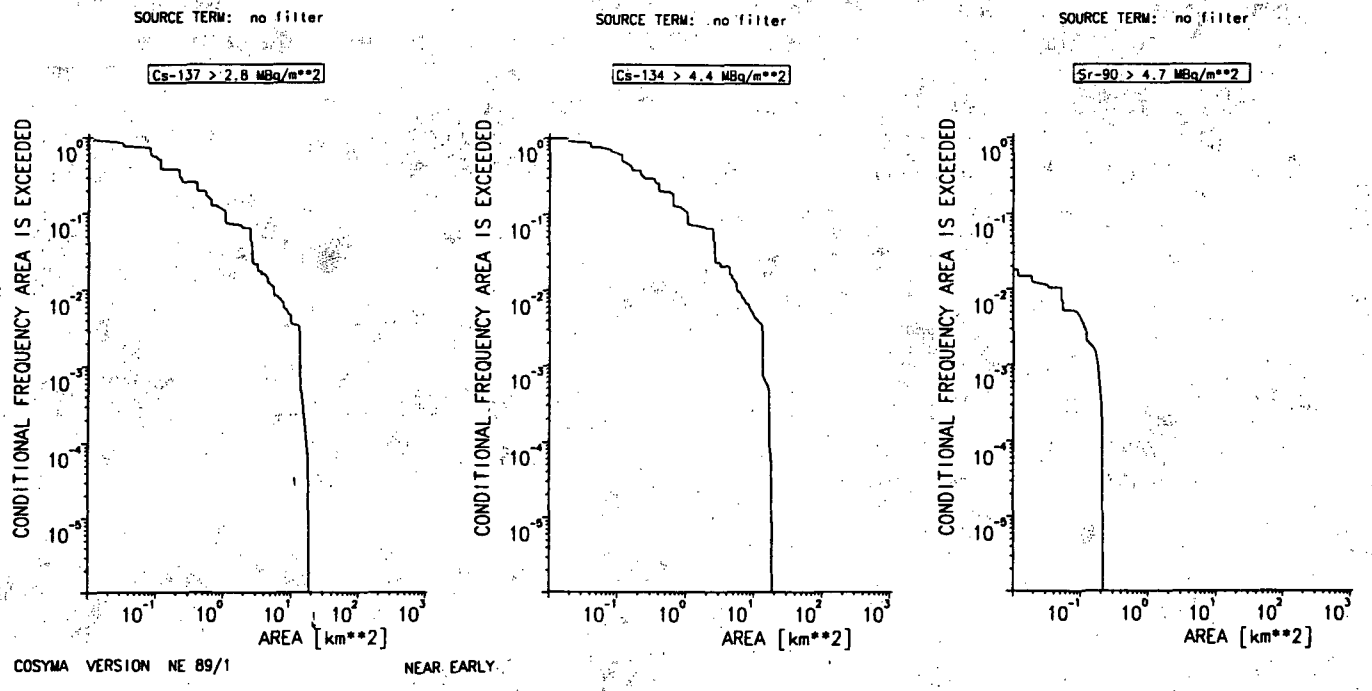

Figure 3 CCDF's for ground contaminations with long-living nuclides without the use of a filter

Effect of iodine species

A test was conducted on the sensivity of the results to the CH_3I content in the release. As the filter factor for this gas is set at unity in the calculations, a high sensivity can be expected. In Figure 5 the results are given for some percentages of CH_3I, expressed as fractions of total I-content in the core. The difference in doses between the highest and lowest fractions are about a factor 50. It can be concluded that the speciation of iodine plays a dominant role in the consequences of a filtered release. The capability of filters to retain organically bound iodine has to be considered.

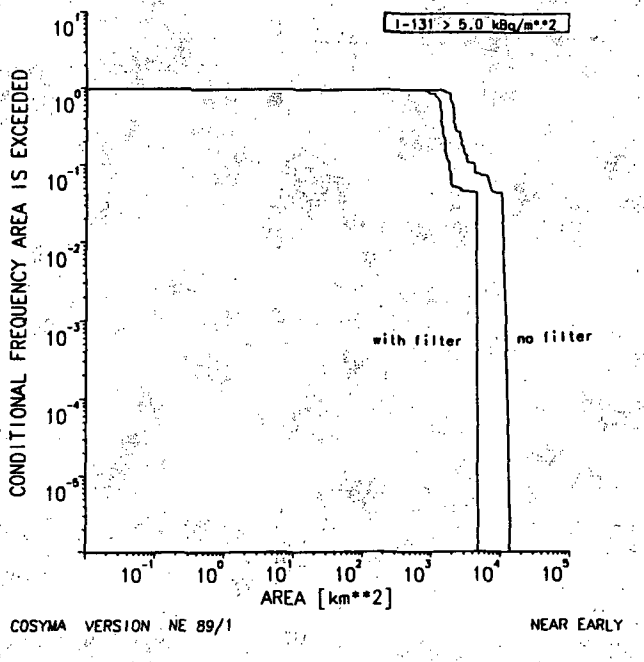

Figure 4 CCDF for contamination with I-131

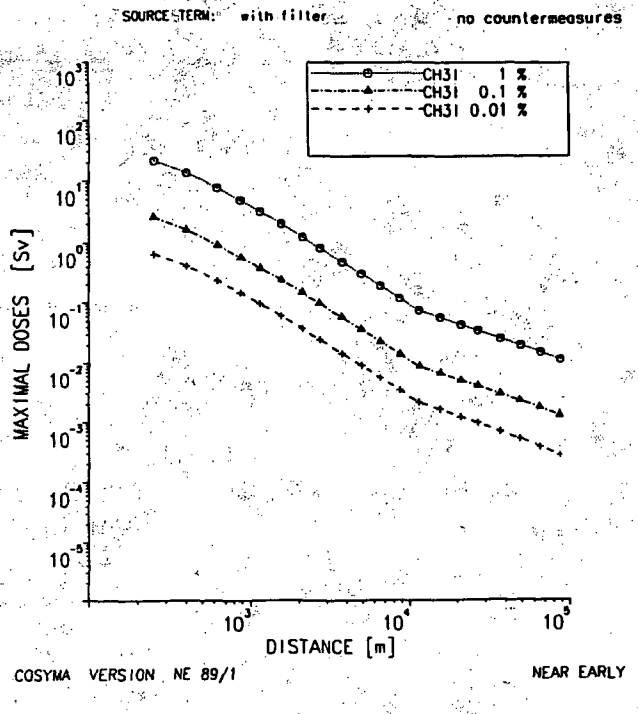

Figure 5 Influence of CH_3I as function of core content on thyroid dose

Influence of filter efficiency.

Inert gases are not filtered. The dose caused by the inert gases is therefore the same in filtered and unfiltered releases. However, in case of filtered venting, the dose will be governed by the inert gases. This is demonstrated in Figure 6. Increasing the efficiency of the venting filter will hardly lead to any more decrease of the dose. As stated before, we have conservatively supposed in our calculations that the filter efficiencies are a factor 10 lower than specified for the design. There is no reason to strive for higher efficiences for lowering the doses. Even the low figures used in the calculations should be acceptable. Only the areas contaminated with iodine might be decreased further.

V. CONCLUSIONS

From calculations performed with the probabilistic ACA-code COSYMA it is demonstrated that a venting filter is able to keep the doses in the environment below the intervention levels in most circumstances. Only in extreme weather conditions may the doses exceed these levels, but the probability of occurrence is very low.

The area contaminated with I-131 above the intervention level for grazing can be quite large, depending mainly on the filter efficiency for methyliodide. On the other hand, such contamination does not last very long. With filtering of a release the contamination with long living nuclides remains under the levels.

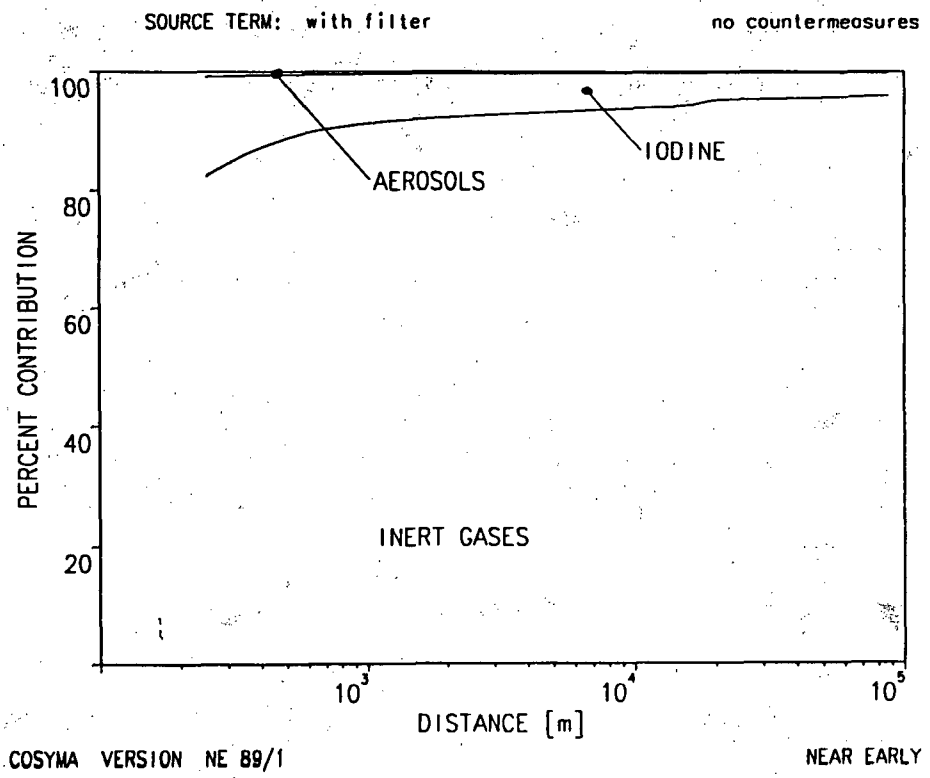

Figure 6 Relative contribution of nuclides groups to the effective dose

Acknowledgment

This study was performed under commission of Elektriciteits-Produktiemaatschappij Zuid-nederland, the owner of the nuclear power plant Borssele. The authors are very grateful for their permission for the publicing of the results.

REFERENCES

1 COSYMA, a new program package for accident consequence assesment. Commission of the European Communities, publication no. EUR 13028 EN, Brussels-Luxemburg, 1990.

2 COSYMA User Guide. Commission of the European Communities, publication no. EUR 13045 EN, Brussels-Luxemburg, 1990.

3 Seabrook Station Probabilistic Safety Assesment, Vol. 1 to 6, PICKARD, LOW and GARRRICK, INC., PLG-300, 1983.

4 Sizewell-B Probabilistic Safety Study, WCAP-1991, Rev.1, WESTINGHOUSE ELECTRIC CORPORATION, 1982.

5 Reactor Risk Reference Document, NUREG 1150
US Nuclear Regulatory Commission, Washington DC, 1987.

6 Severe Accident Risks - An Assesment for five US Nuclear Power Plants, US Nuclear Regulatory Commission, Washington DC, 1989.

7 Deutsche Risikostudie Kernkraftwerken, Phase B, GRS,Köln, 1990 (in German).

8 Soffer, L., Revision of Reactor Accident Source Term and Implications for Nuclear Air Cleaning Requirements. Proc. 22th Nuclear Air Cleaning and Treatment Conference, 1992.

9 Comparison exercise performed by the Commission of the European Communities of fission product source term within a licensing framework, Document WGI-88/P26, 1988.

10 Parameters in het lange-termijnmodel verspreiding luchtverontreiniging - nieuwe aanbeveling, TNO - Delft, 1984 (in Dutch).

SESSION 13

PANEL SESSION: CARBON TESTING

Thursday: August 27, 1992
Moderator: J. L. Kovach

Panel Members: J. R. Pearson
J. J. Hayes
C. F. Gill

OPENING COMMENTS OF PANEL MODERATOR KOVACH

RESPONSE OF NRC REGION III TO PERCEIVED LACK OF FILTER TESTING EXPERTISE CONCERNS
C.F. Gill

METHYL IODIDE TESTS ON USED ADSORBENTS
J.L. Kovach

PANEL DISCUSSION

CLOSING COMMENTS OF PANEL MODERATOR KOVACH

OPENING COMMENTS OF PANEL MODERATOR KOVACH

KOVACH: Panel members are Dr. Charles Gill, US NRC, Region III; Jack Hayes, US NRC, Headquarters; John Pearson, NCS Corporation

RESPONSE OF NRC REGION III TO PERCEIVED LACK OF FILTER TESTING EXPERTISE CONCERNS

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ABSTRACT

During the 21st (1990) DOE/NRC Nuclear Air Cleaning Conference, several papers, presentations and panel discussions raised concerns regarding the perceived lack of Nuclear Air Treatment System (NATS) filter testing expertise allegedly exhibited by some NRC licensees and inspectors. The NRC Region III responded to these concerns by significantly improving the filter testing training course and ensuring that appropriate Regional inspectors, their supervision and management attended the course. The extensive training program, improved inspections and resultant licensee corrective actions have significantly improved filter testing expertise and the quality of Region III licensee filter testing programs.

I. INTRODUCTION

Each year potentially generic technical deficiencies of significance to the nuclear industry are identified in technical journal articles and conference and professional society meeting papers. Once the NRC becomes aware of these reported deficiencies, the staff reviews each item and responds as deemed appropriate by management. The NRC staff's response mechanisms include: Generic Letters, Bulletins, Information Notices, Standard Review Plan (NUREG-0800) revisions, docketed Final Safety Analysis Report (FSAR) questions, special studies, special (reactive) inspections, and inspection and training program revisions. At the 19th (1986) Nuclear Air Cleaning Conference, a paper was presented regarding the reactive inspection response of the NRC Region III to potential technical deficiencies identified in the 17th (1982) and 18th (1984) Nuclear Air Cleaning Conference papers and proceedings.[1]

This paper deals with the response of the NRC Region III to potential technical deficiencies identified in recent Nuclear Air Cleaning Conference papers and proceedings. Specifically, during the 21st (1990) DOE/NRC Nuclear Air Cleaning Conference, several papers and panel discussions raised concerns regarding the perceived lack of Nuclear Air Treatment System (NATS) filter testing expertise allegedly exhibited by some NRC licensees and inspectors. These concerns and the status of the Regional response are discussed below.

The NATS filter testing implementation aspects relevant to this discussion are the in-place penetration tests [dioctyl phthalate (DOP) challenges to high-efficiency particulate air (HEPA) filters and refrigerant tracer gas ("Freon") challenges to impregnated activated charcoal (carbon) adsorbers] and laboratory penetration tests (radioactive methyl iodide challenges to carbon adsorber samples). Nuclear Power Plant (NPP) licensees are required by their plant-specific technical specifications (TS), periodically and under certain plant conditions, to test specified NATS filters to required acceptance criteria (testing protocols and penetration limits). The bases for the TS requirements are nominally Regulatory Guides (RG) [e.g., Revision 2 of RG 1.52[2] and Revision 1 of RG 1.140[3]] or industry consensus standards [e.g., ANSI/ASME N510-1989[4] and ANSI/ASTM D3803-1989[5]]. Licensee NATS TS are also voluntarily revised based on guidance presented in NRC Generic Letters (GL) [e.g., GL No. 83-13[6]], Information Notices (IN) [e.g., IN 86-76[7] and 87-32[8]], and NRC contractor reports [e.g., EGG-CS-7653[9], and NUREG/CR-4960[10]].

II. CONCERNS

During the 21st (1990) DOE/NRC Nuclear Air Cleaning Conference (NACC), several papers and panel discussions expressed concerns that apparently some NPP licensees and NRC inspectors lacked a significant depth of NATS filter testing expertise. The concerns expressed by four individuals are discussed in this paper. These specific expressions of concern were chosen because they are representative of those discussed during the conference and were presented by reputable NATS filter testing experts.

Fellow panel member and NRC employee, Jack Hayes, gave an excellent presentation entitled, "Changes in Adsorber Testing as a Result of NRC Generic Information," at the 21st NACC[11]. His paper was based on survey results received from a questionnaire he sent to NRC NPP licensees. The questionnaire dealt almost exclusively with laboratory methyl iodide testing protocols and penetration acceptance criteria for carbon adsorber samples. Among the NRC generic information documents referenced in the questionnaire were IN 87-32[8], "Deficiencies in the Testing of Nuclear-grade Activated Charcoal," and the companion NRC contractor report, EGG-CS-7653[9]. The results of the questionnaire study revealed that very few licensees had implemented the generic information and few were contemplating utilizing the information. The study also showed that the limited implementation was typically incomplete or incorrect.

During the 21st NACC Panel Session on ANSI/ASME N510 Testing, Louis Kovach had the following comments regarding the filter testing expertise of some NRC inspectors[12]: "Maybe we need to have better training given at the NRC Regions to bring all the inspectors up to some minimum understanding of what it is they are trying to enforce. It is my understanding that some training has been offered but it does not seem to be enough to assure good

quality NRC personnel at the sites in regard to indepth understanding of air cleaning issues."

Jack Jacox and Ray Weidler, also during the 21st NACC Panel Session on ANSI/ASME N510 Testing, noted a perceived lack of filter testing expertise among the NPP licensees[13]. It was stated that there were fewer and fewer NPP licensees willing to pay for expertise in HVAC systems, including filter testing.

Based on filter testing program weaknesses identified by NRC Region III inspectors, the above perceived lack of expertise was apparently a significant contributor to the general failure of the NPP industry to utilize the NRC generic information documents on HVAC systems and NATS filter testing. This failure was identified by the questionnaire survey conducted by Jack Hayes.[11]

This general lack of expertise among NPP licensees, as well as initially for some NRC inspectors, was readily apparent with regard to IN 87-32, "Deficiencies in the Testing of Nuclear-grade Activated Charcoal," and the companion NRC Contractor report, EGG-CS-7653. Many NPP licensees, as well as NRC inspectors, initially assumed that as long as the licensees used one of the two laboratories that met the acceptance criteria for methyl iodide penetration testing using the EG&G protocol, they had fully followed the Information Notice recommendations. Later inspections in Region III corrected these misconceptions. However, licensee misconceptions are not limited to methyl iodide testing. Inspections in Region III have also identified NPP licensee misconceptions regarding in-place NATS filter testing programs.

III. NRC REGION III RESPONSE TO CONCERNS

The NRC Region III realized that the above concerns expressed at the 21st NACC had some validity and proceeded to improve the filter testing training program for appropriate region-based inspectors. In the past two years, NRC Region III has expanded the one-day orientation filter testing course for NRC inspectors to a two-day comprehensive theory and practical factors course and completed the training for nearly all materials and reactor radiation protection inspectors, their supervisors and managers. It is now a formal course sponsored by the NRC Technical Training Center and available to all NRC personnel, including resident inspectors and NRR technical reviewers.

The inspectors' critiques of the course showed that it achieved its goal of providing a good basic understanding of filter testing sufficient to inspect this aspect of their licensees' programs. Because of this improved NRC training program and the resultant improved inspections, Louis Kovach's comments of two years ago about the quality of NRC inspectors in the area of filter testing is certainly no longer valid for Region III radiation protection inspectors.

Now that our region-based inspectors are better prepared to review licensees' filter testing programs, they routinely assess the technical expertise of NPP personnel who are responsible for ensuring that the filter testing program is correctly implemented. Section IV below discusses an effective program review technique that is available for use by NRC inspectors to ascertain if our licensees have any basic filter testing program requirement misconceptions.

IV. EFFECTIVE INSPECTION TECHNIQUE

The NRC core inspection procedures will assure that licensees have complied with their plant specific NATS filter testing TS requirements. Although these procedures will assure regulatory compliance, licensee misconceptions about filter testing requirements and regulatory guidance may still result in safety concerns.

Therefore, in addition to the line item core inspection procedure checklist for filter testing program implementation review, an overview technique may be used to ascertain if licensees have any basic filter testing program requirement misconceptions. The completion of the following six-item comparison list for what should be compatible aspects of the program is one possible method for identifying underlying safety concerns.

- Test Results
- TS Requirements
- Procedural Requirements
- Purchase Order Criteria
- Design Basis Removal (or Efficiency) Credit
- NRC Regulatory Guidance

If there are apparent discrepancies in the filter testing acceptance criteria stated in the above items, a potential exists for safety concerns that need resolution.

V. CONCLUSION

The NRC Region III responded to concerns expressed two years ago at the 21st NACC regarding perceived lack of filter testing expertise by some NPP licensees and NRC inspectors. The extensive NRC training program, improved inspections and resultant licensee corrective actions have significantly improved filter testing expertise and the quality of our NPP licensees' program implementation.

VI. REFERENCES

1. Gill, C. F., "Reactive Inspection Response of NRC Region III to Potential Technical Deficiencies Identified in Recent Nuclear Air Cleaning Conference Papers," Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0086, CONF-860820, Volume 1, Page 527 (August 1986).

2. U.S. Nuclear Regulatory Commission, "Design, Testing, and Maintenance Criteria for Post Accident Engineering-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants," Regulatory Guide 1.52, Revision 2 (1978).

3. U.S. Nuclear Regulatory Commission, "Design, Testing, and Maintenance Criteria for Normal Ventilation Exhaust System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants," Regulatory Guide 1.140, Revision 1 (1979).

4. American National Standard, "Testing of Nuclear Air-Cleaning Systems," ANSI/ASME N510-1989, The American Society of Mechanical Engineers (1989).

5. American National Standard, "Standard Test Method for Nuclear-Grade Activated Carbon," ANSI/ASTM D3803-1989, American Society for Testing and Materials (1990).

6. U.S. Nuclear Regulatory Commission (NRC) Generic Letter No. 83-13,"Clarification of Surveillance Requirements for HEPA Filters and Charcoal Adsorber Units in Standard Technical Specifications on ESF Cleanup Systems," issued to all applicants for operating licenses and holders of construction permits for nuclear power reactors on March 2, 1983.

7. U.S. Nuclear Regulatory Commission, "Problems Noted in Control Room Emergency Ventilation Systems," Information Notice No. 86-76 (1986).

8. U.S. Nuclear Regulatory Commission, "Deficiencies in the Testing of Nuclear-Grade Activated Charcoal," Information Notice No. 87-32 (1987).

9. Scarpellino, C. D. and Sill, C. W., "Final Technical Evaluation Report for the NRC/INEL Activated Carbon Testing Program," EGG-CS-7653 (1987).

10. Driscoll, J. W., "Control Room Habitability Survey of Licensed Commercial Nuclear Power Generating Stations," NUREG/CR-4960, ANL-87-22 (1987).

11. Hayes, John J., "Changes in Adsorber Testing as a Result of NRC Generic Information," Proceedings of the 21st DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0116, CONF-900813, Volume 2, Page 607 (August 1990).

12. Kovach, J. L., "Panel Discussion: How to Use N510 Testing Methods and Acceptance Criteria for Air Treatment Systems Not Constructed According to N509," Proceedings of the 21st DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0116, CONF-900813, Volume 1, Page 333 (August 1990).

13. Weidler, R. R. and J. W. Jacox, "Panel Discussion: How to Use

N510 Testing Methods and Acceptance Criteria for Air Treatment Systems Not Constructed According to N509," Proceedings of the 21st DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0116, CONF-900813, Volume 1, Pages 338 and 339 (August 1990).

DISCUSSION

DUBOIS: What percent of your resident inspectors get this special training, is it only the Region III and headquarters based inspectors?

GILL: Only the health physics staff at the Region III office have had the training at this time. A concerted effort has been made to make sure that all the health physics inspectors have had this training. The deputy director of our division is on the regional training council and he has been spearheading the effort to get people to take this course. He intends to have as many of our region's inspectors take this course as he can and to encourage other regional managers to support this effort. I hope this initiative becomes very widespread within the NRC.

METHYL IODIDE TESTS ON USED ADSORBENTS

J. L. Kovach
NUCON International, Inc.

Background

This Paper discusses the history of events leading to the current problems in radioiodine test conditions. These radioiodine tests are performed on the adsorbent media from both safety and non-safety related Nuclear Air Treatment Systems (NATS).

During the development of laboratory tests for radioactive methyl iodide removal efficiency of adsorbents at ORNL and later by the ASTM D28 Committee in the mid 1960's, three typical test parameter ranges were evaluated. These test conditions were selected to challenge the adsorbent at the various temperatures and humidity values which may occur in operation and presumed accident conditions of the nuclear power plant (NPP). The then selected temperature - humidity pairs were:

30°C	95% RH
80°C	70% RH
130°C	95% RH (DBA environment in containment)

which were incorporated into the original issue of the standard test procedure ASTM D3803-1979.

The early laboratory test assemblies used to perform these tests, had great difficulty in maintaining 95% RH (steam-air mixture) at 130°C due to test control problems. The test adsorbent samples were often flooded (supersaturated with water) during this test resulting in widely scattered radioactive methyl iodide removal efficiencies. On the basis of the initial preponderance of low efficiency results obtained at 130°C and 95% RH there may have been an initial presumption that the high temperature/high RH test was the "most severe" and, therefore, most conservative in evaluating the performance of the adsorbent. Based on this presumption, the 130°C, 95% RH test was prescribed by the NRC even for Main Control Room NATS methyl iodide removal efficiency tests which in an accident scenario would never be exposed to temperatures and relative humidities in this range.

Over the years as the test precision improved, it became clear that the performance of the adsorbent is, in fact, improved at high temperature and low RH and that the most conservative test is the low temperature-high RH (i.e. 30°C, 95% RH) test. This conclusion has been published in the open literature(1) and its findings have been accepted by both US and International experts in the field of adsorbent testing. ASTM D-3803 was revised in 1989 to reflect the more precise test protocol and conservative test parameters based on USNRC funded research at Idaho National Engineering Laboratory (INEL).(2)

When preparing specifications and purchase orders for the testing of used adsorbents, NPP personnel are not sure which ASTM D3803 (or ANSI/ASME N509 and N510) issue to use; in some cases they specify performance of multiple tests on the same sample to assure both a technical correctness based on current test procedures and a technical specification requirement based on outdated test protocols required by current issue of Reg. Guide 1.52. To further complicate matters, some NRC regions have requested NPP personnel to modify test parameters on a plant by plant basis.

Problem Statement and Discussion

Currently there are still numerous plant technical specifications for NATS which reference outdated test protocols for the surveillance testing of the radioactive methyl iodide performance of the adsorbents.

Additionally, it has been found that high temperature (≈130°C) pre-equilibration* of used adsorbent, in fact regenerates the carbon by stripping off the poisoning contaminants and results in a "false" high methyl iodide removal efficiency, while the same adsorbent shows much lower performance under low temperature test conditions.(4)

As an example, an adsorbent removed from a Nuclear Power Plant (NPP) Main Control Room NATS showed the following efficiencies when tested in the laboratory under the various test conditions.(3)

Temperature of Test	RH %	$CH_3{}^{131}I$ Efficiency % Sample #1	Sample #2
30°C	95	33.79	37.37
80°C	95	60.45	--
130°C	95	99.87	98.34

These test data, which are typical, (4) clearly show that the most conservative test for testing methyl iodide removal efficiency is the low temperature, (i.e. 30°C) test.

The performance of the test at 95% RH requires a very precise control of the relative humidity by the laboratory apparatus controls. The test series performed at INEL(2) concluded that the original ASTM D3803-79 temperature and relative humidity tolerances were too wide. As an example, the originally permitted ± 2% RH tolerance could result in methyl iodide penetrations (100 - efficiency) as follows (2):

93% RH	0.29 ± 0.07% penetration
95% RH	0.56 ± 0.11% penetration
96% RH	1.12 ± 0.2% penetration
97% RH	4.85 ± 1.2% penetration

Based on the round robin tests performed by the ASME CONAGT(5) and INEL(2), sensitivity data were obtained which permitted the revision of ASTM D3803 in the 1989 version for the 30°C, 95(+1, -2)% RH test protocol which the ASTM Committee considered suitably conservative test conditions. While the test parameter tolerance limits for test conditions other than the 30°C 95% RH test were not established, it was recommended by the ASTM D28 Committee that if the test condition tolerances in ASTM D3803-1989 for the 30°C, 95% RH test were followed, tests at the 80°C, 95% RH, 80°C, 70% RH, etc. conditions could also be performed in a reproducible manner. (This recommendation has been validated in the tests being performed by at least one test laboratory).(7)

The INEL study also indicated that a significantly more conservative test result is obtained at 30°C (for the used carbons tested) if the sample is first pre-equilibrated for 16 to 18 hours at 95% relative humidity (at 30°C) compared to unpre-equilibrated test conditions. While such high relative humidity may not always exist in NATS without humidity control, there were observations that 95% RH had been experienced. Therefore, for systems without qualified humidity control, the performance of the methyl iodide removal test at a pre-equilibrated water loading equivalent to 95% RH is justified.

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* Pre-equilibration is the 16-hour exposure of the adsorbent sample to a specified relative humidity air prior to the introduction of the radioactive methyl iodide tracer.

Where properly designed humidity control exists, which prevents the water loading of the absorbent above 70% RH, corresponding equilibrium conditions can be justified such that the used carbon test can be performed at 70% RH. It is important to note here that systems which are exposed to higher than 70% RH in standby mode would dry out to a 70% RH equilibrium water condition only after many hours of air flow at the <70% RH air stream. Therefore, the provision of normally de-energized heaters, without prevention of higher than 70% RH equilibrium water loading will not provide assurance of instantaneous performance corresponding to a 70% test condition. As a matter of fact, if the carbon in the standby mode is loaded to a higher than 70% RH equivalent condition, the desorption of the water from the front of the bed will decrease the temperature and increase the relative humidity in the downstream side of the carbon bed.

It is important to establish iodine adsorbent test conditions based on realistic accident scenarios so that the test results obtained can be better correlated to the required dose analysis, while keeping in mind that there is no direct correlation between a test performed under arbitrary selected conservative conditions and the actual performance of a system during a particular accident. The test, in fact, is a benchmark performance test for the establishment of the appropriate dose reduction credit.

New (unused) carbon efficiency requirements currently specified in ANSI/ASME N509-1989 and in Section FF of the ANSI/ASME AG-1 Code for a 2.0 inch bed depth are 3% maximum penetration at 30°C and 95% RH (Commercial carbons are available which provide < 1.0% penetration under the above conditions). Significant aging or weathering of the carbon during use in NATS will result in a higher penetration than that for the new carbon. The aging and weathering of the carbon cannot be accurately predicted because it depends on type and frequency of exposure to adsorbable chemical compounds (painting, cleaning, welding, etc.) during its life. But in all cases the methyl iodide removal efficiency will be less than that of the new carbon. Therefore, if the maximum permissible penetration for new carbon is 3.0% maximum, then the in-service test result has to be acceptable at some higher penetration. This acceptance limit has to be based on the specific realistic dose assessment for the particular NATS application.

Conclusions and Recommendations

The current widespread references to USNRC Regulatory Guide 1.52 Rev. 2 are no longer valid, because the Guide and its revisions were written based on outdated test methods and test conditions. The change from old test methods to the pre-equilibrated 30°C, 95% RH or other pre-equilibration temperature and humidity test results also needs to be reflected in changes of the various NPP Technical Specification acceptance limits which are based on Table 2 of the outdated Regulatory Guide 1.52 Rev. 2.(6) The best solution would be the timely issue of the long promised Rev. 3 of Reg. Guide 1.52, which would recognize the existing air cleaning technology knowledge and industry standards. In the absence of a technically sound Reg. Guide 1.52 the burden of justifying individual plant related changes on acceptable methyl iodide penetration will result in further confusion at a considerable expense.

Therefore, an industry-wide revised Standard Technical Specification needs to be drafted in conjunction with the issue of USNRC Reg. Guide 1.52 Rev. 3.

References

1. Deuber, H & Gerlach, K — "Parametric Investigations on the Retention of Methyl Iodide by a KI Impregnated Activated Carbon", (KfK Karlsruhe) Reports KfK 3594 (1983) KfK 3594 (1984) and Nuclear Safety Vol 26. No. 2 pp 157-169 (1985).

2. Scarpellino, C.D. et al. — "Technical Evaluation Report of Testing Procedures for Activated Carbon Adsorbers in Ventillation Filter Assemblies in Nuclear Power Plants", EG&G Idaho Report EGG-CS-7131 (1985) and Final Technical Evaluation Report for NRC/INEL Activated Carbon Testing Program EGG-CS-7653 (1987).

3. Kovach, J. L. — Notes on Radioiodine Adsorption. NUCON Report 265 (1987)

4. Freeman, W. P. — Radioiodine Testing of Used Nuclear Grade Activated Carbon: Penetration Results from Samples Tested with and without Moisture Equilibration According to a Draft Revision of ASTM D3803 USNRC Report NUREG/CP-0098 pp 997-1002 (1988).

5. First, M. W. — Tabulation of ASME CONAGT Round Robin Test Results (1983).

6. Dick, R. L. — Letter dated 30 September 1991 to Dr. Thomas Murley, USNRC.

7. Freeman, W. P. — Personal communication. 1990.

DISCUSSION

OLSON: I agree with everything you said and I appreciate your support for plant engineers that have a difficult time. Something I want to mention that was not brought out here but goes back to Mr. Gill's presentation, is bypass leakage under DOP and Freon testing. I believe the material you gave for methyl iodide is all published in standards and Tech Specs. Also there were some changes related to bypass leakage. Would you comment on this, please?

HAYES: There was a generic letter, numbered 83-13, (GL 83-13) issued in 1983, after the TMI accident. It attempted to make sure that everyone had ESF filter Tech. Specs. and to ensure that the TS contained the same standard requirements. Unfortunately, that generic letter included an error in the footnote in terms of the allowable penetration for the in-place DOP and Freon tests and for the laboratory testing criteria for charcoal. The correct value for the in-place test should be .05% penetration for both Freon and DOP. We have, in the past allowed some leeway, up to, 1%, for systems that have a built-in bypass. By built-in bypass, I am talking about systems where there are diverting dampers that, in normal operations, allow air flow to bypass the filter units. In order to initiate filter unit operation, you have to close some dampers and direct the flow through the filter units. In the past, the NRC has recognize the problem associated with by-pass leakage for those types of dampers. However, a point that licensees have missed is that they have not included the 1% by-pass in their accident calculations. You have to make sure that the two go hand-in-hand. But you are right, there has been a problem perpetuated by that generic letter.

OLSON: One other thing. Not to harp on revisions to Reg. Guide 1.52, but are the right people involved with the preparation of standard Tech. Specs. instead of just referencing Reg. Guide 1.52?

HAYES: I look at the lack of a recent revision of Reg. Guide 1.52 to be somewhat of a cop-out on the part of industry. There is nothing to prevent industry from adapting either a new ANSI standard or a new ASTM standard. However, even if a revision to RG 1.52 was to be issued, there is nothing that requires licensees to implement that particular revision of the Reg. Guide.

OLSON: I agree. I didn't mean to suggest that a new Reg. Guide 1.52 would take care of all the problems. We have mentioned that a number of times at this meeting. I agree, a revision of Reg. Guide 1.52 is not going to resolve all the issues, but I hope that in the future by taking a little more careful look at our Tech. Specs., and additions to Tech. Specs., we might be able to resolve some of these problems upfront.

KUMAR: The relative humidity that the system would see should be the governing testing criterion rather than the presence or absence of heaters in the system.

HAYES: If we were to establish laboratory test conditions based upon the anticipated relative humidity that the system would see in the event of an accident, we would have more test conditions then we presently have. Therefore, the NRC addresses two situations, high relative humidity, i.e., >70% RH and low relative humidity, i.e., <70%. To address these two situations, the charcoal testing industry developed two test conditions, 70% RH and 95% RH. The NRC has implemented the 70% test condition for systems with heaters and 95% for systems without heaters. There are situations where relative humidity may be controlled such that the laboratory test could be conducted at 70% RH even though no heaters are present. A possible example would be the control room. However, with or without relative humidity control, one should ensure that condensation is not occurring in the adsorber unit when it is idle and that the air to be treated is always at a low relative humidity.

BURWINKEL: Something left out this morning is, when you test according to ASTM D3803-89, and the penetrations are calculated per your credited allowance, should your test bed depth be the actual installed bed, or should it be a standard 2"?

HAYES: It should be based upon your actual bed depth. Let me bring up a situation that is occurring now. We have one licensee in the enviable situation where they have a 4" bed but they only need a 30% credit for the accident evaluation. Would you have them test that type of charcoal with an acceptance criterion for each 2" increment of 50%? We have presently taken the position that 50% charcoal is unacceptable. Charcoal should perform much better than that. However, the matter is still under discussion as to whether this licensee should be allowed to test the 4" bed at an acceptance criterion associated with 30%. Usually, bed depth of test samples should be the same as the actual bed depth. However, the NRC may limit the sample depth if it perceives that allowance of the bed depth to be sampled and tested would be a laboratory test of charcoal such that the acceptance criteria would call into question the worthiness of the charcoal to remove radioiodine. It is one of the reasons why we may not allow degradation to "as low as possible." For example, testing a four inch bed tested to 10% allowable penetration would only show a removal efficiency of approximately 68% per two inch bed. Charcoal which performs at this level is unsuitable in a nuclear installation. So there may be a level below which the NRC may not allow charcoal acceptance criteria to go.

BURWINKEL: What I have heard is that there is some lower limit that ought to be imposed on carbon performance.

HAYES: I think it is realistic to believe that charcoal should not last forever. To my recollection, there is a part of Reg. Guide 1.52 or N-510 that said, after 5 or 6 years you replace the charcoal.

BURWINKEL: The other thing I wanted to point out is that I continually hear that we need to test to ASTM D-3803-89, and I agree with that. But that is a 95% relative humidity test on a 2" bed. We need to make sure that people understand that the test we are looking for is under D3803-89 conditions at the specified relative humidity and test bed depth.

HAYES: If you read my paper, I think it will be clear. That is, not everyone will be testing at 95% R.H.

PEARSON: What would you tell a client that was considering changing to the 1989 version of ASTM who had a technical specification calling for 1%.

HAYES: A 2" bed and 95% R.H.?

PEARSON: Yes, with or without heaters. It really doesn't matter. He is in a position that he can't win. He would like to do it, but how? Is the Commission willing to relax his technical specification.

HAYES: We had at least one incident where we had relaxed the safety factor associated with the adsorber. I think that was probably the first one we went through in terms of re-licensing. My personal opinion (and it is not based upon test data) is that I don't envision licensee's having much of a problem meeting 99% doing the test with heaters at 70% R.H., if they have good charcoal to begin with. The people who really know whether this is correct are you and Kovach; you have that information. As I pointed out on the last viewgraph, what is important to me is, what is the charcoal capable of retaining if it really is at 95%? That is the real issue. I think you would have a difficult time meeting the 1%. I would be skeptical that you could meet it, to be honest with you. The unfortunate thing is, I don't believe we have enough data to say that this is the true capability of the charcoal.

PEARSON: How does a facility with a 99% T.S. change to ASTM D3803-1989?

HAYES: The problem licensee's face with changing to the ASTM D3803-1989 method is, can they meet their T.S. value with the new method? My opinion is, they probably can if they have heaters. If they don't have heaters, then I believe that it may be difficult for licensees to meet their acceptance criteria. The question then becomes, does the NRC safety factor change or does the adsorber efficiency credited for radioiodine removal change? The NRC prefers the latter. If such changes to adsorber efficiency do change, then it is necessary to reanalyze the doses

associated with accident analyses. As long as GDC 19, Part 100 doses, and SRP doses are met, credit for lower efficiencies may be granted. It would be useful if, at the next Air Cleaning Conference, you and Pete Freeman could present a paper giving the results of a comparison in testing results using the D-3803-1989 and other test methods.

PEARSON: I agree with John Peterson's comments. If utilities change to the 30/95 or 30/70 test, 99% efficiency may be an unrealistic requirement.

GUEST: I have been listening to this discussion about regulations and rules concerning the many combinations of ways to do the tests. And there are all kinds of arguments on bed depth, humidity, and so on. But I have not, as yet, heard one single word discussing the real problem, this is, how do you get a sample out of the filter that represents all of the material that is in there? You can discuss all the ways to conduct correct carbon tests, but if your sample doesn't represent what is in the filter, the information you generate by testing it is absolutely useless.

HAYES: I will be honest, I didn't realize that sampling was such a big problem.

KOVACH: After a number of presentations, the problem of representativeness is thrown back to the designer. The correct standards and AG-1 code require that whatever sampling methods are used must be verified to give samples representative of the actual conditions. I agree with you, that the current sampling canisters and some trays, which have a few sample canisters, are, in a few cases, absolute abominations. We have seen standard trays interspaced with so-called test canister trays, but the test canister tray pressure drop, at the same flow, was more than twice as high as the standard tray. Obviously, flow is not going to be the same through all of these units. Unfortunately, AG-1 is designed for only two reactors that we know about, both of which will be built everywhere else except in the United States in the future. There is presently no requirement in any of the standards to make sure that sampling now being done according to some of the old ASTM and ASME procedures is correct. As a matter of fact, one of the ASME standards, N-510 or N-509, shows that the testing tray method that is currently endorsed by the Reg. Guide and by a number of Tech. Specs. absolutely won't work. Yes, we have a very big problem to assure that samples are actually representative.

GUEST: We have, as you know, previously presented data at these conferences where we have taken samples from different places in the filter, and came up with different results. That is why we have gone to an in-situ test. Not because of any deficiencies in D3803, but because be don't believe we can get a sample that means anything. Until there is some requirement, such as use of test canisters with flow measuring devices on them, that assures the same flow through the test sample canisters as through the

rest of the filter, you are probably going to need some sampling design changes because charcoal packs down when you get closer to the bottom of the bed than the top. Until all these problems are resolved, I really don't think there is an awful lot of point fiddling around with D3803.

KOVACH: I am in full agreement with you.

FREEMAN: I think that John Pearson's issue is relevant. That is the issue facing most of the clients that I am dealing with. They have problems with the 1% penetration, 30° C, and 70% R.H. test. I think that, based on the results I have seen in my laboratory, a 1% penetration would be an unrealistic criterion to put on the charcoal. To say, it is "bad" charcoal, because it had 1% penetration at 30° C and 70% R.H., is not in agreement with what we have been doing all these years.

HAYES: I would like to respond in two ways. First, I would like to say that I think it would be valuable if both you and John presented papers at the next Air Cleaning Conference indicating what you believe is the true capability of charcoal. You state that, based upon the relative humidity of the system from which it comes, the charcoal will do this or that. In terms of what licensees can do, they can come in with a submittal that says instead of claiming 95% total efficiency, we are going to claim 88%. And then, depending upon whether they have heaters or not, you are talking about roughly 96% or 97% removal efficiency (3% or 4% penetration). Do you believe they can live with those values?

FREEMAN: My suggestion was 95% in the paper I gave. That is reasonable. The problem is, after they claim a penetration, whether they will violate their eventual calculated release.

HAYES: That is correct, the two go hand-in-hand. Therefore, if you assume an adsorber efficiency, you have to assure that the dose will be below the requirements of Part 100, or GDC 19, whichever one is more limiting. In most of the recent accident evaluations that I have done, there has not been a problem with offsite releases in terms of meeting Part 100. But we have run into problems with the control room operator doses meeting GDC 19. The big problem is the in-leakage which is assumed initially, to be 10 cfm, but is grossly underestimated. The real value is much larger and it is usually compensated for by the higher adsorber efficiency in the dose calculations. That is the way the criterion of GDC 19 is met.

FREEMAN: I think only some plants have real problems. I think what you're saying refers to a plant that has a spent fuel pool system that has problems. They were replacing charcoal at 1% penetration. I am not sure how that protects the public when the source term is going to change eventually and the calculated source term is outdated to begin with. It is convoluted, don't you think.

HAYES: For that specific example, I would offer the following: First, the fuel handling accident analysis would not be a function of the new source term. The source term remains unchanged. Second, I believe that the standard review plan limit of 75 rem for the thyroid would not be exceeded even if no credit were taken for the adsorber at many installations. Even those who have filter systems with capabilities that perform less well in terms of charcoal efficiency can probably go with lower adsorber efficiency and still be within the NRC standard review plan design doses. I think that may be a possible solution to this problem.

KUMAR: The question of ninety percent efficiency for old charcoal came up at EG&G. You need 99% efficiency initially when you buy charcoal. If we can't reach it, where do we stand, will our Tech. Spec. be changed? Are they going to change refueling outages? These questions come up. The basic thing is, we have to use 97% and 90% for new and used charcoal. How the technical specifications are going to be tied together, should be thought about clearly. I think that is very important.

KOVACH: I will comment on the first part. Another thing that is not really made clear by most purchasers of new carbon is what they want. Sometimes they put together specifications that conflict with each other instead of saying, we want a carbon based on N-509 requirements except for an efficiency of 99% instead of 97%. Carbons are available that are significantly better on a penetration basis. You can get carbons that are 3 to 4 times better than those currently required. But the tendency of people who write specifications for carbons is never to delete old specifications. They leave the old one in and then add all the new ones until you can give them almost anything because their specification ultimately calls for anything from carbon meant for Noah's Ark to something that is in draft form. So, if you specify what you want, you can get carbon that is better. As Jack Hayes mentioned, the source term we are talking about revising is the core source term. Reg. Guide 1.52 was not based on the core source term but on an efficiency based on accident conditions in the containment, during fuel handling, and for other conditions. So, let's not blame everything on the source term. There is no clear agreement about what can be done. Then we get into a public discussion and people talk about what they are forced to do. I think that we are passing the buck around. It would be much simpler to get an informed group from NRC, utilities, vendors, etc. to sit down and straighten this thing out in a very short time.

KUMAR: I think that is the right way to go.

JACOX: How are we using this data to improve the performance of the system? Could ISNATT or CONAGT use this type of data to inform relevant parties outside the immediate air cleaning community who have input to the NATS.

KOVACH: I agree totally. Thank you for the comment. I think ISNATT is perhaps the organization best suited to pass on this information and will formally suggest to the membership that the project be undertaken.

CLOSING COMMENTS OF PANEL MODERATOR KOVACH

I feel that we did make improvements, as Dr. Gill stated. I think that the discussions we had here were on a higher level then in the past, and I think there is now a better understanding of the problems. We hope that changes will not be made on a plant-by-plant, or a region-by-region basis, but that we can come up with a uniform, standardized procedure for power plants. I think they are scheduled for the year 2005 so we are not trying to set too short a schedule. However, I think this is a small problem that those who are involved in air cleaning can resolve without major problems. I think that if the standard Tech. Spec. modifications relating to testing are copied in exactly the same way from all utilities, we would not have to wait four years for changes. It could go a little faster if the same thing that has already been done and approved for some of the plants were extended to all. We should spend a little effort and money on technical discussions with audiences such as this one. I think that we could justify the cost/benefit of doing this. But at the same time, I would hate to go through the reverification of all the various test conditions. There is still a tendency by some people at times to pick some conditions for which there is no solution and I think we have to stop it. I think we are on the right road and it would be very beneficial to convene a task group from headquarters, the regions, ASME-CONAGT, ASTM, and several of the utilities to come up with a draft recommendation to address the problem. Then the draft could be sent to everyone for review and additional input to arrive at a common approach to solve this problem. I think that approach would resolve the issue a little faster.

SESSION 14

VENTILATION SYSTEMS

Thursday: August 27, 1992
Co-Chairmen: J. D. Paul
R. R. Weidler

DEVELOPMENT OF A COMPUTER DESIGN SYSTEM FOR HVAC

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Abstract

The development of a computer design system for HVAC (Heating, Ventilating and Air Conditioning) system is presented in this paper. It supports the air conditioning design for a nuclear power plant and a reprocessing plant. This system integrates various computer design systems which were developed separately for the various design phases of HVAC. The purposes include centralizing the HVAC data, optimizing design, and reducing the designing time. The centralized HVAC data are managed by a DBMS (Data Base Management System). The DBMS separates the computer design system into a calculation module and the data. So, the design system can be expanded easily in the future.

I. Introduction

In the last 10 years computers have been applied intensively in the design, engineering, manufacturing and construction of nuclear power plants and they have contributed greatly to the increased productivity of the Mitsubishi Nuclear Group in its nuclear power plant work. In most cases, these systems have been developed separately and utilized independently. Recently, the requirements for nuclear power plants have become more strict with regard to safety, reliability and economy. So, we have started to integrate various systems and to upgrade them.

In this paper, we have described the integrated computer design system for HVAC, which is one part of these systems. The HVAC system for a general nuclear power plant consists of more than 20 systems. So, the cost of the design, engineering, and manufacturing is high and it is related to many of the plant systems. And its design has been modified many times with the progress made during the engineering step, because the HVAC system is dependent on the designing of the other systems. Especially, concerning a reprocessing plant in Japan, which we are constructing, the scale is greater than that of the former LWR (Light Water Reactor) and the initial cost of the HVAC system accounts for a large part of the plant cost. So we must maintain the economy of the system scale in order to reduce the cost. Therefore, we started development to integrate various computer systems for the HVAC system. The purposes include centralizing the HVAC data, optimizing design with improving engineering precision, estimating the amount of materials early, and reducing the design period by creating various tables and drawings automatically. In other words, we started the development of computer systems which support systematic design and engineering, precise and rapid work management.

II. System Configutation

The concept for the integrated system is represented in Figure 2.1. This system covers all aspects of the HVAC system from basic design through field construction. And it has a centralized data base as its core, as well as various subsystems, almost all of which have been

developed separately and have been upgraded to be able to use the data base. The subsystems are as follows:

1. The application programs for design tools

   They have been upgraded to use the data base and have been used for some kind of calculations defining the HVAC system specifications.

2. The dialog interface program

   It is for retrieving, deleting, and updating the centralized data.

3. The three dimensional modeling system

   It is for layout design of equipment, ducts, cable trays, concrete, and components.

The hardware for this system is a large host computer. It dose not include the three dimensional modeling system, for which the hardware is an engineering workstation for high-speed graphics processing.

System Features

Features of this system are as follows.

1. Covering all aspects from basic design through detailed design

   This system supports each phase of design, for example, calculating air flow rate, calculating specifications for equipment, estimating material accounts, making specification sheets for order, and estimating ability of trial operation, and so forth.

2. Centralized data base includes almost all data for design

   Centralized data base system manages almost all the data for each design phase. Therefore, problems which occur when the data is shifted from a basic design to a detailed one, could be reduced.

3. Isolating programs and data

   Design tool programs are divided into modules by function, and physical data is isolated from the design tool programs by the DBMS. Therefore we can easily revise and expand the system.

4. Using the three dimension model

   We used a three dimensional solid model for design, so we can easily design the layout.

System Flow

Figure 2.2 shows the flow of the system design. We designed the system in the following order.

1. Basic Design Phase

   (a) The HVAC system configuration is entered into the data base, based on the equipment layout.

   (b) The room specifications are calculated from the data that was entered using the air flow rate calculation program.

(c) The routes for the ducts are set based on the HVAC system configuration, and the layouts of the ducts and equipment are adjusted with the three dimensional plant model. Then the result is translated and put into the data base by the interface program.

(d) Pressure drops in every system are calculated from the duct routes. And the room specifications for the fans and air conditioning units are set by the equipment specifications calculation program.

2. Manufacturing and Construction Phase

- The amount of material is estimated by the duct material accounting program.
- The specification sheets for the requisitions are made by the specification sheet making program.
- The system diagrams are made by the system diagram drawing program using the duct route data.

3. Trial Operation Phase

- We adjust the damper opening rate with the damper opening rate adjustment program.

In the later chapters, we will describe the subsystems in detail.

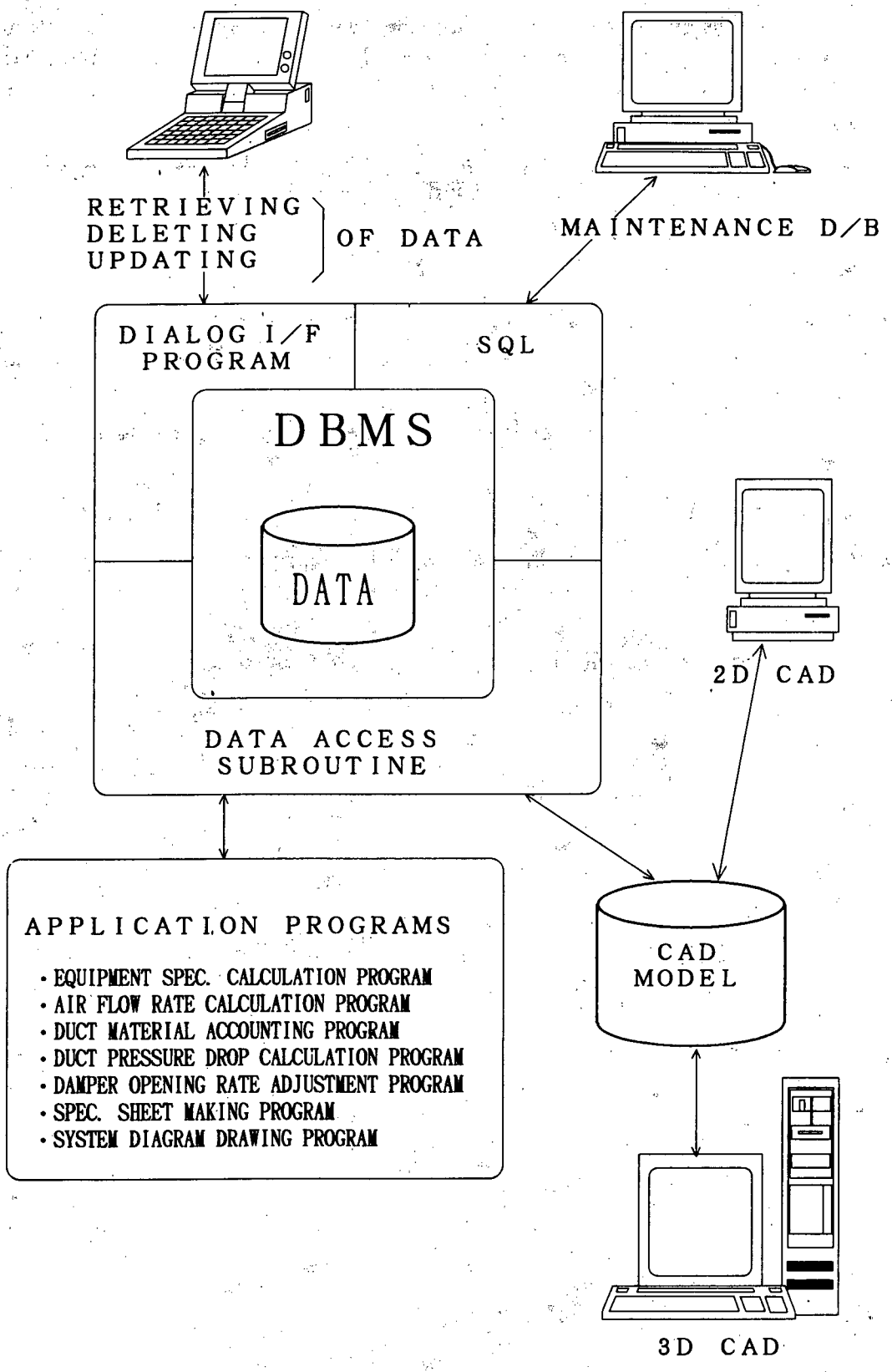


Figure 2.1 System Concept

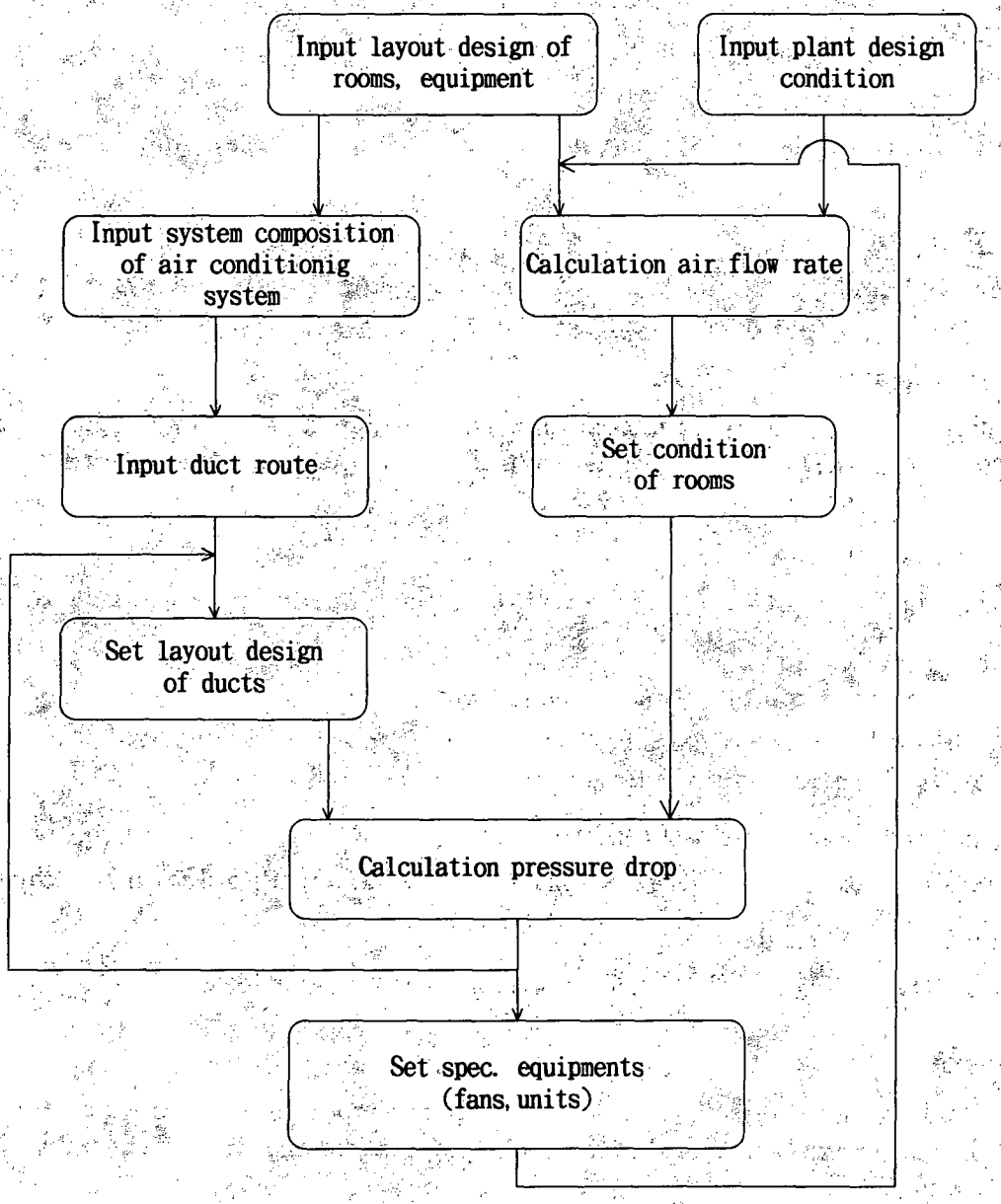


Figure 2.2 Design flow chart

III. Data Base System

The HVAC data are centralized by the data base system. This system consists of a relational data base. Because a relational data base can be expanded easily, we will add operation records data and repair records data to the data base in the future.

Data Base Tables

This system contains the following tables:

1. Design condition data

   It includes the basic plant conditions, for example, temperature, and humidity of the intake air at the site.

2. System data

   It includes common design conditions for each system, for example, system composition and the method of air conditioning.

3. Room condition data

   It includes the area, the volume, the temperature setting, the radiating account, the air flow rate, and so forth under various conditions. (For example, during operation or the plant maintenance)

4. Equipment specification data (for fans)

   It includes the static pressure, the air flow rate, the temperature, the setting location, and so forth of the fans.

5. Equipment specification data (for air conditioning units)

   It includes the flow rate, the specifications for the filters, the volume of heating or cooling, and so forth of the air conditioning units.

6. Equipment specification data (for motor units)

   It includes the power, the voltage, the frequency, and so forth of the motor units.

7. Duct line specification data

   It includes the routes and the specifications for the ducts.

Data Base Interface

The DBMS manages these data and acts as a connection between the data and the subsystems, so the subsystems are independent of the physical construction of the data. Therefore, we can easily expand the system.

The methods for accessing the data base are as follows:

1. Data access subroutines

   The subroutines connect the application programs and the interface program with the three dimensional model.

2. Dialog interface program

   The dialog interface program is used for retrieving, deleting, and updating the data by the computer terminals, so it is easy to control the data base.

3. SQL

   SQL is used for informal access and basic maintenance of the data base.

The data reliability has been kept high, because we restrict the access methods to the data base which include the previously mentioned methods only. So, the data cannot be destroyed easily if an application program contains bugs. So many people can develop some types of application programs to be used for design tools, which carry out some kind of calculations defining the HVAC specifications.

IV. Application Program

The application programs, in Figure 2.1, act as the design tools, which are used for some kind of calculation using the data base and the results are registered in the data base. We developed seven types of application programs which are as follows.

1. Equipment specification calculation program: It is for calculation of specifications for a piece of equipment (fan, cooling coil, etc.).
2. Air flow rate calculation program: It is for calculation of the air flow rate in each room.
3. Duct material account program: It is for estimating the duct material account for every kind of duct and making the estimation lists.
4. Duct pressure drop calculation program: It is for calculation of a drop in duct pressure between a piece of equipment and the end of a duct.
5. Damper opening rate adjustment program: It is for calculation of the damper opening rate which adjusts the pressure drop balance in various duct routes.
6. Specification sheet making program: It is for making specification sheets from the data base.
7. System diagram drawing program: It is for drawing various system diagrams automatically, which show the system composition plainly as well as various system engineering specifications.

Each program is described in detail in the following section.

(1) Equipment Specification Calculation Program

It is for calculation of various equipment specifications. The kinds of equipment which are supported by this program are described bellow.

1. Filter

   The air flow rate and the number of filter elements are estimated. The subject rooms are derived from the duct specification data base, and the air flow rate is estimated by adding the air flow rates in the rooms.

2. Fan

   The axis power of the motor is estimated from the pressure drop, which itself is estimated by the duct pressure drop calculation program, along with the designed flow rate, which is estimated in the same way as the filter.

3. Cooling coil

   The air flow rate, the cooling load, and the amount of cooling water for the cooling coil are estimated. The cooling load is estimated from the difference in the enthalpy of both sides of the coil. The enthalpy of the exit point of the coil is assumed to be constant. And the entrance enthalpy is estimated from the intake air and the returned air conditions. The amount of cooling water is estimated on the condition that the efficiency of the coil is assumed to be constant.

4. Heating coil

   The air flow rate, the heating load, and the amount of heating water(steam) are estimated in the same way as the cooling coil.

5. Humidifier

   The air flow rate and the amount of steam needed for humidifying are estimated.

The temperature of the exit point for every piece of equipment is estimated from its specification and the air temperature of the entrance point. The condition data which are used for calculation are registered in the data base and the results of the calculations are registered in the equipment data base.

(2) Air Flow Rate Calculation Program

The planning of the air flow rate for each room is completed by this program. It selects the higher air flow rate needed for cooling and ventilation. The input parameters for this program are geometric conditions, temperature, humidity, heat radiation, supplied air temperature, and the number of ventilations. The parameters are registered in the data base and the results of this program are registered in the data base.

(3) Duct Material Account Program

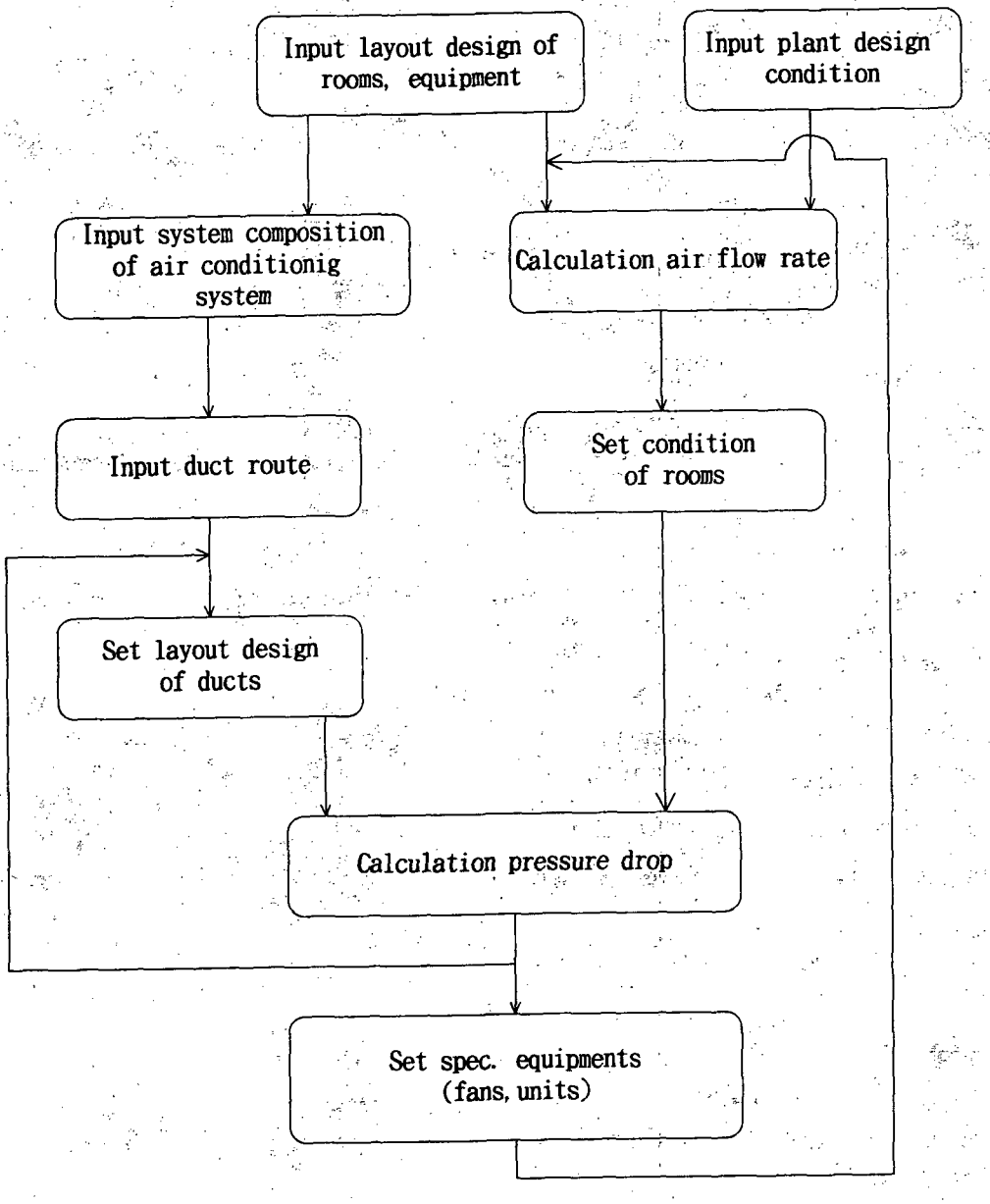
This program estimates the material account (the number of parts, weights, and so on) of the duct system for each duct accessory. The results are used for cost accounting.

(4) Duct Pressure Drop Calculation Program

This program estimates the duct pressure drop between a fan and an exhaust or an intake. It contains many kinds of pressure drop coefficients in table form, so the calculation result is precise. Therefore, we can check duct size carefully and optimize it.

(5) Damper Opening Rate Adjustment Program

This program estimates the damper opening rate which adjusts the pressure drop balance in the various duct routes. Resistance is needed to adjust the pressure drop imbalance and the planning air flow rate. Therefore we have to adjust the damper opening rate to create this resistance. At first, we estimate the pressure drop imbalance. And then the damper opening rate is calculated from the air flow rate and the imbalance.



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   It includes the routes and the specifications for the ducts.

Data Base Interface

The DBMS manages these data and acts as a connection between the data and the subsystems, so the subsystems are independent of the physical construction of the data. Therefore, we can easily expand the system.

The methods for accessing the data base are as follows:

1. Data access subroutines

   The subroutines connect the application programs and the interface program with the three dimensional model.

2. Dialog interface program

   The dialog interface program is used for retrieving, deleting, and updating the data by the computer terminals, so it is easy to control the data base.

3. SQL

   SQL is used for informal access and basic maintenance of the data base.

The data reliability has been kept high, because we restrict the access methods to the data base which include the previously mentioned methods only. So, the data cannot be destroyed easily if an application program contains bugs. So many people can develop some types of application programs to be used for design tools, which carry out some kind of calculations defining the HVAC specifications.

IV. Application Program

The application programs, in Figure 2.1, act as the design tools, which are used for some kind of calculation using the data base and the results are registered in the data base. We developed seven types of application programs which are as follows.

1. Equipment specification calculation program: It is for calculation of specifications for a piece of equipment (fan, cooling coil, etc.).
2. Air flow rate calculation program: It is for calculation of the air flow rate in each room.
3. Duct material account program: It is for estimating the duct material account for every kind of duct and making the estimation lists.
4. Duct pressure drop calculation program: It is for calculation of a drop in duct pressure between a piece of equipment and the end of a duct.
5. Damper opening rate adjustment program: It is for calculation of the damper opening rate which adjusts the pressure drop balance in various duct routes.
6. Specification sheet making program: It is for making specification sheets from the data base.
7. System diagram drawing program: It is for drawing various system diagrams automatically, which show the system composition plainly as well as various system engineering specifications.

Each program is described in detail in the following section.

(1) Equipment Specification Calculation Program

It is for calculation of various equipment specifications. The kinds of equipment which are supported by this program are described bellow.

1. Filter

   The air flow rate and the number of filter elements are estimated. The subject rooms are derived from the duct specification data base, and the air flow rate is estimated by adding the air flow rates in the rooms.

2. Fan

   The axis power of the motor is estimated from the pressure drop, which itself is estimated by the duct pressure drop calculation program, along with the designed flow rate, which is estimated in the same way as the filter.

3. Cooling coil

   The air flow rate, the cooling load, and the amount of cooling water for the cooling coil are estimated. The cooling load is estimated from the difference in the enthalpy of both sides of the coil. The enthalpy of the exit point of the coil is assumed to be constant. And the entrance enthalpy is estimated from the intake air and the returned air conditions. The amount of cooling water is estimated on the condition that the efficiency of the coil is assumed to be constant.

4. Heating coil

   The air flow rate, the heating load, and the amount of heating water(steam) are estimated in the same way as the cooling coil.

5. Humidifier

   The air flow rate and the amount of steam needed for humidifying are estimated.

The temperature of the exit point for every piece of equipment is estimated from its specification and the air temperature of the entrance point. The condition data which are used for calculation are registered in the data base and the results of the calculations are registered in the equipment data base.

(2) Air Flow Rate Calculation Program

The planning of the air flow rate for each room is completed by this program. It selects the higher air flow rate needed for cooling and ventilation. The input parameters for this program are geometric conditions, temperature, humidity, heat radiation, supplied air temperature, and the number of ventilations. The parameters are registered in the data base and the results of this program are registered in the data base.

(3) Duct Material Account Program

This program estimates the material account (the number of parts, weights, and so on) of the duct system for each duct accessory. The results are used for cost accounting.

(4) Duct Pressure Drop Calculation Program

This program estimates the duct pressure drop between a fan and an exhaust or an intake. It contains many kinds of pressure drop coefficients in table form, so the calculation result is precise. Therefore, we can check duct size carefully and optimize it.

(5) Damper Opening Rate Adjustment Program

This program estimates the damper opening rate which adjusts the pressure drop balance in the various duct routes. Resistance is needed to adjust the pressure drop imbalance and the planning air flow rate. Therefore we have to adjust the damper opening rate to create this resistance. At first, we estimate the pressure drop imbalance. And then the damper opening rate is calculated from the air flow rate and the imbalance.

(6) Specification Sheet Making Program

This program makes specification sheets using the data base. It supports the editing function, which is used for adding and replacing the sheet data. Sheets can be output for all the equipment.

(7) System Diagram Drawing Program

This program draws system diagrams automatically, which show the system engineering specifications clearly. The kinds of system drawings are listed bellow.

1. Earthquake-proof area system diagram
2. Highest temperature and pressure area system diagram
3. Duct specifications area system diagram
4. Thermal insulation setting area system diagram

V. Three Dimensional Model

The three dimensional model consists of the concrete building data, the components data, the piping data, the cable tray data, and the duct data. We use this model for the layout design. This is one of the most important points for the HVAC design. And the results are put in the data base by the interface program and are used for the duct material accounting, making specification sheets, and drawing system diagrams. Also, we are now trying to translate the data into a two dimensional graphic design system from the model for making various drawings.

The hardware for this modeling system is an engineering workstation for high-speed graphics processing. The engineering workstation is connected with the large host computer, which acts as the hardware for the data base system, by the ethernet LAN (Local Area Network).

VI. Conclusion

The features of an efficient HVAC design system using the centralized data base was presented. By applying a part of this system to the FBR(Fast Breeder Reactor), 'MONJU', the cost of design and of functional testing at the site have been reduced by about 30 percent. Now, it has been applied to a reprocessing plant. Also the DBMS separates the program into the calculation module and the data, so the design system can be expanded easily. In the future, not only an engineering design data base, but also a system operation records data base, and a repair records data base will be constructed. Following these, this system will be upgraded to an optimizing design system and an efficient repair system by referring to these data bases.

DISCUSSION

MIYAZAKI: First, what is the interface between your program for HVAC with the other disciplines? Secondly, what are the duct optimization objectives, what optimization method for duct sizing is used? Also are you using T-method duct design from the ASHRAE 1989 Handbook?

TSAL: In answer to your first question, a 3-D-engineering model (by CAD system). Second, for reducing the quantity of the duct material, reducing the duct size except the duct of the maximum pressure drop. Thirdly, no, we do not use that method.

CHIPULI S: I would like to know whether this HVAC design computer program for Nuclear Facilities is based on the ALARA criteria. I mean from low radiation areas to high radiation areas?

MIYAZAKI: The computer program does not have this system yet. At this moment, designers can check the above situation based on calculations.

BERGMAN: Have you confirmed the accuracy of the computer code with experimental measurements?

MIYAZAKI: Not yet. We are applying this system to a reprocessing plant that is under design now.

22nd DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

DESIGN AND CHARACTERISTICS OF ANNULUS VENTILATION AND HVAC SYSTEM FOR PROTOTYPE FBR MONJU

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Abstract

The MONJU annulus ventilation system keeps the annulus below a pressure of -15 mmAq as a secondary containment during reactor operation to assure -6 mmAq even in the case of accident. To minimize release of radioactive substances, the system adopts a charcoal filter with a thickness of 20 cm whose efficiency of iodine removal is over 99 %. Rooms for components containing radioactive sodium are maintained in a nitrogen atmosphere during ordinary operation by the inert gas cooling system, and form gastight cells for which atmospheric leakage is designed to achieve below 100 %vol/day at a pressure differential of 100mmAq. Design specifications of annulus ventilation and HVAC system are determined by experimental data and computer analyses for the accident. Function and performance of the annulus ventilation and HVAC system have been confirmed by pre-operational tests.

Ⅰ. Introduction

MONJU is a 280MWe prototype fast breeder reactor, which was completed in its construction in April 1991, and pre-operational tests are now underway. The plant is a loop-type consisting of three primary and secondary sodium loops, and is equipped with a reactor containment vessel. A sectional view of main building is shown in Figure 1. The reactor and the primary sodium loops are located in the reactor containment vessel surrounded by the outer shield building. An annular part which exists between the reactor containment vessel and the outer shield building is held at a slightly negative pressure during reactor operation to prevent radioactive substances from dispersing. Areas where components containing radioactive sodium are installed are kept in a nitrogen atmosphere to suppress sodium combustion in the event of sodium spill. This paper describes design features and results of pre-operational tests for the annulus ventilation and HVAC system of MONJU.

Ⅱ. Outline of HVAC Systems of MONJU

HVAC systems of MONJU are composed of twenty-two systems shown in Table 1, and are designed in accordance with the design criteria by the authorities and the following principles.

R/B : Reactor building
A/B : Reactor auxiliary building
T/B : Turbine building
D/B : Diesel building
M/B : Maintenance & waste disposal building

1 Turbine generator
2 Steam generator
3 Intermediate heat exchanger
4 Reactor vessel
5 Operating floor
6 Ex-vessel fuel strage tank
7 Ex-vessel fuel transfer machine
8 Maintenance area
9 Annulus

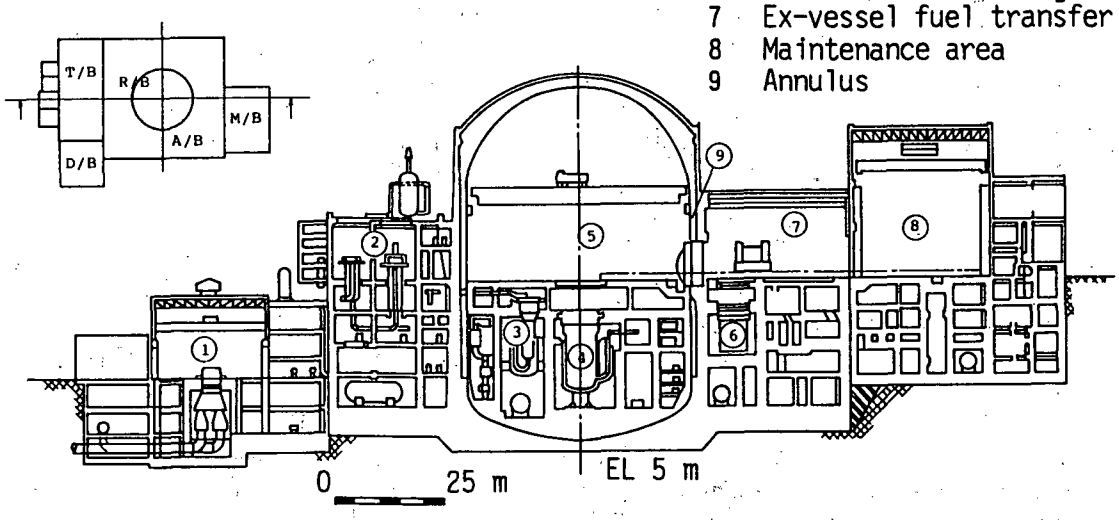

Figure 1 Sectional view of main building

(1) HVAC systems shall be classified into radiation controlled and non-controlled areas, and separated into several systems in each area by functional demands of facilities.
(2) Fresh air flow shall be from clean areas to radioactive contaminated areas, and exhaust air shall be filtrated by HEPA or charcoal filters.
(3) Ventilating capability shall be enough to remove the heat evolved from components or to supply the fresh air required by design guidelines.
(4) Gastight cells shall be constructed for rooms where components containing radioactive sodium are installed, and kept in a nitrogen atmosphere during ordinary operation. At maintenance, these cells shall be ventilated from nitrogen to air.
(5) In the event of accident, the annulus kept in a negative pressure shall gather radioactive substances leaked from the reactor containment vessel and lead them to a vent stack after filtration to minimize radiation doses of the neighbouring public.
(6) In the event of accident, an air handling system for main control room shall isolate the room from the outer field and select a recirculation mode through the charcoal filter to protect operators from internal radiation doses.
(7) HVAC systems shall equip ducts with fire dampers to prevent a fire from spreading, if necessary.

MONJU employs sodium as coolant and the sodium spill is a design basis accident, therefore (4) and (5) are key features of HVAC systems of MONJU.

Table 1 HVAC Systems of MONJU

Classsification	Building	Division of HVAC System	Temp.[℃]	Remark
Radiation Controlled Areas	R/B	Annulus Ventilation System	——	A1
		C/V Ventilation System	——	
		C/V Air Recirculation System	10 ~ 40	
		Reactor Cavity Inert Gas Cooling System	≦ 55	S1
		PHTS Cells Inert Gas Cooling System (pl.)	≦ 55	S1
	A/B	Fuel Handling Facility Room Inert Gas Cooling System	≦ 55	S1
		Fuel Handling Facility Area Ventilation System	10 ~ 40	
		Fuel Transfer Machine Passageway Air Cleaning System	——	A1
		Controlled Access Area Air Handling System	21 ± 5	
	M/B	M/B Ventilation System	10 ~ 40	
Non-controlled Areas	A/B	Main Control Room Air Handling System	21 ± 5	A2
		A/B Ventilation System	5 ~ 40	
		Steam Generator Area Ventilation System (pl.)	≦ 55	S2
		Secondary Maintenance System Room Ventilation System	≦ 55	S2
		Electric Equipment Room Air Handling System Ⅰ	5 ~ 40	
		Electric Equipment Room Air Handling System Ⅱ	5 ~ 40	
		Electric Equipment Room Air Handling System Ⅲ	5 ~ 40	
		EVST Cooling System Area Ventilation System (pl.)	≦ 55	S2
	T/B	T/B Ventilation System	5 ~ 40	
	D/B	D/B Electric Equipment Room Ventilation System	5 ~ 40	
		Diesel Generator Room Ventilation System	5 ~ 45	
		D/B Ventilation System	5 ~ 40	

R/B:Reactor Building, A/B:Reactor Auxiliary Building, M/B:Maintenance & Waste Disposal Building,
T/B:Turbine Building, D/B:Diesel Building, PHTS:Primary Heat Transfer System,
EVST:Ex-vessel Fuel Storage Tank, pl.:Three systems exsist for ABC loops,
S1:HVAC for radioactive sodium area, S2:HVAC for non-radioactive sodium area,
A1:HVAC for minimizing radioactive mateials in accident,
A2:HVAC for protecting operaters from radiation doses

Ⅲ. Annulus Ventilation System

A. Design Features

The annulus ventilation system is provided to maintain a slightly negative pressure in the annulus by modulating exhaust and recirculation air, and to remove radioactive materials leaking from the reactor containment vessel(C/V) to reduce radiation doses to the general public in the case of accident. This system includes two fans of 100 percent capacity and two filter units connected by ducts to each fan. Exhaust is all filtrated by a medium and a HEPA or a charcoal filters, and returned to the annulus with partial discharge through the vent stack. A flow diagram of the system is shown in Figure 2. During normal plant operation, the exhaust from the annulus is led to a HEPA filter unit and through a bypass line of a charcoal filter unit and partially discharged to keep the negative pressure in the annulus. In the event of sodium spill accident, the flow line is changed to the charcoal filter line and the radioactive substances leaking from the C/V are gathered in the the annulus and captured by the HEPA and charcoal filters.

The annulus ventilation system is one of the engineering safety systems for the plant and has the following characteristics.

(1) Redundancy and independency

Single failure of active components is considered in the system design. Then, two independent and individual lines are provided for redundancy and independency. During normal plant operation, one line is working while the other remains in standby. In the case of accident, the C/V isolation signal would make two lines work automatically, and operators would confirm the operating condition, then stop one of the lines.

(2) Consideration of loss of off-site power supply

Electric power is connected to the emergency power supply, considering loss of off-site power. Each electric line of the systems is connected to a different unit of the emergency diesel generator.

(3) Keeping of negative pressure in the annulus

The negative pressure of -6 mmAq[1] should be kept in normal operation and accident as a secondary reactor containment system. A credit value of the negative pressure in the annulus is determined less than -15 mmAq, since pressure rising would be occurred by temperature elevation of 15℃/h in the event of sodium spill accident and by a time lag below ten seconds in the case of diesel generator starting.

(4) Cleaning of radioactive substances

Radioactive substances are removed as much as possible to decrease the potential of public exposure risk. The HEPA filer is designed to the U.S. regulatory guide, and its efficiency is more than 99 % for removal of 0.7μm particles. The charcoal filter employs a bed type with a thickness of 20 cm considering a span of life time and filtrating efficiency. The efficiency is more than 99 % of iodine absorption, which is rather high compared with LWR plants.

(5) Consideration of sodium aerosol

The charcoal filter is protected against sodium aerosol which would be produced at the sodium spill accident. The HEPA filter unit is arranged in upstream of the charcoal filter unit. The HEPA

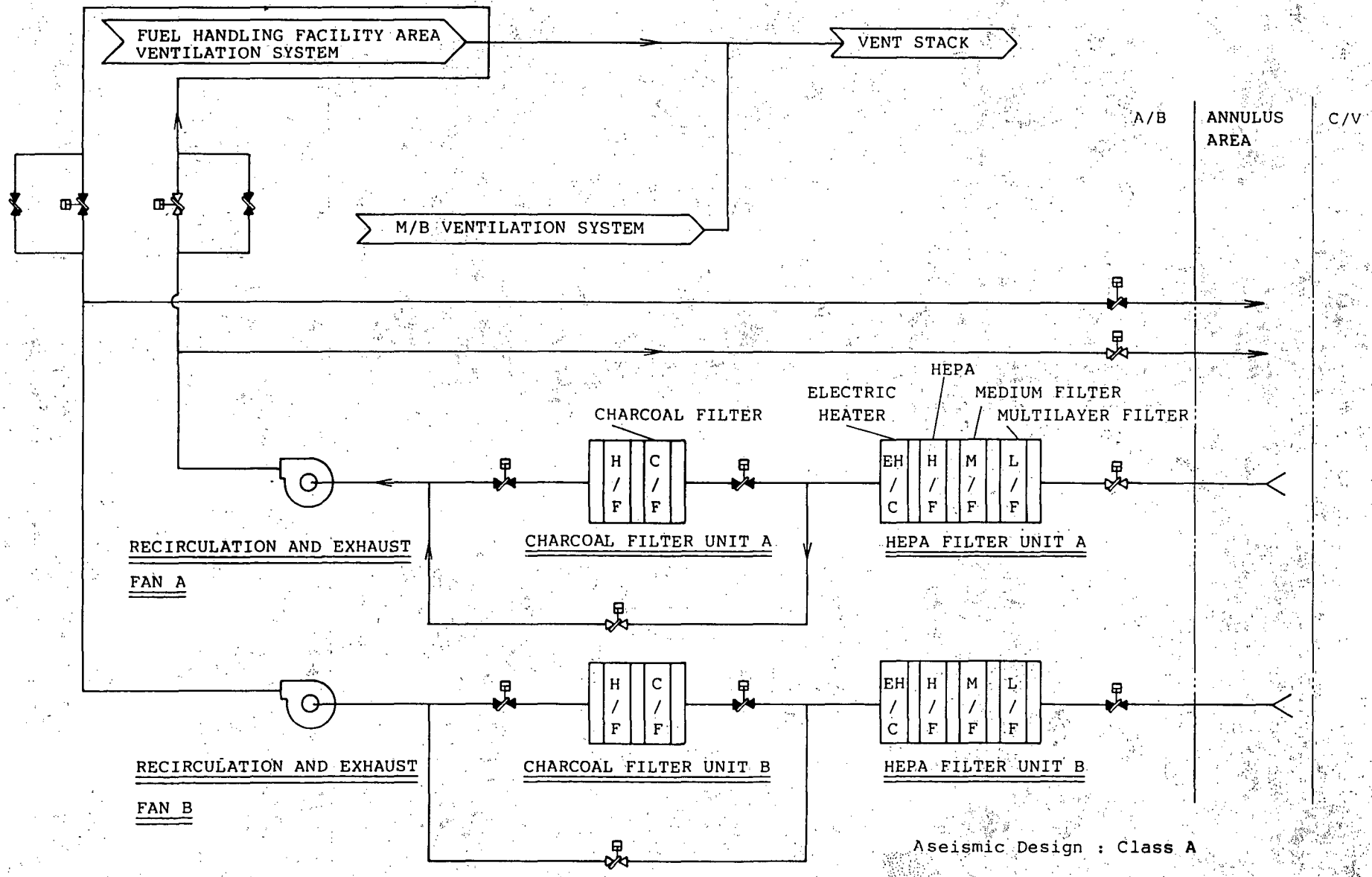

Figure 2 Flow diagram of the annulus ventilation system

filter unit is composed of a multilayer filter(L/F), a medium-efficiency filter(M/F) and a HEPA filter. The L/F is for sodium aerosol and consists of five layers which have a lot of openings to avoid blocking by absorbing the sodium aerosol.

B. Analysis and Experimental Data for Design

1. Analysis for Flow Rate

In order to determine flow rates of the annulus ventilation system, several cases were analyzed by using the parameters of C/V leakage rates, decrease of sodium aerosol caused by plate-out phenomenon, recirculating flow rates and release passes of radioactive materials. The exhaust flow rate through the vent stack is 20 m³/min to keep the negative pressure in the annulus. The limit of radiation doses to the general public is set a twenty-fifth times as small as the LWR's criteria. Since this plant is the first prototype FBR plant in Japan, more conservative value was selected. Figure 3 shows one of analytical

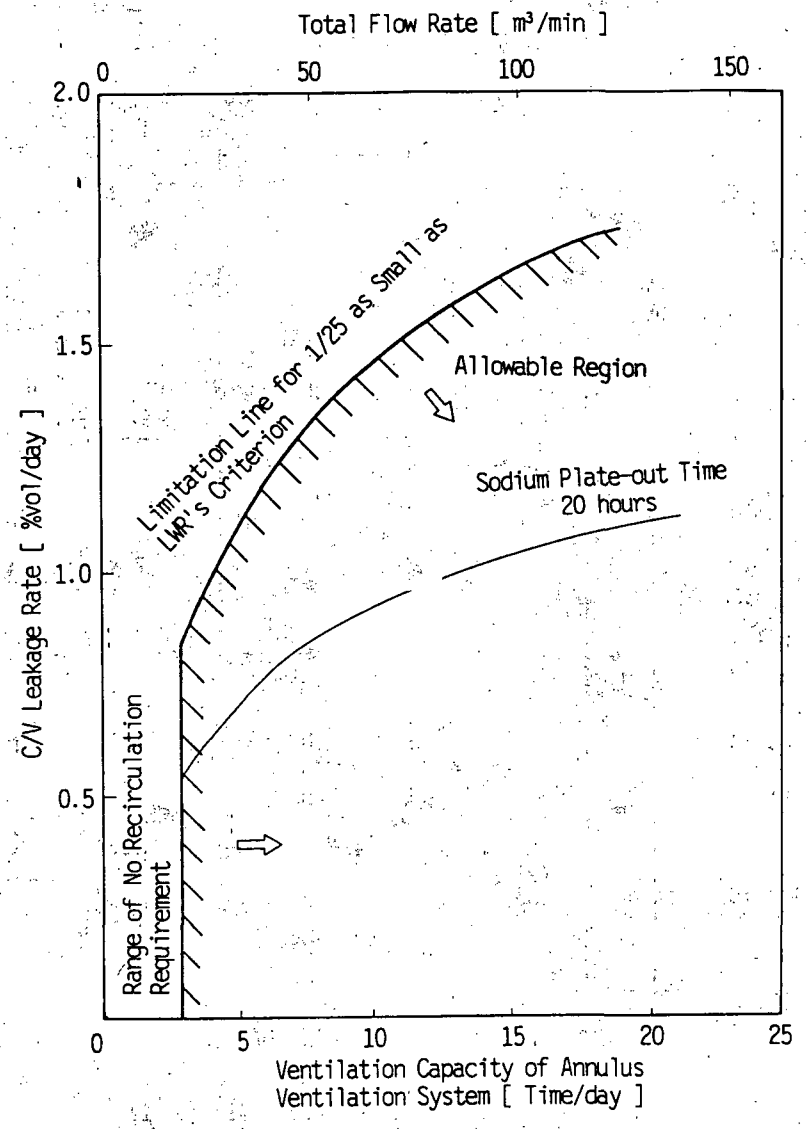

Figure 3 Ventilation capacity required for the annulus ventilation system by safety analysis

results. A thick line represents the criterion for ventilation capacity, while a thin line represents more conservative estimation fixing the sodium plate-out time in 20 hours. The C/V design leakage rate is 1 %vol/day in MONJU. If the total flow rate is over 100 m^3/min under the exhaust flow rate of 20 m^3/min, the amount of radioactive materials is significantly decreased. Based on this result, the rates of recirculating and total flow were determined as 100m^3/min and 120 m^3/min respectively.

2. Filtration of Sodium Aerosol

There is a possibility that the sodium aerosol would occur and leak into the annulus in the event of sodium spill accident. The multilayer type air filter was developed in order to protect the function of HEPA filter from clogging[2]. The sodium aerosol would be filtrated by the multilayer filter, the medium-efficiency filter and the HEPA filter in series. Table 2 shows the specification of multilayer filter and Figure 4 shows the data for the relation between amount of sodium collection and pressure drop. The number of layers for the filter is determined based on the calculation of an amount of sodium aerosol occurrence and an allowable pressure drop of the system.

Table 2 Specifications of multilayer filter

Items	Specifications
Material	High-Silicate Glassfiber Mat
Thickness	6 mm
Diameter of hole	20 mm
Opening percentage of holes	20.4 %
Number of layers	5

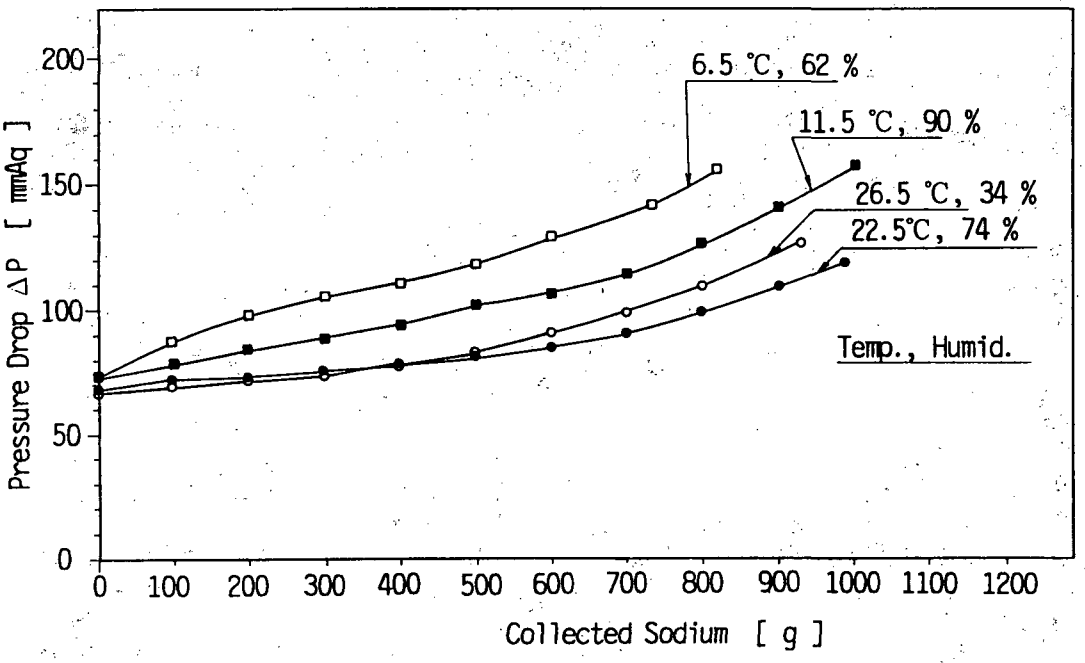

Figure 4 Changes of pressure drop during loading of sodium aerosol [2]

3. Confirmation of Charcoal Filter Efficiency

Efficiency of the charcoal filter was confirmed by a laboratory test before filling up the units. The test was carried out by using ten small cartridges — 5 cm in diameter and 1 cm in thickness — , and pre-heating was treated for twelve hours to obtain the uniform temperature and humidity. Figure 5 shows a result of iodine absorption test that the filter of 6 centimeters is thick enough to obtain the required filtrating efficiency, though the thickness of filter bed is 20 cm.

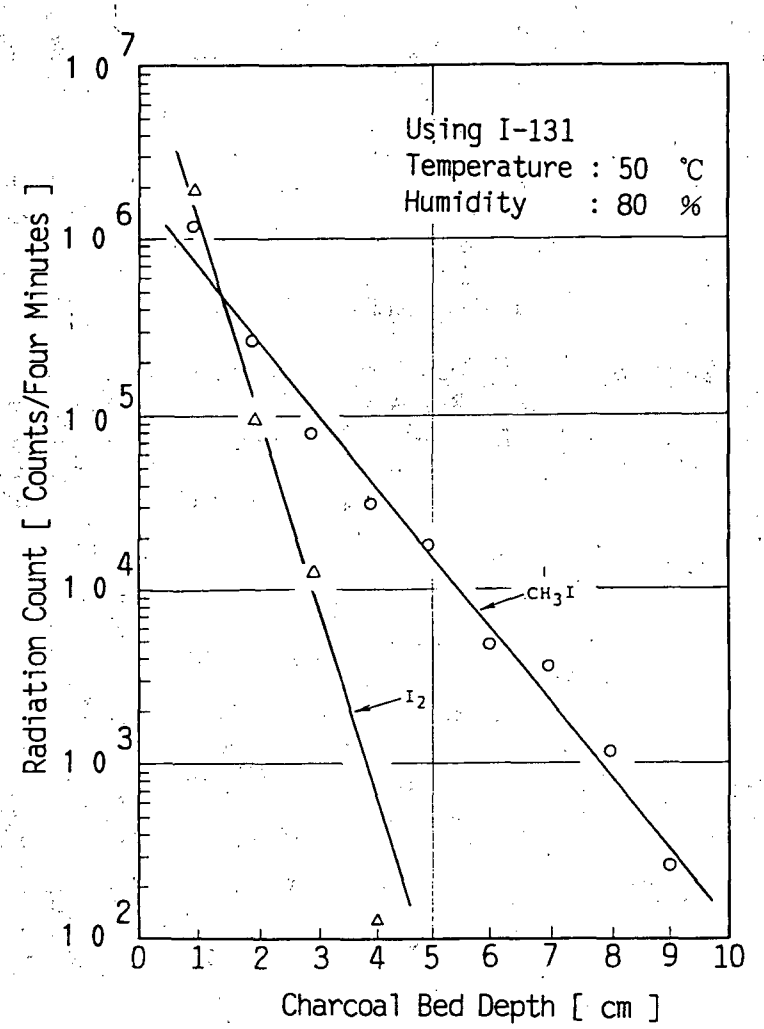

Figure 5 Efficiency of charcoal filter

4. Safety Analysis

The accident analyses for design basis accidents and hypothetical accidents were conducted to verify that the public radiation dose would be under a certain level. The analyses were performed by using the appropriate values which gave some margins to the size of crack opening of pipings, contents of iodine in the reactor vessel, transfer quantity of iodine to the reactor containment vessel, decline of aerosol caused by plate-out and others according to circumstances. For the annulus ventilation system, the analysis assumed 99 % or 95 % of the

charcoal filter efficiency, 0.83 of the recirculation ratio, 120 m^3/min of the total flow rate and 1.0 %vol/day of the C/V leakage rate. The analytical results showed that radiation doses to the general public would be sufficiently low compared with the criteria.

C. Results of Pre-operational Tests

The function test of fans, the interlocking and alarm tests, the air flow rate test, the negative pressure test and the filter efficiency test were carried out to confirm the performance of the system. The filter efficiency test was conducted for the HEPA filter unit and the charcoal filter unit at the plant site in addition to the factory tests. The results of both filter units were quite satisfied with the requirements as shown in table 3.

Table 3 Results of filter efficiency tests

	Factory Test		Plant site Test	
	Requirement	Result	Requirement	Result
HEPA	≧ 99 % *1	99.99 %	≧ 99 % *2	99.99 %
Charcoal	≧ 99 %	99.99 %	≧ 99 %	99.99 %

* 1 : 0.3 μm particles , * 2 : 0.7 μm particles

There are a lot of penetration through the annulus. The penetration of the reactor containment vessel(C/V) is strictly controlled by the C/V leakage test, while penetration of the outer shield building is loosely gastight. Leakage from the penetration of the outer shield wall was checked at a slightly negative pressure from inside and outside of the annulus before the negative pressure test. The negative pressure reached -70 mmAq at the exhaust flow rate of 15 m^3/min.

The flow rates of recirculating and total flows are maintained with the values used in the safety analysis in any conditions except for the plant maintenance. At this point, it is necessary to consider that back-pressure from the vent stack affects the exhaust flow rate of the annulus ventilation system, since the exhaust line is connected to the vent stack with the other systems. The influence of other systems against the exhaust flow rate was measured at the air flow rate test by various operational conditions. The flow rates of the annulus ventilation system were adjusted by controlling damper openings to

Table 4 Pressure and exhaust flow rate of the system

Condition	Pressure	Exhaust flow
Design Value	≦ - 15 mmAq	≦ 20 m^3/min
With Other Systems Operation	Approximately - 21 mmAq	Approximately 8 m^3/min
Without Other Systems Operation	Approximately - 46 mmAq	Approximately 12 m^3/min

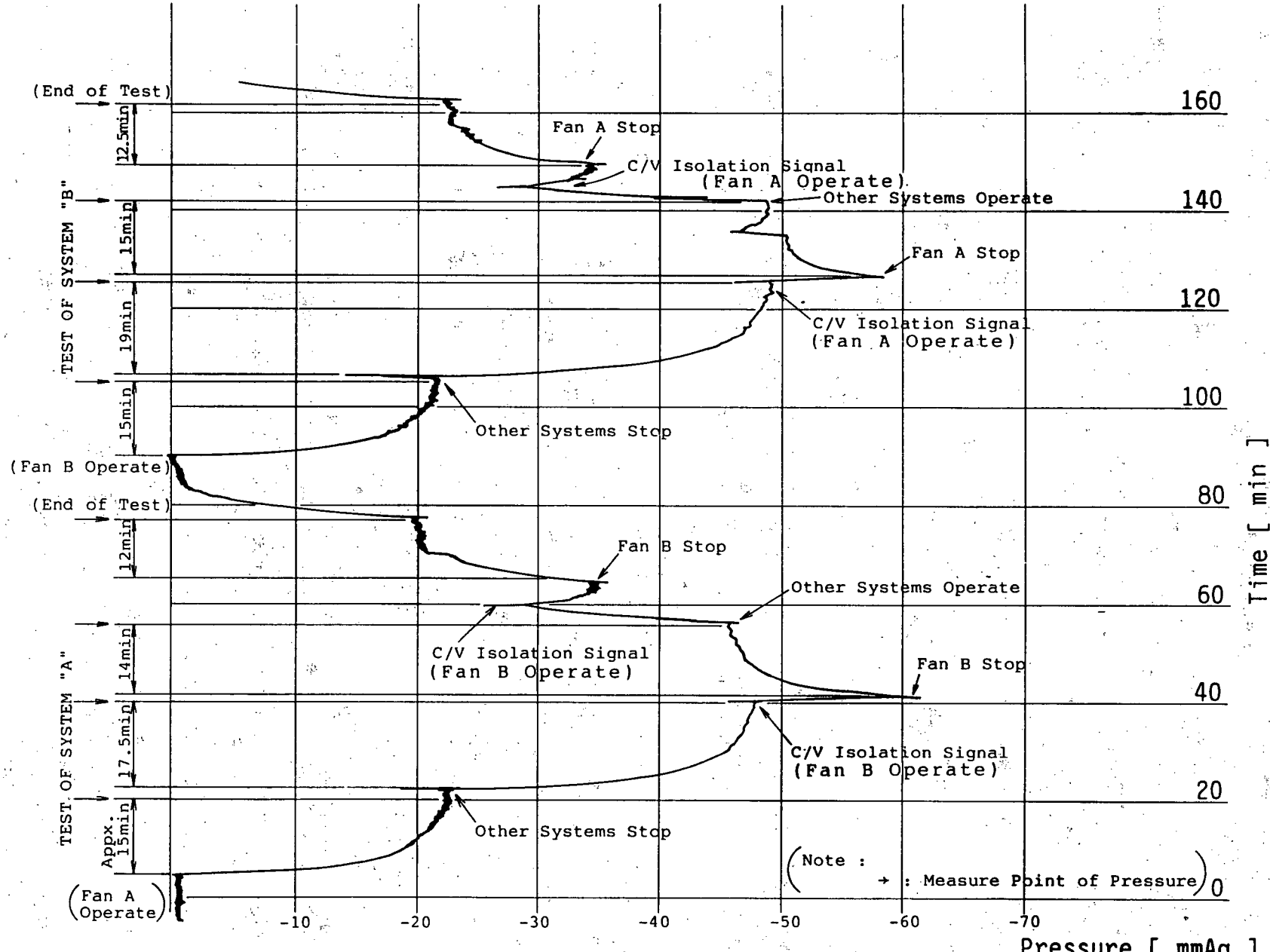

Figure 6 Recorder chart of the annulus negative pressure test

meet with the flow rates used in the safety analyses and the negative pressure required for the annulus, considering the back-pressure from the vent stack. Table 4 and Figure 6 show the fluctuation of pressure and exhaust flow rate affected by operational conditions.

Ⅳ. HVAC Systems for Primary Sodium Areas

A. Design Features

The sodium spill accident is considered in the design of the areas for components containing radioactive sodium such as the reactor vessel, the primary cooling loops and the ex-vessel fuel storage tank. HVAC systems for these areas have the following characteristics.

Rooms of these areas are lined with steel liners as shown in Figure 7 and form gastight cells. The atmospheric leakage rate of the cells is limited below 100 %vol/day in-leakage or out-leakage at a pressure differential of 100 mmAq. During ordinary operation, the cells are kept in a nitrogen atmosphere — oxygen concentration below 3 %vol — and are maintained at a slightly positive pressure to prevent air intrusion. At maintenance of the components, the cells are ventilated from nitrogen to air. In the event of sodium spill, the accident signal trips HVAC system, and then the liners and ducts of HVAC confine radioactive materials inside the cell boundary. HVAC systems, except the accident areas, can be re-started to cool the interior concrete and components, if necessary.

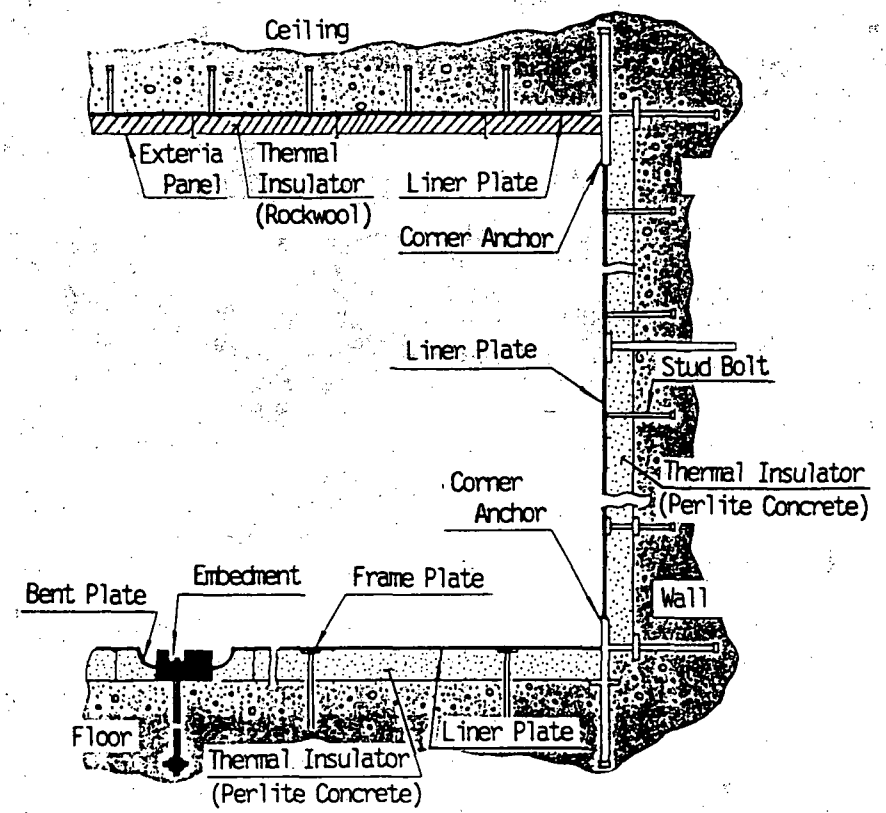

Figure 7 Structure of cell liners[3] (Fixed type)

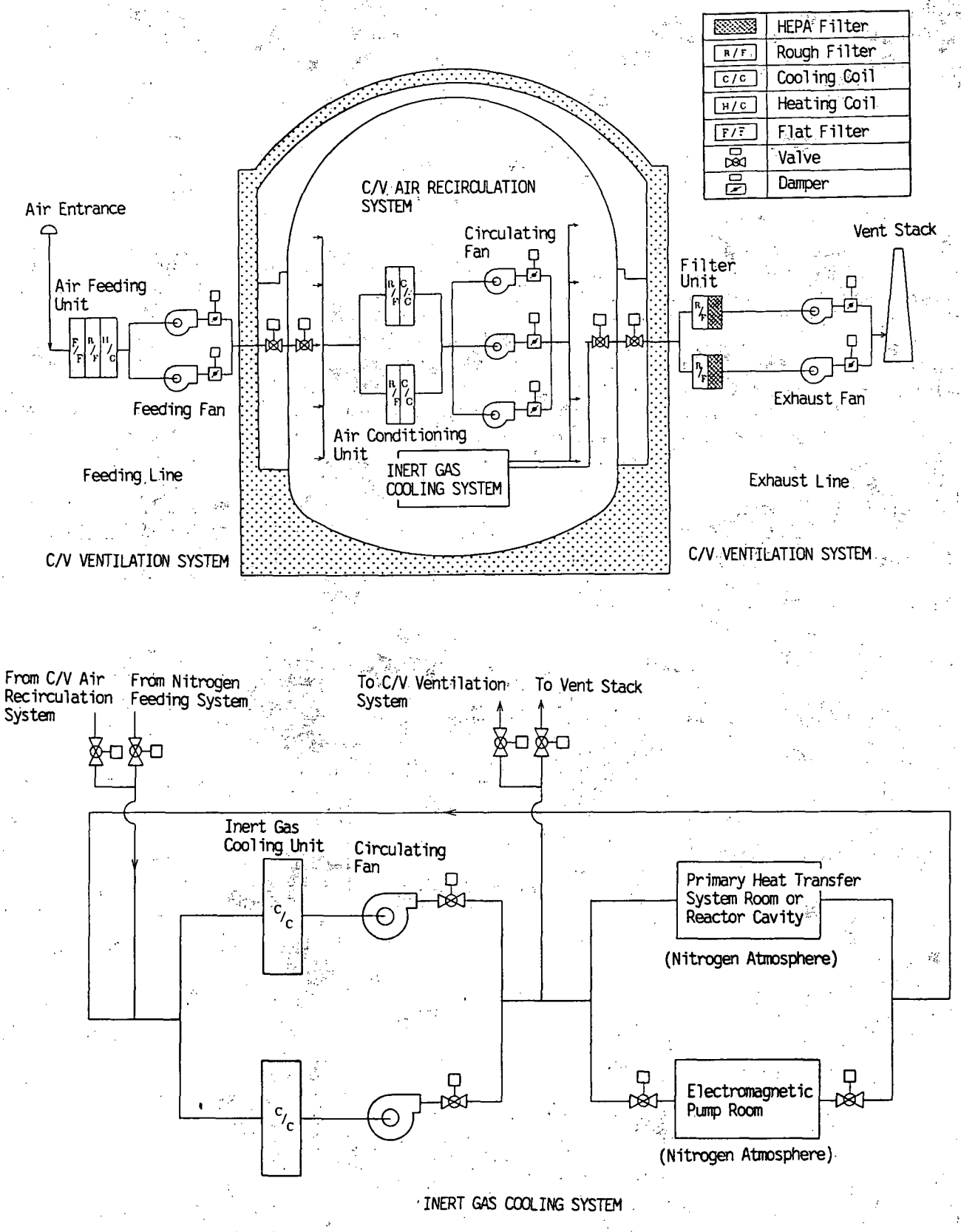

Figure 8 Explanation diagram of the HVAC system for the C/V

As shown in Table 1, HVAC system for the reactor containment vessel(C/V) is composed of a C/V ventilation system, a C/V air recirculation system, a reactor cavity inert gas cooling system and a PHTS(primary heat transfer system) cells inert gas cooling system. The C/V ventilation system feeds fresh air to the C/V and exhausts contaminated air through HEPA filter when personnel enters the C/V. The C/V air recirculation system controls the temperature of the air area in the C/V within 10 ~ 40 ℃, and is equipped with a rough filter and cooling coil. The inert gas cooling systems for these gastight cells of the reactor cavity and PHTS cells keep them nitrogen atmosphere and temperature below 55℃. Pressure adjustment in the cell is performed by monitoring the pressure differential(Δ P) between the cell and the operating floor in the C/V. When Δ P decreases under 10 mmAq, the inert gas cooling system feeds nitrogen gas to the cell up to 20 mmAq. The C/V operating floor pressure is also controlled by a differential from the atmospheric pressure out of the C/V. In the event of sodium spill, the C/V isolation signal trips the system and closes lines connected to electromagnetic-pump rooms so as not to damage the pump by thermal effect. When personnel enter the primary heat transfer system rooms for maintenance, the inert gas cooling system is switched to the C/V ventilation system and the rooms are purged from nitrogen to air. Figure 8 shows an explanation diagram of the HVAC systems for the C/V.

B. Analysis for Design

Computer analysis was necessary for estimating design specifications of HVAC systems of MONJU. For the sodium component areas, sodium spill accidents were analyzed by computer programs of SOFIRE-MⅡ and SPRAY-Ⅱ which were developed and modified on the bases of experimental data[4] [5]. SOFIRE-MⅡ can deal with sodium pool fire, and can calculate atmospheric temperature and pressure. This program let a combustion rate of sodium be determined by the quantity of atmospheric gases approaching the sodium surface and concentration of oxygen. Thermal transfer models are of convection and radiation between the sodium surface and the atmospheric gases, of convection between the gases and the liners, and of conduction in the structural materials. SPRAY-Ⅱ can deal with sodium spray combustion, and can calculate atmospheric temperature and pressure. This program let a combustion rate of sodium be derived from the oxygen concentration and the humidity, and the quantity of sodium vapour from the drops moving into combustion regions. Thermal transfer models are of convection and radiation between the sodium drops and the combustion region, of convection of the gases between the combustion region and the spray region, of radiation from the combustion region to the walls, of transfer of the gases between the spray region and the atmosphere, of convection from the atmospheric gases outside of the spray to the walls, of convection of the atmospheric gases close to the surface of the sodium pool, of conduction from the sodium pool to the floor, and of conduction in the structural materials.

Figure 9 shows a analytical result of the primary cooling room in the case of sodium spill from hot leg piping. Analytical assumptions severer than the actual accident were taken to get more credible results. Sodium would leak from the slit with length of 1/2D and width of 1/2t, where D and t were a diameter and a thickness of the pipe respectively. The atmospheric leakage rate of 100 %vol/day was assumed at the pressure differential of 100 mmAq. Initial oxygen concentration

in the cell was presumed 3 %vol in the analysis to cover the design value of 2 %vol. Reaction between sodium and oxygen was considered as $2Na + O_2 \rightarrow Na_2 + O_2 + 435$ kJ/mol. Receiving these analytical data, design specifications of the HVAC systems and the cell liners were discussed and estimated. In this way, the cell boundaries of HVAC systems were designed to endure against a pressure of 98 kPa and a temperature of 300℃ respectively.

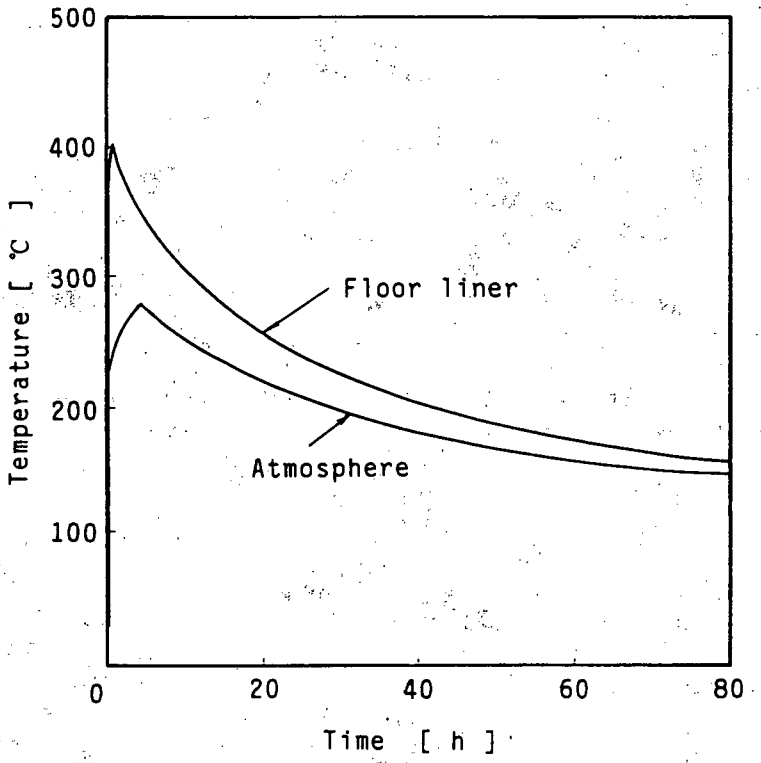

Figure 9 Transition of temperature in a lowermost room at the sodium spill from hot leg piping

C. Results of Pre-operational Tests

The function test of fans, the interlocking and alarm tests, the air flow test, the filter efficiency test and the temperature measurement test were carried out for the HVAC systems at the pre-operational test stage. In addition, the atmospheric leakage rate test and the atmospheric gas purging test have been conducted for the gastight cells and the inert gas cooling systems.

The total area of approximately 12,000 m² is lined with steel plates to form the gastight cells, for which the allowable leakage rate is 100 %vol/day out-leakage or in-leakage at the pressure differential of 100 mmAq. To achieve acceptable gastightness, much quality control work was applied to materials, welders and welding methods. All welding lines were non-destructively examined by visual inspection, vacuum box inspection and liquid penetrant inspection. Then ducts and units of the inert gas cooling systems were examined by soap bubble test. Table 5 shows the results of atmospheric leakage rate test for 24 hours. Owing to the strict quality control, the cells obtained good gastightness of less than one-hundredth compared with the design allowance. Results were sufficiently contented with the value of 1 %vol/day which is a design target to reduce the nitrogen leakage

from the cell.

Table 5 Results of atmospheric leakage rate test for 24 hours[3]

Area	Design	Volume	Test Results
R/B-A	100 %vol/day at 100 mmAq	4,180 m³	0.49 %vol/day
R/B-B & R/C		8,040 m³	0.14 %vol/day
R/B-C		3,960 m³	0.46 %vol/day
A/B-E		3,730 m³	0.40 %vol/day

R/B : Reactor building, R/C : Reactor cavity,
A/B : Reactor auxiliary building, -A.-B.-C.-E : Cell division

With regard to substitution of nitrogen for air in the cells, the inert gas cooling systems can adopt both a batch method and a continuous flowing method. The batch method means that exhaust is done after pressurization and repeated, while the continuous flowing method means that continuous feed and exhaust are carried out until density of oxygen is below 2 %vol. Either method is to be selected according to the exhaust line condition of the HVAC systems. The continuous flowing method is superior in shortening of the ventilating time, while infe-

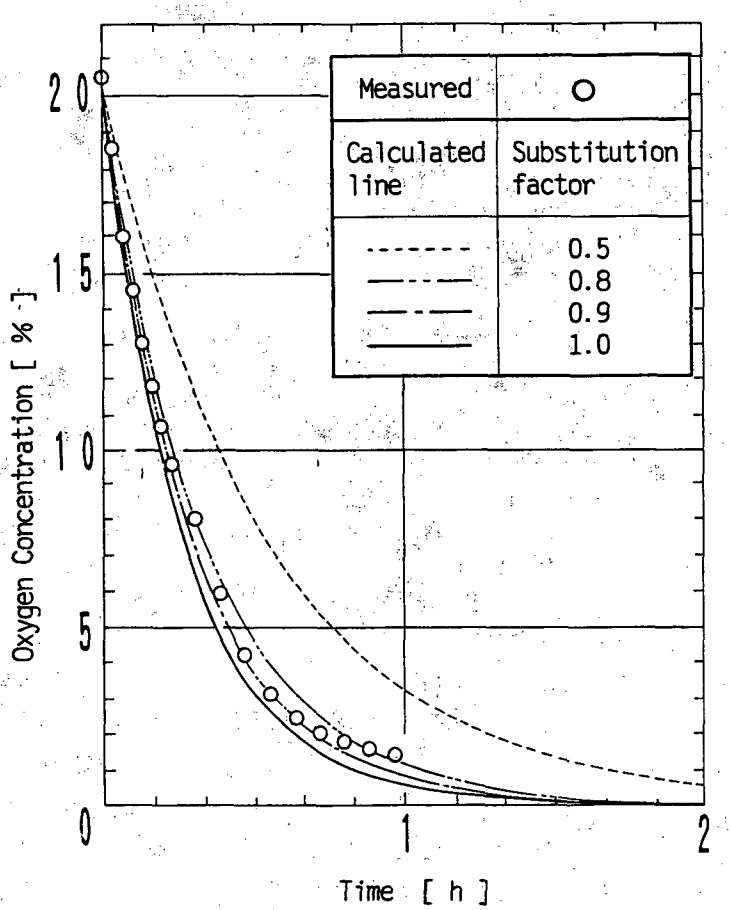

Figure 10 A result of atmospheric gas purging test by the continuous flow method for the fuel handling facility inert gas system

rior in consuming nitrogen gas. Moreover, the continuous flowing method is easier to operate than the batch method. The amount of nitrogen gas required for ventilation depends on a substitution factor, though the factor is rather hard to predict by calculation. The substitution factor means S in the following equation.

$$D = (D_0 - D_I)\, e^{-Sqt/V} + D_I \qquad (1)$$

D : Oxygen Density in Cell, D_0 : Initial Oxygen Density in Cell
D_I : Oxygen Density of Inlet Gas, S : Substitution Factor
q : Inlet Gas Flow Rate, t : Time, V : Volume of Cell

At an economical point of view, a large substitution factor is preferable because it makes ventilating time shorter and consuming nitrogen gas smaller. Figure 10 shows a result of atmospheric gas purging test by the continuous flowing method for the fuel handling facility inert gas cooling system. The concentration of oxygen in the cell decreased sharply and the substitution factor of approximately 0.9 was obtained. The value of 0.9 by the continuous flowing method is so large that the batch method is unnecessary to use for saving the nitrogen gas.

V. Conclusions

MONJU is the first prototype FBR in Japan which employs sodium as coolant. The sodium spill is a design basis accident and is also considered in the design of HVAC systems of MONJU. The characteristics and performances of the HVAC systems can be summarized as follows.

(1) The annulus is a gastight structure as a secondary reactor containment and is kept in a negative pressure less than -15 mmAq by the annulus ventilation system during reactor operation.

(2) Caused by the back-pressure from the vent stack, the exhaust line of the annulus ventilation system is difficult to maintain the required negative pressure and exhaust flow ratio. However, the negative pressure and exhaust flow ratio have been confirmed to meet the design values by controlling damper openings based on the pre-operational test data.

(3) To minimize release of radioactive substances, the annulus ventilation system is equipped with the bed type charcoal filter having a thickness of 20 cm, and its efficiency of over 99 % was confirmed by the laboratory and the pre-operational tests.

(4) Sodium spill accident is considered in the design of the annulus ventilation system, and the multilayer filter is provided in the filter unit to prevent sodium aerosol from clogging the HEPA filter.

(5) Rooms for components containing radioactive sodium are lined with steel plates to form gastight cells, and are kept in a low oxygen atmosphere less than 3 %vol to suppress sodium combustion by the HVAC systems.

(6) The leakage rates from the cells have achieved less than 1 %vol /day at a pressure differential of 100 mmAq, which is sufficiently low compared with the design value of 100 %vol/day.

(7) Substitution factor of approximately 0.9 has been obtained by the atmospheric gas purging test of the EVST rooms from air to nitrogen.

References

(1) U.S. NRC,'Standard review plan', Sec.6.5.3, NUREG-75/087
(2) A.Otaka, O.Nozaki,'Experiment on a multilayer type air filter for the filtration of sodium aerosol', 19th DOE/NRC Nucl. Air Clean. Conf., vol.1, 408-425, (1986)
(3) M.Ikeda, K.Kawata, M.Sato, M.Ito, K.Hayashi, S.Kunishima,'Design and construction of reactor containment systems of the prototype fast breeder reactor MONJU', Inter. Conf. of Fast Reactor and Related Fuel Cycles, vol.1, 8.7,(1991)
(4) T.Sano, Y.Abe, T.Kiyokawa,'Experimental studies on sodium columnar fire and pool fire', Fast Reactor Safety Meeting, Lyon, vol.Ⅲ, 13-22,(1982)
(5) R.Kawabe, A.Suzuki, N.Sagawa,'Experiment and analyses of sodium spray combustion', Fast Reactor Safety Meeting, Lyon, vol.Ⅲ, 65-70,(1982)

DISCUSSION

PORCO: What is the filtering medium for multilayer filters and what are the loading characteristics for the sodium aerosol?

FUJIMORI: The filtering medium for the 5-layer multilayer filter is made from high-silica glass fiber. The multilayer filter has some holes to avoid plugging by the sodium aerosol. Detailed information has been provided at the 19th DOE/NRC Air Cleaning Conference.

MODERN TECHNOLOGY TOOLS FOR IMPROVEMENT OF NPP RELIABILITY

-CASE STUDY OF NPP FILTRATION SYSTEMS VALIDATION-

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Abstract

The relationship which describes influence of ageing, relative humidity and organic poisons on the adsorption quality of coconut charcoal has been established. On the basis of the established relationship the computer program, for easy calculations of the reliable operation time of the adsorbent media in the charcoal filters of any single nuclear air cleaning system, was proposed. The program enables determination the life time of charcoal filters in the standard cases of working regime or in a real time.

Introduction and Scope

During normal working regime of NPP or possibly an unlikely event, as reactor accident, the certain amount of radioactive materials will be released to the containment atmosphere and become airborne and potentially dangerous for the environment. Among these radioactive materials iodine is the most important nuclide due to the volatility of its compounds and great radiological effects. Activated charcoal, as the adsorbent media, arranged in filters either as the absorber cells (Type II) or as the sorbers (Type III)[(1)] is used for trapping radioiodine released during these events, as well as during the normal operation of a reactor. These makes charcoal filters the most responsible component of an nuclear air-cleaning system in the view of environmental protection from gaseous and volatile effluents during normal and accidental operation of NPP. At the same time carbon looses its adsorption properties due to ageing, poisoning, oxidation of the surface,

humidity and the temperature of air. For prediction of the reliability of filter media or carbon filter systems complete relations between the adsorption quality of carbon and influence of the poisons have to be known.

The first such relationship was made only for ageing.[2] In the literature exist a lot of experimental data of influence of water and other poisons on adsorption quality of carbon[3-12] and on the basis of these experimental results we have made the relationship which connect the influence of "all poisons" (ageing, humidity and air borne organic compounds) on adsrpption quality of carbon.[13]

The aim of this work is to establish, on the basis of this relationship,[13] the numerical simulation model for prediction of the life time of the filter media and filter systems as a function of the time from the last in-service inspection and laboratory control of carbon adsorption parameters and known parameters of air stream (T^0C, RH, content of poisons) obtained in NPP in the meantime.

The numerical model will enable construction of computer program for easy and fast calculation of the life time of carbon in Nuclear Air Treatment Systems (NATS).

Principle

A brief statement of the construction procedure of the dependence of life time of carbons on all poisons concentration is given here while the details are available elsewhere.[13]

The studies of adsorption on active carbon have shown,[14,15] that its external surface is negligible but is permeated by micropores-pores, whose diameter range is believed to be between 5-20 Å. The adsorption of volatile iodine compounds take place in these pores, and at the same time is seriously thwarted by a competitive interaction of water and air borne organic compounds adsorption, which might easily turn into insufficient decontamination degree of carbon.

In the literature, the experimental data of organic poisons diameters can not be found. In this work, we consider the possibility to calculate these diameters using the charge density calculations established by Bader et al.[17,18] They concluded that in general over 95% of molecular charge lies within the 0.02 contour, so that the dimensions of this contour may provide a useful theoretical measure of molecular size. To be consistent we have also calculated the diameter of water molecule.

To find a complete relation of adsorption capacity of carbon, it is necessary to consider separately the effects on adsorption

capacity of carbon for each of the poisons.

Influence of ageing

The relationship for ageing:[2]

$$\log K = \log K_0 - 0.3\times10^{-8}N - 1.3\times10^{-3}t \qquad (1)$$

where: t-age of charcoal in weeks; K_0-initial performance index of the trap; K-performance index after time t; N-number of air changes to which the trap is exposed from the start of in-service life.

Influence of water

Relative humidity appears to be a very important parameter in reduction of the adsorption capacity of carbon. The quantity of adsorbed water on carbon depends on its concentration in air, which is proportional to vapor pressure of water on given temperature and relative humidity.

On the basis of these experimental results[3-8] the following relationship was established:[13]

$$\log K = \log K_0 - Atp_w \qquad (2)$$

where: A is the constant depending on kind of carbon, for coconut carbon $A=5.9\times10^{-5}$; p_w is the vapor pressure of water on the given temperature and relative humidity (mm Hg).

Influence of air borne organic compounds

Aliphatic and aromatic organic compounds were detected on the charcoal taken from NPP in-service filters,[6,9] and experimental results[6,9] show that the adsorption of aliphatic organic compounds (nonane to tetradecane) and xylene on charcoal cause fastest decrease of K factor.

The diameter of these compounds calculated by Bader[16,17] charge density values is from 7.1 Å for nonane to 8.1 Å for tetradecane, so that all of them can be adsorbed in micropores of carbon.

Investigation of adsorption of aliphatic organic compounds on active carbon showed that nonane is adsorbed on micropores of carbon stronger than other compounds and disable their adsorption.[15,10,11] For this reason nonane was chosen as the representative organic molecule for calculation of the influence of

organic poisons, and the following relationship has been established:[13]

$$\log K = \log K_0 - BtC_p p_p \qquad (3)$$

where: B is the constant depending on the kind of carbon, for coconut carbon it is 0.226; C_p is the concentration of organic compounds in air stream; p_p is vapor pressure of nonane, representative compound, on given temperature; t is the time in weeks.

Influence of all poisons

Influence of aging and all poisons (humidity and air borne organic compounds) on adsorption quality for coconut carbon can be presented by one equation having in mind next assumptions:
- concentration of water in air stream is proportional to vapor pressure on given temperature and relative humidity,
- air borne organic can all be represented as nonane.
Equations (1-3) give the final relationship:[13]

$$\log K = \log K_0 - 0.3\times10^{-8}N - 1.3\times10^{-3}t - 5.9\times10^{-5}tp_w - 0.226tC_p p_p \qquad (4)$$

where: K - index of performance after time t; K_0 - index of performance of the trap obtained by the last laboratory control; N - number of air changes; t - time in weeks; p_w - vapor pressure of water on the temperature and relative humidity of considered case; C_p -concentration of air borne organic compounds; p_p - vapor pressure of nonane at the temperature of considered case.

Life time of carbon under various conditions

Equation (4) can be rearranged so that the validity time of carbon filter, in normal regime or from the beginning of accident or incident, can be simply calculated . The term $0.3\times10^{-8}N$, in equation (4), is too small comparing with the others and can be neglected, so the expression for t can be presented as:[13]

$$t = \frac{\log K_0 - \log K}{1.3\times10^{-3} - 5.9\times10^{-5}p_w - 0.226C_p p_p} \text{ (weeks)} \qquad (5)$$

The equation (5) can be now used as the basis for a computer program.

Description of CarbExp Computer Program

In the literature we find only in the paper of W.P.Freeman and J.C.Enneking[12] that the computer program was used for calculation of the amount of evaporated solvents in NATS.

According to the equation 5 presented above, a computer program CarbExp was made, in order to enable quick prediction of filter media life time. CarbExp is user friendly, written in high level language and therefore highly portable.

Program user can input the relevant parameters either through the interactive dialogue, or in the text file. The results obtained are presented in the table form for various values of K-factor. Every table entry contains results for four working regimes of NPP characterized by specific temperature, relative humidity and concentration of poisons. Parameters for four characteristic working regimes can be redefined for any particular case. Parameters assumed in this paper are:

NORMAL OPERATION	-> $T=25^0C$; RH=40%; $c_p=0.0001\%$
FIRST INCIDENT	-> $T=80^0C$; RH=70%; $c_p=0.0015\%$
SECOND INCIDENT	-> $T=90^0C$; RH=95%; $c_p=0.0015\%$
ACCIDENTAL SITUATION	-> $T=60^0C$; RH=98%; $c_p=0.0020\%$

The presented life time values of filter media validity can be durations in hours or absolute dates computed relatively to the moment of filter installation.

Example given in Table 1. shows entire dialogue with input parameters and obtained results.

Special feature of the program makes possible the examination of the specific situation which can occur during normal operation. The value of temperature, relative humidity and concentration of poisons for the specific situation must be given, as well as its duration in hours. Two successive values of Ko at the beginning and at the end of the specific situation are computed, and table entries for K-factor between those values are filled in with *. An example for such a case is presented in the Table 2.

Finally, if computed Ko is less than critical value of K, denoted as Kc, the table is not presented, and the operator is instructed to change the carbon immediately, as shown in the Table 3.

Conclusion

The results obtained by equation (5), Tables 1 - 3, also show that the equation is promising for quick prediction of validity time of carbon filters in many various situations. If it is accepted that the carbon filter is the most sensitive component of the filtration unit of air cleaning system in NPP, the usage of the equation (5) may contribute in bringing a relevant decision, from the control room of the NPP,about the reliability of filter systems working time, in the normal, incidental and accidental situations. With CarbExp application a regular maintenance plan for carbon filters could be improved, the final result being the impact on improvement of reliability of the NPP.

Further development of CarbExp will lead to NATSExp (Nuclear Air Treatment System Expert) development as a complete expert system for filtration system validation, which will include reciprocal influence and mutual impact of all exchangeable components of filtration unit and may become a regular working tool for predicting the filtration system performance.

Acknowledgment

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References

1. Code on Nuclear Air Cleaning and Gas Tretment, ASME/ANSI AG-1-1988.
2. Radioiodine Removal in Nuclear facilities, Technical Report Series No. 201, IEAE, Vienna 1980, p. 20.
3. Lj.VUJISIĆ and D.Lj.VUČKOVIĆ, Investigation of Removal of ^{131}I from Off-Gas Stream from Nuclear Power Plant Krško, *IAEA Research Contract No. 4080/R2/RB, Final Report,* 1988; and unpublished data.
4. B.H.M. BILLINGE and D.BROADBENT, The Effects of Temperature and Humidity on the Ageing of TEDA Impregnated Charcoals, *IAEA Contract 4360/R1/CF, Progress Report*, 1986.
5. H.DEUBER and J.G.WILHEM, Retention of Elemental Radioiodine by Deep Bed Carbon Filters Under Accident Conditions, *Proceedings of the 17th DOE Nuclear Air Cleaning Conference, Ed. M.W.First,* **Vol. 1,** p. 248, 1983.
6. D.BROADBENT, The Ageing and poisoning of Charcoal used in Plant Air Cleaning Systems, *Gaseous Effluent Treatment in Nuclear Installations, Eds. G.Fraser and F.Luykx,* Graham & Trotman, p. 463, 1985.
7. M.G.EVANS and J.J.HILLARY,Recent Studies on the Performance of Impregnated Charcoals for Trapping Methyl Iodide, after Exposure to Moist Air, *Gaseous Effluent Treatment in Nuclear Installations, Eds. G.Fraser and F.Luykx,* Graham & Trotman, p. 475, 1985.
8. C.D.SCARPELLINO and C.W.SILL, Final Technical Evaluation Report for the NRC/INEL Activated Carbon Testing Program, *Prepared for the U.S. Nuclear Regulatory Commission, Under DOE Contract No. DE-AC07-76ID01570*, April 1987.
9. H.DEUBER, K.GERLACH, V.GIRAUD and R.KAEMPFFER, Investigation of the Aging of various Activated Carbons in the Exhaust Air of PWR Over an Extended Period of Time, *Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference, Ed. M.W.First*, **Vol. 1,** p. 243, 1986.
10. F.RODRIGUEZ-REINOSO, J.M.MARTIN-MARTINEZ, M.MOLINA-SABIO, R.TORREGROSA and J.GARRIDO-SEGOVIA, Evaluation of the Microporosity in Activated Carbons by n-Nonane Preadsorption, *J.Colloid Interface Sci.,* **106**,315(1985).
11. J. de D.CASQUERO-RUIZ, J.M.GUIL, J. de D.LOPEZ-GONZALEZ and A.RUIZ-PANIEGO, Study of the Porous Structure of Active Carbons by Nitrogen Adsorption and n-Nonane Preadsorption, *Carbon,* **26**,646(1988).
12. W.P.FREEMAN and J.C.ENNEKING, AStudy of the Effects of the Coatings Operation on Radioiodine Removing Adsorbents, Proceedings of the 21st DOE?NRC Nuclear Air Cleaning Conference, San Diego, 1990.
13. Lj.VUJISIĆ and Z.DRACE, to be published.
14. A.J.JUHOLA and E.O.WIIG, Pore Structure in Activated Charcoal. I. Determination of Micro Pore Size Distribution, *J.Am.Chem.Soc.*,**71**,2069(1949).

15. S.J.GREGG and J.F.LANGFORD,Evaluation of Microporosity with Special Reference to a Carbon Black, *Trans.Faraday Soc.*, **65**,1394(1969).
16. R.F.W.BADER and W.H.HENNEKER, Molecular Charge Distribution and Chemical Binding, *J.Chem.Phys.*, **46**,3341(1967).
17. R.F.W.BADER, M.T.CARROLL, J.R.CHEESEMAN and C.CHENG, Properties of Atoms in Molecules: Atomic Volumes, *J.Amer.Chem.Soc.*, **109**,7968(1987).

Table 1.

CarbExp **Bgd, 1992.**

CARBON FILTER VALIDATION PROGRAM

Enter the name of the system >**VA 441 PLM01**
Enter the time of carbon exchange:
--Year-->**1992**
--Month->**7**
--Day--->**16**
--Hour-->**16**
Time after last exchange is 0.00 weeks.
Enter the initial producer value of K-factor (Kp) >**17**
Enter the number of air changes per week (B) >**2520**
Enter the range for user K-factor:
--Max-->**17**
--Min-->**10**
Enter the value of increment between K values in table >**1**
Do You want Standard cases table or Your case table (S/Y) >**S**
Do You want absolute Dates or durations in Hours (D/H) >**D**

LIFE TIME OF THE FILTER MEDIA
FOR THE VARIOUS VALUES OF K-FACTOR

Values for system VA 441 PLM01: Current date is: 16-07-1992 17h

K	NORMAL OPERATION	FIRST INCIDENT	SECOND INCIDENT	ACCIDENTAL SITUATION
17.000	16-07-1992 16h	16-07-1992 16h	16-07-1992 16h	16-07-1992 16h
16.000	18-10-1992 19h	21-07-1992 04h	19-07-1992 09h	24-07-1992 12h
15.000	27-01-1993 00h	26-07-1992 00h	22-07-1992 07h	01-08-1992 22h
14.000	14-05-1993 03h	31-07-1992 04h	25-07-1992 09h	10-08-1992 21h
13.000	06-09-1993 05h	05-08-1992 17h	28-07-1992 17h	20-08-1992 12h
12.000	08-01-1994 12h	11-08-1992 17h	01-08-1992 08h	30-08-1992 21h
11.000	23-05-1994 15h	18-08-1992 05h	05-08-1992 06h	11-09-1992 05h
10.000	18-10-1994 15h	25-08-1992 09h	09-08-1992 13h	23-09-1992 14h

Table 2.

```
CarbExp                                                    Bgd, 1992.

                    CARBON FILTER VALIDATION PROGRAM

Enter the name of the system >VA 441 PLM01
Enter the time of carbon exchange:
--Year-->1992
--Month->6
--Day--->16
--Hour-->17
Time after last exchange is   4.29 weeks.
Enter the initial producer value of K-factor (Kp) >17
Enter the initial concentration of poissons (Cpo) >0.0001
Enter the number of air changes per week (B) >2520
Enter the range for user K-factor:
--Max-->17
--Min-->5
Enter the value of increment between K values in table >1
Do You want Standard cases table or Your case table (S/Y) >Y
Do You want absolute Dates or durations in Hours (D/H) >D
Enter Your value of temperature in C degrees (T) >90
Enter Your value of humidity in % (RH) >98
Enter Your value of concentration of poissons (Cp) >0.015
Enter the value of critical K factor (Kc) >8
Enter the time of the begining of abnormal situation:
--Year-->1992
--Month->7
--Day--->16
--Hour-->17
Duration of normal operation was   4.29 weeks.
Enter duration time of abnormal situation in hours (Ta) >15
```

Table2. cont.

LIFE TIME OF THE FILTER MEDIA
FOR VARIOUS VALUES OF K-FACTOR AFTER SPECIFIC SITUATION

Values for system VA 441 PLM01 First Ko: 16.673 Second Ko:15.358

K	NORMAL OPERATION	FIRST INCIDENT	SECOND INCIDENT	ACCIDENTAL SITUATION
17.000	17-06-1992 06h	15-07-1992 22h	16-07-1992 12h	14-07-1992 20h
16.000	**********	**********	**********	**********
15.000	22-08-1992 23h	19-07-1992 02h	18-07-1992 09h	20-07-1992 09h
14.000	08-12-1992 02h	24-07-1992 06h	21-07-1992 12h	29-07-1992 08h
13.000	02-04-1993 04h	29-07-1992 19h	24-07-1992 20h	07-08-1992 23h
12.000	04-08-1993 11h	04-08-1992 19h	28-07-1992 10h	18-08-1992 09h
11.000	17-12-1993 14h	11-08-1992 07h	01-08-1992 08h	29-08-1992 16h
10.000	14-05-1994 14h	18-08-1992 10h	05-08-1992 15h	11-09-1992 01h
9.000	25-10-1994 05h	26-08-1992 08h	10-08-1992 09h	24-09-1992 17h
8.000	26-04-1995 03h	04-09-1992 03h	15-08-1992 16h	10-10-1992 01h
7.000	19-11-1995 11h	14-09-1992 03h	21-08-1992 16h	27-10-1992 09h
6.000	15-07-1996 20h	25-09-1992 16h	28-08-1992 15h	16-11-1992 09h
5.000	24-04-1997 23h	09-10-1992 07h	05-09-1992 20h	10-12-1992 02h

Table 3.

```
CarbExp                                                    Bgd, 1992.

                    CARBON FILTER VALIDATION PROGRAM

Enter the name of the system >VA 441 PLM01
Enter the time of carbon exchange:
--Year-->1989
--Month->6
--Day--->16
--Hour-->17
Time after last exchange is 160.86 weeks.
Enter the initial producer value of K-factor (Kp) >17
Enter the initial concentration of poissons (Cpo) >0.0001
Enter the number of air changes per week (B) >2520
Enter the range for user K-factor:
--Max-->17
--Min-->8
Enter the value of increment between K values in table >1
Do You want Standard cases table or Your case table (S/Y) >Y
Do You want absolute Dates or durations in Hours (D/H) >D
Enter Your value of temperature in C degrees (T) >90
Enter Your value of humidity in % (RH) >98
Enter Your value of concentration of poissons (Cp) >0.015
Enter the value of critical K factor (Kc) >8
Enter the time of the begining of abnormal situation:
--Year-->1992
--Month->7
--Day--->16
--Hour-->17
Duration of normal operation was 160.86 weeks.
Enter duration time of abnormal situation in hours (Ta) >15


                    Evaluated K is:  7.562
                EXCHANGE CARBON IMMEDIATELLY !!!
```

HEATER SELECTION CRITERIA FOR ENGINEERED SAFETY FEATURES ATMOSPHERE FILTRATION SYSTEMS

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Abstract

U.S. nuclear power plants incorporate engineered safety features atmosphere filtration systems (ESFAFS) in their design as a means of limiting radiation exposure to individuals in the event of a design basis radiological accident. These systems typically utilize heaters to limit the relative humidity of the filtered air to 70 percent or less in order to obtain the desired level of efficiency from the charcoal adsorbers. ANSI/ASME N509 requires that these heaters be sized to reduce the maximum expected relative humidity of the airstream to approximately 70 percent at the system design flowrate. However, in some cases the criteria used to select these heaters may not consider the worst case conditions that could occur both during and following a design basis accident. Degraded electrical system voltage, airflow variations, and accident condition heat loads are significant factors in the heater selection process that are commonly overlooked.

The Vogtle Electric Generating Plant ESFAFS heaters were originally selected without considering these worst case conditions. As a result, several systems were found to have insufficient heater capacity to maintain the previously assumed humidity levels and filtration efficiency. To compensate for the undersized heaters, the Technical Specifications and accident analysis were revised to reflect the potential impact of increased relative humidity on the charcoal adsorber filtration performance.

I. Introduction

The ESFAFS at the Vogtle Electric Generating Plant* are designed to perform two major functions in the event of a design basis radiological accident:

1. Limit the radiation exposure to individuals located offsite to within the guidelines established in 10 CFR 100.[1]
2. Limit the radiation exposure to operating personnel located in the control room to within the limits established in 10 CFR 50, Appendix A, GDC 19.[2]

To ensure that the ESFAFS can remove the required level of radioactive iodine from the filtered air, the activated charcoal adsorbers are conservatively designed to be consistent with the decontamination efficiencies and laboratory test requirements given in Table 2 of Regulatory Guide 1.52.[3] Plant Vogtle's 4-inch deep charcoal adsorbers are assigned a decontamination efficiency of 99.0 percent with a corresponding laboratory test criteria of 99.8 percent, based on a system with the relative humidity (RH) controlled to 70 percent or less. The assigned decontamination values are then used in the plant accident analysis to verify conformance with the radiation exposure criteria.

To verify that the ESFAFS maintain the assigned efficiencies, periodic surveillance tests are performed in accordance with ANSI/ASME N510-1980[4] and the plant Technical Specifications.[5] These surveillance tests verify, among other functions, that the heaters dissipate specific power levels in accordance with the project specifications. The Plant Vogtle Technical Specifications require that the heater power dissipation be verified within a specific kilowatt (kW) range (i.e., kW ± kW). These values were originally derived on the basis of heat transfer calculations, performed in accordance with Section 5.5.1 of ANSI/ASME N509-1980,[6] to ensure that the maximum expected RH of the entering air is reduced to approximately 70 percent at the system design flowrate.

Although the calculation method used to size the ESFAFS heaters included the design air flowrate and assumed 100-percent RH entering air, the following plant design basis conditions were not considered in the selection process:

- Degraded electrical distribution system voltage under design basis accident conditions.
- Maximum system air flowrate allowed by the Technical Specifications.
- Accident condition heat loads (maximum inlet temperature).

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* Westinghouse 4-loop PWR operated by Georgia Power Company

II. Criteria Discussion

Electrical Distribution System Degraded Voltage

Degraded voltage is a factor that should be considered within the context of a specific electrical distribution system design. The Plant Vogtle electrical distribution system design criteria require that the safety-related loads on the 480 Vac distribution system provide rated performance at 460 volts ± 10 percent. Therefore, the ESFAFS heaters that are supplied power from the 480 Vac distribution system should be sized to function with the minimum design voltage (414 Vac). However, the ESFAFS heaters were originally sized without consideration of degraded voltage and were purchased to provide the required heat dissipation at a nominal 480 volts. Per ANSI/IEEE Standard 141,[7] "The energy input and, therefore, the heat output of resistance heaters varies approximately as the square of the impressed voltage". Therefore, when the minimum design voltage available is considered, the output of the heater would be reduced as follows:

$$kW_{MINIMUM} = \left(\frac{Voltage_{MINIMUM}}{Voltage_{RATED}}\right)^2 \times kW_{RATED} \quad (1)$$

Where: Heater resistance is constant and the power factor is 1.0

Maximum System Air Flowrate

Air flowrate above the system nominal design values should also be considered in the ESFAFS heater selection process. The Plant Vogtle Technical Specification surveillance tests require that the ESFAFS design flowrate be verified within ± 10 percent on a periodic basis, which is consistent with the Standard Technical Specifications for Westinghouse Plants[8] and Section 8.3.1 of ANSI/ASME N510-1980. This flow tolerance allows the design airflow to be verified under actual field conditions at the minimum and maximum filter pressure drop. Since the maximum allowable mass flowrate results in maximum required heater capacity, the Technical Specification upper limit (nominal design flow + 10 percent) should be used in the heater sizing calculations.

Maximum Inlet Temperature

Another factor that is commonly overlooked in ESFAFS heater selection is the maximum inlet temperature combined with the worst case humidity. Some of the calculations for the Plant Vogtle ESFAFS failed to account for the elevated temperatures that may be experienced during accident conditions. For example, the fuel handling building post-accident filtration system heater calculations assumed the entering air temperature to be at the minimum normal conditions (60°F). However, the postulated accident conditions could result in inlet temperatures in excess of 100°F. Although the impact of inlet temperature variations on required heater capacity is relatively small when compared to degraded voltage and increased air flow, it is a criterion that should be considered in the overall heater selection process.

III. System Analysis

When combined, the additional criteria can have a significant impact on the ESFAFS heater selection process. The following analysis of a Plant Vogtle ESFAFS demonstrates the combined effect that the worst case conditions can have on heater size requirements:

System Name: Piping Penetration Area Filtration and Exhaust System (PPAFES)

1. Original Specification Design Parameters

Heater Voltage:	480 Vac
System Flowrate:	16,000 ft^3/min
Inlet Air Temp:	104°F
Inlet Air RH:	100%
Humidity Control (RH):	70%

Required Heater Capacity Based on Original Design Parameters

$$q = m_a(h_2-h_1) \quad [9] \qquad (2)$$

where: q = required sensible heat input (Btu/hr)
m_a = mass flowrate of dry air (lb/hr)
h_1 = entering coil enthalpy *
h_2 = leaving coil enthalpy *

* Btu/lb dry air and associated moisture

$$q = \left(\frac{0.06525\ lb}{ft^3} \times \frac{16{,}000\ ft^3}{min} \times \frac{60\ min}{hr} \right) \left(\frac{82.6\ Btu}{lb} - \frac{79.4\ Btu}{lb} \right)$$

q = 200,448 Btu/hr

Required Heater Capacity = 58.7 kW

2. Revised Criteria Design Parameters

Heater Voltage:	414 Vac	(460 -10%)
System Flowrate:	17,050 ft^3/min	(Tech Spec + 10%)
Inlet Air Temp:	168°F	(Accident Heat Loads)
Inlet Air RH:	100%	(Steam Environment)
Humidity Control (RH):	70%	

Required Heater Capacity Based on Revised Criteria

$$q = \left(\frac{0.03855\ lb}{ft^3} \times \frac{17{,}050\ ft^3}{min} \times \frac{60\ min}{hr} \right) \left(\frac{502.7\ Btu}{lb} - \frac{496.0\ Btu}{lb} \right)$$

q = 264,226 Btu/hr

Required Heater Capacity = 77.4 kW

The actual heater specified and installed in the Vogtle PPAFES is rated for 80 kW at 480 Vac. This specified value was used as the basis for the Technical Specification surveillance test acceptance criterion of 80 ± 4 kW. However, the Technical Specification did not specify the voltage that the acceptance criterion was based upon. When the specified heater capacity is adjusted to compensate for the nominal design voltage (460 Vac), the actual heater capacity is reduced to 73.5 kW. When the heater is further derated to the minimum design voltage (414 Vac), the actual heater capacity is reduced to 59.5 kW. This indicates that the PPAFES specified heater is deficient by approximately 18 kW when the minimum voltage capacity (59.5 kW) is compared with the revised criteria required capacity (77.4 kW). A properly specified heater for this system would require a minimum rating of 95.6 kW at 460 Vac in order to provide the required 77.4 kW heat dissipation under the worst case accident conditions to maintain 70 percent relative humidity.

A complete analysis of all Plant Vogtle ESFAFS was conducted to verify heater performance with the revised criteria. This analysis included the PPAFES, the Control Room Emergency Filtration System (CREFS), and the Fuel Handling Building Post Accident Filtration System (FHBPAFS). The results of this analysis, as shown in Table 1, indicated that only the CREFS had sufficient capacity to limit the filtered air to 70 percent RH or less. Since no credit was originally taken for the FHBPAFS operation in the plant accident analysis, the immediate operability concerns were focused on the PPAFES. To address this problem, the system was evaluated based on the actual field conditions obtained by Technical Specification surveillance tests.

Table 1

System	Specified Heater Capacity (480 Vac)	Minimum Voltage Capacity (414 Vac)	Revised Criteria Required Capacity	Revised Criteria Relative Humidity
CREFS	118 kW	87.8 kW	74.0 kW	≤ 70%
PPAFES	80 kW	59.5 kW	77.4 kW	74.1%
FHBPAFS	20 kW	14.9 kW	24.9 kW	80.4%

These tests revealed that the actual system flow was not at the maximum Technical Specification allowable value, and that the calculated voltage drop would not reach the design criteria minimum 414 Vac. When the actual test conditions were considered, the air entering the charcoal absorbers was shown to be controlled below the 70 percent RH limit.

The Nuclear Regulatory Commission (NRC) granted Plant Vogtle a temporary waiver of compliance from the Technical Specification surveillance requirement of verifying a specific heater kW, based on the systems ability to meet the 70 percent RH criterion under the actual test conditions. However, since there was very little safety margin remaining under the test conditions, a commitment was made to consider plant modifications that would increase the margin between the actual heater power and the power required to fulfill the heater design function.

IV. Corrective Actions

In order to provide the PPAFES and the FHBPAFS with additional heater capacity safety margin, the following options were evaluated:

1. Physically modify the heaters and/or the electrical supply system to increase the heater output.
2. Revise the acceptance criteria used to perform the ESFAFS charcoal laboratory testing and the credited decontamination efficiency used in the plant accident analysis.

The first option, although it would clearly provide additional margin by increasing the power output, was by far the most expensive option, considering the safety qualification requirements of the ESFAFS heaters. In addition, a physical modification would be the least desirable from a plant operation standpoint. Therefore, the second option was chosen on the basis that a revision to the plants operating license:

- Was less expensive.
- Involved no physical plant modifications.
- Maintained doses within radiation exposure guidelines.

To implement option two, the charcoal laboratory test conditions were revised from 70 to 95 percent RH to more accurately reflect the reduced capacity humidity control available from the heaters. By increasing the lab test criteria to 95 percent RH, the system would be consistent with the test conditions recommended by ASTM Standard D3803-1989.[10] In addition, the 95 percent RH test condition is generally accepted in the nuclear industry for systems without heaters.[11]

To account for the reduced charcoal efficiency associated with the increased RH conditions, the laboratory test acceptance criteria and the assigned decontamination efficiency were revised to be consistent with Regulatory Guide 1.52 for a system designed to operate inside primary containment (i.e., uncontrolled RH) as indicated in Table 2. The revised values also conform with the recommended safety margin for systems without heaters.[3,11]

Table 2

Regulatory Guide 1.52 Parameter (Organic Iodide)	Old Value	New Value
Lab Test Penetration Criteria	0.2%	10.0%
Accident Analysis Penetration	1.0%	70.0%
Safety Margin	5	7

Accident Analysis Review

To determine the impact of the revised filter efficiencies on the previously calculated radiation dose rates, a new analysis was performed using the new decontamination values. A preliminary analysis indicated that the new decontamination values would result in unacceptably high radiation dose rates if the previous analysis radiation source term assumptions were used. However, a review of these assumptions revealed excessive conservatism in the amount of Emergency Core Cooling System (ECCS) recirculation loop leakage assumed in the Auxiliary Building area served by the PPAFES. The new calculations were performed with a significant reduction in the assumed ECCS leakage and, therefore, a substantially reduced radiation source term. The revised filter conditions in conjunction with the revised radiation source term assumption resulted in an overall reduction of the calculated offsite and control room radiation dose rates.

Technical Specification Changes

The following revisions were made to the Plant Vogtle Technical Specifications to reflect the new ESFAFS surveillance test requirements and provide a basis for the changes:

1. The CREFS heater surveillance test criterion was revised to reflect the lower heat dissipation needed to maintain the original 70 percent RH requirement. The previous test value of 118 kW ± 6 kW was changed to a minimum of 95 kW. The bases to this Technical Specification were revised to clarify that the verification of heater power dissipation for surveillance testing is referenced to 460 volts. This revision will provide verification that sufficient capacity is available under design bases accident conditions to meet the 70 percent relative humidity criterion without being overly restrictive. The charcoal laboratory test conditions remained at 70 percent relative humidity with an efficiency of 99.8 percent.

2. The PPAFES heater surveillance test criterion was revised from 80 kW ± 4 kW to a minimum of 65 kW. The Technical Specification bases were revised to clarify that the heater surveillance test is referenced to 460 volts. The bases were also revised to indicate that since no credit was taken for heater performance in the dose analysis, the heaters would remain in place to provide defense-in-depth. The charcoal lab test conditions were changed from 99.8 percent efficient at 70 percent relative humidity to 90.0 percent efficient at 95 percent relative humidity.

3. The FHBPAFS heater surveillance test criterion was revised from 20 kW ± 2 kW to a minimum of 16 kW. The bases to this Technical Specification currently reflect that no credit is taken for system operation in the safety analysis, and the system remains in place for defense-in-depth. The Technical Specification bases were revised to clarify that the heater surveillance test is referenced to 460 volts. The charcoal lab test conditions were changed from 99.8 percent efficient at 70 percent relative humidity to 90.0 percent efficient at 95 percent relative humidity.

V. Summary

ESF atmosphere filtration systems are designed to operate during accident conditions that can significantly affect the systems heater performance and thus filtration efficiency. In addition to assuming the maximum inlet air relative humidity, the heater selection criteria should also consider the following design basis accident conditions:

- Degraded electrical distribution system voltage.
- Highest allowable system flowrate.
- Accident condition heat loads (maximum inlet temperature).

When the heater selection process fails to consider these design basis accident conditions, the ESFAFS heater may not provide the required performance needed to maintain the filtration efficiency assumed in the plant accident analysis. When an existing system is found to have insufficient heater capacity to maintain the previously assumed filtration efficiency, several options to correct the deficiency are available:

1. Physically modify the heaters and/or the electrical distribution system to increase heater output.
2. Revise the charcoal filter efficiencies to be consistent with the increased relative humidity.

If deficient heaters and/or the electrical distribution system are not modified to increase heater capacity, the credited adsorber decontamination efficiency and charcoal laboratory testing criteria must be revised to reflect the potentially increased relative humidity. A new radiation dose analysis is then required to verify that the revised filter efficiency will not increase dose rates in excess of the established radiation exposure criteria.

References

1. Code of Federal Regulations, Title 10 - Energy, Part 100, "Reactor Site Criteria", (1991).

2. Code of Federal Regulations, Title 10 - Energy, Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants", Criterion Number 19 - "Control Room", (1991).

3. U.S. Nuclear Regulatory Commission, "Design, Testing, and Maintenance Criteria for Post Accident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants", Regulatory Guide 1.52, Revision 2 (1978).

4. The American Society of Mechanical Engineers, "Testing of Nuclear Air-Cleaning Systems", ANSI/ASME N510 (1980).

5. Vogtle Electric Generating Plant Units 1 & 2 Technical Specifications, Docket Nos. 50-424 & 50-425, Appendix A to License Nos. NPF-68 and NPF-81.

6. The American Society of Mechanical Engineers, "Nuclear Power Plant Air Cleaning Units and Components", ANSI/ASME N509 (1980).

7. The Institute of Electrical and Electronics Engineers, IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants, ANSI/IEEE Standard 141 (1986).

8. U.S. Nuclear Regulatory Commission, "Standard Technical Specifications for Westinghouse Pressurized Water Reactors", NUREG-0542, Revision 4 (1981).

9. The American Society of Heating, Refrigerating and Air-Conditioning Engineers, "ASHRAE Handbook - 1981 Fundamentals."

10. American Society for Testing and Materials, "Standard Test Method for Nuclear-Grade Activated Carbon", ASTM D 3803 (1989).

11. Hayes, J.H., "Changes in adsorber testing as a result of NRC generic information." Proceedings of the 21st DOE/NRC Nuclear Air Cleaning Conference, NUREG/CP-0116, CONF-900813, Vol. 2, pp. 607-625 (1990).

DISCUSSION

PORCO: 1) Was your radioiodine lab test velocity increased by 10% to simulate worst case? (40fpm +10%) Was your system (i.e., HEPA filter & charcoal adsorbers) designed for worst case (17,050 cfm vs 16,000)?

HAYES, T: 1) The lab test velocity was not increased. 2) Yes, the system filters remained within the design flowrate limits when the worst case conditions were considered.

WEIDLER: Did you revise your charcoal test method to be consistent with the new system conditions?

HAYES, T: Yes, we included a reference to the 1989 version of ASTM D3803 in our Tech. Spec revision at the NRC's request. We had no problems committing to the new test standard since we were already testing to the more stringent requirements based on the INEL study.

CONTROL ROOM INLEAKAGE TESTING USING TRACER GASES AT ZION GENERATING STATION

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Abstract

In order to assess the amount of air inleakage into the Control Room Envelope at Zion Generating Station (ZGS), a series of tracer gas tests using sulfur hexafluoride (SF_6) were performed on the Control Room ventilation system (PV system) and the Computer Room/Miscellaneous Area ventilation system (OV system) during February, 1991. Two redundant trains, denoted A and B comprise the PV system. Inleakage was measured for each train. An OV supply duct passes through the Control Room Envelope. Leakage from this duct into the Control Room would constitute air leakage into the Control Room Envelope and hence any potential leakage had to be quantified. Each test attempted to measure the contribution (if any) of a particular section of PV return duct or OV supply duct to the total air inleakage into the Control Room.

I. INTRODUCTION

A series of tracer gas tests were performed during February 1991 in order to quantitatively investigate the amount of air leakage into the Control Room Envelope at ZGS. Each test attempted to measure the contribution of a particular section of Control Room Ventilation System (PV) return or Computer and Miscellaneous System (OV) supply duct to the total air leakage into the Control Room Envelope. Figure 1 schematically illustrates the physical relationship of the PV ducting to the various levels within the plant. Note that much of the PV system return duct work is located outside the Control Room Envelope. Thus, inleakage into this portion is of potential concern in studies of Control Room Habitability. Figure 2 provides a schematic view of the OV duct work passing through the Control Room Envelope.

Testing was performed either by creating a homogeneous volume of tracer gas surrounding a run of return duct passing through one of the rooms shown in Figure 1 and sampling within the duct for the presence of tracer gas, or by injecting tracer at a constant rate into a run of duct and sampling within the volume surrounding the duct for the presence or absence of tracer gas.

The electronegative gas, Sulfur Hexafluoride (SF_6), was used as a tracer. This gas is generally recognized as non-toxic, non-reactive, and inert. Since it is easily detectable in minute quantities by means of electron capture gas chromatography, SF_6 is an ideal tracer gas for ventilation system performance investigations. Analytical sensitivity to this gas ranged from 10 parts per million to approximately 50 parts per trillion. Thus, for reasonable injection concentrations, dilutions on the order of 10,000 were easily measured. All tracer gas measurements were performed by means of gas chromatographic instrumentation manufactured for field use.

The testing of both the PV and OV systems was complicated by the existence of flow communication between the PV and OV air handling units both of which are located in the HVAC Equipment Room. Any leakage of air, and hence tracer, from the positive pressure section of the PV system would ultimately be picked up by the PV return and circulated through the PV system. In addition, during the OV system testing, tracer leakage out of the positive pressure portion of the OV system communicated with the negative pressure portion of the PV system which then circulated additional tracer to the Control Room. Thus extreme care had to be exercised in the performance of these tests.

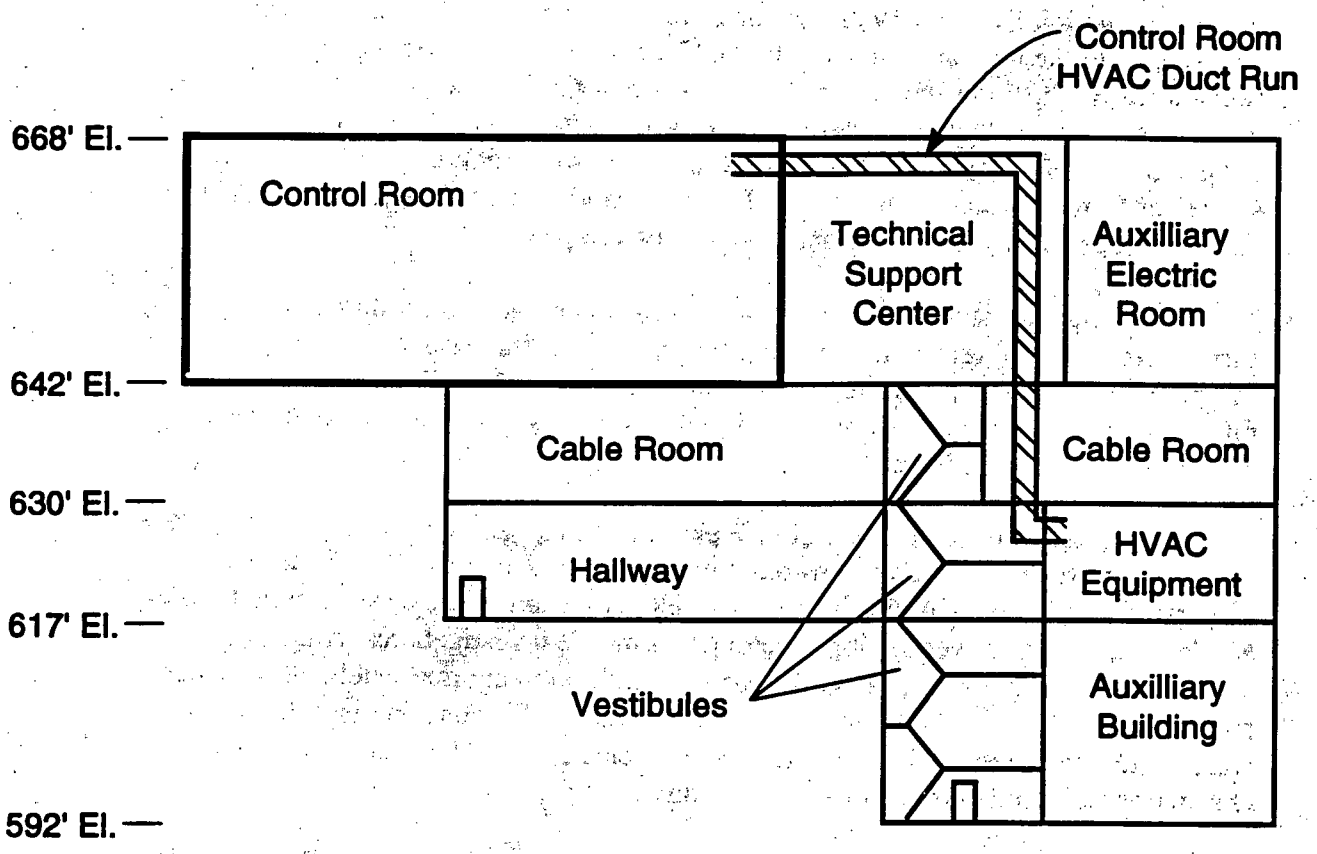

Figure 1. PV Duct runs through plant.

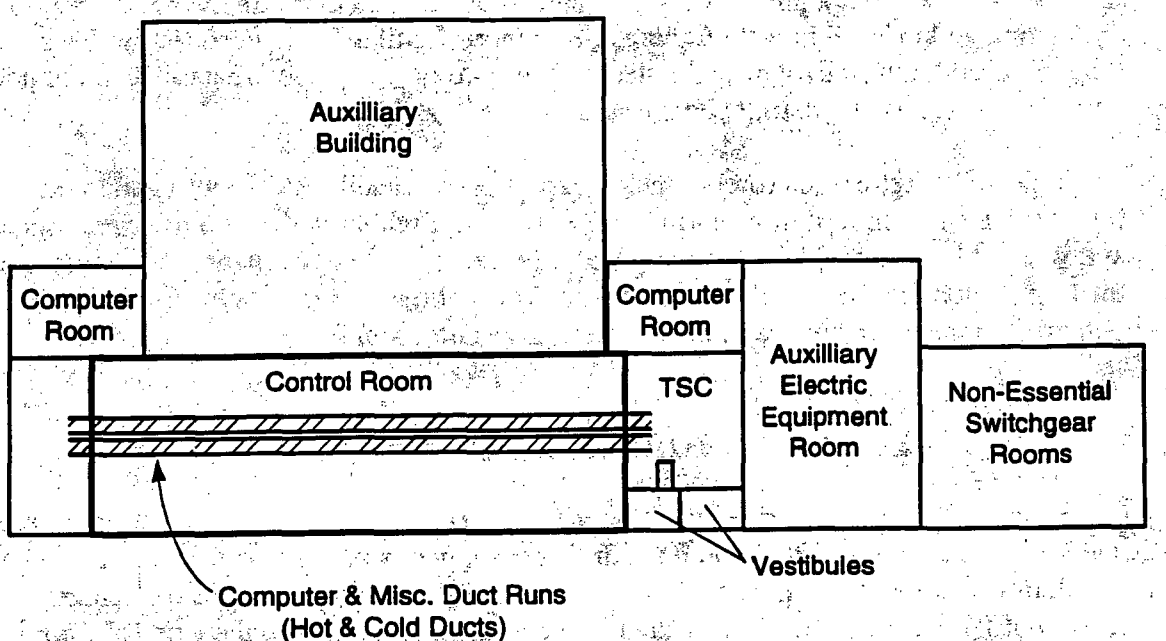

Figure 2. Schematic view of OV duct through Control Room Envelope.

II. TRACER GAS TESTING

The use of a tracer gas(es) to investigate the flow, migration and dispersion of potentially harmful, noxious, or toxic gases and vapors is well established within the industrial hygiene, indoor air quality, and ventilation engineering communities (1,2,3). During the last few years tracer testing results specific to concerns within the nuclear industry have appeared in the literature (4,5). In simplest terms, tracer gas testing provides a means to document the actual performance of an operating ventilation system by tagging and unambiguously tracing one or more ventilation induced flows. This is done by introducing easily measurable, inert, non-toxic, non-reactive gases that are not part of the common industrial background.

The theoretical interpretation and experimental detail necessary to undertake tracer gas testing of complex ventilation systems is provided in the five prior references and will not be discussed further. Application of the principles of mass conservation to tracer injection and tracer measurement conditions allows quantitative information to be obtained on the performance of actual operating ventilation systems.

III. CONTROL ROOM INLEAKAGE TESTING

In order to characterize the amount of inleakage into the Control Room Envelope tracer gas tests were undertaken on six different segments of the Control Room ventilation system. Each test attempted to measure the contribution of a particular section of PV return or OV supply duct to the total air leakage into the Control Room Envelope. With the exception of the OV supply duct test, two tests were performed for each section of duct work--one with the A Train operating and one with the B Train operating. In each test, tracer gas samples were obtained by means of penetrations through access doors in the supply and return ducts located in the Cable Spreading Room.

As a part of each of these tests the PV system supply and return flow rates were measured in the supply and return ducts passing through the Cable Spreading Room using a hot wire anemometer. Duct flow data were taken immediately prior to the initiation of each tracer test. Also, before each test the pressures within the Control Room and the Auxiliary Building were also recorded. These are provided in Table 1.

In the following, the testing on the various portions of the PV return or OV supply ducting is described. A simplified schematic of the Control Room PV system is provided in Figure 3. For convenience, each test sequence is described individually. Inleakage data obtained during each sequence is provided for those portions of ductwork where testing was possible.

IV. HVAC EQUIPMENT ROOM DUCT INLEAKAGE

The negative pressure section of PV duct within the HVAC Equipment Room was tested. Tracer was injected over a 2 minute period at multiple locations within the HVAC Equipment Room. A number of portable fans were used to mix the tracer to assist in homogenizing the tracer concentration. Concentrations were measured at 5 locations within the HVAC Equipment Room. By measuring the average concentration of tracer within the room as well as the tracer concentration within the supply and return ducts it is possible to calculate the inleakage into the PV system using a mass balance equation. Figure 4 illustrates the flow paths for the PV inleakage test.

Table 2 provides measured tracer concentration data and calculated inleakage rates. As can be seen the A Train data at 5, 6, 7, and 8 minutes yield an approximately constant inleakage rate. One can see a similar trend in measurements for the B Train. Thus, for both the A and B Train tests, the data from 5, 6, 7, and 8 minutes have been averaged to provide an estimate of the inleakage. Data obtained at later times were inconsistent due to flow communication between the PV and the OV system.

V. PURGE PLENUM INLEAKAGE

The PV/OV normal outside air intake duct was tested. For each test a tracer gas concentration was established within the Purge Plenum surrounding the PV return duct. Two fans were located within the plenum to ensure adequate mixing. Gas samples within the plenum were obtained by means of a recirculating pump. This allowed samples to be obtained from within the plenum without having to enter it and possibly alter the tracer concentration.

During an initial test, the tracer concentrations obtained in the PV supply and return ducts were much higher than expected implying the existence of a very high inleakage rate into the section PV return duct located within the purge plenum. It was also observed that the concentration within the Purge Plenum itself decayed rapidly

TABLE 1

Pressure Measured During Testing

Test	Auxiliary Bldg Delta P	Control Room Delta P
TSC-A	-0.125	+0.10
TSC-B	-0.250	+0.05
Vestibule-A	-0.35	+0.05
Vestibule-B	-0.25	+0.025
HVAC-A	-0.10	+0.125
HVAC-B	-0.20	+0.07
Purge Rm-A	-0.15	+0.25
Purge Rm-B	-0.15	+0.10
CS Rm-A	-0.35	+0.10
CS Rm-B	-0.30	+0.05
OV CR Flow	-0.10	+0.15

Pressures in Inches of Water Gauge with Respect to Atmosphere

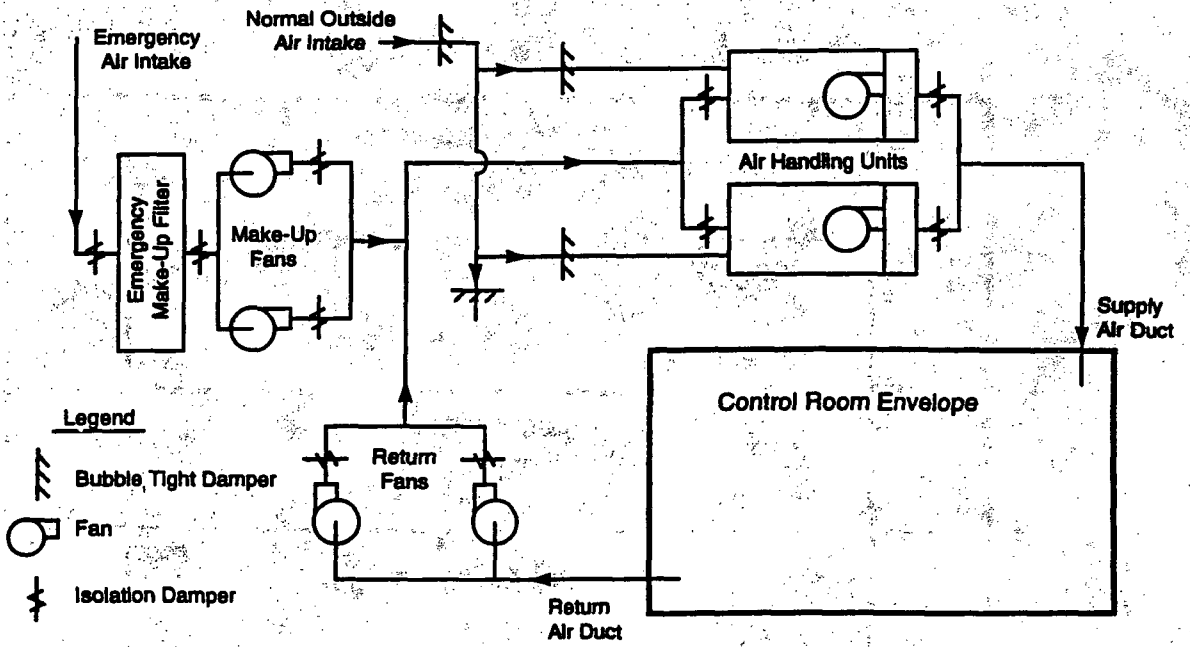

Figure 3. Schematic of Control Room PV system.

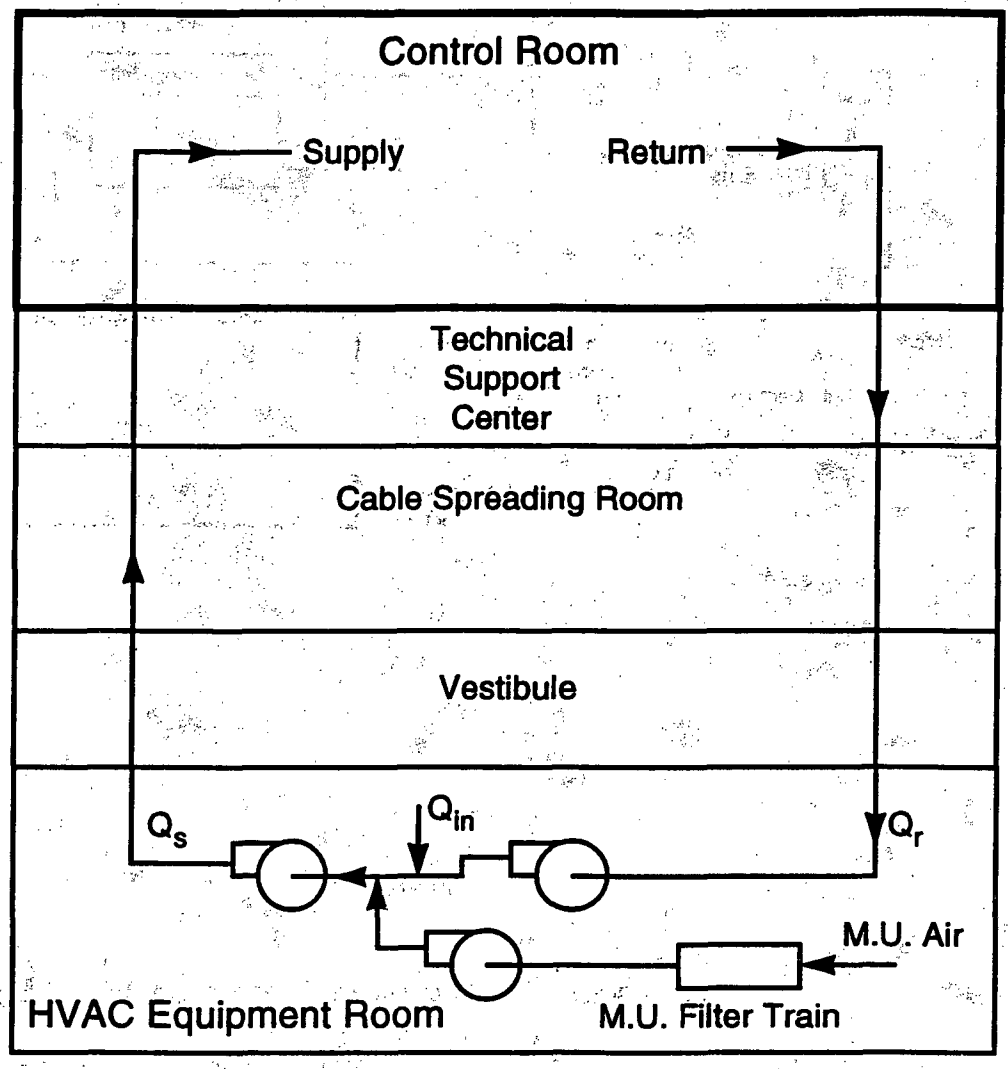

Figure 4. Flow Paths for PV Inleakage Test

TABLE 2

HVAC Equipment Room
PV Duct Inleakage

A Train

Time	Room Conc. (ppb)	Supply Conc. (ppt)	Return Conc. (ppt)	Flow (CFM)
5	30.0	500	92	153
6	28.3	460	92	147
7	26.7	460	118	147
8	25.2	480	120	164

Inleakage Estimate = 153 ± 11 CFM

B Train

Time	Room Conc. (ppb)	Supply Conc. (ppt)	Return Conc. (ppt)	Flow (CFM)
5	35.3	410	32	112
6	31.3	435	67	125
7	27.8	410	90	124
8	24.7	375	140	122

Inleakage Estimate = 121 ± 9 CFM

TABLE 3

Purge Plenum Duct Leakage

A Train

Purge Plenum Conc. (ppb)	PV Supply Conc. (ppt)	PV Return Conc. (ppt)	Inleakage (CFM)
640	520	225	5.5

B Train

Purge Plenum Conc. (ppb)	PV Supply Conc. (ppt)	PV Return Conc. (ppt)	Inleakage (CFM)
550	670	400	6.5

TABLE 4

OV System Leakage into Control Room

Time (min)	Average CR Conc. (ppb)	PV Supply Conc. (ppb)	PV Return Conc. (ppb)	OV Supply Conc. (ppm)	Control Room Inleak (CFM)
15	38.0	12.5	25.0	3.0	115
20	56.3	24.0	27.0	3.0	134

OV System Leakage = 124 $\pm$ 10 CFM

Measured Make-up Flow = 1700 CFM
Measured PV Return Leakage = 153
Total Infiltration Leakage =1853

again implying a very high leakage rate. Additional investigation was undertaken at which time it was discovered that a substantial unsealed penetration existed between the Purge Plenum and the HVAC Equipment Room where the PV duct passed through the HVAC Equipment Room wall. This opening was approximately 2 inches wide and at least 48 inches high. Subsequent testing demonstrated that substantial tracer migrated through this opening almost immediately upon initiation of a test.

Because of this substantial inleakage it was felt that only the "first arrival" measurement of supply and return concentration could provide a realistic estimate of the inleakage in this section of PV duct. Data for both tests are provided in Table 3. These values represent a crude estimate due to the fact that the rapidly increasing tracer concentration within the HVAC Equipment Room affected the measured concentrations within the supply and return duct due to inleakage. However, the estimate is probably good to within a factor of 2.

VI. OV DUCT LEAKAGE INTO CONTROL ROOM ENVELOPE

The OV system positive pressure duct passing through the Control Room Envelope was tested. For this test, tracer gas was injected into the OV supply duct immediately upstream of the A OV supply fan within the HVAC Equipment Room. Two different tests were undertaken. The first was undertaken to establish the existence of any possible leakage from the OV system into the Control Room without regard for quantifying the amount of leakage. This test was performed by injecting tracer into the OV supply duct and sampling by means of a battery operated pulse pump to fill 5 liter Mylar sample bags. The pump was connected to a stainless steel sample wand. This wand was passed over one joint of the OV duct at a time during which a sample bag was filled. The finding of tracer in several these bags demonstrated the existence of OV duct leakage into the main Control Room and necessitated a second OV system test.

For the second test a number of fans were used to mix any tracer gas entering the Control Room Envelope. Tracer was injected into the OV supply duct at a constant rate and air samples were obtained at three locations within the Control Room as well as from the PV supply duct, the PV return duct, and the OV Supply Duct immediately upstream of the OV supply fan. The OV system A Train was chosen for testing due to its evidencing higher static pressure. This test was limited in time due to the discovery of substantial external flow communication between the OV and the PV air handling units which are both located within the HVAC Equipment Room. This external flow communication resulted in the PV system supplying tracer to the Control Room along with the OV system. This occurred by means of PV return system inleakage picking up

and then circulating tracer leaked into the HVAC Equipment Room by the OV supply system. Accordingly, the tracer concentrations within the PV supply and return ducts were monitored with an eye toward terminating the test when this flow communication occurred.

Tracer concentration data along with OV leakage into the Control Room are provided in Table 4. The tracer concentration data were analyzed as follows. For this test both the make-up flow rate (by measurement at the emergency make-up filter unit) and the inleakage rate (from the PV test) are known. As such these comprise the total infiltration or dilution air. Now, since the volume of the Control Room is also known, it is possible to calculate an inleakage rate into the Control Room even though the tracer concentration is not in steady state. So long as the Control Room can be considered a well mixed zone, it is possible to use the mass conservation equation to calculate an inleakage rate.

As can be seen, the data points at 15 minutes and 20 minutes are approximately equal. Accordingly, these two values provide an estimate of the OV supply duct leakage into the Control Room. The scatter in these two numbers also provides an estimate of the uncertainty in the measurement.

VII. VESTIBULE PV RETURN INLEAKAGE

The negative pressure PV duct in the vestibule outside the HVAC Equipment Room was tested by erecting temporary visqueen tent around the ductwork. Tracer was injected into the visqueen tent and mixed for 5 minutes by shaking the walls of the tent. After an initial test determined that samples from different locations within the tent gave similar concentration decay rates, samples were drawn at a single location within the tent as well as from the PV supply duct, the PV return duct, and within the HVAC Equipment Room itself. The tracer concentration data obtained from samples within the supply and return duct could not be interpreted in terms of a duct inleakage since it was demonstrated that substantial tracer gas leakage (and hence, flow from the tent) occurred into the HVAC Equipment Room almost immediately upon initiation of the test. Accordingly for this test, the best that could be done was to estimate the total inleakage by assuming that the decay in tracer concentration within the vestibule tent was totally due to inleakage into the PV return duct within this tent. Using the concepts embodied in the tracer dilution measurement technique (ASTM Standard E741) concentration decay rates and leak rates shown in Table 5 were obtained.

VIII. TSC DUCT INLEAKAGE

The negative pressure PV duct in the vertical chase up to and including the duct in the ceiling of the TSC was tested. For this test tracer gas was released within a temporary visqueen tent which surrounded the PV return ductwork within the TSC. Tracer gas concentration was sampled from the tent as well as from the PV supply and return ducts. An initial test disclosed unreasonably high inleakage rates.

Upon investigation a substantial leakage from the tented volume within TSC into the Cable Spreading Room and thence into the HVAC Equipment Room was discovered. Hence, it was not possible to perform a meaningful inleakage test on this portion of duct work.

IX. CABLE SPREADING ROOM INLEAKAGE

The negative pressure PV duct located in the Cable Spreading Room was tested. at the access door portion of the duct. A small visqueen tent was erected around the access door. Tracer was injected into this tent and homogenized by oscillating the tent wall. Tracer concentrations were measured in the tent and in the return duct. The resulting data were analyzed as a concentration decay test as per ASTM E741. Results for both the A and B Train are shown in Table 6.

X CONCLUSIONS

It should be noted that the testing of both the OV and PV system were complicated by the existence of external flow communication between the PV and the OV system within the HVAC Equipment Room. The ability to take early time discrete samples in the supply and return ducts allowed data to be obtained which were consistent.

Table 7 provides a summary of the total inleakage into the Control Room Envelope as a result of the PV return system and the OV supply system. The significance of these data is that they represent *measured* inleakage rates which can be used in Control Room Habitability analyses in place of engineering assumptions. To our knowledge these are the first published data on Control Room Envelope Inleakage rates obtained under actual operating conditions.

Note that the measurements provided in Table 7 do not include an estimate for leakage of the duct run extending from the floor of the TSC to the ceiling of the TSC, as duct leakage in this run could not be measured due to floor leakage between the TSC and the Cable Spreading Room.

Based on the magnitude of the measured inleakage rates enhanced maintenance was undertaken in order to reduce inleakage into the Control Room Envelope. Additional tracer testing is planned to document any reduction of inleakage achieved by the enhanced maintenance. This maintenance effort is ongoing.

XI. REFERENCES

1. Lagus, P.L. and Grot. R.A., 1991, "Airborne Hazardous Substance Assessment by Tracer Gas Methods", Industrial Hygiene News, September.

2. Grot, R.A., Hodgson, A.T., Daisey, J.M., and Persily, A., 1991, "Indoor Air Quality Evaluation of a New Office Building", ASHRAE Journal, September.

3. Lagus, P.L. and Persily, A., 1985, "A Review of Tracer Gas Techniques for Measuring Airflows in Buildings", ASHRAE Trans., Vol. 91, Part 2.

4. Hockey, E.E., Stoetzel, G.A., Olsen, P.C., and McGuire, S.A., 1991, "Air Sampling in the Workplace", NUREG-1400, U.S. Nuclear Regulatory Commission.

5. Lagus, P.L., Kluge, V., Woods, P., and Pearson, J., 1988, "Tracer Gas Testing within the Palo Verde Nuclear Generating Station Unit 3 Auxiliary Building", in Proceedings of the 20th NRC/DOE Air Cleaning Conference, Boston, MA.

TABLE 5

Leakage of Vestibule Portion of PV Return Duct

A Train		B Train	
Time (min.)	Concentration (ppb)	Time (min.)	Concentration (ppb)
10	14	9	65
13	3.55	12	28.5
16	1.52	15	14
19	0.85	18	7.7
I = 18.5 ACH		I = 14.2 ACH	
Inleak = I x VOL		Inleak = I x VOL	
= 15.4 CFM		= 12 CFM	

TABLE 6

Cable Spreading Room Duct Leakage

Train	Enclosure Conc. (ppb)	Return Duct Conc. (ppt)	Return Duct Flowrate (CFM)	Inleakage Rate (CFM)
A	650	75	8999	1.04
B	1900	263	8791	1.2

TABLE 7

Total Unfiltered Leakage

Source	A Train Inleakage (CFM)	B Train Inleakage (CFM)
TSC	N.M.	N.M.
Cable Spread Access Door	1	1.2
HVAC Equipment Room	153	121
Purge Plenum	5.5	6.5
Vestibule	15.4	12
OV Leakage	124	124
Total Unfiltered Inleakage	299*	265*

* Rounded to Nearest Whole Number

N.M.--not measured

DISCUSSION

WEIDLER: That was a pretty high leak rate that you found. What did the utility do to repair the leaks after you found them?

LAGUS: All of the access doors and other closures were regasketed, number one, and number two, many of them were then sealed with an elastomeric sealer. After the doors were sealed, a change in procedure was instituted so that when the doors needed to be opened for access, you would have to break this nice seal. Then it was required that they be resealed. Joints in the ductwork were sealed with an appropriate sealer. All of the expansion boots, both supply and return on the A and the B trains, were replaced with new material and then sealed with elastomeric compounds because every one exhibited a greater or lesser degree of in-leakage.

WEIDLER: Was there a retest?

LAGUS: Yes, there was a retest and the results were much, much better than 50% by the time everything was done. There was a significant improvement across the board by undertaking this preventive maintenance activity.

PARKER, W.: I am wondering how your results compare to any assumptions that you might have made?

DUBOIS: The focus of the paper is not on that work, we were working with the NRC. We just wanted to give our test results. We reduced leakage to gain a greater tolerance.

MILATOVIC: Prior to this test, were these gaskets maintained as required. Was the leakage due to aging? Did you find the leakage by a test, without previous knowledge of it?

DUBOIS: The gaskets on these parts were installed prior to TMI. We have replace the doors and we have upgraded the doors on our air handling units. It sounds like the gaskets were leaking badly but we found the bigger leaks in the expansion boots. That was a major contributing factor. We used smoke pencils to identify where the leakage was; basically, by following air currents. Any area that we could get to with smoke pencils, we tested. When we found a leak, we repaired it. We had replaced gaskets after the first test, but I was not satisfied with the gasket replacement. The doors in the air handling units are not the bulkhead type, so we decided to use the elastomeric sealant on them also.

MILATOVIC: The reason I asked is because from my experience these gaskets only last 3 to 5 years. They have to be replaced whether you open the door or not and that is why it is so important for the safety of your handling units. When you install gaskets, you have to design them for the particular door, otherwise you are just wasting your time, leakage will occur.

DUBOIS: I agree to that.

SESSION 15

OPEN END

Thursday: August 27, 1992
Chairman: M. W. First

SURVEY OF LIFE-CYCLE COSTS OF GLASS-PAPER HEPA FILTERS
P. Moore, W. Bergman, H. Gilbert

CONCEPT FOR A PASSIVE HEAT REMOVAL AND FILTRATION SYSTEM UNDER CORE MELTDOWN CONDITIONS
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SURVEY OF LIFE-CYCLE COSTS OF GLASS-PAPER HEPA FILTERS*

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Abstract

We have conducted a survey of the major users of glass-paper HEPA filters in the DOE complex to ascertain the life cycle costs of these filters. Purchase price of the filters is only a minor portion of the costs; the major expenditures are incurred during the removal and disposal of contaminated filters. Through a combination of personal interviews, site visits and completion of questionnaires, we have determined the costs associated with the use of HEPA filters in the DOE complex.

The total approximate life-cycle cost for a glass-paper HEPA filter is $3,000 for one considered low-level waste (LLW), $11,780 for transuranic (TRU) and $15,000 for high-level waste (HLW). The weighted-average cost for a standard HEPA filter in the complex is $4,753. Although the cost estimate represents an average for all sizes and types of HEPA filters used in DOE facilities, the majority of the filters are 2' x 2' x1' filters with wooden frames, deep pleated glass-fiber media, and an adhesive sealant.

I. Introduction

We have been working on a project to develop a cleanable, re-usable stainless steel HEPA filter (1). The steel filter will be more reliable than the glass-paper filter due to its higher strength. We also believe that the steel filter will be more cost-effective over its life-cycle than the glass-paper filter, due to the re-usability of the steel filter. In order to make this comparison, we needed to have information about the life-cycle costs of the glass-paper filters. Therefore, we initiated this survey and cost analysis.

Previous cost studies were not adequate for our needs. None of the work was current, nor looked specifically at the cost of HEPA filters, only at the cost of the entire air cleaning systems, including capital costs, ongoing maintenance and replacement of parts and filters. Researchers from Harvard University (2,3,4,5) conducted a multi-year study of many AEC sites and air cleaning systems. They found that the initial capital costs were approximately 20% of the cost of the systems, and that filter replacement (materials and labor) represented 65% or more of the cost of the system (4). They noted that data on

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operational costs was more difficult to obtain than data on purchase and installation costs, and that the compilation of the data represented broad averages that could have significant deviations [5]. Jordan [6] made a detailed cost study of 3 different air cleaning systems, none of which contained HEPA filters. However, one comment in his report is also applicable in explaining the high handling and disposal costs of HEPA filters. He notes "the matter of requiring men to enter highly contaminated areas in protective equipment to change filter media should receive more attention. The men generally earn hazard pay and must work at a slower rate."

II. Filter Usage

We gathered data on filters processed through the three DOE filter test and certification stations (Hanford, Oak Ridge and Rocky Flats) for the period 1987-90. We created a database from this information, which allowed us to identify the number of filters tested in each fiscal year, major users, mix of filter sizes in use, and mix of manufacturers. That data is shown in Appendix A (Figure 1 and Tables 1-3).

Highlights of that data:

- Average annual filters tested/used - 11,478
- Largest user - Rocky Flats - 3,476 annually or 30%
- Most common capacity/size - 1000 cfm, 24"x24"x12" - 64%
- Most common vendor - Flanders - 74%

III. Cost of Glass-Paper Filters

The typical stages or costs in the life cycle of a glass-paper HEPA filter are as follows:

1. purchase, receipt and certification
2. filter change-out (remove used filter, install new filter)
3. in-place leak testing of new filter
4. pre-packaging assay of used filter
5. filter packaging/size reduction
6. post-packaging assay
7. shipping and handling
8. final disposal
9. administrative overhead

Generally, the costs related to HEPA filters are not tracked separately; they are included in various departments or waste disposal groups along with all other types of waste handled. To gather specific and detailed information on

these different stages, we sent questionnaires, made site visits and had telephone conversations with various personnel at different user locations. We were primarily interested in the top four DOE filter users (Rocky Flats, Savannah River, Oak Ridge and Hanford), as they comprised 73% of all filters used in the DOE complex.

We were able to obtain data about the number of personnel or man-hours involved in each life cycle stage fairly easily. Labor rates, overhead rates and other costs were more difficult. Based on the cost data we were able to obtain, we have used $60 per hour as an average, fully loaded labor rate, and applied that to the time data for the various stages.

We will discuss each of these stages in the following sections. The various costs and calculations are summarized in Appendix B, Tables 1-2, and the text will be referencing those figures. In generating the figures for Table 2, we have assumed that all other locations not surveyed will have similar costs as those of Hanford, which has multiple single filter sites. We have also assumed that the LLW/TRU mix is approximately the same as the overall mix of the top 4 users, or 80%:20%.

Purchase, Receipt and Certification

We have estimated that the cost of purchasing, receiving and certifying a HEPA filter to be approximately $450 per filter. This includes:

-purchase cost from the vendor,
-purchasing overhead
-shipping charges (to a certification station and to the user location)
-transportation labor and overhead
-receiving labor and overhead
-storage costs
-quality assurance costs.

We received detailed information on this process from the Hanford Plant, and during visits and conversations, found the handling at the other plants to be very similar. We therefore used one cost as representative of all locations. Any variances from plant to plant would be minimal.

Filter Change-Out

The process of removing the old contaminated filter and installing a new filter is the most labor-intensive stage of the life-cycle. We received estimates ranging from 210 to 360 man-hours for changing large banks of filters (18-30 filters), and from 16 to 40 man-hours to change small locations (1-2 filters). A brief description of the various locations follows.

Rocky Flats typically utilizes 4 to 10 people (technicians inside and outside the plenum, supervisors, health & safety technicians, waste coordinators) at various stages of the process, and changes a bank of 30 filters

in about 210 man-hours. Approximately 50% of the time is related to setting up and taking down the various tools, instruments and safety equipment used in the operation; this set up and take-down process is very similar whether 1 filter or 30 filters are being changed. Also, they make no allowances for whether the filters are LLW or TRU; their process is the same. 210 man-hours times $60 per hour divided by 30 filters equals a cost of $420 per filter to change.

Savannah River basically follows the same process; their time estimate was approximately 360 man-hours, as they use 9 people for a week. However, as they are typically changing a bank of only 18 filters, the set-up time is spread over a smaller number of filters, and when combined with the higher number of overall hours, the per unit cost to change the filters is much higher than Rocky Flats. 360 man-hours times $60 per hour divided by 18 filters equals a cost of $1200 per filter to change. They have both LLW and TRU filters, but the change-out process is the same.

The large majority of the filter locations at Oak Ridge are 1-filter sites. They can change a filter with 4 people in 4 hours; again, the bulk of the time is spent in set up and take-down of the safety equipment. 16 man-hours times $60 per hour equals $960 per filter. Oak Ridge has only LLW filters.

Hanford is similar to Oak Ridge in that the majority of the sites contain only 1 filter. However, they estimate that they have more TRU (60%) sites than LLW (40%), and they estimate that it takes them 25% less time to change LLW filters than TRU filters. They take approximately 27 man-hours on a TRU filter, and approximately 20 hours on an LLW filter. Twenty-seven man-hours times $60 per hour equals $1,620, and with some materials costs added (bag for used filters), the total cost is $1,650 per filter. A LLW filter would cost $1,250 at 75% of the time and with the same bag costs.

An important point to note here is that the set-up and take-down time makes up a large part of the total process, and that it is more or less the same whether there is one filter being changed or 30 filters. The marginal amount of time needed to change additional filters once set-up is complete is very small. Therefore, those locations with filter sites where multiple filters can be changed for one set-up and take-down process will have lower per-filter costs, as this "fixed" cost can be spread over more filters.

In Place Leak Testing

In-place leak testing is similar to the change-out situation, in that there is significant set-up and take-down time whether there is one filter to be tested or many. Again, the more filters tested, the more the "fixed" set-up/take-down costs are spread, and the lower the cost per filter.

Rocky Flats uses 3-5 people for approximately 44 man-hours, and tests a bank of 30 filters. This works out to a cost of approximately $90 per filter for testing. They utilize the same procedure for LLW or TRU filters.

The data from Savannah River showed that they have a budget of approximately $400K per year, and they annually test approximately 2,000 filters. This works out to a cost of $200 per filter. They have 3 people and one truck assigned full-time to test filters throughout the plant, and utilize the same procedure for LLW or TRU filters.

Oak Ridge utilizes 3 people for 2 hours to test a filter. 6 hours times $60 per hour equals $360 per filter. They only have LLW filters.

Hanford uses 6 people for approximately 25 man-hours to test TRU filters. This works out to a total of $1,500, and is applicable to only 1 filter, which makes up the majority of their filter sites. Again, the costs are decreased for LLW filters to approximately $1,125 per filter.

Pre-Packaging Assay

Rocky Flats utilizes 8 people in their assay department (supervisor, handling technicians, health safety technicians and clerical staff), and processes approximately 30-40 filters in an 8-hour shift. This works out to a cost of $100-130 per filter. We have used the more conservative lower cost for purposes of this analysis. They use a LOSAC system (LOw Specific Activity Counter) to separate LLW from TRU filters, using 100 nanocuries of plutonium per gram of matrix material as the separation threshold. The counters operate by measuring gamma rays emitted from 55 gallon drums through a sodium iodide detector. The gamma emissions are converted to numeric data through a digital analyzer, and evaluated by the software in the counter. The software compensates for density of material, subtracts background radiation, and generates assay values. The assay department conducts assays on many other items in addition to HEPA filters. Other plants seemed to use the same process as Rocky Flats, so we have utilized this cost as representative for all locations. Even significant variances in costs would have little or no impact on the overall cost, as this is a small part of the total.

Filter Packaging/Size Reduction

Rocky Flats is the only location of the top four users that performs any size reduction of the filters. They crush LLW filters only, and the size reduction process allows them to reduce their overall cost. They utilize 17 people, and in a typical 8 hour shift (115 total man-hours), can crush 24 filters for storage in one box. The size reduction cost works out to approximately $300 per filter. The filters are put into a special box which costs $960, which gives the filter packaging cost of $40 ($960 divided by 24 filters). TRU filters are simply put into a special TRUPACT box, with a minimal amount of labor. The box costs approximately $1,140, and total labor time is one hour, giving a total packaging cost for TRU filters of $1,200.

Savannah River puts 8 LLW filters into a B-25 box, which costs $400. This makes the per filter packaging cost $50. They put TRU filters into the same box as Rocky Flats; thus the $1,200 cost.

Oak Ridge puts 8 LLW filters into a metal box that costs approximately $800, giving a cost of $100 per filter.

Hanford quoted a cost of $325 for the box to store LLW wastes, and $1,150 for the box to store TRU waste. They also quoted an "average" of 5 man-hours per box, or $300 at $60 per hour. This may be a combined average of labor on TRU and LLW boxes, but we were unable to clarify. These figures provide the totals of $625 for LLW and $1,450 for TRU filters.

Post-Packaging Assay

Rocky Flats used the same procedure to assay the packaged filters as they used to assay the unpackaged filters. They spent less time on the LLW filters after packaging, and the same on TRU filters after packaging. Other plants followed a similar process, and we have used the one set of costs as representative of this stage.

Shipping and Handling

All locations estimated the time needed to prepare a packaged filter for shipment at 2-4 man-hours, which includes palletizing, completing shipping paperwork, loading onto appropriate transportation, etc. They also noted that slightly more time was spent on TRU shipments than LLW. The $150 and $200 figures are averages of those estimates. Hanford has also included a one-time temporary storage charge that they incur before shipment to a final disposal site. Costs also include any transportation charges, which would only be a few dollars per filter.

Final Disposal

Depending on whether the filter is classified as low level waste (LLW), transuranic waste (TRU) or high level waste (HLW), the filter will eventually be sent to the Nevada Test Site (NTS), the Waste Isolation Pilot Plant (WIPP) or the Yucca Mountain burial site, respectively.

NTS charges $10 per cubic foot, and the measurement is based on the outside dimensions of the item being stored.

WIPP has a cost per cubic foot of approximately $900. The operating budget for WIPP for the planned 25-year life of the facility is $4.5 billion, and the capital budget for the facility is $1 billion. The storage capacity will be 6.2 million cubic feet. $5.5 billion divided by 6.2 million cubic feet is $887 per cubic feet; we rounded to $900 for purposes of the disposal calculations.

Rocky Flats sends 24 crushed LLW filters in a 4'x4'x7' (112 cubic feet) to NTS. At $1,120 per box, divided by 24 filters, the final disposal cost is approximately $50 per filter. They send 13 TRU filters in the same box to WIPP.

112 cu. ft. times $900 per cubic ft, divided by 13 filters, equals a per filter cost of $7,750.

Savannah River stores their LLW filters on site; they estimate the burial cost to be $25 per cubic foot. The B-25 boxes are approximately 45 cubic feet, and hold 8 filters. This works out to a cost of approximately $140 per filter. TRU filters are in TRUPACT boxes, and are being held for eventual shipment to WIPP. Cost of storage at WIPP will be approximately $6,200 per box, as each box is 6.88 cubic feet, at $900 per cubic foot.

Oak Ridge sends their LLW filters to be destroyed by a private vendor. They are charged $2 per pound, and estimate that the used filters weigh 50 lbs. on the average. They also use approximately 2 hours tracking time. $100 for the filter and $100 for labor gives the $200 disposal cost.

Hanford has an on-site burial ground for LLW filters; they estimate the cost per cubic foot of the burial ground to be approximately $30. The filters in boxes are about 5 cubic ft., giving a total cost for LLW of $150. TRU filters are sent to WIPP, and will have the same cost as Savannah River of $6,200.

Administrative Overhead

In all discussions with various personnel at the different plants, they noted that there were always "administrative paperwork costs" or "tracking costs" related to handling of the filters. There were also supplies consumed, equipment costs, time in handling of filters between stages, etc. that related to filters, but also to all other waste items processed through the plants. They could not quantify in hourly terms or dollars a direct amount, but estimates ranged from 5% to 20%. We have added this category, and used a slightly higher amount for TRU filters than LLW filters.

High Level Waste

There seemed to be very few instances of filters that qualified as high-level waste. Hanford noted some, but had no estimates of time or costs, as those filters received very special treatment and were infrequently handled. An educated guess by them put the cost at approximately $15,000-20,000. We have used the low end of the estimate to be conservative. We also estimate that there are less than 1% of the filters in use that are HLW; we therefore used 100 annually in our calculation of the average cost of a filter in the complex. The total cost average would only be affected by only 3% even if we were 100% wrong in our estimate on these filters, so these figures should be adequate for this analysis.

IV. Summary

We conducted a survey of the major users of glass-paper HEPA filters in the DOE complex to ascertain the life cycle costs of these filters. Purchase price

of the filters is only a minor portion of the costs; the major expenditures are incurred during the removal and disposal of contaminated filters. Through a combination of personal interviews, site visits and completion of questionnaires, we determined the costs associated with the use of HEPA filters in the DOE complex.

Utilizing information from the 4 DOE filter test stations, we created a database of information and found the number of HEPA filters used annually by location, sizes of HEPA filters most commonly used and major vendors. This allowed us to focus our investigations.

We identified 9 different stages in the life-cycle of the HEPA filter, and determined the various material and labor costs for each stage. From that information, we calculated total costs per filter for the 4 largest HEPA filter users in the DOE complex. We then used the cost per plant figures to calculate a weighted average cost (by type of waste) for HEPA filters across the DOE complex.

The total approximate life-cycle cost for a standard (2'x2'x1') glass-paper HEPA filter is $3,000 for one considered low-level waste (LLW), $11,780 for transuranic (TRU) and $15,000 for high-level waste (HLW). The weighted-average cost for a standard HEPA filter in the complex is $4,753.

V. Bibliography

1. Bergman, W. et al "Development and evaluation of a cleanable high efficiency steel filter," in Proceedings of the 22nd DOE/NRC Nuclear Air Cleaning Conference, Denver, CO, Aug. 24-27, 1992.

2. Dennis, R., Billings, C.E. and Silverman, L., "Economic Survey of Air and Gas Cleaning Operations within the AEC" in Proceedings of the 5th AEC Air Cleaning Conference, pp. 92-97 (1958).

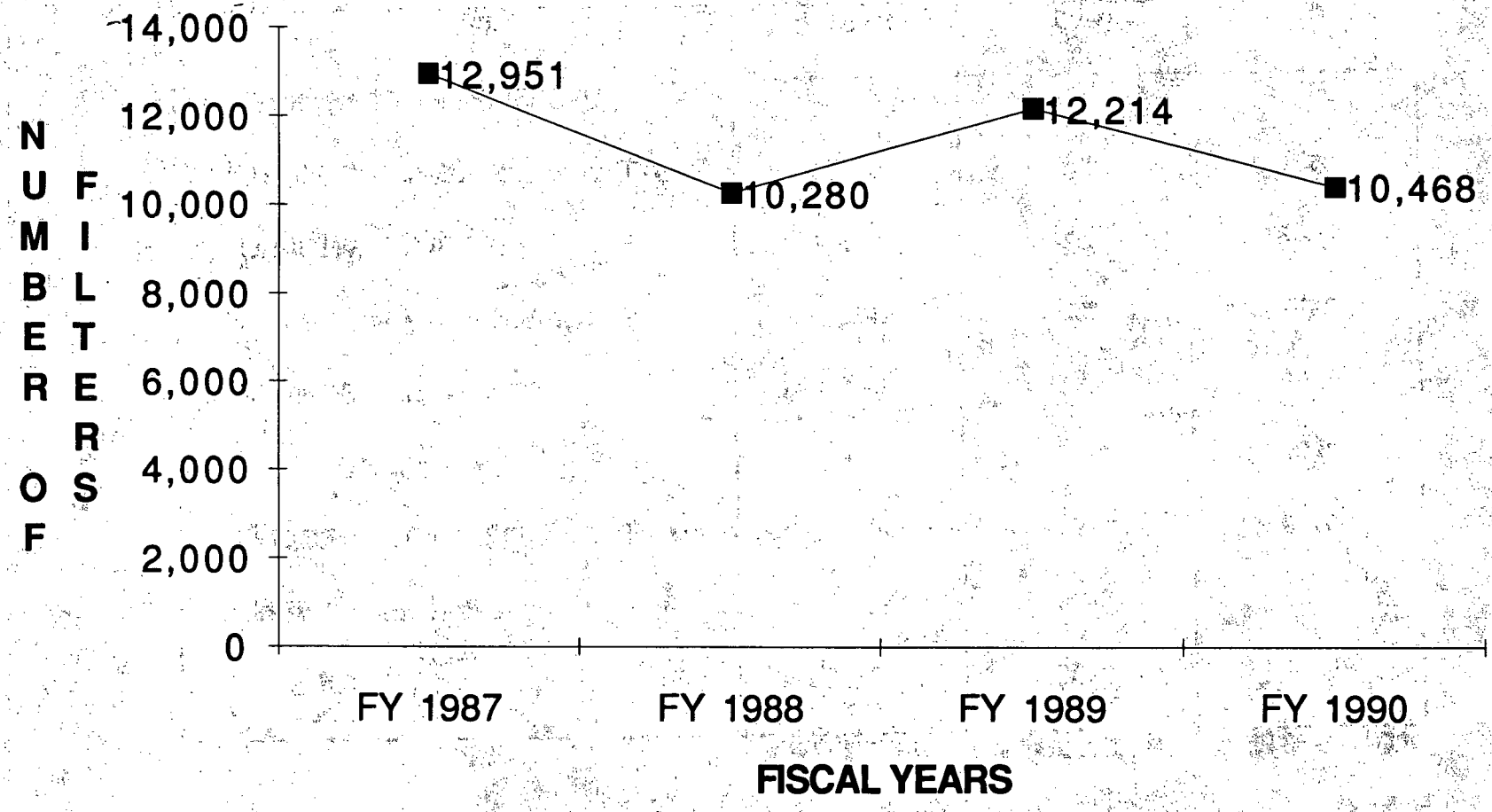
3. Fitzgerald, J.J., Silverman, L., Dennis, R. and Billings, C. E., "Economic Survey of Air and Gas Cleaning Operations within the AEC" in Proceedings of the 6th AEC Air Cleaning Conference, pp. 257-290 (1959).

4. First, M.W., Silverman, L., Fitzgerald, J.J., Billings, C.E. and Dennis, R. "Economic Survey of Air and Gas Cleaning Operations within the AEC" in Proceedings of the 7th AEC Air Cleaning Conference, pp. 406-415 (1961).

5. First, M.W. and Silverman, L., "Final Report of Economic Survey of Air and Gas Cleaning Operations in the AEC", in Proceedings of the 8th AEC Air Cleaning Conference, pp. 145-154 (1963).

6. Jordan, H.S., "Air Cleaning Costs - a Study of Three Systems", in Proceedings of the 5th AEC Air Cleaning Conference, pp. 98-107 (1958).

Appendix A - Figure 1 - Filter Usage 1987-90



Appendix A - Table 1
Major Filter Users
Fiscal Years 1987 - 1990

USER	# FILTERS	% OF TOTAL	CUM % OF TOT
ROCKY FLATS PLANT	13,902	30%	30%
SAVANNAH RIVER PLANT	8,175	18%	48%
OAK RIDGE NATIONAL LAB/Y-12 PLANT	7,092	15%	64%
HANFORD RESERVATION	4,549	10%	73%
LOS ALAMOS NATIONAL LAB	3,010	7%	80%
IDAHO NATIONAL ENGINEERING LAB	2,795	6%	86%
ARGONNE NATIONAL LAB	1,529	3%	89%
LAWRENCE LIVERMORE NATIONAL LAB	1,409	3%	92%
43 USERS @ < 500 FILTERS USED	3,452	8%	100%
TOTAL	**45,913**	**100%**	
ANNUAL AVERAGE	**11,478**		

Appendix A - Table 2
Ranked by Filter Size
Fiscal Years 1987-90

CAPACITY	SIZE	# FILTERS	% OF TOTAL
1000 CFM	24"X24"X12"	29,273	63.76%
50 CFM	8"X8"X6"	6,196	13.50%
1250 CFM	24"X24"X12"	2,698	5.88%
125 CFM	12"X12"X6"	2,358	5.14%
25 CFM	8"X8"X3"	2,217	4.83%
500 CFM	24"X24"X6"	1,177	2.56%
1500 CFM	24"X24"X12"	585	1.27%
2000 CFM (MINI-PLEAT)	24"X24"X12"	28	0.06%
OTHER FILTER SIZES		1,381	3.01%
	TOTAL	45,913	100.00%

Appendix A - Table 3
Ranked by Manufacturer
Fiscal Years 1987-90

MANUFACTURER	# FILTERS	% OF TOTAL
FLANDERS	33,790	73.60%
CAMBRIDGE	7,090	15.44%
AMERICAN AIR FILTER	3,623	7.89%
21 MANUFACTURERS <550 FILTERS	1,410	3.07%
TOTAL	45,913	100.00%

Appendix B - Table 1
Cost Breakdown by Plant

PLANT	ROCKY FLATS		SAVANNAH RIVER		OAK RIDGE		HANFORD	
WASTE TYPE	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU
PURCH, RECEIPT & CERT	450	450	450	450	450	n/a	450	450
FILTER CHANGE-OUT	420	420	1,200	1,200	960	n/a	1,250	1,650
IN-PLACE TESTING	90	90	200	200	360	n/a	1,125	1,500
PRELIMINARY ASSAY	100	100	100	100	100	n/a	100	100
FILTER PACKAGING	40	1,200	50	1,200	100	n/a	625	1,450
SIZE REDUCTION	300	0	0	0	0	n/a	0	0
FINAL ASSAY	70	100	70	100	70	n/a	70	100
SHIPPING/HANDLING	150	200	150	200	150	n/a	150	420
FINAL DISPOSAL	50	7,750	140	6,200	200	n/a	150	6,200
ADMIN OVERHEAD	400	500	400	500	400	n/a	400	500
TOTAL COST	**2,070**	**10,810**	**2,760**	**10,150**	**2,790**	**0**	**4,320**	**12,370**

Appendix B - Table 2
Average Life-Cycle Cost Calculations

FILTER USAGE MIX

	LLW	TRU	TOTAL
ROCKY FLATS	2,933	517	3,450
SAVANNAH RIVER	1,863	207	2,070
OAK RIDGE	1,725	0	1,725
HANFORD	345	805	1,150
ALL OTHER LOCATIONS	2,362	621	2,983
HLW FILTERS (ALL LOCATIONS)			100
	9,228	2,150	11,478

TOTAL COST BY PLANT

	LLW $	TRU $	TOTAL
ROCKY FLATS	6,070,275	5,588,770	11,659,045
SAVANNAH RIVER	5,141,880	2,101,050	7,242,930
OAK RIDGE	4,812,750	0	4,812,750
HANFORD	1,490,400	9,957,850	11,448,250
ALL OTHER LOCATIONS	10,203,840	7,681,770	17,885,610
HLW FILTERS (EST. $15K EA.)			1,500,000
	27,719,145	25,329,440	54,548,585
AVG LIFE-CYCLE COST/FILTER	3,004	11,781	**4,753**

CONCEPTS FOR PASSIVE HEAT REMOVAL AND FILTRATION SYSTEMS UNDER CORE MELTDOWN CONDITIONS

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Abstract

The objective of the new containment concept being developed by KfK is the complete passive enclosure of a power reactor after a core meltdown accident by means of a solid containment structure and passive removal of the decay heat. This is to be accomplished by cooling the containment walls with ambient air, with thermoconvection as the driving force.

The concept of the containment will be described. Data will be given of the heat removal and the requirements for filtration of the exhaust air, which is contaminated due to the leak rate assumed for the inner containment. The concept for the filter system will be described. Various solutions for reduction of the large volumetric flow to be filtered will be discussed.

I. Introduction

The potential occurrence of a core meltdown accident which so far has not been considered to be a design basis accident has become the most significant argument against nuclear energy in the public after the Chernobyl accident. This is true in particular in the Federal Republic of Germany where contamination of agricultural products has caused considerable damage and it may be recommended still today to refrain from consuming mushrooms and game.

With a view to further reducing the probability of occurrence of a core meltdown and to limit its consequences, discussions are being held about to improving emergency cooling, installing additional components such as coolers, core catchers, and providing further engineering measures in the reactor system which concern inter alia the reduction of reactor power and power density, respectively, in the reactor core. Independent of these discussions, considerations are being made on the ways and means of limiting the consequences of a core meltdown on the surrounding area of an NPP by improving the reactor containment.

Work carried out by members of the KfK staff is aimed at giving an answer to the question of the loads to which a reactor containment is exposed in a core meltdown accident, and in which way these loads can be accommodated by design measures.

Besides containment loading due to temperature and pressure resulting from the evolution of decay heat in the core melt, major impacts originate in the reaction of the melt with water and concrete, the explosion of the large amounts of hydrogen generated during such reaction in the oxygen bearing atmosphere of the containment and the steam explosion, e.g. as a result of slumping of the molten core into the lower reactor pressure vessel head and by high pressure failure of the reactor pressure vessel. The investigations carried out so far suggest that the loads to be assumed to act on the containment can be controlled by design measures so that its integrity is maintained (1, 2).

II. The Passive Heat Removal Concept

II.1 Decay Heat Removal by the Ambient Air

It is one of the essential goals of work in progress to improve of the containment system to develop a concept for passive removal of the decay heat and reaction heat from the containment. As the containments of light water reactors of German design have been built from steel, it has been examined whether the amounts of heat involved can actually be removed in a passive mode through the containment wall. The necessity of filtering in conformity with the valid rules the exhaust air from the space, which lies between the inner steel containment and liner, respectively, and the external concrete containment, proved to be a restriction on such a concept. The containment system conforming to the standard design in Germany is shown in Fig. 1. The space between the pressure accommodating steel containment and the surrounding concrete reactor building might be contaminated by leaks in the steel containment at penetrations and locks as well as by components in the annulus, and it is therefore vented by the emergency stand by filters installed to remove airborne particulates and iodine.

According to an advanced containment system presently studied a pressure accommodating inner steel liner and an external reinforced concrete containment are provided - the latter designed to largely diminish the high pressure loading acting on the liner via suitable connections to the liner. It has appeared from preliminary calculations that the decay heat of a 3600 MW_{th} reactor can be removed in a passive mode to the ambient air over the external side of the steel liner so that an intolerable pressure buildup in the interior can be avoided. Figure 2 shows the principle of passive air cooling of the containment. The heat is transferred from the melt to the inner wall of the steel liner by the steam condensing on the inner wall; the condensate flows back to the melt where it is evaporated again. Due to the thermal conductivity of steel the heat is carried through the steel wall onto the external side of the steel liner where it is directly discharged to the air stream passing by. The fins arranged in the annulus between the steel liner and the concrete containment constitute vertical stacks with open top and bottom ends. Besides, a considerable portion of the heat generated in the steel liner is given off by heat radiation to the side walls (fins) and the rear wall of the stacks (reinforced concrete) and from there to the convective air flow.

II.2 Unfiltered Cooling Air and Leaking Air

The following boundary conditions were assumed in the calculations based on estimates:

Reactor power 1300 $MW_{el.}$, max. decay heat to be removed by natural air convection 8 MW, diameter of steel liner 60 m, wall thickness 38 mm, outer containment made of reinforced concrete with 2 m wall thickness, annulus between concrete containment and steel liner 80 cm, partitioned by fins running longitudinal at 50 cm distance from each other, height of the stacks formed by these fins 40 m.

The power of the decay heat source was supposed to be 8 MW in all subsequent considerations, a value calculated by making use of the heat capacity of the concrete and steel components which are heated in the interior of the steel liner. With a mean air velocity in the stacks of 2.8 m/s, an inlet temperature of the ambient air of 30 °C and an outlet temperature of 50 °C, a temperature of 148 °C, corresponding to 4.5 bar steam pressure, is established within the steel liner. The reinforced concrete of the containment enclosing the annulus towards the outside is heated to 83 °C.

II.3 Filtered Cooling Air and Leaking Air

When the exhaust air from the stacks is filtered by the standard HEPA filters with a total open face area of 300 m^2, a differential pressure across the stacks and filters of about 39 Pa is obtained, with the rest of conditions unchanged, which corresponds to an air velocity of 1.05 m/s in the stacks at 87 °C outlet temperature of air, 164 °C inner temperature of the steel liner corresponding to 6.8 bar pressure of steam and a temperature of the concrete containment of 105 °C on the annulus side.

The throughput of ambient air is 474,000 m^3/h. The relation

$$\Delta p = 0.08v + 0.012v^2,$$

v = mean linear gas velocity at the HEPA filter open face area (m/s)

Δp = differential pressure across the HEPA filter (kPa)

determined as the mean value for non-loaded HEPA filters in the experiment, was assumed to describe the dependency of the differential pressure on the air velocity [3]. Figure 3 shows the differential pressure occurring across the non-loaded filter as a function of the open face area of all HEPA filters taken together. The total open face area needed is very large in case the differential pressure is to remain low so that a high throughput of the coolant air can be maintained.

Figure 4 is a plot of the temperature in the liner atmosphere, the pressure of the steam depending on it, and the temperature on the inner side of the concrete containment, versus the open face area of the total number of HEPA filters installed. Fixing an open face area of 125 m^2 would give the following values: differential pressure for filters and stacks 61 Pa, air velocity in the stacks 68 cm/s, air outlet temperature 124 °C, inner temperature of steel liner 180 °C,

steam pressure 9.9 bar, concrete temperature on the annulus side 125 °C, throughput of ambient air 306,000 m^3/h. These values are considered to constitute the upper limit of temperature in the steel liner.

It is evident from the computations that due to coupling of the flow resistance with the throughput and, as a consequence, with the temperature in the steel liner, and of the concrete of the containment, a satisfactory solution cannot be found with filters whose flow resistances correspond to that of the standard HEPA filters. Moreover, it should be possible to remove also gaseous radioiodine.

II.4 Possible Solutions

Four ways should be examined which might lead to a solution:

(a) Development of a new filter material with a flow resistance corresponding to approximately half that of the current HEPA filter medium.

(b) Intensifying the stack draft by connection to the main stack of the nuclear power plant whose diameter should be increased, if needed (Fig. 5).

(c) Dividing the exhaust air from the annulus into a non-filtered portion (cooling air) and a filtered portion which does not noticeably contribute to cooling (Figs. 6 and 7).

(d) Dispensing with passive cooling of the steel liner by external air, applying instead internal passive cooling with water of the melt (Fig. 8).

ad (a) This solution is presently being studied. The use of loosely packed fiber media without any bonding material gives better values relative to those obtained with the usual HEPA filter media. The possibilities should be examined of removing radioiodine in addition without integrating further structural material in the filter. Eligible base materials for trapping the particulates are e.g. fine steel fiber fleeces with high porosities.

ad (b) This solution allows a higher flow resistance of the filter. Together with a filter material whose flow resistance is reduced, it offers the best solution which allows the requirements to be met with respect to cooling, filtration and environmental impact, thanks to the great altitude of emission. First computations based on the input data mentioned on p. 3 have yielded the following values:

Stack height producing an additional effect 140 m, stack inner diameter 5 m, open face area of all HEPA filters taken together 50 m^2, differential pressure across filters and stacks 320 Pa, differential pressure across filters 259 Pa, air velocity in the cooling stacks 0.95 m/s, air outlet temperature 94 °C, inner temperature of steel liner 167 °C,

steam pressure 7.3 bar, concrete temperature on the annulus side 108 °C, throughput of external air 429,000 m^3/h.

With the rest of conditions unchanged and an open face area of as little as 30 m^2, corresponding to a differential pressure across the filter and stacks of 402 Pa, 362 Pa of that value occurring across the filters, an inner temperature of the steel liner of 176 °C and a pressure of the steam of 9.0 bar were calculated. The throughput of ambient air is 334,000 m^3/h.

ad (c) Two versions are feasible:

1. Filtering the leaking air from the entire outside surface of the containment. (Fig. 6)

2. Filtering the leaking air solely of the bottom part of the containment. (Fig. 7)
This separation of the filtered air from most of the annulus implies that all penetrations, locks, etc. running through the steel liner as well as all external, activity bearing plant components are arranged in the bottom part of the annulus and that only the exhaust air from that part is filtered.

The relatively small volume of leaking air can be introduced in both versions into the main stack of the reactor block and kept at a slight negative pressure due to the stack draft. This makes less difficult the task of designing a passive exhaust air filter.

It seems feasible in this way to reduce the volume of exhaust air to be filtered by factors up to approx. 10, provided that approval is obtained from the licensing authority to discharge unfiltered cooling air which has been passed solely over the undisturbed surface of the steel liner.

ad (d) The decay heat is removed from the core catcher with the sump water and given off in a passive mode to the ambient air via large cooling basins. It is doubtful whether the core catcher can be sufficiently flooded with sump water. The volume of air to be filtered would be on the order of 1000 m^3/h.

III. Summary

It is evident from the calculations that the decay heat of a 1300 MW_{el} reactor can be removed in a passive mode after a core meltdown accident by cooling of the steel containment with ambient air.

The throughput of air exclusively generated by thermoconvection is greatly reduced by flow resistances. By introduction of the cooling and leak air streams into an exhaust air stack of a height as already built today, the admissible differential pressure across the filter can be raised by about one order of magnitude and hence the filter size can be reduced accordingly. The design of exhaust air filters for cooling and leak air filtering must be such that differ-

ential pressures of a few 100 Pa can be accommodated. Besides airborne particulates, also gaseous radioiodine should be removed on the filters. For this to be achieved, new filter media will have to be developed which cause a much lower flow resistance than the usual HEPA filter media. Should this not be feasible, the exhaust air from the containment must be divided into an unfiltered cooling air portion and a filtered leaking air portion in order to be able to choose reasonable dimensions for the open face area of the filter. Otherwise, the decay heat would have to be removed on different paths, e.g. by passive water cooling.

IV. References

(1) J. Eibl et al.: An Improved Design Concept for Next Generation PWR-Containments, Fifth Workshop on Containment Integrity, Washington DC, May 12-14, 1992.

(2) R. Krieg, J. Eibl et al.: Extreme Loadings of Inner Structures of Next Generation PWR-Containments, Fifth Workshop on Containment Integrity, Washington DC, May 12-14, 1992.

(3) V. Rüdinger, C.I. Ricketts, J. G. Wilhelm: Differenzdruckbelastbarkeit von Schwebstoffiltern, Schriftenreihe Reaktorsicherheit und Strahlenschutz, Filter für kerntechnische Anlagen, S. 59, BMI-1985-099, (1985).

Annex

Boundary Conditions for Calculation of the Thermohydraulics in Heat Removal to Air by Natural Convection

Decay heat power to be removed	8 MW
Diameter of steel containment	60 m
Wall thickness of steel containment	38 mm
Effective cylindrical height of individual stacks	40 m
Azimuthal width of individual stack	50 cm
Radial depth of individual stack	80 cm
Width of fins between stacks	10 cm
Number of stacks on the perimeter	314
Emission ratio of stack walls, achieved by suitable treatment	0.9
Absolute roughness of stack walls	1 mm
Useful height of main stack	140 m
Mean diameter of main stack	5 m
Length of connection line from air outlet at the containment up to main stack	50 m
Diameter of connection line	5 m
Inlet temperature of the cooling air	30 °C

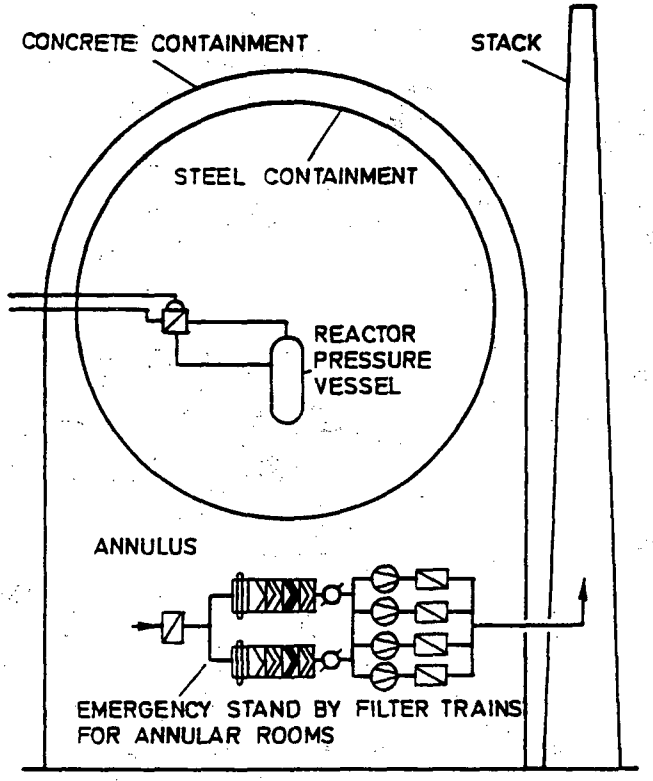

FIG. 1

FILTERING OF ANNULUS EXHAUST AIR

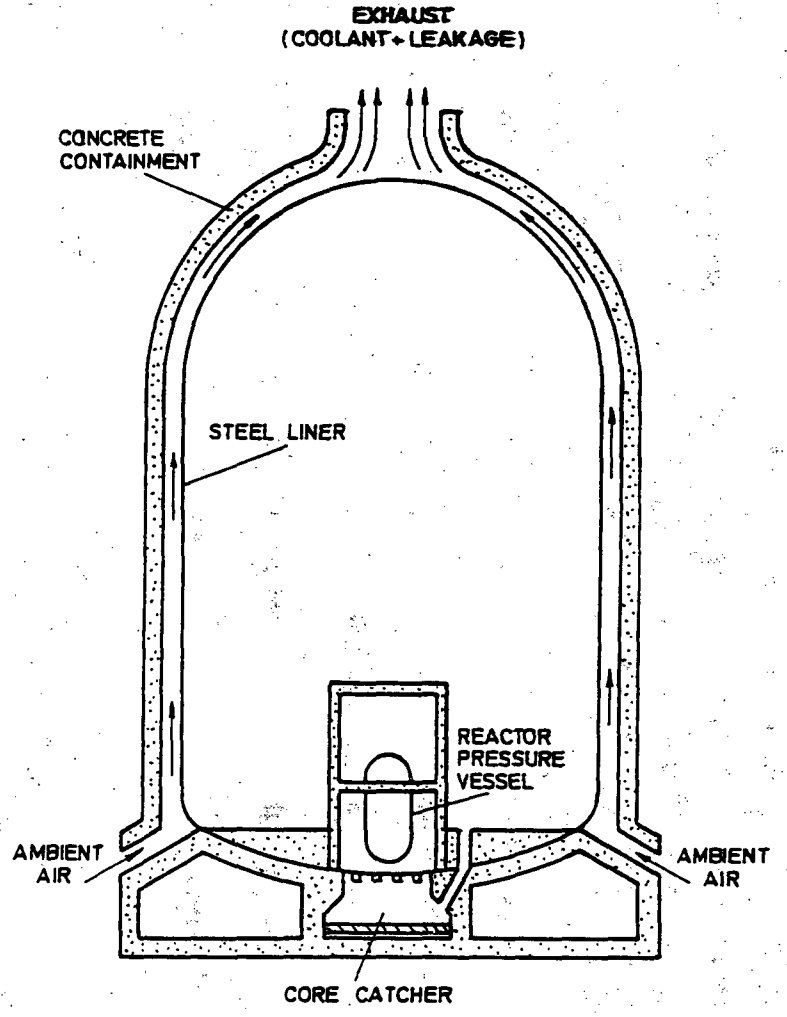

FIG. 2

CONCEPT OF PASSIVE DECAY HEAT REMOVAL

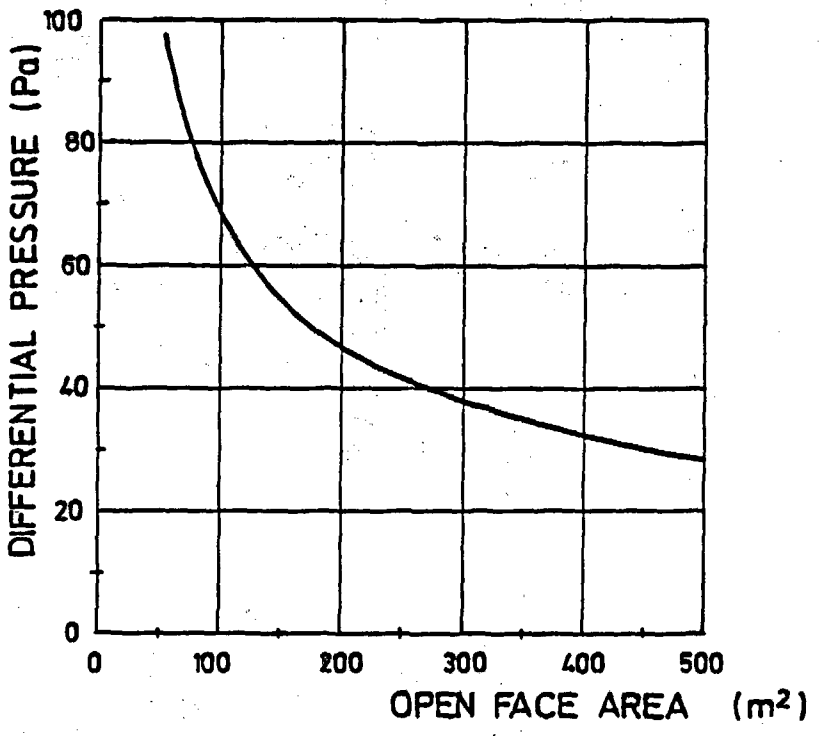

FIG. 3

CONTAINMENT 2000, HEPA - FILTER DIFFERENTIAL PRESSURE AS A FUNCTION OF THE OPEN FACE AREA

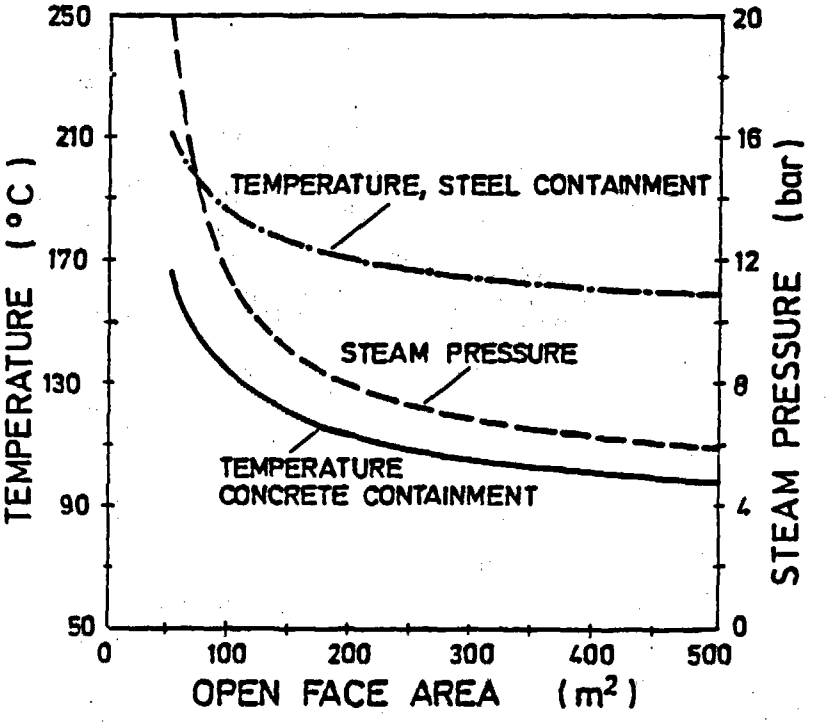

FIG. 4

CONTAINMENT 2000, TEMPERATURE AND PRESSURE AS A FUNCTION OF THE HEPA - FILTER OPEN FACE AREA

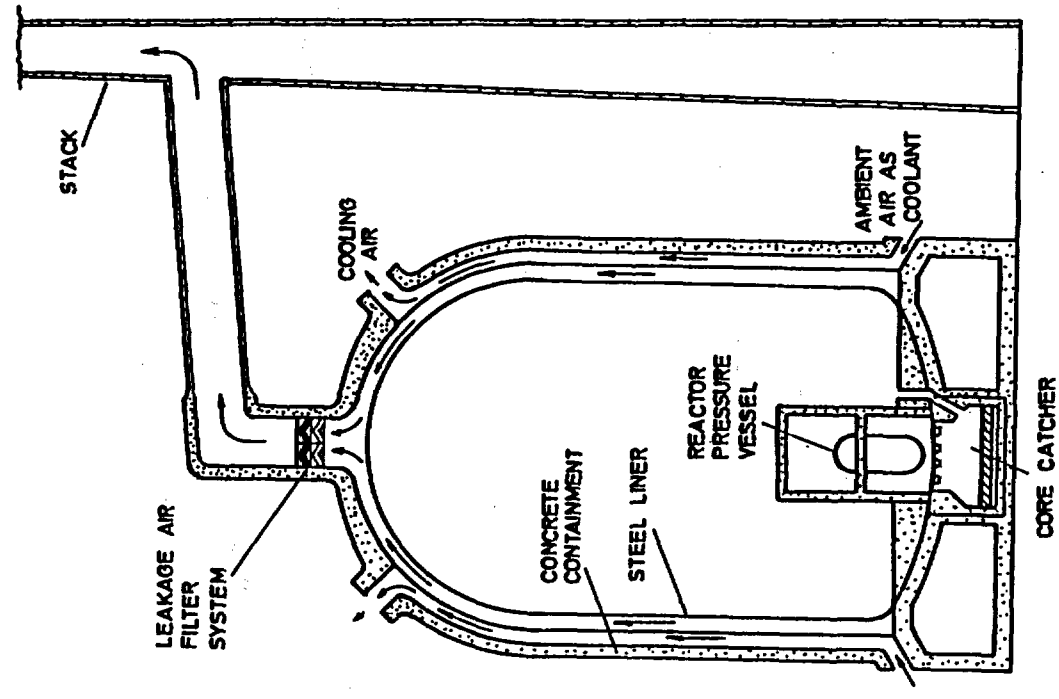

FIG. 6 CONTAINMENT 2000
LEAKAGE AIR FILTERED
COOLANT AIR UNFILTERED

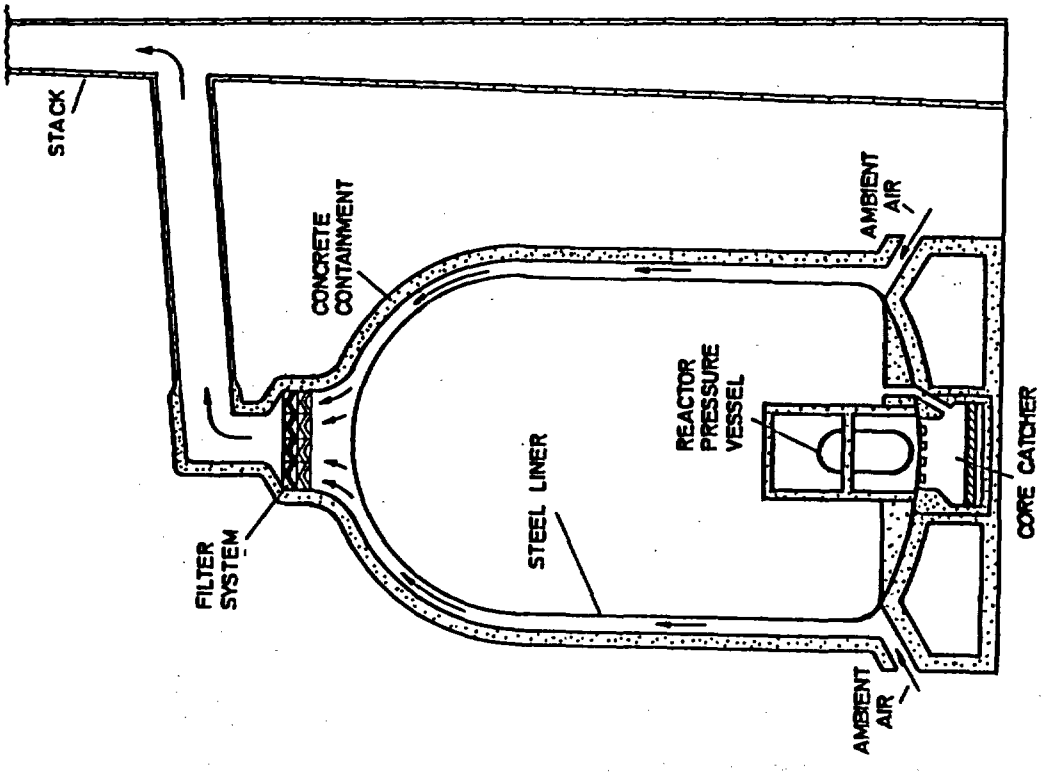

FIG. 5 CONTAINMENT 2000
COOLANT AND LEAKAGE FILTERED

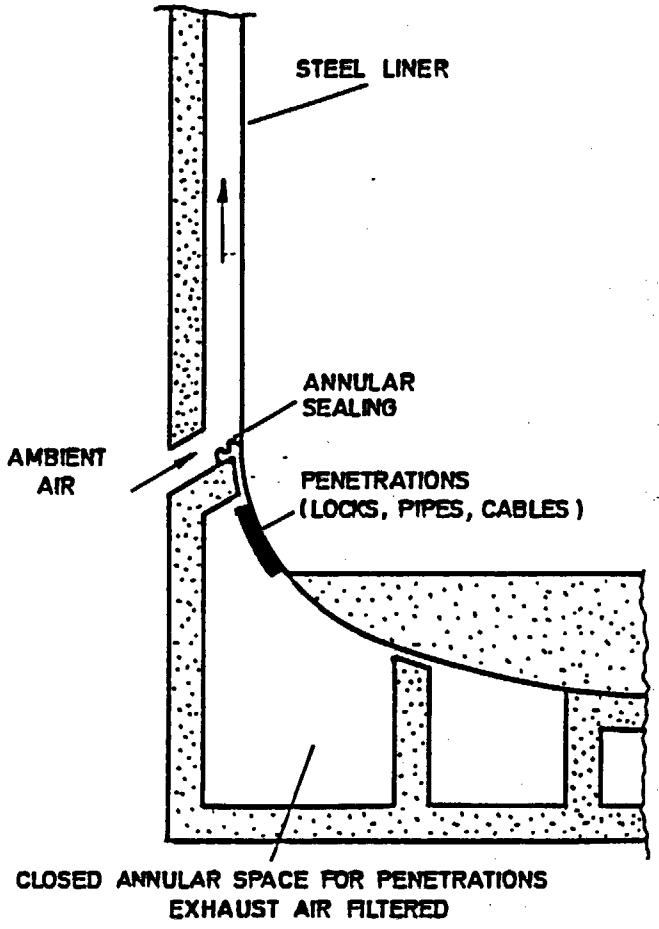

FIG. 7

CONTAINMENT 2000
FILTERED CONTAINMENT AREA
FOR PENETRATIONS

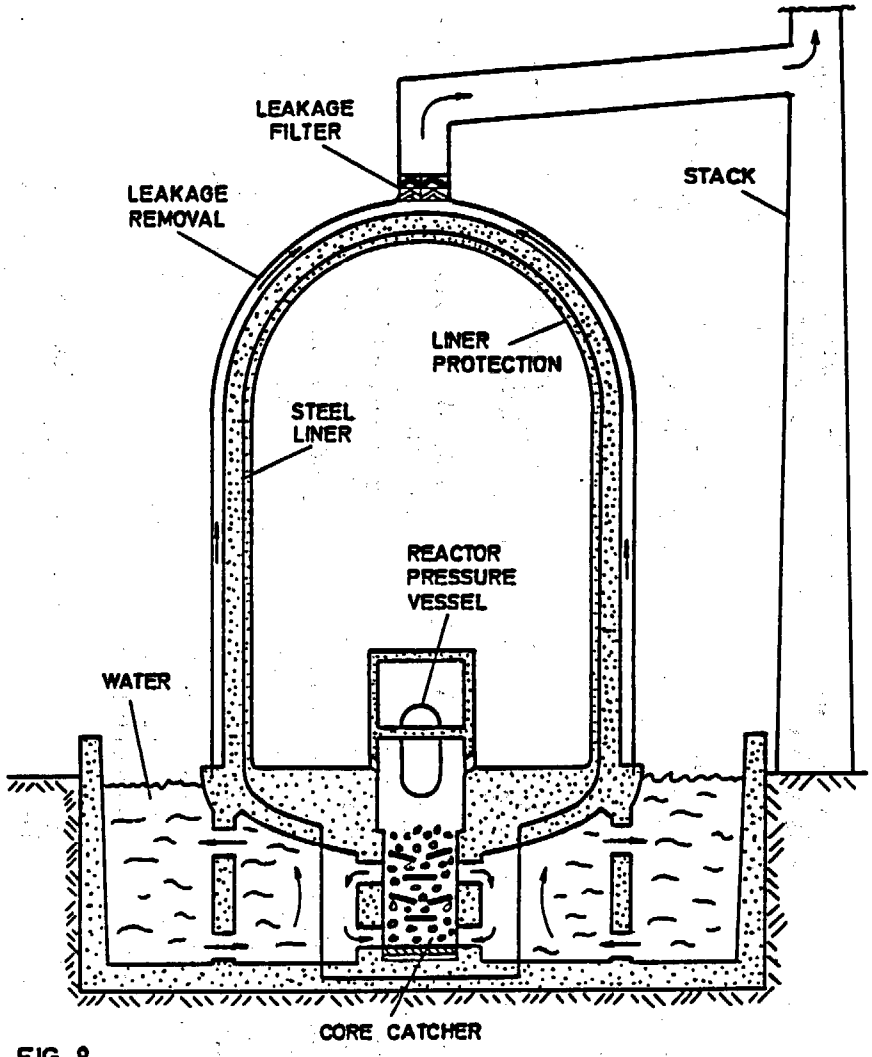

FIG. 8

CONTAINMENT
MOLTEN CORE WATER COOLED

DISCUSSION

KUMAR: Seems to be a nice concept, but if the containment structure is about 200 meters tall, the stack will have to be much, much higher for natural flow. There is no fan, is there?

WILHELM: No, no fans. The containment itself is 40 meters high. We calculated that the stack needed to be 180 meters. That means, 140 meters stack height in addition to the 40 meters of containment to produce the needed suction.

KUMAR: In that case, do we have to worry about tornado protection? Do you have to design for that?

WILHELM: Yes, we have to design the containment to withstand airplane impacts and any other external or internal events. The concrete containment will be built so that it can withstand any impact from the outside. Between the concrete containment and the inner steel containment there will be connections so the concrete containment can gain strength from the steel containment which can withstand very high pressure. At the moment, we are thinking about short pressure peaks of 35 or more bar from a hydrogen or a steam explosion. Tornados are not design basis for stacks in Germany. Maximum wind speed considered in stack design is 45.6 m/s for a height above 100 (DIN 1055).

BERGMAN: Since the differential pressure is the key impediment to this concept, would you care to share some thoughts on the directions you would take to design such a filtration system?

WILHELM: I think there is only one way. One has to lower the packing density of the filters. We have a new development in which we use the same weight per unit area but with lower packing density of the fibers. One comes up practically with the same removal efficiency.

DEVELOPMENT OF A PERSONAL COMPUTER CODE FOR FIRE PROTECTION ANALYSIS OF DOE FACILITY AIR-CLEANING SYSTEMS

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Abstract

The United States Department of Energy (DOE) has sponsored development of a computer code to aid analysts performing fire hazards analyses for DOE facilities. The code selected for this application was the FIRAC code developed by the Los Alamos National Laboratory for the Nuclear Regulatory Commission. The original code has been modified by the Westinghouse-Hanford Company. The FIRAC code simulates fire accidents in nuclear facilities and predicts effects of a hypothetical fire within a compartment and its effect throughout the rest of the facility, particularly the air-cleaning systems.

The FIRAC code was designed to run on Cray supercomputers. The input format is difficult to use. For this code to be useful to the DOE fire protection community, it had to be converted to run on an IBM PC and couple with a menu-driven pre-processor that would make preparation of the input easy to use for fire protection engineers. In addition, a graphical display of the analysis results was required.

In this paper we will describe the pre-processor, the PC version of FIRAC, and the post-processor graphics package. In the presentation, a demonstration of how to set up a problem and use the code will be made.

Introduction

The United States Department of Energy (DOE) has sponsored development and conversion of an existing fire modeling computer code into a fire hazard analysis tool that can be used throughout the DOE nuclear complex. The base code used in this effort is the FIRAC code developed by the Los Alamos National Laboratory for the United States Nuclear Regulatory Commission. The primary objective of the DOE effort was to convert the computer program to run on the IBM PC and to develope a pre- and post-processor for the code. The pre-processor had to be very easily used by the practicing fire protection engineer. Similarly, the post-processor had to include output results in graphical form rather in numerical form for easy and quick interpretation.

A description of the features of the FIRAC computer program and its fire compartment module, FIRIN, will be given. Application of the program to a real facility will be described. Demonstration of how to set up a problem using the pre- and post-processor will be made in the presentation.

Background

The FIRAC computer code allows an entire facility to be modeled in a systems analysis fashion. That is, the interconnection of all the facility rooms, corridors, and heat, ventilating, and air conditioning (HVAC) systems is taken into account. The interdependency of these elements and the feedback effect on the fire are the strengths of the model. FIRAC features the following capabilities.

- A lumped-parameter formulation allows the zones of a facility to be modeled in either coarse or fine detail.
- All HVAC components, such as blowers, dampers, ducts, glove-boxes, and filters are modeled.
- A fire compartment model called FIRIN is included.
- The inlet and outlet flow, temperature, and pressure from the fire are strongly coupled.
- The heat transfer from duct walls is taken into account.
- Blower out-running or back-flow is modeled.
- Smoke, gas, and radioactive species transport are modeled, including gravity settling, turbulent deposition, bend deposition, and filter depletion.
- Filter models that include particulate plugging and variable efficiency are included.
- Transient air pressure, density, temperature, and flow are calculated throughout the facility.
- Transient aerosol concentration, mass flow, mass fraction, deposition, and entrainment are calculated for all locations.

The fire compartment module used in FIRAC is called FIRIN and was developed by Battelle Northwest Laboratories. The strength of this compartment model is its ability to simulate radioactive contaminated burning of materials with the associated radioactive aerosol release. The primary features of the FIRIN fire compartment model are

- burning of radioactive solids and liquids,
- oxygen depletion,
- fire growth approximated by a burning-order concept,

- fire growth approximated by an ignition energy concept with autoignition of combustibles at risk (Factory Mutual data),
- Factory Mutual burning rate database,
- flaming combustion and limited smoldering combustions,
- burning rates as a function of available oxygen,
- wall and equipment heat absorption,
- water vapor formation,
- flame radiation as a function of material burned,
- aerosol depletion mechanisms that include gravity settling,
- brownian diffusion, diffusiophoresis, and thermophoresis.

There are several limitations associated with the FIRAC code and the FIRIN fire compartment module. The FIRAC code is limited by the fact that spatial variations can only be handled in an approximate way; for example, a length of duct can be subdivided into discreet lumps or control volumes to obtain spatial resolution. In addition, bidirectional flow in ductwork is not allowed with the lumped-parameter formulation of the FIRAC code. The FIRIN module is limited in the sense that it is a zone model; that is, it models the burning process by assuming that there is a hot and cold layer. The hot layer moves as a function of time and the appropriate inlet/outlet fluxes are calculated accordingly. Spatial variation in the vertical direction is handled well by the zone model, but horizontal effects are only approximated.

The FIRAC code has been applied to several facilities. The Lawrence Livermore National Laboratory (LLNL) fire test cell and special fire experiments performed by Factory Mutual for Sandia National Laboratories have been analyzed. The code has been used to simulate fire scenarios in several nuclear plants. One example is the plutonium processing facility at Los Alamos. In this analysis the effect of a fire in one part of the plant on final exhaust high-efficiency particulate filters in another area of the plant was determined. A second example was an application to the West Valley, New York storage facility. A third example is a current study applying the code to the DOE Waste Isolation Pilot Plant at Carlsbad, New Mexico. A fourth example is an analysis of a hydrogen burn in one of the waste tanks at the Hanford site near Richland, Washington.

PC FIRAC Version

The PC version of the FIRAC computer code runs relatively fast when compared to running time on the CRAY Y-MP. A moderately sized problem takes 10 min on the Cray and would require 100 min on the IBM PC.

It is difficult to describe the pre- and post-processor graphical packages for the PC version of FIRAC. It is much easier to demonstrate

their capabilities. However, we have included four figures to show the IBM PC display screens. Figure 1 is a blank screen that is ready for construction of the FIRAC facility model. Figure 2 shows a model of the fire test cell at LLNL. The model was constructed using the icons on the left-hand side of the screen. The fire room is shown with a flame icon. Using the menu displayed in Fig. 1, the fire room can be selected with the shift f3 key, or if the user has a mouse, he can click on the fire room icon in the model. When the fire room is selected, another screen appears for the FIRIN module input with its icons and menus. Figure 3 is an example of a blank screen with the menus listed below. Again clicking on the appropriate area or using the keyboard allows other menus to be selected for input entry. During presentation of the paper, we will include a short demonstration of the process.

The pre-processor automatically creates the input file for running the FIRAC PC code and also prepares a document listing all of the parameters that were used for input. After FIRAC has run the problem, it provides an output file for the post-processor. Activation of the post-processor gives another menu that allows the user to select a variety of graphical or tabular displays. Figure 4 is one example of the kind of information one can access from the post-processor. In this figure all of the thermal effects in the fire compartment are grouped together to provide a composite of all the important fire scenario parameters. Any one of these plots can be displayed individually on a full screen for more resolution.

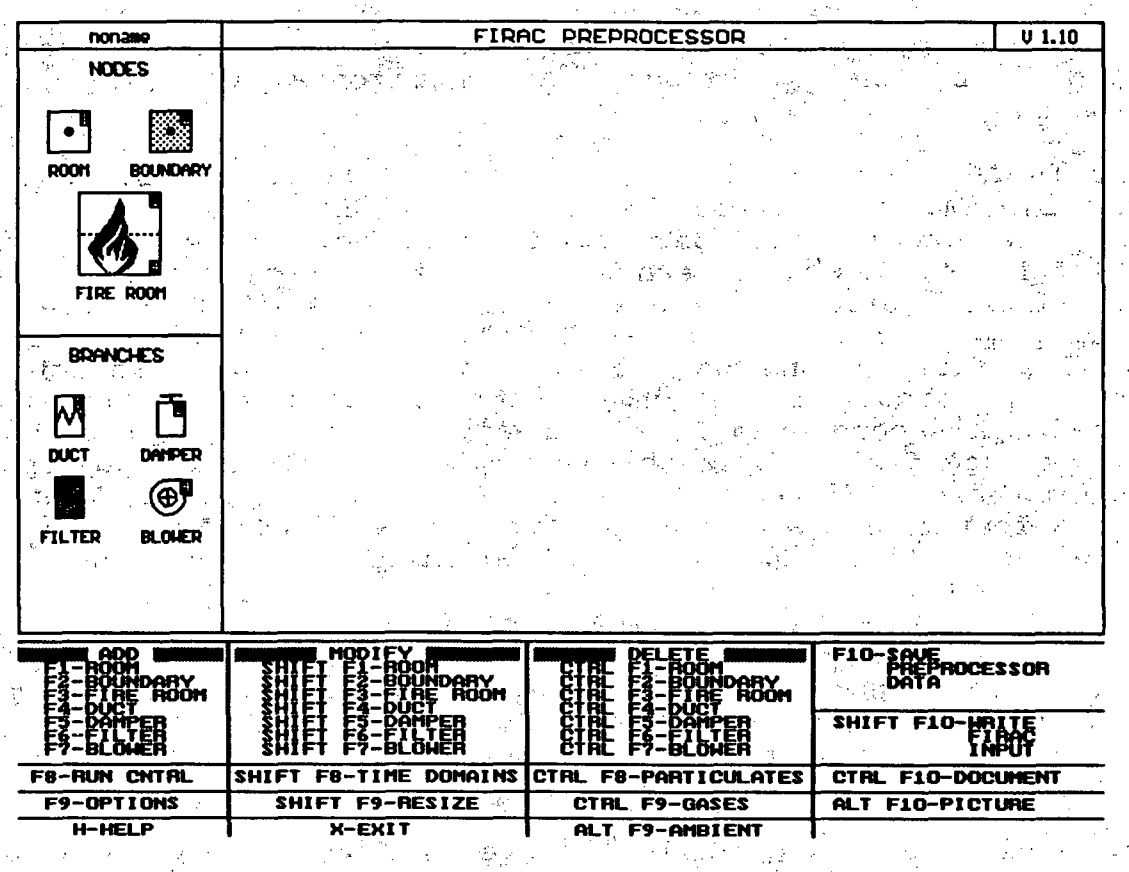

Figure 1. FIRAC pre-processor screen.

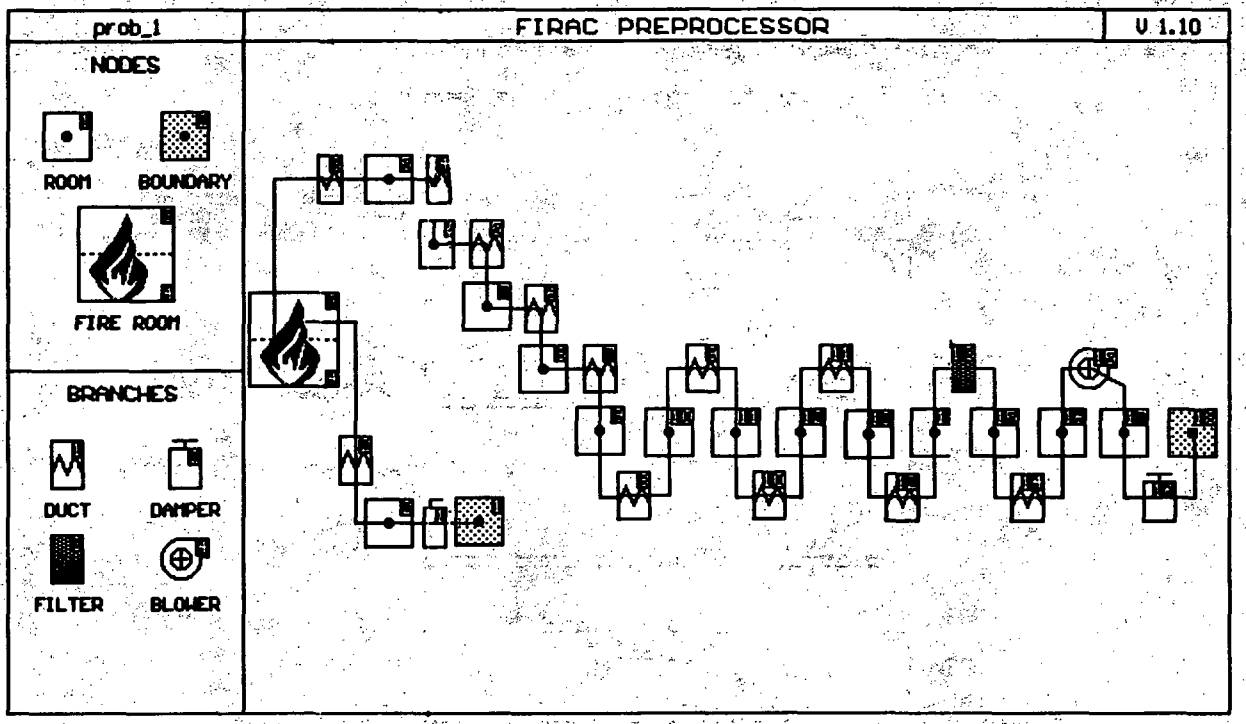

Figure 2. FIRAC pre-processor sample problem.

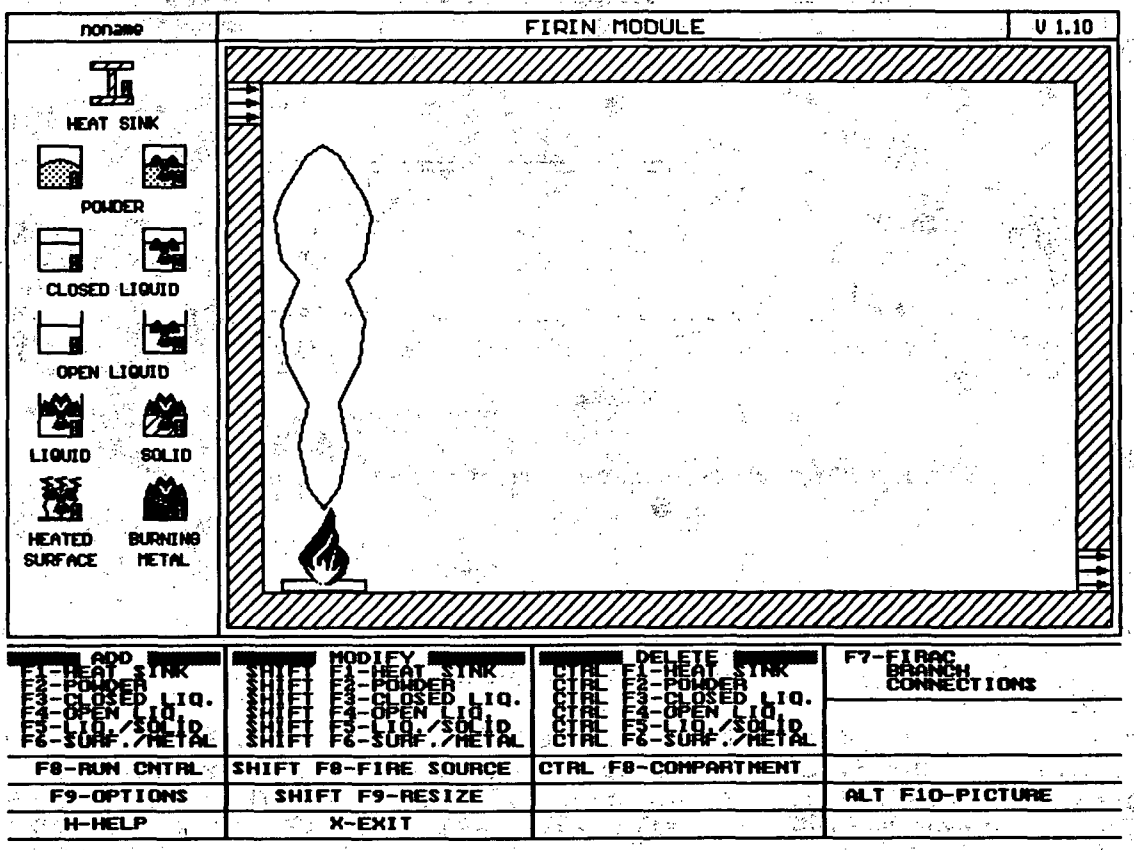

Figure 3. FIRIN module screen.

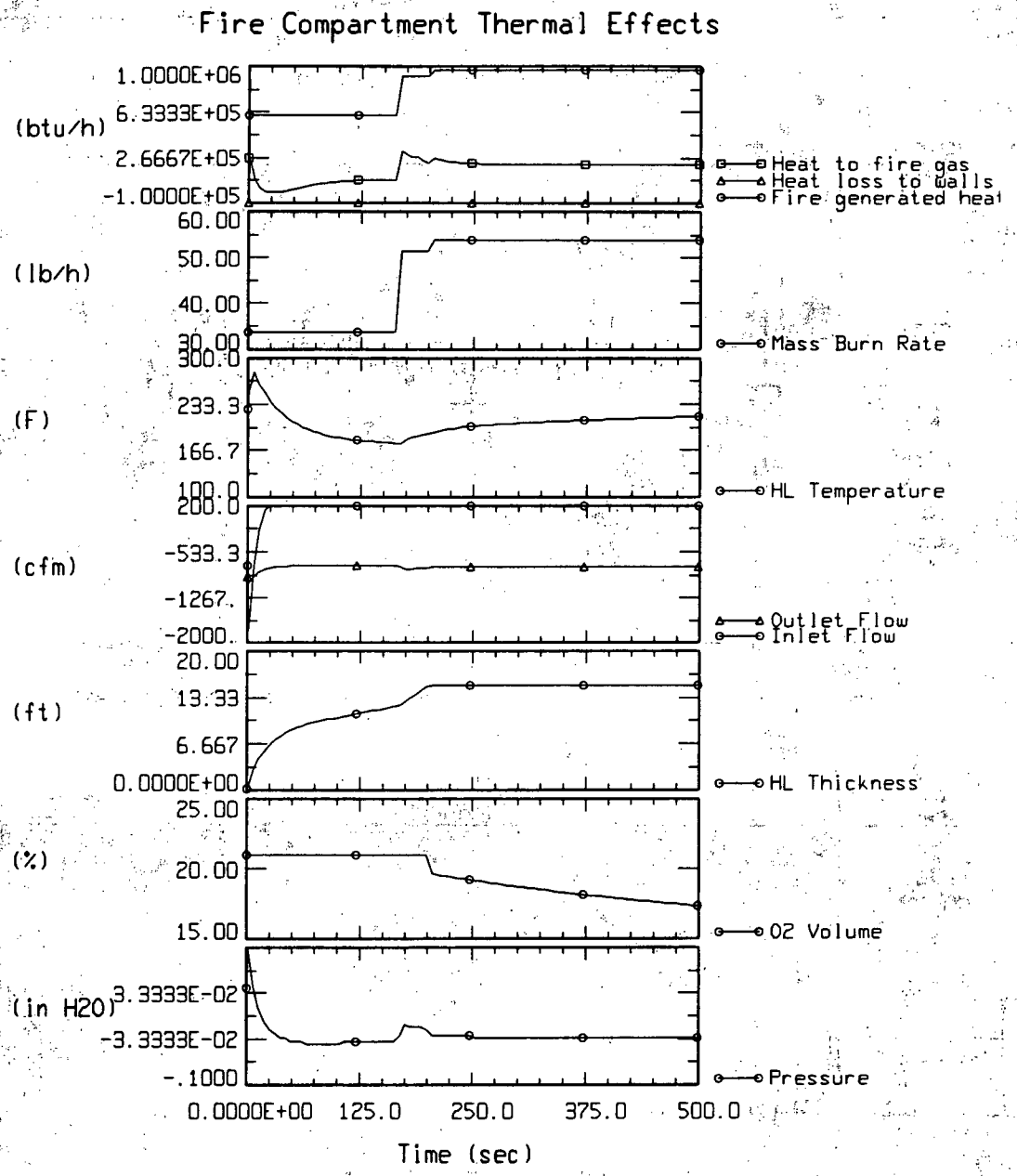

Figure 4. Fire compartment thermal effects.

Summary

Conversion of a fire modeling research tool (FIRAC) into a practical, user-friendly, PC-based tool for the fire protection engineer has been described. A description of the attributes and limitations of the FIRAC code and its fire compartment module, FIRIN, and several applications of the code were discussed. We believe that this tool can now be used by fire protection engineers to perform fire hazard analyses as necessary.

DISCUSSION

TSAL: I would like to ask you about your items. I do not see fittings. We now have more than 200 fittings, of different kinds. What happens if I need to use transitions, junctions, not just dampers?

GREGORY: With the fact that you can specify K-values, you can input K-values which could represent various fittings, or bends, or what have you.

TSAL: But there are variable K-values. In the tables there are variable functions of flow but you don't know the flow until you calculate it in your program.

GREGORY: That is right. The best we can do right now is try to get a steady-state value and go with that. The only one that varies right now with time is the filter, because it will become plugged as particles enter it.

EFFICIENCY TEST FOR ULTRA HIGH EFFICIENCY METAL AIR FILTERS

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Abstract

Pall has qualified a DOP penetration test for single stage filters to ULPA and higher efficiencies. This test is specifically designed for simplicity, speed, and to use instrumentation presently on-site at U.S. D.O.E. Filter Test Facilities. It employs a standard DOP penetrometer as aerosol generator and a laser spectrophotometric particle counter as detector, thus providing diameter dependent efficiency data.

Reliable data have been collected at penetrations to as low as E-8.

A summary of qualification testing performed by Pall's Scientific and Laboratory Services Department (SLS) is provided herein; and examples of metal filter efficiency data.

Introduction

Environmental protection is the prime objective in design and testing of nuclear off-gas and building exhaust systems. Toward this end, systems are often constructed with two or more stages of HEPA filter in series.

Multiplicity serves safety expectations by redundancy; further providing additional effluent cleanliness. In the U.S. and elsewhere, mandates for nuclear facilities calling for multistage HEPA containment also require in-place filter efficiency test. Well established methodology accepted by U.S. Department of Energy facilities employs DOP smoke as controlled contaminant for filter challenge. Smoke dispersion and detection geometries can vary by system configuration.

Sensitivity limitations of conventional light scattering detectors dictate in-place multistage HEPA testing be performed one stage at a time. Multistage testing is further complicated by problems of representative sampling and adequate smoke dispersion when these are done between stages.

By strict definition, maximum penetration of 0.3μ DOP smoke for two filters in series, each HEPA rated at 99.97% efficiency, is 9E-8. In application, removal efficiency of the train is often accepted as ≥99.999%. Single stage filters validated as providing removal efficiency at this value are known by the designation ULPA (1).

Pall has undertaken to provide an ULPA rated filter at ≤2"H_2O in stainless steel medium and welded construction to Battelle Northwest Laboratories for evaluation in radioactive waste vitrifier off-gas service. The filter will provide efficiency equivalent to two stages of HEPA in series, conforming to 1000-fold DOP reduction at 0.1μ in the first stage, 100-fold reduction in the second (99.999% filter efficiency).

Data concerning Pall metal filter technology in additional Nuclear Air Cleaning applications are presented at this Conference by other workers (2,3,4).

As result of test method qualification, and SLS tests of a variety of cartridge constructions, Pall has assembled a full-size filter comprising an assembly of 14 cartridges for laboratory evaluation preceding Battelle's pilot application. It is expected that filters of this type can be employed successfully to eliminate redundant HEPA stages and upgrade safety.

The potential value of alternative detection equipment, such as laser spectrophotometers in DOP aerosol measurement, has been recognized by DOE Filter Test Facilities (5). To encourage acceptance of single stage filters at multiple HEPA efficiencies, Pall has constructed and qualified a penetration test employing methods closely similar to those in current use. It shares the laser detection method employed by HFATS (5), diverging from HFATS by relying upon conventional hot DOP aerosol generating equipment.

Data measured to qualify this method, to define a recommended range of use, and in its initial application are presented herein.

Test Methods

Key to measuring particle penetrations for ultra-high efficiency filters is to combine high detection sensitivity with high particle density in a controlled aerosol.

We set about to measure particle count as a function of diameter and of time in DOP smoke generated by an Air Techniques Incorporated (ATI) model Q127 penetrometer. This instrument is rated to 3CFM by its manufacturer. The smoke generator was used in accordance with standard settings. Aerosol particle size distribution was measured using a Particle Measurement Systems Las-X counter. A similar combination has been used with single stage HEPA filters in evaluating hot aerosol contaminants as alternatives to DOP (6).

We began prepared for the possibility that ultimately we would be required to increase particle density beyond that standard settings produce. We constructed the initial test loop to evaluate dilution ratio required to ensure non-saturation of the Las-X counter, as depicted in Figure 1. Diluters were TSI, Model 3302. Where two diluters were used sequentially, the first was modified by duplication of its cleanup filters as a second stage in series.

Particle count as a function of dilution is given in Graph 1 for

the 0.20-0.25μ bin, chosen for reference. At 10000 fold dilution, several thousand counts per minute were typically registered in the bins close to 0.3μ. Background was typically of the order of 1 count per minute. It was concluded to proceed, at dilution ratios ≥2000, provided stability of particle count obtained.

Particle count stability was monitored as a function of diameter over a period of several days. Representative particle count as a function of diameter is given in Graph 2. Comparison with Graph 3 shows typical reproducibility after overnight Q127 cooldown and restart of the hot DOP aerosol generator the next day.

After screening Pall candidate stainless steel filter media in flat sheet, a higher flow rate system was required for evaluating pleated filter elements. For this purpose, an ATI Q76 DOP penetrometer was employed as aerosol generator in conjunction with a PMS Las-X spectrophotometer, as depicted schematically in Figure 2. The aerosol was similarly qualified for population and stability.

Typical particle count as a function of diameter between 0.1 and 0.3μ is given in Graph 3. To compare particle size distribution with that of aerosol from the Q127, a plot in the manner of Graph 2 is given for Q76 data as Graph 4. At standard settings, aerosol population in bins between 0.1 and 0.3μ was consistently about an order of magnitude lower using the Q76 generator.

The Q76's particle size distribution was modified in some aerosol qualification trials by non-standard instrumental settings suggested by the manufacturer. During these, using a 0.20-0.25 bin as reference, it was observed that a change in population as recorded by the Las-X counter was registered by the Q76 penetrometer detection circuit in identical proportion.

It was concluded that aerosol population was adequate for the present filter studies at standard instrumental settings, and these were subsequently employed.

A housing to test individual pleated filter elements at 22CFM was constructed to fit within an existing chuck.

Sampling performance of a non-isokinetic probe within the chuck was compared filter-absent with that of a downstream isokinetic probe in the effluent duct (Figure 2), placed 8 duct diameters from the chuck exit. Counts registered in size ranges of interest were expected to be the same (particle pathway dominated by Brownian motion), and their correlation is shown in Graph 5. Measured equivalence of these counts was taken as a further indicator of instrumental reproducibility and non-interference of test stand construction.

DOP efficiency for a series of cylindrical element candidate constructions was then tested and, subsequently, a 14 element assembly (below).

Results and Discussion

The filter for Battelle will provide efficiency equivalent to two

stages of HEPA in series, conforming to 1000-fold DOP reduction at 0.1um in the first stage, 100-fold reduction in the second (99.999% overall). Design of the full scale 14 element system is shown schematically in Figure 3.

Test results for a single Pall cartridge of design selected for full scale application are given in Table 1.

Elements of this type were assembled and shipped to Pall's 300CFM test facility for DOP test. Elements were sealed to tube sheet via gaskets; installed at factory under torque specification, six threaded studs per module (7 modules). A photograph of the assembly is reproduced as Figure 4.

DOP test results are given as Table 2. Production unit will have elements welded to tube sheet for highest seal integrity. (Tube sheet assembly with welded elements to ship in its own cradle apart from housing.)

At this writing gasketed seal to tube sheet is being confirmed in preparation for a DOP test:Backwash:repeat DOP test sequence for third party witness.

Conclusions

1. DOP efficiency test has been designed capable of demonstrating ULPA and finer efficiencies. Based upon in-house testing, source aerosol density and background count considerations, it is concluded that diameter dependent penetrations to as low as E-8 are reliably measured.

2. The DOP penetration test described herein is expected to be implemented readily by U.S. D.O.E. Filter Test Facilities should they choose to do so. Such Facilities in possession of DOP smoke generators normally part of existing DOP penetrometers, and also in possession of a laser counter and diluter(s) (e.g. as is part of an HFATS unit) are already quite well equipped.

3. The test herein described is expected to facilitate in-place test of single stage ULPA filters, pending evaluation of aerosol density produced by field smoke generators. This method is also expected potentially to simplify in-place test of multiple stage HEPA installations.

4. In most cases, duration of test is comparable with that of conventional hot DOP penetrometer test.

5. Pall has successfully demonstrated ULPA filter efficiency to beyond proof-of-concept in single stage all-welded stainless steel filters at <2"H_2O pressure drop.

References

1. W.L. Anderson, "Making Sense of HEPA Filtration," Filtration and Separation, November/December, 1989.

2. W. Bergman, G. Larsen, F. Weber, P. Wilson, R. Lopez, G. Valha, J. Conner, J. Garr, K. Williams, A. Biermann, K. Wilson, P. Moore, C. Gellner, D. Rapchun, K. Simon, J. Turley, L. Frye, "Development and Evaluation of a Cleanable High Efficiency Steel Filter", 22nd DOE/NRC Nuclear Air Cleaning Conference.

3. G. Grewal, Z. Milatovic, F.L. Landon, William Harty, "Application of High Efficiency Metal Fiber Filters in Ventilation Systems of Non-Reactor Nuclear Facilities," 22nd DOE/NRC Nuclear Air Cleaning Conference.

4. M.V. Kaercher, "Design of a Prefilter to Improve Radiation Protection and Filtering Efficiency of the Containment Venting System," 22nd DOE/NRC Nuclear Air Cleaning Conference.

5. R.C. Scripsick, R.L. Smitherman, S.A. McNabb, "Operational Evaluation of the High Flow Alternative Filter Test System," Proceedings, 19th DOE/NRC Nuclear Air Cleaning Conference, 1987.

6. H.R. Carlon, U.S. Army CRDEC, personal communication.

Test Assembly For Evaluating Dilutions

Note: Mixing chamber used only for dilutions >10000:1

Note: Diluter #1 was modified to employ two stages of HEPA filtration

Figure 1

Filter Assembly DOP Test Loop

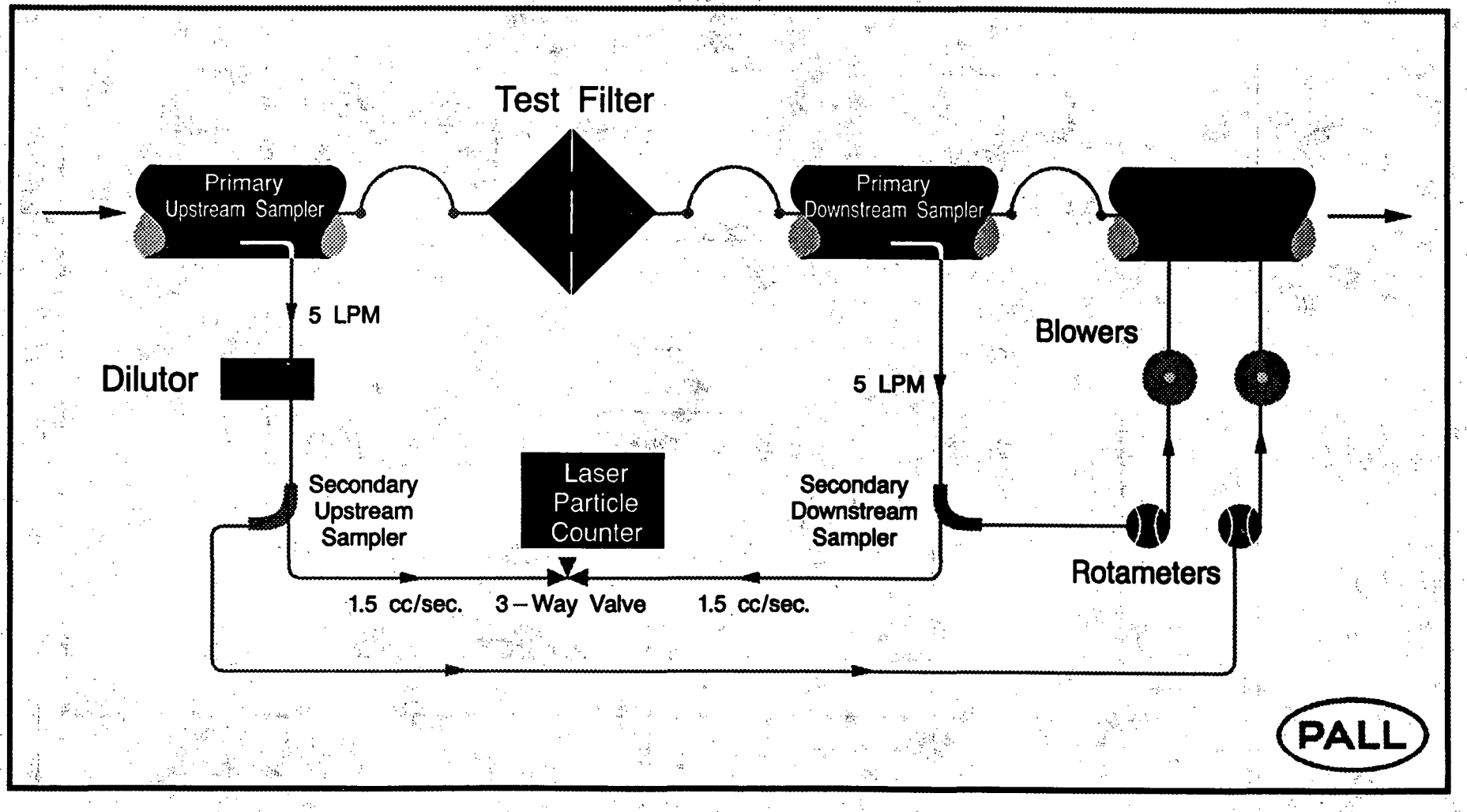


Figure 2

Melter Off-Gas Filtration System

PALL

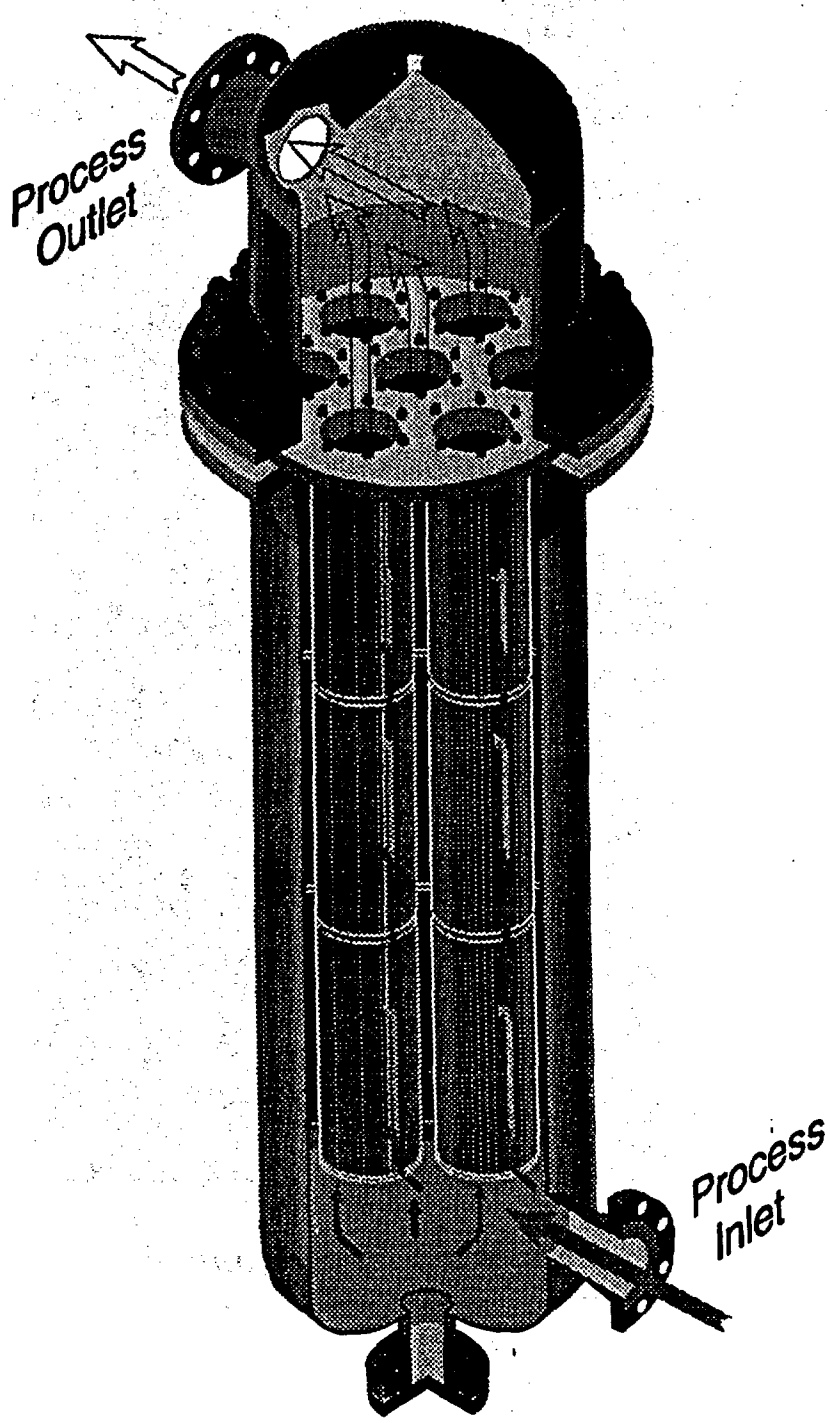
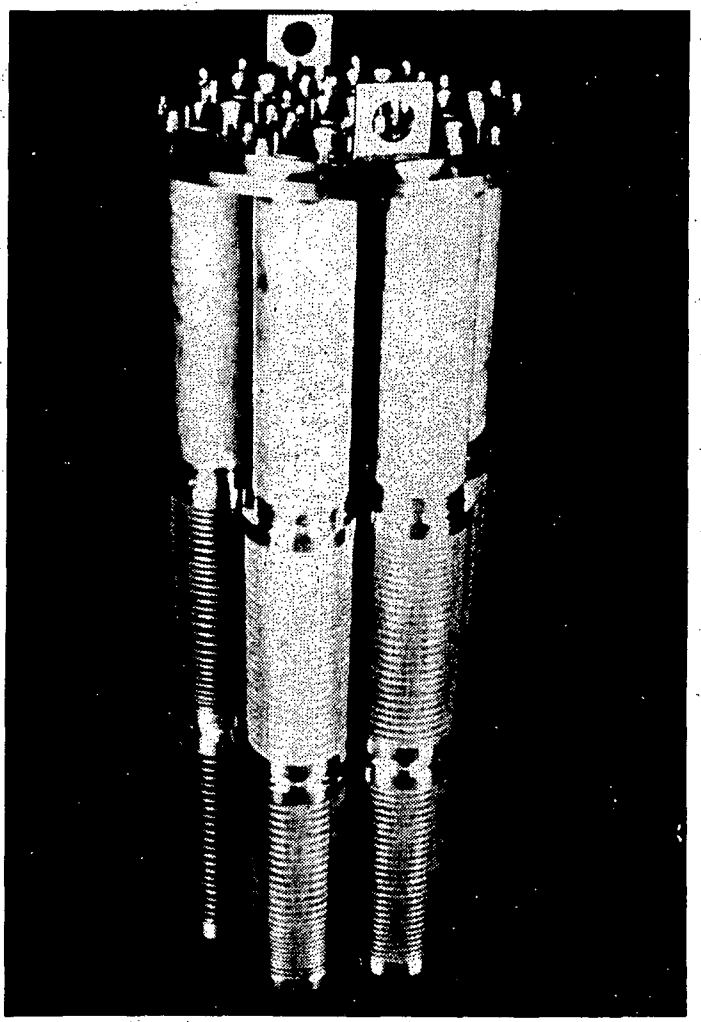


Figure 3
95" OAL
20" Diameter Housing
Total Filter Area 230 ft²

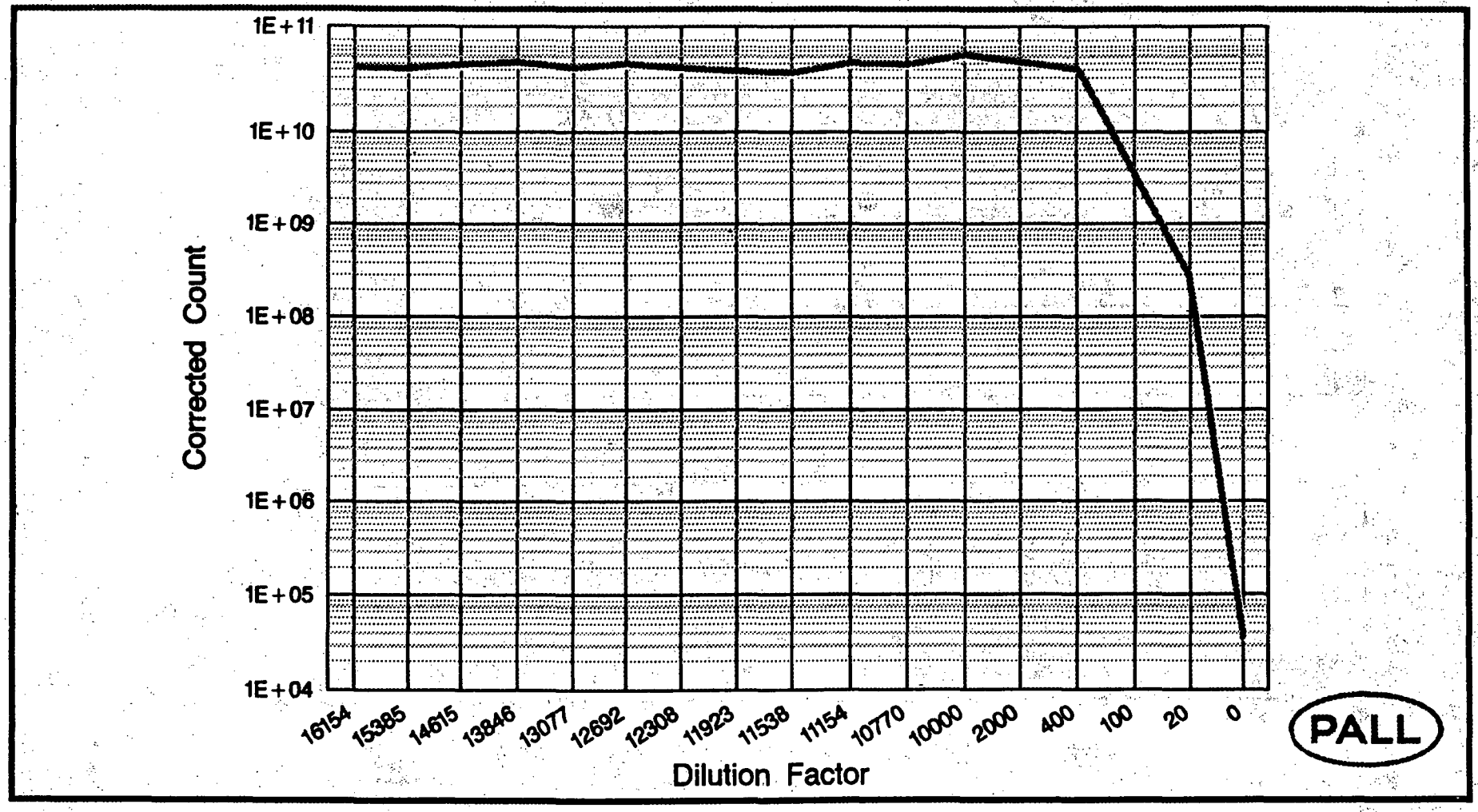
Pall Ultramet™ Multi-Cartridge Assembly



Absolute Performance℠

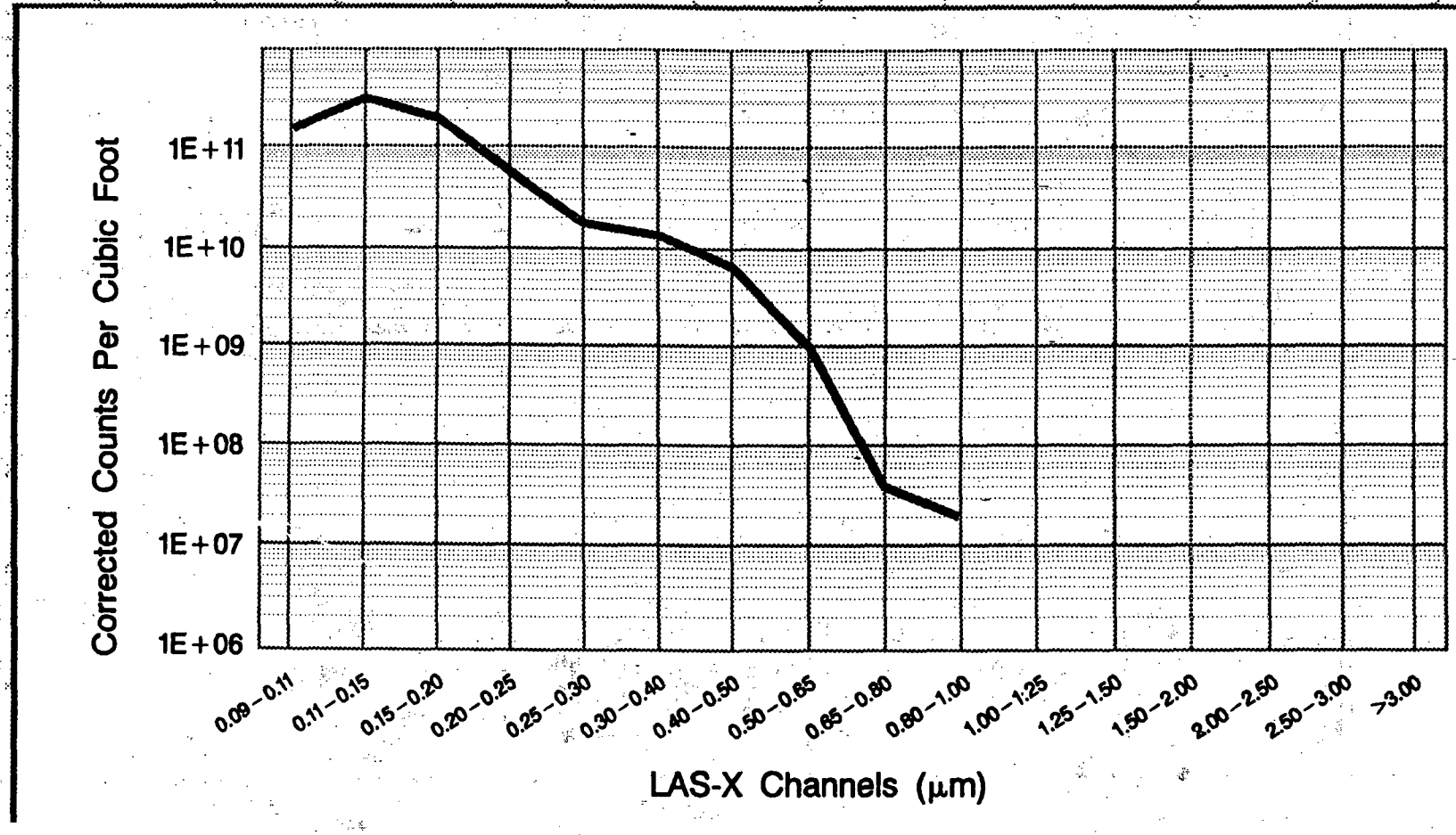
Figure 4

DOP Counts as a Function of Dilution
LAS – X Counter, 0.20 – 0.25μm



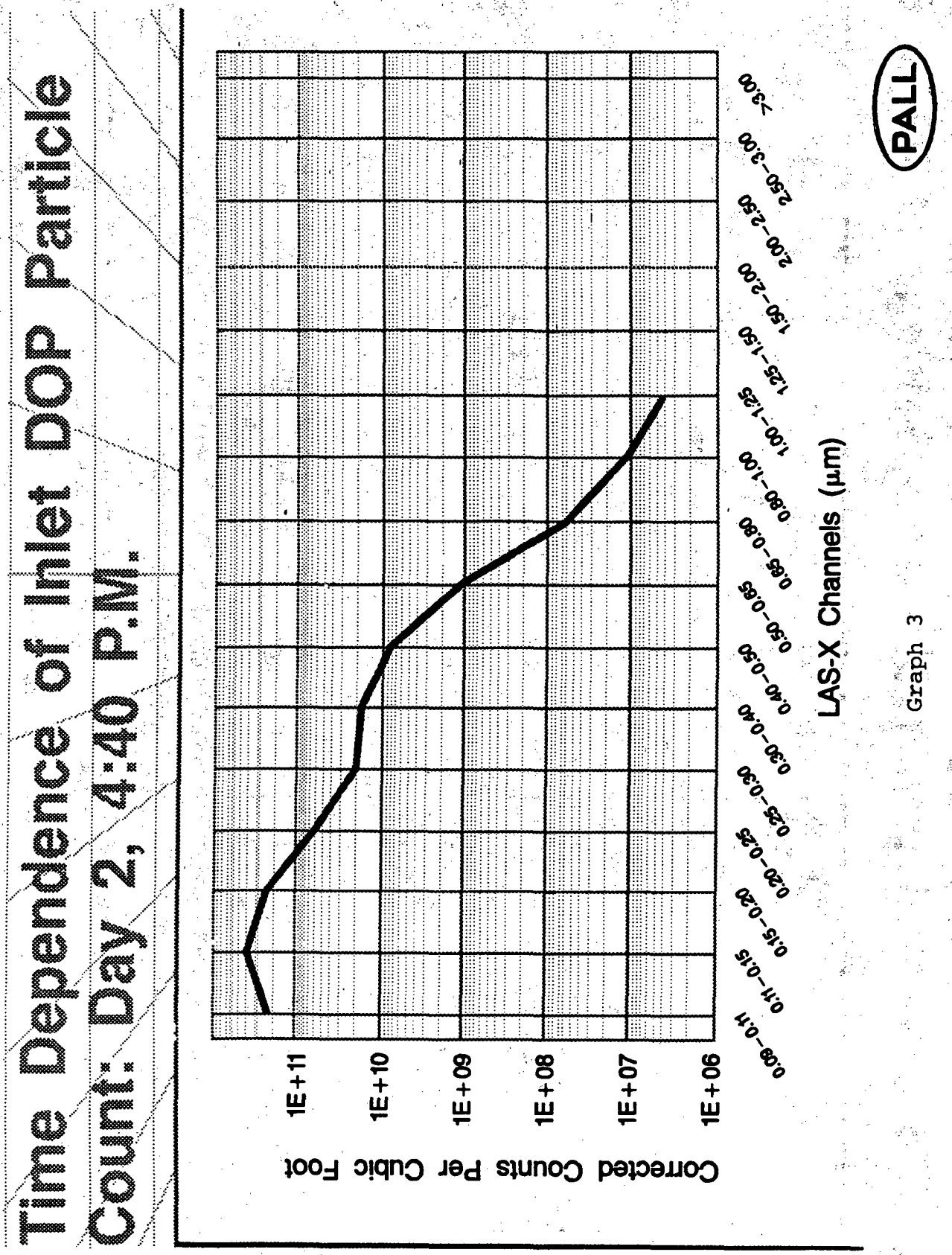
Graph 1

Time Dependence of Inlet DOP Particle Count: Day 1, 4:15 P.M.



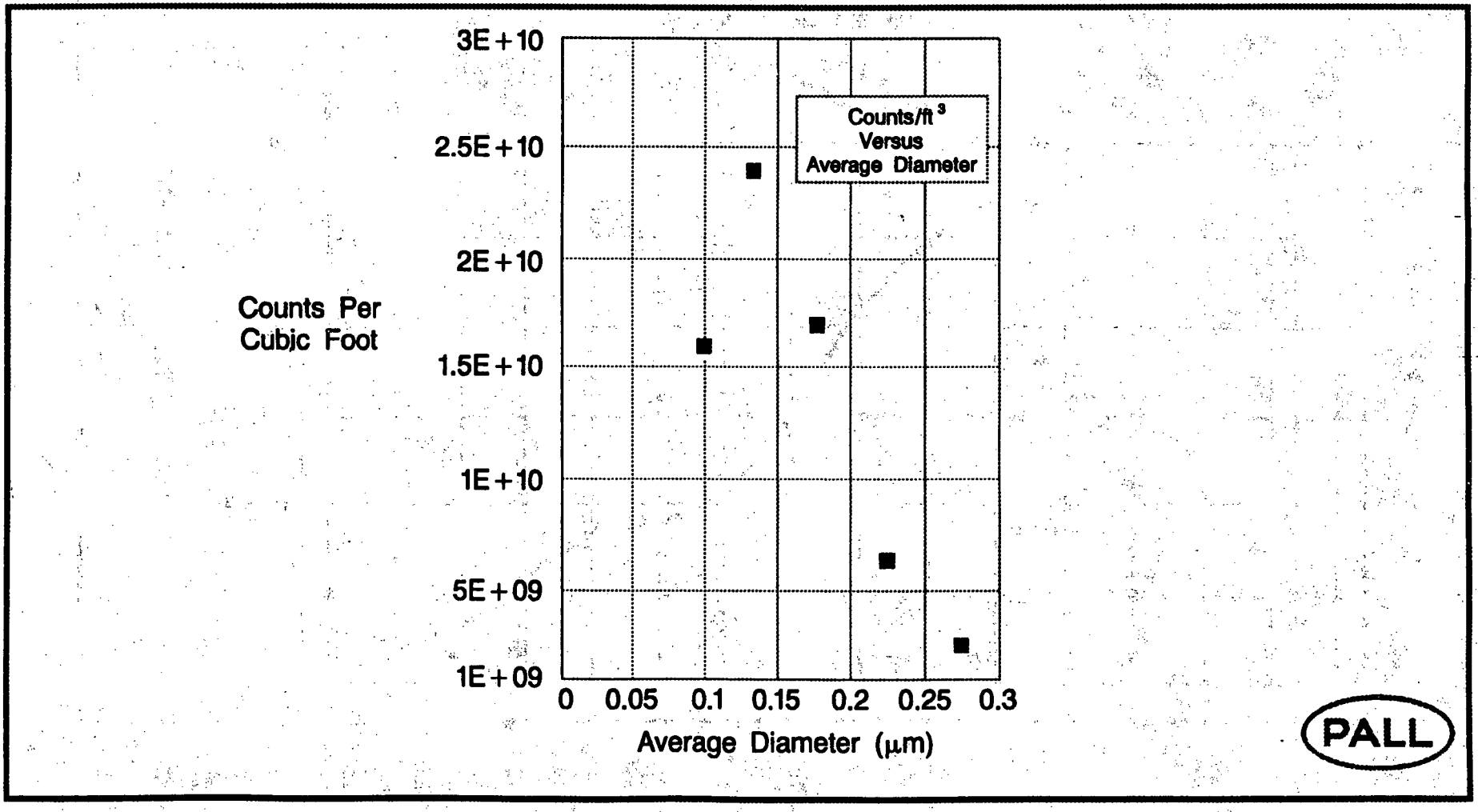
PALL

Graph 2


Time Dependence of Inlet DOP Particle Count: Day 2, 4:40 P.M.
Corrected Counts Per Cubic Foot
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
0.08–0.1
0.1–0.15
0.15–0.20
0.20–0.25
0.25–0.30
0.30–0.40
0.40–0.50
0.50–0.65
0.65–0.80
0.80–1.00
1.00–1.25
1.25–1.50
1.50–2.00
2.00–2.50
2.50–3.00
>3.00
LAS-X Channels (µm)
PALL

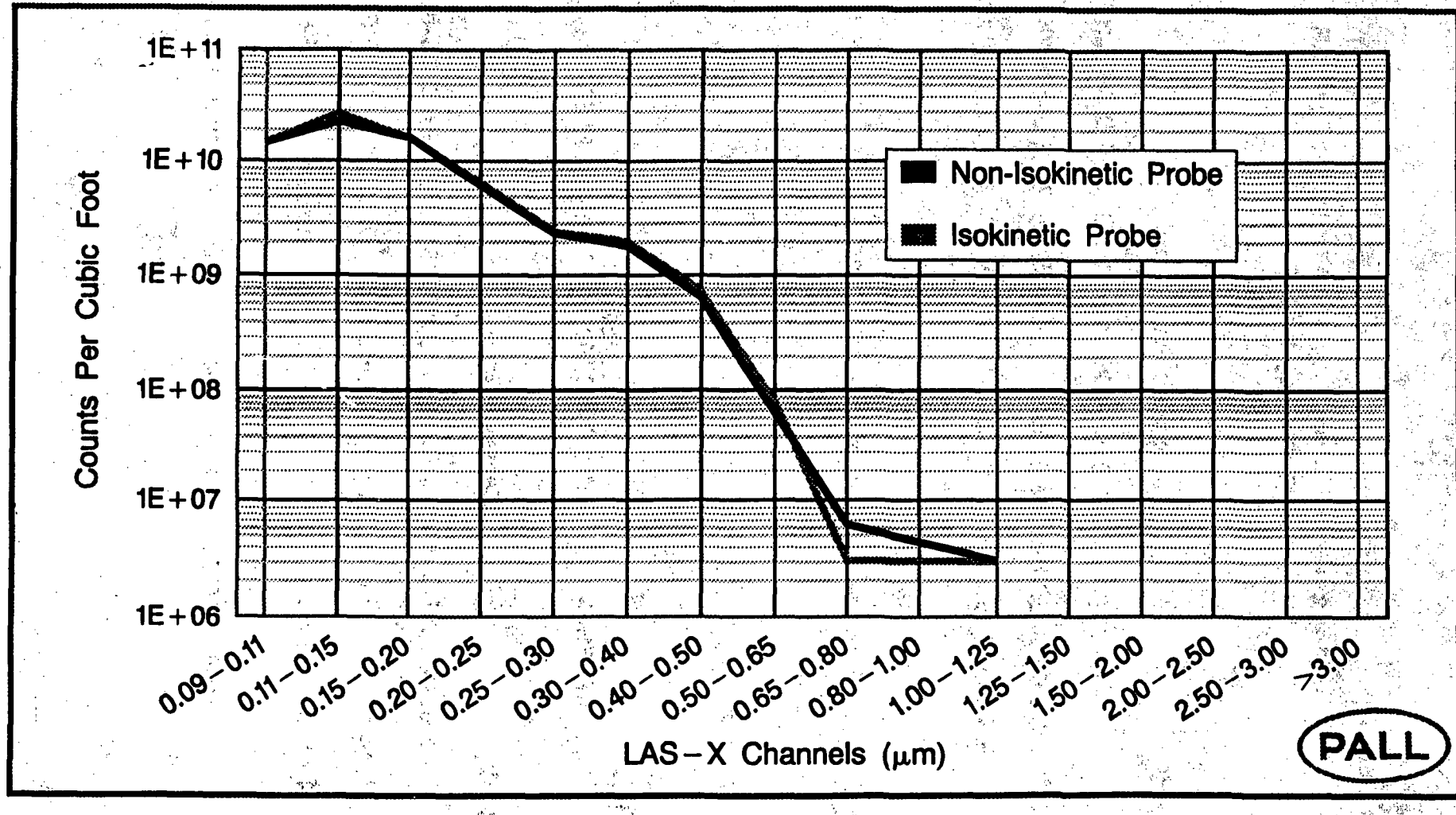
Graph 3

Dilution Corrected DOP Aerosol
ATI Q76 Operated Under Standard Settings at 22 SCFM



Graph 4

Filter Inlet Counts, Q76, 22 SCFM



Graph 5

Table 1
REPRESENTATIVE DOP PENETRATION PALL FILTER ASSEMBLY AT 300CFM.

Test	Diameter Range, um					
	0.09-0.11	0.11-0.15	0.15-0.20	0.20-0.25	0.25-0.30	0.30-0.40
1	2.0E-5	2.2E-5	2.7E-5	2.8E-5	2.6E-5	2.5E-5
2	2.1E-5	2.4E-5	2.9E-5	3.0E-5	2.9E-5	2.7E-5

Pressure drop across assembly and tube sheet was 1.7" H_2O.

Table 2
REPRESENTATIVE DOP PENETRATION PALL ELEMENT, 22CFM

Test	Diameter Range, um					
	0.09-0.11	0.11-0.15	0.15-0.20	0.20-0.25	0.25-0.30	0.30-0.40
1	4.9E-6	5.3E-6	5.9E-6	6.3E-6	6.2E-6	6.0E-6
2	4.4E-6	4.9E-6	5.6E-6	6.0E-6	6.0E-6	5.9E-6

Pressure drop across housing containing test element was 1.6" H_2O.

DISCUSSION

BERGMAN: The data on the efficiency results that you showed has a flat response as a function of particle size. That indicates to me that you have a significant leak and the true efficiency should be dramatically higher than what you reported.

WEBER: I want to thank you for making that comment. I think you are right. As a matter of fact, as I may have mentioned, the difference is that it was not welded construction at this point as it will be for field operation. It was a gasketed construction at the tube sheet. One of our tasks now is to go back and retorque to make sure that it is at the correct torque specification for that particular test. In the case of the single element, however, I beg to differ, I think there is a loose end somewhere. I have noticed in your work that frequently the difference in penetration between the most penetrating particle size and 0.3 micrometers is a factor of 2 or 3, whereas, we have a factor of 50% in some cases. However, for the single module, I didn't have a chance to test different flow rates. I found that a factor of two in velocity would make a factor of 10 difference in efficiency. In cases where I have detected leaks in the past, I have noticed that you have a flat response and I think that is a dead giveaway. The single element test results were just as flat, however, showing an extremely sharp flex dependence. So I agree with you, but I also think there is a loose end which bears investigating.

REYNOLDS: With your testing experience with metal media, what recommendations would you suggest to do an in-place test, and will the results be comparable to an in-place test for a glass filter?

WEBER: When you are testing a multistage HEPA filter, you must get in between the two stages to be able to do it with a standard penetromometer. In this case, there is only one stage at a time giving efficiency, enabling you to eliminate redundancy in the system. For single stage HEPA efficiency tests, the only thing needed is to take filter geometry into account. For tests of filters containing more than one stage, a laser detector may be needed for required sensitivity - but this may be usable with existing field aerosol generating equipment. I think it will be interesting to qualify these generators as to suitability for testing the higher efficiency filters. My recommendations are to investigate existing equipment with field DOP generators, and I would simply say, lets go out to a site, maybe one of the filter test facilities, and do a test there using portable equipment and a laser detector to get the higher sensitivity that is needed. In other words, use a portable DOP generator, a hot DOP generator, and a laser detector.

REYNOLDS: Could you successfully run an in-place test using the TDA5A?

WEBER: Well, we would like to use the flowtometer. Unless there is one that I don't know about that is sensitive enough to look in

the 10^{-5} penetration range to verify two-stage HEPA. You know that in a regulatory sense, some of them give you 1,000 full decontamination factor for the first stage, 100 full for the second, which is 10^{-5}. In some case they could demand 0.03% squared, or 9×10^{-8}. I think there might be penetromometers sensitive enough for 10^{-5}, but I doubt 10^{-8}. There, I would recommend a laser detector.

REYNOLDS: My reason for the question is, I am in the process of doing exactly what I am asking you. I want to make sure I am getting reliable results to do that type testing in-place.

WEBER: I will be happy to discuss your test in some detail with you later because it is very interesting.

FIRST: I get the impression from your brief description (which is probably somewhat unfair to you) that you are going on the assumption that the minimum filterable size for your filter will be the same as for the conventional glass paper filter. I think that would be a remarkable coincidence because of the differences in structure, fiber size, etc. It seems to me that it is important to explore the matter more thoroughly, although you have some preliminary data. The other point is that you seem to be comparing two different things. When you do the flowtometer test, you are getting your measurement in terms of a light scattering function whereas when you do it with a laser particle counter you are obviously getting a particle number. The relationship between these two is not necessarily one-to-one. Therefore, when you talk about efficiency with the laser spectrometer and compare the numbers with the photometer, I think you have to be a little cautious.

WEBER: I think both points are very well taken and I am not convinced that, in fact, it isn't the structural differences in this particular filter which make the distribution curve on penetration so flat relative to even other stainless steel filters that have been tested. We have considered the point and I think it is an excellent point for future work. We have identified a theoretical researcher in the field, who, in fact, does calculations of most penetrating particle size in fibers and I think that is a good direction to go. As to penetromometer vs laser, I recognize that too. What we look for here is a test that is familiar, rather than to reinvent the wheel. We borrowed hot DOP, and we borrowed the HFATS detector. I think you are absolutely right. It is important not to try to correlate the readings of the two overly closely.

A REVIEW OF LICENSEE EVENT REPORTS RELATING TO NUCLEAR AIR TREATMENT SYSTEMS AND HEATING, VENTILATING, AIR CONDITIONING SYSTEMS FILED DURING THE PERIOD 1988-1991

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Abstract

This paper reviews Licensee Event Reports relating to nuclear air treatment systems and heating, ventilating and air conditioning systems (NATS/HVAC) from 1988 through 1991 filed by operators of U.S. nuclear power plants. It is a continuation of papers presented at past Air Cleaning Conferences by Dr. D. W. Moeller and associates[1234] and John W. Jacox[5].

NUREG/CR-2000 "Licensee Event Report (LER) Compilation"[6] was the basis for this paper. LER abstracts from 1988-1991 were reviewed and those related to NATS/HVAC were categorized and tabulated. The categories were then divided into root (primary) and secondary causes. A total of 10,687 LER's were filed during 1988-1991. Out of this total, 1730 (16.2%) were NATS/HVAC related. Of these, 59.9% were filed by PWR's, 40.0% by BWR's and 0.1% by HTGR operators. Although the total number of LER's filed per year since 1988 have gradually declined, many problem areas of the NATS/HVAC systems remain the same.

This paper is intended to provide information to the nuclear power industry which can be utilized as a basis to review problem areas. It also indicates that several areas continue to require attention.

Introduction

The monthly publication, NUREG/CR-2000, a compilation of LER abstracts from 1988 through 1991, was the basis for this paper. Each NATS/HVAC related LER was first divided into specific categories then divided into root (primary) and secondary causes. They were then further divided into Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) related LER's.

In most cases the LER abstract was sufficient to categorize each LER. If there were no specific statements identifying the root cause, the cause was determined by the authors. Some difficulty arose in determining secondary causes. Since each LER was written with a different focus based on the root cause, determining these secondary causes for NATS/HVAC related LER's was at times difficult. As an example, some cases involving isolation valves and area monitors which may have lead the system to activate, but no activation occurred were not included. If activation occurred as a result of these items, it was included in the tabulation.

The results are presented in Tables 1 and 2. Table 1, "Tabulation of LER's by Root and Secondary Causes," lists sixteen categories and gives a breakdown of the number of root and secondary causes for each category for 1988-91. Table 2, "NATS & HVAC Related LER's Filed By Date and Reactor Type (PWR/BWR)," includes the dates between 1984-1991; and, Table 3, "Secondary Causes Categorized by Root Causes," summarizes secondary causes compared to root causes for 1988-91.

Discussion

A total of 1730 NATS/HVAC related LER's were filed by commercial nuclear power plants from 1988-1991. As illustrated in Table 2 "NATS & HVAC Related LER's By Date and Reactor Type (PWR/BWR)," 59.9% of the LER's filed were PWR related, 40.0% were BWR related and 0.1% HTGR related. It should be noted that of the total generating capacity of our domestic nuclear program, 66.7% is generated from PWR's and 33.3% from BWR's.

Table 1, "Tabulation of LER's By Root and Secondary Causes," indicates there are five categories that contain the majority (73%) of root causes. Personnel Error resulted in 29.5%, followed by Design or Installation Error and Procedure Related with 12.1% each. LER's related to Electrical Components were 9.9% and those related to Radiation Monitors were 9.4%.

The majority of secondary causes (81.9%) were divided among three categories: Radiation Monitors, 52.4%, Electrical Components, 17.1% and Mechanical Components, 12.4%.

Root Causes

The largest number of root causes were personnel error. Over 40% of these errors resulted in Engineered Safety Feature (ESF) actuations. The majority occurred while installing an electrical jumper, checking relays or calibrating radiation monitors. Other areas include misread samples and exceeded time intervals for vent of area sampling or testing. In most of these LER's, personnel error was declared the root cause; however, the procedure or component design was often at fault. This indicates that the number one root cause is closely related to the number two secondary cause, procedure and design or installation errors.

The second largest number of root causes were procedural problems. Nearly 40% of these resulted in ESF actuations. A common problem was improper surveillance testing of NATS components and radiation monitors. In some cases, the required surveillance time interval was exceeded or a test was not performed at all.

Problems associated with design and installation errors fell largely under single failure criteria concern for control room emergency ventilation, containment ventilation and standby gas treatment systems. When a system or component did not meet the single failure criteria, it often led to an unanalyzed condition which led to an LER being filed. Fire damper design and improper installation continue to be an item of concern. There were also cases of damper inoperability, failure to close in flow conditions, and, in one case, a damper was not even installed. Failure positions continue to be a problem of isolation dampers. There were several cases of damper failure "as-is" positions that were not evaluated, or dampers were failing to the wrong position.

Problems related to electrical component failure were the following: relays, breakers, fuses, inverters, loose/bad connections and faulty circuits. About 75% of these resulted in ESF actuations. In comparison, nearly all radiation monitor failures related to components resulted in ESF actuations. These included loss of power, bad power supply, fuses, loose/bad connections, circuit boards, tubes and detectors. As has been reported in earlier papers, one of the largest single causes is from electrical noise, spikes and radio frequency interference.

Secondary Causes

Two of the three most frequent secondary causes were the same as two of the top root causes: one being the radiation monitor and the other electrical component failures. As in the case of root causes, radiation monitor problems revolved around electrical component failures including, relay, loose/bad connector, power supply and circuit errors. The close relation between electrical component failure, electronic noise and spikes to radiation monitors account, in part, for the high number of radiation monitor secondary failures. Personnel error and procedure inadequacies again were a major part of these monitor failures. In the case of electrical components, the failures also paralleled the relay, breaker, fuse, and circuitry problems found in root causes. Various mechanical component failures made up the third largest category.

Comments and Summary

A number of observations can be made from this review. Out of the total number of LER's filed, almost half resulted in an inadvertent ESF actuation. The categories largely contributing to these actuations were Personnel Error, Procedural Error, Electrical Components, Radiation Monitors, and Design and Installation Errors. It should be noted that these categories make up the majority of Root Causes in this review and also in the previous review presented by John W. Jacox[5]. This indicates that the same problems continue to occur. The percent distribution of some categories between the previous review and this review are similar. Some distribution differences occur due to the subjective aspect of this paper in selecting and including LER's that may have been vague and possibly foster varied interpretations.

A pronounced lack of NATS related LER's derived from adsorber, HEPA, and airflow problems discovered during surveillance testing were noted by the authors. Only two LER's were the result of adsorbers failing the in-place surveillance test (99.0% or 99.95% required leak tightness in most cases); and no LER's were filed as a result of the HEPAs failing the in-place surveillance test. Through experience, the authors have found that the major problem encountered during in-place surveillance testing is that of air flows. Oftentimes the flow is out of specification ($\pm 10\%$ of design, normally) by being too high or too low, however, these do not appear in LER's.

To conclude, problem areas of NATS/HVAC systems of the past remain the common issues that trouble the industry today. A closer evaluation of these problems continue to require attention by power plant operators. It should be evident that in the future a more detailed review of initial design and installation and surveillance procedures would greatly reduce the number of NATS/HVAC related LER's filed. Perhaps the codification of requirements by the ASME AG-1 Code will assist in this effort.

TABLE 1

TABULATION OF LER'S BY ROOT AND SECONDARY CAUSES

	Category	Root Cause	Cause %	Secondary Cause	Cause %
I.	Adsorbers	7	0.4	9	1.2
II.	Design or Installation Errors	209	12.1	11	1.5
III.	Electrical Components	172	9.9	123	17.1
IV.	HEPA Filters	3	0.2	2	0.3
V.	Test or Technical Specification Violations	8	0.5	---	---
VI.	Mechanical Components	86	5.0	89	12.4
VII.	Personnel Error	511	29.5	15	2.1
VIII.	Procedure Related	209	12.1	17	2.4
IX.	Radiation Monitor	162	9.4	377	52.4
X.	Toxic Gas Monitor	80	4.6	45	6.2
XI.	Weather Related	21	1.2	---	---
XII.	Electrical Noise and Spikes	132	7.6	4	0.5
XIII.	Fire Protection	14	0.8	28	3.9
XIV.	Radiation Levels	6	0.3	---	---
XV.	Unknown	36	2.1	---	---
XVI.	Other	74	4.3	---	---

TABLE 2

NATS & HVAC RELATED

LER'S FILED BY DATE AND REACTOR TYPE (PWR/BWR)

Year	Reactor Type		Total/Year
	PWR (%)	BWR (%)	
1984*	1 (50)	1 (50)	2
1985*	0 (0)	1 (100)	1
1986*	8 (66.7)	4 (33.3)	12
1987*	26 (53.1)	23 (46.9)	49
1988	309 (56.8)	235 (43.2)	544
1989	250 (58.7)	176 (41.3)	426
1990**	283 (66.3)	144 (33.7)	427
1991**	159 (59.6)	108 (40.5)	267
Totals	1036 (59.9)	692 (40.0)	1728

* Not filed until 1988. This also includes any revised versions during this time period.

** 1-HTGR brings Total/Year to 1730

	% of Total
PWR	59.9
BWR	40.0
HTGR	0.1

TABLE 3
SECONDARY CAUSES CATEGORIZED BY ROOT CAUSES

Root Cause	Secondary Cause										
	Radiation Monitor	Electrical Components	Mechanical Components	Toxic Gas Monitor	Fire Protection	Procedure Related	Personnel Error	Design or Installation Errors	Adsorbers	Electrical Noise and Spikes	HEPA Filters
Personnel Error	134	50	24	15	12	14	--	2	3	1	1
Design or Installation Errors	38	12	20	9	7	1	4	--	--	--	--
Procedure Related	32	9	15	2	5	1	9	3	3	--	1
Electrical Components	41	--	6	3	1	--	1	1	--	--	--
Radiation Monitor	--	39	4	1		--	--	4	--	--	--
Electrical Noise and Spikes	119	--	--	5	--	--	1	1	--	--	--
Mechanical Components	2	1	--	1	3	1	--	--	--	--	--
Toxic Gas Monitor	—	—	—	—	—	—	—	—	—	2	--
Other	4	7	12	--	--	--	--	--	1	--	--
Unknown	3	5	6	--	--	--	--	--	--	--	--
Weather Related	4	--	1	9	--	--	--	--	--	1	--
Fire Protection	--	--	1	--	--	--	--	--	2	--	--
Totals	377	123	89	45	28	17	15	11	9	4	2

REFERENCES

1. "Commentary in Nuclear Power Plant Control Room Habitability - Including A Review of Related LERs (1981 - 1983)," Moeller, D. W., Kotra, J. P., ACRS/USNRC, 18th NACC, CONF-840806, 1984.

2. "Failures In Air-Cleaning, Air Monitoring and Ventilation Systems in Commercial Nuclear Power Plants (1978 - 1981)," Moeller, D. W., Sun, L. S. C., ACRS/USNRC, 17th NACC, CONF-820833, 1982.

3. "Review of Failures in Nuclear Air Cleaning Systems," Moeller, D. W., ACRS/USNRC, 15th NACC, CONF-780819, 1978.

4. "Performance of Air Cleaning Systems in Nuclear Facilities," Moeller, D.W., ACRS/USNRC, 13th NACC, CONF-740807, 1974.

5. "Review of Nuclear Air Treatment System Related License Event Reports for the Period 1985-1987," Jacox, John W., DOE/USNRC, 20th Nuclear Air Cleaning Conference. 1988.

6. "License Event Report (LER) Compilation," NUREG/CR-2000, Monthly, USNRC, Washington, DC.

DISCUSSION

KOVACH: First of all, it is a good sign that we see very few root causes associated with adsorbers and HEPA filters. I think our air cleaning components are behaving much better then I think we sometimes make them out to be. At the same time, I wonder what sort of feedback we get from this type of presentation that we have had for a number of years. To people such as those in the radiation monitoring and manufacturing industries as well as to people who never attend this Conference. I think we are dealing here with the air cleaning technology part of it and I think either ISNATT or CONAGT or some other group could pass the information on to people who are much more closely involved with these problems that tend to shut down the entire system. We could utilize these organizations to assure that there is some improvement in the operation of the overall system.

JACOX: I think that is an excellent suggestion and one that would be particularly appropriate for ISNATT to do. I probably should have mentioned that there are only two or three adsorber related LERs and no HEPA related LERs, a much better record than I reported two years ago. Then, there were quite a few adsorber problems, although it may be considered a fire control problem rather than an adsorber problem when you get water on the carbon from a false fire alarm. As a member of ISNATT, I suggest that we use it for effective feedback because we are "preaching to the choir" here. That is an excellent suggestion.

PATLOVANY: Up until last January I was a member of Power Plant A. I have been in their safety engineering group for three years. One of the things that we did was to look at the licensee event reports and perform a root cause analysis to provide input into this kind of a table. One of the things that I noticed was that a lot of the personnel error judgments had a lot to do with licensing department language being different than root cause analysis language. A lot of times you couldn't resolve the differences between the two. Going to a deeper level, you could find a lot of these 500+ personnel error events really had design related and procedure related causes. This is what I found from my personal experience. I understand why there are so many personnel errors. In I&C maintenance, personnel errors accounted for the largest number for that period of time I was in there. Although I&C technicians seem to have the lead in personnel errors, a lot of it has to do with lack of design and testability from the start. That you are in there with a jumper or alligator clip has a lot to do with the initial design of the equipment as to its testability.

JACOX: I appreciate the comments and I agree completely. When I was writing the paper four years ago, I wrestled with the idea that you could almost make a case that everything is a personnel error in the sense that people do everything. If something has to be tested, it must be made testable, particularly when designing the electrical and the toxic gas alarms which were such a problem in the last seven analyses. In the air treatment area, CONAGT goes to extreme lengths to insist in the standards and codes that things be testable. Obviously, that doesn't happen in the electrical area and this would be an area where feedback, as Lou Kovach mentioned, should be emphasized to send this important information to the right people.

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This document contains the papers and the associated discussions of the 22nd DOE/NRC Nuclear Air Cleaning Conference. Major topics are: (1) advanced reactors, (2) reprocessing, (3) filter testing, (4) waste management, (5) instruments and sampling, (6) reactor accidents, (7) filters and filter performance, (8) adsorber testing and performance, (9) carbon testing, and (10) ventilation systems.

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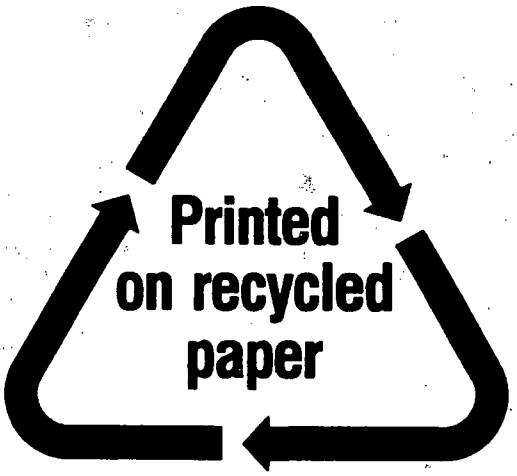

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