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# Proceedings of the Advisory Committee on Reactor Safeguards Workshop on Future Reactors

June 4 - 5, 2001

U.S. Nuclear Regulatory Commission
Advisory Committee on Reactor Safeguards
Washington, DC 20555-0001

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## ABSTRACT

This report contains the information presented at the Advisory Committee on Reactor Safeguards Workshop on Future Reactors held at the Nuclear Regulatory Commission headquarters in Rockville, Maryland, on June 4-5, 2001. Included are the subject matter summaries, followed by the presentation material and selected participants discussions.

The primary purpose of the workshop was to identify the regulatory challenges associated with future reactor designs. A list of such challenges was developed from the workshop notes, the various presentations, the panel discussions and the question and answer sessions. This list is included in the Introduction section of this document.

The titles of the papers and the names of the authors have been updated and may differ from those that appeared in the final workshop agenda.


In addition to the summaries and presentation materials, these Proceedings contain selected discussions which were extracted from the workshop transcripts. Where practical, the participants were given an opportunity to review and edit their individual contribution. The discussions can be found immediately following each presentation.

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## EXECUTIVE SUMMARY

### Introductory Remarks

T. Kress, Chairman of the Advisory Committee on Reactor Safeguards (ACRS) Subcommittee on Future Reactors convened the meeting and introduced Subcommittee members in attendance, key participants, and presenters. He presented the planned agenda for the first day of the Subcommittee meeting/workshop and offered members of the public opportunities to ask questions and to provide comments on the matters discussed. G. Apostolakis, ACRS Chairman, introduced the keynote speaker, NRC Commissioner Nils J. Diaz, and provided a brief summary of his extensive experience in matters related to nuclear power and research and development of nuclear technology.

### Subcommittee Presentations

Commissioner Diaz provided an overview of his paper entitled, "Disciplined - Meaningful - Scrutable." He stated nuclear power has entered the national energy debate on the future of America's energy supply and emphasized that nuclear safety is a priority on everyone's agenda. He stated that the priority should be on what should be done better rather than what was done wrong in the past. Commissioner Diaz stated that the Commission relies on the ACRS for expert advice and the recommendations of the Committee will be valuable to the Commission as regulatory changes are made. He noted that an important change to the regulatory structure has been risk-informed regulation which has enabled both the licensee and NRC to focus on safety issues and reduce unnecessary regulatory burden. He stated that the future of nuclear power is dependent on economic trends and events, the safety and reliability of plants, and the political environment. He expressed the view that it is possible to resolve safety and environmental issues before nuclear plants are built. An important element will be the readiness of the NRC for potential new plant applications but also that the NRC should not become an impediment to meeting the energy demands of the country. He reiterated that every step will need to be disciplined, meaningful, and scrutable and suggested that the industry and NRC will need to proceed in a disciplined and patient manner to ensure that errors are avoided. Commissioner Diaz qualified these statements as being his individual views and noted that they do not represent the views of his fellow Commissioners or the NRC.

W. Magwood of the U.S. Department of Energy (DOE) led the discussions for the DOE staff. W. Magwood provided an overview of the Generation IV Initiative to evaluate candidate technology concepts for a new generation of nuclear power plants. R Verslius, DOE, presented the Generation IV goals, roadmap effort, and concept evaluation. T. Miller discussed the Near-Term Deployment Working Group (NTDG) formed to identify actions and evaluate options necessary for DOE to support new plants. DOE has established a Nuclear Energy Research Advisory Committee

(NERAC) to provide independent evaluation and feedback on the establishment of goals and objectives and to examine progress in evaluating candidate nuclear energy concepts. DOE has also established a Generation IV Roadmap NERAC Subcommittee (GRNS) to serve as an advisory group in establishing a proposed roadmap along with a Roadmap Integration Team (RIT) for its implementation. Candidate technologies must be deployable by 2030. Nuclear systems are expected to meet sustainability goals (resource inputs, waste outputs, and nonproliferation), safety and reliability goals (operating maintainability excellence, limiting core damage risk, and reduced need for emergency response), and economic goals (reduced life-cycle costs and risk to capital). Criteria and metrics for each goal are being developed by an Evaluation Methodology Group (EMG), RIT, and the GRNS. DOE plans to evaluate all candidate concepts equally without prejudice toward existing technologies (e.g., light-water reactors) but recognizes that most energy generation units are likely to be fission based. DOE is presently considering 94 concepts. The output of the Generation IV Program is expected to be a research and development plan to support future commercialization of the best concepts.

W. Sprout of Exelon Generation and J. Slabber of the Pebble Bed Modular Reactor (PBMR) Demonstration Project in the Republic of South Africa (RSA) provided a presentation on the safety design aspects and licensing challenges for the PBMR. The PBMR is a modular high-temperature gas-cooled reactor (HTGR). It is helium cooled and uses a graphite moderator (approximately 110 MWe). The PBMR is nearing completion of the preliminary design phase. The feasibility study for application in the United States is in preparation for investor decisions by the end of 2001. RSA demonstration plant construction is expected to begin in late 2002. The PBMR design approach is intended to employ both passive and active design features, provide prevention and mitigation capability, and reduce dependence on operator actions. Central to this approach is the spherical fuel design involving carbon-coated uranium oxide fuel manufactured into a fuel particle or sphere. Key technical licensing challenges include: lack of a gas reactor technical licensing framework; fuel qualification and fabrication; source term; containment performance requirements; probabilistic risk assessment (PRA); regulatory treatment of non-safety systems; classification of structures, systems, and components (SSCs); and lack of technical expertise on gas reactors for both the NRC and the industry. Key licensing challenges include: Price-Anderson Act indemnity, NRC operational fees, decommissioning trust funding, untested provisions of 10 CFR Part 52, and the potential number of exemptions that may be required by the NRC.

M. Carelli of Westinghouse Science and Technology provided a presentation on the International Reactor Innovative and Secure (IRIS) nuclear reactor design. IRIS is a small to medium sized pressurized water reactor (100-300 MWe) that utilizes a 5- to 8-year option fuel cycle. The IRIS safety philosophy is "safety by design." Like current generation PWRs, IRIS is designed to have a reactor containment structure. However, Westinghouse proposes to perform scaling tests rather than loss-of-coolant accident

(LOCA) analysis. IRIS is scheduled for initial deployment in 2010-2015.

L. Parme of General Atomics (GA) provided a presentation on the GA Gas Turbine - Modular Helium Reactor. He discussed the history of GA as a pioneer of gas reactor technology and noted that the proposed GA design is similar to the PBMR in its use of ceramic carbon-coated spherical fuel. The fuel is passive by design in that the fission products are retained in the coated particles or spheres. Worst-case fuel temperature is limited by low-power density, low thermal rating per module, use of an annular core design, and passive heat removal. GA proposes to apply a risk-informed approach to licensing using performance assessment methods.

A. Rao of GE Nuclear Energy provided a presentation on the Evolutionary Simplified Boiling Water Reactor (ESBWR). The ESBWR is a 1380 MWe boiling water reactor with improved operating safety margins and passive safety systems. He stated that the ESBWR derived from earlier GE plant design certification efforts and is the result of eight years of international cooperative work. He stated that the biggest challenge is to cross the regulatory hurdles associated with the inspections, tests, analyses, and acceptance criteria (ITAAC) and combined license (COL) programs. He further stated that he did not know how long it might take to license the ESBWR, in part, because the last GE design certification took about 8 to 10 years. Dr. Rao also provided a brief overview of the GE Nuclear Advance Liquid Metal S-PRISM design.

M. Gamberoni, NRR, led the discussion for the NRC staff. N. Gilles, NRR discussed the future licensing organization and inspection readiness assessment (FLIRA). T. Kenyon, NRR, discussed early site permits (ESPs), ITAAC and COL programs. A. Rae discussed the Westinghouse AP1000 review and E. Benner, NRR, discussed issues related to the regulatory infrastructure. J. Wilson, NRR, also participated. J. Flack and S. Rubin, RES, provided a brief discussion on research activities in support of possible future plants. The staff stated that an assessment of licensing and inspection readiness is ongoing and is scheduled to be completed by September 28, 2001. The staff is working to develop lessons-learned from past design certifications, preparing guidance on ESPs, and responding to the Nuclear Energy Institute (NEI) petition for rulemaking to 10 CFR Part 52. The staff is reevaluating its ITAAC/COL programs. Short-term plans are to address existing regulations, license conditions, and exemptions. Long-term actions are expected to addressed via rulemaking. The staff stated that there is a limit on how far they can pursue these initiatives and/or allocate resources without formal submittals by licensees and industry organizations.

**Subcommittee Questions/Comments on Presentations**

Significant points raised by members of the Subcommittee during the presentations include:

G. Apostolakis questioned what DOE representatives considered to be the two most important regulatory challenges facing the NRC in licensing new reactors. DOE representatives stated that the key challenges will be related to making the regulatory environment as risk-informed and performance-based as practicable. DOE representatives stated that the NRC process must be predictable in both its review time and its decisions. D. Powers questioned the extent to which performance indicators (PIs) might further performance-based considerations. G. Apostolakis suggested that reliability goals be numerical. DOE representatives stated that the it is difficult to place goals on PIs or reliability without knowing more about the detailed designs.

T. Kress and D. Powers questioned the nature of fuel performance for the PBMR. T. Kress questioned how fuel manufacturing quality and integrity will be ensured. D. Powers questioned how friction, ramp rates, and other operating characteristics would be addressed considering the fact that there was limited operating experience for this type of fuel. Exelon and RSA representatives stated that fuel would be subjected to extensive quality assurance and quality control requirements during fabrication and that operating performance would be monitored using gamma spectroscopy for each of the 212,000 fuel spheres cycled through the core.

G. Apostolakis and J. Garrick questioned how the Commission's Safety Goal Policy Statement would be considered for the PBMR. They noted that Safety Goal's use of core damage frequency (CDF) might be challenged if applied to the collective population of modular units at reactor sites across the country. Exelon and RSA acknowledged that this is an issue to be addressed in characterizing the risk metrics. They noted that the modular approach to siting will have substantial licensing expense ramifications as well (i.e., licensing fees per reactor).

T. Kress questioned the PBMR and GA Gas Turbine - Modular Helium Reactor proposals to limit or eliminate the use of primary containment structures and reducing emergency planning zones. He questioned the prudency of this given that the uncertainties that have not been quantified. He also noted that Chernobyl had a graphite core and it burned. D. Powers noted that there is a substantial difference between point-ignition and diffuse-ignition of core materials and that one of the largest catalysts in fuel performance is cesium. The GA representative stated that the fuel will not burn in the normal sense of a chain reaction and that most analyzed failures have been associated with fuel oxidation. He also stated that the MHTGR has circulators designed to reduce temperature.

**<u>Panel Discussion</u>**

The Subcommittee and participants extensively discussed the use of risk information in considering future nuclear plants. G. Apostolakis stated that there seems to be a gap between the staff and industry thinking concerning the importance of risk assessment. He stated that he is not sure that there is a full appreciation how important risk assessment is in the design, licensing, and operation of nuclear power plants. M.

Bonaca stated that there seems to be a perception that risk is a regulatory constraint rather than a safety benefit. The staff stated that the Commission has been very clear in directing the staff to use risk analysis in deciding what information and analysis is needed. The staff also stated that more confidence is needed than just demonstrating that the Commission's Safety Goals are met.

J. Garrick expressed concern that an important opportunity was being missed in the rush to license new reactors. He stated that there could not be a better time to consider risk. D. Powers stated that there is not much risk information available concerning the proposed plants designs and suggested that the NRC will need to perform confirmatory analyses to ensure that vulnerabilities have not been missed. He also stated that the staff will need to perform tests (e.g., to ensure that particle-type fuel does not burn) and testing programs to ensure that actual operating performance reflects design characteristics and to validate thermal-hydraulic modeling and component performance. The staff stated that 10 CFR Part 52 requires licensees to conduct PRAs. Exelon representatives stated that existing bodies of data must be utilized and that they must pursue a COL first, rather than design certification, based on the RSA Demonstration Project.

P. Ford noted that the presentations involved little discussion of material degradation, embrittlement, or cracking. Industry representatives stated that materials were not a top priority at this early stage. They stated that their focus was on design first with consideration of materials later. The staff stated that the Commission expects these designs to be safer than the current generation of plants and that issues such as pressurized thermal shock (PTS) will certainly be addressed.

T. Kress questioned how defense in depth will be considered in new plant designs. Commissioner Diaz offered his views on the importance of considering defense in depth in the design stage of reactors. G. Apostolakis stated that he was encouraged br recent government-wide initiatives to consider both risk information and defense in depth. He expressed concern, however, over the argument that PRA might be viewed as a major challenge if it makes plants uneconomical. He stated that risk analysis is necessary to reduce the uncertainty in new and untested designs.

**June 5, 2001**

**Introductory Remarks**

T. Kress, Chairman of the ACRS Subcommittee on Future Reactors convened the meeting and introduced Subcommittee members in attendance, key participants, and presenters. He presented the planned agenda for the second day of the Subcommittee meeting/workshop and offered members of the public opportunities to ask questions and to provide comments on the matters discussed.

## Subcommittee Presentations

R. Simard of the Nuclear Energy Institute (NEI) provided a brief presentation on the state of energy demand in the United States and discussed the improving economics for new nuclear power plants. He discussed the consolidation of companies under deregulation and suggested that these larger companies will be better able to undertake large capital projects such as nuclear power plant construction. He discussed efforts under way to support a new generation of plants but noted that there needs to be greater certainty in the licensing process. He discussed infrastructure challenges in terms of people, hardware, and services to support new and current plants. He stated that there needs to be fair and equitable licensing fees and decommissioning funding assurance for innovative modular designs such as the PBMR. He concluded that NRC challenges will include resolving 10 CFR Part 52 implementation issues; establishing an efficient and predictable process for siting, COL permits and inspection; and an increasing regulatory workload.

N. Todreas of the Massachusetts Institute of Technology (MIT) provided a discussion on safety goals for future nuclear power plants. He stated that this effort is focused solely on future power plants and not the current NRC Safety Goals and associated quantitative health objectives that use core damage frequency (CDF) and large early release frequency (LERF) as surrogate measures. This work is being sponsored by DOE for Generation IV Initiative technology goals. These goals are being developed for systems to be deployed from 2011 to 2030. They are intended to guide in making trade-offs in the evaluation of candidate technologies. The goals will partition the systems according to categories of sustainability, safety and reliability, and economics. The outcome is expected to a framework that encourages fundamental design directions that promote safety.

A. Kadak of MIT presented an approach to licensing Generation IV technologies entitled "License by Test." He stated that the major challenges for new reactors are driven by a regulatory framework that generally supports light-water-reactor technology. He stated that both licensees and the NRC staff lack sufficient knowledge in non-light-water reactor technologies and that the regulatory system is overly rigid in adjusting to change. He suggested that the NRC adopt a risk-informed approach to licensing whereby a safety basis would be established using risk-based techniques to identify dominant accident sequences and systems and components, establishing confidence levels to bridge deterministic and probabilistic approaches, and implementing a license by test approach using a full-size demonstration plant. Successful demonstration would provide the basis for reducing uncertainty and for certifying the design. Traditional performance tests would still be required to demonstrate reliability. However, license by test would serve to validate analyses, shorten time for paper reviews, and demonstrate safety. He suggested that the PBMR be used as the prototype for this licensing approach.

M.Golay of MIT and G. Davis of Westinghouse provided a presentation on a Nuclear Energy Research Initiative (NERI) Project sponsored by DOE. The focus of the NERI Project is to take future plant designs and use risk information to evaluate what new design and regulatory processes must be developed to support new plant license applications for Generation IV concepts. M. Golay stated that there is a need to improve the regulatory process and suggested that the overall national effort in support for reactors suggests that there is a need for change. These activities are being coordinated with NEI which will be initiating the industry-sponsored development of new regulations. NERI will address the overall risk-informed design and regulatory process. Sandia National Laboratories (SNL) is also providing technical support.

C. Forsberg of Oak Ridge National Laboratory provided a presentation on the economy of nuclear-generated hydrogen production. He stated that there is enormous need for increased hydrogen production to support the U.S. chemical industry (oil refineries) which uses 5% of all the natural gas consumed in this country. He stated that the major reason for the need is increased use of more abundant heavy-sour crude oils which require more energy to process than the more scarce light-sweet crude oil. He noted that non-light-water reactors (e.g., molten salts) are better suited for this type of application and suggested that an advanced high-temperature reactor (AHTR) could provide dual-purpose electric generation and hydrogen production. This is a joint DOE effort with Sandia National Laboratories (SNL).

A. Heymer of NEI provided a brief discussion on the benefits of establishing a new regulatory framework. He suggested that a new paradigm in regulatory thinking is needed and stated that the reactor oversight process (ROP) serves as the appropriate basis for starting these discussions. He suggested that the ROP cornerstones of safety be used as the starting point for developing a new set of General Design Criteria (10 CFR Part 50, Appendix A). He suggested that new operating criteria, generic risk-informed and performance-based regulations be developed with associated design-specific and regulation-specific regulatory guides.

**Subcommittee Questions/Comments on Presentations**

Significant points raised by members of the Subcommittee during the presentations include:

D. Powers questioned the NEI contention that DOE energy demand estimates are consistently low. He stated that the critics have argued that efficiency and conservation can do the job. R. Simard agreed that efficiency and conservation play an important role but concluded that it is unrealistic to suggest that new electricity generation is not needed.

D. Powers expressed appreciation for the systems-approach and use of trade-off studies in evaluating new plant designs and safety goals. N. Todreas stated that the goal is to stimulate innovation and not to go back to existing reactors as the standard for the future. He stated that they are looking at a balance of utilization in terms of whole fuel cycle, e.g., economics, waste, diversion, etc.

D. Powers questioned why the safety goals could not be expressed in terms of release of radioactivity. G. Wallis expressed concern that this approach might overly constrain the evaluation of certain designs and lock the evaluation into certain design directions. J. Garrick stated that the evaluation should not focus too heavily on fission products as the actinides drive much of the risk in high-level waste. G. Apostolakis suggested that safety and reliability can also be expressed in terms of investment protection. He noted that serious plant damage can occur without having releases and suggested that it may be worthwhile to distinguish between technology goals and safety goals. G. Wallis suggested that life-cycle costs also be expressed in terms of external costs in comparing candidate nuclear technologies with alternate fuels, e.g., adverse effects of fossil fuels killing fish in New England via acid rain.

G. Wallis questioned how human performance would be evaluated using the "license by test" approach. G. Leitch stated that the major advantage of license by test appears to be a reduction in the time and costs for paper reviews associated with the licensing process and questioned what technical merits would be derived. J. Sieber questioned who should finance the costs of such a facility. A. Kadak stated that a containment should be constructed on the PBMR Demonstration Project only for the purpose of demonstrating safety and suggested that operators be allowed to take non-conservative actions to test the robustness of the design. A Kadak stated that the PBMR Demonstration Project should be a legitimate government expense (i.e., DOE) as it is still a concept, and the plant has not yet been designed. He stated that much work needs to be done to develop the models and codes necessary to validate the design.

G. Apostolakis questioned whether the licensing process can be made performance-based. A. Heymer of NEI stated that the inspection process can be made performance-based as evidenced by the reactor oversight process (ROP). He also noted that certain regulations can be made more performance-based (e.g. 10 CFR Part 20). A. Heymer suggested that risk-informing 10 CFR Part 52 will be very important for new reactors. G. Apostolakis stated that the ROP is an evolution of the existing regulatory system and suggested that the risk for new reactors may be different thereby requiring a different approach. He noted that NEI does not normally want to depart too substantially from the existing regulatory structure.

**Panel Discussion**

R. Barrett, NRR, offered a four-pillar approach to licensing new nuclear power plants. He stated that success will be based on assuring safety, streamlining the organization to be efficient and effective, not imposing unnecessary regulatory burden, and maintaining public confidence. G. Wallis stated that it is not good enough to provide public access to NRC decisionmaking. R. Barrett agreed and stated that they need to identify public concerns and act on them.

N. Todreas of MIT provided a brief presentation on regulatory challenges mostly related to fuel and clad materials. He stated that longer operating cycles and higher operating temperatures will result in challenges related to waste toxicity and volume, corrosion control of coolant impurities, qualification of fuel particles or spheres, and new maintenance practices to support longer operating cycles. T. Kress suggested that new reactor licensing may be somewhat like digital instrumentation and control in that the NRC controls the process and not the product. J. Garrick stated that the regulatory process, like people, are slow to change.

E. Lyman of the Nuclear Control Institute (NCI) provided a presentation that focused on the role of government in energy matters. He stated that public money should not be spent as a taxpayer subsidy for utilities. He stated that the performance data on PBMR fuel is "spotty" and that the German graphs illustrating the 10% release fraction of Cs-137 were flawed. He also stated that British Nuclear Fuels falsified fuel performance data sent to Japan on this matter. E. Lyman suggested that the NRC establish an ITAAC for PBMR fuel manufacture and acceptance. He questioned how the Chernobyl event could not happen at a PBMR and suggested that ignition fuel temperatures could be achieved through sabotage. He stated that the Commission's Safety Goals are not conservative enough and concluded that there is no technical basis for relaxing containment and emergency preparedness requirements. He noted that about half of the U.S. nuclear plants failed the NRC Operational Safeguards Response Evaluation (OSRE) safeguards inspection.

W. Hauter of Public Citizen provided a brief presentation concerning the state of energy deregulation and the need for new nuclear power plants. She stated that the demand for and acceptance of nuclear power is being painted as a "rosy picture" based on a recent poll in California. She stated that 58% of the public disapprove of President Bush's energy plan and the public always supports renewable energy as the first option. She suggested that the apparent energy crisis is being misrepresented in order to justify using taxpayer money to subsidize a resurgence of nuclear power and the associated research and development costs for new reactors. She questioned the safety of "merchant" nuclear plants and expressed concern that the recent work on health effects is being conducted with the improper intent of reducing the waste classification of certain radiological materials. W. Hauter suggested that licensing is being used as a new code word for deregulation. She stated that the biggest challenge is the issue of subsidies to the utilities and questioned the theme of the Subcommittee meeting/workshop as being biased toward further deregulation that favors getting new plants licensed. T. Kress and G. Wallis expressed concern over the lack of public interest in ACRS meetings and questioned how to get the public more involved in providing broader perspective. W. Hauter suggested that meetings be held around the country outside normal business hours (i.e., in the evening) so that interested parties could more conveniently attend after work.

**Expected Subcommittee Action**

At the conclusion of the meeting, T. Kress stated that the purpose of this meeting was to explore the regulatory challenges associated with future nuclear power plants and for the Subcommittee to examine technical issues for the ACRS to consider in evaluating the safety of candidate reactor designs and applications. The Subcommittee plans to continue its discussion of these matters during future meetings.

Summary prepared by Michael T. Markley, ACRS Senior Staff Engineer.

## ABBREVIATIONS

| | |
|---|---|
| ACRS - | Advisory Committee on Reactor Safeguards |
| ABWR - | Advanced Boiling Water Reactor |
| ACRS - | Advisory Committee on Reactor Safeguards |
| AHTR - | Advanced High-Temperature Reactor |
| ALARA - | As Low As Reasonably Achievable |
| ALWR - | Advanced Light Water Reactor |
| ATWS - | Anticipated Transients Without Scram |
| BWR - | Boiling Water Reactor |
| CBD - | Commerce Business Daily |
| CFR - | Code of Federal Regulations |
| COMNJD - | Commissioner Niles J. Diaz |
| COL - | Combined Operating License |
| DBA - | Design Basis Accident |
| DBE - | Design Basis Event |
| DOE - | Department of Energy |
| EMG - | Evaluation Methodology Group |
| EPZ - | Emergency Planning Zone |
| ESP - | Early Site Permit |
| ESBWR - | European Simplified Boiling Water Reactor |
| FLIRA - | Future Licensing and Inspection Readiness Assessment |
| FP - | Fuel Particles |
| GIF - | Generation IV International Forum |
| GCFR - | Gas-Cooled Fast Reactor |
| GDC - | General Design Criteria |
| GDCS - | Gravity Driven Cooling System |
| GRNS - | Generation IV Roadmap NERAC Subcommittee |
| IC - | Isolation Condenser |
| IRIS - | International Reactor Innovative and Secure |
| IAEA - | International Atomic Energy Agency |
| LBT - | License By Test |
| LMFBR - | Liquid Metal Fast Breeder Reactor |
| LOCA - | Loss of Coolant Accident |
| LEU - | Low Enriched Uranium |
| LWRs - | Light Water Reactors |
| MIT - | Massachusetts Institute of Technology |
| MLD - | Master Logic Diagram |
| MOX - | Mixed-Oxide Fuel |
| MHTGR - | Modular High-Temperature Gas Reactor |
| NERAC - | Nuclear Energy Research Advisory Committee |
| NRC - | Nuclear Regulatory Commission |
| NRR - | Office of Nuclear Regulatory Regulation (NRC) |
| NTDG - | Near-Term Deployment Group |
| NEI - | Nuclear Energy Institute |

| | |
|---|---|
| OECD - | Organization For Economic Cooperation Development |
| ORNL - | Oak Ridge National Laboratory |
| PBMR - | Pebble Bed Modular Reactor |
| PCCS - | Passive Containment Cooling System |
| PRA - | Probabilistc Risk Assessment |
| RAI - | Request for Additional Information |
| R&D - | Research and Development |
| RES - | Office of Nuclear Regulatory Research (NRC) |
| RFI - | Request for Information |
| RIT - | Roadmap Integration Team |
| RCCA - | Rod Cluster Control Assembly |
| RDAS - | Risk Dominant Accident Sequence |
| RSA - | Republic of South Africa |
| SAR - | Safety Analysis Report |
| SBWR - | Simplified Boiling Water Reactor |
| SG - | Steam Generator |
| SSC - | Systems, Structure and Component |
| T/H - | Thermal Hydraulic |
| TWG - | Technical Working Group |
| WANO - | World Association of Nuclear Power Operators |

## INTRODUCTION

Because of the large amount of regulatory activity that is anticipated for licensing future reactor concepts, the ACRS decided to hold this workshop on "Regulatory Challenges for Future Reactor Designs." The workshop was held primarily for the benefit of the Committee – to acquaint the members with the various design concepts and to identify potential regulatory and policy issues for which ACRS may be called upon to give advice to the Commission. It was also believed that the workshop would be of benefit to the NRC staff as well as to the industry in getting an early dialogue started on the possible regulatory approaches to licensing future reactor designs. These designs are expected to be significantly different from the LWRs which are the primary focus of the current regulations and regulatory system.

The primary purpose of the workshop, as indicated by its title, was to identify the regulatory challenges. A list of such challenges identified by the workshop was developed from the workshop notes, the various presentations, the panel discussions, and the question and answer sessions.

The concept of defense in depth and its application to future reactor designs is of great interest to the Committee. The traditional interpretation of this concept asserts that defense in depth is embodied in the structure of the regulations and in the design of the facilities built to comply with those regulations. The requirements for defense in depth are derived by repeated application of the question, "What if this barrier or safety feature fails?" This is the *structuralist* interpretation of defense in depth[1]. It is the cornerstone of traditional regulations. In recent years, the maturity of Probabilistic Risk Assessment (PRA) methodology has led to the *rationalist* interpretation. This interpretation asserts that defense in depth is the aggregate of provisions made to compensate for uncertainty and incompleteness in our knowledge of accident initiation and progression. The successful implementation of this interpretation of defense in depth requires robust PRAs and risk acceptance criteria. In this context, the Committee was interested in the following questions:

1. Should we "force-fit" non-LWR designs into the current regulatory structure that is heavily focused on LWRs and the structuralist approach to defense in depth or should licensing take a "clean-sheet" risk-based approach?

2. Do we need additional risk acceptance criteria (e.g., frequency-consequence curves) for designs for which core damage frequency and large, early release frequency are ill-posed concepts?

3. How do we quantify and deal with PRA uncertainty for the new concepts?

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[1] J. N. Sorensen, G. E. Apostolakis, T. S. Kress, and D. A. Powers, "On the Role of Defense in Depth in Risk-Informed Regulation," *Proceedings of PSA '99, International Topical Meeting on Probabilistic Safety Assessment,* Washington, DC, August 22 - 26, 1999, American Nuclear Society, La Grange Park, Illinois.

4. How robust must the containment (if any) be in view of the lack of experience with new designs and potentially large uncertainty in risk assessments?

5. What is the acceptability of significantly reduced emergency response for designs with low source terms and long warning times before release?

6. What is the acceptability of no additional ECCS for designs that have a great deal of water in the primary vessel and no pipes to break at locations that would drain the water (e.g., IRIS)?

7. What role will "licensing by test" play in the regulatory process?

8. Can the frequency of air ingress and a graphite/fuel fire be demonstrated to be acceptably low for those designs that use coated particle fuel?

9. How de we establish LOCA frequencies for new plants for which there is not an extensive data base? The reliability of simplified passive safety systems?

10. For the new designs, will we have appropriately qualified/validated PRAs and T/H, neutronic, and safety assessment codes?

11. Are there any new human performance and I&C issues?

In addition to these questions, the Committee raised a number of issues that will have to be addressed in the licensing process of future reactor designs:

12. What process will be used to develop design basis accidents for the new designs? How will risk-significant SSCs be identified? What will be the regulatory treatment of non-safety systems?

13 What use can be made of previous NRC reviews of derivative designs?

14. For the new designs, what will be the regulatory approach with respect to: a) many new plants; b) multi-unit/module sites?

15. How can we assure the required fuel quality for designs for which the safety case relies heavily on fuel integrity (focus on process vs. product)? Validation of fuel performance? Accident source terms for design basis events? High burnup?

16. How will once-through cores that last 5 - 10 years be monitored and inspected? Acceptability of new "smart" on-line health monitoring systems?

17. How will financial related requirements apply to the new concepts and business environment? Extension of Price-Anderson? NRC fee structure for multi-modules? Decommissioning?

18. What is the acceptability of natural circulation cooling as an accident recovery strategy? What is the availability and validation status of appropriate analytical models?

19. What database exists for the lifetime temperature and irradiation behavior of graphite? How do the "new" graphites compare to the "old" ones?

20. Can the NRC develop the manpower, resources, and technical expertise required for assessing the future concepts?

21. Is there a sufficient database on high temperature material behavior for the gas-cooled concepts with high exit temperatures? What are the gas turbine safety issues for high temperature helium cycles?

22. What new NRC research is needed? Participation with Industry? Use of international research and data bases?

23. Are new approaches/criteria needed for licensing multi-purpose plants (e.g., power plus desalination, industrial/residential heating, hydrogen production, coal conversion)?

24. What will be the spent fuel storage requirements for new fuel types/geometries? Potentially damaged fuel spheres/particles?

The workshop provided a forum for raising and discussing these questions. We hope that both the industry and the NRC will find these proceedings useful in their search for answers.

We thank all the speakers and participants for their contributions in making this workshop a success. We thank Richard P. Savio, Michael Markley, Medhat El-Zeftawy, and the staff of the ACRS Operations Support Branch for their efforts in the conduct of the workshop. Special thanks are given to Jenny Gallo of the ACRS Office for her outstanding efforts in overseeing the publication of this document.

Thomas S. Kress, Chairman
Subcommittee on Future Reactors

George E. Apostolakis
ACRS Chairman

# Disciplined - Meaningful - Scrutable

Remarks of Commissioner Nils J. Diaz

United States Nuclear Regulatory Commission

ACRS Workshop on Advanced Reactors

June 4, 2001

It is a real pleasure to participate in this workshop to discuss regulatory challenges for advanced nuclear power plants. It is particularly appropriate that the Advisory Committee on Reactor Safeguards is hosting this meeting, at this time. The discussion on nuclear power has now fully entered the national debate on the future of America's energy supply, and nuclear safety is going to be a priority on everybody's agenda. The Commission relies on the ACRS for expert advice on the safety of reactors, existing or submitted for licensing. The recommendations of the Committee will be of particular value for the Commission deliberations on the licensing of new reactors. I will be presenting my individual views today. They do not necessarily represent the views of the U.S. Nuclear Regulatory Commission (NRC), except when indicated.

I want to premise my remarks with a few selected quotes from a "couple" of speeches during my tenure as a Commissioner.

- "There is no credible regulator without a credible industry. There is no credible industry without a credible regulator."
- "It is essential for the regulator to be cognizant of the technology. It is essential for the industry and technologists to be cognizant of the regulations."
- "Regulations need to result in a benefit or they will result in a loss."
- "My goal is to ensure the paths are clearly marked. A path that is clear of obstacles and unnecessary impediments, with well defined processes, will provide regulatory predictability, equity and fairness."
- "We are learning how to define adequate protection in more precise terms, and to define it in terms that make sense to the American people."
- "We have learned from our mistakes and we are bound not to repeat them."

At the 2001 US NRC Regulatory Information Conference, I said: "We might be asked, as would other government agencies and the private sector, to sharpen our skills, and improve our efficiency to meet the needs of the country". We have been asked. It is worthwhile to try to understand why the President and the Vice-President of the United States have brought nuclear power generation to center-stage in the debate on the energy policy for our country. Shown in Table 1 is a compilation of important aspects of the debate, summarizing what has changed in 20 plus years.

The NRC has been changing to meet the challenge of what must be changed and to strengthen what must be conserved. I submit to you that we have changed for the better, especially the last three years, and that improvements in regulatory effectiveness and efficiency are changing from goals into reality. It has not been easy, and there are still lessons to be learned. I must say that there is one change that I believe speaks louder than words for the NRC staff and the agency as a whole: priority is now placed on what should be done better rather than on what was done wrong.

This is a cultural change that is needed to enable the consideration of newer, better and enduring ways to exercise the mandate entrusted to the NRC by the people of this country: to license and regulate the peaceful uses of nuclear energy, with adequate assurance of public health and safety. I believe that we are now capable of meeting the regulatory challenges that we face today regarding advanced nuclear power plants. The improved industry performance over the past decade has enabled the NRC to initiate and implement reforms that are progressively more safety-focused. Furthermore, it allowed the industry to concentrate resources on the issues important to safety which provided a sharper focus to regulatory improvements. Safety and overall performance, including productivity, became supporters of each other, with the clear and unmistakable proviso that safety is first.

For existing nuclear power plants, the list of profound regulatory changes and accomplishments, many done under the mantle of the so-called risk-informed regulation, would occupy the rest of this meeting. Five of them stand out: the revised rule on changes, tests, and experiments for nuclear power facilities (10 CFR § 50.59); the new risk-informed maintenance rule (10 CFR § 50.65 (a)(4)); the revised reactor oversight process; the new guidance on the use of PRA in risk-informed decision-making (Regulatory Guide 1.174); and the revised license renewal process (10 CFR Part 54). The list is growing. About two weeks ago, the Commission approved COMNJD-01-0001 instructing the staff to give high priority to power uprates and allocate appropriate resources to streamline the NRC power uprate review process to ensure that it is conducted in the most effective and efficient manner. All of these and most of the other regulatory improvements conform to the Commission's decision to focus attention on real safety. The resulting improvements in rules, regulations and processes, including changes to the hearing process and enhanced stakeholders participation, are assuring the nation that a fair, equitable, and safety-driven process is being used.

I mentioned risk-informed regulation as an important component of the changed NRC regulatory structure. I want to be sure you know what I mean when I use the term risk-informed regulation, so I am going to present you with my own, personal definition of it:

> Risk-informed regulation is an integral, increasingly quantitative approach to regulatory decision-making that incorporates deterministic, experiential and

probabilistic components to focus on issues important to safety, which avoids unnecessary burden to society.

The definition can also be used for risk-informed operations, risk-informed maintenance, risk-informed engineering, risk-informed design....
For new license applications, much groundwork has been done, and a lot of it is useful to address today's issues. In the statements of consideration for 10 CFR Part 52, the Commission stated that the intent of the regulation was to achieve the **early** resolution of licensing issues and **enhance** the safety and reliability of nuclear power plants. The Commission sought nuclear power plant standardization and the enhanced safety and licensing reform which standardization could make possible. In addition, the 10 CFR Part 52 process provides for the early resolution of safety and environmental issues in licensing proceedings. The statement of considerations for 10 CFR Part 52 goes on to say "...the Commission is not out to secure, single-handedly, the viability of the [nuclear] industry or to shut the general public out. The future of nuclear power depends not only on the licensing process but also on economic trends and events, the safety and reliability of the plants, political fortunes, and much else. The Commission's intent with this rulemaking is to have a sensible and stable procedural framework in place for the consideration of future designs, and to make it possible to resolve safety and environmental issues before plants are built, rather than after."

In February of this year, the Commission directed the staff in COMJSM-00-0003 to assess its technical, licensing, and inspection capabilities and identify enhancements, if any, that would be necessary to ensure that the agency can effectively carry out its responsibilities associated with an early site permit application, a license application and the construction of a new power plant. In addition, the Commission directed the staff to critically assess the regulatory infrastructure supporting both 10 CFR Parts 50 and 52 with particular emphasis on early identification of regulatory issues and potential process improvements. The focus of these efforts is to ensure that the NRC is ready for potential applications for early site permits and new nuclear power plants, certified designs or designs to be certified, and the NRC does not become an impediment should society decide that additional nuclear plants are needed to meet the energy demands of the country. Necessary safety-focused regulations, yes; unnecessary, not safety-focused regulations, no. The staff is working hard to carry out this direction and I am sure you will hear about some of our efforts over the next two days.

Risking being repetitive, I am going to re-start at the beginning. The US Nuclear Regulatory Commission has a three-pronged mandate:

- To protect the common defense and security
- To protect public health and safety, and
- To protect the environment

by the licensing and regulation of peaceful uses of atomic energy. I have long advocated that an adequate and reliable energy supply is an important component of our national security. I firmly believe that our three-pronged mandate is going to endure the test of time because it is good, and it is balanced.

Within that mandate, I am an advocate of change, functioning under the rule of law. As we face the regulatory challenges that are sure to be posed by the certification and licensing of new designs, a series of familiar requirements will have to be met, regardless of the licensing path chosen:

- Public Involvement
- Safety Reviews
- Independent ACRS Review
- Environmental Review
- Public Hearing
- NRC Oversight

I am convinced, by practical experience, that the present pathway for potential licensing success of certified or certifiable new reactor applications is Part 52. First, it exists - not a minor issue; second, it contains the requirements for assurance of safety and the processes for their implementation. Lastly, it can be upgraded to meet technological advances that require new licensing paths, without compromising safety. Windows of opportunity can be opened, yet the price is always the same: reasonable assurance of public health and safety. A new technology, with different design basis phenomenology, e.g., single phase coolant, could present the need for a different pathway. Yet, it would have to face the same requirements listed above. What could be different is the manner in which some of these requirements are addressed. There is definitely room for innovation and improvement, within the safety envelope that has to be provided for assurance of public health and safety.

I am also convinced that the NRC and all stakeholders need to apply common criteria to the tasks at hand. Every success path, however success is defined, should follow these simple criteria: Every path, every step has to be disciplined, meaningful and scrutable.

Allow me to consider widely different roles. The NRC has the statutory responsibility for conducting licensing and regulation in a predictable, fair, equitable and efficient manner to ensure safety. Every step of the licensing and oversight has to be disciplined, meaningful and
scrutable.

Applicants need to satisfy the technical, financial, and marketplace requirements, and meet the NRC and other regulatory requirements. Every step has to be disciplined, meaningful and scrutable.

I have no doubt that there will be objections and opposition and the law of the land will respect them and give them full consideration. The objections will have to be disciplined, meaningful and scrutable.

These common criteria are necessary but they are not sufficient. It is indispensable that what we have learned - and it is much - be incorporated into the science, engineering and technology supporting any new reactors; they have to be as good as the state-of-the-art permits. So it should be for the regulatory processes. I happen to believe that risk information can be a contributor to disciplined, meaningful and scrutable processes, and to the underlying science and technology.

Someone once wrote a phrase framing how to achieve high performance expectations, and it may be appropriate for this occasion:

Promise... to think only the best,<br>
to work only for the best<br>
and<br>
to expect only the best

# Nuclear Power Generation
## - Perception and Reality -

| | 1973 - 1982 | 2001 |
|---|---|---|
| Interest Rates | High & Unstable | Low & Stable |
| Inflation | High & Unstable | Low & Stable |
| Electrical Demand | Decreasing | Increasing |
| Socio-political Climate | Negative | Improving |
| Technical Maturity | Low | High |
| Regulatory Framework | Low Predictability | High Predictability |
| Economical Performance | Poor & Unstable | Good & Improving |
| Environmental Image | Poor | Improving |
| Safety Image | Poor | Good & Improving |
| Expectations | Too High | Realistic |
| Competition/Deregulation | None | High |
| Standard (certified) Designs | None | Three + |
| Combined License | No | Yes |
| Important to National Security | Yes | Yes |
| Financial Risk | High | Improving |
| Public Credibility | Low | Good & Improving |
| **Bottom Line** | **Low Predictability** | **Good Predictability** |

*United States*
*Nuclear Regulatory Commission*

## Disciplined - Meaningful - Scrutable

**Commissioner Nils J. Diaz**

Remarks Before the ACRS Workshop
Advanced Reactors
June 4, 2001

- "There is no credible regulator without a credible industry. There is no credible industry without a credible regulator."
- "It is essential for the regulator to be cognizant of the technology. It is essential for the industry and technologists to be cognizant of the regulations."
- "Regulations need to result in a benefit or they will result is a loss."

Figure 1

- "My goal is to ensure the paths are clearly marked. A path that is clear of obstacles and unnecessary impediments, with well defined processes, will provide regulatory predictability, equity and fairness."
- "We are learning how to define adequate protection in more precise terms, and to define it in terms that make sense to the American people."
- "We have learned from our mistakes and we are bound not to repeat them."

Figure 2

Nuclear Power Generation
- Perception and Reality -

| | 1973 - 1982 | 2001 |
|---|---|---|
| Interest Rates | High & Unstable | Low & Stable |
| Inflation | High & Unstable | Low & Stable |
| Electrical Demand | Decreasing | Increasing |
| Socio-political Climate | Negative | Improving |
| Technical Maturity | Low | High |
| Regulatory Framework | Low Predictability | High Predictability |
| Economical Performance | Poor & Unstable | Good & Improving |
| Environmental Image | Poor | Improving |
| Safety Image | Poor | Good & Improving |
| Expectations | Too High | Realistic |
| Competition/Deregulation | None | High |
| Standard (certified) Designs | None | Three + |
| Combined License | No | Yes |
| Important to National Security | Yes | Yes |
| Financial Risk | High | Improving |
| Public Credibility | Low | Good & Improving |
| **Bottom Line** | **Low Predictability** | **Good Predictability** |

Figure 3

Priority is now placed on
what *should be done better*
rather than on
what *was done wrong*

Figure 4

**Key NRC Regulatory Improvements**

- revised rule on changes, tests, and experiments ( 10 CFR 50.59 )
- new risk-informed maintenance rule ( 10 CFR 50.65 A.4 )
- revised reactor oversight process
- new guidance on the use of PRA in risk-informed decision-making ( Regulatory Guide 1.174 )
- revised license renewal process ( 10 CFR 54 )

Figure 5

Improvements in rules, regulations, and processes are assuring the nation that a fair, equitable, and safety-driven process is being used.

Figure 6

Risk-informed regulation is an integral, increasingly quantitative approach to regulatory decision-making that incorporates deterministic, experiential and probabilistic components to focus on issues important to safety, which avoids unnecessary burdens to society.

Figure 7

Statement of Consideration Part 52

"The future of nuclear power depends not only on the licensing process but also on economic trends and events, the safety and reliability of the plants, political fortunes, and much else."

Figure 8

Necessary
safety focused regulation - YES

Unnecessary,
not safety focused regulation - NO

Figure 9

## Regulatory Requirements

- Public Involvement
- Safety Reviews
- Independent ACRS Review
- Environmental Review
- Public Hearing
- NRC Oversight

Figure 10

## Criteria for Success

Every path, every step has to be:

**Disciplined**

**Meaningful**

**Scrutable**

Figure 11

Promise……

to think only the best,

to work only for the best,

and

to expect only the best

Figure 12

**E. Quinn, Consultant, General Atomics:** The combined operating license part of Part 52 is unproven. We haven't run through that yet, as well as early plant siting. Can you define how the Commission can help the staff to provide, to make this a more stable process as we go through it so that the financial community will help us to get these through?

**Commissioner Diaz:** It's a very good point. We have it, it's there. We've been looking at it for some time, but it's not been tested. The issue is how do we make sure that it works the way it should be, effectively and efficiently.

I think we learned a lot at the license renewal process. I believe that what I have learned the last few years is that Commission involvement is very necessary in this step.

I will use one of the first phrases I used in a meeting down there that the enemy of the good is the better and the enemy of the better is the best. Therefore, we are going to have to be in very close contact with the staff. I believe the Commission will actually take an important role in making sure that the processes are timely.

In this respect what we have done among many other things the last 3½ years, is we have maintained our doors open. We have allowed stakeholders from all different areas to come and visit and let us sometimes close this little gap that exists, it is vital information to us how stakeholders, whether they're industry or there are other, you know, groups that have an interest in the proceedings, let us know how things are going. That has worked very well. It keeps the Commission informed early. Sometimes, the staff protects the Commission and shields us from knowing the little problems that are happening. And sometimes that is fine. There are times in which we need to know ahead of time.

I think this combined operating licensing process should be very similar with the Commission, really on top of it all the time.

**D. Powers, ACRS Member:** I'd like to phase in the issue of nuclear waste, which comes up repeatedly in connection with all the discussions of nuclear power, especially as we go to looking at maybe an increased use of nuclear power.

Are we making any progress on this nuclear waste issue? Is there something that the NRC can do or is this totally in the hands of the Department of Energy?

**Commissioner Diaz:** I think the NRC has done as much as it can do. We have engaged in the process all the way. We have tried to make sure that everybody understands that we believe there is the science and technology that offers a better pathway that ensures public health and safety.

I think the decisions right now are practically at final stages. I cannot comment on them. I think that we are going to do what we do best; we're going to take whatever the country decides in the Congress of the United States and the President, and EPA and we're going to work with them. We're going to try to make it a scrutable process. That is what we do best.

Whatever is coming down, we're going to use it. If an application is submitted, we're going to try to license it working through a process. The licensing, is not assured and we're going to have to look at the process every step of the way. Hopefully the Department of Energy will do a good job. We would like to ensure that the process is open to the public. We need to make sure that this is disciplined, meaningful and scrutable.

**T. Kress, Chairman, Subcommittee on Future Reactors:** With some of the new reactor concepts, I see one of the hard places in the regulatory challenges to be in the area of defense- in-depth, which is a general guiding principle for regulation.

Do you think the concept of defense-in-depth is sufficiently rigorously defined for some of the newer reactor concepts or will we have to rethink what we think defense-in-depth is?

**Commissioner Diaz:** I think, those of us who worked in reactor science know what defense-in-depth really is and what are its limitations. I think we have actually reached the limitations of defense-in-depth, and that it is time to move forward and use it in the best possible manner, but complimented with everything else that we can to make sure that we don't make cumbersome design requirements or cumbersome regulatory requirements. I go back to that definition, the end of the definition and risk-informed regulation, which avoids unreasonable burden. That is what we have to do, because eventually the burden is on the people of the United States.

So, I believe that we need to relook and resharpen our focus. I know the ACRS has been working on this, and I share a lot of your views.

**G. Apostolakis, Chairman, ACRS:** This is related to the use of risk-information in licensing and regulations. We hear that the agency may, in fact, receive license application in the very near future. Do you believe, Commissioner, that the regulatory system is ready to review such a license application or does it require some fundamental changes, which will take time, of course?

**Commissioner Diaz:** We will work hard at it. The ACRS is going to need to come and pitch in. I think everybody is getting their attention focused on how can we move in this area, what is it that we know sufficiently that will provide answers within that envelope that I keep referring to provide the protection of all the processes. I think there are hard decisions to be made.

**H. Feinroth, Gamma Engineering:** As I listened to some questions from the ACRS and also the DOE presentation I see it different -- there's a gap between what the DOE is focusing on, which is the entire fuel cycle not just the reactor and their interest is in the goals that they've described to achieve safety and public health for the entire fuel cycle. Whereas the ACRS is focused, I believe, in the past and I think still on reactors only. It seems to me that this is more of an observation than a question. I don't believe that the question has an answer. The regulators need to look at the whole fuel cycle as well and not just the reactor as they provide advice or input to the DOE in their section process.

The gentleman asked about the source term. Well, the source term of importance to public health is not just what's in the reactor, but what gets transported, but gets recycled, what gets sent to a repository. So I think the context that DOE is looking at this is correct. And I think the regulatory agency needs to figure out how to address the imbalance and the public health from the different parts of the fuel cycle. My concern is the ACRS just looks at the reactor.

I don't know if anybody has a response to that, but I think that's an issue that needs to be addressed by the regulatory agency.

**D. Powers, ACRS Member:** Well, we'll comment quickly that we do have the Chairman of the Advisory Committee on Nuclear Waste look at the waste portion of it. And that ACRS does also look at the fuel fabrication part of the problem as well, though we probably haven't focused on it very much in the discussion today because the fuel cycle has only been mentioned briefly here as being changed.

**T. Kress, Chairman, Subcommittee on Future Reactors:** I think the questioner had a good point. I did want to point out that the ACNW also focuses on regulations related to sensitive materials and materials applications.

Perhaps ACRS could do a little more on the fuel cycle parts, but our conception, at least our feeling is, the real risk part of the thing is in the reactor or perhaps in the fuel fabrication.

**G. Apostolakis, Chairman, ACRS:** We also have a joint Committee with the ACNW when the issues warrant it. It's certainly a good thought.

**Department Of Energy (DOE) Summary**

Prepared by ACRS Staff for DOE

William D. Magwood IV of the U.S. Department of Energy (DOE) led the discussions for the DOE staff. Dr. Magwood provided an overview of the Generation IV Initiative to evaluate candidate technology concepts for a new generation of nuclear power plants. Robert Verslius, DOE, presented the Generation IV goals, road map effort, and concept evaluation. Mr. Thomas P. Miller discussed the formation of a Near-Term Deployment Working Group (NTDG) formed to identify actions and evaluate options necessary for DOE to support new plants. DOE has established a Nuclear Energy Research Advisory Committee (NERAC) to provide independent evaluation and feedback on the establishment of goals and objectives and progress in evaluating candidate nuclear energy concepts. DOE has also established a Generation IV Road map NERAC Subcommittee (GRNS) to serve as an advisory group in establishing the road map along with a Road map Integration Team (RIT). Candidate technologies must be deployable by 2030. Nuclear systems are expected to meet sustainability goals (resource inputs, waste outputs, and nonproliferation), safety and reliability goals (operating maintainability excellence, limiting core damage risk, and reduced need for emergency response), and economic goals (reduced life-cycle costs and risk to capital). Criteria and metrics for each goal are being developed by an Evaluation Methodology Group (EMG), RIT, and the GRNS. DOE plans to evaluate all candidate concepts equally without prejudice toward existing technologies (e.g., light-water reactors) but recognizes that most primary energy generators are likely to be fission based. DOE is presently considering 94 concepts. The output of the Generation IV Program is expected to be a research and development plan to support future commercialization of the best concepts.

# Generation IV Initiative

**Presentation at ACRS Workshop**
**"Regulatory Challenges for Future Nuclear Power Plants"**

*June 4, 2001*

***William D. Magwood IV, Director***
***Office of Nuclear Energy, Science and Technology***

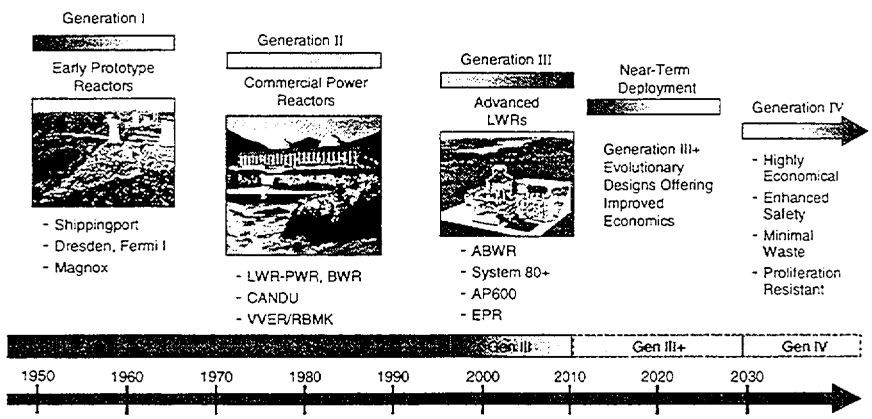


## Systems

- **Nuclear energy systems deployable by 2030**
- **Systems offering significant advances in**
  - sustainability
  - safety and reliability
  - economics
- **Systems include fuel cycle and power conversion**
- **Diversity of applications (electricity, H2, water, heat)**
- **Deployable in a wide range of markets**

*Office of Nuclear Energy, Science and Technology*

## ...of Nuclear Power




*Office of Nuclear Energy, Science and Technology*

## ...Research Advisory Committee (NERAC)

- **Subcommittee on Generation IV Technology Planning**
  - Established in October 2000 to provide guidance on development of the Generation IV Technology Roadmap
  - Membership from U. S. Industry, laboratories, and academia
  - Co-chaired by Neil Todreas, MIT and Sal Levy, GE (retired)

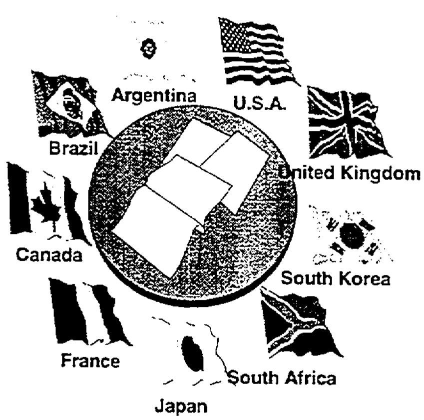
*Office of Nuclear Energy, Science and Technology*

## Energy Research Advisory Committee (NERAC)

- **Subcommittee Charter: Gen IV Technology Roadmap**
  - Establish goals that define the requirements for Generation IV nuclear energy plants
  - Suggest paths forward to resolve technical and institutional issues for Near-Term Deployment (by 2010)
  - Recommend Gen IV R&D Plan
    - Sequencing of R&D task and initial cost estimates
    - National and international collaboration
    - Systems must be deployable by 2030

*Office of Nuclear Energy, Science and Technology*

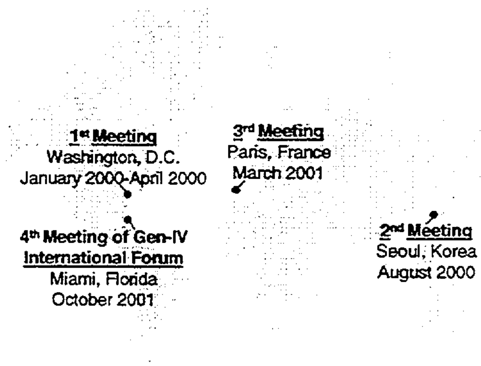
## International Forum




- **Facilitate research planning and international cooperation between countries interested in the future of Nuclear Energy**
- **Led by Policy Committee, composed of senior nuclear technology official representing member governments**
- **Observers from:**
  - International Atomic Energy Agency
  - OECD/Nuclear Energy Agency
  - European Commission
  - U.S. Nuclear Regulatory Commission
  - U.S. Department of State

## International Forum

- Endorsed Gen-IV technology goals
- Internationalized the Gen-IV Technology Roadmap effort
- Finalized charter governing memberships and objectives






## Initiative

### Near-term Objectives

- Establish Near-term Deployment Working Group
- Identify institutional and regulatory barriers to new plant deployment in the U.S.
- Provide recommendations on appropriate government actions to assist in addressing barriers (complete by September 2001)

### Long-term Objectives

- Establish Gen-IV Technology Project
- Identify and evaluate most promising nuclear energy system concepts
- Provide comprehensive R&D plan to support future commercialization of the best concepts (complete by September 2002)

# Generation IV Goals and Roadmap Effort

Presentation at ACRS Workshop
"Regulatory Challenges for Future Nuclear Power Plants"

*June 4, 2001*

*Dr. Rob M. Versluis*
*Office of Technology and International Cooperation*



## Generation IV Technology Roadmap

- **Identify and evaluate most promising nuclear energy system concepts (Oct '00 - Sep '02)**
- **Advisory group: Generation IV Roadmap NERAC Subcommittee (GRNS)**
- **Working Groups:**
  - ~50 U.S. experts from industry, labs, academia
  - ~40 experts from Generation IV International Forum (GIF) member countries & organizations
- **R&D Plan to support future commercialization of the best concepts**

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## Generation IV Technology Roadmap: Goals

*Goals*

- **Reflect mid-century vision of energy needs (2030)**
- **Provide basis for evaluating nuclear energy systems and identify the most promising concepts**

| *Sustainability Goals* | *Safety & Reliability Goals* | *Economics Goals* |
| --- | --- | --- |
| *•Resource inputs* | *•Excellence* | *•Life cycle cost* |
| *•Waste outputs* | *•Core damage* | *•Risk to capital* |
| *•Nonproliferation* | *•Emergency response* | |

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## Definition: System

*Generation IV System:*

- **An entire energy production system, including**
  - nuclear fuel cycle front and back end
  - nuclear reactor
  - power conversion equipment and its connection to the distribution system
  - electricity, hydrogen, fresh water, process heat, district heat, propulsion
  - infrastructure for manufacture and deployment of the plant
- **Limited to systems that are likely to be commercially viable by 2030**
- **Primary energy generators based on critical fission reactors**

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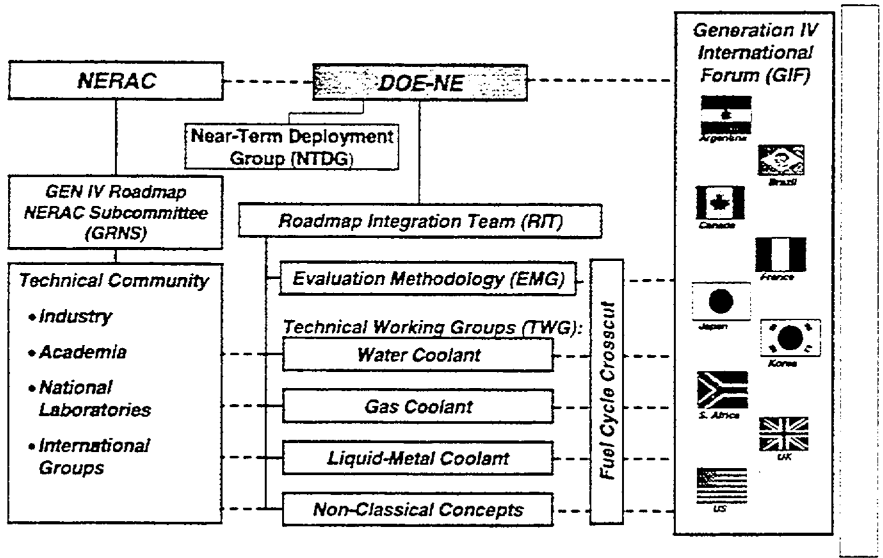
## Generation IV Technology Roadmap: Organization

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## Schedule for Producing the Roadmap

*Four Phases over Two Years:*

**Phase I: Initial work**
Oct '00 – Jan '01 – Completed

**Phase II: Needs assessment**
Jan '01 – Jan '02 – Jan '02 Draft Roadmap

**Phase III: Response development**
Oct '01 – May '02 – May '02 Interim Roadmap

**Phase IV: Implementation planning**
May '02 – Sep '02 – Sep '02 Final Roadmap

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## First Steps: Goals and Plans

**Derive technology goals based on industry needs**

- Goals have been drafted by GRNS and GIF
- Captured in Technology Goals Document

**Plan the activity**

- Roadmap Development Guide drafted by RIT
- Working groups have been convened including international participation

**Determine how to measure concepts against goals**

- Develop criteria and metrics for each goal
- Continue on to develop evaluation methodology
- Conducted by EMG, with the RIT and GRNS

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## Next Steps: Concepts

**Identify concepts for evaluation**

- Drawn from a broad international base
- Concepts adopted or synthesized by TWGs
- Concepts grouped into "concept sets"

**Detail the most promising concepts**

- Interactions between TWGs & concept teams/advocates
- Active study and comparison of underlying technology
- "Screening for Potential" guided by EMG criteria
- Evaluations guided by EMG metrics

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## Definition: Concepts

**Concept:**

A technical approach for a Gen IV system with enough detail to allow evaluation against the goals, but broad enough to allow for optional features and trades.

**Concept Set:**

A logical grouping of concepts that are similar enough to allow their common evaluation.

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## The Second Year: Evaluate & Assemble

**Evaluate the most viable concepts**

- Compare concept performance to goals
- Identify technology gaps
- TWGs lead – RIT/EMG reviews – DOE approves – GIF endorses

**Assemble Roadmap to support the most promising concepts**

- Identify R&D needed to close gaps in areas of crosscutting technology
- Assemble a program plan with recommended phases
- Groups report – RIT integrates – DOE approves – GIF endorses

## Planned Evaluation Stages

- *Request for information* — ***March 2001***
  - Concept elicitation, sorting, and characterization
- *Screening for Potential* — ***July 2001***
  - Concept studies
  - (assessment of technical needs by concept)
- *Final screening* — ***April 2002***
  - R&D plan development
- *Roadmap completion* — ***September 2002***

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- Viability R&D
- *First down-selection*
  - Performance R&D (industry participation)
- *Second down-selection*
  - Demonstration w/industry, design, regulatory reviews



## Technology Working Groups 1–4

**Charter**

- Identify Gen IV concepts for evaluation, evaluate their potential against the goals, their technology gaps and needs, and recommended R&D priority.

**Special Features**

- Groups will author major sections of the roadmap on concepts, technology gaps and R&D needs
- Group members will staff the crosscut groups in the second year

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## ...ation Methodology Group

**Charter**

- Develop a process for the systematic evaluation of the comparative performance of proposed Gen IV concepts against the established Gen IV goals.

**Special Features**

- Early delivery of products in Feb/Mar and May 2001
- Continued refinement of methodology
- Review of the TWG analyses to assure a consistent approach

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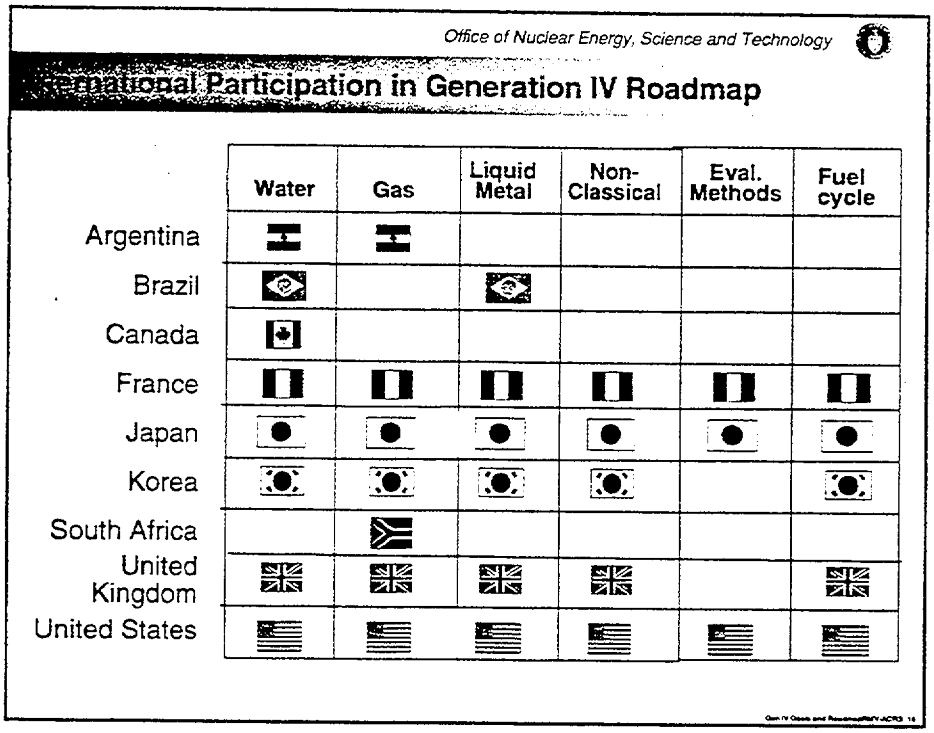
## ...el Cycle Crosscut Group

**Charter**

- Examine fuel resource input and waste output from a survey of Generation IV fuel cycles, consistent with projected energy demand scenarios. The survey of fuel cycles will include currently deployed and proposed fuel cycles.

**Special Features**

- Members mostly drawn from the TWGs and EMG
- 8–10 month time frame for delivery of products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Participation in Generation IV Roadmap
Water
Gas
Liquid Metal
Non-Classical
Eval. Methods
Fuel cycle
Argentina
Brazil
Canada
France
Japan
Korea
South Africa
United Kingdom
United States

# Department of Energy Near-Term Deployment Working Group

**Presentation at the ACRS Workshop - Regulatory Challenges in the Licensing of Generation 3+ and Generation 4 Reactors**

***Thomas P. Miller***

June 4, 2001

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## Near-Term Deployment Group

- **Mission - Identify the technical, institutional and regulatory gaps to the near term deployment of new nuclear plants and recommend actions that should be taken by DOE.**
  - Orders by 2005
  - Multiple plants in commercial operation by 2010
- **Participants - multi-disciplined nuclear industry group**
  - Nuclear Utilities - Duke, Southern Nuclear, Exelon
  - Reactor Vendors - Westinghouse, General Electric, General Atomics
  - National Laboratories - ANL, INEEL
  - Academia - Penn State
  - Industry - EPRI
  - Government - DOE-NE
  - NERAC

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## Near-Term Deployment Group

- **Deliverables**
  - Near-Term Actions for New Plant Deployment
  - Near-Term Deployment Report (Roadmap)
- **Near-Term Actions For New Plant Deployment**
  - Overview of recommended DOE activities and FY 02/03 funding needs
  - Intended for use during DOE budget hearing process and DOE-NE input to VP Energy Task Force
  - Presented to NEI and New Plant Task Force
  - Significant Activities include:
    - Early Site Permit Demonstration (10CFR52)
    - Combined Construction/Operating License (COL)Demonstration (10CFR52)
    - Design Certification of 1000+ MWe ALWR
    - Confirmatory Testing and Code Validation of Advanced Reactor Utilizing New Technology

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## Near-Term Deployment Group

- **Near-Term Deployment Report**
  - To be Issued by September 30, 2001
  - Based on evaluation of industry response to RFI
- **Request for Information (RFI)**
  - Issued April 4, 2001 to reactor designers, AEs, nuclear plant owners/operators, Gen IV participants, and other stakeholders
  - Issued to NEI New Plant Task Force members
  - Public notice through Commerce Business Daily (CBD)
  - Solicits identification of design-specific, site-related and generic barriers to deployment of new nuclear plants by 2010
  - Responses due May 4, 2001- received responses from 12 organizations
  - RFI response under review

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## Near-Term Deployment Group

**RFI requested information in two areas:**

- **Specific Deployment Candidate Designs that meet six criteria**
  - Credible plan for gaining regulatory acceptance
  - Existence of industrial infrastructure
  - Credible plan for commercialization
  - Cost-sharing between industry and government
  - Demonstration of economic competitiveness
  - Reliance on existing fuel cycle structure
- **Generic & Design Specific Gaps**
  - Known gaps provided requiring ranking and possible solutions
  - Other gaps to be identified by respondent

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## Near-Term Deployment Group

### Design Specific Responses

| | |
|---|---|
| SW 1000 | Framatome |
| PBMR | Exelon/PBMR |
| AP600/AP1000 | Westinghouse |
| IRIS | Westinghouse |
| GT-MHR | General Atomics |
| ABWR | General Electric |

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## Near-Term Deployment Group

### Generic Gaps Responses

- ESP Demonstration
- COL Demonstration
- Construction Inspection & ITACC
- Risk-Informed Regulation for Future Design Certifications
  - » Emergency Planning and Plant Security
- Advanced Fabrication, Modularization and Construction Technologies,
- Standardized Life-Cycle Information & Configuration Control Systems
- High Level Waste Disposal Resolution
- Risk Management Tool
- Public Influence and Acceptance
- Appropriate Resource and Financial Arrangements

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# Generation IV Concepts

Presentation at ACRS Workshop
"Regulatory Challenges for Future Nuclear Power Plants"

*June 4, 2001*

*Dr. Rob M. Versluis*
*Office of Technology and International Cooperation*

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## Overview

- Request for concept information (RFI)
- RFI response
- Concept statistics & key features
- Grouping of concepts
- Current activities on concept evaluation

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## Key Definition: Concepts

**Concept:**

A technical approach for a Gen IV system with enough detail to allow evaluation against the goals, but broad enough to allow for optional features and trades.

**Concept Set:**

A logical grouping of concepts that are similar enough to allow their common evaluation.

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## Concept Statistics (5/18/2001)

**Total: 94**

**By reactor coolant type**

- **Water** 28
- **Gas** 17
- **Liquid Metal** 32
- **Non-classical** 17

**By organization type**

- **University** 27
- **Industry** 22
- **Laboratory** 45

**By country**

- **France** 3
- **Japan** 19
- **Korea** 10
- **UK** 4
- **US** 45
- **7 Others*** 13

*Argentina, Brazil, Canada, Germany, Italy, Netherlands, Russian Federation

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## Concepts with Water Coolant

**Variables**

- Coolant ($H_2O$, $D_2O$)
- Coolant phase & conditions
- Spectrum (thermal, epi-thermal, fast)
- Primary system layout (conventional, integral)
- Fuel cycle (U vs.Th, once-through vs. recycle)
- Thermal output
- Maturity

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## Concepts with Water Coolant (cont)

**Crosscutting R&D Issues**

- High temperature materials
- Modular manufacturing technologies
- Internal control rods
- I&C

## Concepts with Gas Coolant

**Variables**

- **Reactor concepts**
  - ➢ GT-MHR
  - ➢ PBMR
  - ➢ Fluidized Bed Reactor
  - ➢ GCFR
- **Applications of fission heat**
  - ➢ Electricity generation: direct vs. indirect cycle
  - ➢ Process heat applications (industrial smelting, petroleum refining, hydrocarbon reforming, coal conversion, etc.)
  - ➢ Desalination



## Concepts with Gas Coolant (cont'd)

- **Fuel forms and fuel cycles**
  - ➢ LEU
  - ➢ Thorium
  - ➢ U-Pu
- **Generic R&D issues**
  - ➢ Fuel fabrication quality assurance
  - ➢ Fuel performance -- integrity and FP retention
  - ➢ Lifetime temperature and irradiation behavior of graphite structure
  - ➢ High temperature materials and equipment
  - ➢ Passive decay heat removal for fast-spectrum concepts

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## Concepts with Liquid Metal Coolant

- **Variables**
  - ➢ Size (large/monolithic, modular, transportable) and targeted clients
  - ➢ Coolant (Na, Pb-alloy, Pb, ...)
  - ➢ Fuel type (oxide, metal, nitride, composites)
  - ➢ Primary system layout (loop, pool)
  - ➢ BOP options and energy products
  - ➢ Energy conversion options
  - ➢ Fuel recycle technology (aqueous, dry)

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## Non-Classical Concepts

- **Focus: adequately defined concepts with significant potential**
- **Variables**
  - ➢ Cooling approach (convection, conduction, radiation)
  - ➢ Coolant (molten salt, organic coolant)
  - ➢ Fuel phase (solid, liquid, gas/vapor)
  - ➢ Electricity generation technology conversion (turbine, gas MHD, direct conversion of fission-fragment energy)
  - ➢ Alternative energy products or services
  - ➢ Fuel cycle

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## Non-Classical Concepts (cont)

- **Crosscut issues**
  - ➢ Modular deployable
  - ➢ Hydrogen production and very high temperature systems
  - ➢ Advanced fuels and fuel management techniques
  - ➢ Energy conversion systems (esp. non-Rankine)

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## Concept Grouping

- **TWG's have grouped concepts into "concept sets"**

- **Concept sets share**
  - ➢ Technology base
  - ➢ Design approach

- **Rationale for grouping**
  - ➢ Efficient division of TWG analysis effort
  - ➢ Streamline evaluation process
  - ➢ Avoid premature down-selection

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## Concept Grouping: Water TWG

- PWR loop reactors (3)
- Integral primary system PWR's (6)
- Integral BWRs (6)
- Pressure tube reactors (3)
- High conversion cores (11)
- Supercritical water reactors (3)
- Advanced fuel cycle concepts (14)
  - MOX
  - Thorium
  - DUPIC
  - Marble Fuel
  - Neptunium

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## Concept Grouping: Gas TWG

- Pebble bed modular reactor concepts (5)
- Prismatic modular reactor concepts (5)
- Very high temperature (~1500°C) reactor (1)
- Fast-spectrum reactor concepts (5)
- Others (4)
  - Fluidized bed
  - Moving ignition zone concepts

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## Concept Grouping: Liquid Metal TWG

- **Four major categories of concepts:**
  - ➢ Medium-to-large oxide-fueled systems (6)
  - ➢ Medium-sized metal-fueled systems (8)
  - ➢ Medium-sized Pb/Pb-Bi systems (8)
  - ➢ Small-sized Pb/Pb-Bi systems (6)
- **Liquid Metal TWG is also examining three supporting technology areas**
  - ➢ Fuels (oxide, metal, nitride)
  - ➢ Coolants (Na, Pb/Pb-Bi)
  - ➢ Fuel Cycle (advanced aqueous, pyroprocess)

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## Concept Grouping: Non-Classical Systems TWG

- **Eutectic metallic fuel** (2)
- **Molten salt fuel** (4)
- **Gas core reactor** (1)
- **Molten salt cooled/solid fuel** (1)
- **Organic cooled reactor** (1)
- **Solid conduction/heat pipe** (1)
- **Fission product direct energy conversion** (2)

## Current Activities

- **TWG's are analyzing the candidate concepts for**
  - ➢ Performance potential relative to the technology goals
  - ➢ Technology gaps

- **A report will be prepared this fiscal year describing**
  - ➢ Concepts
  - ➢ R&D needs
  - ➢ Results of the initial "screening for potential" evaluations

# Next Steps Generation III+/IV

**Presentation at ACRS Workshop**
**"Regulatory Challenges for Future Nuclear Power Plants"**

***June 4, 2001***

***R. Shane Johnson, Associate Director***
***Office of Technology***
***and International Cooperation***

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# Near-Term Deployment of Advanced Reactors

## Near-Term Actions

- Complete report on recommended DOE activities
  - Report will reflect generic and design specific issues
  - Report to be issued by September 30, 2001
- Significant activities expected to include:
  - Development of Regulatory Framework for Gas Reactor Technologies
  - Early Site Permit Demonstration
  - Combined Construction/Operating License Demonstration
  - Design Certification of Advanced Reactors

# Technology Roadmap

## Near-Term Actions

- Evaluate the most viable concepts
- Compare concept performance to technology goals
- Identify technology gaps
- Identify R&D needed to close technology gaps
- Prepare comprehensive report on most promising concepts including detailed R&D plan

**T. Clements, Nuclear Control Institute:** I was a little confused during the DOE presentation about the relationship between the roadmap and the review you're doing and what's happening with the Exelon pebble bed reactor. From what I hear, depending on what happens in South Africa, they plan to start construction in 2004 and have a reactor operating in this country in 2006. It sounds to me like you're behind the curve on what's happening with that reactor. Are you going to ask them to slow down their decision process in pursuing this with NRC? You're behind the curve on what they're doing here on the ground with the NRC or do you assume that you're going to include this reactor in your roadmap? I'm just confused about the relationship between what you're doing and the pebble bed.

**W. Magwood IV, DOE:** The pebble bed reactor that R. Versluis spoke to, is a class of PBMRs, those are not necessarily , in fact may not really be the reactor that Exelon is interested in and is now being discussed in South Africa. That specific design is being discussed as part of the near-term deployment activities. And, as I've mentioned, those activities are largely complete and will be final -- scheduled to be final through the NERAC process in September, and include largely institutional issues that are being raised by NERAC that are fully in concert with the schedule that PBMR corporation is on.

And, in fact, there are representatives of Exelon on some of the working groups that are providing information about the schedule and trying to keep everything in concert.

So that PBMR is slated for near-term deployment as opposed to being in the longer term Generation IV activities. And that's simply because of the fact that it's of near-term interest to a utility and, therefore, it's appropriate that we look at it as something to be deployed by 2010. And whether it actually gets deployed by 2010 or not is up to Exelon and others.

**E. Quinn, Consultant, General Atomics:** We've read the Vice President's report -- or the President's report and it addresses investment in new technologies for renewables, for coal for example, and some of the 105 recommendations address advance nuclear designs. Can you advise in FY '02 and beyond how those recommendations will come into DOE planning?

**W. Magwood IV, DOE:** No. To expand on. No. Let me just say that, obviously, our international partners are all very pleased with the outcomes that were in the Vice President's review and have every hope that eventually there'll be more resources devoted to nuclear research and development by the government. Certainly there would have to be to do any of the things that we've talked about today.

What will happen in specific fiscal years, 2002 in particular, I simply don't have an answer for you. I think that as the government continues to digest results of the review, we'll begin to talk more in terms of what do we have to do, to actually implement those things, and those discussions have already started moving.

But I wouldn't expect to hear any specific implementation announcements other than what you may have already heard from the Secretary. I think he made some announcements recently about specific things in non-nuclear aspects. But on the nuclear aspects it's going to take a while to adjust it, move on it and to formulate those implementation activities.

So I would expect that over the course of the next few months, those would start to come out.

**G. Apostolakis, Chairman, ACRS:** If you had to give us the two most important regulatory challenges for meeting all these wonderful initiatives, what would they be?

**W. Magwood IV, DOE:** That's a good question. I think I'll answer the question a little more generic.

I think that it's extremely important the NRC move as close to performance based risk-informed regulation as possible. Because these technologies are dissimilar in so many ways, and you're already starting to see it. There's already a large discussion going forward about the pebble bed reactor versus light water reactor technology and how you license those.

The only way to do that successfully with these different concepts floating around out there is to move to a technology- independent regulatory approach. And unless you do that, you're going to inhibit the development of these new technologies because people will not have the confidence that NRC can respond quickly enough to regulate these technologies.

I know there's a lot of concern about how long it's going to take to get regulations for the pebble bed reactor. And we're working with General Atomics at DOE with the development of their system, and that presents similar challenges. So I think that the larger issue is the one you have to deal with.

In the nearer term, I think it's really more a job of demonstrating the pieces are already out there. But even as we look at these newer technologies coming in before now, they present issues, many that you are already very familiar with.

So I would say that pushing as fast as possible towards a new regulatory regime that will support new technologies in the next century is really going to be -- should be a high priority.

**D. Powers, ACRS Member:** Well, it seems to me that if you're going to encourage people to move to a performance- based regulatory system, that must mean surely you're looking at performance indicators for these new generation? Is that the case?

**W. Magwood IV, DOE:** I think the answer to that is yes. If you look at our technology goals, and I think you're going to get a rundown of that.

You'll see a very high level version of what those performance goals are. On a regulatory space, you're talking about safety. You'll see some indications where we think things should go, but not to the level of detail because these technology goals are very, very high level. You're not going to see a low level of detail, but you will see an overall vision.

**E. Lyman, Nuclear Control Institute:** I think there are public issues that really have to be thought about before large expansion in DOE's research budget has to be contemplated. Because these days you have to really worry about whether what looks like government subsidization of one energy technology over another, how that will be perceived, especially by small scale generators using other competitive fossil fuel technology. And in a deregulated environment that's going to be a greater concern.

So, I was encouraged when these reports of a task force on near-term deployment that recently reported to NERAC discussed a cost sharing program with industry for near-term deployment. I was wondering if industry had actually made any firm commitments in that regard, since this would be a positive step since I don't think they've put any money down so far in these initiatives?

**W. Magwood IV, DOE:** First, it's important to clarify, and I think you raised a good point. There's two things really important to clarify.

First, in general, you know our office is not in the business of corporate welfare. We're not here to make technologies marketable that wouldn't otherwise be marketable, you wouldn't otherwise compete on it. In fact, our goals, and you'll hear about it, for our Generation IV have a lot of built into them about the need to be economically competitive. That's a hallmark of what we're trying to do.

And let me say for the record that there should not be a new nuclear power plant that's not economically competitive in this country. It shouldn't be built because we're not going to subsidize it and if industry is not willing to go off and do it because they can make money, it shouldn't happen. It shouldn't be done.

Now, regarding the specific point you raised, I think that where we are right now -- well, first it's important to recognize that this is a NERAC advisory group, so we're not at the point where we're making commitments on a policy basis on behalf of the industry. We have asked certain experts in industry along with academia and working with our national laboratories to come together and make recommendations. These recommendations will flow up through the NERAC process and if it comes out the other side, NERAC will make a recommendation to DOE that we should go pursue a program in that vein.

But at that stage, if that were to happen, we would be in a position to approach the industry and say "Okay, your people were on this panel, here's the recommendation that they made, Mr. CEO do you want to buy into this?" And if they don't want to buy into it, we don't have to do it. But, you know, it's a recommendation. It's not a commitment on anyone's part, especially ours.

You know, with my budget I couldn't commit to anything they recommended at this point. So, it's really a recommendation for the future.

The question we asked was if we were going to solve these problems, how would we go about it? And that's what these recommendations gives us. It gives us a way of solving the problems.

It doesn't mean that we have to do it. It doesn't mean the industry has to do it, but it gives us a methodology.

So the answer to your question is no, no one's made any commitments, nor would it be appropriate to at this point in time.

**D. Powers, ACRS Member:** I have a question that comes to mind when I see these plans for Generation IV reactors. My good friends at the Nuclear Energy Institute regularly provide me metrics on the performance of the current generation of plants in a variety of areas, including resources, safety and economics. And they show excellent performance, just outstanding performance in the last ten years.

In all this roadmapping exercise, do you carry along some representative of the current generation plants as a comparison so you can see if you're really going to accomplish anything with these new plants.

**R. Versluis, DOE:** Well, it's a good question because the initial screenings are really not much more than comparing in a number of different areas with the Generation III technology. So, they are qualitative comparisons, and that's how we approach it, is comparing it with the Generation III technology.

**D. Powers, ACRS Member:** We don't have a whole lot of performance and data on those Generation III plants the way we do with the existing plants?

**R. Versluis, DOE:** We think at this point with the amount of data that we have on the various concepts, there is no need to be very, very precise about these things. What the schedule, the last slide really showed is that we need to do a certain amount of viability research where we get a better handle on how to measure, how we can measure the various indicators before we can do a more sophisticated screening.

**J. Garrick, Chairman, ACNW:** It might be important to point out, too, that GRNS has put a lot of emphasis on the total energy system concept, and that has kind of evolved. When we first got together, that wasn't so much an emphasis. And when you think about performance indicators, you've also got to think about the scope that we're addressing this time, namely the total energy system.

So, it would seem that if we're going to go in the direction of performance indicators that are compatible with risk-informed performance based regulatory practice, we'll be talking about probably a different structure and at least a more range of indicators that we've perhaps ever seen before. Is that not correct?

**R. Versluis, DOE:** Yes. For example, the base case we're comparing with, of course, has a once through fuel cycle. We have various criteria that have to do with the waste and use of fuel, but particularly the waste forms that can be achieved by other fuel cycles.

So, you're very right that we are not just looking at the reactor, but the entire system from soup to nuts, so to speak.

**G. Apostolakis, Chairman, ACRS:** Now when you say reliability goals, I mean are they goals the way we understand them, numerical goals for reliability?

**R. Versluis, DOE**: That's where we would like to end up, but reliability you can't really put a metric of reliability together until you know the design pretty well. And so early on we are really looking at very general indicators that might lead to reliability, but it's not -- as I remember well, it's actually not a screen for potential criteria. It doesn't come into play until later.

**W. Shack, ACRS Member:** One of the things I noticed this morning in the whole discussion of the Generation IV thing was that the word "severe accident" never appeared anywhere. Do you envision that as being a technology need that will have to be addressed in the R&D program?

**R. Versluis, DOE**: Yes. One of the goals, the second safety and reliability goal has to do with core damage. And then the third goal has to do with the emergency response. So in both of these goals severe accidents are an issue.

And the second goal will assume the performance of a PRA. And the third goal will have to involve all the severe accident, that could lead to a release off-site.

**P. Ford, ACRS Member:** We've been told earlier on that risk-informed regulation is going to be a part of your strategy, and yet we're looking at a whole lot of new systems here for which we have no experience at all in terms of time dependent degradation. As you're going through your screening process, does the time needed for R&D to resolve those questions, enter into your timing and your decision making?

**R. Versluis, DOE**: Yes, it does. And certainly we hope or we intend but in early on in particular to focus on those issues where there's a large amount of uncertainty and try to reduce that uncertainty. That's how we will focus what we call the viability R&D, so that we have a better idea of what the potential is.

**P. Ford, ACRS Member**: And have you also taken into account the question of the manpower capability of doing that research?

**R. Versluis, DOE**: Well, there will of course be as part of the roadmap an estimate of required manpower, resources and infrastructure. But we are certainly aware that there is a lot of work needed there and a lot of investment needs to be made.

**E. Lyman, Nuclear Control Institute:** I just have to follow up from my earlier question, because I think what we've just heard is a list of activities which I don't think it's appropriate for the government to be funding. These are activities which are associated with providing a regulatory climate or easing licensing advanced reactors. And I think in today's context, that's a cost that really should be born by the applicants.

Licensing is expensive, but that is part of the package for trying to develop a new nuclear reactor and market it. And so I think it raises real questions whether DOE should be involved in trying to facilitate or come up with ways of easing the site permits and other regulatory activities.

I'm also concerned about DOE proposing a licensing framework for reactors and then a way of meeting those licensing criteria. I think there really has to be a separation maintained between the licensing standards and the actual applicant. Because otherwise these criteria could be gerry-rigged to justify or to facilitate the particular reactor you're pushing.

**W. Magwood IV, DOE**: What we're doing, Ed, and for everyone else who had concern about this, is we're focusing on generic issues, and this is something that DOE has done basically throughout history.

For example, in the case of gas reactors there are some very generic issues related to the implementation of gas reactor technology in the United States whether it's a pebble bed or GT-MHR or something else, you have to deal with, for example -- and this is something that we've had a lot of very important discussions about. If in the case of a gas reactor you're relying very heavily on the quality of the fuel, how does one go about thinking about fuel manufacturing in concert with the design of a power plant? You can't separate it as easily as you can in the light water reactor. That's a very, very broad generic technology issue. And I think it's entirely appropriate for DOE to be involved in that.

What we will not be involved in are the specific -- and NRC, by the way I'll point this out, NRC's Office of General Counsel has been very, very diligent about keeping both NRC and DOE straight about this issue.

We will not contribute to the specific design related regulatory activities NRC will be participating in with the vendors. There will be a separate activity that will probably be coming on in the next year or so. We expect that Exelon, or whoever, will come to the

NRC and will be obligated to pay for those activities. We don't anticipate being involved in that.

But the generic activities are things that we think the government ought to be involved in and should be involved in. And I'll be happy to talk with you more about that later, but I think it's entirely appropriate what we're doing as long as you stay on this generic level. I think there has to be a distinction.

**R. Uhrig, ACRS Member**: There's a number of rather exotic materials involved in the various concepts that have been talked about this morning. Is there any consideration or any time being spent looking at the availability of these? Even something as common as helium, there's a limited amount of that unless you want to produce it artificially. And I just wondered if this is an issue that's going to be brought into the consideration?

**W. Magwood IV, DOE:** That's a really good question, and something that I've actually started to worry about myself. The answer to the question is no, we haven't done this stage. And the reason we haven't is because we haven't reached this 2002 target of narrowing down the number of options. When we know what concepts we're really going to spend our energies on, we're going to really have to deal with those materials issues.

And I can't talk too much about this, but we are expecting in the next few weeks to really strengthen our materials activities within the DOE infrastructure and start to have more focus on these issues. Because I think they're too disperse right now. We need to really focus our energies there, and we're going to be doing that very soon. We'll make some announcements about that.

But your question is really good one, and we're worried about it but it's too early for us to really go a whole lot further.

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**Presentation Summary**
**Safety Design Aspects**
**And**
**U.S. Licensing Challenges**
**Of the**
**Pebble Bed Modular Reactor**
**By**

**Ward Sproat – Exelon Generation**
**Dr. Johan Slabber – PBMR Pty.**

This presentation consists of three sections: An overview of the status of the PBMR project in South Africa, a review of the design features and philosophy being utilized to design the PBMR, and a summary of the key licensing issues that Exelon has identified in assessing the licensability of the PBMR for application in this country.

Project Status

The PBMR project is currently completing the Preliminary Design Phase. Based on the information developed, a Detailed Feasibility Study is currently being performed and the report will be issued in mid-summer. The investor companies will make their decisions regarding investing in the next phase of the project based on the report's findings and their own investigations. If the decision is made to proceed, and if the South African government agrees, a PBMR demonstration plant will be constructed near Cape Town, starting in late 2002.

Safety Design Aspects

The PBMR design philosophy is to use both passive and active engineered features to provide both prevention and mitigation capability as well as to reduce dependence on operator actions. The PBMR reactor is being designed to a set of principles that is intended to assure fuel integrity, provide multiple fission product barriers to the environment, and to provide safeguards against nuclear material proliferation.

Fuel integrity will be assured by quality controls on the fuel manufacturing process, minimizing excess reactivity, assuring excess heat removal from the fuel, prevention of chemical attack on the fuel, and preventing excess burnup.

Multiple layers of fuel particle coatings, the primary pressure boundary system, and the containment structure will provide barriers to fission product release.

Nuclear material proliferation is addressed in the inherent design of the fuel and politically through agreements by the Republic of South Africa with international agencies.

## Licensing Issues

Exelon has determined that a number of technical and non-technical issues will need to be addressed during the licensing of the PBMR. These issues may affect the ability to license the design in the US at a cost-competitive price. Some of the issues will require exemptions, rulemaking or legislation to address the unique aspects of small modular reactors.

# Safety Design Aspects and U.S. Licensing Challenges of the PBMR

Ward Sproat - Exelon Generation
Dr. Johan Slabber – PBMR Pty.

## Agenda

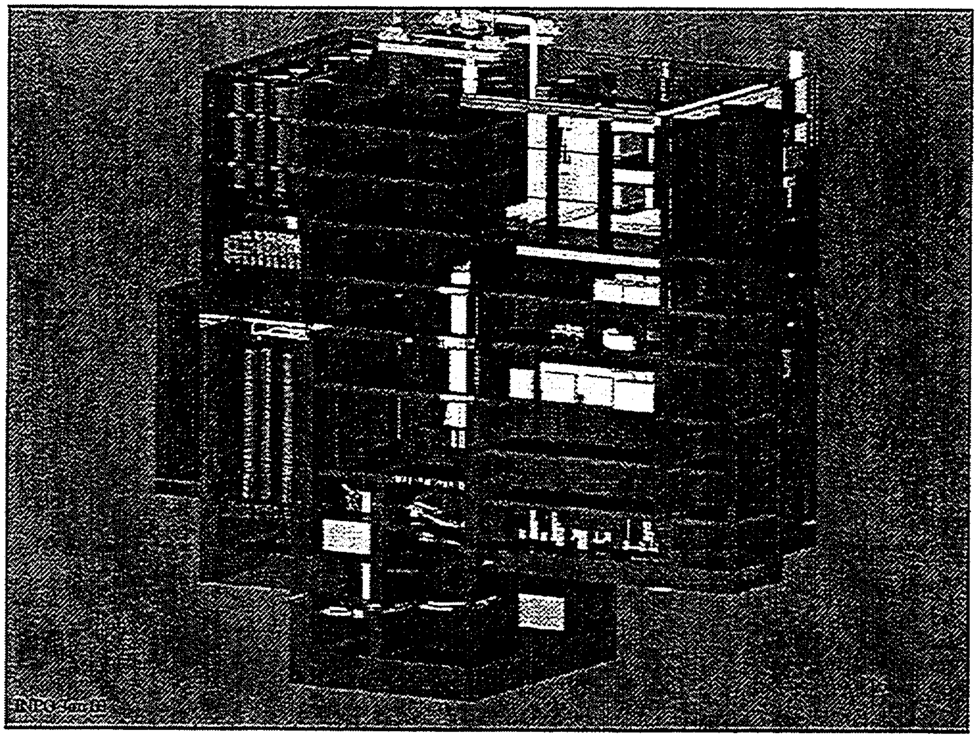
- Project Overview
- PBMR Safety Design Features
- U.S. Licensing Challenges

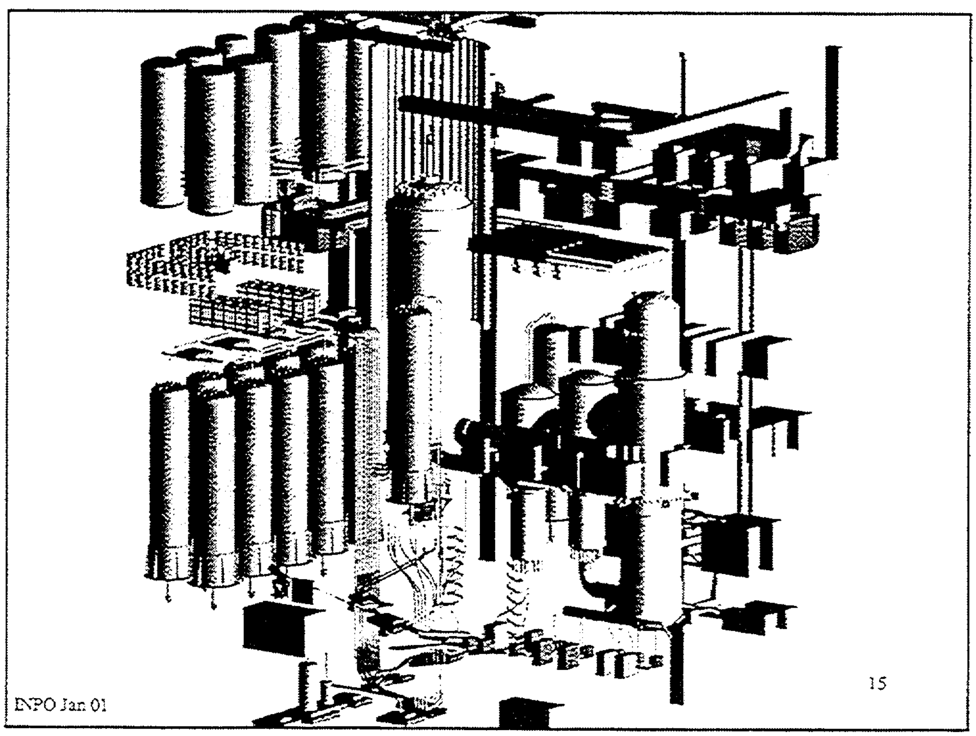
# PBMR Project Overview

- Ending Preliminary Design Phase
- Feasibility Study in preparation
- Investors' decisions by end of year
- RSA demonstration plant construction start in late 2002 pending approvals
- Exelon decisions hinge on economics and technical risks

# Design Philosophy

- Employ passive and active engineered features
- Provide prevention and mitigation capability
- Reduce dependence on operator actions

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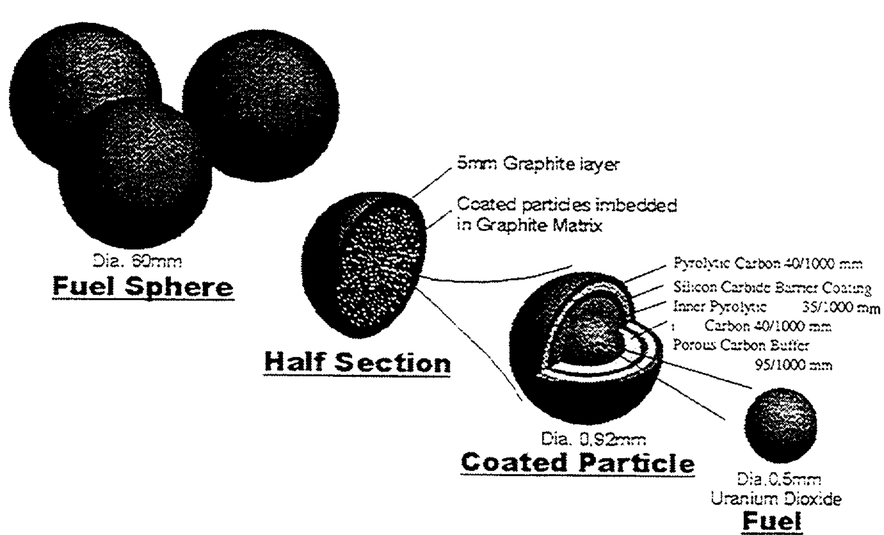
# Reactor Safety Design Principles

- Assure fuel integrity
- Multiple fission product barriers to the environment
- Nuclear material proliferation safeguards

FUEL ELEMENT DESIGN FOR PBMR

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## Reactor Design Principles

- Assure Fuel Integrity
  - Assure Fuel Quality
  - Control Excess Reactivity
  - Assure Heat Removal from Fuel
  - Prevention of Chemical Attack
  - Prevent Excess Burnup

## Assure Fuel Integrity

- Assure Fuel Quality
  - Fuel Design has been proven internationally
  - Fuel Qualification Program
    - Fuel Performance Testing Program
    - Fuel Fabrication Quality Assurance Program
  - Operational fuel integrity assurance by monitoring primary coolant activity online

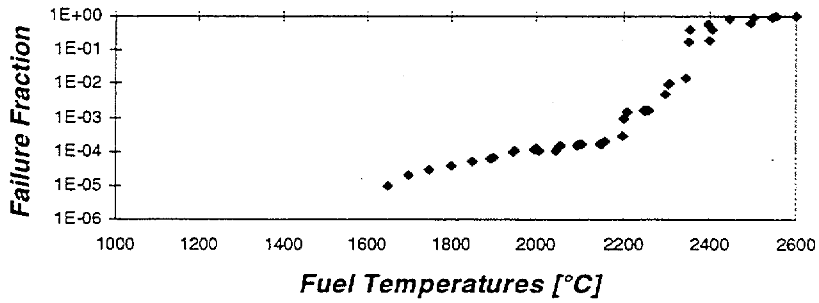
## Assure Fuel Integrity (cont'd)

- **Control of Excess Reactivity**
  - Low Excess Reactivity = 1.3% delta k effective
  - Core geometry maintained by design for all credible events
  - PBMR core design precludes Xenon oscillations
  - Demonstrable large Negative Temperature Coefficient of Reactivity
  - Criticality safety assured for spent and used fuel

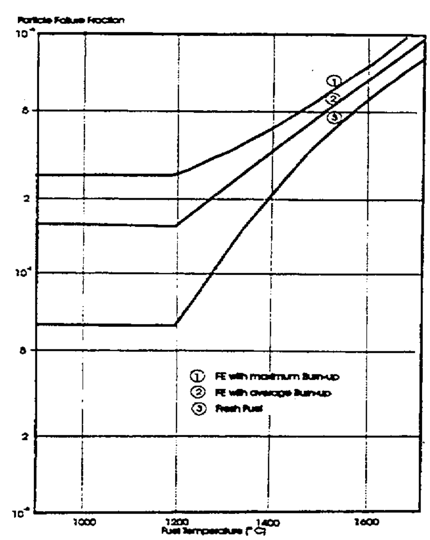
## Assure Fuel Integrity (cont'd)

- **Assure Heat Removal From Fuel**
  - Materials properties and design features assure heat transfer from fuel to RPV
  - Passive heat sink provided by the Reactor Cavity Cooling System for extended period
  - The reactor cavity including its structures will maintain geometry during all credible events.

# Fuel Performance at Elevated Temperatures




# Nominal Fuel Performance



## Assure Fuel Integrity (cont'd)

- **Prevention of Chemical Attack**
  - Water systems at a lower pressure than that of the primary coolant system during operation
  - Water ingress to reactor when depressurized prevented by physical design
  - Primary coolant system monitored to detect, and cleaned to remove moisture and air
  - Graphite oxidation due to air ingress prevented by physical design of reactor, gas manifold and citadel

## Assure Fuel Integrity (cont'd)

- Prevention of Excess Burn-up
  - Physical core design
  - On-Line gamma spectrometric system to measure fuel burn-up

# Fission Product Barriers to Environment

- Individual fuel kernels with 3 layers
- High integrity primary pressure boundary
- Containment (Confinement)
  - Reinforced concrete structure
  - Filtered vent path
  - Hold up of fission products
  - Plate out
  - Auto-close blowout panels
  - Late release

# Nuclear Material Proliferation Safeguards

- International Atomic Energy Agency (IAEA) / Government of the Republic of South Africa Safeguards Agreement
- Non-Proliferation attributes inherent in fuel design

## Key Technical Licensing Challenges

- Lack of gas reactor technical licensing framework
- Fuel qualification and fabrication process licensing (South African Fuel)
- Source Term: Mechanistic or Deterministic
- Containment performance requirements
- Computer code V&V
- PRA - Uncertainties, Initiators and End States
- Regulatory treatment of non-safety systems
- Classification of SSC's
- Lack of technical expertise on gas reactors

## Key Legal Licensing Challenges

- Price Anderson indemnity
- NRC operational fees
- Decommissioning trust funding
- Untested Part 52 process
- Potential number of exemptions

**T. Kress, Chairman, Subcommittee on Future Reactors:** Do you have a goal for how many particles can be failed within the core before you violate 10 CFR 100?

**W. Sproat, Exelon**: This is clearly an issue that we're going to have to wrestle with the staff, once we decide ourselves how we think the appropriate way of addressing it, is what's the source term? Is it mechanistically determined source term or deterministically determined source term.

**T. Kress, Chairman, Subcommittee on Future Reactors:** Isn't the answer obvious there?

**W. Sproat, Exelon**: No, the answer's not obvious. I know what we would like to do, but the issue of how good are your goods analyzing your diffusion coefficients and being able to provide an analytic framework for migration of fission products from the core to the environment is going to be a challenge. It's going to be a challenge.

Obviously, containment performance requirements, Johan talked about the containment design and whether or not a zero leakage or a LWR type containment would be required versus moderate to high leakage filtered containment would be required is obviously an issue that's going to be discussed at some length.

**T. Kress, Chairman, Subcommittee on Future Reactors**: And that would be linked to the fuel quality?

**W. Sproat, Exelon:** Absolutely, and to the source term. The issue of the various computer codes that are being used in South Africa to design this plant, how they're verified and validated and how they're benchmarked against the other existing codes will be an extensive effort associated with that.

The PRA itself that's being developed in South Africa that we're advising them on, it's kind of interesting. If you have -- what's your endstate if core melt isn't a valid endstate for your reactor? Than what is your endstate? What are your initiators and how do you determine your uncertainties of the various accident sequences?

**T. Kress, Chairman, Subcommittee on Future Reactors:** Your endstate is quantity of fission products. Frequency of fission products.

**W. Sproat, Exelon:** It might be. The point is that we're exploring some new ground here and, obviously, there'll be some discussions with staff about how we go and do that.

The regulatory treatment of nonsafety systems and how we classify the SSCs, the safety system components, will really be a key issue.

Finally, an issue that I lumped in the technical area, but it's a real practical issue is there aren't a lot of people left in the U.S., in the NRC, in the national labs or in DOE that have gas reactor experience and understanding. Obviously, I think you've gotten a sense as we go forward with this, if we submit an application having people who understand the technology, understand the science and can provide good independent review of the submittal is going to be a real challenge.

On the last slide I have is the nontechnical, what I'll call the legal licensing challenges. I personally believe we have a very good chance at satisfactorily resolving a number of the technical issues that I showed on the previous slide. I'm not as confident about some of these, because some of these are potential deal breakers for moving forward with merchant nuclear power plants in this country. That's what we're talking about here; this is not a power plant or nuclear plant that's going to go into a rate base somewhere. This is a merchant plant where the shareholders are going to take the risk of building and operating this plant and whether or not it makes money in the deregulated marketplace is solely dependent on the technology and the company that runs it.

So, the first issue up here is Price Anderson. The current law and the way it's currently interpreted by the NRC is that each reactor in the country is assessed a retrospective premium of $90 million per reactor in the case of an accident anywhere in the U.S. associated with any reactor. If I've got a 2200 megawatt light water reactor plant, like our Limerick plant, that means my retrospective premium at risk due to a reactor accident somewhere in the U.S. is $180 million retrospective premium associated with that plant.

If I have the same capacity of pebble bed modular reactors under today's law, my retrospective premium would be $1.8 billion for that same amount of capacity. Even I would have difficulties selling our board of directors to take that kind of a risk associated with that kind of retrospective premium associated with an accident from a reactor that we don't own or operate. So that's got to be addressed somehow.

The second issue up there is the NRC operational fees. Right now the operational fees are approximately $3 million per reactor. Again, say at the Limrick plant, that means about $6 million a year for the two reactors. The same size for 2200 megawatts, you're talking about $60 million a year in NRC licensing fees for a 2200 megawatt set of string of PBMRs.

The decommissioning trust fund is another issue that's clearly going to have to be addressed. The law gives a number of different alternatives, but those alternatives have presupposed that generally the plant is going to be operated by a regulated utility and that in the rate base in which the plant is based rate, you have a set aside income stream that goes and funds the decommissioning trust fund. In our case that won't be the case. These plants won't be in a rate base. How we fund the decommissioning trust fund, how much we have to put up front and what we can put into a sinking fund needs to be resolved. The law is not clear on that at this point in time.

Clearly, Part 52 licensing process which is, we think, the right way to go is untested at this point in time. Nobody's actually done it. So the staff will be learning, the applicants will be learning, and how we actually work our way through that and how long it takes is going to be a key challenge for us.

Finally, I have up there the potential number of exemptions. As I talked about earlier, there is no gas reactor licensing framework. If there's not when we go with an application, the staff might decide that a number of the things we're asking for are very appropriate to license this plant, but will require exemptions from the existing regulatory framework. Obviously, it would be undesirable to all of us to have the first advanced reactor in place with a significant number of exemptions. It just doesn't work.

So, those are the key issues and challenges we see on the licensing side, both from the technical side and the legal side. As I said, we are considering all that and now we'll go into our decision making process as to whether or not to proceed with both the venture in South Africa and the licensing process here in the U.S. by sometime around the end of the year.

**T. Kress, Chairman, Subcommittee on Future Reactors:** These appear to me like mostly policy issues rather than technical ones related to the reactor design?

**W. Sproat, Exelon:** A number of these will require some policy statements and decisions by the Commission itself, yes.

**T. Kress, Chairman, Subcommittee on Future Reactors:** Very good. Is there any discussion or questions for either of our two speakers?

**G. Apostolakis, Chairman, ACRS:** Yes, I have a question. As I recall in one of your communications to the staff in addressing these issues, the key legal licensing issues, you proposed that a site with ten units be considered as one reactor?

**W. Sproat, Exelon:** One facility.

**G. Apostolakis, Chairman, ACRS:** One facility.

Now, if this is accepted by the staff, then should we also be applying the same idea to various safety goals and say, assuming that the concept of core damage makes sense here, that if the goal is 10 to the minus 4 and that would apply to the facility, so each unit then would have to be ten to the minus 5? Given the fact that you have ten of them, you have some synergistic effects, maybe it'll have to be even lower than ten to the minus 5.

**W. Sproat, Exelon:** Well, synergistic effects is not intuitively obvious to me. There are synergistic effects when in fact the risk is from one reactor to the other. I'm not ready to concede that point at this point.

**G. Apostolakis, Chairman, ACRS:** Okay. Fine.

**T. Kress, Chairman, Subcommittee on Future Reactors:** Some common mode.

**G. Apostolakis, Chairman, ACRS:** Some common mode, perhaps. Anyway, but how about the thought process here that you would apply stricter criteria --

**T. Kress, Chairman, Subcommittee on Future Reactors:** Yes, instead of calling it core melt, call it fission product release --

**G. Apostolakis, Chairman, ACRS:** Call it something else. Yes, fission product release.
If we treat 10 PBMRs as one facility with respect to these five bullets that you showed us, shouldn't we be doing the same when it came to risk and treat it as one facility and apply the goals to the facility, in which case of course we will have much lower goals for each individual unit?

**W. Sproat, Exelon:** Well, we certainly haven't done that for two and three unit light water reactors. So, I hesitate to do that for a smaller, supposedly safer reactor.

**G. Apostolakis, Chairman, ACRS:** For a two unit reactor there are some PRAs where they look at these things. A factor of two in the goals really doesn't mean anything. When you talk about ten, a factor of ten, then you're beginning to see some difference.

So it seems to me that if we are to apply this idea to the five legal licensing challenges you mentioned, maybe we ought to think about doing the same thing to the goals. Now, you don't have to answer right now, but --

**W. Sproat, Exelon:** I would probably disagree with that, but that's okay.

**D. Powers, ACRS Member**: Explain why you would disagree other than the fact that you wouldn't like the numbers when they came out.

**W. Sproat, Exelon:** No. What would the basis be for doing that? For example, in airline travel there's a certain risk associated with flying on an airplane. Now, the fact that there are increasing numbers of airplanes in the air doesn't necessarily mean that your risk of being killed on an airplane has proportionally increased.

**G. Apostolakis, Chairman, ACRS:** The societal risk has.

**D. Powers, ACRS Member**: Right.

**G. Apostolakis, Chairman, ACRS:** The individual risk has not.

**T. Kress, Chairman, Subcommittee on Future Reactors:** You don't fly the same number of people on the airplanes. What you have is a site with a given fixed population around it, for example. That population is exposed to either one module or ten modules who could fail independently of each other, and in fact that's probably the assumption. But the risk of being on that site and associated with those reactors is, in my mind, ten times when you have ten modules over one module.

**D. Powers, ACRS Member**: Isn't it even higher than that because you've got a mode failure with the--

**T. Kress, Chairman, Subcommittee on Future Reactors:** Yes. And then if there's common mode failures, it's even higher.

**D. Powers, ACRS Member**: Especially if you go up --

**T. Kress, Chairman, Subcommittee on Future Reactors:** And that would be the reasoning behind --

**D. Powers, ACRS Member**: to a centralized control room?

**T. Kress, Chairman, Subcommittee on Future Reactors:** Yes. So you treat it as one reactor, but in order to accommodate the ten of them you have to do something to one end; you either up the frequency by ten or the lower safety goal by --

**W. Sproat, Exelon:** Well, then clearly you have to take into account in that kind of an analysis the concept of coincident events happening in multiple units at the same time.

**T. Kress, Chairman, Subcommittee on Future Reactors:** No, no, that's not --

**D. Powers, ACRS Member**: It's just common mode failure is what we are talking about here.

**T. Kress, Chairman, Subcommittee on Future Reactors:** But that's not what I had in mind.

**W. Sproat, Exelon:** Assuming there is a common mode failure that --

**D. Powers, ACRS Member**: But that's not what we're saying.

**T. Kress, Chairman, Subcommittee on Future Reactors:** Yes, but that's not what we're saying. I mean, that's another issue, coincidence events and common mode failures. No, I'm not just talking about an independent frequency of something happening to one or something happen to the other independently.

**W. Shack, ACRS Member:** Of course, now he does get something back because he probably has a smaller source term.

**T. Kress, Chairman, Subcommittee on Future Reactors:** Oh, I think that's a -- for this concept, that's --

**G. Apostolakis, Chairman, ACRS:** I didn't say anything about the assessment.

**G. Apostolakis, Chairman, ACRS:** I'm just talking about the goals.

**T. Kress, Chairman, Subcommittee on Future Reactors:** I'm sure they could meet the ten times or the ten percent --

**G. Apostolakis, Chairman, ACRS:** You don't use a facility of ten PBMRs only on these things.

**L. Parme, General Atomics:** George, I might add in the mid-80s submittal on the MHTGR where there were multiple reactors coupled to a common steam plant, it was viewed as a plant and we took the safety goals and the release limits that we were analyzing it and considered multiple reactors. In fact, if you look back in the mid-80s submittal you'll see there is at least one event that has all four MHTGR models leaking simultaneously without cooling, and it was handled that way.

It's not quite the case where these reactors are truly independent, but we did consider the four modules to be a plant consistent with your thinking. What would you do with truly independent modules, I guess, is something that one might want to think of.

**G. Apostolakis, Chairman, ACRS:** If we decide, for example, that the appropriate way to formulate the goals here would be through frequency/consequence curves, then it seems to me that you would have one such curve or a family of curves for the facility.

**J. Garrick, ACNW Chairman:** Yes. Well, why wouldn't you have a CCDF for the facility?

**G. Apostolakis, Chairman, ACRS:** For the facility, that's what I'm saying.

**J. Garrick, ACNW Chairman:** Every time you add a module, you get a new CCDF.

**T. Kress, Chairman, Subcommittee on Future Reactors:** Yes, absolutely.

**G. Apostolakis, Chairman, ACRS:** Anyway, that's just a point.

**T. Kress, Chairman, Subcommittee on Future Reactors:** But it's a thought.

**W. Sproat, Exelon:** Understood.

**P. Gunter, Nuclear Information Resource Service:** Obviously fuel integrity is a big question here. What I would like to get a little better idea of, is have you looked at the

# IRIS SUMMARY

Mario D. Carelli
Westinghouse Science & Technology

The IRIS (International Reactor Innovative & Secure) reactor is described in the first part of the presentation. IRIS is a light water cooled reactor with an integral configuration, where steam generators, pumps and pressurizer are inside the reactor vessel. Partially funded by the DOE NERI program, IRIS is being developed by an international consortium of 16 organizations from seven countries. A key IRIS characteristic is its "safety by design" approach which strives to eliminate, by design, as many accidents as possible rather than coping with their consequences. Initial returns are very positive; out of the eight Class IV accidents considered in the AP600 only one remains as a Class IV in IRIS, and at much reduced probability. Small-to-medium LOCAs have minimal consequences as the core remains safely under water for days, without the need for safety injection or water makeup. In spite of its novelty IRIS is firmly grounded on proven LWR technology and therefore a prototype is not needed to assure design certification. Rather, very extensive scaled tests will be performed to investigate the performance of in-vessel components such as steam generators and pumps, both individually and as interactive systems. Accident sequences will also be simulated and tested to prove IRIS safety by design claims. The first core fuel is less than 5% enriched and the fuel assembly is very similar to existing PWR assemblies, so there is no licensing challenge regarding the fuel. Because of the safety by design approach, yielding simplifications in design and accident management (e.g., IRIS does not have an emergency core cooling system), some accident scenarios are eliminated and others have lesser consequences. Thus, simplification and streamlining of the regulatory process might be possible. Risk informed regulation will be coupled with safety by design to show lower accident and damage probabilities. This could lead to a relaxation of siting regulatory requirements. It is believed that the IRIS licensing process will not present major challenges, actually it might be simplified. An aggressive schedule could lead to deployment early in the next decade. It is imperative, however, that tests, planning, and pre-licensing activities start as early as FY02.

# IRIS

## International Reactor Innovative and Secure

M. D. Carelli
Westinghouse Science & Technology

ACRS Subcommittee Workshop on Advanced Reactors

June 4, 2001

6/4/01
Viewgraph 1

Westinghouse Science & Technology

## OUTLINE

- Overview
  - Team Partnership
  - Funding
  - Schedular Objectives
- Fuel Designs
- Configuration (Integral vessel, internal shield, steam generators)
- Enhanced Safety Approach (Safety by Design)
- Maintenance Optimization
- Issues
- Conclusions

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Viewgraph 2

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# OVERVIEW

6/4/01
Viewgraph 3

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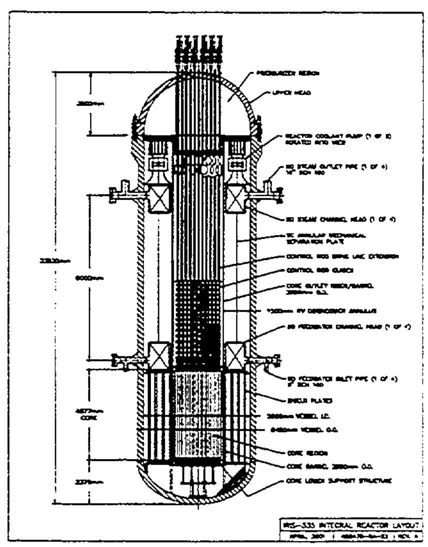
## IRIS is a Modular LWR, with Emphasis on Proliferation Resistance and Enhanced Safety

- Small-to-medium (100-300 MWe) power module
- Integral primary system
- 5- and 8-year straight burn core
- Utilizes LWR technology, newly engineered for improved performance
- Most accident initiators are prevented by design
- Potential to be cost competitive with other options
- Development, construction and deployment by international team
- First module projected deployment in 2010-2015



6/4/01
Viewgraph 4

Westinghouse Science & Technology

# IRIS AND GENERATION IV GOALS

| Design feature | GOAL | | |
|---|---|---|---|
| | Sustainable development | Safety and Reliability | Economics |
| Modular design | | ✓ | ✓ |
| Long core life (single burn, no shuffling) | ✓ | | ✓ |
| Extended fuel burnup | ✓ | | ✓ |
| Integral primary circuit | ✓ | ✓ | ✓ |
| High degree of natural circulation | | ✓ | |
| High pressure containment with inside-the-vessel heat removal | | ✓ | ✓ |
| Optimized maintenance | ✓ | ✓ | ✓ |

∴ **Attractive Commercial Market Entry**

6/4/01
Viewgraph 5

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Viewgraph 6

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## IRIS Consortium Members

| Team Member | Function | | | Scope |
|---|---|---|---|---|
| | Engineering | Supplier | Development | |
| Westinghouse Electric LLC, USA | * | | * | Overall coordination, leadership and interfacing, licensing |
| Polytechnic Institute of Milan, Italy (POLIMI) | | | * | Core design, in-vessel thermal hydraulics, steam generators, containment |
| Massachusetts Institute of Technology, USA (MIT) | | | * | Core thermal hydraulics, novel fuel rod geometries, safety, maintenance |
| University of California at Berkeley, USA (UCB) | | | * | Core neutronics design |
| Japan Atomic Power Company, Japan (JAPC) | * | | * | Maintenance, utility feedback |
| Mitsubishi Heavy Industries, Japan (MHI) | * | * | * | Steam generators, modularization |
| British Nuclear Fuels plc, UK (BNFL) | * | * | * | Fuel and fuel cycle, economic evaluation |
| Tokyo Institute of Technology, Japan (TIT) | | | * | Novel fuel rod geometries, detailed 3D T&H subchannel characterization, PSA |
| Bechtel Power Corp., USA (Bechtel) | * | * | * | Balance of plant, cost evaluation, construction |
| University of Pisa, Italy (UNIPI) | | | * | Containment analyses, transient analyses |
| Ansaldo, Italy | * | * | * | Steam generators, reactor systems |
| National Institute Nuclear Studies, Mexico (ININ) | | | * | Core neutronics |
| NUCLEP, Brazil | * | * | | Containment, vessel, pressurizer |
| ENSA, Spain | * | * | | Reactor internals, steam generators, vessel |
| Nuclear Energy Commission, Brazil (CNEN) (Pending) | * | | * | Transient, structural analyses, testing |
| Oak Ridge National Laboratory, USA (ORNL) | * | | * | Core analyses, safety, cost evaluation, diagnostic |
| <u>Associates</u> | | | | |
| University of Tennessee, USA | | | * | Modularization, transportability |
| Ohio State University, USA | | | * | Novel In-Core Power Monitor |
| Iowa State University (Ames Lab), USA | | | * | NDE |

## FUNDING

| | | | |
|---|---|---|---|
| DOE NERI | ~ $1.6M over 3 years (9/99 - 8/02) | | |
| Consortium Members | ~ $4M | in | 2000 |
| | ~ $8M | in | 2001 |
| | $10-12M anticipated in 2002 | | |

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Viewgraph 8

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## IRIS SCHEDULAR OBJECTIVES

- Assess key technical & economic feasibilities (completed) — End 2000
- Perform conceptual design, preliminary cost estimate — End 2001
- Perform preliminary design — End 2002
- Pre-application submitted — ?
- *Decision to proceed to commercialization End 2002*
- Complete SAR — 2005
- Obtain design certification — 2007
- First-of-a-kind deployment — 2010-2015

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Viewgraph 9

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# IRIS FUEL DESIGN OPTIONS

IRIS 5-YEAR DESIGN — *FIRST CORE*
- CURRENT FUEL TECHNOLOGY
- PROVIDES MINIMUM-RISK PATH FORWARD
- (DETAILED CORE DESIGN IN PROGRESS)

IRIS 8-YEAR DESIGN — *RELOADS*
- BOTH $UO_2$ and MOX MAY BE USED
- EMPHASIZES PROLIFERATION RESISTANCE
- (SCOPED INTERCHANGEABLE CORE DESIGN)

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Viewgraph 10

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# CONFIGURATION

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Viewgraph 11

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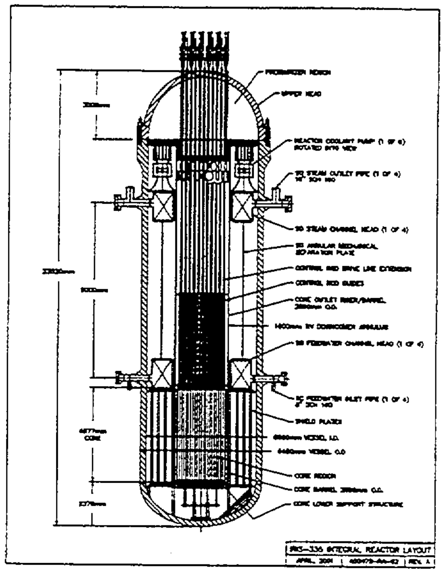
## 335 MWe LAYOUT



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Viewgraph 12

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## INTERNAL SHIELDS

- A "gift" of integral configuration
- Dose rate outside vessel surface as low as $10^{-6}$ mSv/h
- No restrictions to workers in containment
- Simplified decommissioning
- Vessel (minus fuel) acts as sarcophagus

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Viewgraph 13

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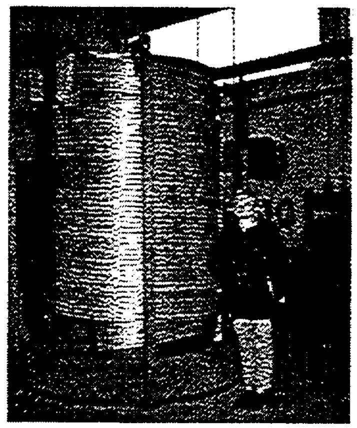
## ANSALDO PHOTO

Ansaldo 20 MW Mock-up at SIET



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Viewgraph 14

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## HELICAL STEAM GENERATOR

- LWR and LMFBR experience
- Fabricated and tested
- Test confirmed performance (thermal, pressure losses, vibration, stability)
- 8 SGs practically identical to Ansaldo modules will be installed in IRIS

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Viewgraph 15

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# ENHANCED SAFETY APPROACH
# (Safety by Design)

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Viewgraph 16

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## SAFETY PHILOSOPHY

- Generation II reactors cope with accidents via active means
- Generation III reactors cope with accidents via passive means
- Generation IV reactors (IRIS) emphasize prevention of accidents through "safety by design"

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Viewgraph 17

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## IRIS SAFETY BY DESIGN APPROACH

**Exploit to the fullest what is offered by IRIS design characteristics (chiefly, integral configuration and long life core) to:**

- **Physically eliminate possibility for accident(s) to occur**
- **Lessen consequences**
- **Decrease probability of occurrence**

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Viewgraph 18

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# IMPLEMENTATION OF IRIS SAFETY BY DESIGN

| Design Characteristic | Safety Implication | Related Accident | Disposition |
|---|---|---|---|
| Integral reactor configuration | No external loop piping | Large LOCAs | Eliminated |
| Tall vessel with elevated steam generators | Can accommodate internal control rod drives | Reactivity insertion due to control rod ejection | Can be eliminated |
| | High degree of natural circulation | LOFAs (e.g., pump seizure or shaft break) | Either eliminated (full natural circulation) or mitigated consequences (high partial natural circulation) |
| Low pressure drop flow path and multiple RCPs | N-1 pumps keep core flow above DNB limit, no core damage occurs | | |
| High pressure steam generator system | Primary system cannot over-pressure secondary system | SGTR | Automatic isolation, accident terminates quickly |
| | No SG safety valves required | Steam and feed line breaks | Reduced probability<br>Reduced consequences |
| Once through SG design | Low water inventory | | |
| Long life core | No partial refueling | Refueling accidents | Reduced probability |
| Large water inventory inside vessel | Slows transient evolution<br>Helps to keep core covered | Small-medium LOCAs | Core remains covered with no safety injection |
| Reduced size, higher pressure containment | Reduced driving force through primary opening | | |
| Inside the vessel heat removal | | | |

## AP600 CLASS IV ACCIDENTS AND IRIS RESOLUTION

| Accident | IRIS Safety by Design | IRIS Resolution |
|---|---|---|
| 1. Steam system piping failure (major) | Reduced probability<br>Reduced consequences | Can be reclassified as Class III |
| 2. Feedwater system pipe break | | |
| 3. Reactor coolant pump shaft seizure or locked rotor | Reduced consequences | Can be reclassified as Class III |
| 4. Reactor coolant pump shaft break | | |
| 5. Spectrum of RCCA ejection accidents | Can be eliminated | Not applicable (with internal CRDMs) |
| 6. Steam generator tube rupture | Reduced consequences | Can be reclassified as Class III |
| 7. Large LOCAs | Eliminated | Not applicable |
| 8. Design basis fuel handling accidents | Reduced probability | Still Class IV 1/3-1/5 lower probability |

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Viewgraph 20

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## IRIS CONTAINMENT

- **It performs containment function**

**plus**

- **In concert with integral vessel, it practically eliminates LOCAs as a safety concern**

**On first principles**

**Pressure differential (driving force through rupture) is lower in IRIS because**

- **Containment pressure higher (lower volume, higher allowable pressure)**
- **Vessel pressure lower (internal heat removal)**

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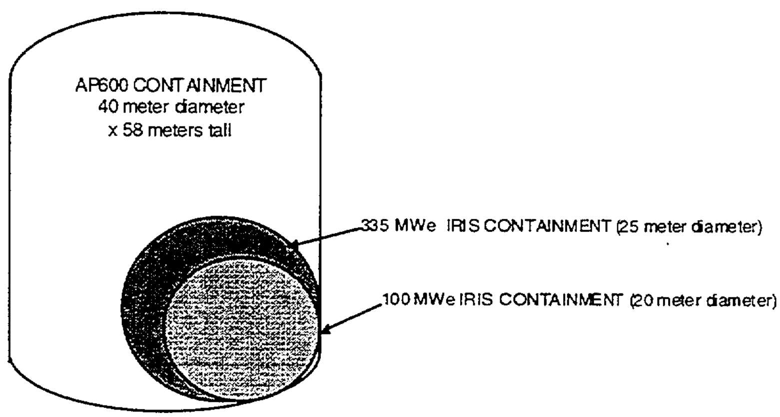
## AP600/IRIS Containment Size Comparison

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Viewgraph 22

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## ANALYSES PERFORMED

- **Break size: 1, 2, 4"**
- **Elevation: Bottom of vessel, above core (inside and outside cavity), 12.5 m above bottom**
- **No water makeup or safety injection**
- **Three codes provided consistent results**
  - Proprietary (POLIMI)
  - GOTHIC (Westinghouse)
  - FUMO (Univ. Pisa)

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Viewgraph 23

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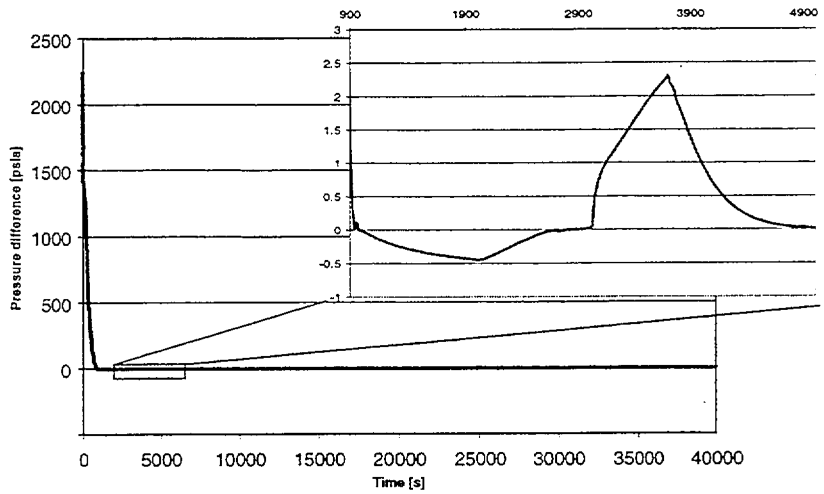
## REACTOR VESSEL/CONTAINMENT PRESSURE DIFFERENTIAL EQUALIZES QUICKLY

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Viewgraph 24

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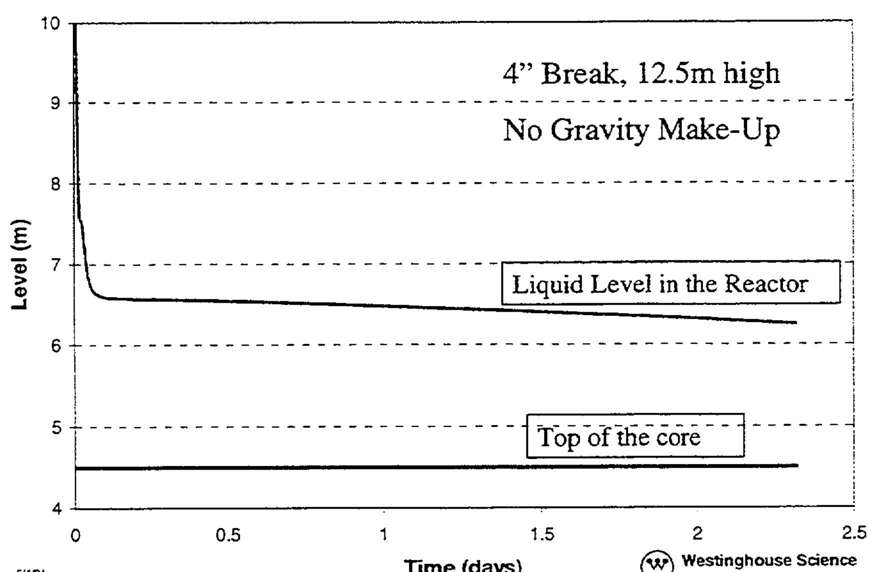
## CORE STILL UNDER 2 METERS OF WATER AFTER 2 DAYS




6/4/01
Viewgraph 25

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# A LICENSING CHALLENGE

".....simultaneous loss-of-coolant accident, loss of residual heat removal system, and loss of emergency core cooling.....PMBR can meet that challenge.....but "you can't assume that sequence for any LWR" even advanced units....."

Nucleonics Week 5/10/01 Pg. 10

## IRIS CAN MEET THAT CHALLENGE

| | |
|---|---|
| • Loss of coolant accident | Safety by design |
| • Loss of residual heat removal system | Three independent diverse systems |
| • Loss of emergency core cooling | Not needed (gravity makeup available anyway) |

6/4/01
Viewgraph 26

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# MAINTENANCE OPTIMIZATION

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Viewgraph 27

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## GOAL

- Perform maintenance shutdowns no sooner than 48 months

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Viewgraph 28

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## SURVEILLANCE STRATEGY

*"defer if practical, perform on-line when possible, and eliminate by design where necessary"*

*Design where necessary:*

- **Utilize existing components**
- **Utilize existing technologies**
- **Request rule changes**
- **Develop new components/systems**
- **Develop new technologies**

**Direction of increasing cost, design effort, and risk**

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Viewgraph 29

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## THE BOTTOM LINE

- IRIS must utilize components and systems which are either *accessible on-line* for maintenance or *do not require any off-line* maintenance for the duration of the operating cycle
- IRIS must utilize *high reliability* components and systems to minimize the probability of failure leading to unplanned down-time during the operating cycle

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Viewgraph 30

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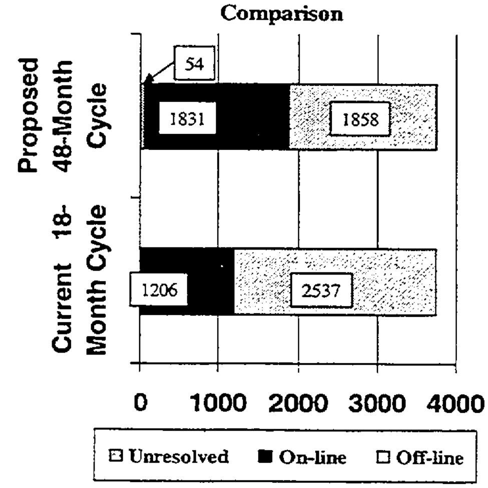
## EXTENDED FUEL CYCLE PROJECT

- Study completed in 1996 investigated extending PWR to 48 month cycle
- Recategorized all off-line maintenance as either:
  - Defer to 48 months
  - Perform on-line
  - Unresolved

PWR Surveillance Program Comparison

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Viewgraph 31

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# ISSUES

6/4/01
Viewgraph 32

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## DEVELOPMENT APPROACH

- No need for prototype since no major technology development is required
- First-of-a-kind IRIS module can be deployed in 2010 or soon after
- Future improvements can be implemented in later modules (Nth-of-a-kind)

6/4/01
Viewgraph 33

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## LICENSING CHALLENGES AND OPPORTUNITIES VS. GEN II REACTORS

- First core fuel well within current state of the art
- Reload, higher enrichment fuel (post 2015) handled through licensing extension
- IRIS does have containment which in addition to its classic function is thermal-hydraulically coupled with integral vessel to choke small/medium LOCAs
- Safety by design approach eliminates some accident scenarios and significantly diminishes consequences of others. Simplification and streamlining possible.
- Risk informed regulation will be coupled with safety by design to show lower accidents and damage probabilities
- How can we translate IRIS improved safety into licensing opportunity, e.g., site requirements relaxation?
- Are regulatory changes necessary to accommodate extended maintenance?
- Multiple modules plants with common functions, e.g., control room

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Viewgraph 34

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## IRIS APPROACH TO LICENSING, CONSTRUCTION AND OPERATION VS. GEN II REACTORS

- *Licensing*
  - No unique major changes identified at this time
  - Testing to confirm IRIS unique traits (safety by design, integral components, maintenance optimizations, inspections)
- *Construction*
  - Modular fabrication and assembly
  - Use of advanced EPC tool sets (Bechtel)
  - Multiple, parallel suppliers
  - Staggered modules construction
- *Operation*
  - Extended cycle length straight burn
  - Maintenance shutdown intervals no shorter than 48 months
  - Refueling shutdowns every 5 to 10 years
  - Reduced number of plant personnel
  - Multiple modules operation

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Viewgraph 35

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## DO SCHEDULES SUPPORT PLANNED LICENSE APPLICATIONS/DEPLOYMENT?

Achieving 2007 design certification requires:

- Lead testing (safety by design) be initiated in 2002
- IRIS Consortium members decision by end 2002 to pursue commercial effort
- Continuous NRC interaction beginning late 2001/early 2002

Achieving early deployment (2010 or soon after) requires US generator interested by 2005

6/4/01
Viewgraph 36

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## SUMMARY AND CONCLUSIONS

- IRIS specifically designed to address Gen IV requirements
- Modularity and flexibility address utility needs
- Enhanced safety through safety by design and simplicity
- IRIS is based on proven LWR technology, newly engineered for improved performance
- Testing program needs to start in 2002 on selected high priority tests. Early interaction with NRC and ACRS will be extremely beneficial.

6/4/01
Viewgraph 37

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**T. Kress, Chairman, Subcommittee on Future Reactors:** Would your SAR follow the SAR process that we use now for light water reactors?

**M. Carelli, Westinghouse**: Yes. When the issue is safety, I think it should be simplified. Should be a simplified SAR. We'll see.

**T. Kress, Chairman, Subcommittee on Future Reactors:** When you change out the core, do you also change out the steam generator?

**M. Carelli, Westinghouse**: No. I'm coming to the steam generators. The IRIS steam generators are based on the helical steam generators which Ansaldo designed for Super Phenix. They tested the steam generators and the picture in viewgraph number 14 shows a 20 megawatt -- steam generator mockup. They tested it. Now, I want to make a point. The perception is we have so much trouble with steam generators. This crazy guy wants to put the steam generator inside the reactor and this makes even worse. But there are things you have to think about.

First of all, if you put a steam generator inside, the primary fluid is now outside the tubes so the tubes are in compression instead of tension. Now, you don't have any more of the tensile stress cracking. Also, our IRIS steam generator doesn't have a bottom in terms of deposits. The bottom of the steam generator is the bottom of the vessel, and the chemistry is much better. So there are a bunch of things that the steam generator has a different environment in an integral reactor versus a loop reactor.

What they did in Ansaldo, is that they tested the steam generators. First of all, there is experience with Super Phenix and the LMFBR experience. Then they designed an intergal LWR reactor with similar helical steam generators. So they fabricated, tested, and confirmed the performance and by some stroke of luck, The IRIS design is such that it has eight steam generators practically identical to the model Ansaldo had fabricated. This brings up another important item. What we have now, is eight steam generators for a total of 300 megawatts. So we're talking a high level of redundancy. That's exactly what we want to do because the steam generators have a very critical safety function and you are going to see in a second what it is.

**G. Leitch, ACRS Member:** The reactor vessel in the drawing looks as though it's large enough to facilitate internal control rod drives.

**M. Carelli, Westinghouse:** Absolutely. When I look at that geometry, it is a waste of a prime real estate to have all that room above the core full of control drivelines. The internal CRDMs are ideally set for integral reactor. Absolutely.

**G. Leitch, ACRS Member:** The CRDMs are going to be internal? Has that decision been made?

**M. Carelli, Westinghouse:** I would like to have internal CRDMs. The present design shows the CRDMs as regular CRDMs because the technology has not yet been developed to the point out that we are comfortable in incorporating the internal CRDMs as the reference design. There are essentially two designs of internal CRDMs. One is electromagnetic driven internal CRDMs done by the Japanese. MHI is the one that's been testing for 10 years and again, MHI is one of our team members. The second design is hydraulically controlled rods. That is a solution chosen by the Argentinean, in the CAREM reactor, and also by the Chinese. The Chinese have a reactor in Beijing that is running right now, operating with internal CRDMs.

So both technologies are not a far fetch. There are reactors already operating or being designed. What, right now, I do not know is which one is better. There are two. So I have to decide which one.

**G. Leitch, ACRS Member**: If they are external, you haven't eliminated the rod ejection problem. If they're internal, you have introduced some new technology.

**M. Carelli, Westinghouse:** Yes. You're absolutely right. The issue is whether a deployment by 2012 is compatible with incorporating internal CRDMs. However, we're not starting from scratch. It has been done. There has been 10 years work on that. What I need is about one or two years to select a technology. At that point, we'll see how long it takes to implement. Can we make it or 2012 or not? That will be the decision.

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Presentation Summary

**GT-MHR**

U.S. and European technology provide the bases for the Gas Turbine - Modular Helium Reactor (GT-MHR). For more than 4 decades, High Temperature Gas-cooled Reactors (HTGRs) have been under development in multiple countries. Numerous prototypes and demonstration plants have been constructed and operated beginning with the Dragon plant in the early 1960s. At the time of these initial plants, the vision was one of scaling up the technology to large, steam cycle plants comparable to modern LWRs, thus benefitting from economy of scale. However, in the early 1980s, both in the U.S. and the Federal Republic of Germany, a shift in paradigm occurred. Smaller, modular plants offered simplification in safety design, shortened construction schedules, and incremental capacity addition. The MHTGR was the U.S. developed modular plant and underwent preapplication review by NRC. The GT-MHR represents a further refinement on this concept with the steam cycle being replaced by a closed loop gas turbine (Brayton) cycle.

The reactor system is contained in a 3 vessel, side-by-side arrangement. The reactor and a shutdown cooling system are in one vessel, and the gas turbine based power conversion system, including the generator, in a second parallel vessel. A small horizontal vessel provides coaxial ducting of gas between the reactor and power conversion system. The entire nuclear unit is located in a below grade silo with service areas above. The silo provides containment and protection of the reactor but is not designed to hold pressure. Naturally circulating water or air in panels around the reactor vessel carry off heat radiated from the uninsulated vessel and provide reactor cavity cooling.

A more detailed look at the system shows the compact arrangement of gas turbine, compressors, recuperator, heat exchanges, and generator. All rotating machinery is on a common shaft. A central feature of the U.S. modular reactors is the annular core. Notice that the annular arrangement provides a high surface to volume ratio and a relatively short conduction path between any fueled block and the vessel wall. Fueled blocks are stacked in three concentric rings with inert graphite blocks making up the inner and outer reflectors. Operating control rods are located outside the active core while startup control rods and channels for reserve shutdown pellets are located near the core center.

Ceramic coated fuel is the key to the GT-MHR's safety and economics. A kernel of Uranium oxycarbide (or $UO_2$) is placed in a porus carbon buffer and then encapsulated in multiple layers of pyrolytic carbon and silicon carbide. These micro pressure vessels withstand internal pressures of up to 2,000 psi and temperatures of nearly 2,000 °C providing extremely resilient containment of fission products under both normal operating and accident conditions. The fuel particles are blended in carbon pitch, forming fuel rods, and then loaded into holes within large graphite fuel elements. Fuel elements are stacked to form the core.

As alluded to earlier, modular gas reactors and the GT-MHR represent a fundamental shift in reactor design and safety philosophy. Up through approximately 1980, HTGR development proceeded on a path of scaling up core size in the interests of economics. In the process of this scaleup, core power density was kept nearly constant while the L/D ration was kept as close to unity as possible. As a consequence of this thinking, maximum accident temperatures increased well above the temperature capabilities of the fuel particles. This placed ever increasing reliance on engineered safety features to assure continued core cooling and to contain released fission products should this cooling be lost. The modular reactor represents a 180 degree turn around in design philosophy. From its inception, the modular design first addresses safety, sacrificing size and optimized nuclear geometry to ensure that regardless of cooling system operation or coolant boundary integrity, fuel temperatures will never exceed the point at which fission products would be released. Having first addressed safety with the inherent features available in the gas-cooled reactor, good economics are sought in the efficient Brayton cycle and plant simplification.

Fuel particle testing in Japan, Germany, and U.S. has repeatedly demonstrated the high temperature resilience of coated particle fuel to temperature approaching 2,000°C. As an conservative design goal, GT-MHR has been sized to keep maximum fuel temperatures below 1,600 °C during the limiting accident condition of lost coolant circulation, pressure, and all AC power. Like other reactor types, the GT-MHR has a negative temperature coefficient. But unique to reactors with an all refractory, high temperature core there a several hundred degrees of temperature margin in the core design to make full use of this feedback mechanism.

The GT-MHR licensing builds on the mid-80s submittal to NRC for the steam cycle MHTGR. Because of the unique design approach, especially with regards to safety, employed, the a licensing approach returns to the basics goals and rebuilds a licensing frame work that includes conventional deterministic analyses and safety classification. However, this framework is derived recognizing that safety functions and the means to achieve them in this concept can be expected to differ from those of LWRs. Furthermore, they are derived using the systematic plant evaluation offered by PRA techniques.

The GT-MHR is now being developed in Russia under a joint U.S./Russian Federation agreement aimed at the destruction of surplus weapons plutonium. In addition to the U.S. and Russia, the program is sponsored by Japan and France. Conceptual design is completed and preliminary design is on schedule for completion in early CY 2002. Startup of the first module is currently scheduled for 2009 with a 4 module plant scheduled for completion in 2015.

The path to commercialization involves the importation of the Russia design with a U.S. designed LEU core replacing the Plutonium core. A licensing submittal would be prepared in the U.S. and submitted to NRC. The first U.S. module could be online approximately 1 year after the first Russian module.

In summary, the GT-MHR is rooted in decades of international HTGR technology development and builds on the mid-1980s MHTGR experience. The design features optimization of characteristics inherent to high temperature gas reactors to achieve high thermal efficiency, and easily understood, assured safety. The international program facilitates the near term deployment of this concept.

Presenter:

Laurence L Parme
Manager – Safety & Licensing
General Atomics Company

## *ACRS WORKSHOP*

### *Regulatory Challenges for Future Nuclear Power Plants*

Gas Turbine - Modular Helium Reactor

4 - 5 June 2001

Laurence L Parme
Manager: Safety & Licensing
Power Reactor Division

GENERAL ATOMICS

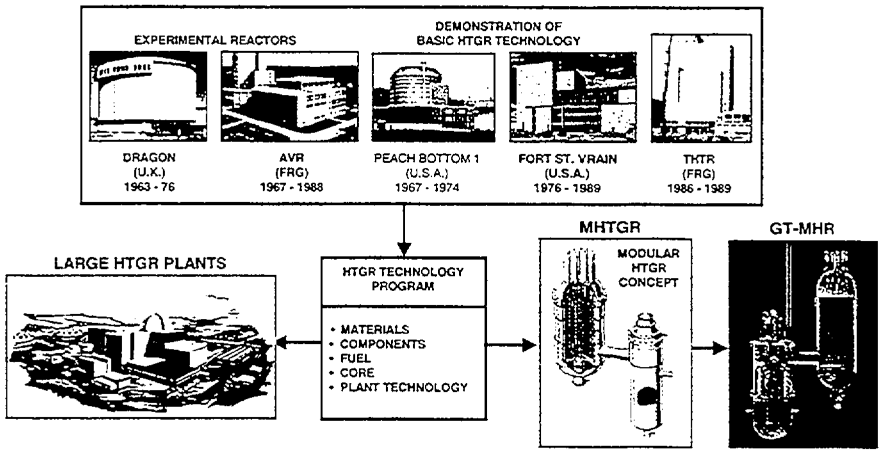
### *Presentation Outline*

- Background and design description
- Key safety features
- Licensing approach
- Design status and deployment schedule
- Conclusions

GENERAL ATOMICS

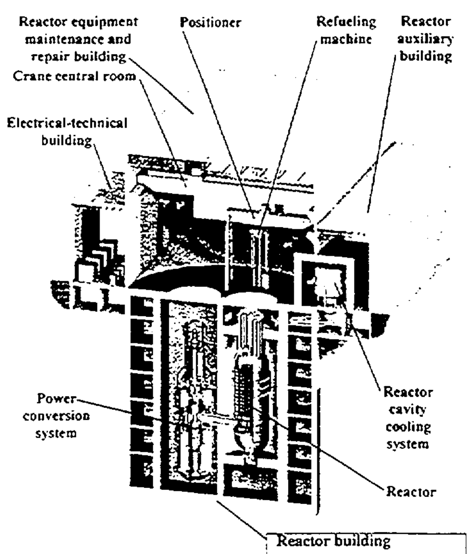
## U.S. AND EUROPEAN TECHNOLOGY BASES FOR MODULAR HIGH TEMPERATURE REACTORS

BROAD FOUNDATION OF HELIUM REACTOR TECHNOLOGY




GENERAL ATOMICS

## 3D Arrangement of Plant

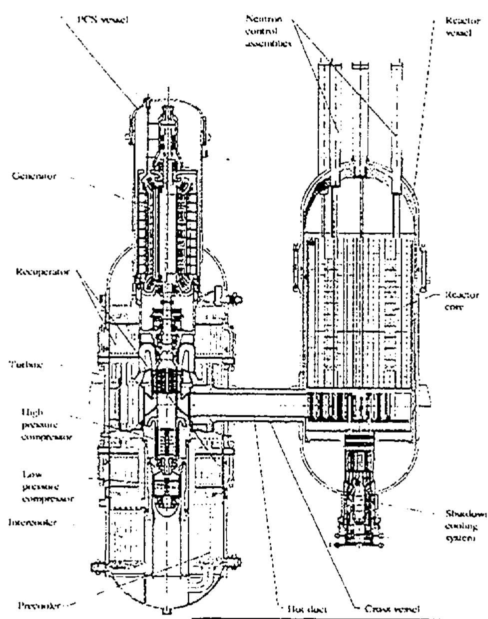



- 600 MW(t) - 285 MW(e)
- Power conversion system integrated in single vessel
- Vented, below grade reactor building
- Continuously operating, natural circulating, air cooled reactor cavity cooling

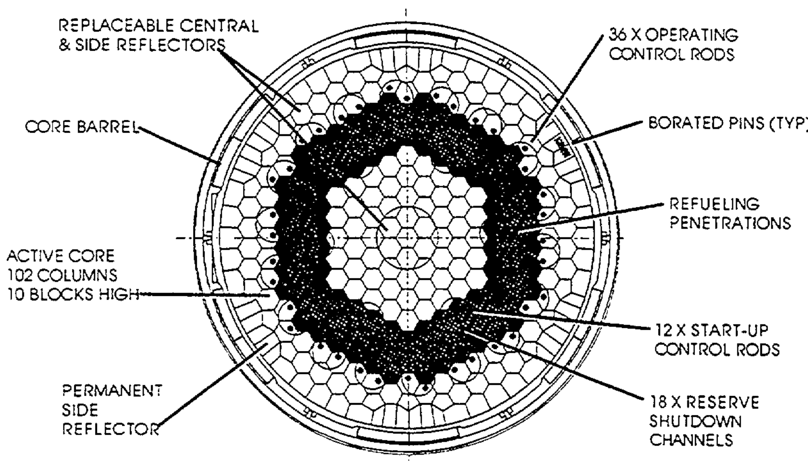
GENERAL ATOMICS

## GT-MHR COMBINES MELTDOWN-PROOF ADVANCED REACTOR AND GAS TURBINE BASED POWER CONVERSION SYSTEM

GENERAL ATOMICS




## ANNULAR REACTOR CORE LIMITS FUEL TEMPERATURE DURING ACCIDENTS

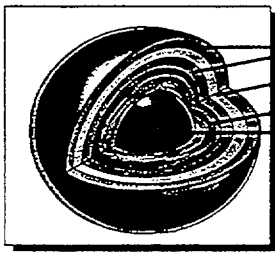



*...ANNULAR CORE USES EXISTING TECHNOLOGY*

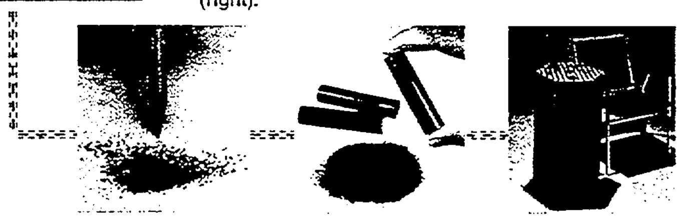
GENERAL ATOMICS

L-199(10)
6-9-95

# CERAMIC COATED FUEL IS KEY TO GT-MHR SAFETY AND ECONOMICS



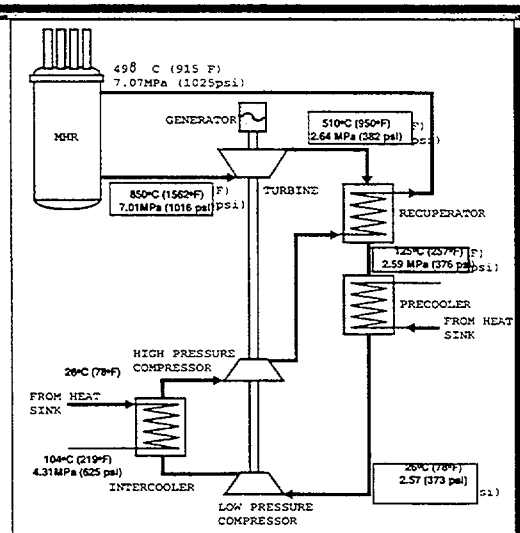

TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).




GENERAL ATOMICS

L-029(5)
4-14-94

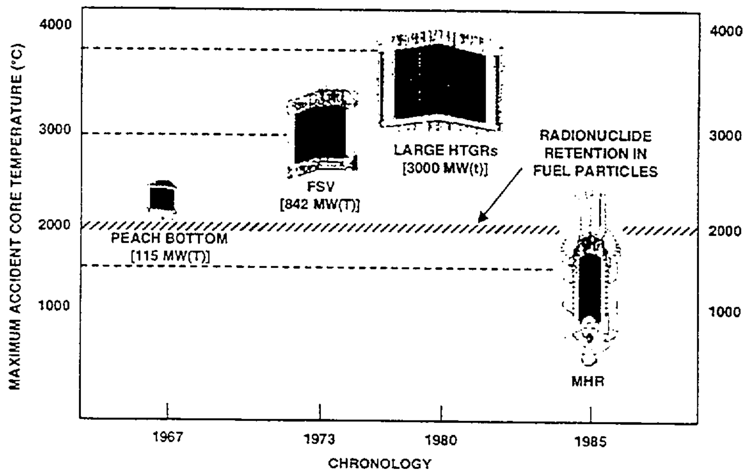
# GT-MHR FLOW SCHEMATIC




GENERAL ATOMICS

L-271(12a)
8-14-94
A-36

## MODULAR HELIUM REACTOR REPRESENTS A FUNDAMENTAL CHANGE IN REACTOR DESIGN AND SAFETY PHILOSOPHY

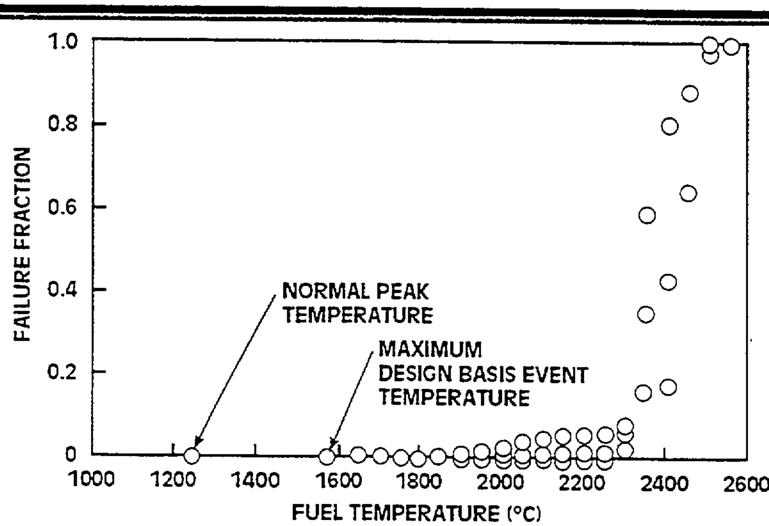



*...SIZED AND CONFIGURED TO TOLERATE EVEN A SEVERE ACCIDENT*

**GENERAL ATOMICS**

I-222(1)
1-12-96

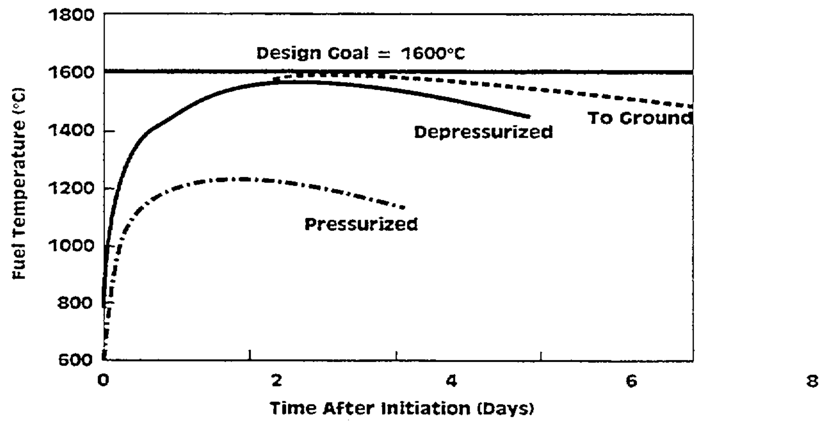
## COATED PARTICLES STABLE TO BEYOND MAXIMUM ACCIDENT TEMPERATURES




**GENERAL ATOMICS**

L-266(1)
7-28-94
W-9

## FUEL TEMPERATURES REMAIN BELOW DESIGN LIMITS DURING LOSS OF COOLING EVENTS




*. . . PASSIVE DESIGN FEATURES ENSURE FUEL REMAINS BELOW 1600°C*

GENERAL ATOMICS

L-340(3)
11-16-94

## PASSIVE SAFETY BY DESIGN

- Fission Products Retained in Coated Particles
  - *High temperature stability materials*
  - *Refractory coated fuel*
  - *Graphite moderator*
- Worst case fuel temperature limited by design features
  - *Low power density*
  - *Low thermal rating per module*
  - *Annular Core*
  - *Passive heat removal* *....CORE CAN'T MELT*
- Core Shuts Down Without Rod Motion

GENERAL ATOMICS

## *Licensing Approach Builds on Mid-80s Submittal to NRC*

- The DOE MHTGR program in the mid-80's utilized a "clean sheet of paper" integrated approach to the conceptual design
  - utilized participant experience in PRA's of HTGRs
  - approach underwent a preapplication review by the NRC/ACRS
- Provided risk-informed MHTGR Licensing Bases
  - Top Level Regulatory Criteria
  - Licensing Bases Events
  - Equipment Safety Classification
  - Safety Related Design Conditions
  - Basis design criteria

GENERAL ATOMICS

## *Bases for Top Level Regulatory Criteria*

- Direct statements of acceptable consequences or risks to the public or the environment
- Quantifiable statements
- Independent of plant design
- Top Level criteria include
  - 51FR130 individual acute and latent fatality risks
    *$5x10^{-7}$/yr and $2x10^{-6}$/yr, respectively*
  - 10CFR50 Appendix I annualized offsite dose guidelines
    *5 mrem/yr whole body*
  - 10CFR100 accident offsite doses
    *25 rem whole body and 300 rem thyroid*
  - EPA-520/1-75-001 protective action guideline doses
    *1 rem whole body and 5 rem thyroid*

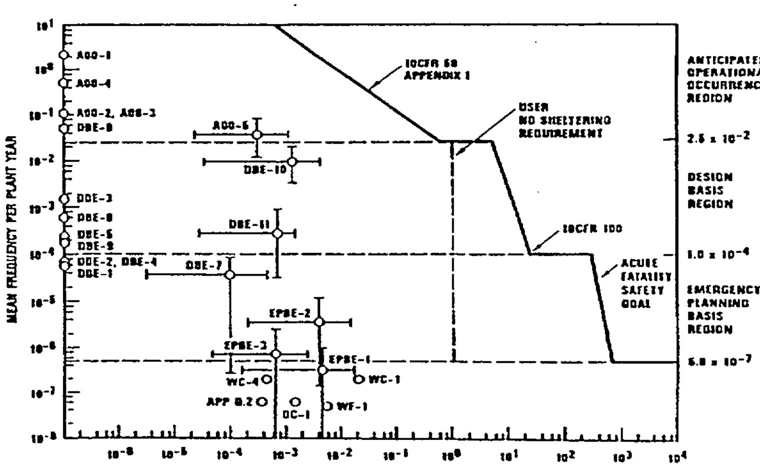
GENERAL ATOMICS

## *Licensing Basis Events*

- Off-normal or accident events used for demonstrating design compliance with the Top Level Regulatory Criteria
- Collectively, analyzed in PRAs for demonstrating compliance with the 51FR130 safety goals
- Encompass following event categories
  - Anticipated Operational Occurrences
  - Design Basis Events
  - Emergency Planning Basis Events

GENERAL ATOMICS

## *Ranges of Top Level Regulatory Criteria and MHTGR Licensing Basis Events*




GENERAL ATOMICS

## *Equipment Safety Classification*

- Safety related systems, structures, and components (SSC) are those performing required functions to meet 10CFR100 doses for DBEs

Retain Radionuclides in Fuel

- Control Heat Generation
- Remove Core Heat
- Control Chemical Attack

*MHTGR functions for 10CFR100 focus on retention within fuel particles*

GENERAL ATOMICS

## *Licensing Bases Application to GT-MHR*

- The above process is generic and should be directly applicable to the GT-MHR
- Prior application to the MHTGR did not reveal a large sensitivity to the power conversion system
- GT-MHR would be expected to have some different LBEs and therefore some differences in safety related SSC
  - potential for new initiating events with rotating equipment in primary system
  - potential for different consequences with higher core rating
  - LBEs involving water ingress very unlikely—no SGs

GENERAL ATOMICS

## *GT-MHR NOW BEING DEVELOPED IN INTERNATIONAL PROGRAM*

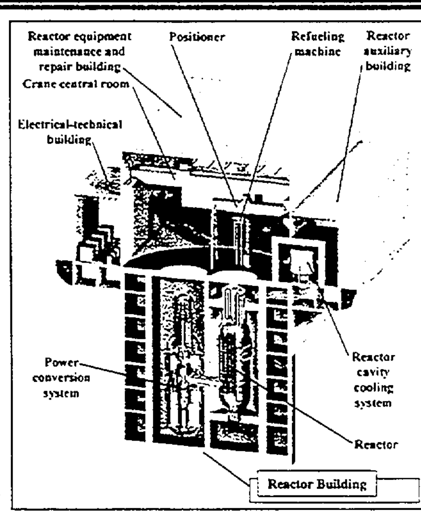
- In Russia under joint US/RF agreement for destruction of surplus weapons Plutonium
- Sponsored jointly by US (DOE) and RF (Minatom); supported by Japan and EU
- Conceptual design completed; preliminary design complete early 2002

GENERAL ATOMICS

## *INTERNATIONAL GT-MHR PROGRAM*

- Design, construct and operate a prototype GT-MHR module by 2009 at Tomsk, Russia
- Design, construct, and license a GT-MHR Pu fuel fabrication facility in Russia
- Operate first 4-module GT-MHR by 2015 with a 250 kg plutonium/ year/module disposition rate

*....Fuel contains Pu only*
*......No fertile component*




GENERAL ATOMICS

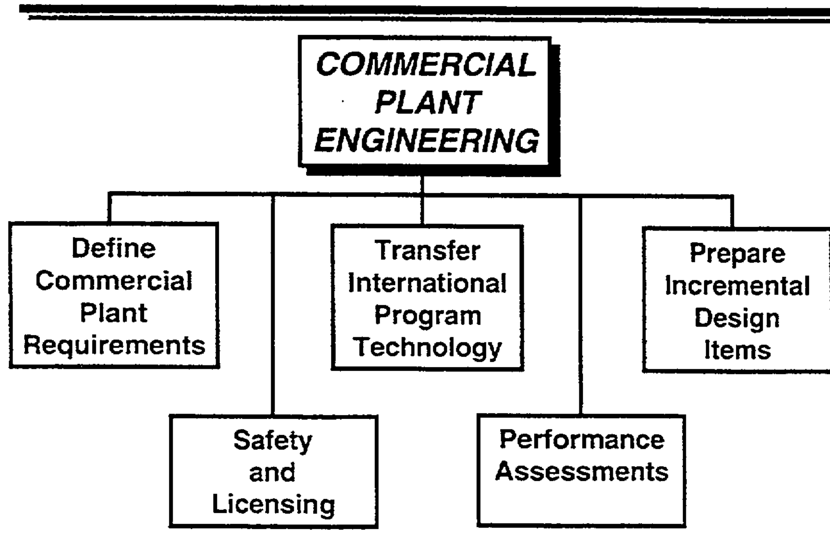
## *COMMERCIALIZATION PROGRAM*

**COMMERCIAL PROGRAM** = INTERNATIONAL PROGRAM TECHNOLOGY + URANIUM FUEL RATHER THAN Pu FUEL

Plant construction can start in 5 years

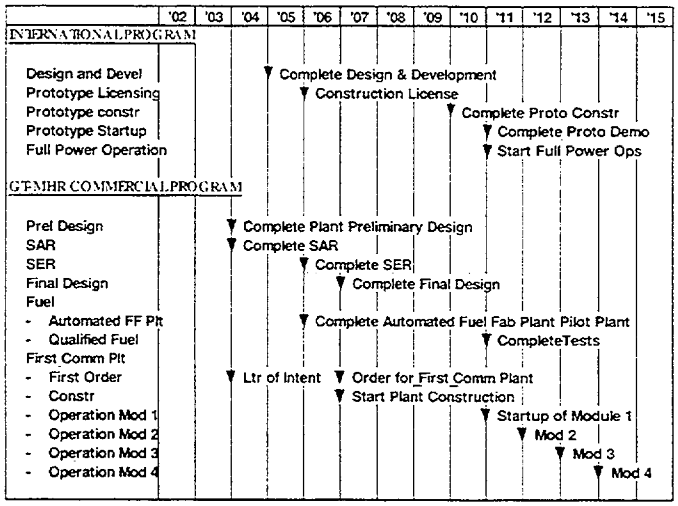
GENERAL ATOMICS

## *LIMITED ENGINEERING WORK REQUIRED*




GENERAL ATOMICS

## COMMERCIAL PROGRAM FOLLOWS INTERNATIONAL PROGRAM




GENERAL ATOMICS

## SUMMARY

- GT-MHR
  - Rooted in decades of international HTGR technology
  - Builds on 1980's (MHTGR) experience
- Optimization of inherent gas-reactor features provides
  - High thermal efficiency
  - Easily understood, assured safety
- International program facilitates near term deployment

GENERAL ATOMICS

**T. Kress, Chairman, Subcommittee on Future Reactors:** For light water reactors, the safety goal that you have is $5 X 10^{-7}$ for early fatalities. You hear statements like, well, that's for light water reactors because we can live with that number. We have some idea of what the uncertainty is in the determination of it. But because those uncertainties are pretty big, we hear statements like well, we're going to not let you do that all with preventing the core damage. We're going to make you have a containment because of uncertainties. There's no quantification in my mind of what that uncertainty level is where you no longer have to have a containment. How are you going to deal with that concept in the regulatory arena?

**L. Parme, General Atomics:** I've heard those kind of questions multiple times. In the '80s, what we submitted first of all is we argued that the goal of the NRC should be to assure the safety of the public, environment if that be also the case, but the criteria for the top level regulatory criteria and going and giving me a criteria on core melt or core damage is not really telling me anything about how safe you want the public. I will admit they didn't full accept that response, but in the case of the high temperature gas cooled reactor, I'd come back in a second. Perhaps it's not such a concern if something like that were imposed on me. In all of the accidents -- and some of the accidents I plotted up there. You'll notice all of those things are less than a rem and typically they're on the order of tens of millirems. Some of those things include assuming that in the steam cycle plant we had lost all electric power on one module, took a break in a steam generator, lost our forced cooling, started pumping steam from one module back to the others for hours on end with nobody taking action. Those are still the kind of doses we got. There's no damage to the core.

However, I will add, we mistakenly in the mid '80s said, what do you mean by core damage? There's no damage. The graphite will stand up to 5,000 degrees Fahrenheit or more before it starts to sublime. It won't be damaged. Well then they started redefining it as a dose over 100 millirem or something like that. I think the argument is tell me how safe you want me to be. If Generation IV or if these newer reactors are supposed to be quantitatively safer --

**T. Kress, Chairman, Subcommittee on Future Reactors**: I'm quite pleased to see your frequency consequence curves because some of us on the ACRS think that's a good way to go, particularly when you don't have core melts.

The other question I wanted to ask you that may come up, I don't know. Chernobyl had a lot of graphite and it apparently burned. You have an air cooled cavity where you're encouraging natural convection. Is there an issue there?

**L. Parme, General Atomics:** Let me say a couple of words. In the NRC interactions we had in the '80s, we did do some analysis of broken vessels, failed vessels, and air ingress. First of all, reactor grade graphite in the U.S., H451 for pebble bed modular reactor. I'm not sure what the grade is but typically the German graphites. They will not burn in the sense of a self-sustaining chain reaction.

**D. Powers, ACRS Member:** Why do you say that?

**L. Parme, General Atomics:** I will say that exactly as follows. Coal will burn, charcoal will burn because of its impurities. Reactor grade graphite -- and there's been tests done at Oak Ridge where an oxyacetylene torch was placed on the graphite.

**D. Powers, ACRS Member**: You're talking of the difference between a point ignition and a homogeneous ignition.

**L. Parme, General Atomics**: In the case where we analyzed air going into the core, and here I'll speak only of the blocks, the reaction rate is driven by temperature that is held up by decay heat. The heat generated from oxidation of the graphite was about-- and it's been 10 years -- but on the order of 10 to 20 percent of the total heat generated was -- in fact, 10 percent or less was due to oxidation. Also the reaction then becomes oxygen-limited as the air passes up the channels. We did an analysis assuming a vessel failure in that cross vessel that connects the two vessels and then assumed that the silo was open and you could get air in that. What you would get was air coming in the hot duct, going up through the core, down through the vessel and out the return duct.

We did the analysis for about 24 hours and I think we did it beyond that but, once again, I'd have to go back and look at the calculations, though it is in Appendix G to the preliminary safety information document that was submitted. I think you see there's no increase in particle failures, but what you do is you are getting releases. They're pretty substantial because they're a driving force and the releases you're seeing and the doses that come with it are due to picking up the contaminants that are within the graphite. As you oxidize the graphite, there are contaminants there. They were -- I want to be careful about quoting the doses. I rather doubt that they stayed within the protection action guides for that accident. However, they were well within the limits of 10 CFR 100.

My comment on combustion was implying just primarily that the reaction is driven by decay heat. It's not as if you had a charcoal pile there. But you will oxidize. There's no question you will oxidize graphite.

Incidentally, in the large HTGR, the approach to that, if you got a break and the primary cooling system got air in the system, it's a coolant. What you do is if you've got a circulator, you turn the circulator on and you cool the core with air. Once the core temperature is down, it will not oxidize so you just run the circulator. That was the design approach for the large HTGRs. If you had a circulator running, that's how you do it. You just turn the circulator on, blow the air around and cool it off.

## General Electric Nuclear Energy

Prepared by ACRS Staff for A. Rao

A. Rao of GE Nuclear Energy provided a presentation on the Evolutionary Simplified Boiling Water Reactor (ESBWR). The ESBWR is a 1380 MWe boiling water reactor with improved operating safety margins and passive safety systems. He stated that the ESBWR derived from earlier GE plant design certification efforts and is the result of eight years of international cooperative work. He stated that the biggest challenge is to cross the regulatory hurdles associated with the inspections, tests, analyses, and acceptance criteria (ITAAC) and combined license (COL) programs. He further stated that he did not know how long it might take to license the ESBWR, in part, because the last GE design certification took about 8 to 10 years. Dr. Rao also provided a brief overview of the GE Nuclear Advance Liquid Metal S-PRISM design.

*GE Nuclear Energy*

# *ESBWR Program and Regulatory Challenges*

*Atam Rao*
*GE Nuclear Energy, USA*

*ACRS Workshop – Regulatory Challenges for Future Nuclear Plants*
*June 4/5, 2001, Rockville, Maryland*

## Overview

- **Design is based on SBWR and ABWR components**
  - **Natural Circulation, ABWR Fuel, Vessel, CRD – just less**
  - **Passive safety systems – based on NRC reviewed SBWR**
  - **Optimized buildings/structures – economics/construction**
  - **8 year international design and technology program**
  - **Goal was to improve performance/safety and economics**
- **Regulatory Issues**
  - How much use can be made of SBWR review by NRC?
  - Extensive new testing completed - Is it enough?
  - Is the regulatory hurdle too high for new plants?

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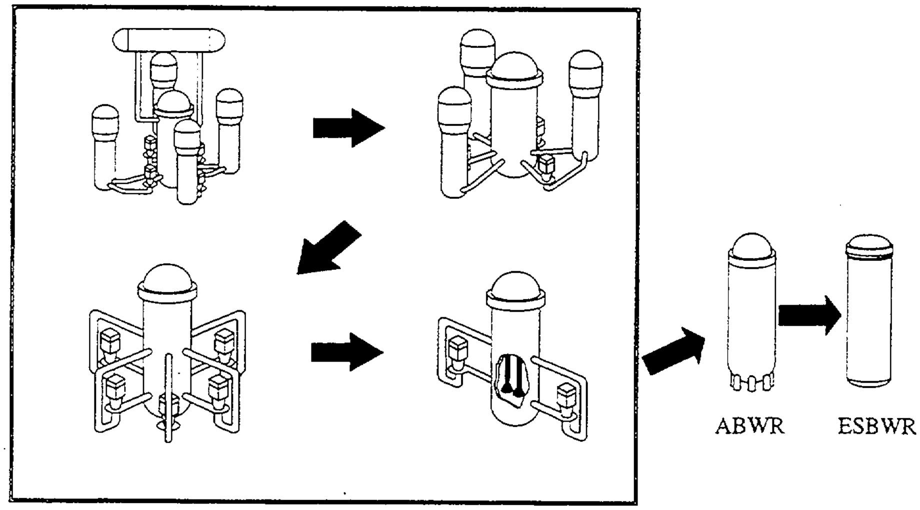
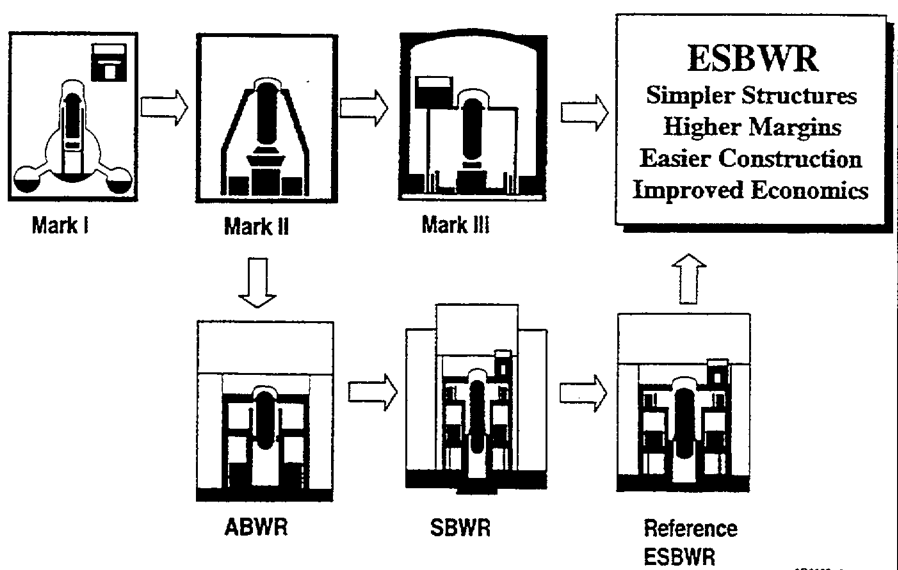
## Evolution of the BWR Reactor Design




**Evolution Towards Simplicity**

AR0103-3

## Evolution of BWR Containments

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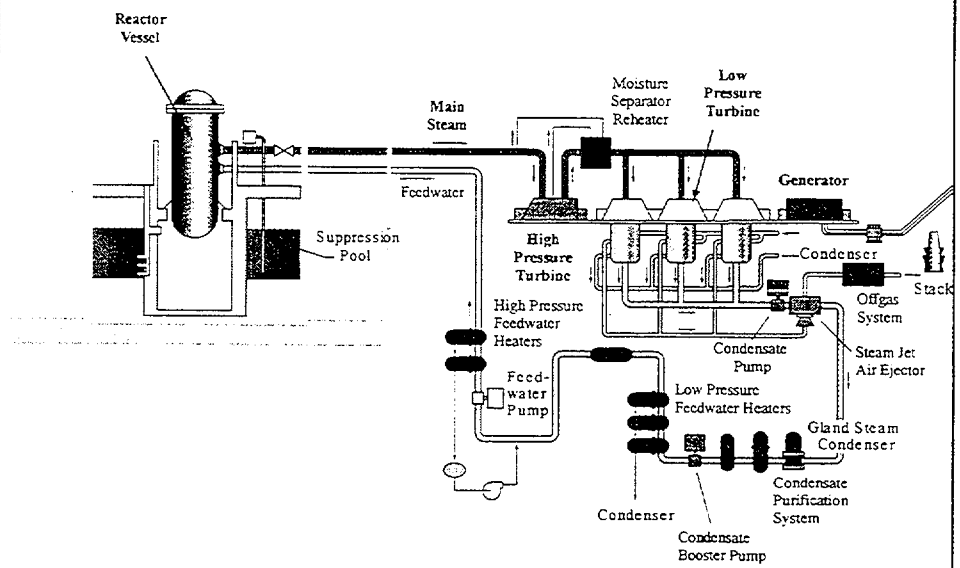
## ESBWR Plant Schematic



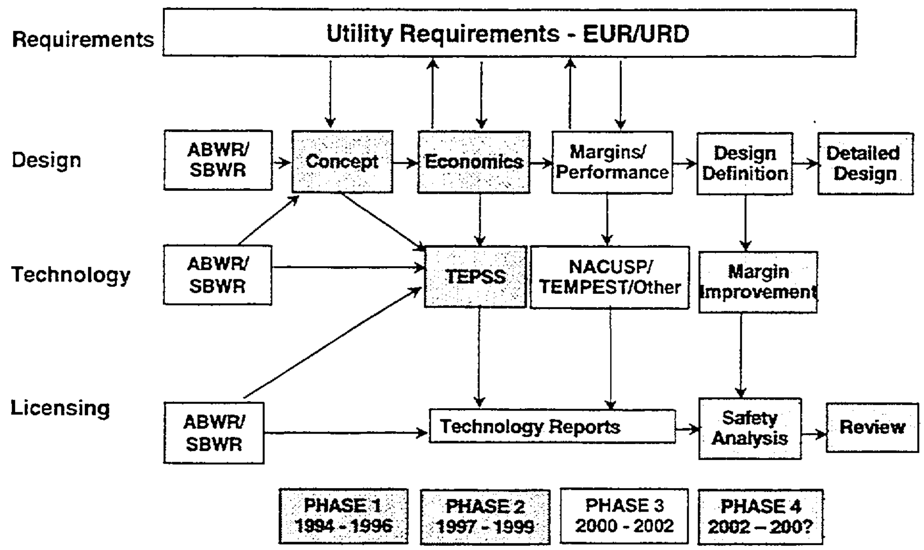

AR0103-5

## Comparison of Key Parameters

| Parameter | ABWR | SBWR | ESBWR |
|---|---|---|---|
| ▪ Power (MWt) | 3926 | 2000 | 4000 |
| ▪ Power (MWe) | 1350 | 670 | 1380 |
| ▪ Vessel height (m) | 21.1 | 24.6 | 27.7 |
| ▪ Vessel diameter (m) | 7.1 | 6.0 | 7.1 |
| ▪ Fuel bundles, number | 872 | 732 | 1020 |
| ▪ Active fuel height (m) | 3.7 | 2.7 | 3.0 |
| ▪ Power density(kw/l) | 51 | 42 | 54 |
| ▪ Number of CRDs | 205 | 177 | 121 |
| ▪ Building Size ($m^3$/MWe) | 195 | 350 | 140 |

AR0103-6

## ESBWR Program Plan

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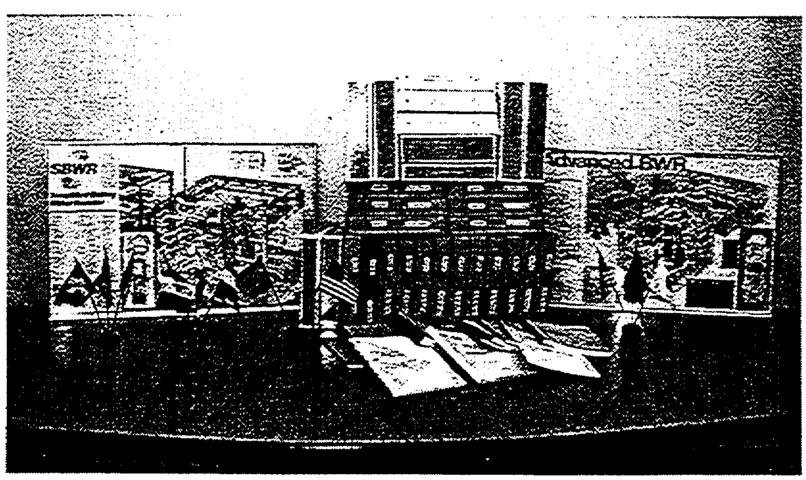
## ESBWR Design/Technology based on SBWR and ABWR

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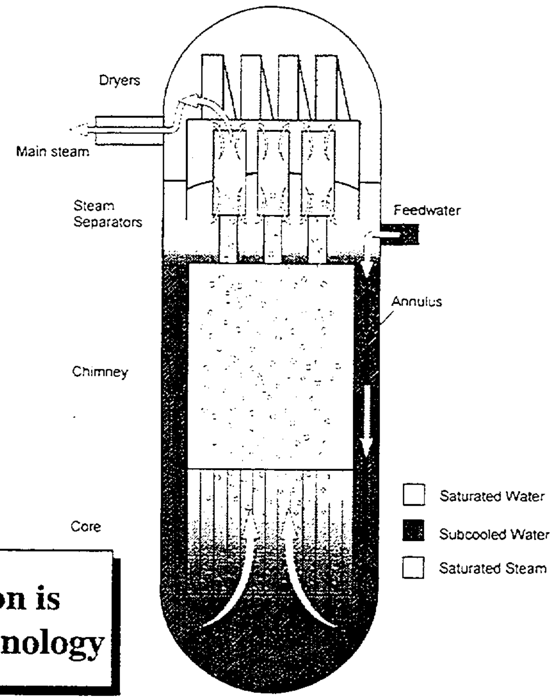
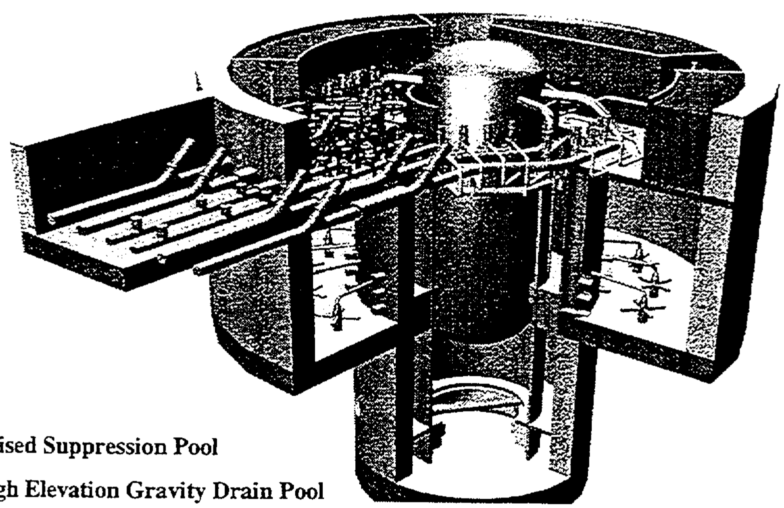
Natural Circulation is Standard BWR Technology



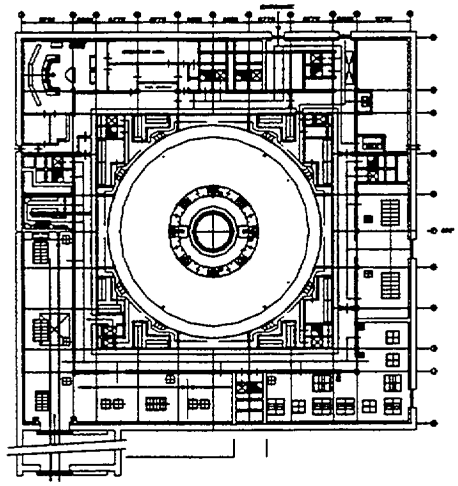

## Safety Systems Inside Containment Envelope



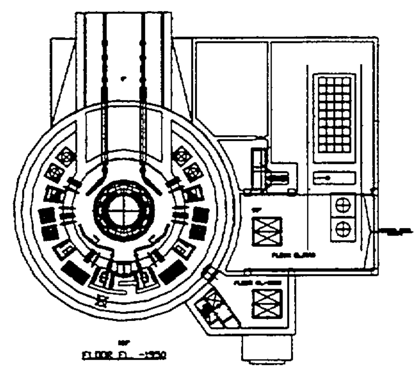
- Raised Suppression Pool
- High Elevation Gravity Drain Pool
- All Pipes/Valves Inside Containment
- Decay Heat Condensers Above Drywell

AR0103- 10

SBWR (670 MWe)

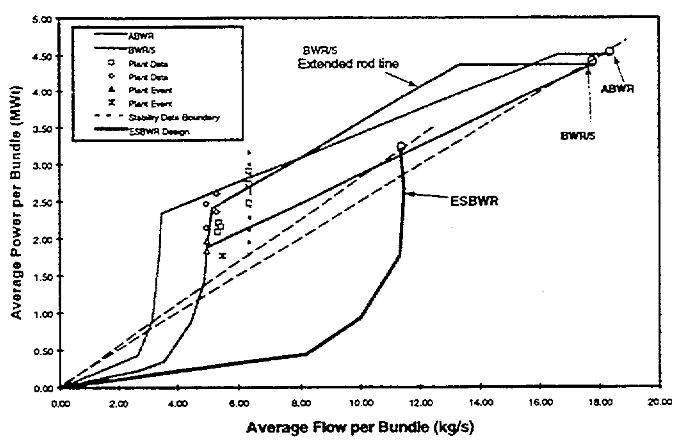


ESBWR (1380 MWe)



***Significant Reduction in Systems & Buildings***

## Bundle Power vs. Flow for various BWRs




POWFLO-2.xls chart 9

***ESBWR has 100% flow margin to stability data boundary***

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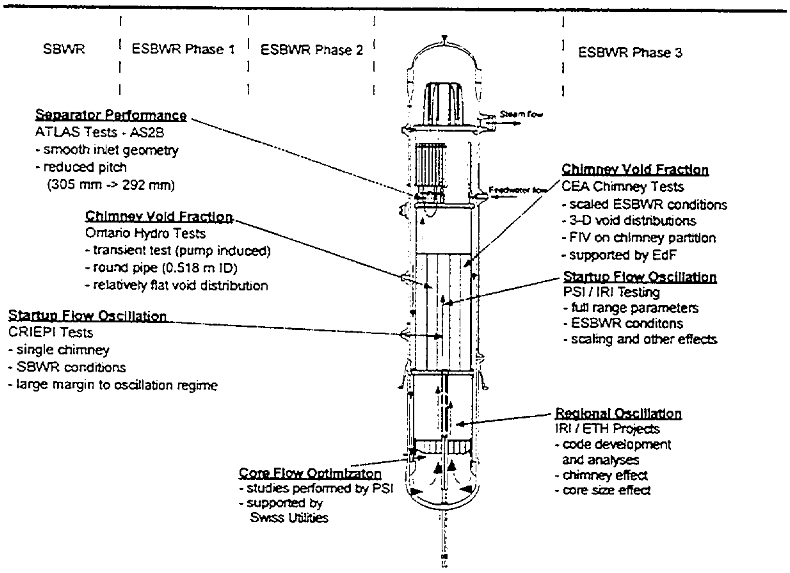
## Natural Circulation Technology Program

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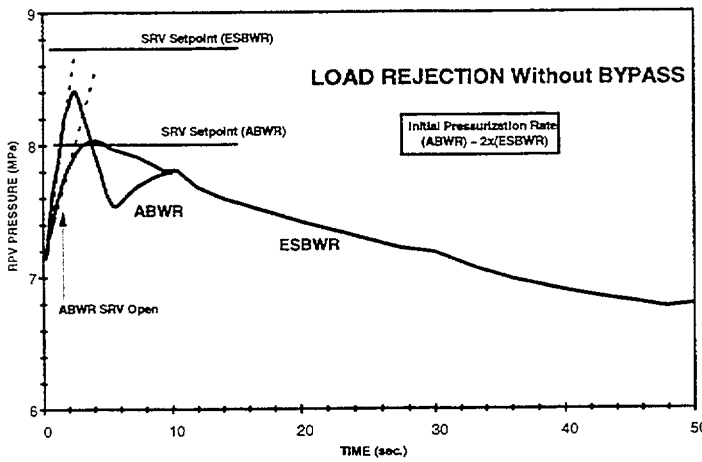
## Comparison of Plant Performance

| *Parameter* | *Typical BWR* | *Passive BWR SBWR* | *Passive BWR ESBWR* |
|---|---|---|---|
| *Natural Circulation flow/bundle, kg/s* | *3.5 - 5* | *8.5* | *10.6* |
| *Power/Flow Ratio, MW/(kg/s)* | *0.25* | *0.31* | *0.26* |
| *Transient pressure rate, MPa/s* | *0.8* | *0.4* | *0.4* |
| *Margin to SRV setpoint during isolation transient, MPa* | *valve opens* | *0.52* | *0.32* |
| *Minimum water level after accident, m above top of fuel* | *0.0* | *1.5* | *2.8* |
| *Post accident containment pressure margin, KPa below design pressure* | *40* | *100* | *200* |

***ESBWR Performance is Better Than or Equal to Most Plants***

AR0103- 14

## Reactor pressure response to isolation events




***ESBWR has slower pressurization***
***No SRV opening***

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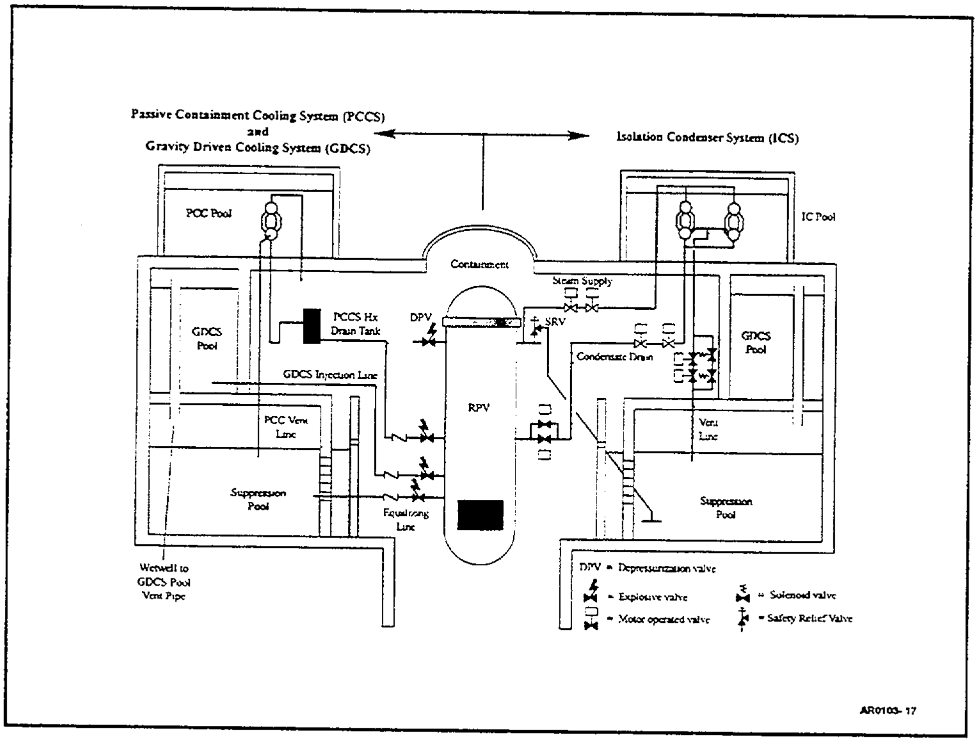
## Passive Safety Systems - Simplify the Plant

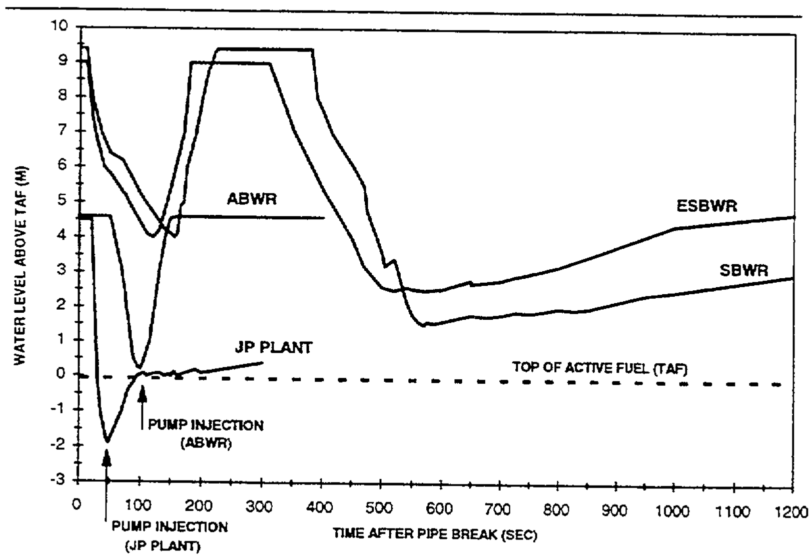
- Reactivity Control
  - Electro-hydraulic control rod drive system
  - Accumulator driven backup boron injection system
- Inventory Control
  - Large vessel with additional inventory
  - High pressure isolation condensers (IC)
  - Depressurization and gravity driven cooling system (GDCS)
- Decay Heat Removal
  - Isolation condensers for transients
  - Passive Containment Cooling System (PCCS) condensers for pipe breaks
- Fission Product Control and Plant Accident Release
  - Passive condensers
  - Retention and holdup with multiple barriers

***Simplified Systems Extending Operating Plant Technology***

AR0103- 16

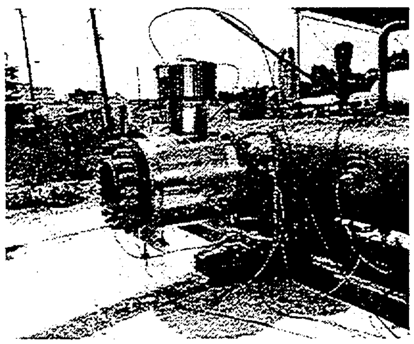



## Water Level in Shroud Following a Pipe Break

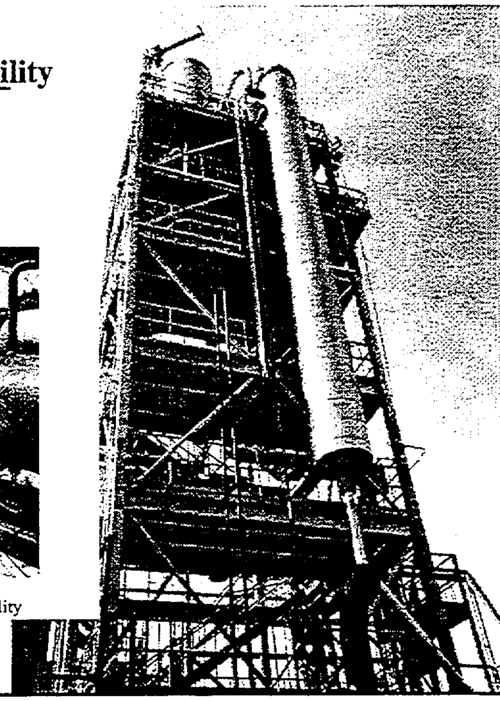



AR0103-18

**Safety System (GIST) Test Facility and Depressurization Valve**



Reactor Depressurization Valve in the Test Facility



## ESBWR Decay Heat Removal

- Remove Decay Heat From Vessel
  - Main Condenser
  - Normal shutdown cooling system
  - Isolation condensers
  - Remove vessel heat through valve opening

- If Needed, Remove Heat From Containment
  - Suppression pool cooling
  - Containment sprays
  - Passive containment cooling (PCCS) condensers

***Several Diverse Means of Decay Heat Removal***

AR0103-20

# Containment Technology Overview

| SBWR and ESBWR Phase 1 | ESBWR Phase 2 | ESBWR Phase 3 |
|---|---|---|

**Condensation with N/C**
MIT - external condensation
UCB - single tube tests
GIRAFFE - component tests
PANTHERS - component tests
PANDA - steady state tests

**PCCS Performance**
Steady-state: PANDA, GIRAFFE, PANTHERS
Start-up: PANDA, GIRAFFE
Secondary Side ht: PANDA, PANTHERS, GIRAFFE
N/C Buildup: PANDA, PANTHERS, GIRAFFE
Interactions: PANDA
Unit interactions PANDA

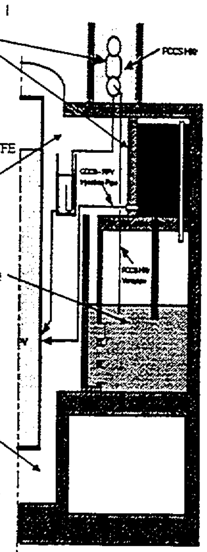
**System Interactions**
PANDA
GIRAFFE

**SP Stratification**
LINX (ALPHA)
PANDA

**DW Stratification and Hideout**
PANDA
GIRAFFE

**Steam Quenching**
Main Vent:
- Horiz. Vent Test/MK III tests (PSTF)
PCC Vent:
- PSI theoretical work (Coddington et al)
- UCB Sparger/Vent chimney
- PANDA

**Heat/Mass Leakage DW to WW**
Finite Element Analysis
VB Testing



**PCCS Performance**
PANDA (TEPSS)
- startup
- interactions
- secondary side ht
- N/C Buildup
- Unit interactions

**ESBWR Configuration**
PANDA (TEPSS)
- reduced cont. volume
- GDCS in WW
- PCCS Condensate to RPV
VTT
- Modeling of larger PCC

**DW Stratification and Hideout**
PANDA(TEPSS)
- Asymmetric loading
- hydrogen

**SP Stratification**
LINX (TEPSS)

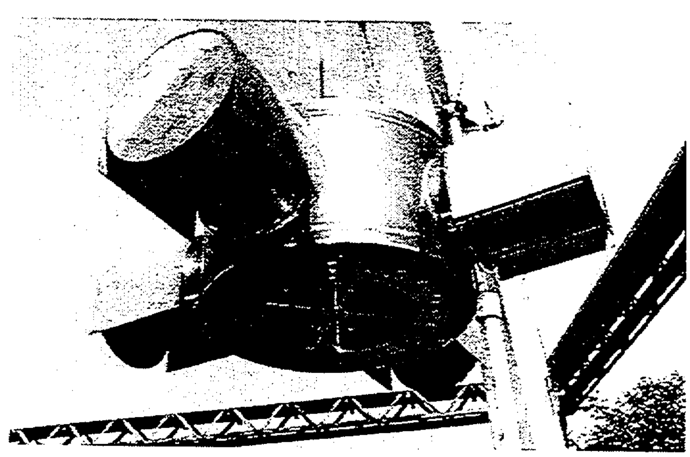
**PCC Hydrogen Distribution**
PANDA + CFD (FFWP)
VTT - CFD

**DW Stratification and Hideout**
UCB + CFD (FFWP)
PANDA + CFD (FFWP)

**WW Gas Stratification**
UCB + CFD (FFWP)
KALI + CFD (FFWP)

AR0103-21

# Prototype Vacuum Breaker



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## Extensive Technology Program to Qualify Features New to SBWR

- Component and Integral tests as part of the SBWR program
  - Full scale components tests - condensers, valves
  - Integral tests at different scales, with the largest test at PANDA
- Testing extended to incorporate European requirements
  - Large hydrogen releases and severe accidents
  - Improvements in the plant design
- Ongoing programs will further quantify margins
  - Natural circulation in the vessel
  - Severe accident performance/features for passive systems
- Testing used to qualify computer codes
- Extensive international cooperation

***A Complete and Thorough Technology Program Supports the Design***

AR0103- 23

## TEPSS Program

Suppression Pool stratification and mixing
  - 9+ tests with flow visualization in LINX
  - CFD analysis using CFX
- Passive Decay Heat Removal
  - 8 Integrated system tests run in PANDA
  - Pre- and post-test predictions using TRACG, TRAC-BF1, RELAP5 and MELCOR
- Passive Aerosol Removal
  - PCCS testing in AIDA
  - Analysis with MELCOR
  - Demonstrate PCCS as fission product aerosol filter
  - Demonstrate ability of PCC to remove decay heat with aerosol build-up

***3 part program extended the SBWR database to ESBWR***

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## Ongoing Simplification Studies

- **Reduce Fuel Bundles, CRD, Vessel - COMPLETE**
  Increase Fuel Length
- **Improve Plant Availability - 5%**
  Refueling and Outage Plan and System Improvements
- **Reduce Buildings and Structures - 30%**
  Reduce Basemat Thickness
  Reduce Containment Design Pressure
  Move Spent Fuel Pool to Grade Elevation/Separate Building
  Separate Reactor Building From Containment

***Normal performance margins maintained while reducing excessive conservatisms in other areas***

AR0103-25

## Ongoing Technology Programs

- **Quantify Natural Circulation Performance Margins**
  NACUSP Programs at IRI, NRG, CEA and PSI
  Additional Testing at IRI and CRIEPI
  Independent Stability Assessment at ETH, IRI
- **Reduce Uncertainty in Natural Circulation Parameters**
  Chimney Tests at CEA
- **Develop Confidence in Safety System Performance**
  TEMPEST Programs at PSI, VTT, NRG, CEA
- **Develop Back-up Systems to Provide Additional Margin**
  TEMPEST Programs at PSI

***Technology programs to confirm that design is robust and provide additional data for code qualification***

AR0103-26

## Program Summary and Conclusion

- **8 year ESBWR program**
  Reduced Components and Systems - simplify
  Reduced the Structures and Buildings - simplify
- **8 year Technology Studies**
  Large margins confirmed – increased over SBWR
  Qualified codes for incremental changes for ESBWR
- **Challenges for the Coming Years**
  Crossing the regulatory minefield? hurdles? resources?

**Improved Safety/Performance and Economics**
**Completed Extensive Technology Program**
**SBWR and ABWR Programs ease Regulatory Challenges**

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