UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

October 5, 2001

MEMORANDUM TO: ACRS Members

FROM: Michael T. Markley, Senior Staff Engineer

SUBJECT: CERTIFICATION OF THE MINUTES OF THE MEETING OF THE ACRS SUBCOMMITTEE ON ADVANCED REACTORS - JUNE 4-5, 2001 - ROCKVILLE, MARYLAND

The minutes of the subject meeting, issued September 11, 2001, have been certified as the official record of the proceedings of that meeting. A copy of the certified minutes is attached.

Attachment: As stated

cc: via E-mail
J. Larkins
S. Bahadur
H. Larson
S. Duraiswamy
ACRS Staff Engineers
ACRS Fellows

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

MEMORANDUM TO: Michael T. Markley, Senior Staff Engineer

FROM: T.S. Kress, Chairman
Advanced Reactors Subcommittee

SUBJECT: CERTIFICATION OF THE MINUTES OF THE MEETING OF THE ACRS SUBCOMMITTEE ON ADVANCED REACTORS - JUNE 4-5, 2001 - ROCKVILLE, MARYLAND

I do hereby certify that, to the best of my knowledge and belief, the minutes of the subject meeting on June 4-5, 2001, are an accurate record of the proceedings for that meeting.

T. S. Kress　　　　Oct. 3, 2001

T.S. Kress, Chairman　　　　Date
Advanced Reactors Subcommittee

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

PRE-DECISIONAL

September 11, 2001

MEMORANDUM TO: Dr. T.S. Kress, Chairman
Advanced Reactors Subcommittee

FROM: Michael T. Markley, Senior Staff Engineer

SUBJECT: WORKING COPY OF THE MINUTES OF THE MEETING OF THE ACRS SUBCOMMITTEE ON ADVANCED REACTORS - JUNE 4-5, 2001, ROCKVILLE, MARYLAND

A working copy of the minutes for the subject meeting is attached for your review. Please review and comment on them at your soonest convenience. Copies are being sent to each ACRS Member who attended the meeting for information and/or review.

Attachment:
As Stated

cc: ACRS Members
J. Larkins
S. Bahadur
H. Larson
S. Duraiswamy
ACRS Staff and Fellows

CERTIFIED BY:
T. Kress - 10/5/01

Date: 9/11/01

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
MEETING OF THE ACRS SUBCOMMITTEE ON ADVANCED REACTORS
JUNE 4-5, 2001
ROCKVILLE, MARYLAND

INTRODUCTION

The ACRS Subcommittee on Advanced Reactors met on June 4-5, 2001, at 11545 Rockville Pike, Rockville, MD, in the Two White Flint North (TWFN) Conference Room. The Subcommittee relocated to on June 4-5 and in Room T-2B3 during the afternoon on June 5. The purpose of this meeting was to discuss regulatory challenges for future nuclear power plants.

The Subcommittee received no written comments or requests for time to make oral statements from members of the public regarding the meeting. The entire meeting was open to public attendance. Michael T. Markley was the cognizant ACRS staff engineer and Designated Federal Official for this meeting. The meeting was convened at 9:00 a.m. and recessed at 7:15 p.m. on June 4. The meeting was reconvened at 8:30 a.m. and adjourned at 5:50 p.m. on June 5. The Subcommittee received no written comments or requests for to make oral statements by members of the public. During the course of the meeting, ACRS members Apostolakis, Leitch, Powers, and Sieber and ACNW member Garrick announced that they have conflicts with certain presentations made to the Subcommittee.

ATTENDEES

ACRS/ACNW

T. Kress, Subcommittee Chairman
G. Apostolakis, ACRS Chairman
M. Bonaca, ACRS Member
P. Ford, ACRS Member
G. Leitch, ACRS Member
D. Powers, ACRS Member
W. Shack, ACRS Member
J. Sieber, ACRS Member
R. Uhrig, ACRS Member
G. Wallis, ACRS Member
J. Garrick, ACNW Member
J. Larkins, ACRS Staff
J. Lyons, ACRS Staff
M. Markley, ACRS Staff
R. Savio, ACRS Staff

Principal NRC Speakers

R. Barrett, NRR*
E. Benner, NRR
A. Cubbage, NRR
J. Flack, RES*
M. Gamberoni, NRR
T. Kenyon, NRR
A. Rae, NRR
S. Rubin, RES
A. Thadani, RES
J. Wilson, NRR

Principal Presenters and Speakers

J. Slaber, PBMR Demonstration Project*
M. Carelli, Westinghouse Science & Technology
G. Davis, Westinghouse Electric Corporation
C. Forsberg, ORNL*
M. Golay, MIT*
W. Hauter, Public Citizen
A. Heymer, NEI*
S. Johnson, DOE*
E. Lyman, NCI*
W. Magwood, DOE
T. Miller, DOE
L. Parme, General Atomics
A. Rao, GE Nuclear Energy*
R. Simard, NEI
W. Sproat, Exelon Generation
N. Todreas, MIT
R. Versluis, DOE

NRR	Office of Nuclear Reactor Regulation
RES	Office of Nuclear Regulatory Research
DOE	U.S. Department of Energy
GE	General Electric
MIT	Massachusetts Institute of Technology
NCI	Nuclear Control Institute
NEI	Nuclear Energy Institute
ORNL	Oak Ridge National Laboratory
PBMR	Pebble Bed Modular Reactor

There were approximately 94 members of the public in attendance at this meeting. A complete list of attendees is in the ACRS Office File, and will be made available upon request. The presentation slides and handouts used during the meeting are attached to the office copy of these minutes.

JUNE 4, 2001

Introductory Remarks

Dr. T.S. Kress, Chairman of the Advisory Committee on Reactor Safeguards (ACRS) Subcommittee on Advanced 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. Dr. George E. 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. Commissioner Diaz stated that 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.

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, roadmap effort, and concept evaluation. Mr. Thomas P. 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.

Ward Sprout of Exelon Generation and Johan 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.D. 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.

Lawrence 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.

Atam 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.

Marsha Gamberoni, NRR, led the discussion for the NRC staff. Nanette Gilles, NRR discussed the future licensing organization and inspection readiness assessment (FLIRA). Thomas Kenyon, NRR, discussed early site permits (ESPs), ITAAC and COL programs. A. Rae discussed the Westinghouse AP1000 review and Eric Benner, NRR, discussed issues related to the regulatory infrastructure. Mr. Jerry Wilson, NRR, also participated. John Flack and Stuart 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:

Dr. 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. Dr. Powers questioned the extent to which performance indicators (PIs) might further performance-based considerations. Dr. 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.

Drs. Kress and Powers questioned the nature of fuel performance for the PBMR. Dr. Kress questioned how fuel manufacturing quality and integrity will be ensured. Dr. 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.

Drs. Apostolakis and 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).

Dr. 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. Dr. 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.

Panel Discussion

The Subcommittee and participants extensively discussed the use of risk information in considering future nuclear plants. Dr. Apostolakis stated that there seems to a gap between the staff and industry thinking concerning the importance of risk. He stated that he is not sure that there is a full appreciation how important risk is in the design, licensing, and operation of nuclear power plants. Dr. Bonaca stated that there seems to 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 demonstrating that the Commission's Safety Goals are met.

Mr. Rosen encouraged Exelon to provide risk information in support of it PBMR plant design. He stated that it will be important in designating systems and components as being important to risk and that both design and risk information will be needed. Dr. 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. Dr. 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 analysis 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. Exelon proposes to certify the design by testing.

Dr. 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.

Dr. 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. Dr. 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

Dr. T.S. Kress, Chairman of the ACRS Subcommittee on Advanced 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

Ron 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.

Neil E. 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.

Andrew C. 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.

Michael Golay of MIT and George Davis of Westinghouse provided a presentation on the NERI Project being conducted for 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. Dr. 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 who 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.

Charles 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).

Adrian 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:

Dr. 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. Mr. Simard agreed that efiiciciency and conservation play an important role but concluded that it is unrealistic to suggest that new electricity generation is not needed.

Dr. Powers expressed appreciation for the systems-approach and use of trade-off studies in evaluating new plant designs and safety goals. Dr. 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.

Dr. Powers questioned why the safety goals could not be expressed in terms of release of radioactivity. Dr. Wallis expressed concern that this approach might overly constrain the evaluation of certain designs and lock the evaluation into certain design directions. Dr. 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. Dr. 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. Dr. 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.

Dr. Wallis questioned how human performance would be evaluated using the "license by test" approach. Mr. Leitch stated that the major advantage of license by test appears to a reduction in the time and costs for paper reviews associated with the licensing process and questioned what technical merits would be derived. Mr. Sieber questioned who should finance the costs of such a facility. Mr. 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. Mr. 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.

Dr. Apostolakis questioned whether the licensing process can be made performance-based. Mr. 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). Mr. Heymer suggested that risk-informing 10 CFR Part 52 will be very important for new reactors. Dr. 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

Richard 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. Dr. Wallis stated that it is not good enough to provide public access to NRC decisionmaking. Mr. Barrett agreed and stated that they need to identify public concerns and act on them.

Neil E. 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. Dr. 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. Dr. Garrick stated that the regulatory process, like people, are slow to change.

Edwin S. 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. Mr. 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.

Winonah 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. Ms. 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. Drs. Kress and 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. Ms. 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, Drs. 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.

Background Materials Provided to the Subcommittee Prior to this Meeting

1. Subcommittee agenda.
2. Subcommittee status report.
3. ACRS reports dated February 19, 1993, from Paul Shewmon, Chairman, Advisory Committee on Reactor Safeguards, to Ivan Selin, Chairman, NRC, Subject: Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and CANDU 3 Designs and Their Relationship to Current Regulatory Requirements.
4. Report dated July 20, 1988, from William Kerr, Chairman, Advisory Committee on Reactor Safeguards, to Lando W. Zech, Jr., Chairman, NRC, Subject: Report on Licensing Issues Associated with DOE Sponsored Reactor Designs.
5. Report dated June 9, 1987, William Kerr, Chairman, Advisory Committee on Reactor Safeguards, to Lando W. Zech, Jr., Chairman, NRC, Subject: ACRS Comments on Draft NUREG-1226, "Development and Utilization of the NRC Policy Statement on the Regulation of Advanced Nuclear Power Plants."
6. Report dated April 16, 1986, from David A. Ward, Chairman, Advisory Committee on Reactor Safeguards, to Nunzio J. Palladino, Chairman, NRC, Subject: ACRS Comments on NRC Review of Advanced Reactor Designs.
7. Report dated October 16, 1985, from David A. Ward, Chairman, Advisory Committee on Reactor Safeguards, to Nunzio J. Palladino, Chairman, NRC, Subject: ACRS Comments on NRC Advanced Reactor Policy Statement.
8. Draft Memorandum dated May 1, 2001, from William D. Travers, EDO, NRC, to The Commissioners, Subject: Staff Readiness for Future Licensing Activities. **(Pre-Decisional Draft).**
9. Draft Memorandum dated April 25, 2001, from William D. Travers, EDO, NRC, to The Commissioners, Subject: SECY-01-0070 - Plan for Preapplication Activities on the Pebble Bed Modular Reactor (PBMR). **(Pre-Decisional Draft)**
10. Letter dated May 10, 2001, from James A. Muntz, Exelon Generation Company, to Thomas L. King, Office of Nuclear Regulatory Research, NRC, Subject: Regulatory Issues related to the Pebble Bed Modular Reactor (PBMR).
11. Memorandum dated February 12, 2001, from Thomas L. King, Office of Nuclear Regulatory Research, NRC, Subject: Meeting with Exelon Generation Company and Other Interested Stakeholders Regarding the Pebble Bed Modular Reactor. (Publicly Available)
12. Handouts from May 7, 2001 meeting, concerning International Reactor Innovative and Secure (IRIS), by M.D. Carelli, Westinghouse Electric Corporation.
13. Handouts from March 2001 meeting, on Gas Turbine-Modular Helium Reactor (GT-MHR): Commercialization Program Briefing, by General Atomics.

14. Handouts from International Symposium on the Role of Nuclear Energy in a Sustainable Environment, presentation entitled, "The GenIV Nuclear Energy System Program: Expectations and Challenges," by Professor Neil E. Todreas, April 20, 2001.
15. Letter dated January 12, 2001, from William D. Travers, EDO, NRC, to James A. Muntz, Exelon Generation Company, Subject: Response to Letter dated December 5, 2000. (Publicly Available)
16. Letter dated December 5, 2000, from James A. Muntz, Exelon Generation Company, to NRC Document Control Desk, Subject: Pebble Bed Modular Reactor Review Requirements.
17. Memorandum dated May 17, 1994, from James M. Taylor, EDO, NRC, Subject: SECY-94-133 - Updated Commission Policy Statement on Advanced Reactors to Reference the Commission's Metrication Policy.
18. U.S. Nuclear Regulatory Commission, NUREG-1226, "Development and Utilization of the NRC Policy Statement on the Regulation of Advanced Nuclear Power Plants.

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Note: Additional details of this meeting can be obtained from a transcript of this meeting available for downloading or viewing on the Internet at "http://www.nrc.gov/ACRSACNW" or can be purchased from Neal R. Gross and Co., Inc., (Court Reporters and Transcribers) 1323 Rhode Island Avenue, N.W., Washington, DC 20005 (202) 234-4433.

INTRODUCTORY STATEMENT BY THE CHAIRMAN OF THE MEETING OF THE ACRS SUBCOMMITTEE ON ADVANCED REACTORS WORKSHOP ON REGULATORY CHALLENGES FOR FUTURE NUCLEAR POWER PLANTS

11545 ROCKVILLE PIKE, TWFN AUDITORIUM
ROCKVILLE, MARYLAND
JUNE 4-5, 2001

The meeting will now come to order. This is the first day of the meeting of the ACRS Subcommittee on Advanced Reactors. I am Thomas Kress, Chairman of the Subcommittee.

Subcommittee Members in attendance are ACRS Chairman George Apostolakis, Mario Bonaca, Graham Leitch, Dana Powers, William Shack, Jack Sieber, Robert Uhrig, and Graham Wallis. Also, attending is ACNW Chairman John Garrick.

The purpose of this meeting is to discuss matters related to regulatory challenges for future nuclear power plants. The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate, for deliberation by the full Committee. Michael T. Markley is the Cognizant ACRS Staff Engineer for this meeting.

The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the *Federal Register* on May 10, 2001. A transcript of the meeting is being kept and will be made available as stated in the Federal Register Notice. We have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting.

In order effectively manage time and allow for maximum member, presenter, and public participation and sharing, the Subcommittee requests the following protocols be adhered to during the meeting:

- Presenters should be allowed to make their presentations without substantial interruption.

- Questions from the audience/stakeholders will be entertained at the end of presentation sessions, not the individual presentations.

- Members of the public/audience should use question cards provided. The ACRS staff facilitator, Mike Markley will collect comment cards, group like comments as practicable, read them into the record, and refer questions/comments to presenters and/or panel participants, as appropriate.

- It may not be possible to respond to all questions and comments. However, all questions/comments will be listed in the meeting proceedings following the workshop.

Opportunities for direct audience participation will be provided during panel discussion sessions each day. Microphones have been arranged for convenience of the audience during this meeting. It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

(Chairman's Comments-if any)

We will now proceed with the meeting and I call upon Dr. Apostolakis to introduce the keynote speaker.

INTRODUCTORY STATEMENT BY THE CHAIRMAN OF THE MEETING OF THE ACRS SUBCOMMITTEE ON ADVANCED REACTORS WORKSHOP ON REGULATORY CHALLENGES FOR FUTURE NUCLEAR POWER PLANTS
11545 ROCKVILLE PIKE, TWFN AUDITORIUM
ROCKVILLE, MARYLAND
JUNE 4-5, 2001

Introductory Remarks by ACRS Chairman, George Apostolakis:

It is with great pleasure and honor that I introduce our keynote speaker for this workshop, Commissioner Nils Diaz.

Before being sworn-in as a Commissioner of the U.S. Nuclear Regulatory Commission in August 1996, Dr. Diaz had 34 years in nuclear and radiological engineering, as a scientist, engineer, researcher, consultant, and entrepreneur. In the research and development arena, Commissioner Diaz worked from mundane light-water reactor safety and advanced designs to more complex space power and propulsion systems, and in the conceptual design and testing of futuristic reactors like the UF6, UF4, and U metal-fueled reactors for the Strategic Defense Initiative.

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Subcommittee Members in attendance are ACRS Chairman George Apostolakis, Mario Bonaca, Peter Ford, Graham Leitch, Dana Powers, William Shack, Jack Sieber, Robert Uhrig, and Graham Wallis. Also, attending is ACNW Chairman John Garrick.

The purpose of this meeting is to continue our discussion of regulatory challenges for future nuclear power plants. The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate, for deliberation by the full Committee. Michael T. Markley is the Cognizant ACRS Staff Engineer for this meeting.

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This afternoon the Subcommittee will reconvene at 2:00 p.m. in the Commissioners' Conference Room, on the lobby elevation of One White Flint North. We will not return to the Two White Flint North Auditorium where we are meeting presently.

(Chairman's Comments-if any)

We will now proceed with the meeting and I call upon Mr. Ron Simard of the Nuclear Energy Institute to begin.

INTRODUCTORY STATEMENT BY THE CHAIRMAN OF THE
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WORKSHOP ON REGULATORY CHALLENGES FOR
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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE MEETING ON THE ADVANCED REACTORS

JUNE 4, 2001
Today's Date

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Alan Levin	OCM/RAM
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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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SUBCOMMITTEE MEETING ON THE ADVANCED REACTORS

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Matt Blevins	NMSS/DWM
UNDINE SHOOP	NRR/SRXB
Merri Horn	NMSS/IMNS
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Stephanie Bush-Goddard	NMSS/IMNS
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Mark Blumberg	NRR/DSSA
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JOHN H. FLACK	RES/DSARE
Torre Taylor	NMSS/IMNS
Betty Ann Torres	NMSS/IMNS
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Millard Wohl	NRR/DSSA/SPSB
BOB YOUNGBLOOD	ISL, Inc.

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Gaku Sato	MIT
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Ed Lyman	NCI
Ward Sproat	Exelon
Jim Muntz	Exelon
Andrew Kadak	MIT
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Sheila R. Fabian	Nuclear Waste News
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W.D. Magwood	DOE
James Moroney	MPR Assoc.
Kiyoshi Ando	NIKKEI News

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Atam Rao	GE
Johan Slabber	PBMR
John Hufnagel	Exelon
Rob Versluis	US DOE -NE
NEILL HOWEY	IDNS
KENNETH ROGERS	SELF
Marty Malsch	Self.
David Sgueurer	Self
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Charles Brinkman	Westinghouse
Steve Routh	Bechtel
JOE HEGNER	DOMINION
MIKE SCHOPPMAN	FRAMATOME ANP

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Bob Twilley	FRA ANP
Robert J. Baker, Jr.	FRA-ANP
Tom Miller	U.S. Department of Energy
Ron Hagen	US Dept of Energy
Larry Parme	General Atomics Co
L.E. Hochreiter	Penn State University
Jim Hammelman	Self
Greg Krueger	Exelon Nuclear
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Mark R. Holbrook	INEEL
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Mario Carelli	Westinghouse
Larry E. Conway	Westinghouse
Paige T. Nichols	GE
Lorne Hay	SERCA Bechtel

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Tatsuya Taminami	Tepco
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Allen Camp	Sandia
Roger Huston	Licensing Support Services
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Maurice Magugumela	PBMR (PTY) LTD
Kevin Borton	Exelon
Jenny Weil	McGraw-Hill
Ron Simard	NEI
Eric Wieser	BPI
Elaine Hiruo	McGraw-Hill

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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Paul Gunter	NIRS
Tyson Slocum	Public Citizen
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Michael Hillman	DOE
Mark Haynes	GA
Charles Forsberg	ORNL
PETER MURRAY	Westinghouse
RON HUTCHINGS	EMBASSY OF AUSTRALIA
Dwight Cates	House Commerce Committee
Russ Bell	NEI
MIKE KNAPIK	McGRAW-HILL

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G. BAGCHI	NRR/DE
Edward D Throm	NRR/DSSA
RICH BARRETT	NRR/FLO
Michelle Snell	NRR/DSSA
Dwight Snowberger	NRR/DSSA
Richard Lee	RES
MARK HOLBROOK	INEEL
Sarah Colpo	NRR
Steve LaVie	NRR/DSSA
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Marsha Gamberoni	NRR/FLO
THOMAS KENYON	NRR/FLO
ALAN RAE	NRR/FLO.
DIANE JACKSON	NRR/FLO
Steve Long	NRR/DSSA/SPSB
Donald E. Carlson	RES
JOHN FLACK	NRC/RES/DSARE

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TIM REED	NRC/NRR/DRIP/RGEB
Norman St Amour	NRC/OGC
JOE WILLIAMS	NRR/ADIP/FLO

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Stuart Rubin	RES
Jerome Murphy	OCFO
Deirdre Spaulding	NRR
Alan Levin	OCM/RAM
Dan Hughes	INEEL
MICHAEL SNODDERLY	NRR/DSSA/SPSB
Tanya Eaton	NRR/DSSA/SPLB
CHIP CAMERON	OGC
JF Costello	RES
Sher Bahadur	RES
N. P. KADAMBI	RES
Katherine Kohlhepp	NMSS/FCSS
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Greg O'Donnell	RES
Nanette Gilles	NRR/FLO

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Vijay M. Nilekani	EXELON.
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Mujid S. Kazimi	MIT
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MIKE CORLETTI	WESTINGHOUSE
Jennifer Ober	Framatome
Roger Huston	LSS
Jim Meyer	ISL
Andrew KADA	MIT
WARD SPROAT	EXELON
George Davis	Westinghouse
Ed Lyman	NCI
ADRIAN HEYMER	NEI.
JESUS(JAY) ARIAS	~~EG~~ FIU-HCET
Eric Wieser	BPI
Russ Bell	NEI
Deann Raleigh	US, Scientech
Thecla Fabian	Nuclear Waste News
Stephen Routh	Bechtel

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Samim Anghaie	UF
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Mario Carelli	W
Jim Muntz	EXELON
Ron Simard	NEI
JOE HEGNER	Dominion
NEIL TODREAS	MIT
Dave Sguarer	self
Michael J. Golay	MIT
Tatsuya Taminami	Tepco
Elaine Hiruo	McGraw-Hill
John R. Guth	Sandia
Allen Camp	Sandia
Xue. Guan	ASTM, Inc.
TED Quinn	GA.
Ed WALLACE	EXELON
John Hufnagel	Exelon
[illegible]	Public Citizen

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YUNG Y. LIU	ANL
C. L. REID	BECHTEL
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NEILL HOWEY	IDNS
Terry Rudek	Westinghouse
William Ascroft-Hutton	HM NII U.K.
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RC TWILLEY	FRA-ANP
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Doug Miller	UCAR
Dan Ingersoll	ORNL
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Dwight Cates	House Commerce

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MIKE KNAPIK	McGRAW-HILL
DOUG WALTERS	NEI
PETER MURRAY	WESTINGHOUSE
MAURICE MAGUGUMELA	PBMR (PTY) LTD

ATTENDANCE SHEETS FOR ADVANCED REACTORS WORKSHOP ON MONDAY, JUNE 4, 2O01

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BJ Snyder	EMC
Gaku Sato	MIT
David Ebert	-
Jennifer Ober	FUSA
Mike Corletti	Westinghouse
DeAnn Raleigh	LIS, Scientech
Frank Lopez Jr	Bechtel
Ed Lyman	NCI
WARD SPROAT	EXELON
JIM MUNTZ	EXELON
ANDREW KADAK	MIT
Doug Miller	UCAR
Sheila R. Fabian	Nuclear Waste News
TODD R ALLEN	ANL-W
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James Moroney	MPR Assoc.
Kiyoshi Ando	NIKKEI News

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Robert J. Baker, Jr.	FRA-ANP
TOM MILLER	U.S. DEPARTMENT of ENERGY
Ron Hagan	US Dept of Energy
LARRY PARME	GENERAL ATOMICS Co
L.E. HOCHREITER	Penn State University
Jim Hammelman	Self
GREG KRUEGER	EXELON NUCLEAR
John Vorees	BNFL INC
Mark R. HOLBROOK	INEEL
William Ascroft-Hutton	HMNII UK
Daniel Ingersoll	ORNL
MARIO CARELLI	Westinghouse
LARRY E. CONWAY	WESTINGHOUSE
Paige T. Nichols	GE
Lorne Hay	SERCA Bechtel

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Tatsuya Taminami	Tepco
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Michael Zavisca	Energy Research, Inc.
Yvel Green	ASTM-Inc.
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Maurice Magugumela	PBMR (PTY) LTD
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NAME	NRC ORGANIZATION
Raymond Durant	Contractor
Joel J. Kramer	NRC/RES/DSARE/~~[illegible]~~ REAHFB
Greg O'Donnell	NRC/RES
Harold Scott	RES
Alan Levin	OCM/RAM
Amy Cubbage	NRR
Nanette Gilles	NRR/FCO
Goutam Bagchi	NRR/DE
N. P. KADAMBI	RES/REAHFB
R. Turtil	DWM/NMSS
Roman Shaffer	RES/ERAB
Eric J. Lee	RES/ERAB
Stuart Rubin	RES
ARTHUR BUSLIK	RES
Eric Benner	NRR
Deirdre Spaulding	NRR
Isabelle Schoenfeld	RES
Cecil Parks	RES

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE MEETING ON THE ADVANCED REACTORS

JUNE 4, 2001
Today's Date

NRC STAFF SIGN IN FOR ACRS MEETING

PLEASE PRINT

NAME	NRC ORGANIZATION
Donald E. Carlson	RES
Michelle Snell	NRR
Dwight Snowberger	NRR
JERRY Wilson	NRR
Steve LaVie	NRR/PSSA
Alan Rae	NRR/FLO.
Daniel Hughes	INEEL
JOE SEBROSKY	NRR/FLO
CATHY Marco	NRC
Sarah Colpo	NRR
Sher Bahadur	RES
Thomas Kenyon	NRR/FLO
Marsha Gamberoni	NRR/FLO
James BONGARRA	NRR/DIPM
Richard Lee	RES
Sudhamay Basu	RES
Ali Behbahani	RES
Diane Jackson	NRR

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Steve Long	NRR/DSSA/SPSB
JOE WILLIAMS	NRR/ADIP/FLO

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RICH BARRETT	NRR/FLU
Katherine Kohlhepp	NMSS/FCSS
MAHESH CHAWLA	NRR/DLPM
Raji Tripathi	RES/DRAA
Matt Blevins	NMSS/DWM
UNDINE SHOOP	NRR/SRXB
Merri Horn	NMSS/IMNS
John A. Calvert	RES/DET/ERAB
Richard J. Eckenrode	NRR/DIPM/IOLB
Stephanie Bush-Goddard	NMSS/IMNS
James SMITH	NMSS/RTG
Mark Blumberg	NRR/DSSA
RALPH CARUSO	NRR/SRXR
Michael McNeil	RES/DET/MEB
JOHN H. FLACK	RES/DSARE
Torre Taylor	NMSS/IMNS
Betty Ann Torres	NMSS/IMNS
MAGGALEAN W. WESTON	ACRS
Millard Wohl	NRR/DSSA/SPSB
BOB YOUNGBLOOD	ISL, Inc.

ATTENDANCE SHEETS FOR ADVANCED REACTORS WORKSHOP ON TUESDAY, JUNE 5, 2O01

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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JUNE 5, 2001
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NAME	AFFILIATION
CAREY W. FLEMING	WINSTON & STRAWN
RICH JANATI	PA DEP/BRP
YUNG Y. LIU	ANL
C. L. REID	BECHTEL
LARRY PARME	GENERAL ATOMICS
PAIGE NEGUS	GE
NEILL HOWEY	IDNS
Terry Rudek	Westinghouse
William Ascroft-Hutton	HM NII U.K.
A GEORGE	PBMR.
R.E. Hagan	DofEnergy
R.J. Baker	Fra. ANP
RC TWILLEY	FRA-ANP
Jolene Robinson	DOE-ID
Doug Miller	UCAR
Dan Ingersoll	ORNL
KENNETH ROGERS	SELF
Gaku Sato	MIT
L.E. HOCHREITER	Penn State University

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Johan Slabber	PBMR
Vijay M. Nilekani	EXELON
Jenny Weil	MGH
Mujid S. Kazimi	MIT
Lance Hoy	GERCH Bechtel
MIKE CORLETTI	WESTINGHOUSE
Jennifer Ober	Framatome
Roger Huston	LSS
Jim Meyer	ISL
Andrew KADA	MIT
WARD SPROAT	EXELON
George Davis	Westinghouse
Ed Lyman	NCI
ADRIAN HEYMER	NEI.
JESUS (JAY) ARIAS	~~EU~~ FIU - HCET
Eric Wieser	BPI
Russ Bell	NEI
Deann Raleigh	US, Scientech
Thecla Fabian	Nuclear Waste News
Stephen Routh	Bechtel

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Atambir Rao	GE
Charles Forsberg	ORNL
Samim Arghare	JF
RAY REITH	INEEL / DOE
Mario Carelli	W
Jim Muir	EXCON
Ron Simard	NEI
JOE HEGNER	Dominion
NEIL TODREAS	MIT
Dave Iguarer	self
Michael J. Golay	MIT
Tatsuya Taminami	Tepco
Elaine Hiruo	McGraw-Hill
John R. Guth	Sandia
Allen Camp	Sandia
Xuu. Guan	ASTM, Inc.
TED QUINN	GA.
Ed WALLACE	EXELON
John Hufnagel	Exelon
[illegible]	Public Citizen

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Charles Brinkman	Westinghouse
John Mongoven	NRC Gross Rptr
MARINA SAVKINA	MIT
MIKE KNAPIK	McGRAW-HILL
DOUG WALTERS	NEI
PETER MURRAY	WESTINGHOUSE
MAURICE MAGUGUMELA	PBMR (PTY) LTD

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NAME	AFFILIATION
Linda Gunter	Edlow Int'l
Dwight Cates	House Commerce

NRC

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C. MARCO	OGC
G. BAGCHI	NRR/DE
Edward D Throm	NRR/DSSA
RICH BARRETT	NRR/FLO
Michelle Snell	NRR/DSSA
Dwight Snowberger	NRR/DSSA
Richard Lee	RES
MARK HOLBROOK	INEEL
Sarah Colpo	NRR
Steve LaVie	NRR/DSSA
Maggalean W. Weston	ACRS
JERRY Wilson	NRR/FLO
Marsha Gamberoni	NRR/FLO
THOMAS KENYON	NRR/FLO
ALAN RAE	NRR/FLO.
DIANE JACKSON	NRR/FLO
Steve Long	NRR/DSSA/SPSB
Donald E. Carlson	RES
JOHN FLACK	NRC/RES/DSARE

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Joel Kramer	RES/DSARE/REAHFB
Eric Benner	NRR/FLO
JOE WILLIAMS	NRR/ADIP/FCO
Amy Cubbage	NRR/FCO
Stuart Rubin	RES
Jerome Murphy	OCFO
Deirdre Spaulding	NRR
Alan Levin	OCM/RAM
Dan Hughes	INEEL
MICHAEL SNODDERLY	NRR/DSSA/SPSB
Tanya Eaton	NRR/DSSA/SPLB
CHIP CAMERON	OGC
JF Costello	RES
Sher Bahadur	RES
N. P. KADAMBI	RES
Katherine Kohlhepp	NMSS/FCSS
S	
Greg O'Donnell	RES
Nanette Gilles	NRR/FLO

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NAME	NRC ORGANIZATION
TIM REED	NRC/NRR/DRIP/RGEB
Norman St Amour	NRC/OGC
JOE WILLIAMS	NRR/ADIP/FLO

(1)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

COMMISSIONER

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 is 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 3 years, and that improvements in regulatory effectiveness and efficiency are changing from goals into reality. But 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 U.S. 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. And 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. And 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,
to work only for the best
and
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**

Table 1

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
SUBCOMMITTEE ON ADVANCED REACTORS
TWO WHITE FLINT NORTH AUDITORIUM
11545 ROCKVILLE PIKE,
ROCKVILLE, MD 20852
JUNE 4 - 5, 2001

Contact: Michael Markley, (301) 415-6885
or MTM@NRC.GOV

REGULATORY CHALLENGES FOR FUTURE NUCLEAR POWER PLANTS

	TOPIC	PRESENTER	TIME
1.	Introduction	Tom Kress George Apostolakis	9:00- 9:15 am
2.	Keynote Address	Commissioner Diaz	9:15- 10:00 am
		BREAK	10:00- 10:15 am
3.	DOE Presentations		
•	Overview and Introduction to Generation IV Initiative	W. Magwood (DOE)	10:15- 10:40 am
•	Generation IV Goals and Roadmap Effort	R. Versluis (DOE)	10:40- 11:00 am
•	Near-Term Deployment Efforts	T. Miller (DOE)	11:00- 11:25 am
•	Generation IV Concepts	R. Versluis (DOE)	11:25- 11:40 am
•	Next Steps Generation III+/IV	S. Johnson (DOE)	11:40- 12.00 pm
		LUNCH	12:00- 1:00 pm
4.	Generation IV Design Concepts		
•	Pebble Bed Modular Reactor	W. Sproat (Exelon)	1:00- 1:45 pm
•	International Reactor Innovative and Secure	M. Carelli (Westinghouse)	1:45- 2:30 pm
•	General Atomic- Gas Turbine Modular Helium Reactor	L. Parme (General Atomics)	2:30- 3:15 pm

	TOPIC	PRESENTER	TIME
		BREAK	3:15- 3:30 pm
•	General Electric Advanced Liquid MetalReactor and ESBWR designs	A. Rao (General Electric)	3:30- 4:15 pm
5.	NRC Presentations		
•	NRR Response to 2/13/2001 SRM on Evaluation of NRC Licensing Infrastructure	M. Gamberoni N. Giles E. Benner A. Rae T. Kenyon	4:15- 5:15 pm
•	Planned RES Activities	J. Flack S. Rubin	5:15- 6:00 pm
6.	Panel Discussion on Industry and NRC Licensing Infrastructure Needed for Generation IV Reactors	Panelists: J. Flack, NRC S. Johnson, DOE W. Sproat, Exelon M. Carelli, Westinghouse L, Parme, General Atomics A. Rao, General Electric	6:00- 7:00 pm
1.	Closing Remarks and Recess	T. Kress, ACRS G. Apostolakis, ACRS	7:00 pm

COMMISSIONER DIAZ

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Remarks of Commissioner Nils J. Diaz

United States Nuclear Regulatory Commission

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- 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. And 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. And 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,
to work only for the best
and
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**

Table 1

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
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Important to National Security	Yes	Yes
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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,

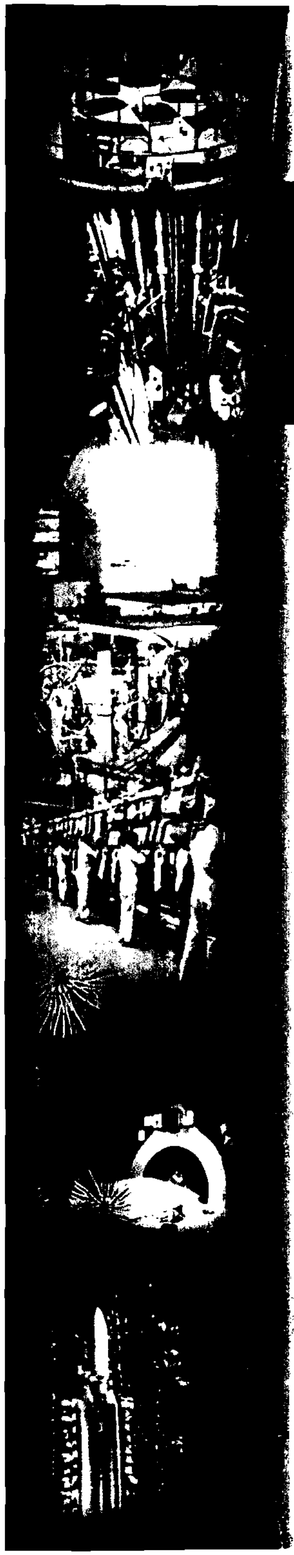
and

to expect only the best

Figure 12

DOE

MAGWOOD, IV



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

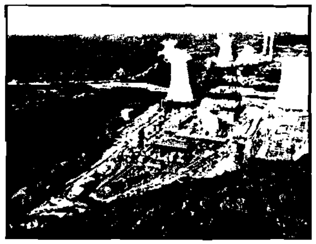
Generation IV Systems

- **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**

The Evolution of Nuclear Power

Generation I

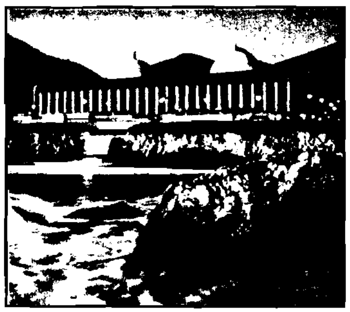
Early Prototype Reactors



- Shippingport
- Dresden, Fermi I
- Magnox

Generation II

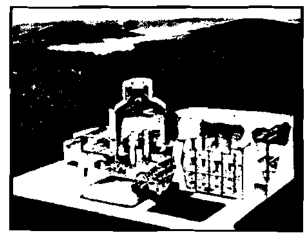
Commercial Power Reactors



- LWR-PWR, BWR
- CANDU
- VVER/RBMK

Generation III

Advanced LWRs



- ABWR
- System 80+
- AP600
- EPR

Near-Term Deployment

Generation III+ Evolutionary Designs Offering Improved Economics

Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant

Gen I | Gen II | Gen III | Gen III+ | Gen IV

1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | 2030

Nuclear Energy Research Advisory Committee (NERAC)

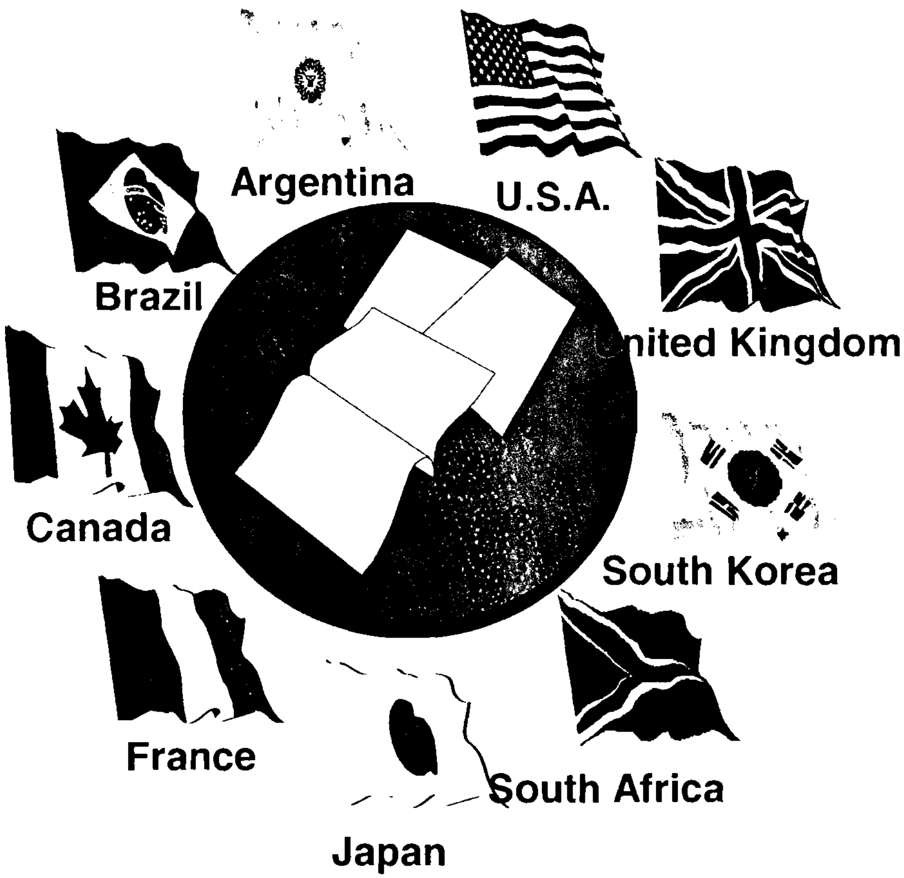
- **Subcommittee on Generation IV Technology Planning**
  - Established in October 2000 to provide guidance on development of the Generation IV Technology Roadmap
  - Membership from U. S. Industry, laboratories, and academia
  - Co-chaired by Neil Todreas, MIT and Sal Levy, GE (retired)

Nuclear 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

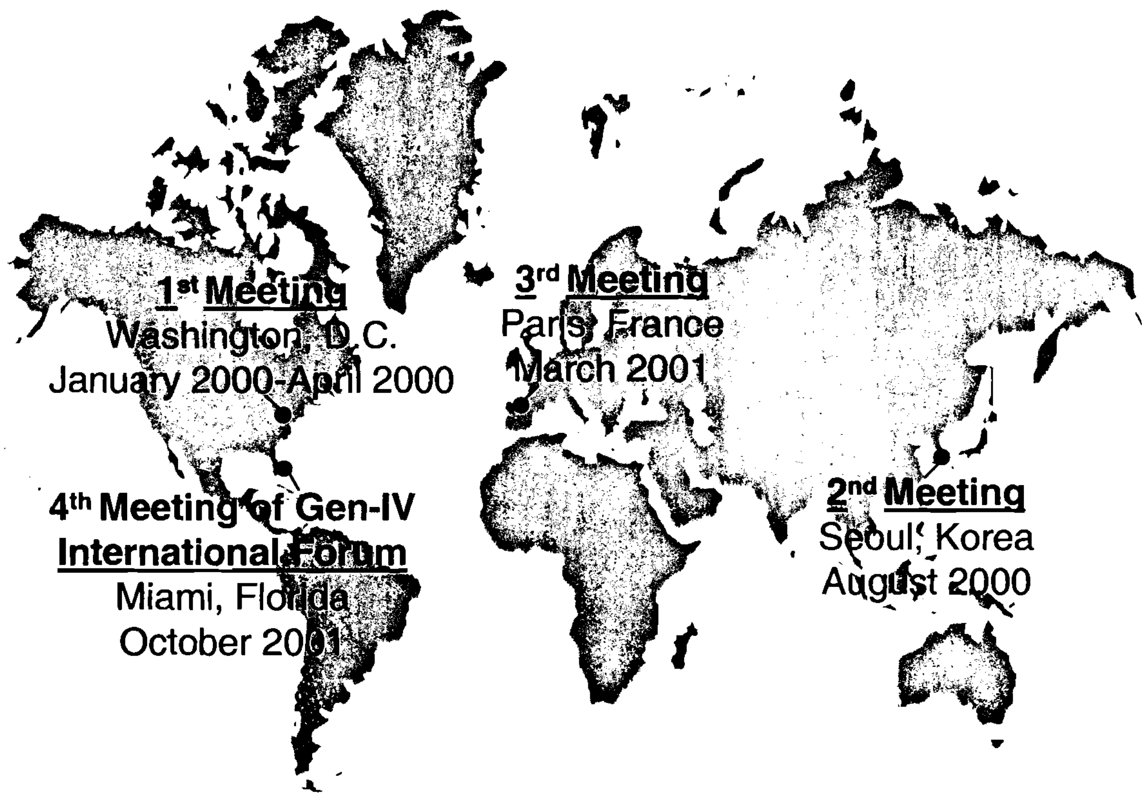
Generation IV International Forum



- 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

Generation IV International Forum

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



Generation IV Initiative

Near-term Objectives

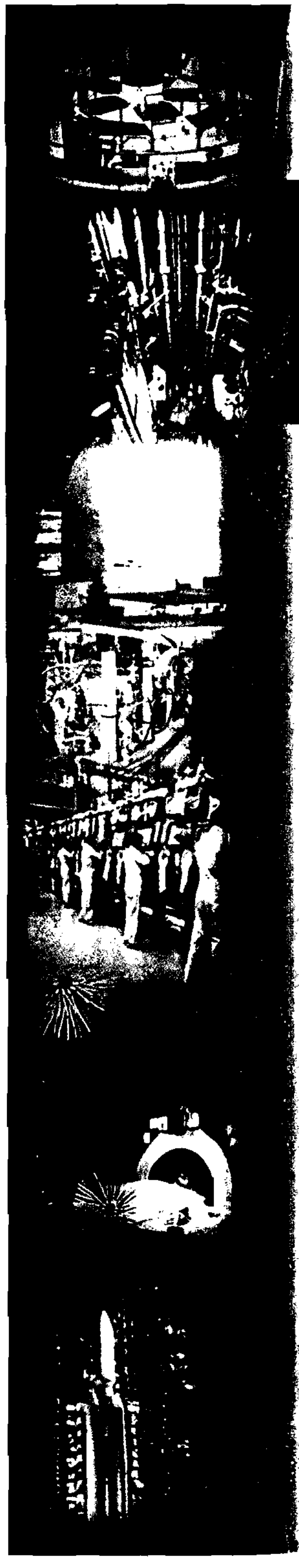
- Establish Near-term Deployment Working Group
- Identify institutional and regulatory barriers to new plant deployment in the U.S.
- Provide recommendations on appropriate government actions to assist in addressing barriers (complete by September 2001)

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)

DOE

VERSLUIS



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**

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
- *Resource inputs*
- *Waste outputs*
- *Nonproliferation*

Safety & Reliability Goals
- *Excellence*
- *Core damage*
- *Emergency response*

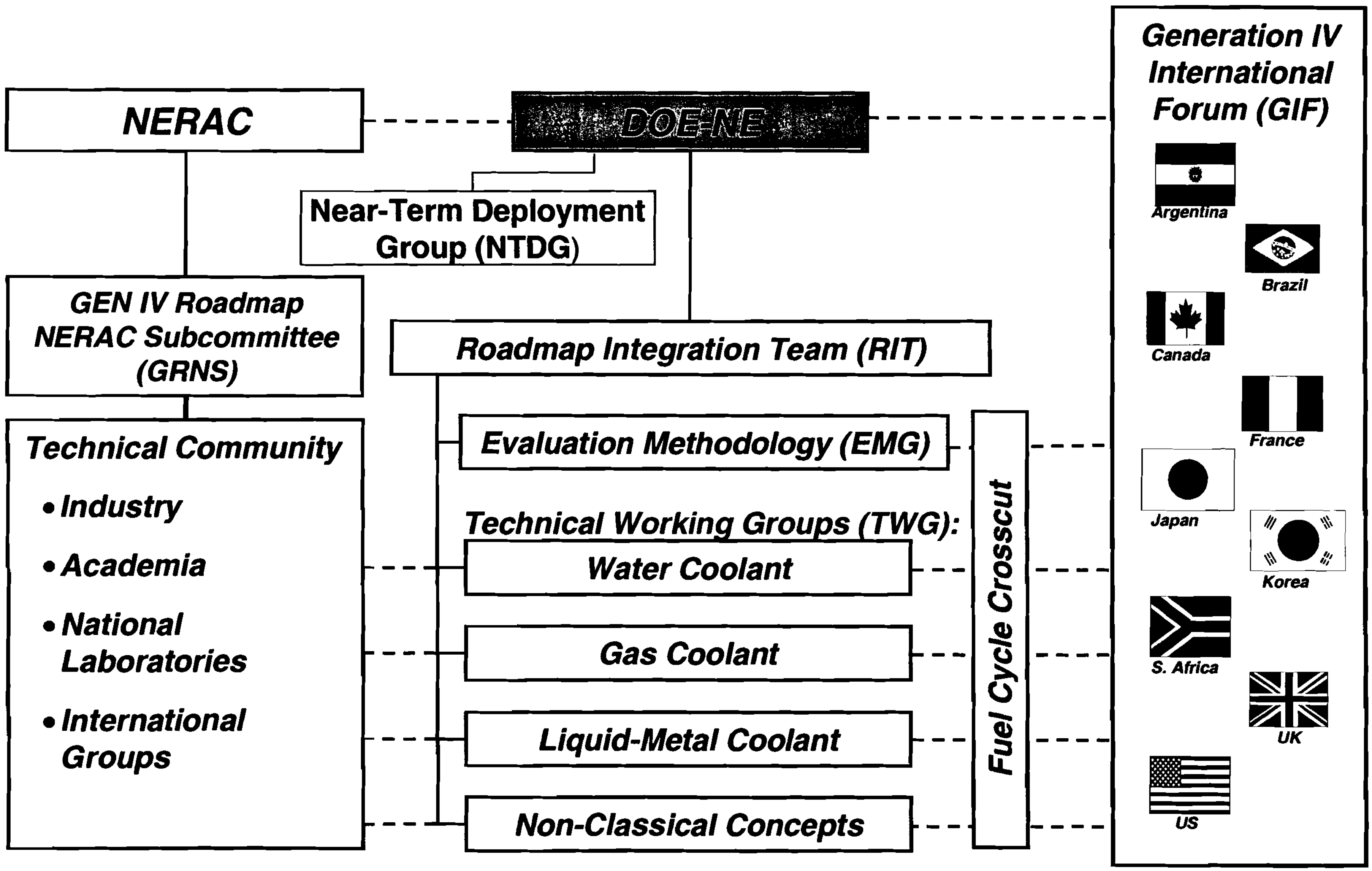
Economics Goals
- *Life cycle cost*
- *Risk to capital*

Key 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**

Generation IV Technology Roadmap: Organization



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

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

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

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.

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*

Viability R&D

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

Backups

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

Evaluation 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

Fuel Cycle Crosscut Group

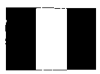
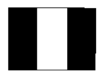
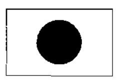
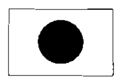
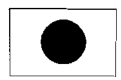
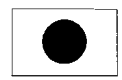
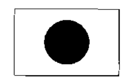
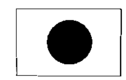
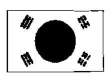
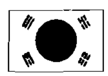
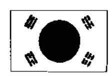
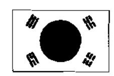
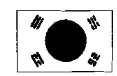
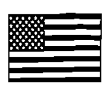
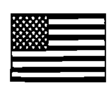
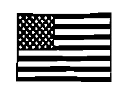
Charter

- 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

International 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						

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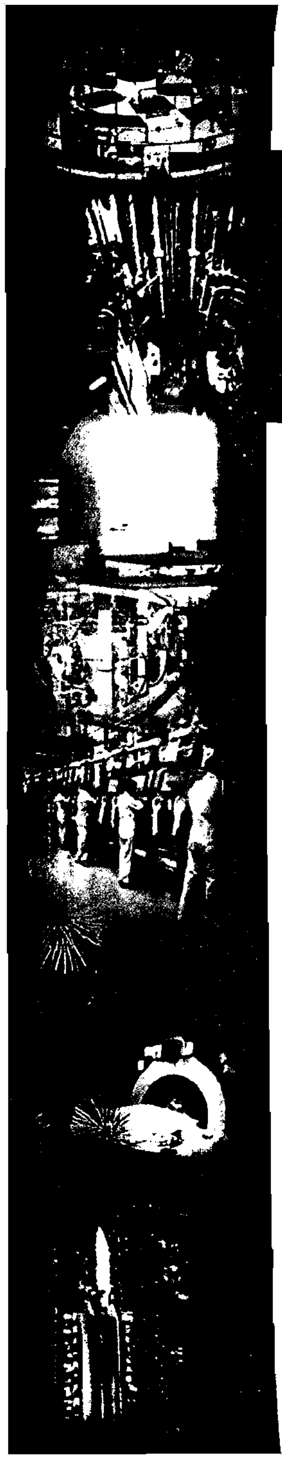


Department of Energy Near-Term Deployment Working Group

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

Thomas P. Miller

June 4, 2001

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

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

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

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

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

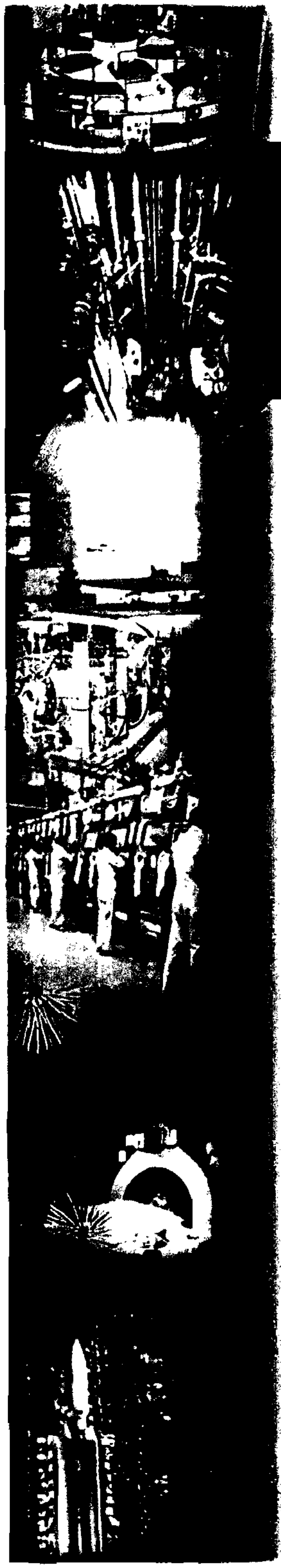
Near-Term Deployment Group

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

DOE

VERSLUIS



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

Overview

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

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.

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

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

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

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)

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

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)

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

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

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

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)

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)

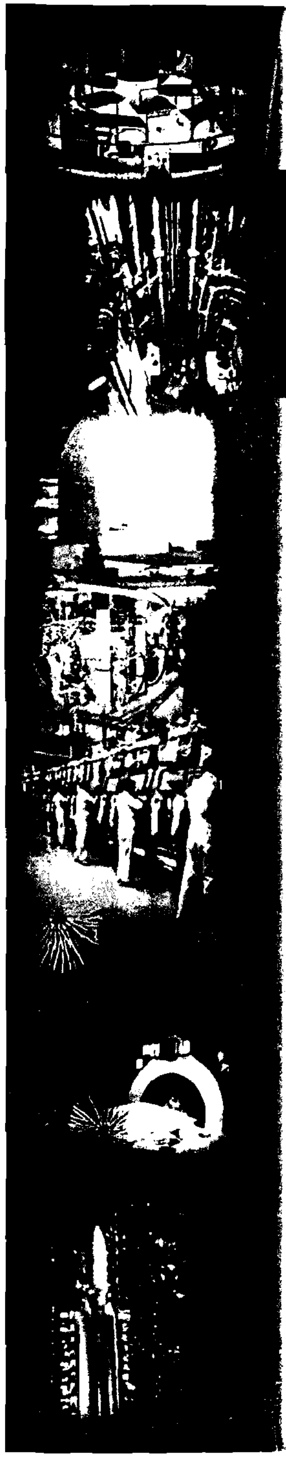
Current Activities

- **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

DOE

JOHNSON



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

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

Generation IV 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

EXELON

SPROAT
SLABBER

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

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

Agenda

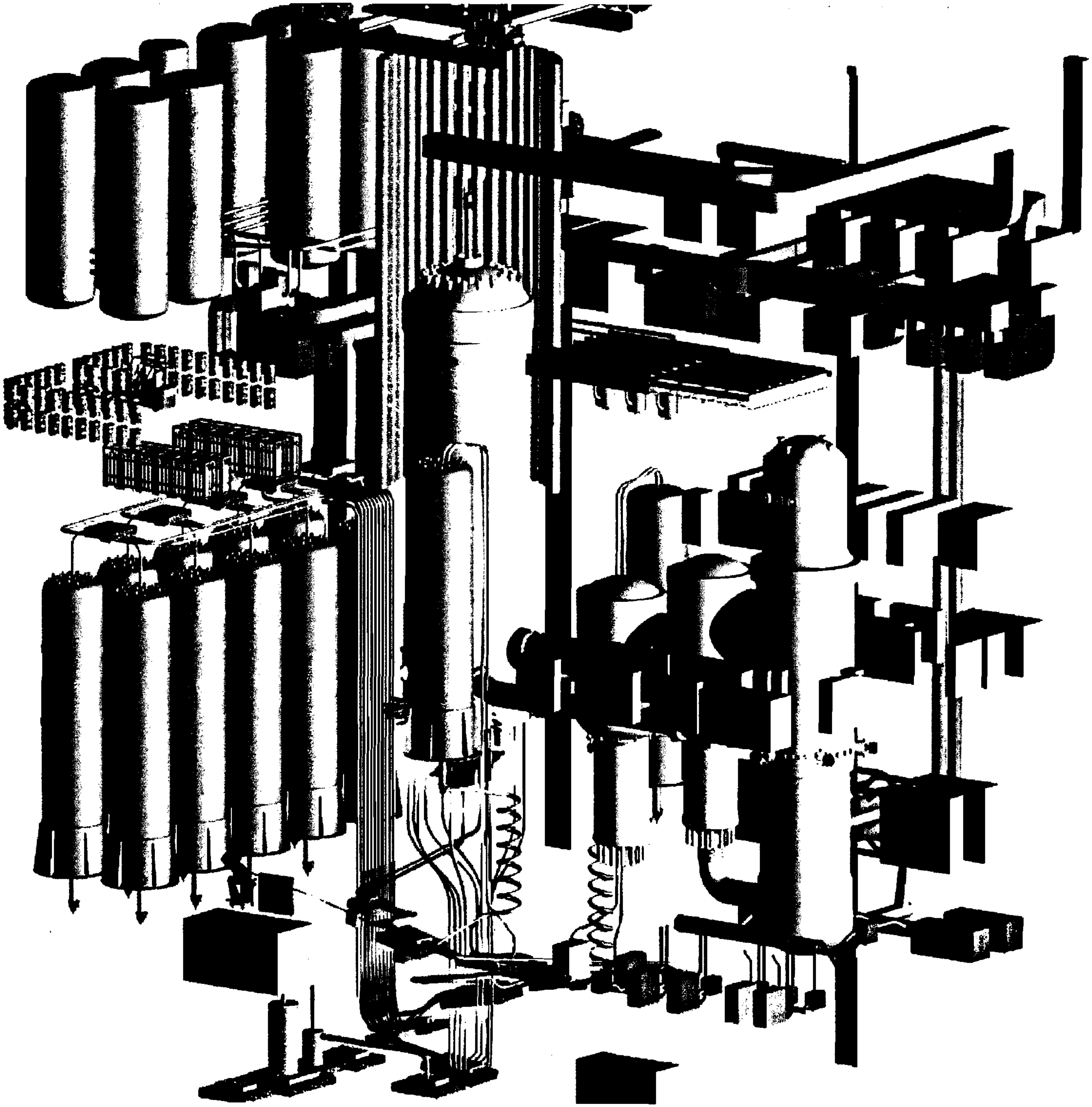
- Project Overview
- PBMR Safety Design Features
- U.S. Licensing Challenges

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

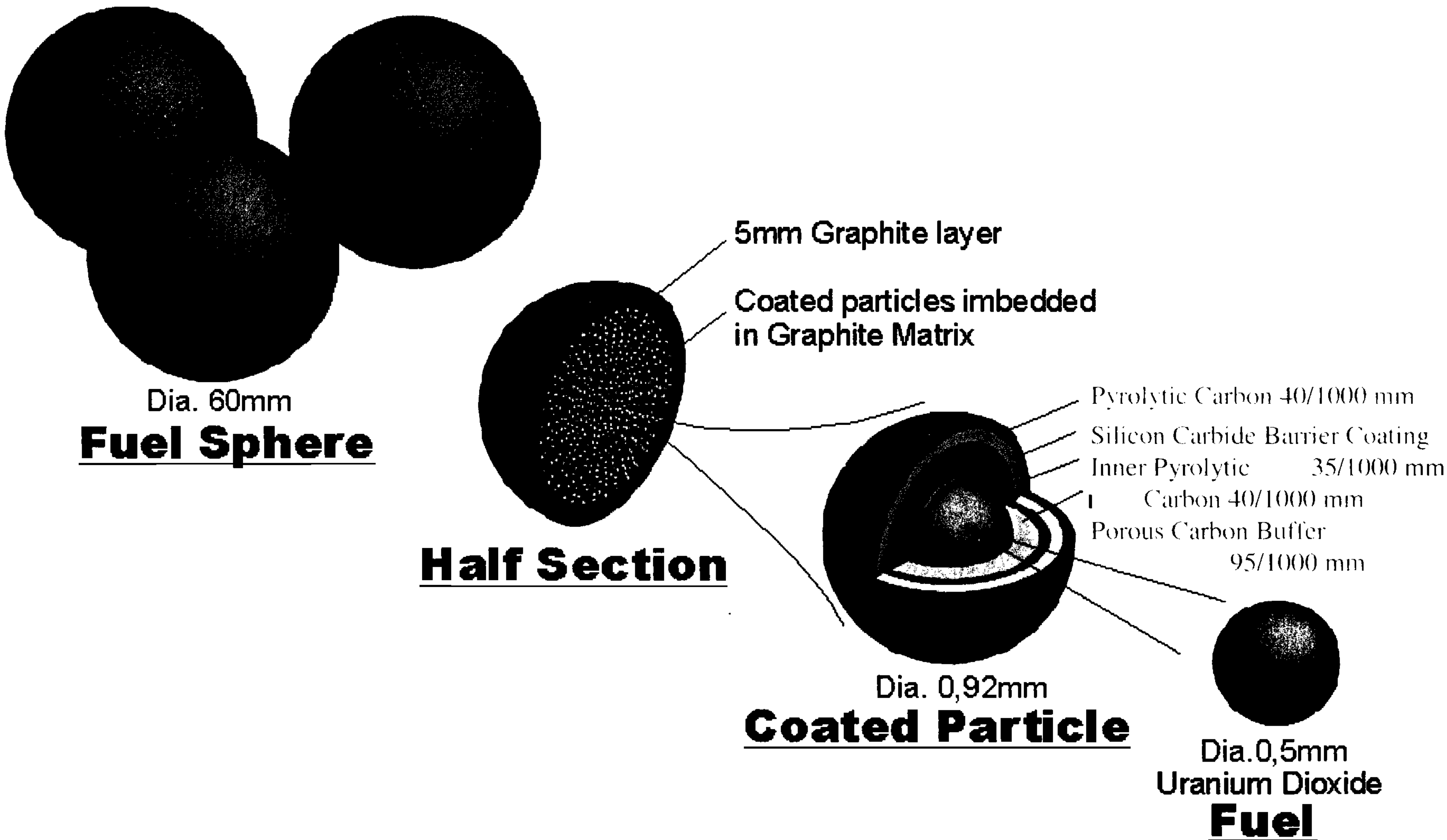
- Employ passive and active engineered features
- Provide prevention and mitigation capability
- Reduce dependence on operator actions



Reactor Safety Design Principles

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

FUEL ELEMENT DESIGN FOR PBMR



Jan 31 2001

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

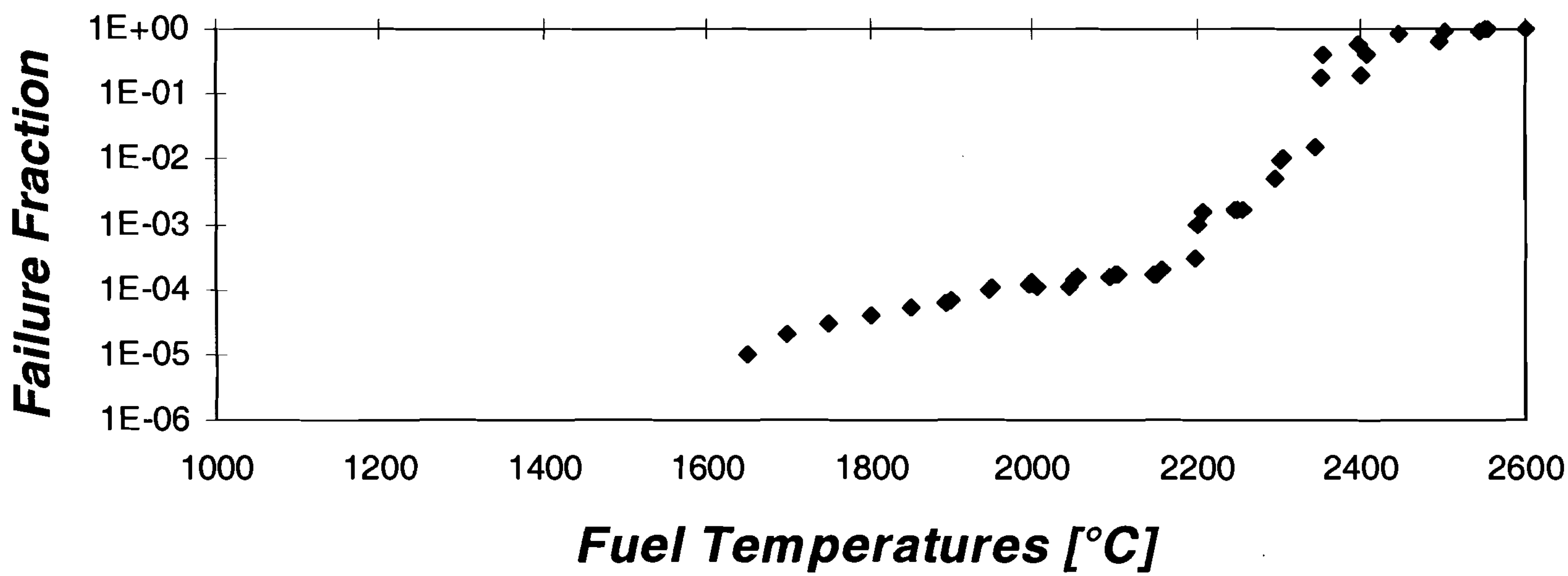
Assure Fuel Integrity (cont'd)

- **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

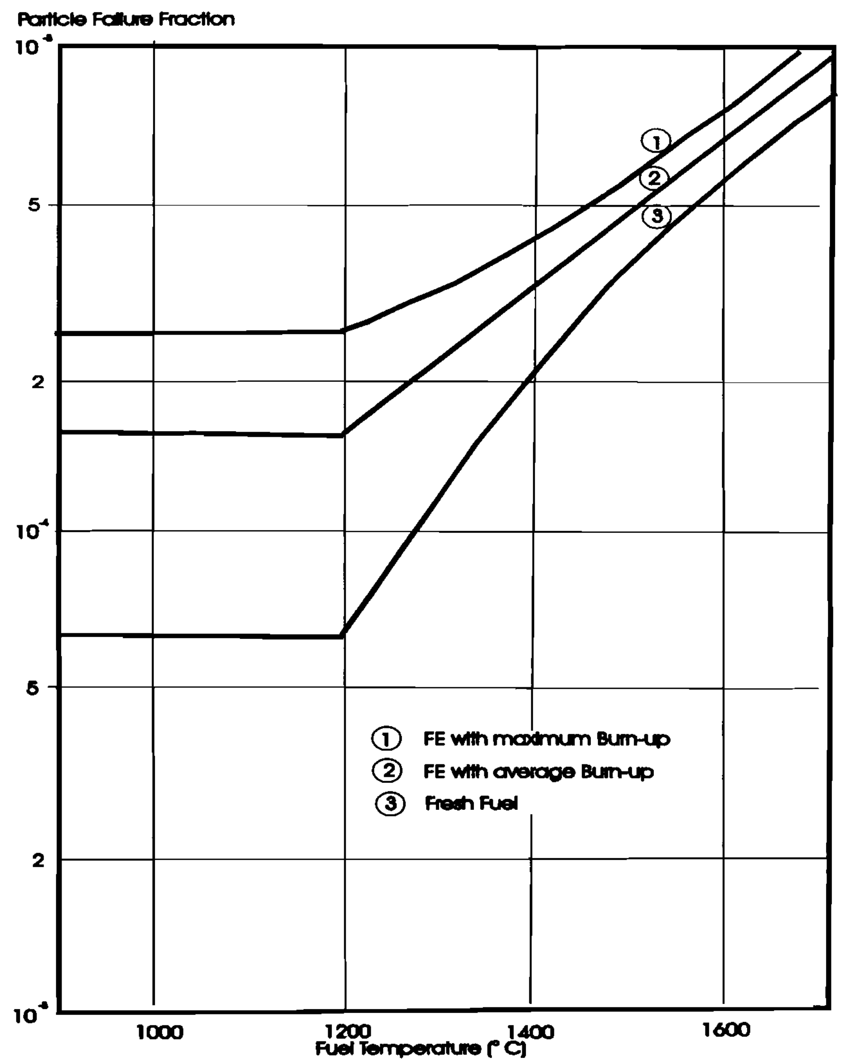
Assure Fuel Integrity (cont'd)

- **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

WESTINGHOUSE
CARELLI

IRIS

International Reactor Innovative and Secure

M. D. Carelli

Westinghouse Science & Technology

ACRS Subcommittee Workshop on Advanced Reactors

June 4, 2001

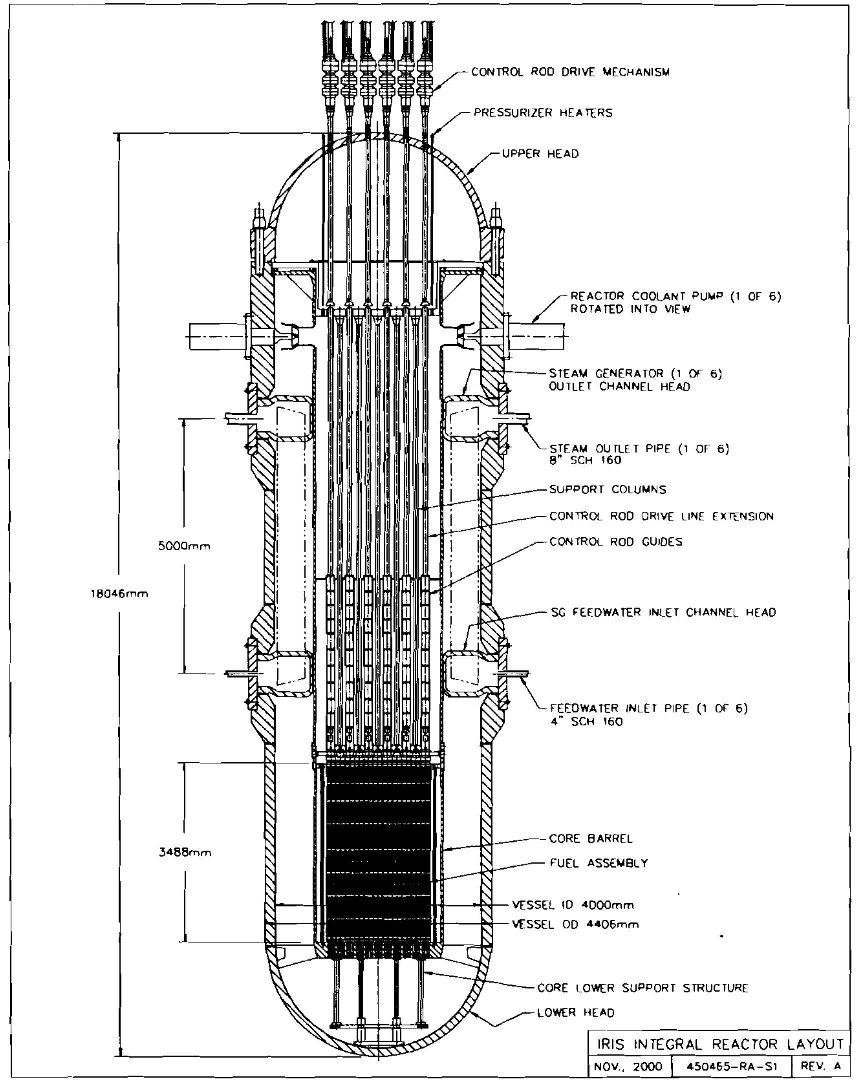
OUTLINE

- 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

OVERVIEW

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



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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 6

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IRIS Consortium Members Functions

Separate file -

IRIS Consortium Members for VG ACRS 60401.doc

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		

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

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)

CONFIGURATION

335 MWe LAYOUT

Separate File -

335 MWe Layout LEC 450475-RA-S2

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

ANSALDO PHOTO

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

ENHANCED SAFETY APPROACH
(Safety by Design)

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"

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

IMPLEMENTATION OF IRIS SAFETY BY DESIGN

Separate file -

Implementation of IRIS Safety by Design
52401 ACRS & Cairo

AP600 CLASS IV ACCIDENTS AND IRIS RESOLUTION

	Accident	IRIS Safety by Design	IRIS Resolution
1.	Steam system piping failure (major)	Reduced probability 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

IRIS CONTAINMENT

- It performs containment function

<u>plus</u>

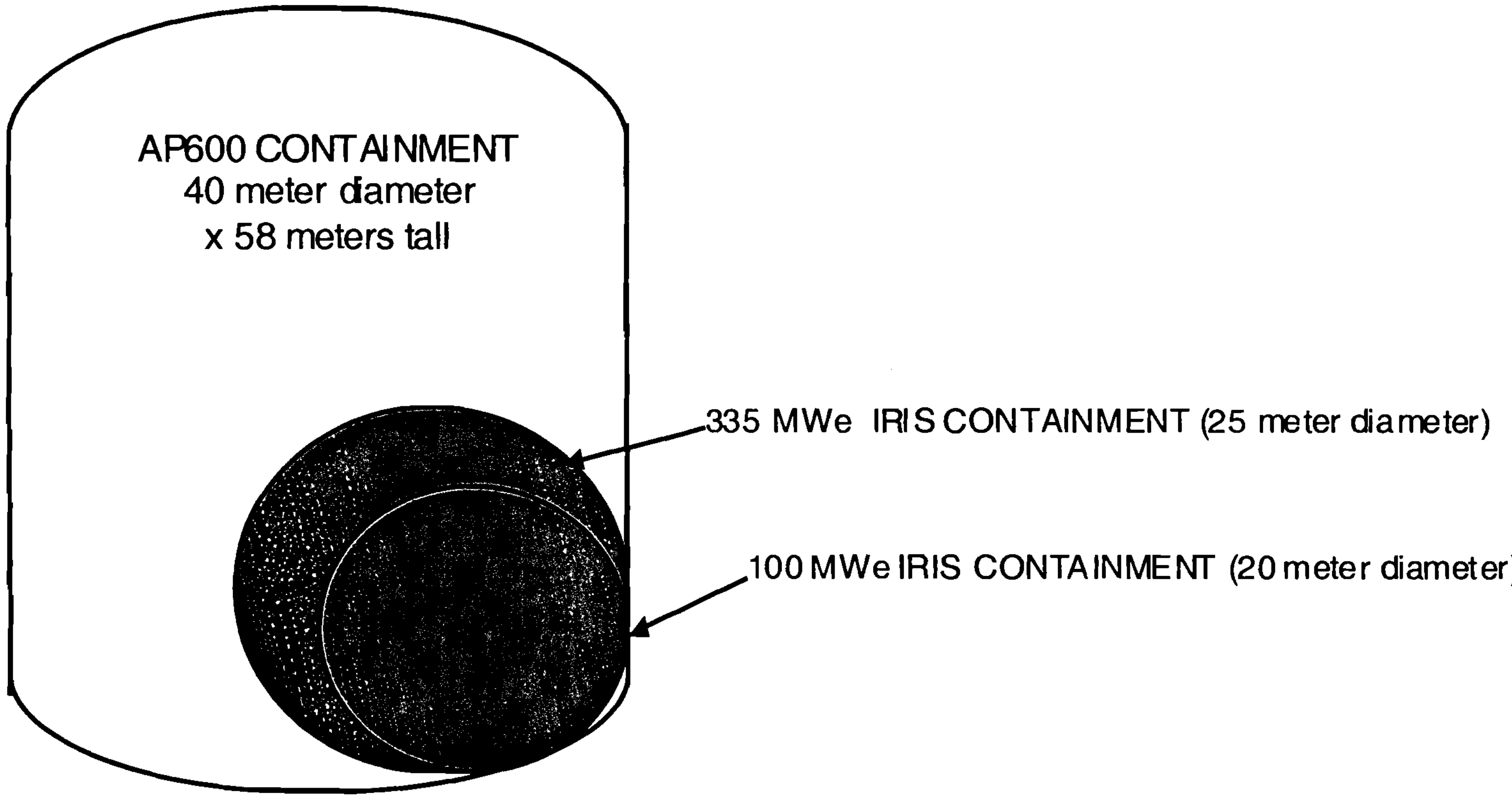
- In concert with integral vessel, it practically eliminates LOCAs as a safety concern

<u>On first principles</u>

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)

AP600/IRIS Containment Size Comparison



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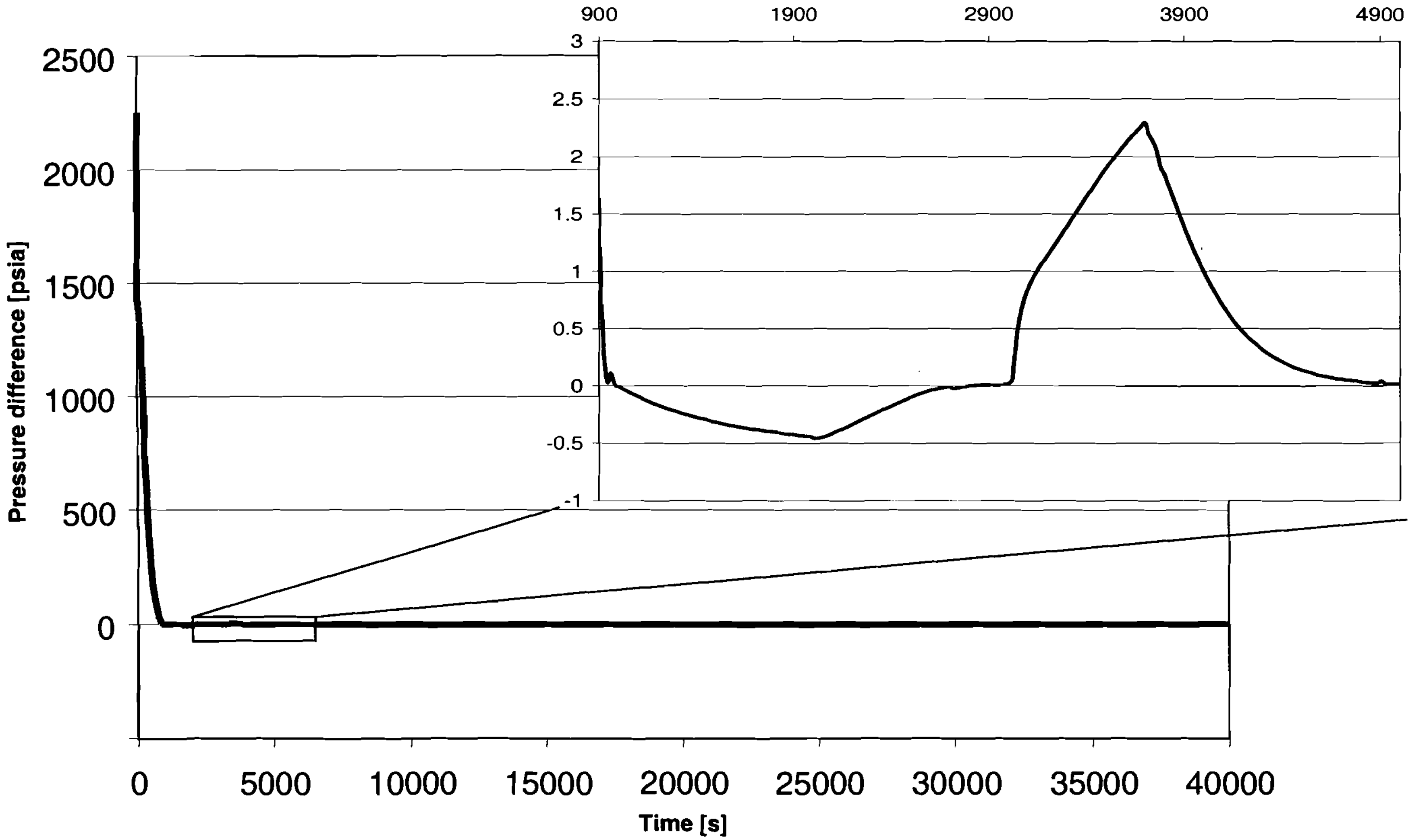
ANALYSES PERFORMED

- **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)

REACTOR VESSEL/CONTAINMENT PRESSURE DIFFERENTIAL EQUALIZES QUICKLY



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Viewgraph 24

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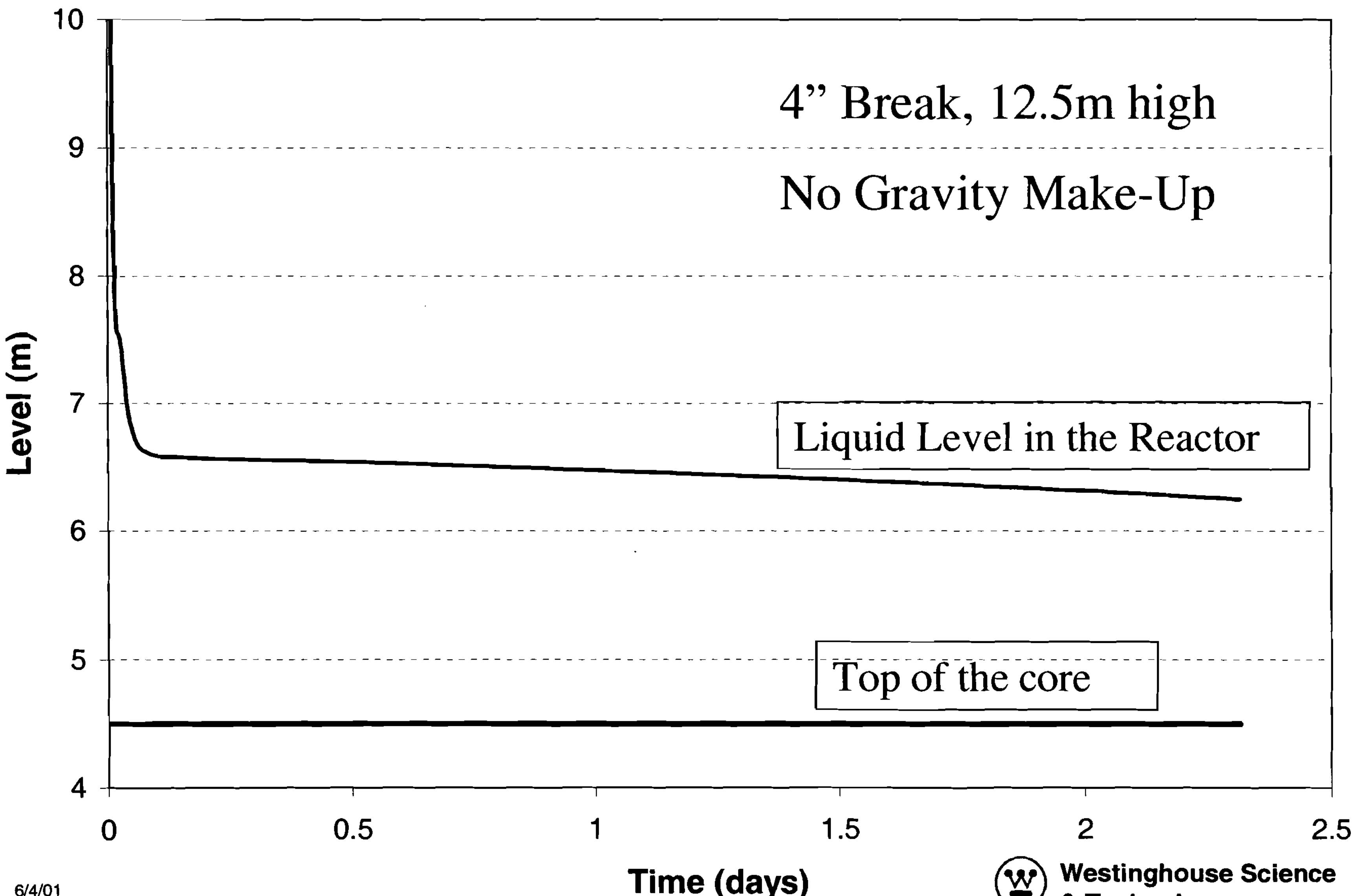
CORE STILL UNDER 2 METERS OF WATER AFTER 2 DAYS



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MAINTENANCE OPTIMIZATION

GOAL

- Perform maintenance shutdowns no sooner than 48 months

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

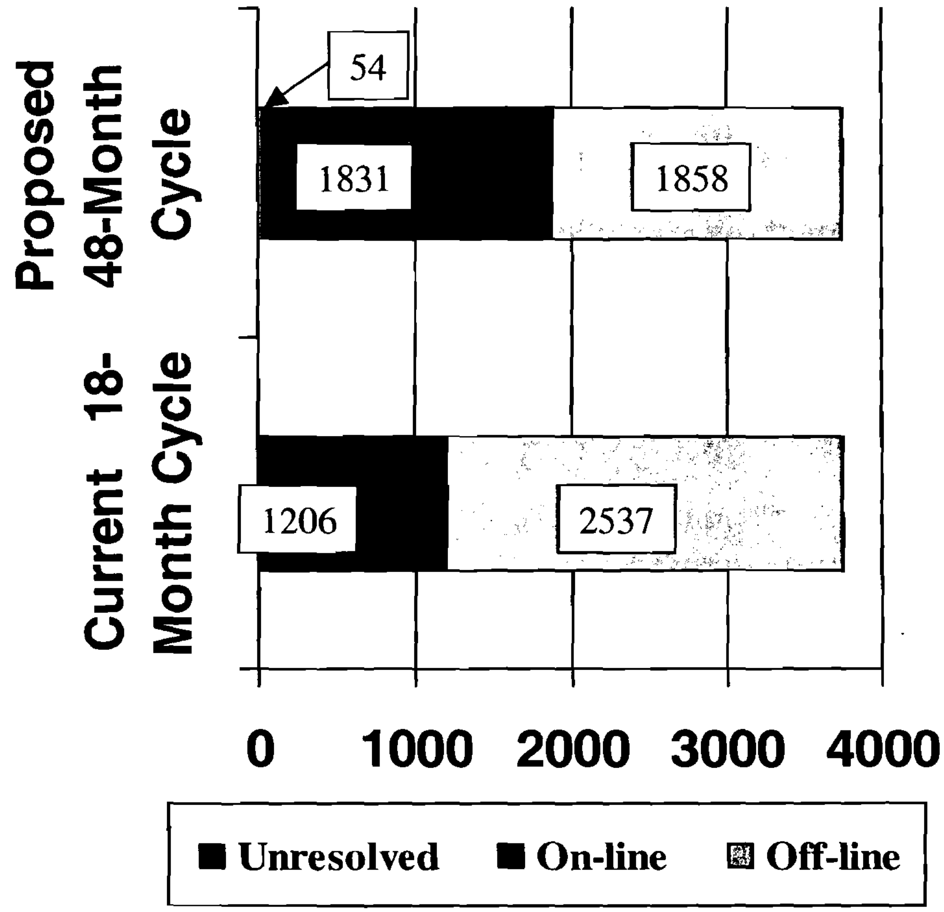
THE BOTTOM LINE

- **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**

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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ISSUES

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)

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

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

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

SUMMARY AND CONCLUSIONS

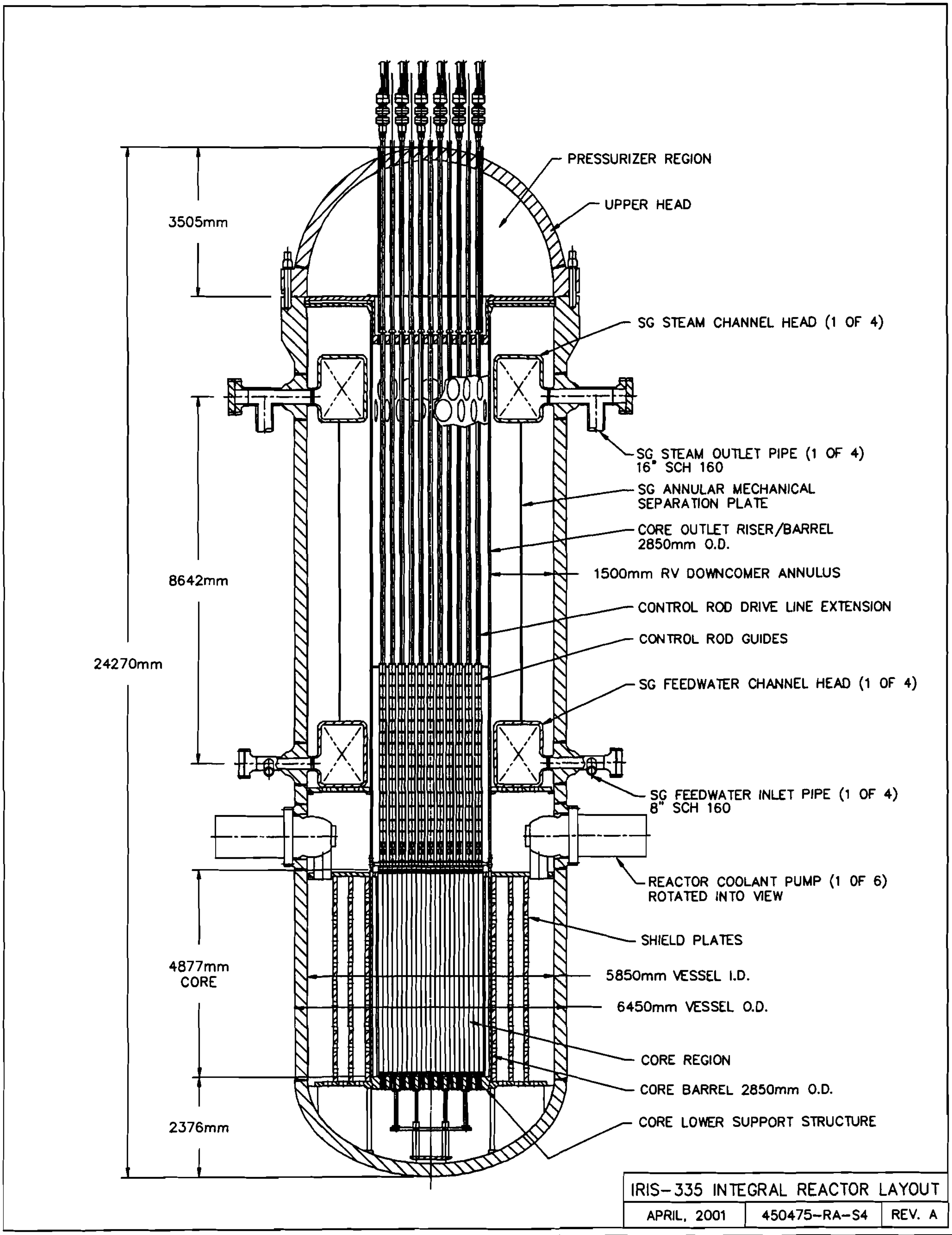
- IRIS specifically designed to address Gen IV requirements
- Modularity and flexibility address utility needs
- Enhanced safety through safety by design and simplicity
- IRIS is based on proven LWR technology, newly engineered for improved performance
- Testing program needs to start in 2002 on selected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

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

335 MWe Vessel Layout



GENERAL ATOMICS
PARME

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

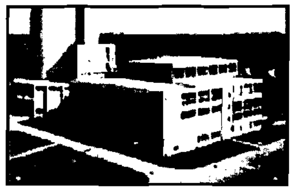
U.S. AND EUROPEAN TECHNOLOGY BASES FOR MODULAR HIGH TEMPERATURE REACTORS

BROAD FOUNDATION OF HELIUM REACTOR TECHNOLOGY

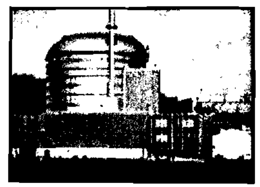
EXPERIMENTAL REACTORS

DEMONSTRATION OF BASIC HTGR TECHNOLOGY

DRAGON
(U.K.)
1963 - 76

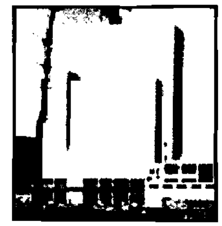


AVR
(FRG)
1967 - 1988



PEACH BOTTOM 1
(U.S.A.)
1967 - 1974

FORT ST. VRAIN
(U.S.A.)
1976 - 1989

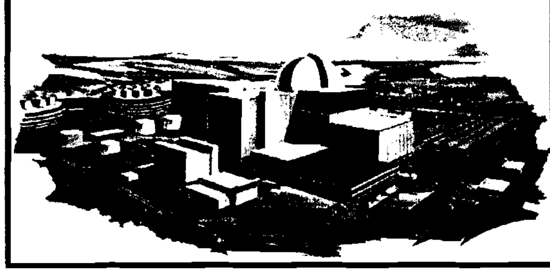


THTR
(FRG)
1986 - 1989

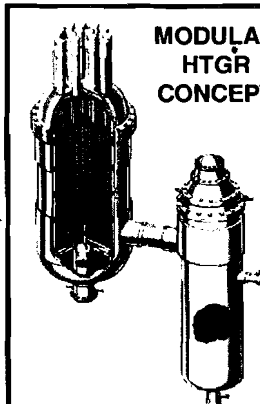
HTGR TECHNOLOGY PROGRAM

- MATERIALS
- COMPONENTS
- FUEL
- CORE
- PLANT TECHNOLOGY

LARGE HTGR PLANTS

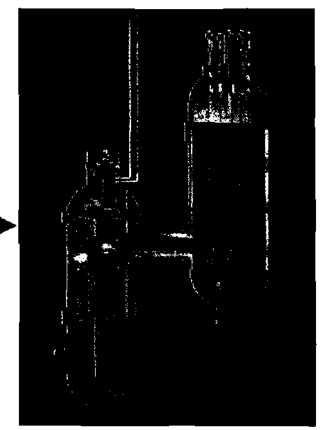


MHTGR



Steam Cycle

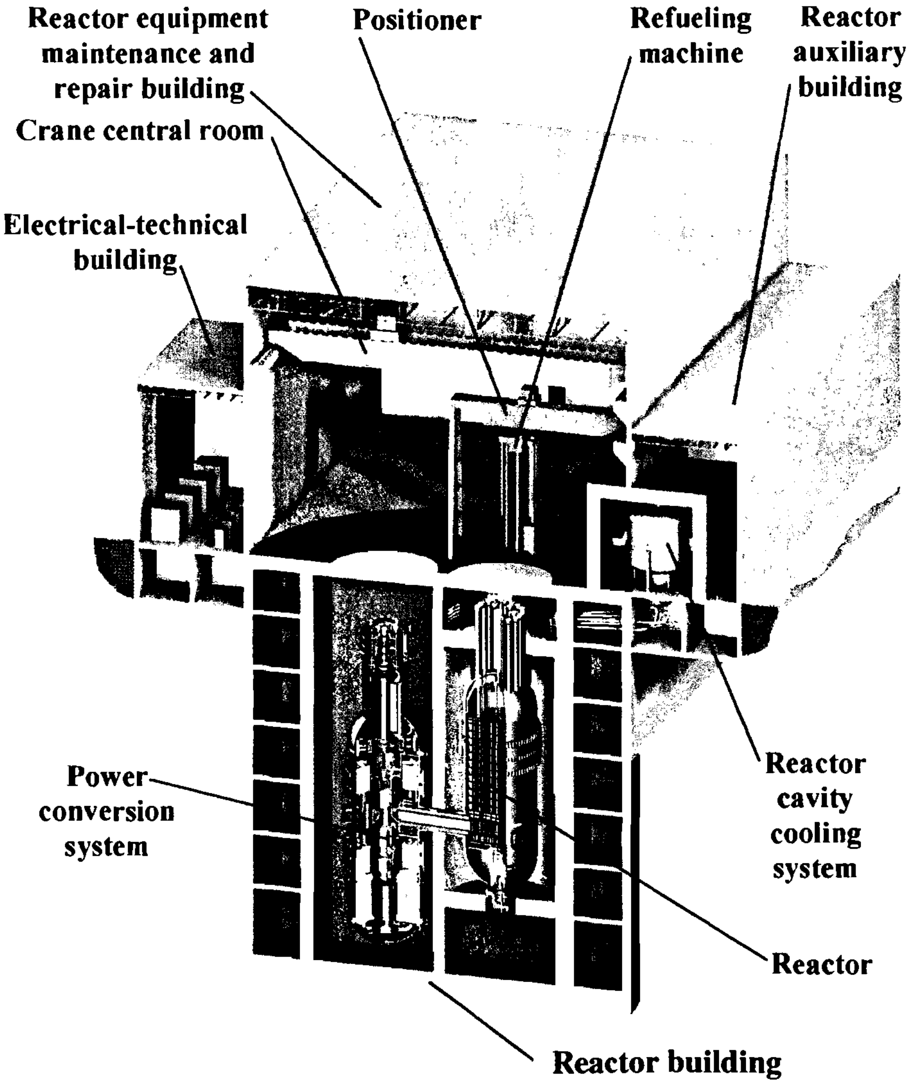
GT-MHR



Gas Turbine Cycle

GENERAL ATOMICS

3D Arrangement of Plant

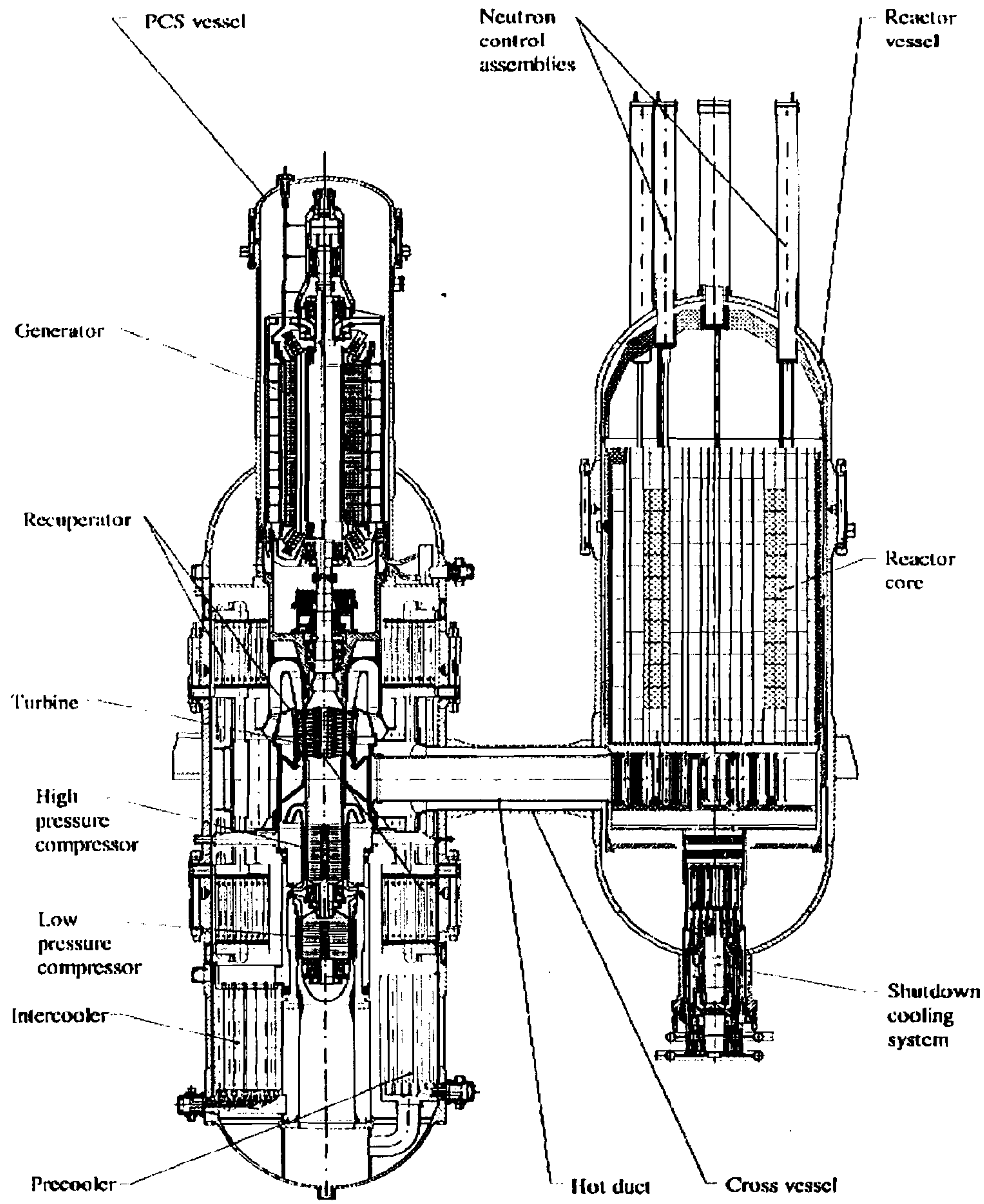


- 600 MW(t) - 285 MW(e)
- Power conversion system integrated in single vessel
- Vented, below grade reactor building
- Continuously operating, natural circulating, air cooled reactor cavity cooling

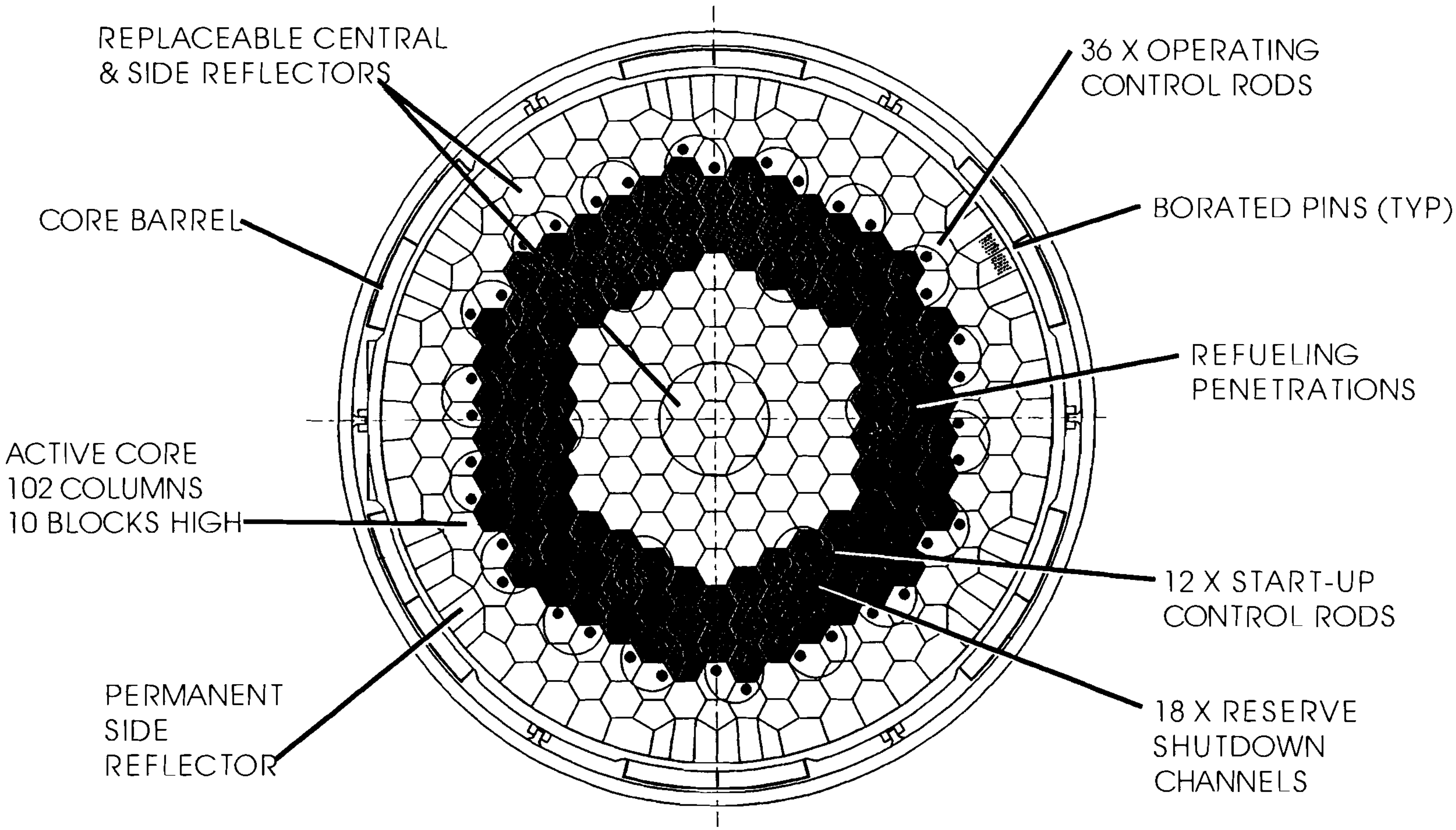
GENERAL ATOMICS

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

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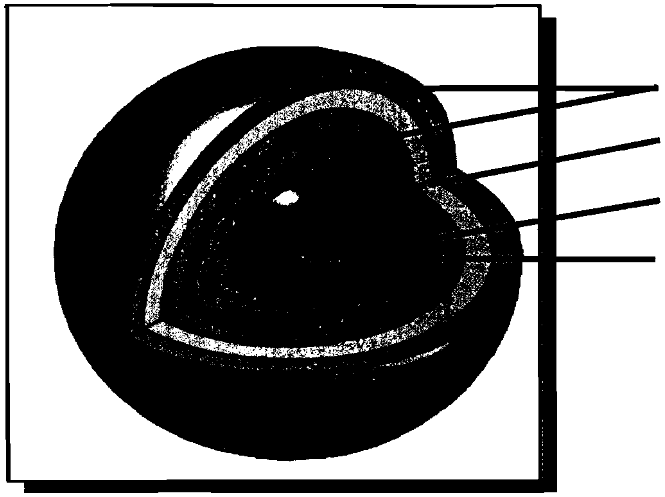
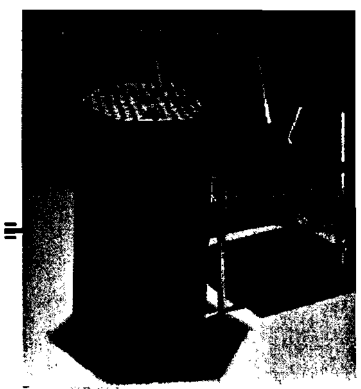
CERAMIC COATED FUEL IS KEY TO GT-MHR SAFETY AND ECONOMICS



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

PARTICLES

COMPACTS



FUEL ELEMENTS

GENERAL ATOMICS

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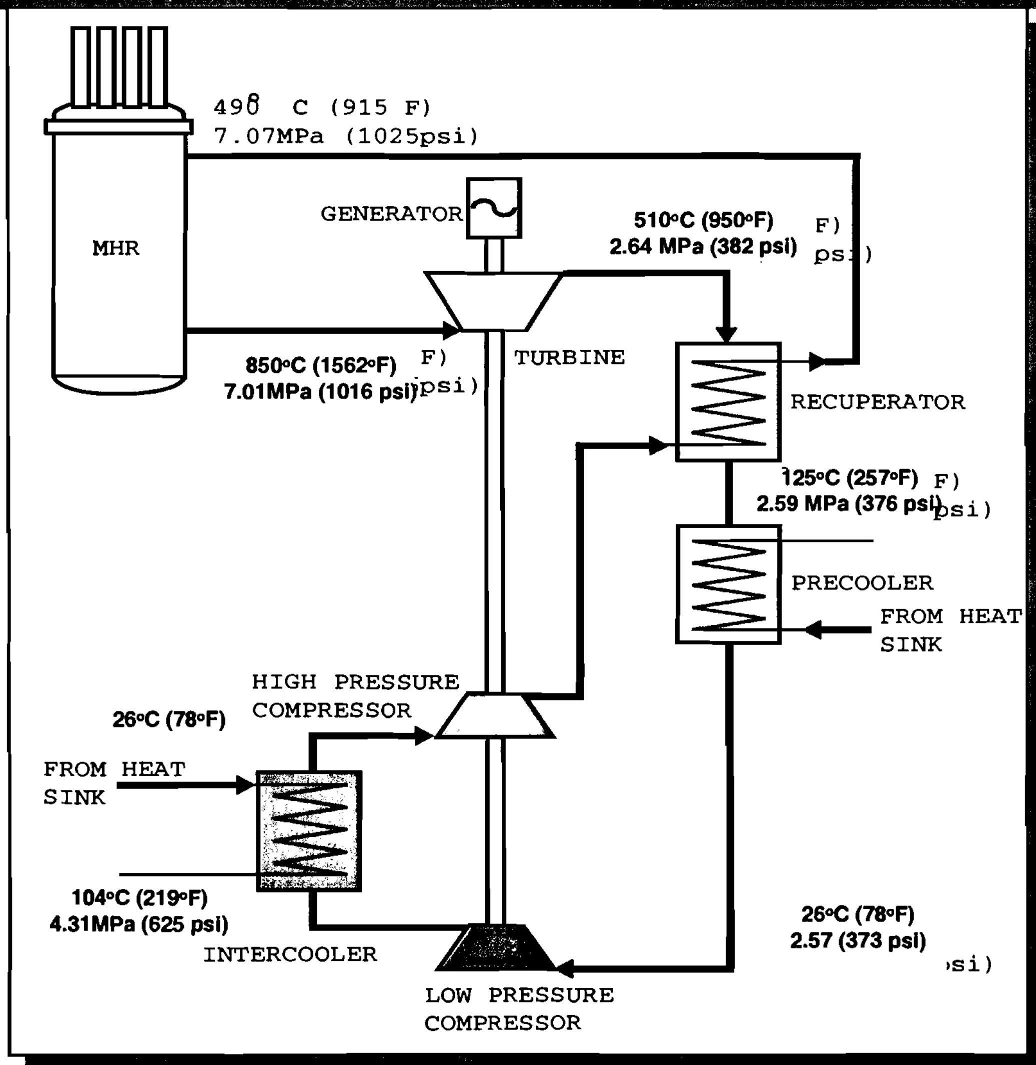
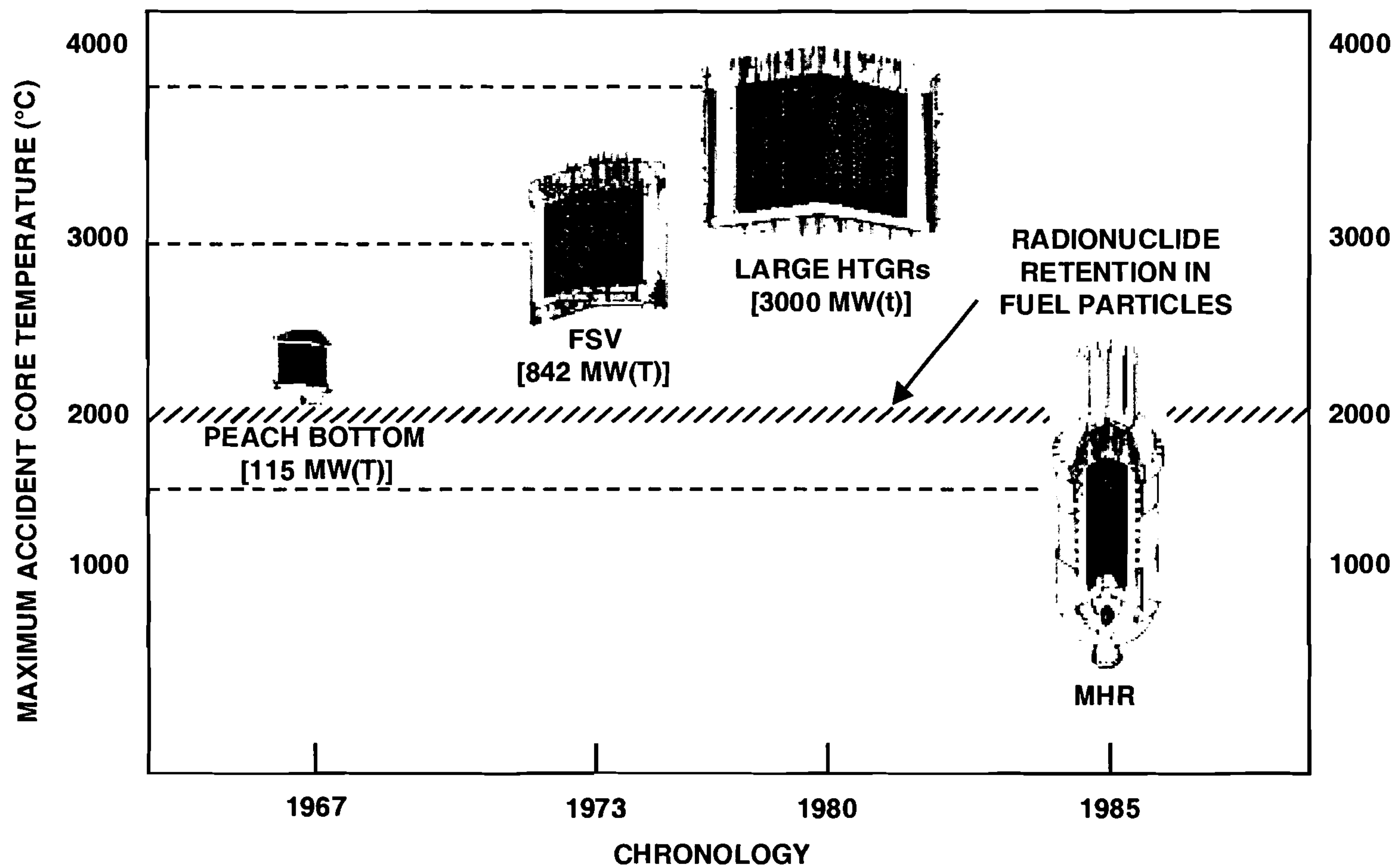
GT-MHR FLOW SCHEMATIC



GENERAL ATOMICS

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

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

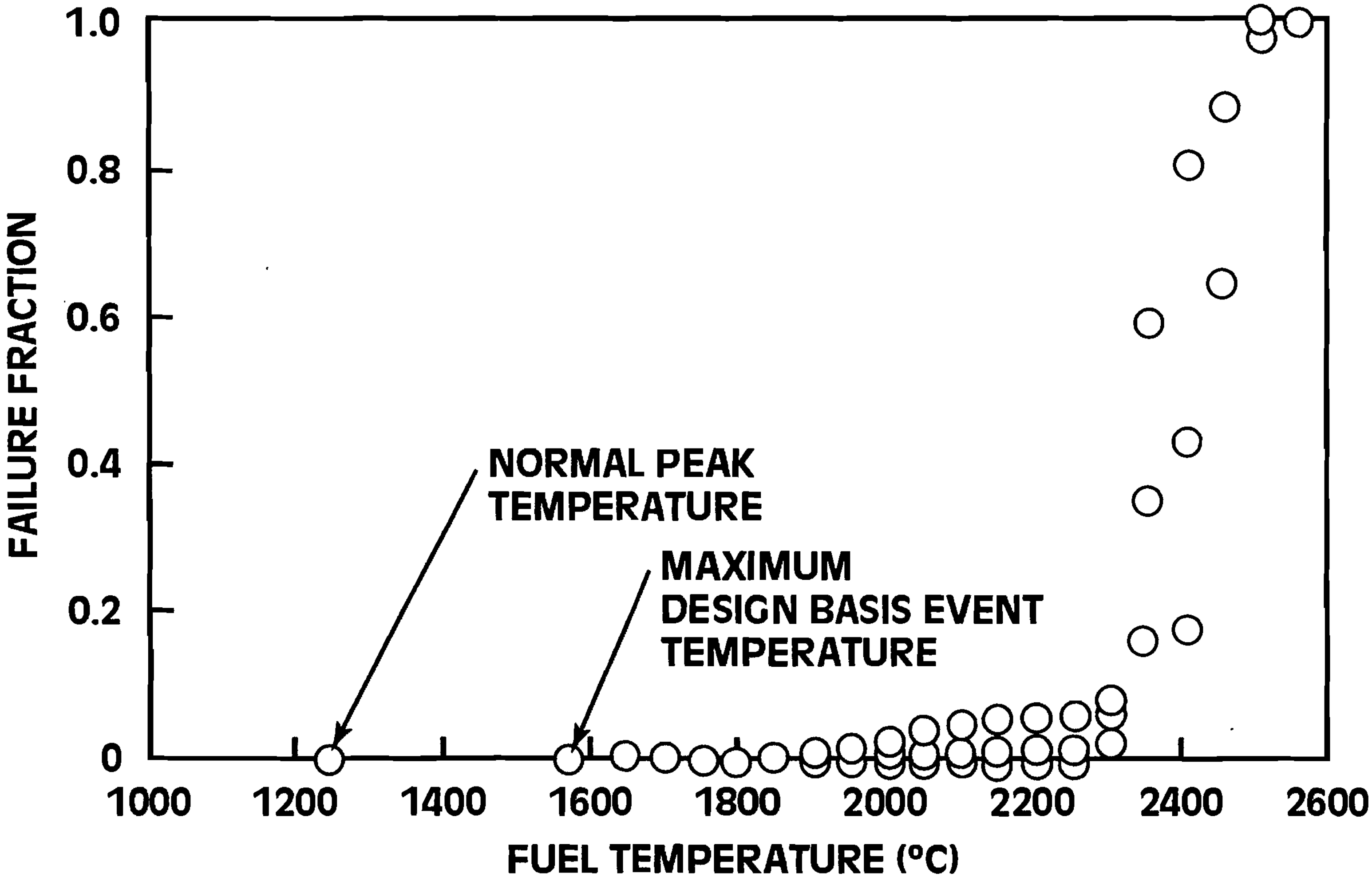


...SIZED AND CONFIGURED TO TOLERATE EVEN A SEVERE ACCIDENT

GENERAL ATOMICS

I-222(1)
1-12-96

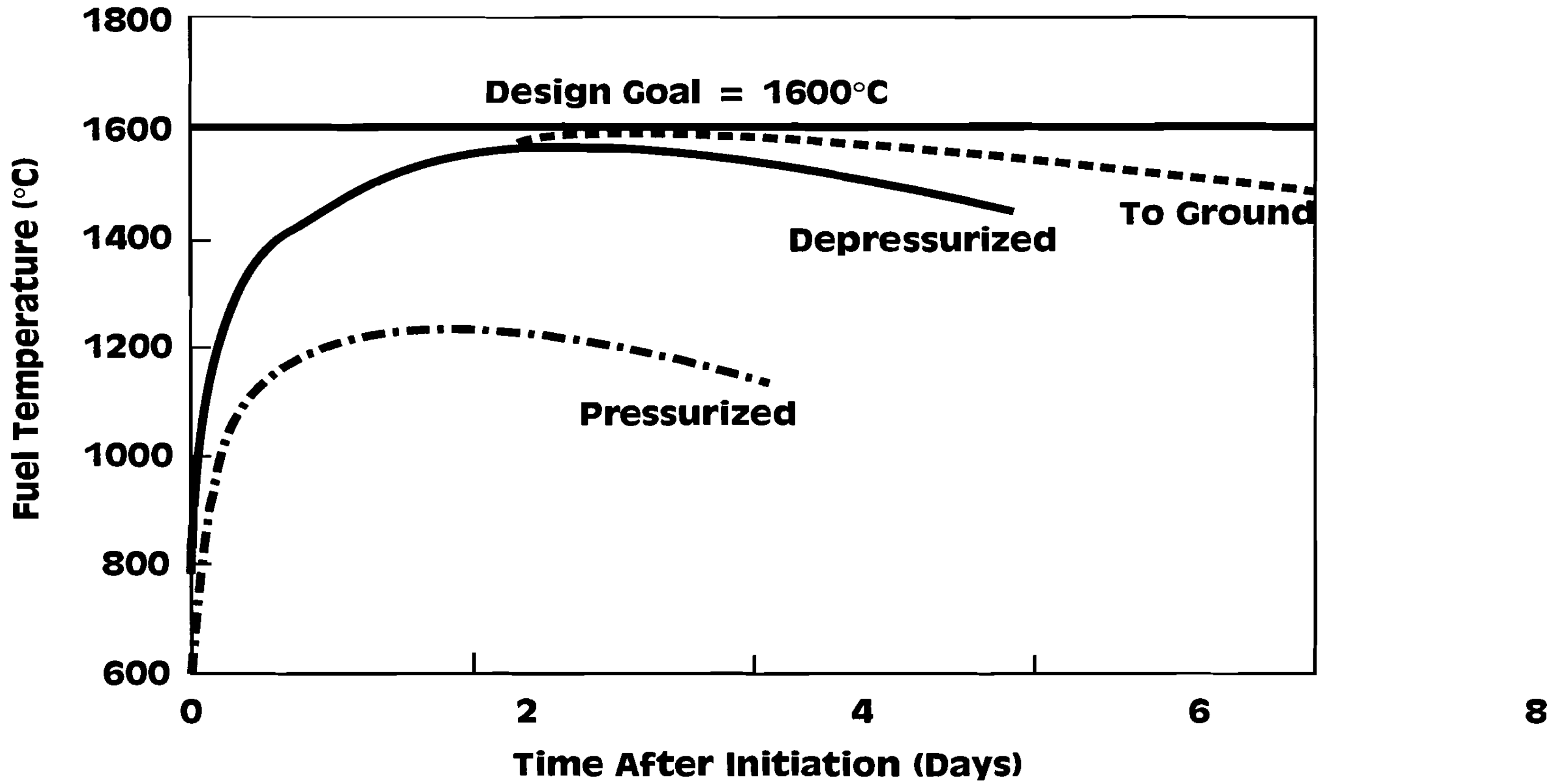
COATED PARTICLES STABLE TO BEYOND MAXIMUM ACCIDENT TEMPERATURES



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
    5×10^{-7}/yr and 2×10^{-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

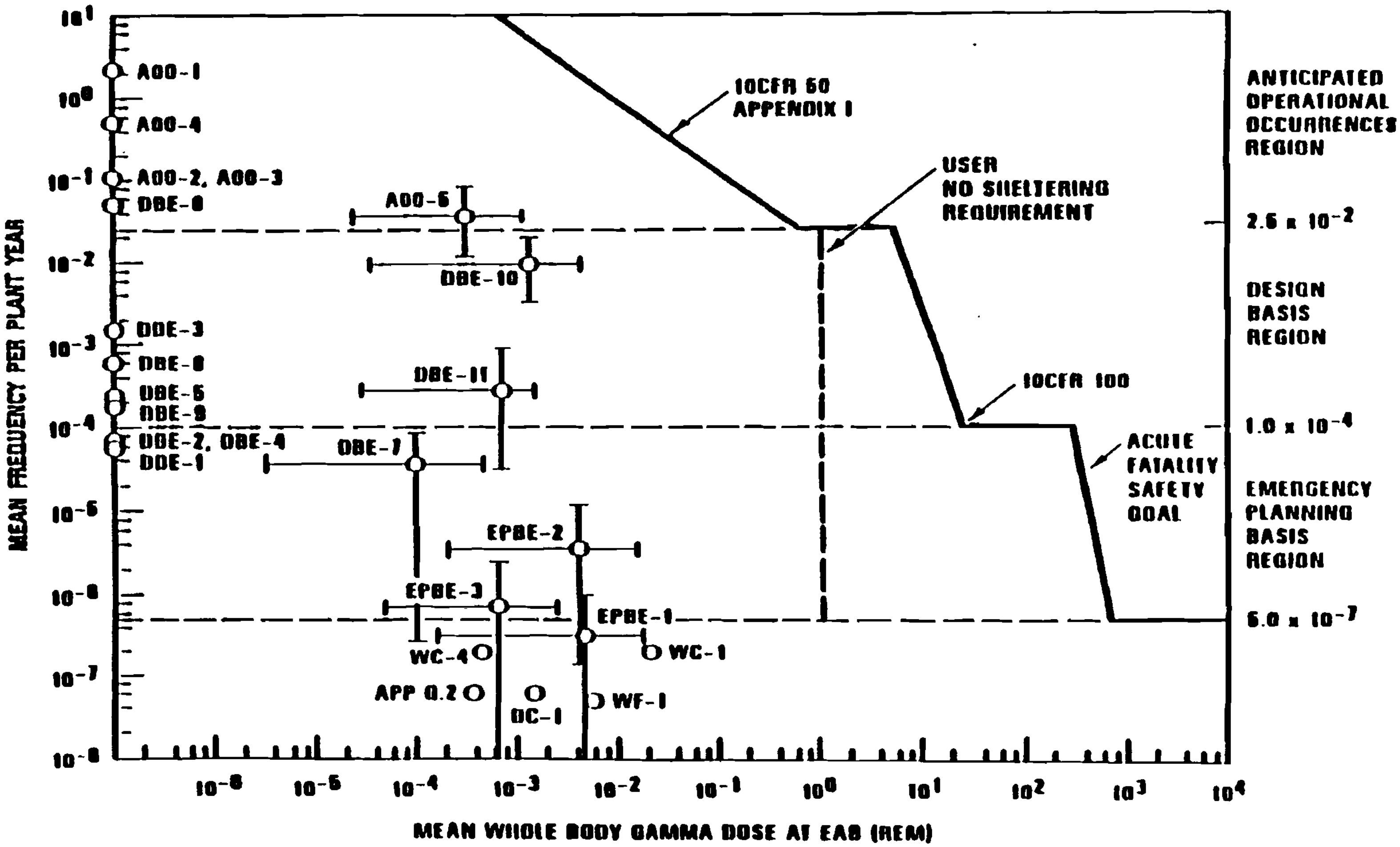
GENERAL ATOMICS

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

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

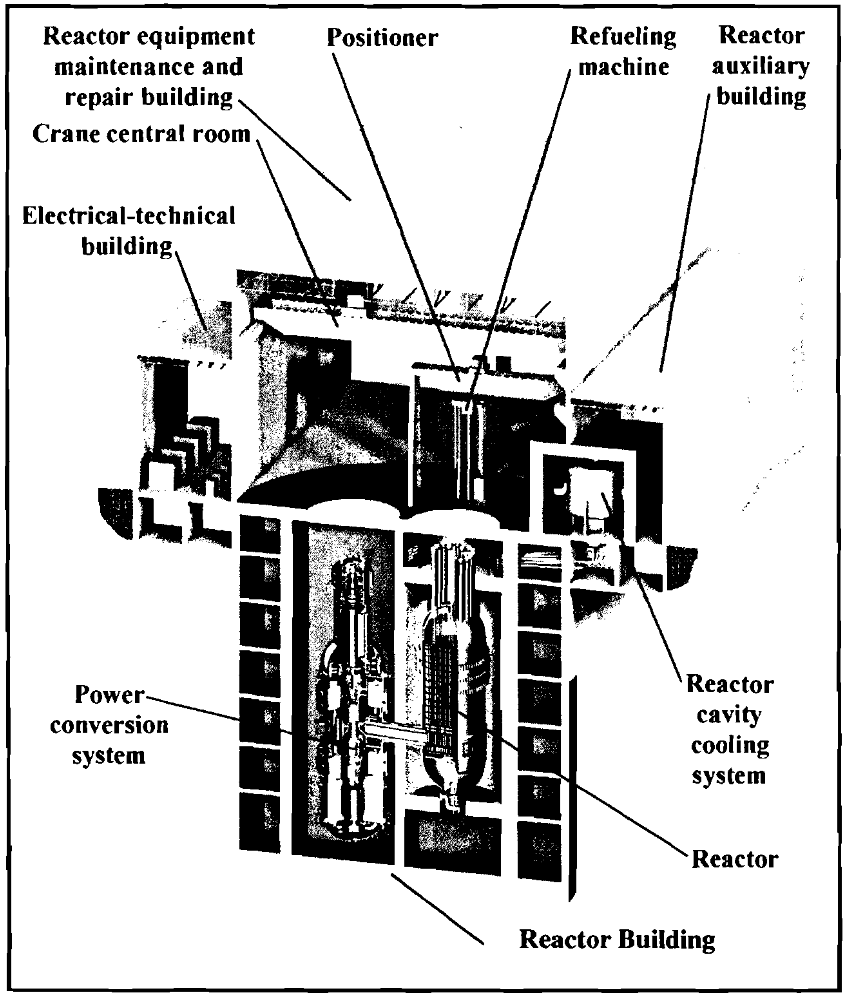
GT-MHR NOW BEING DEVELOPED IN INTERNATIONAL PROGRAM

- 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

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



COMMERCIALIZATION PROGRAM

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

Plant construction can start in 5 years

GENERAL ATOMICS

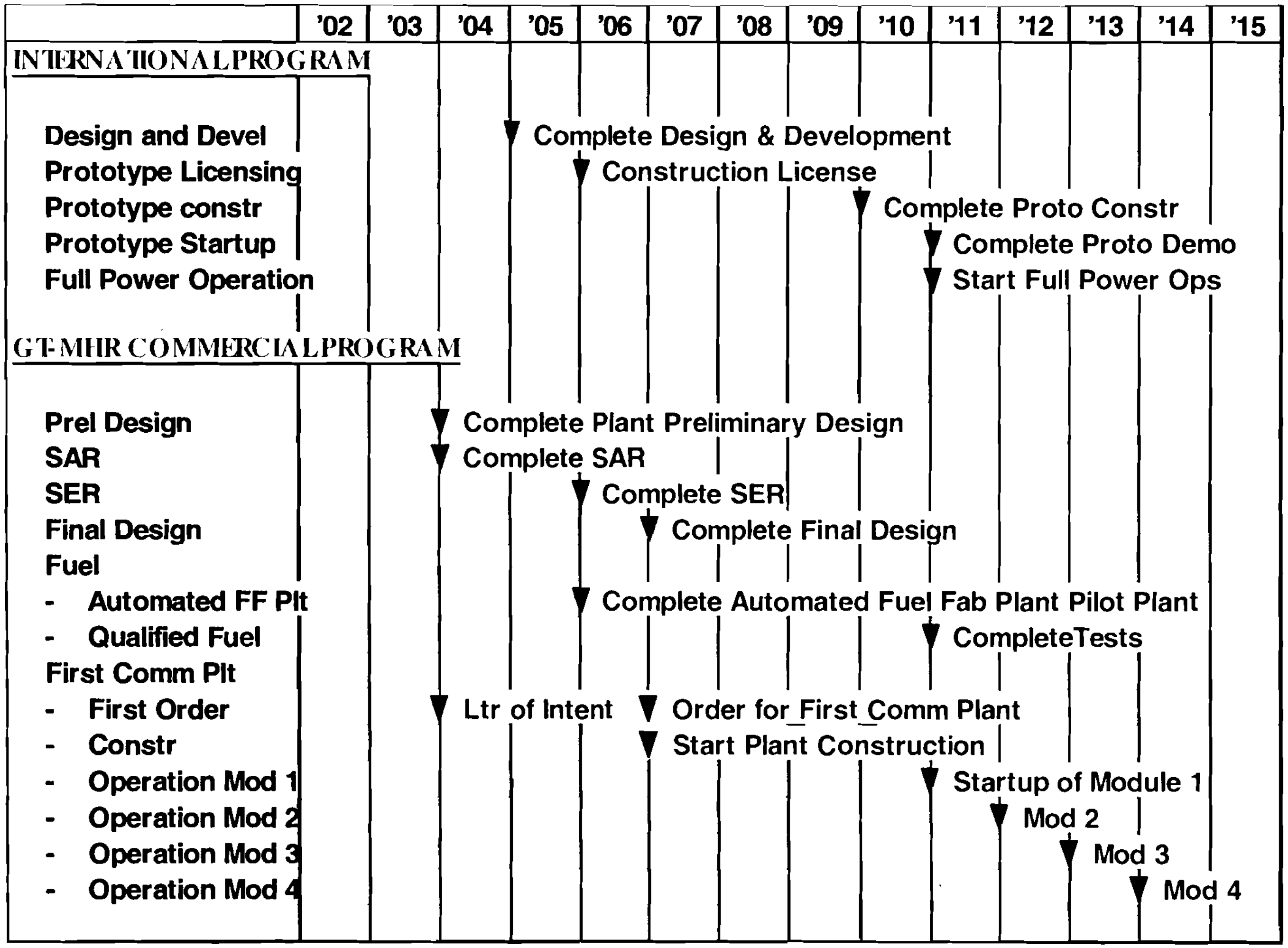
LIMITED ENGINEERING WORK REQUIRED

COMMERCIAL PLANT ENGINEERING

- Define Commercial Plant Requirements
- Safety and Licensing
- Transfer International Program Technology
- Performance Assessments
- Prepare Incremental Design Items

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 ELECTRIC
RAO

GE Nuclear Energy

ESBWR Program and Regulatory Challenges

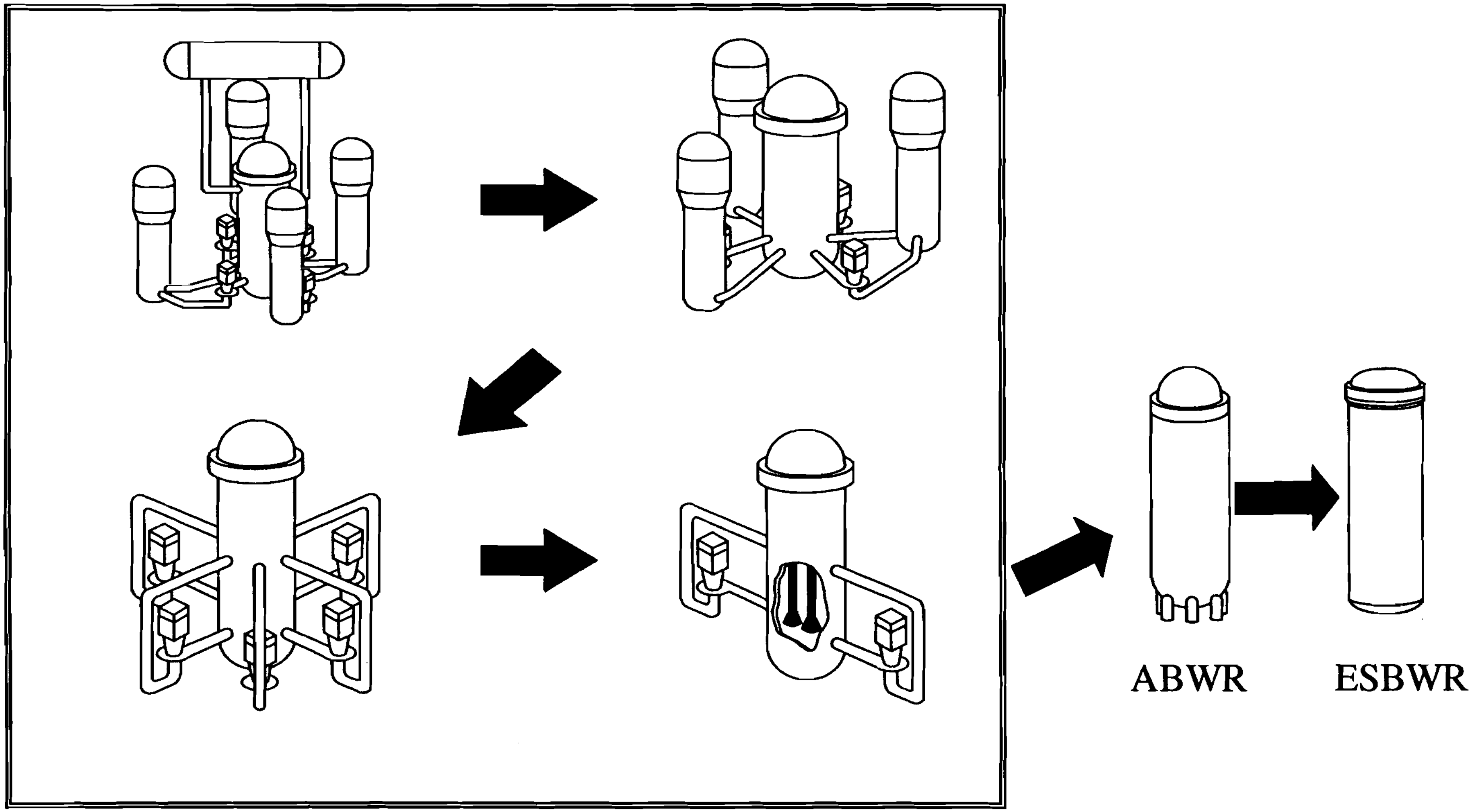
Atam Rao
GE Nuclear Energy, USA

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

Outline

- **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?

Evolution of the BWR Reactor Design



Evolution Towards Simplicity

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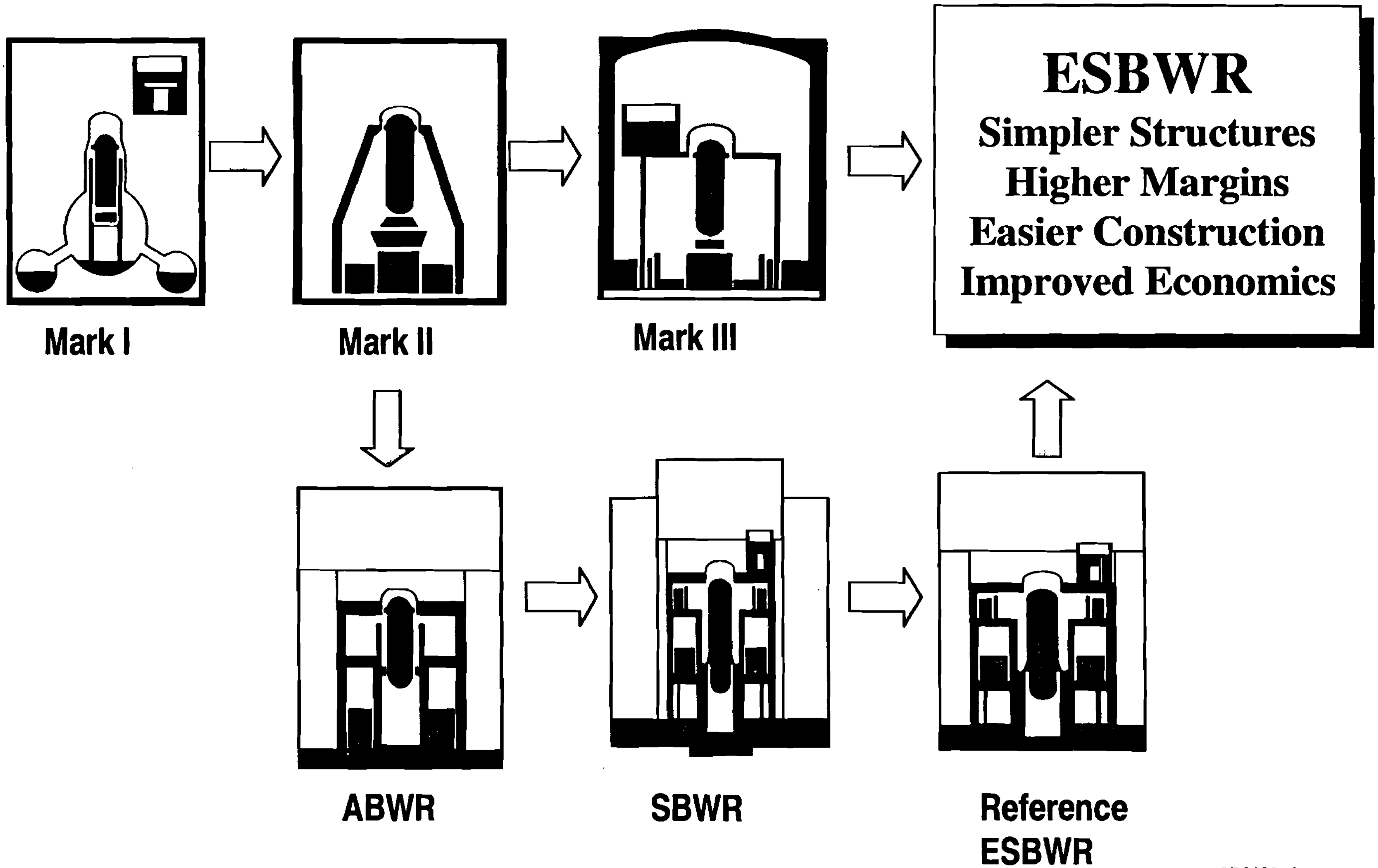
Evolution of BWR Containments



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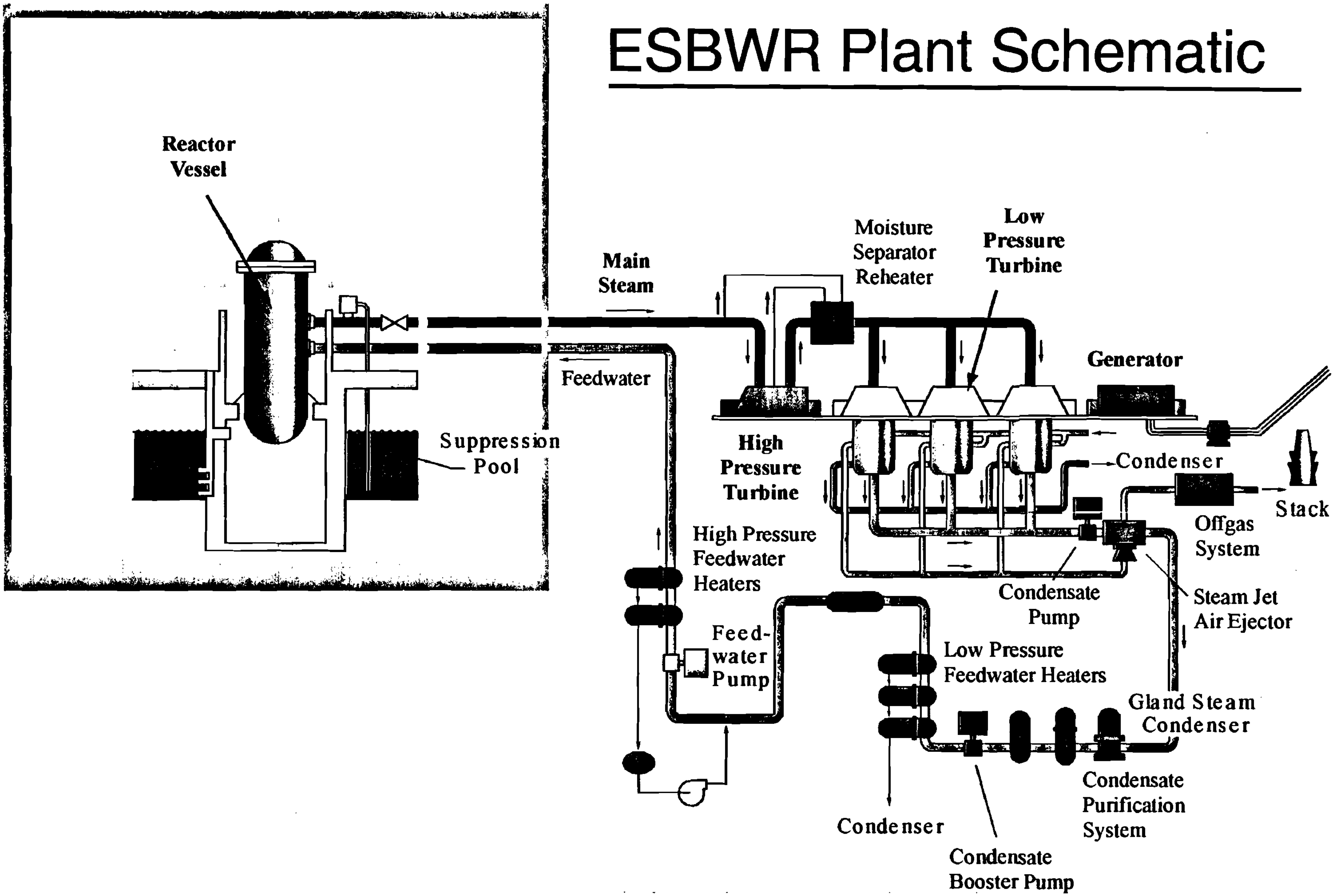
ESBWR Plant Schematic



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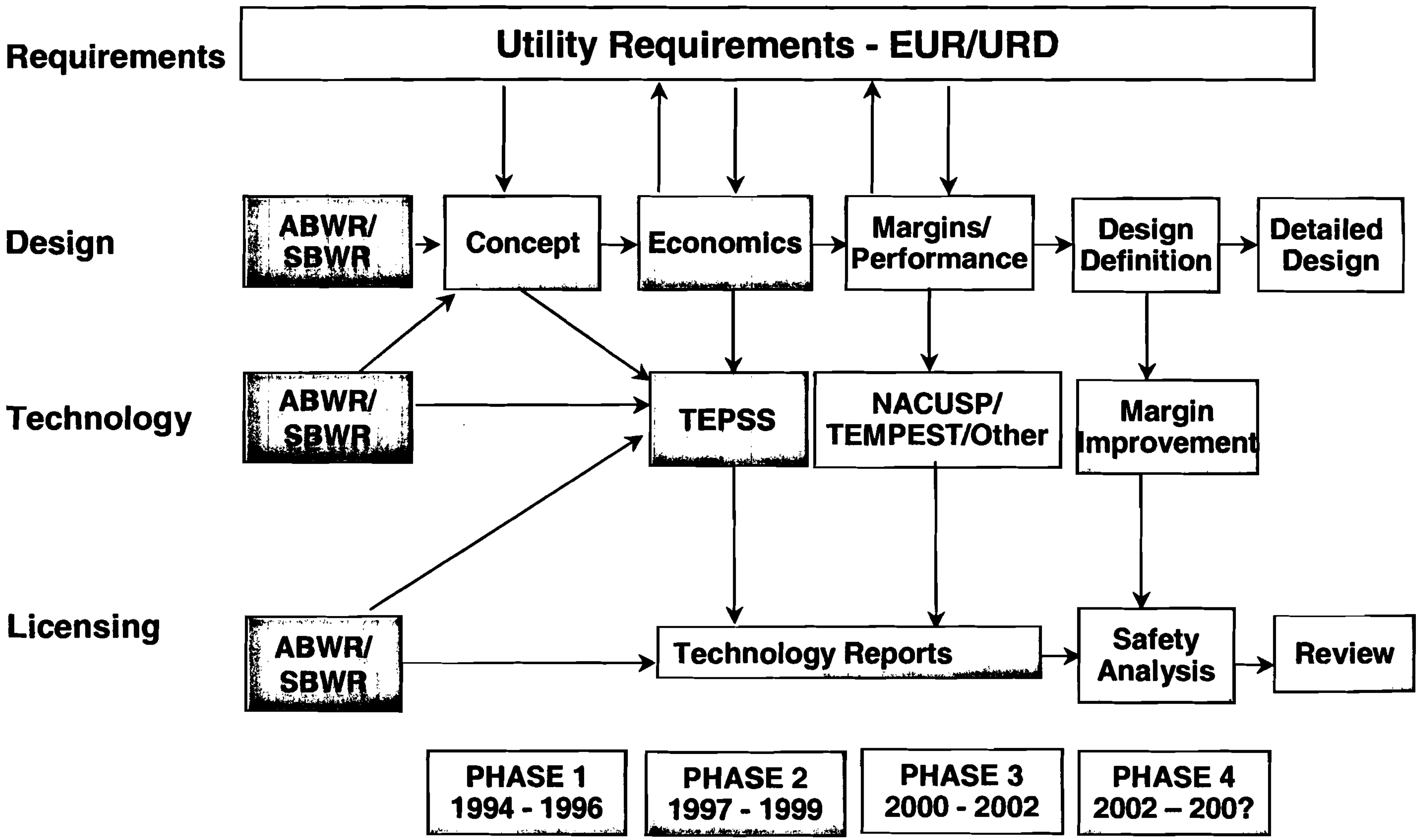
Comparison of Key Parameters

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

ESBWR Program Plan



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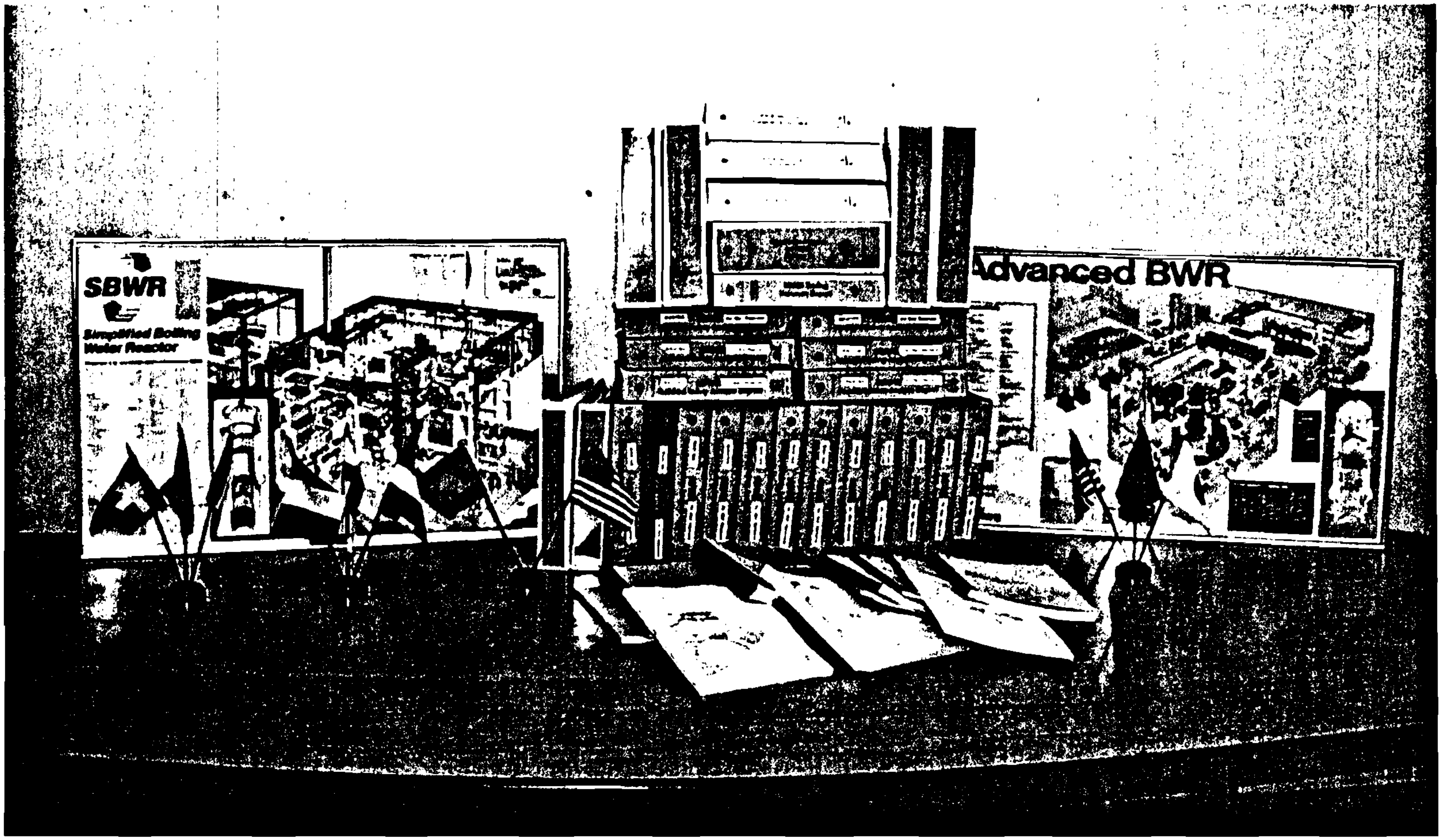
SBWR Simplifies ESBWR Challenges

- ABWR certification provides many inputs/bases
- SBWR program provides a solid base for ESBWR
  - SBWR program was a $200 – 300 million program
  - Completed a complete SAR with technology reports
  - Completed extensive testing and code qualification
  - Completed a multi-year NRC/ACRS review
- 8 year ESBWR program expanded the SBWR base
  - Used essentially the same design features
  - Completed extensive new testing and analysis
  - Improved the overall economics
- SBWR reviewers/developers still around

Increased performance and safety margins

ESBWR Design/Technology based on SBWR and ABWR

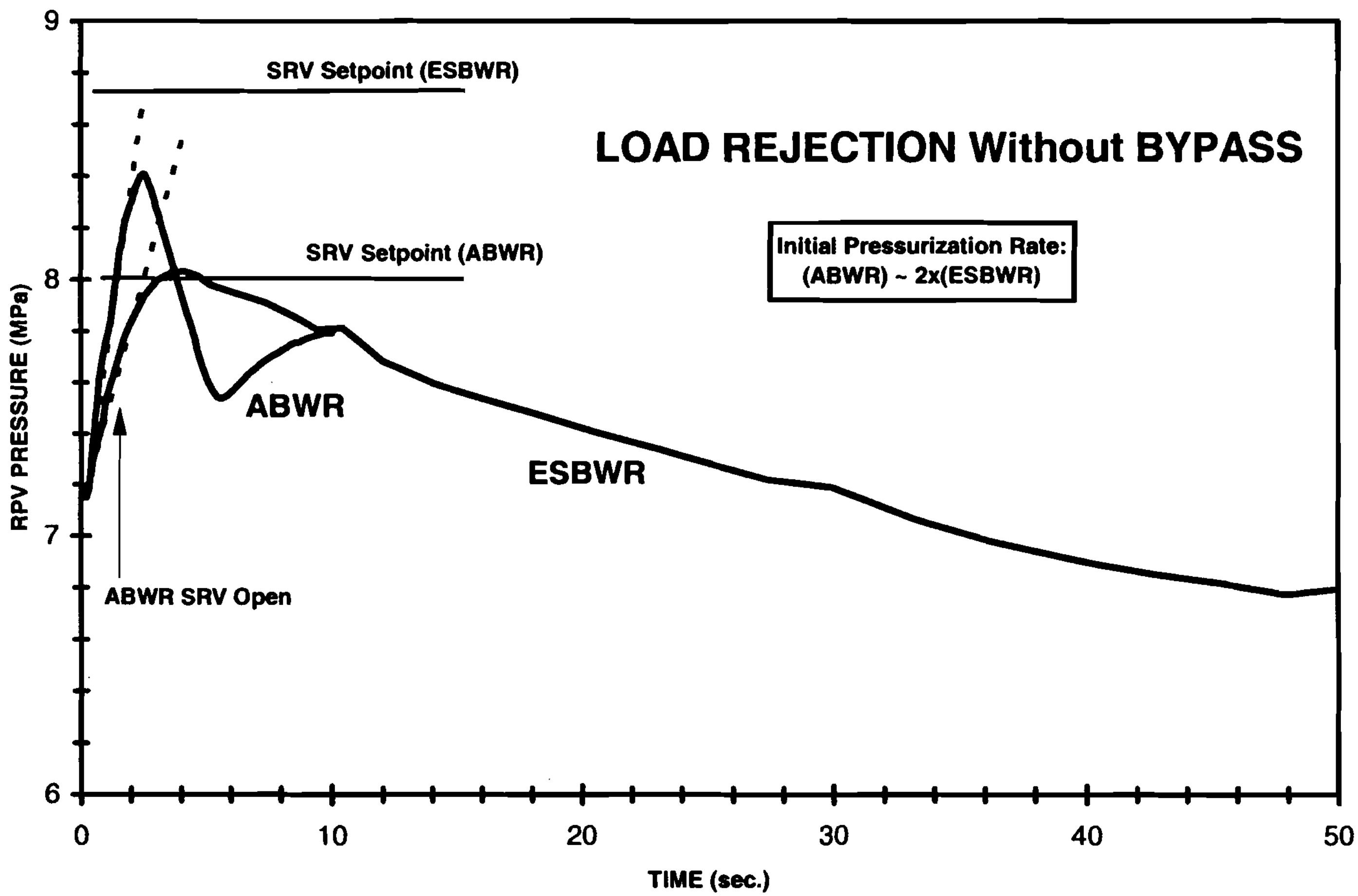


Comparison of Plant Performance

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

Fast pressurization transient

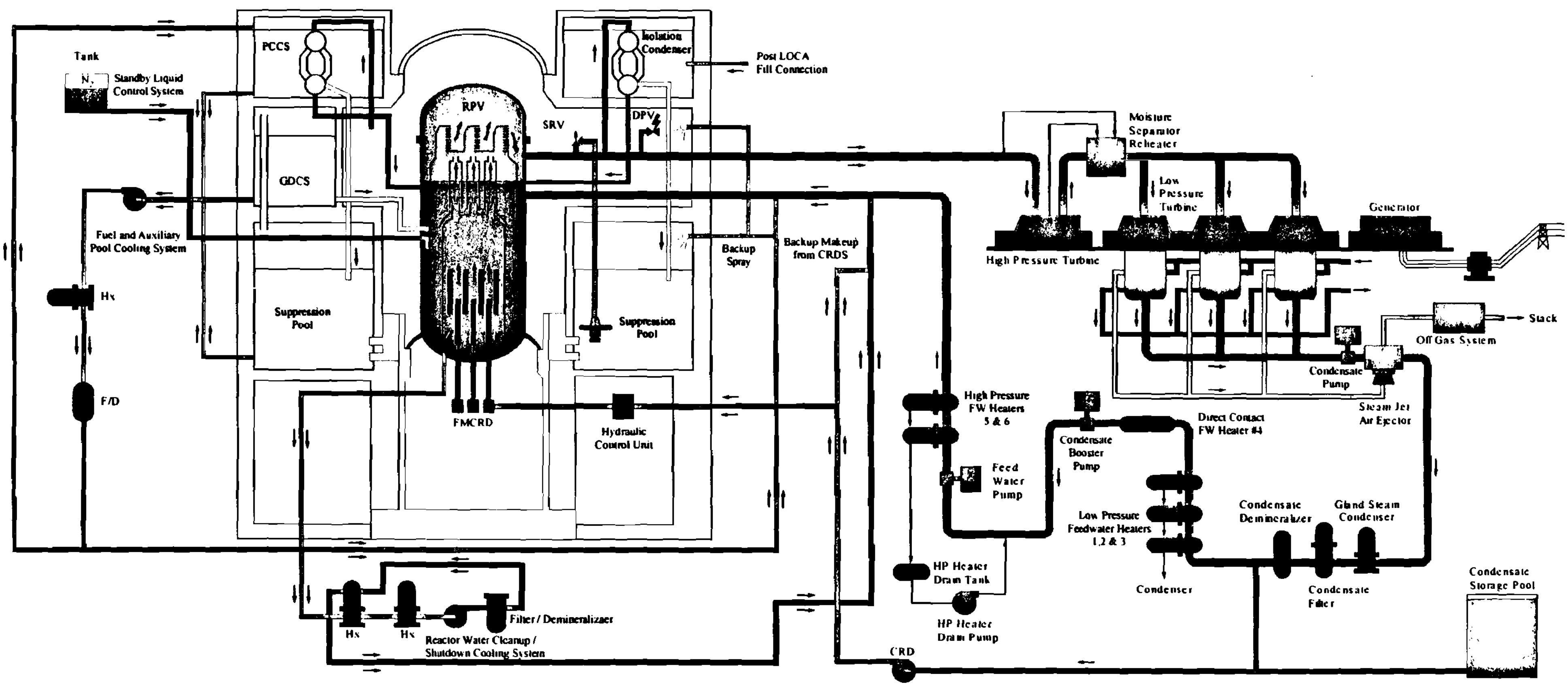


ESBWR: slower pressurization due to large steam volume in chimney; adequate margin to prevent SRV from opening

Factors that Resulted in Improved Economics

- **Economy of Scale**
  - Higher Power Density
  - Higher Plant Power
  - Use of Modular Passive Safety Systems
- **Design Features That Enhanced Economy of Scale**
  - Made GDCS Pool As Part of Wetwell
  - Modular Safety Systems With Little Dependence on Power Level
  - Smaller PCCS Pools and Larger Heat Exchangers
- **Improved the Overall Design**
  - Large Blade Control Rods
  - Simpler Reactor Internals
  - Improved Plant Arrangements
    - Moved Non Safety Systems, Stacked Spent Fuel
    - Flexible Building Embedment - External Cask Hatch

ESBWR Nuclear and Turbine Island Schematic



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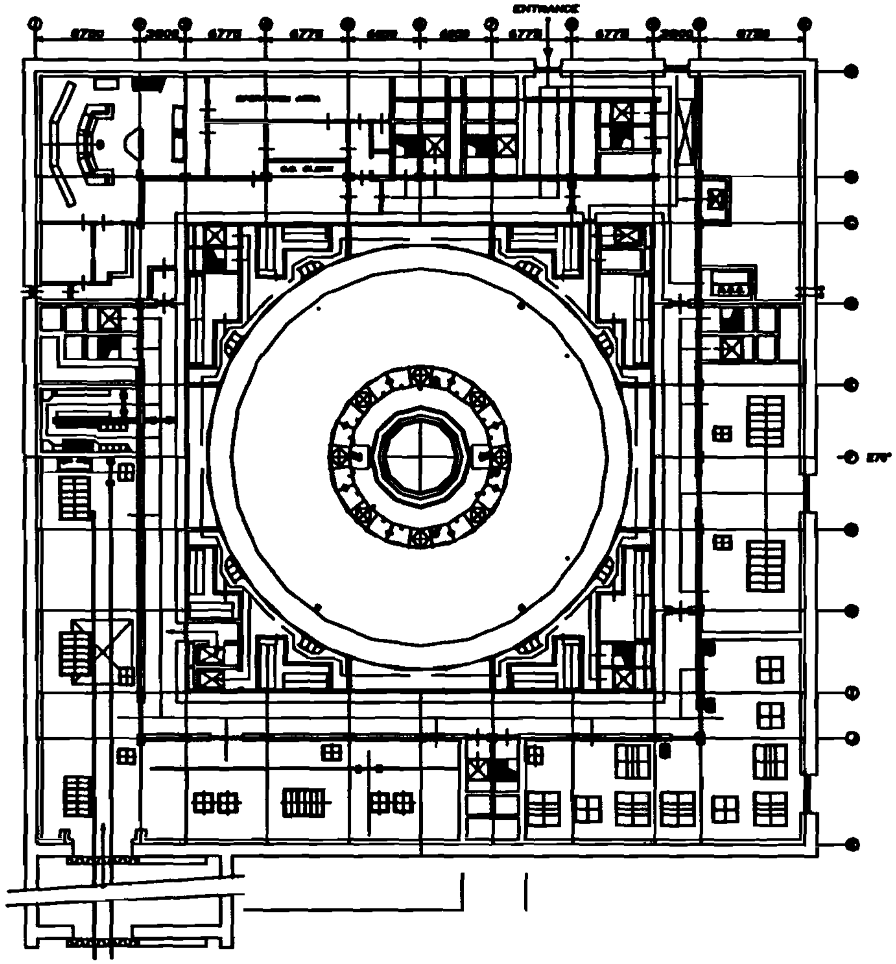
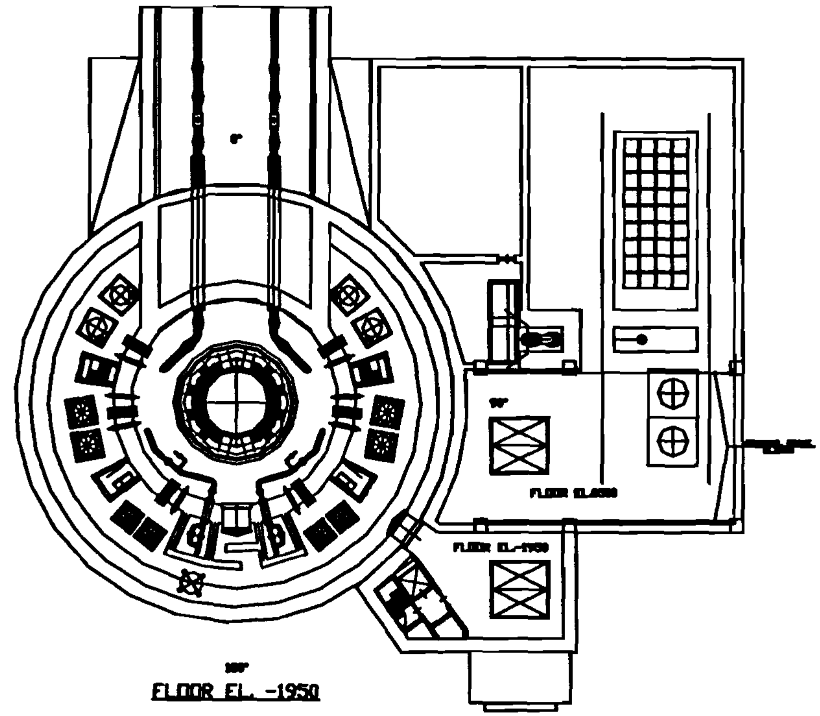
Comparison of SBWR/ESBWR Buildings



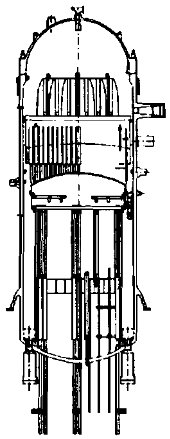
SBWR (670 MWe)



ESBWR (1380 MWe)

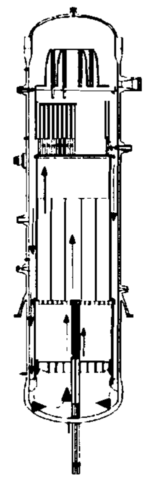
Core Design Evolution

ABWR
3926 MWt
872 bundles
7.1m / 21.4m



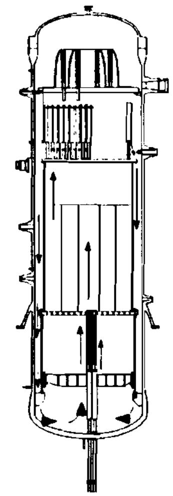
Eliminating pumps, shorten fuel

SBWR
2000 MWt
732 bundles
6.0m / 24.5m



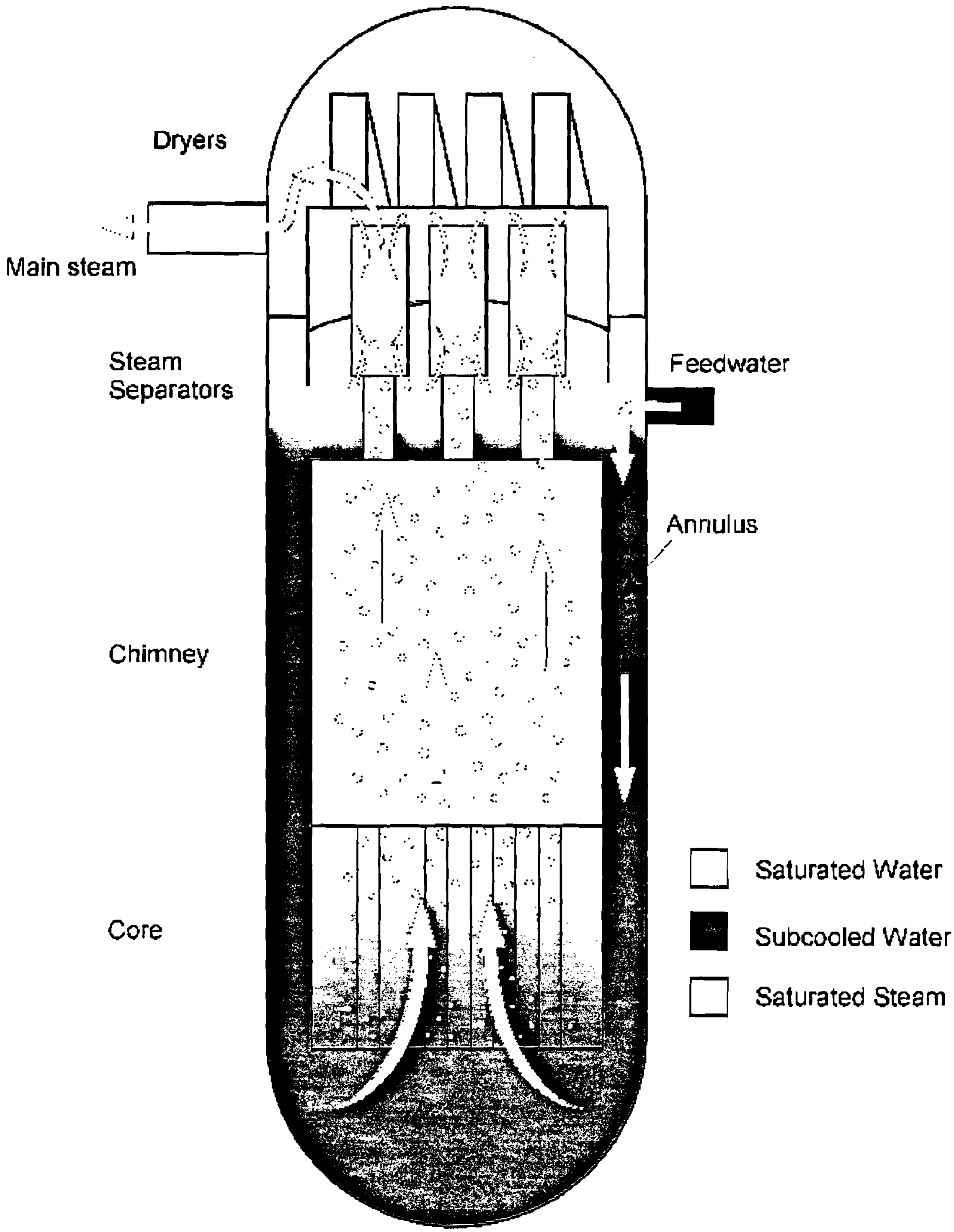
Taller vessel, improved internals

ESBWR
4000 MWt
1020 bundles
7.1m / 27.7m



ESBWR Design Evolution - Core

	ABWR	SBWR	ESBWR – Phase 1	ESBWR – Phase 2	ESBWR – Phase 3
Power (MWt)	3926	2000	3613	4000	4000
RPV Height (m)	21.4	24.5	25.4	25.9	27.7
RPV ID (m)	7.1	6.0	7.1	7.1	7.1
# of bundles	872	732	1132	1132	1020
Active fuel length (m)	3.67	2.74	2.74	2.74	3.05
Power Density (kw/l)	51.0	41.5	48.5	53.7	53.7


Dryers
Main steam
Steam
Separators
Feedwater
Annulus
Chimney
Core
Saturated Water
Subcooled Water
Saturated Steam

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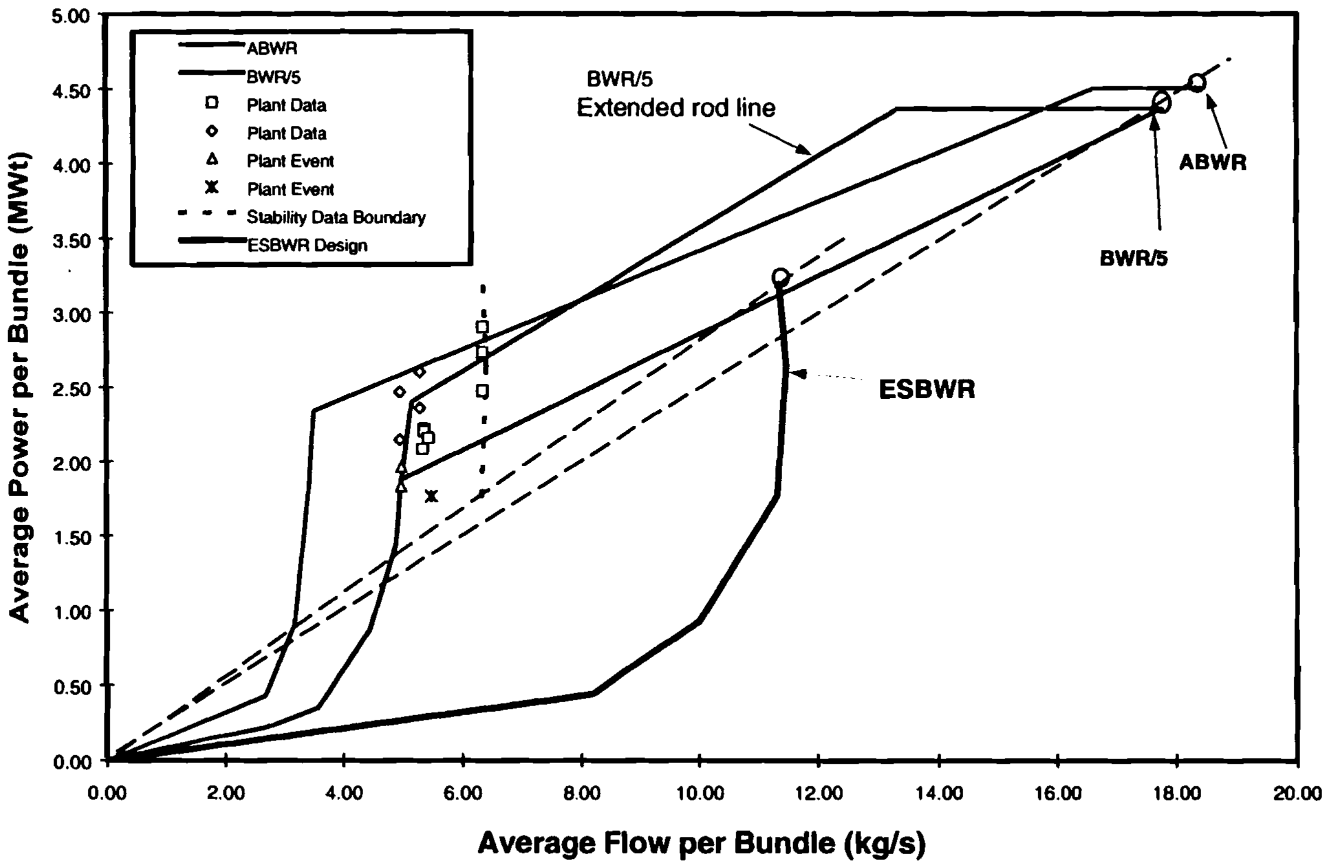
Bundle Power vs. Flow for various BWRs



POWFLO-2.xls chart 9

ESBWR has 100% flow margin to stability data boundary

Natural Circulation Technology Program

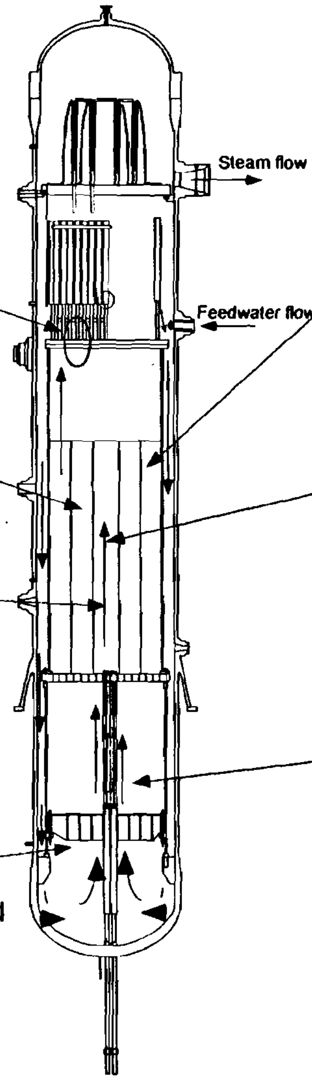
SBWR | ESBWR Phase 1 | ESBWR Phase 2 | ESBWR Phase 3

Separator Performance
ATLAS Tests - AS2B
- smooth inlet geometry
- reduced pitch
  (305 mm -> 292 mm)

Chimney Void Fraction
Ontario Hydro Tests
- transient test (pump induced)
- round pipe (0.518 m ID)
- relatively flat void distribution

Startup Flow Oscillation
CRIEPI Tests
- single chimney
- SBWR conditions
- large margin to oscillation regime

Core Flow Optimizaton
- studies performed by PSI
- supported by
  Swiss Utilities



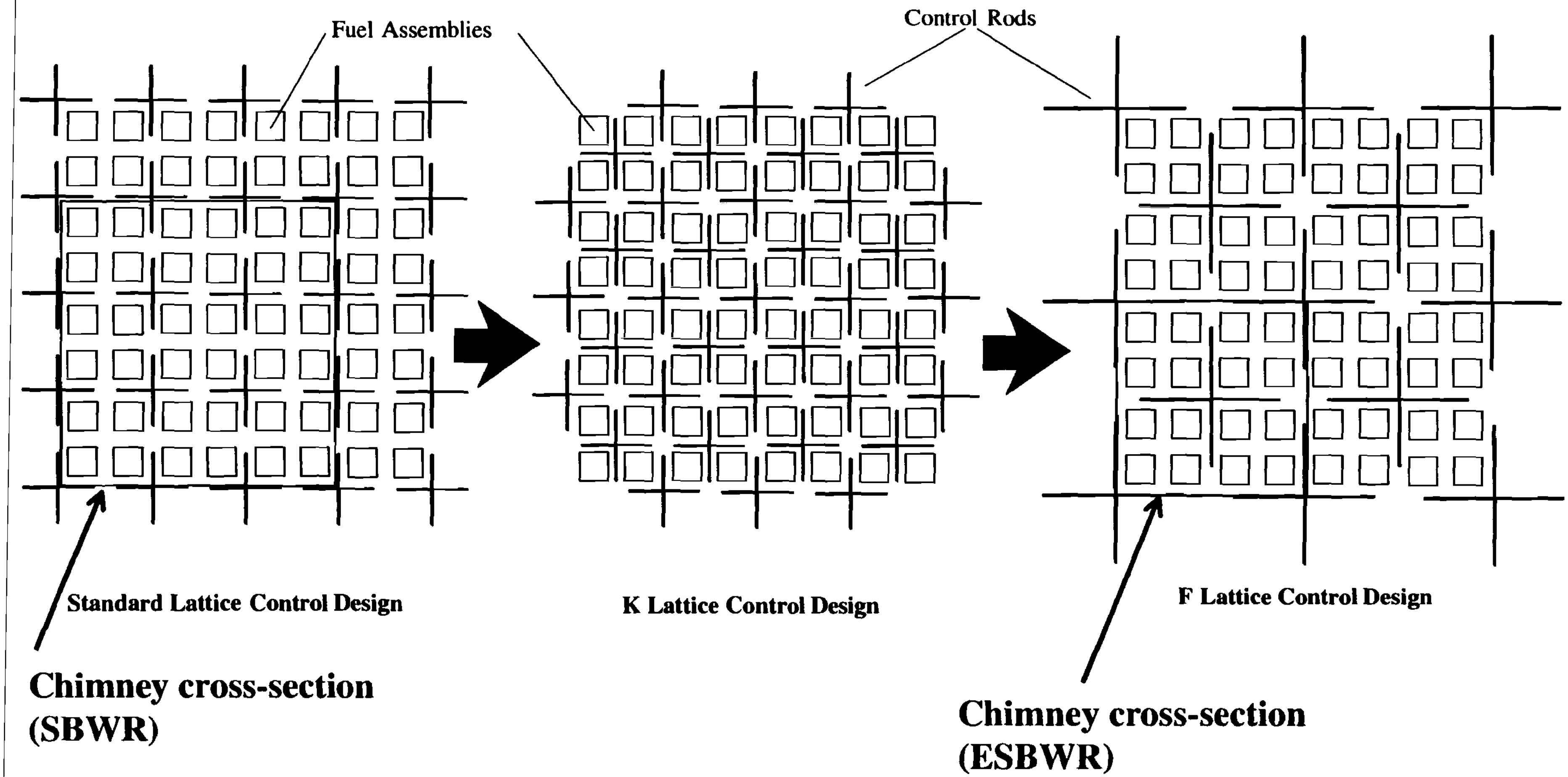
Chimney Void Fraction
CEA Chimney Tests
- scaled ESBWR conditions
- 3-D void distributions
- FIV on chimney partition
- supported by EdF

Startup Flow Oscillation
PSI / IRI Testing
- full range parameters
- ESBWRconditons
- scaling and other effects

Regional Oscillation
IRI / ETH Projects
- code development
  and analyses
- chimney effect
- core size effect

Control Rod Drive Design Evolution

- The “F” lattice is an extrapolation of earlier “K” lattice design

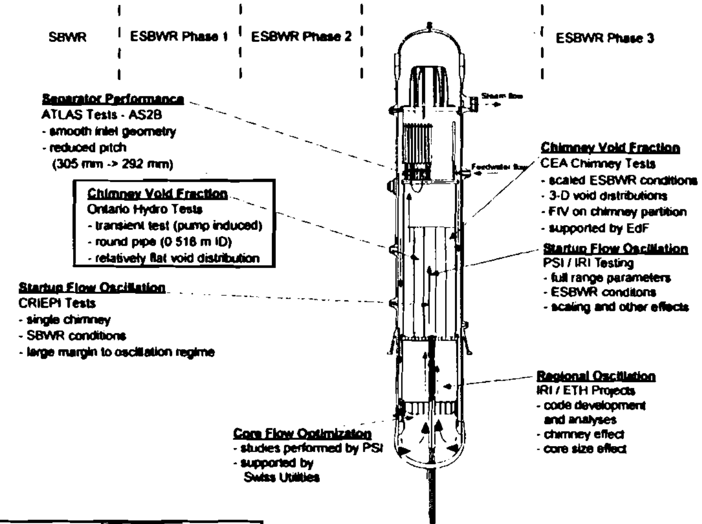


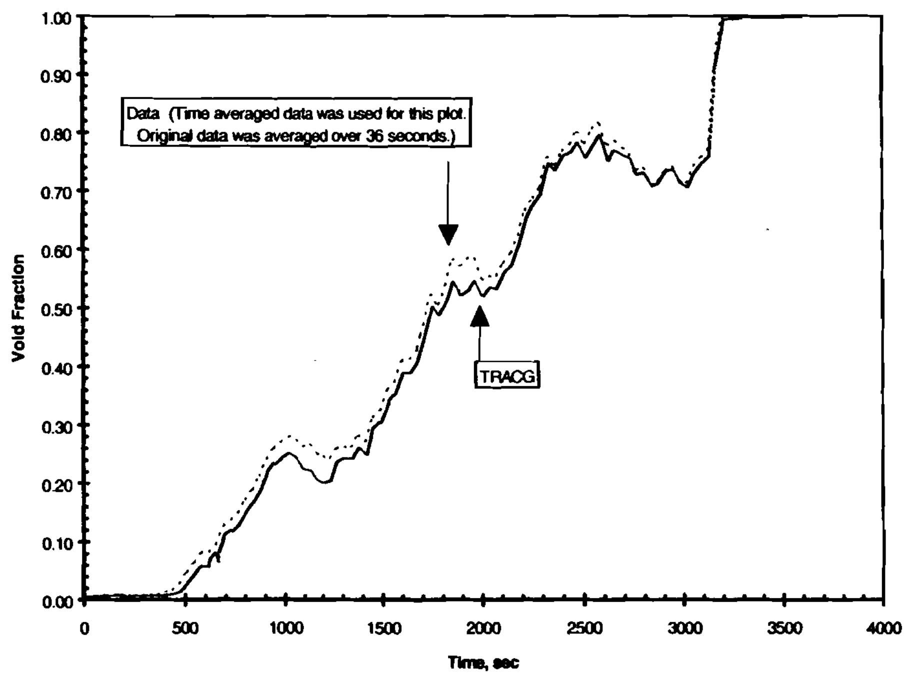
Chimney and Technology Programs

- Chimney provides the driving head for the natural circulation flow
- Flow rate is sensitive to the chimney void fraction
- Test programs to evaluate void fraction profile and to access flow induced vibration on chimney partition

Chimney Void Fraction

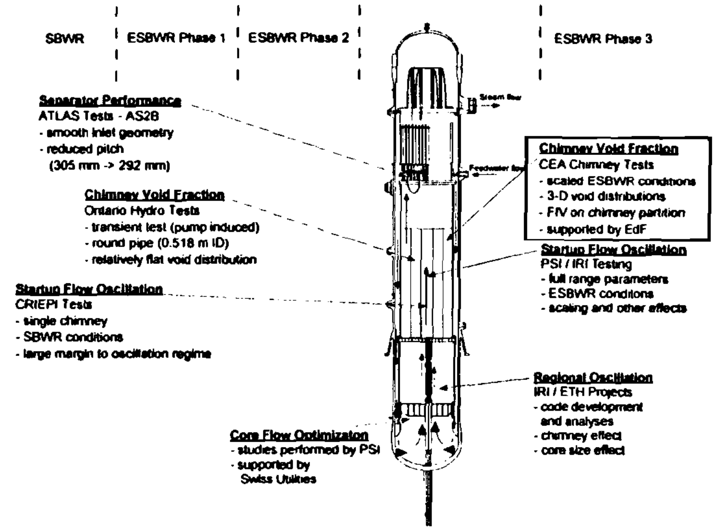
- Ontario Hydro Tests
  - Large pipe void fraction data
  - 0.51 m diameter, 6.4 and 2.8 MPa
- Relatively flat void profile across the pipe section
- Pump induced transient tests





Chimney Void Fraction

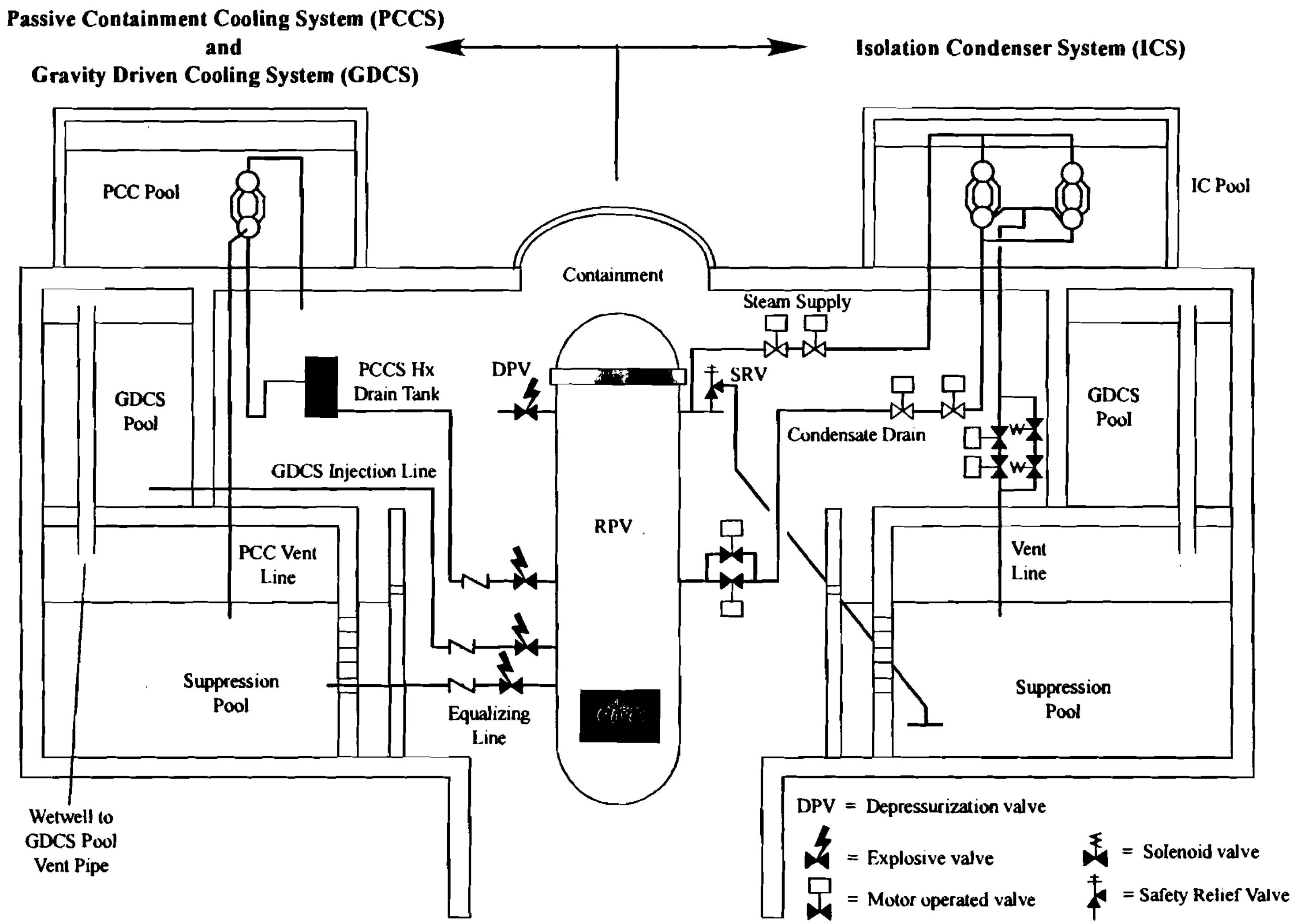
- CEA Chimney Tests
  - scale ESBWR geometry and conditions
  - measure 3-D void distributions
  - evaluate FIV on chimney partition
  - tests supported by EdF



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



Passive Containment Cooling System (PCCS)
and
Gravity Driven Cooling System (GDCS)
Isolation Condenser System (ICS)
PCC Pool
IC Pool
Containment
Steam Supply
GDCS Pool
PCCS Hx Drain Tank
DPV
SRV
Condensate Drain
GDCS Pool
GDCS Injection Line
RPV
PCC Vent Line
Vent Line
Suppression Pool
Equalizing Line
Suppression Pool
Wetwell to GDCS Pool Vent Pipe
DPV = Depressurization valve
= Explosive valve
= Solenoid valve
= Motor operated valve
= Safety Relief Valve

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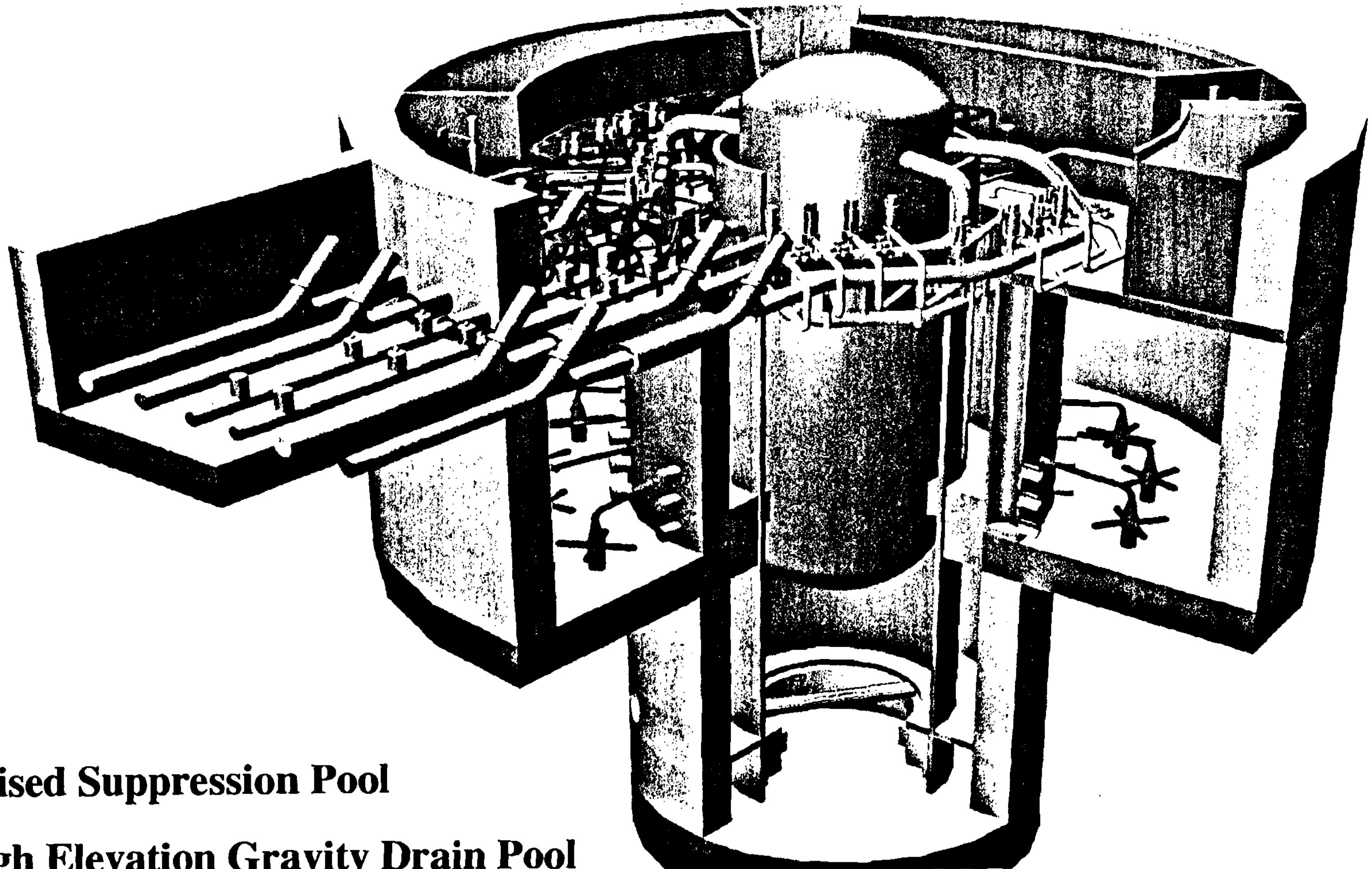
Design Philosophy for the Safety Systems

- Meet all Regulatory Requirements with Simple Passive Systems
  - Emphasis on simplification
  - No operator actions needed for 72 hours for design basis events
- Active Systems Modified Slightly to Enhance Overall Safety
  - Active systems are non safety-grade
  - Minor changes made to improve PSA results
- Plant Shutdown and Accident Recovery
  - Use active systems

Safety Systems Inside Containment Envelope



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

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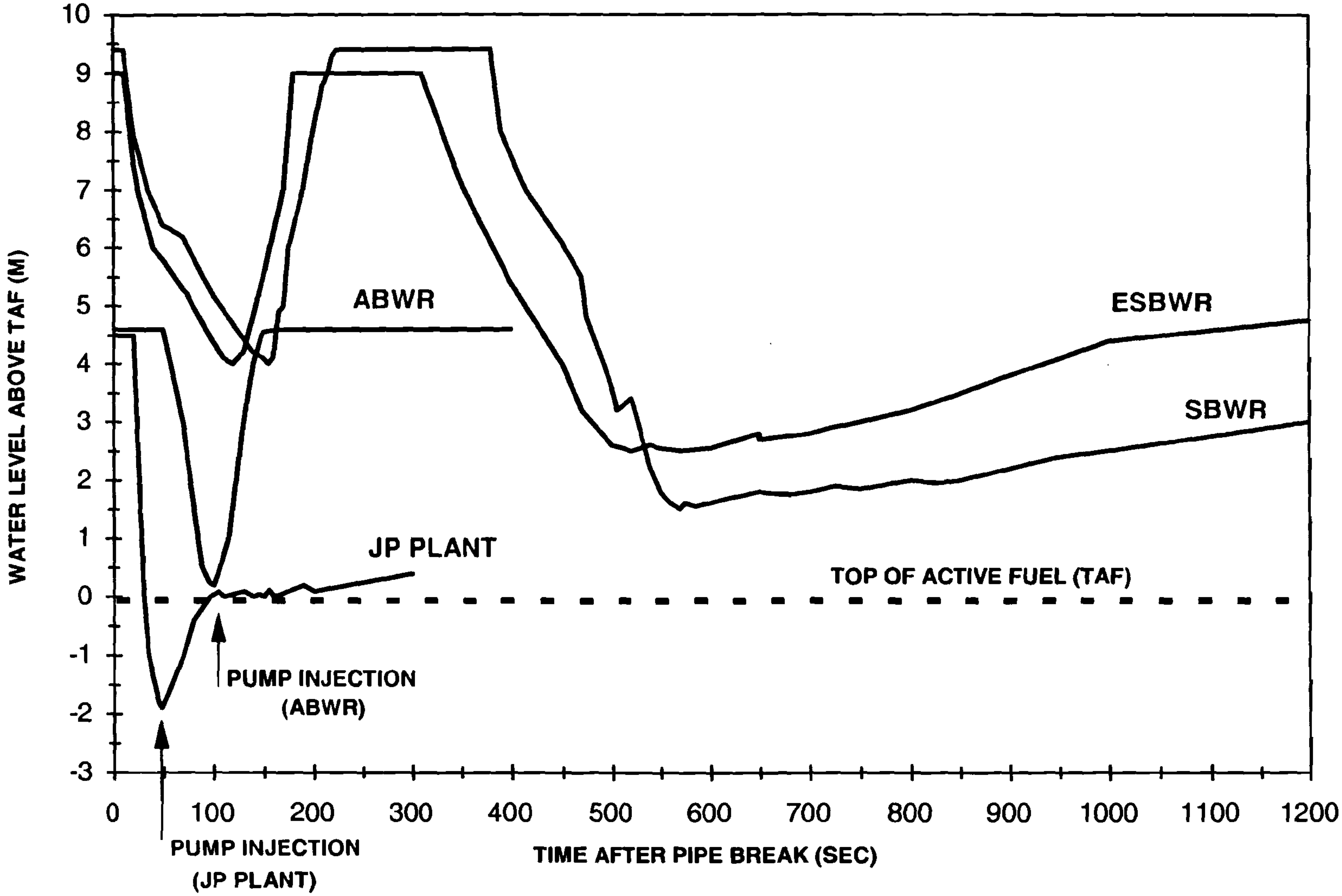
Water Level in Shroud Following a Pipe Break



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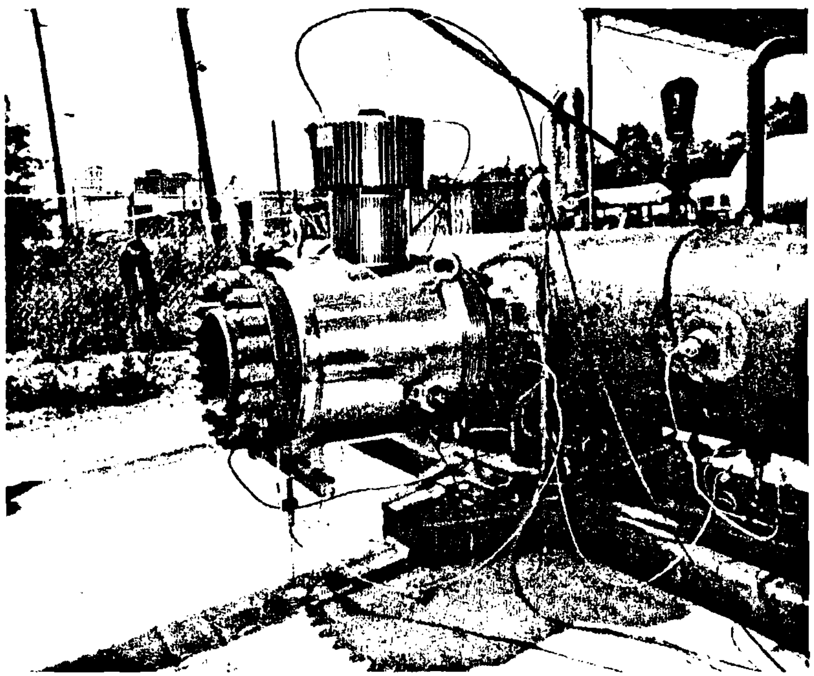
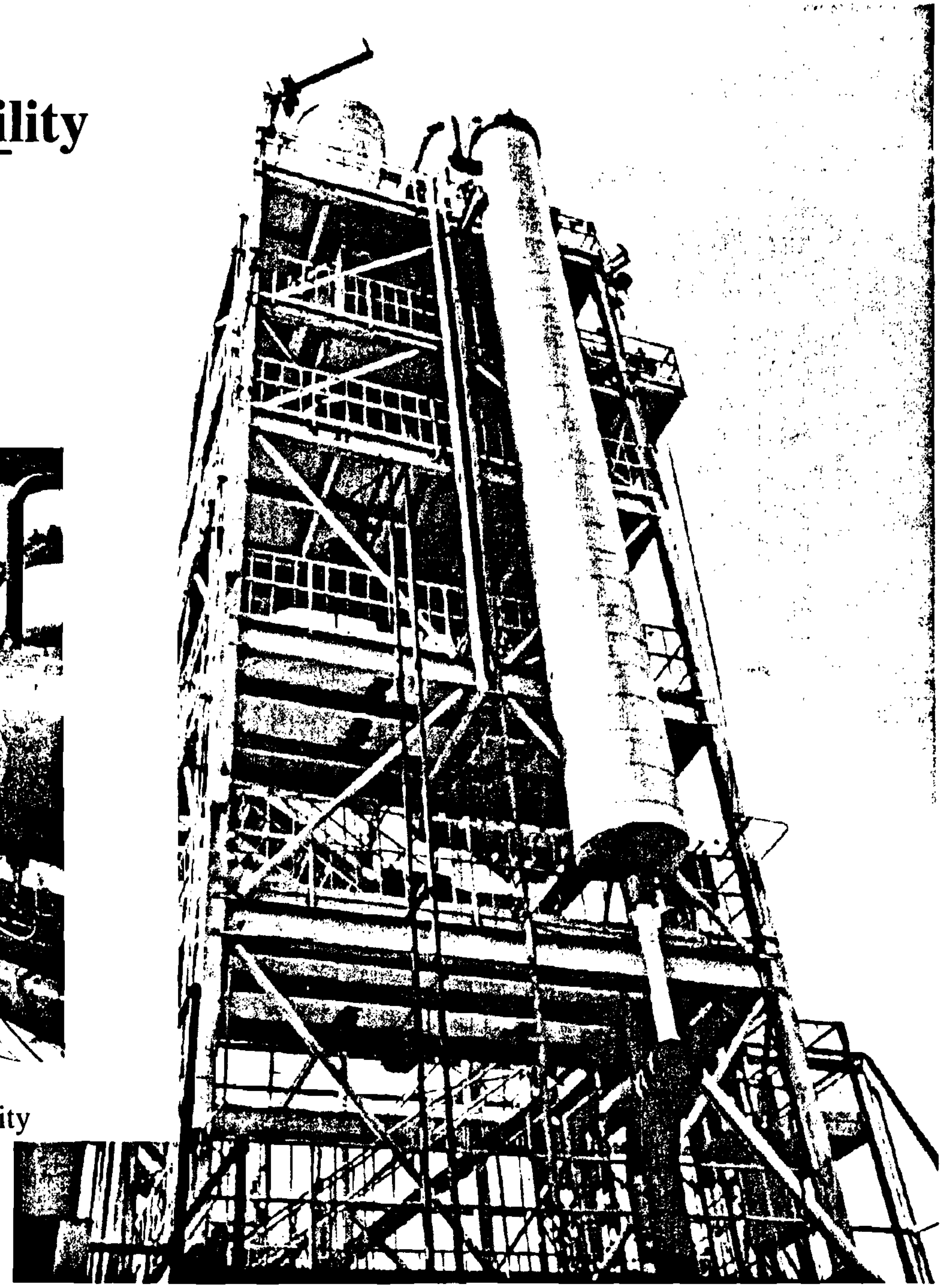
Safety System (GIST) Test Facility and Depressurization Valve


Reactor Depressurization Valve in the Test Facility



Decay Heat Removal/Containment Features and Technology

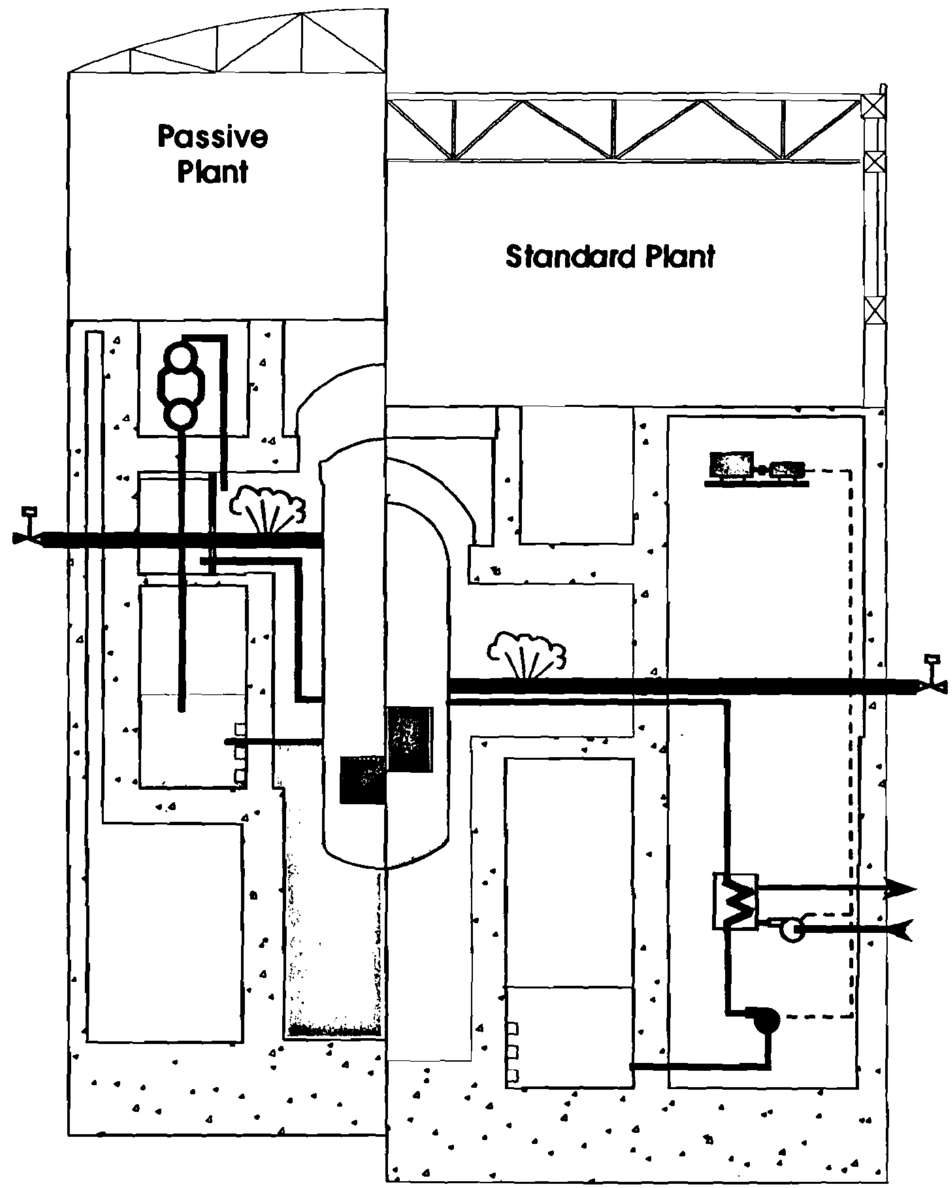
- **Decay Heat Removal Design Features**
- Past Technology Program - SBWR
- ESBWR System Modifications from SBWR
- ESBWR Technology Program
- Conclusions

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



Containment Heat Removal System

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Decay Heat Removal/Containment Features and Technology

- Decay Heat Removal Design Features
- **Past Technology Program - SBWR**
- ESBWR System Modifications from SBWR
- ESBWR Technology Program
- Conclusions

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

Containment Technology Overview

SBWR and ESBWR Phase 1

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

<u>PCCS Performance</u>
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

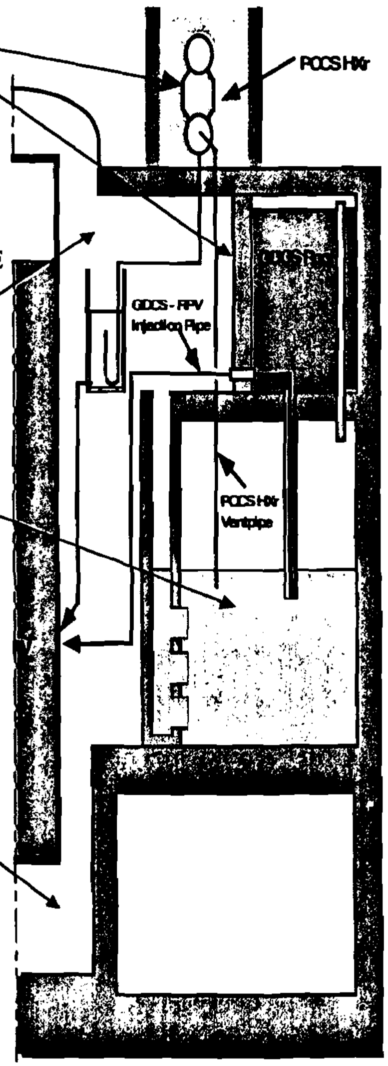
<u>System Interactions</u>
PANDA
GIRAFFE

<u>SP Stratification</u>
LINX (ALPHA)
PANDA

<u>DW Stratification and Hideout</u>
PANDA
GIRAFFE

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

<u>Heat/Mass Leakage DW to WW</u>
Finite Element Analysis
VB Testing



ESBWR Phase 2

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

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

<u>DW Stratification and Hideout</u>
PANDA(TEPSS)
- Asymmetric loading
- hydrogen

<u>SP Stratification</u>
LINX (TEPSS)

ESBWR Phase 3

<u>PCC Hydrogen Distribution</u>
PANDA + CFD (FFWP)
VTT - CFD

<u>DW Stratification and Hideout</u>
UCB + CFD (FFWP)
PANDA + CFD (FFWP)

<u>WW Gas Stratification</u>
UCB + CFD (FFWP)
KALI + CFD (FFWP)

PANTHERS

- Demonstrate that prototype heat exchanger is capable of meeting design requirements
- Provide database for TRACG (code) qualification to predict heat exchanger performance spanning the range of conditions expected in the SBWR (i.e. steam flow, air flow, pressure, temperature)
- Investigate the difference between lighter-than-steam and heavier-than-steam noncondensibles
- Structural component qualification

PANDA-M

- Objectives

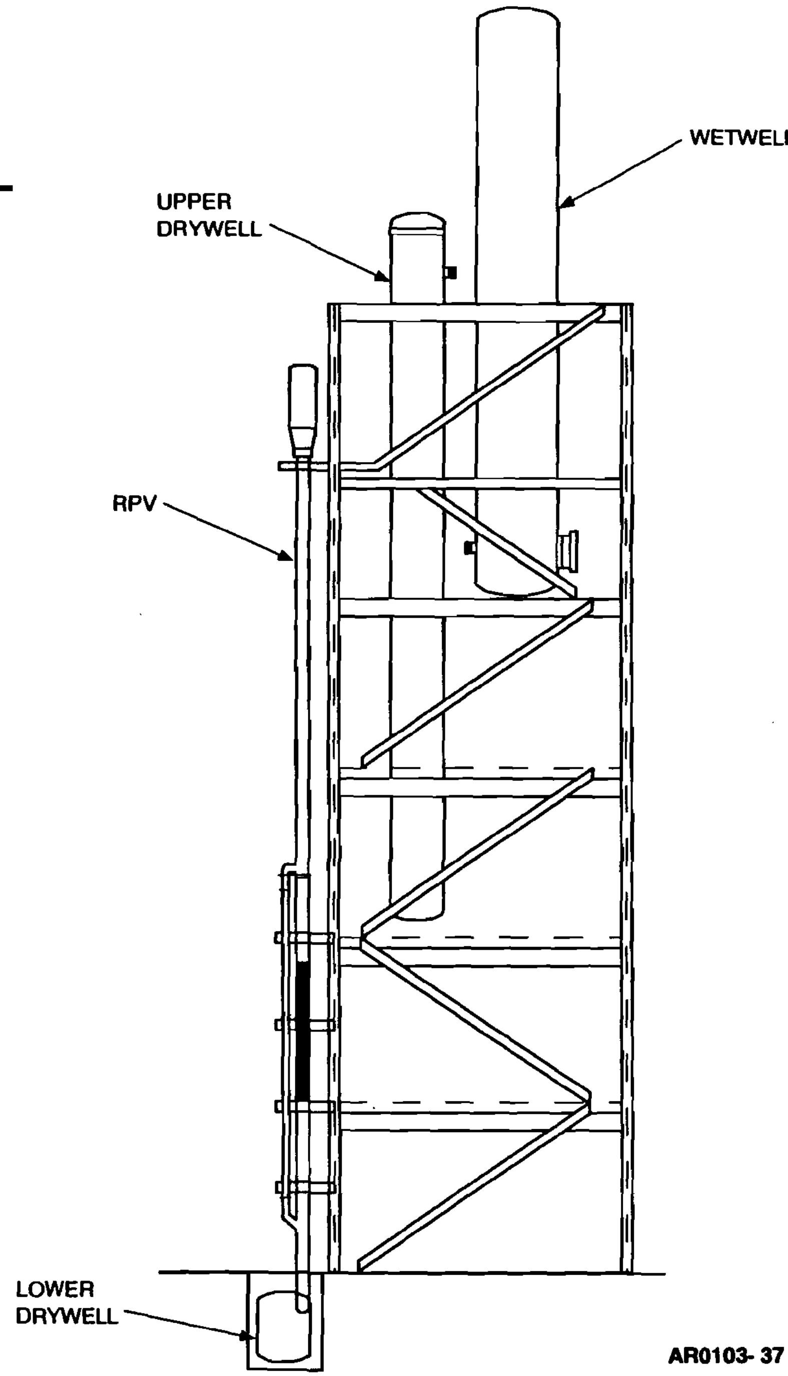
  Demonstrate steady-state, startup and long-term operation of the PCCS system

  Demonstrate effects of scale on PCC performance

  Data for TRACG (code) qualification to predict SBWR containment system performance including potential system interactions
- 10 steady state PCC component tests over a wide range of steam and air flow rates
- 12 transient tests representative of post-loca conditions with different configurations

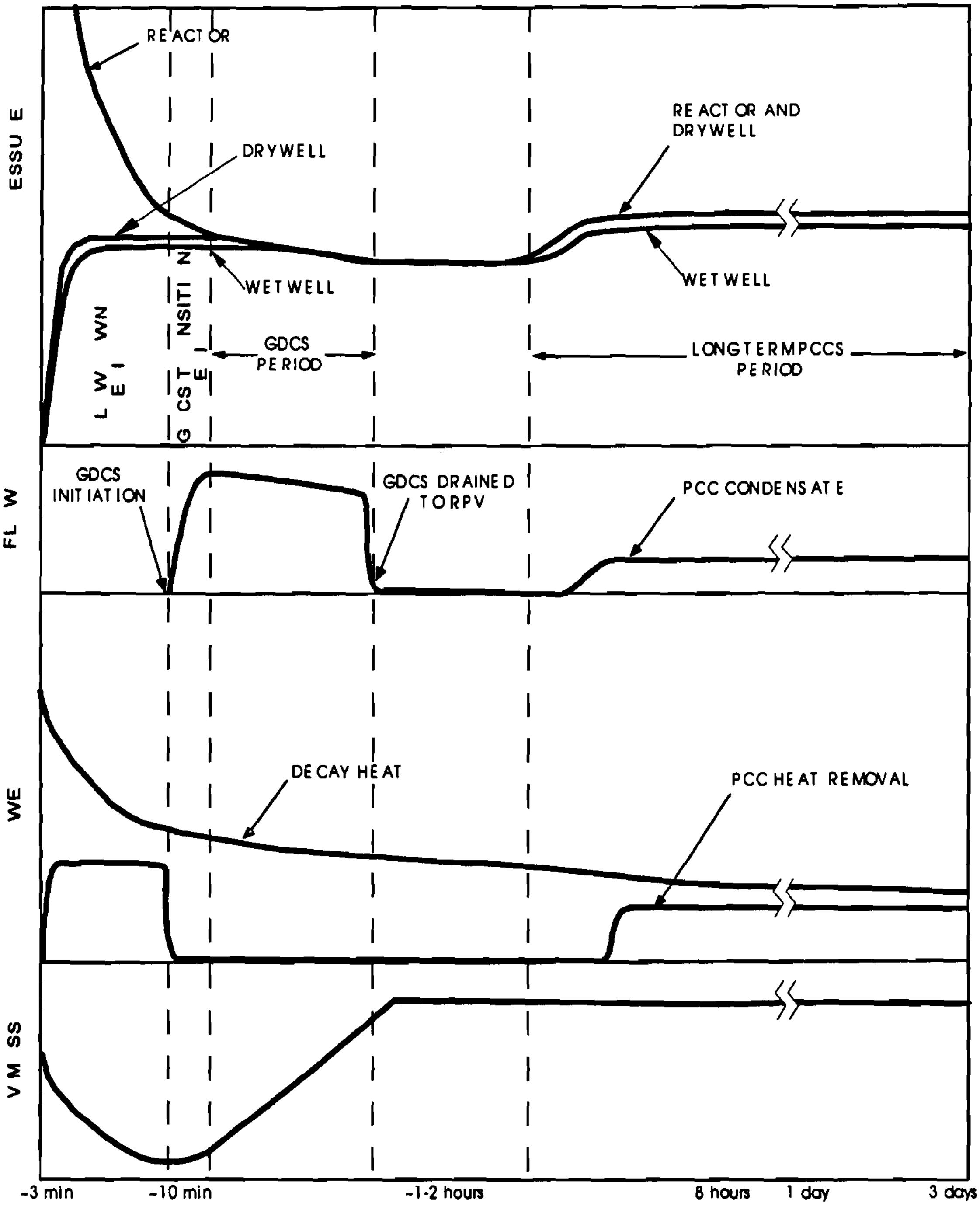
GIST

- Objectives
  - Demonstrate technical feasibility of GDCS concept
  - Database for qualification of TRACG (codes) to predict GDCS initiation times, flow rates and RPV water levels
- 26 tests representing a range of conditions encompassing 3 LOCA's and a no break condition



GIRAFFE

- 3 Test series:
  - GIRAFFE/Helium
    - Demonstrate system operation with lighter-than-steam noncondensibles including purging noncondensibles from the PCC
    - Data for TRACG (code) qualification to predict SBWR containment system performance including potential system interactions with l-t-s gas
  - GIRAFFE/SIT
    - Data for TRACG (code) qualification to predict SBWR ECCS performance during late blowdown/early GDCS phase of a LOCA - specific focus on system interactions
  - GIRAFFE/Step 1 and 3
    - Steady state performance of PCCS
    - System performance



INTEGRAL SYSTEM TRANSIENT TESTS		
GIST		PANDA
GIRAFFE/SIT		GIRAFFE/He
PANDA (GDCS PHASE TEST)		
COMPONENT TESTS: PANTHERS/PCC/IC		

Key Variables and Test Coverage

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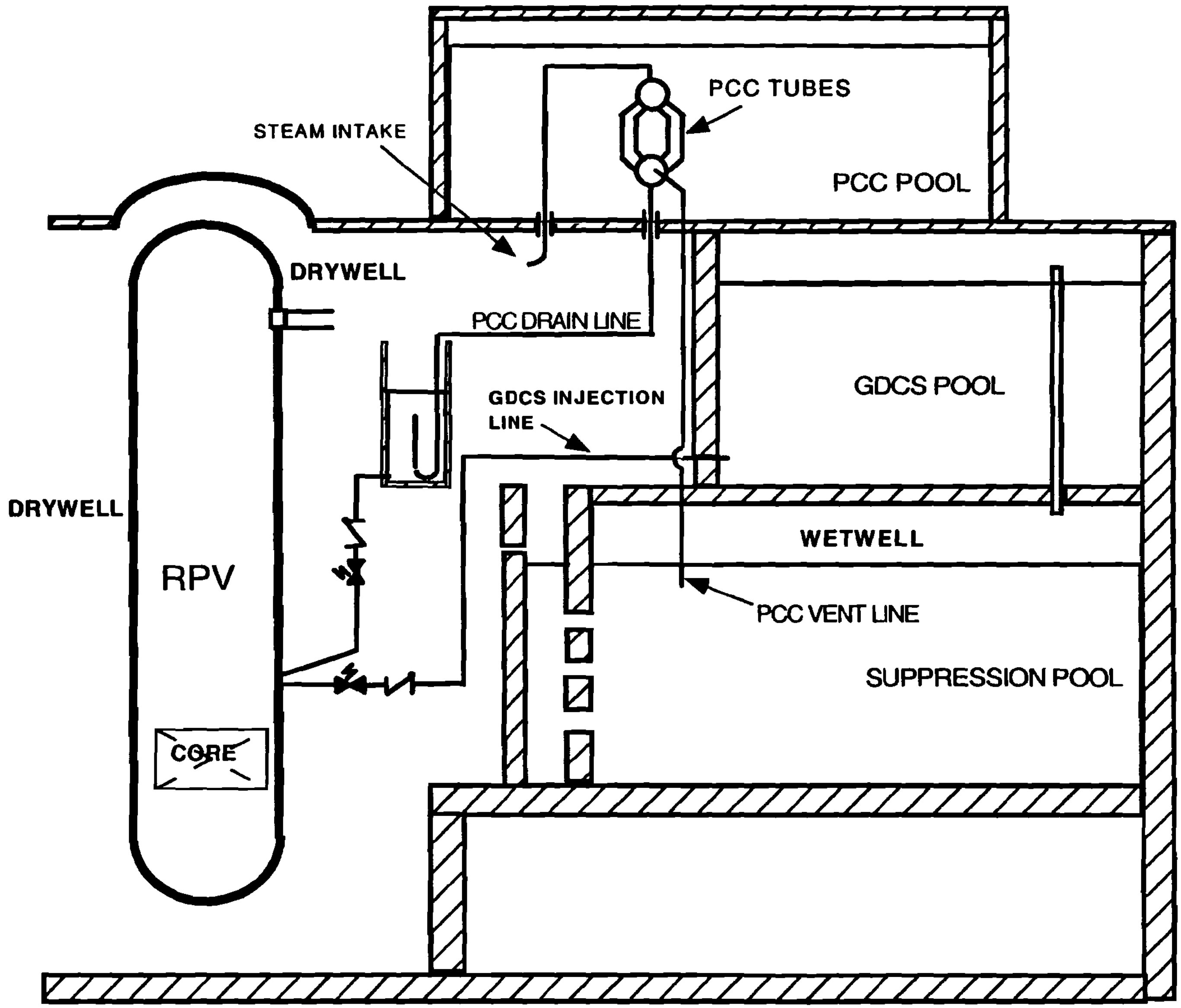
Decay Heat Removal/Containment Features and Technology

- Decay Heat Removal Design Features
- Past Technology Program - SBWR
- **ESBWR System Modifications from SBWR**
- ESBWR Technology Program
- Conclusions

ESBWR System Modifications

- Containment Configuration Optimized
  - Utilize GDCS pool draindown space to provide increased wetwell volume for severe accident (GDCS moved from DW to WW)
  - PCCS Condensate Tank added in DW
- Increased Power
  - Number of bundles, bundle length and power density increased
  - Additional PCC and IC added
  - Increased number of PCCS tubes per unit by 35%

ESBWR System Modifications



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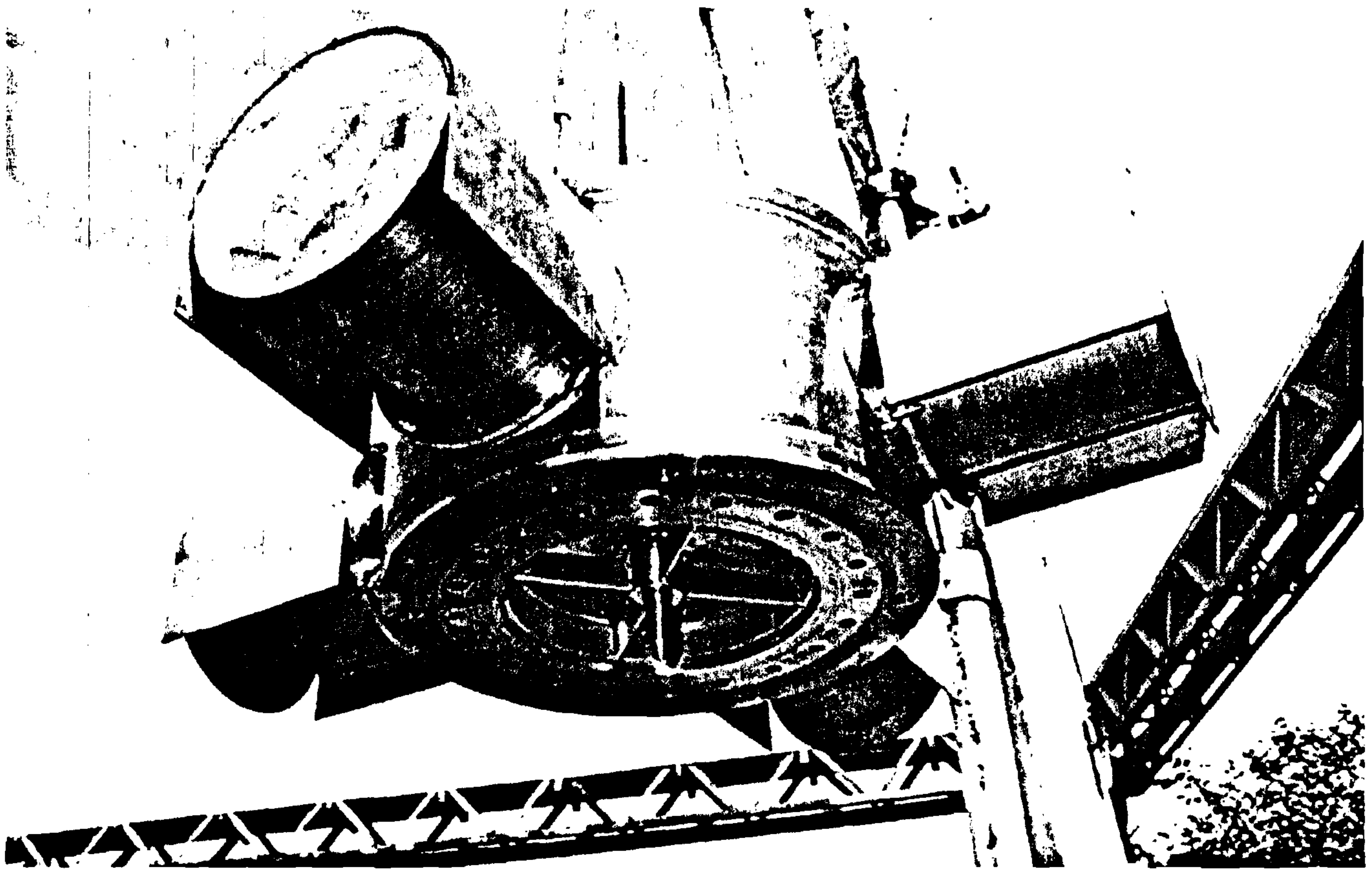
Prototype Vacuum Breaker



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Decay Heat Removal/Containment Features and Technology

- Decay Heat Removal Design Features
- Past Technology Program - SBWR
- ESBWR System Modifications from SBWR
- **ESBWR Technology Program**
- Conclusions

TEPSS Program

3 Part program to extend the SBWR database to the ESBWR

- 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

Suppression Pool Stratification/Mixing (LINX)

- Objectives
  - Improved countermeasures against pool stratification
  - Database for pool mixing models
- Conclusions
  - Steam bypass not expected for ESBWR
    - Bypass onset only at very high pool temperature (very low sub-cooling)
    - Limitations on test vent flow rate so that bypass for worst case ESBWR flow could not be completely excluded
  - Good pool mixing observed
    - Strong mixing for steam-air mixtures
    - Good mixing for steam only flow (less than 4 ºC for worst case)
    - Results may not be scalable
  - Analytical model validated against published plume spreading data

Passive Decay Heat Removal (PANDA-P)

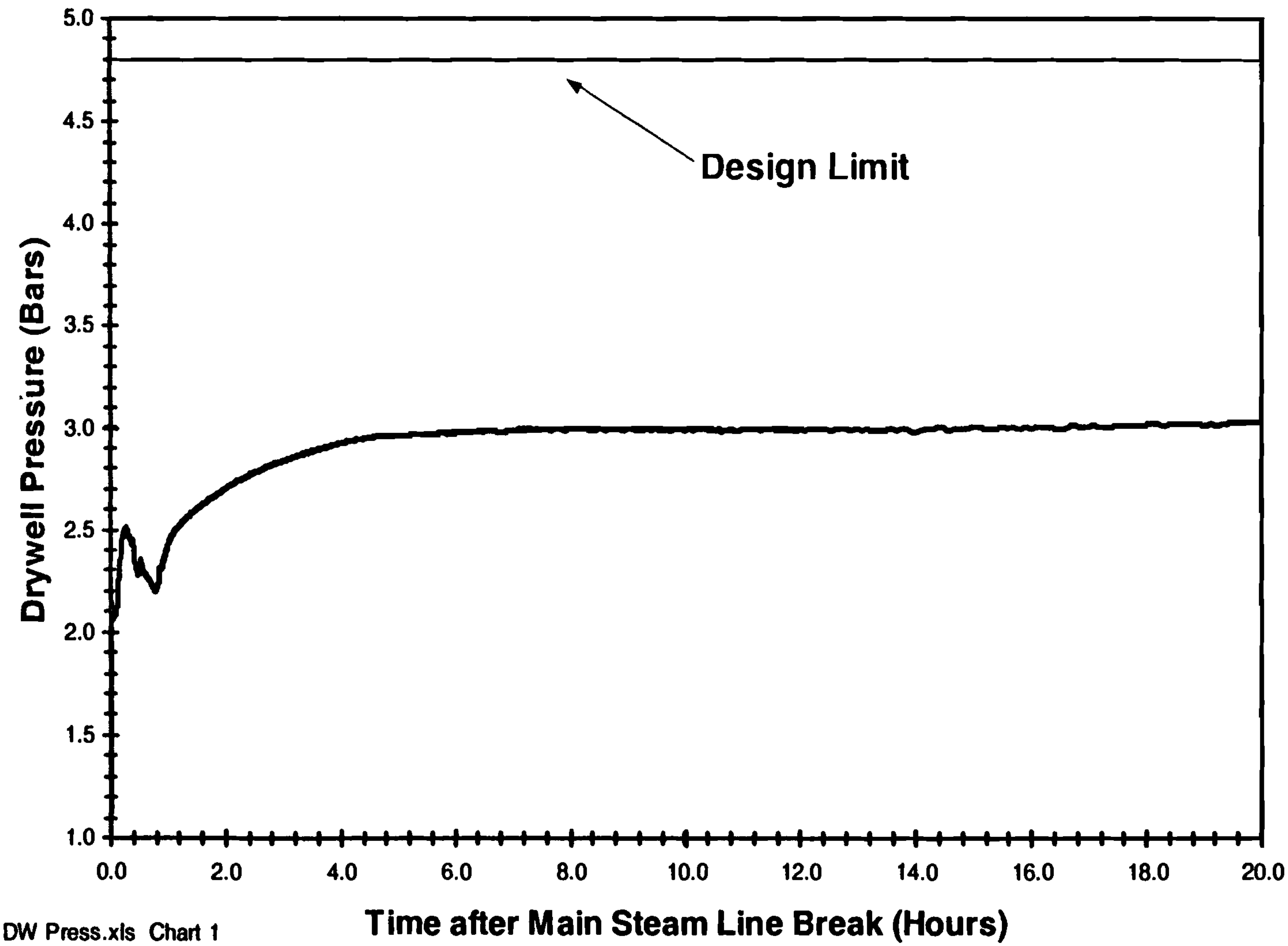
- Objectives
  - Testing of new containment features with respect to: PCCS long-term performance, PCCS start-up and systems interaction and distribution of steam and gases within the containment
  - Database to confirm the capability of TRACG to predict ESBWR containment system performance, including potential systems interaction effects
  - Effect of lighter-than-steam gas on system behavior
- Conclusions
  - Containment system operated robustly over all conditions tested
  - TRAC-BF1, RELAP5 and MELCOR benchmarked against test data
  - Some remaining uncertainties related to hydrogen behavior

TRACG has been benchmarked against the new test data

PCCS Extension

- Objectives
  - Analytical program to investigate the ability to scale up the PCC from 10 MW to 13. 5 MW without adverse effects
  - Investigation of secondary side heat transfer
- Conclusions
  - The PCC heat removal scales approximately linearly with number of tubes
  - Secondary side heat transfer does not limit the condenser performance

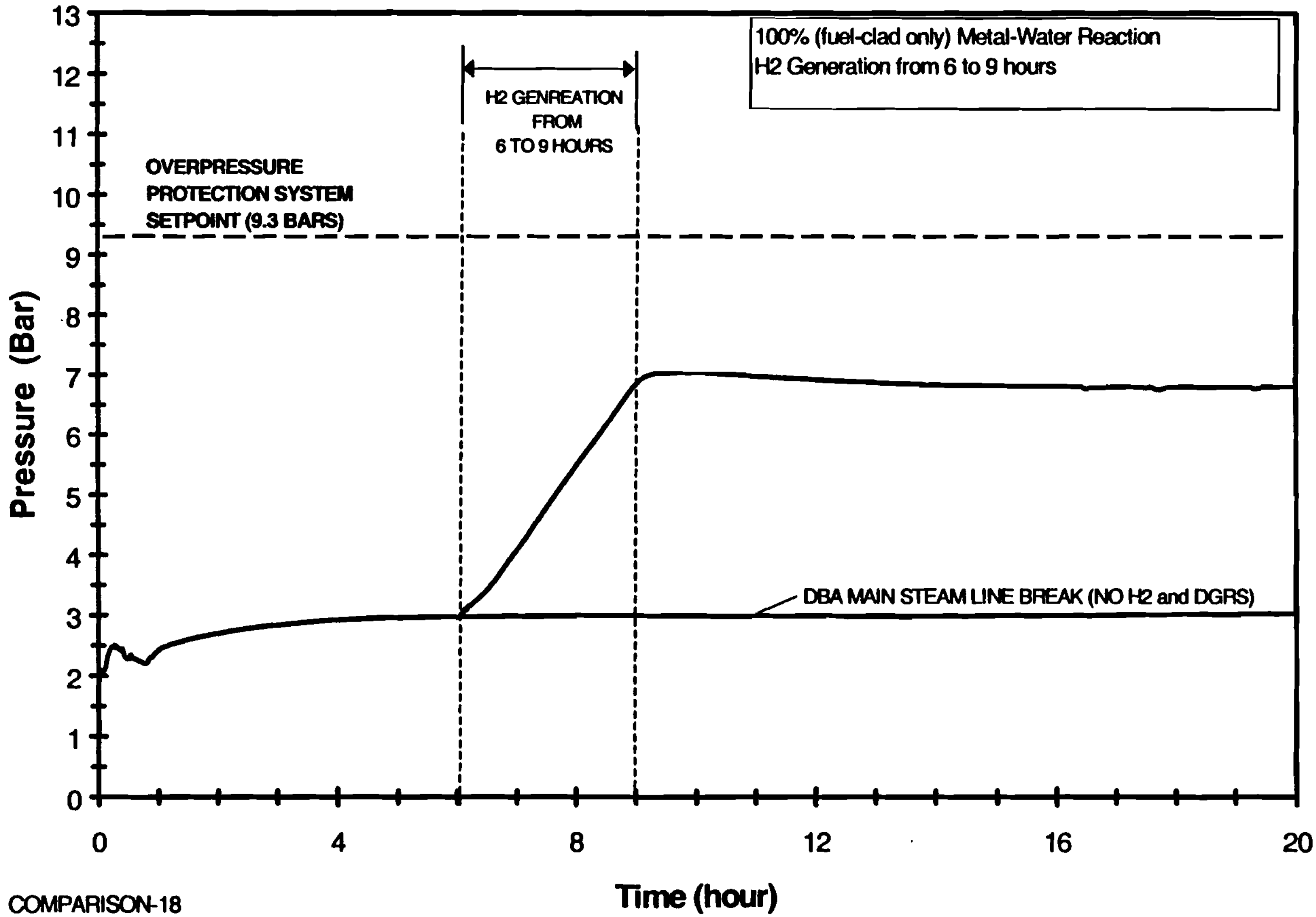
Substantial Margin for DBA Containment Pressure



MSLB DW Press.xls Chart 1

AR0103-49

100% Clad Metal Water Reaction Results



COMPARISON-18

AR0103-50

Decay Heat Conclusions

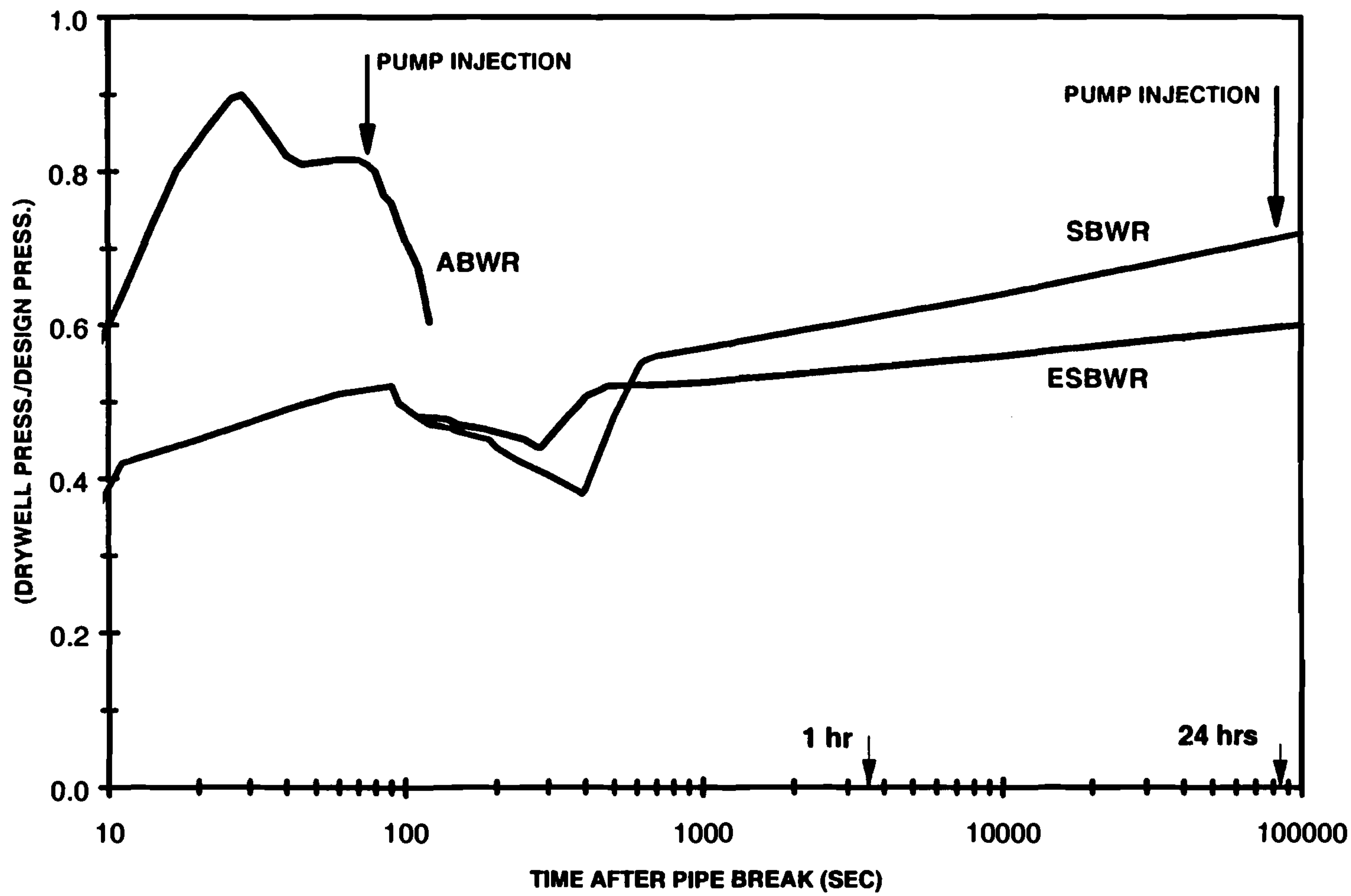
- Robust behavior of ESBWR containment demonstrated
  - ESBWR containment modifications improve pressure performance
  - Significant margins for Design Basis Accidents
  - Asymmetry effects not important
  - System interactions do not adversely effect performance
- PCCS capabilities confirmed
  - Start-up and long-term operation with noncondensibles confirmed
  - Heat removal capability sufficient over the range of conditions expected in ESBWR
  - Good performance with both light and heavy noncondensibles
  - Scalable technology

Decay Heat Conclusions (Cont'd)

- Suppression Pool Performance Good
  - Very little stratification in Suppression Pool
  - No steam PCCS vent bypass expected in ESBWR

Issues related to decay heat removal resolved through extensive testing and analysis programs

Containment Pressure Following a Pipe Break



AR0103-53

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

AR0103-54

Fuel, Vessel and CRD optimization

- **Optimization of Fuel Length**
  - 0.3m Increase in Fuel Length Gives Significant Benefit
  - Performance Margins Are Sufficient
  - Design Options Being Explored to Increase Margins
  - Further Studies Expected to Confirm Margins
- **Reduction in Key Components**
  - Control Rod Drives and Fuel Bundles Reduced 10%
  - Significant Simplification in Vessel and Internals
- **Impact on Building Height Minimal**
  - Other Changes Will Have a Bigger Impact

Selected key parameters to simplify the design

Building/Structures & Refueling Optimization

- **What Controls Building Size**
  - Wetwell, PCCS Parameters and MSIV Access Control Building Height
  - Vessel Height Does Not Control Building Height
  - Refueling Floor Size and Dimensions Control Footprint
  - Refueling Schemes Are Very Important for Optimization
- **What Controls Structures**
  - Containment Design Pressure
  - Plant Seismic Design Basis
- **What is the Impact on the Construction Schedule**

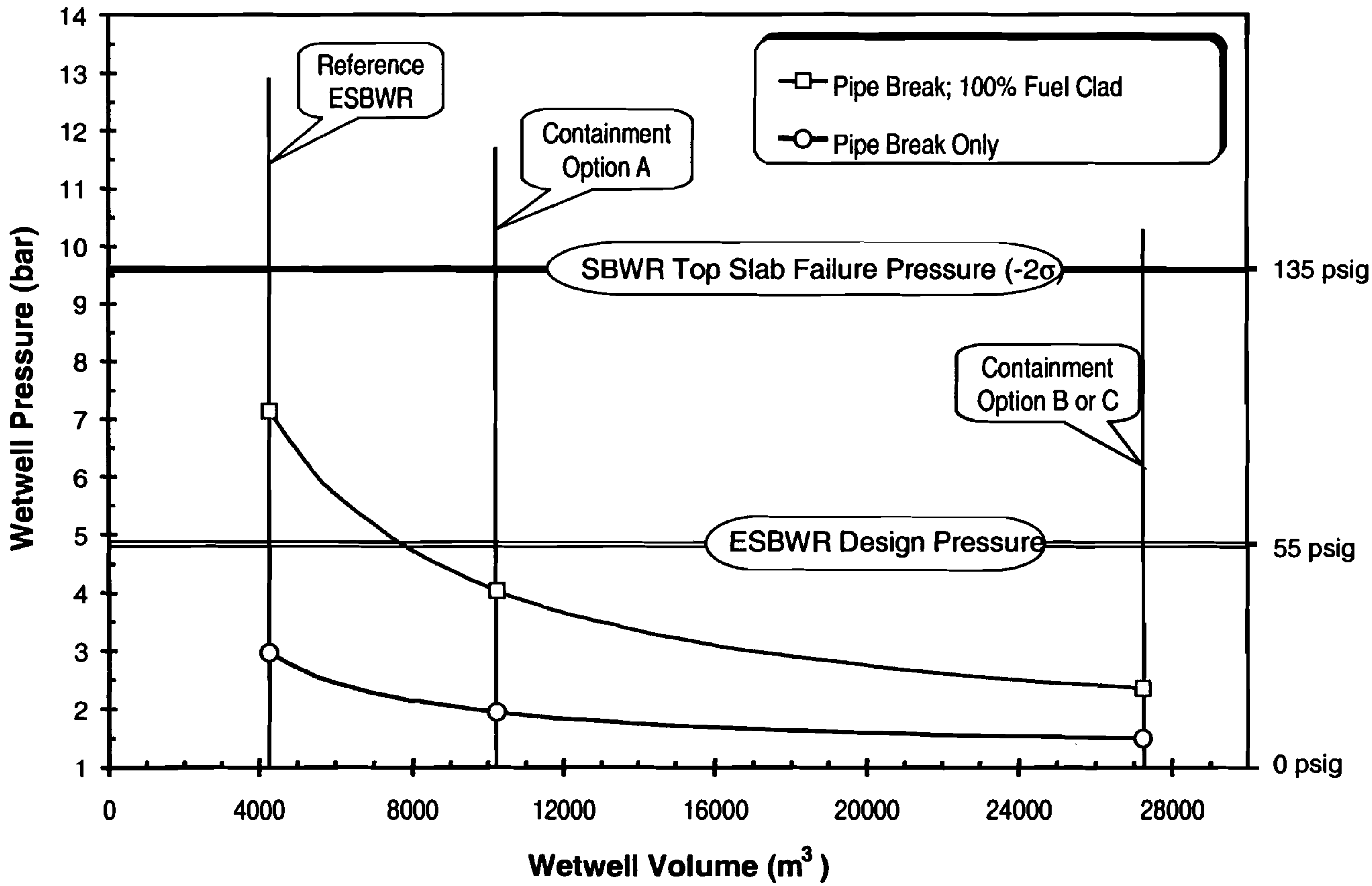
Several interesting options have been identified

Key parameters in Various Options

- **Ways to Reduce Containment Design Pressure**
- **Spent Fuel in Containment or Reactor Building**
  - Horizontal or Inclined Fuel Transfer
  - Stacked Spent Fuel Option
  - Cask Transfer Schemes
  - Size of Spent Fuel Pool
- **Refueling Floor Arrangement**
- **Location of Steam Line**

Several promising choices
All improve margins and reduce building cost

Calculated ESBWR Wetwell Pressures vs. Wetwell Volume



AR0103-58

Key Technology Results and Design Impact

- **Effect of ESBWR Containment Configuration Changes**
  - Allowed Scaleup of Power Without Containment Size Increase
  - Tests Showed Significantly Lower Pressure
- **Effect of Reduced Water Levels in the PCCS Pool**
  - Allowed the Use of a Smaller PCCS Pool, Which Then Kept the Refueling Floor and Building Reasonably Sized
  - Tests Showed That Pool Level (up to a Limit) Has No Effect on Containment Heat Removal and Containment Pressure
- **Effect of Hydrogen on Decay Heat Removal**
  - Allowed the Use a Smaller Containment, Even When Considering Severe Accident Conditions
  - Results Show No Overall Heat Transfer Degradation When Hydrogen Is Present

Technology programs provide confidence in plant design/performance and help reduce costs

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
- **Provide Additional Data for Code Qualification**

Technology programs to confirm that design is robust

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

GENERAL ELECTRIC
RAO

GE Advanced Liquid Metal Reactor

S-PRISM

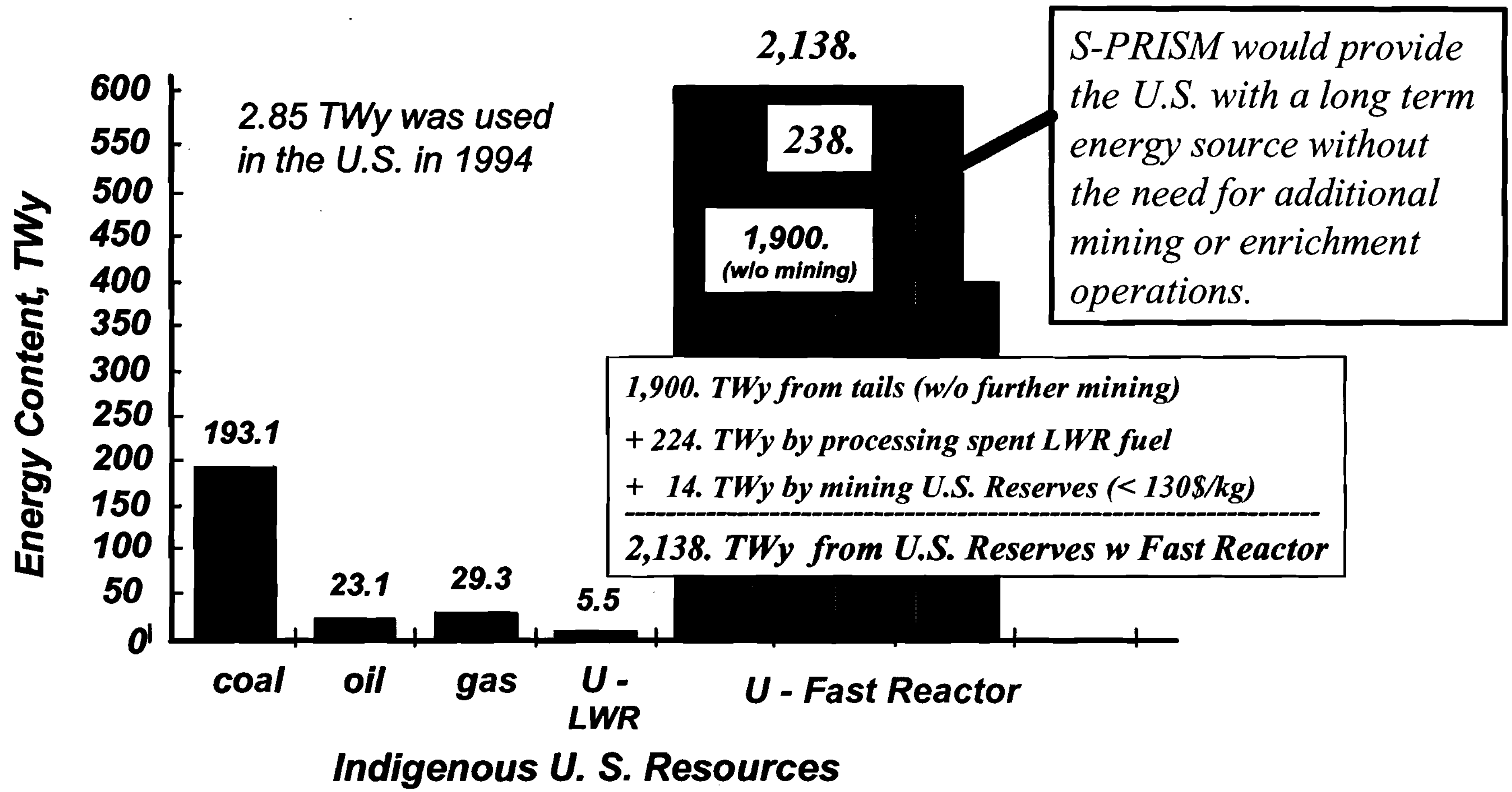
by

C. Boardman
GE Nuclear
San Jose, CA

Topics

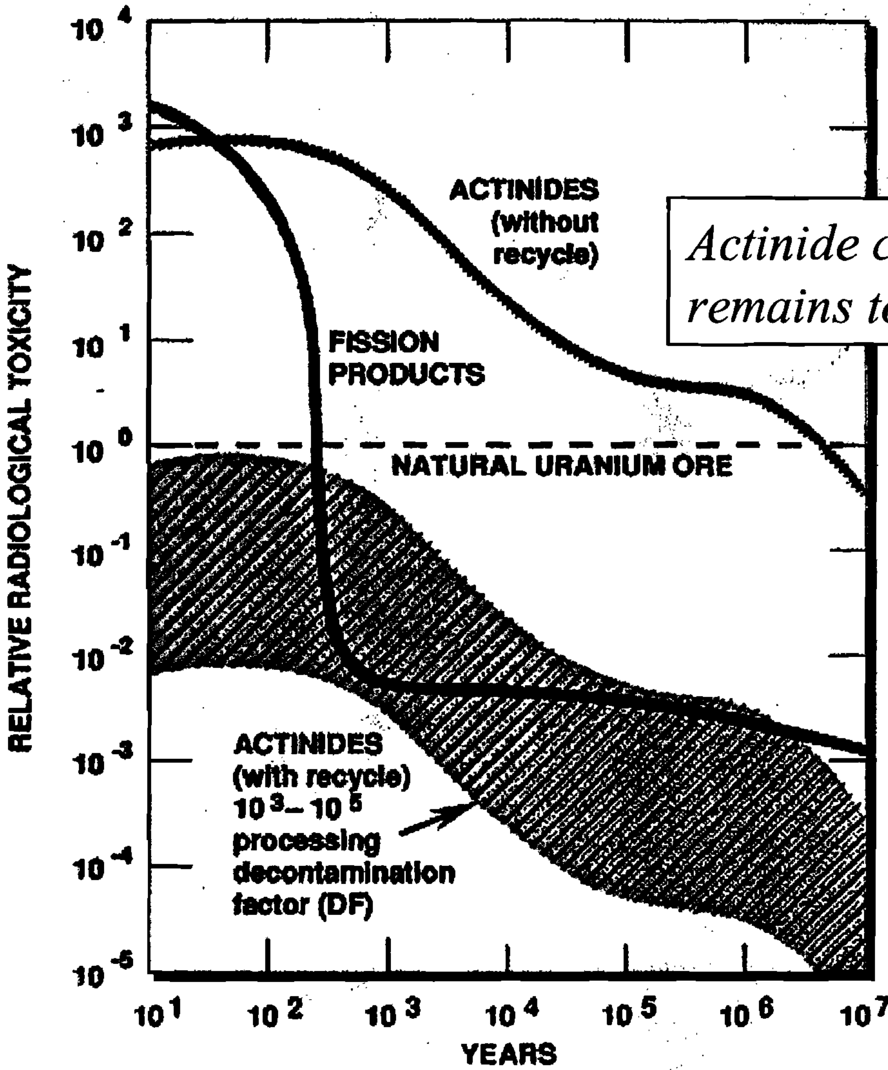
- *Incentive for developing S-PRISM*
- *Design and safety approach*
- *Design description and competitive potential*
- *Previous Licensing interactions*
- *Planned approach to Licensing S-PRISM*
- *What, if any, additional initiatives are needed?*

United States Energy Resources



Energy estimates for fossil fuels are based on "International Energy Outlook 1995", DOE/EIA-0484(95). The amount of depleted uranium in the US includes existing stockpile and that expected to result from enrichment of uranium to fuel existing LWRs operated over their 40-y design life. The amount of uranium available for LWR/Once Through is assumed to be the reasonably assured resource less than $130/kg in the US taken from the uranium "Red Book".

Time Phased Relative Waste Toxicity (LWR Spent Fuel)



Actinide containing LWR spent fuel remains toxic for millions of years

- *Processing to remove the fission products (~3% of LWR spent fuel), uranium (95%), and transuranics prior to disposal shortens the period that the "waste" remains toxic to less than 500 years.*
- *The recovered U and TRU would then be used as fuel and burned.*

Relative Decay Heat Loads of LWR and LMR Spent Fuel

Decay Heat Load	Decay Heat (Watts per kg HM)	
	LWR	S-PRISM
Spent Fuel at Discharge	2.3	11.8
Normal Process Product After Processing Spent Fuel • Pu from PUREX Process for LWR • Pu + Actinides from PYRO Process	9.62	25.31
Weapons Grade Pu-239	1.93	

During all stages in the S-PRISM fuel cycle the fissile material is in a highly radioactive state that always exceeds the "LWR spent fuel standard".

<u>Diversions</u> would be extremely difficult.

Stage of the Fuel Cycle	Material Barriers: Isotopic	Material Barriers: Radiological	Material Barriers: Chemical	Material Barriers: Mass and Bulk	Material Barriers: Detectability	Technical Barriers: Facility Unattractiveness	Technical Barriers: Facility Access	Technical Barriers: Available Mass	Technical Barriers: Diversion, Detectability	Technical Barriers: Skills, Knowledge, Expertise	Technical Barriers: Time
[redacted]	Co-Located Fuel Cycle Facility										
Phase 3: Equilibrium Operations											
Fuel handling				L			VL	I		M	L
Spent fuel storage				L			M	I		M	L
Head-end processing				M			VL	I		I	L
Fuel processing	VL	VL	L	M	VL	VL	VL	I	VL	I	L
Fuel fabrication				L			VL	I		I	L
Reactor operations				L			VL	I		M	L
Waste conditioning				L			VL	VL		I	VL
Waste shipment				VL			VL	VL		I	VL

Phase I
These opportunities for proliferation are not required for S-PRISM.

Phase 2
All operations are performed within heavily shielded enclosures or hot cells at the S-PRISM site.

Phase 3
All operations are performed within heavily shielded and inerted hot cells at the co-located S-PRISM/IFR site.

Key Non-Proliferation Attributes of S-PRISM

1.) The ability to create S-PRISM startup cores by processing spent LWR fuel at co-located Spent Fuel Recycle Facilities eliminates opportunity for diversion within:

- *Phase I (mining, milling, conversion, and uranium enrichment phases) since these processes are not required.*

and

- *Phase II and III (on-site remote processing of highly radioactive spent LWR and LMR fuel eliminates the transportation vulnerabilities associated with the shipment of Pu)*

2.) The fissile material is always in an intensely radioactive form. It is difficult to modify a heavily shielded facility designed for remote operation in an inert atmosphere without detection.

3.) The co-located molten salt electro-refining system removes the uranium, Pu, and the minor actinides from the waste stream thereby avoiding the creation of a uranium/Pu mine at the repository.

Incentive for Developing S-PRISM

- *Supports geological repository program:*
    - *deployment of one new S-PRISM plant per year for 30 years would eliminate the 86,000 metric tons of spent LWR fuel that will be discharged by the present fleet of LWRs during their operating life.*
    - *reduces required repository volume by a factor of four to fifty*
    - *All spent fuel processing and waste conditioning operations would be paid for through the sale of electricity.*
    - *limits interim storage to 30 years*
- *Reduces environmental and diversion risks*
    - *repository mission reduced from >> 10,000 to <500 years*
    - *facilitates long term CO_2 reduction*
    - *resource conservation (fossil <u>and</u> uranium)*
    - *allows Pu production and utilization to be balanced*
    - *utilizes a highly diversion resistant reprocessing technology*

Topics

- *Incentive for developing S-PRISM*
- ***Design and safety approach***
- *Design description and competitive potential*
- *Previous Licensing interactions*
- *Planned approach to Licensing S-PRISM*
- *What, if any, additional initiatives are needed?*

S-PRISM Safety Approach

Exploits Natural Phenomena and Intrinsic Characteristics

- *Low System Pressure*
- *Large heat capacity*
- *Natural circulation*
- *Negative temperature coefficients of reactivity*

Key Features of S-PRISM

- *Compact pool-type reactor modules sized for factory fabrication and an affordable full-scale prototype test for design certification*
- *Passive shutdown heat removal*
- *Passive accommodation of ATWS events*
- *Passive post-accident containment cooling*
- *Nuclear safety-related envelope limited to the nuclear steam supply system located in the reactor building*
- *Horizontal seismic isolation of the complete NSSS*
- *Accommodation of postulated severe accidents such that a a formal public evacuation plan is not required*
- *Can achieve conversion ratio's less than or greater than one*

S-PRISM Design Approach

Simple Conservative Design

- Passive decay heat removal
- Passive accommodation of ATWS Events
- Automated safety grade actions are limited to:
  - containment isolation
  - reactor scram
  - steam side isolation and blow-down

Operation and Maintenance

- Safety grade envelope confined to NSSS
- Simple compact primary system boundary
- Low personnel radiation exposure levels

Capital and Investment Risk Reduction

- Conservative Low Temperature Design
- Modular Construction and seismic isolation
- Factory fabrication of components and facility modules
- Modularity reduces the need for spinning reserve
- Certification via prototype testing of a single 380 MWe module

S-PRISM Features Contribute to:

- Simplicity of Operation
- Reliability
- Maintainability
- Reduced Risk of Investment Loss
- Low Cost Commercialization Path

S-PRISM Design Approach (continued)

1. ***Design basis events (DBEs)***
   - *Equipment and structures design and life basis*
   - *Bounding events that end with a reactor scram*
   - *Example, all rod run out to a reactor scram*

2. ***Accommodated anticipated transients without scram (A-ATWS)***
   - *In prior reactors, highest probability events that led to boiling and Hypothetical Core Disassembly Accidents were ATWS events*
   - *In S-PRISM, ATWS events are passively accommodated within ASME Level D damage limits, without boiling*
   - *Loss of primary flow without scram (ULOF)*
   - *Loss of heat sink without scram (ULOHS)*
   - *Loss of flow and heat sink without scram (ULOF/LOHS)*
   - *All control rod run out to rod stops without scram (UTOP)*
   - *Safe shutdown earthquake without scram (USSE)*

3. ***Residual risk events***
   - *Very low probability events not normally used in design*
   - *In S-PRISM, residual events are used to assess performance margins*

Topics

- *Incentive for developing S-PRISM*
- *Design and safety approach*
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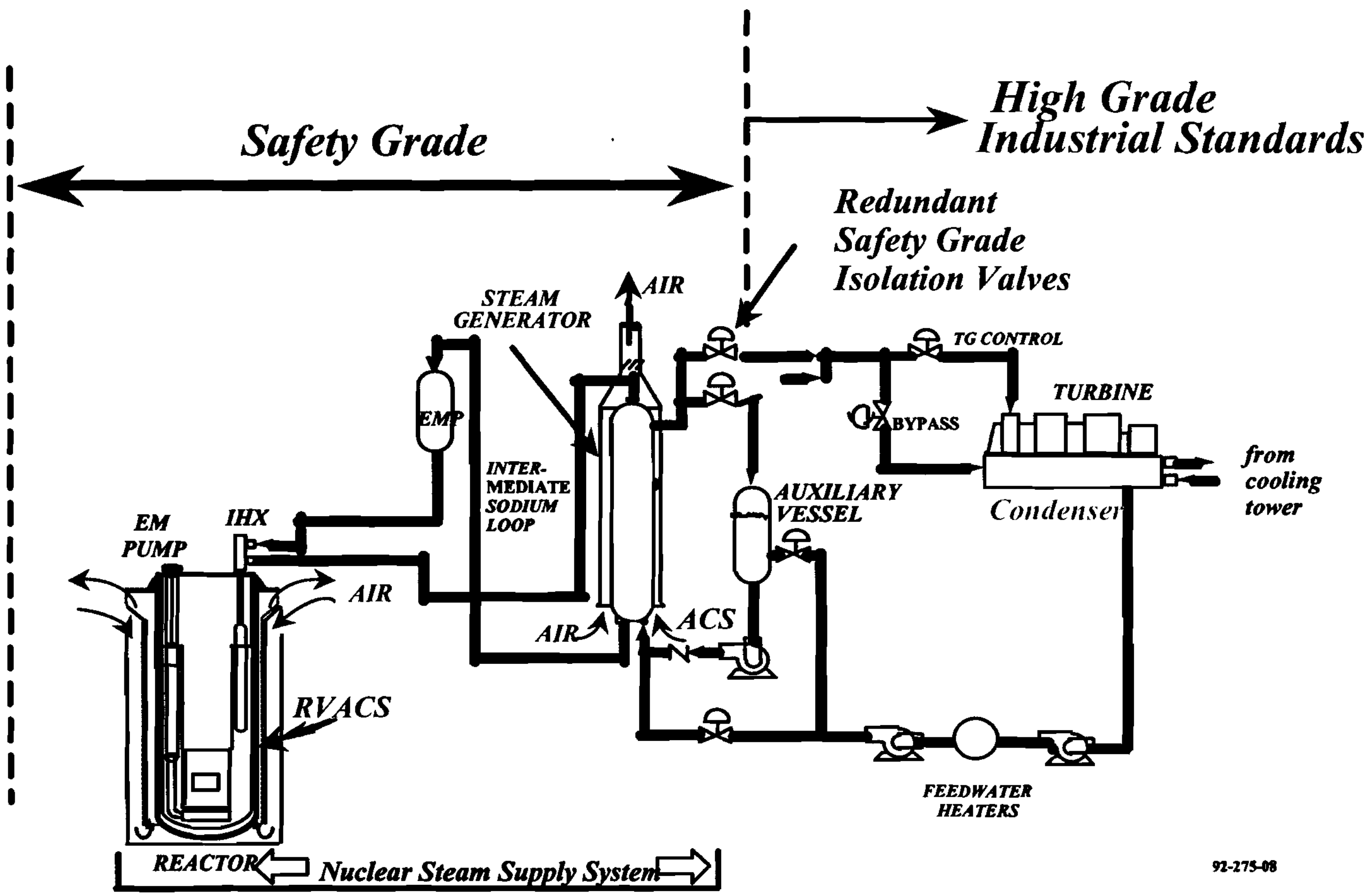
Power Train



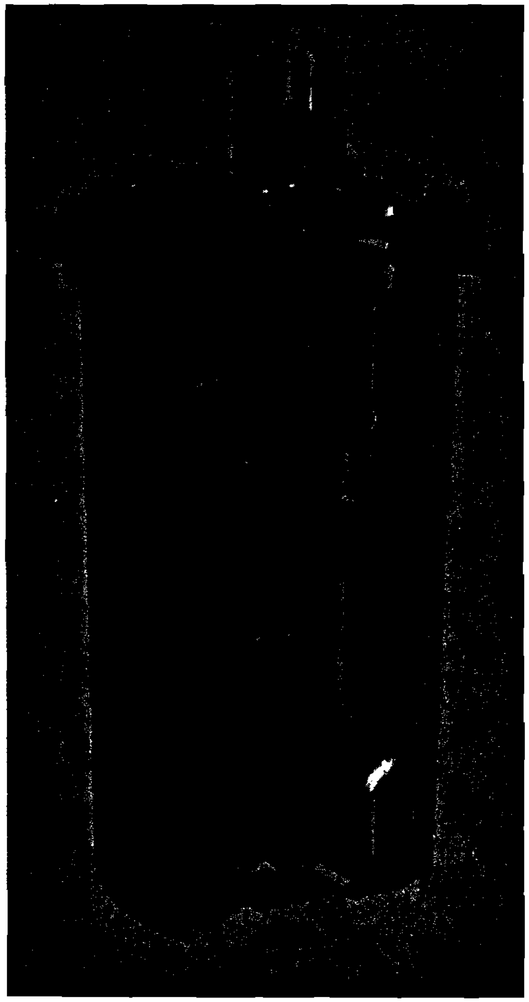
RVACS	ACS	Condenser

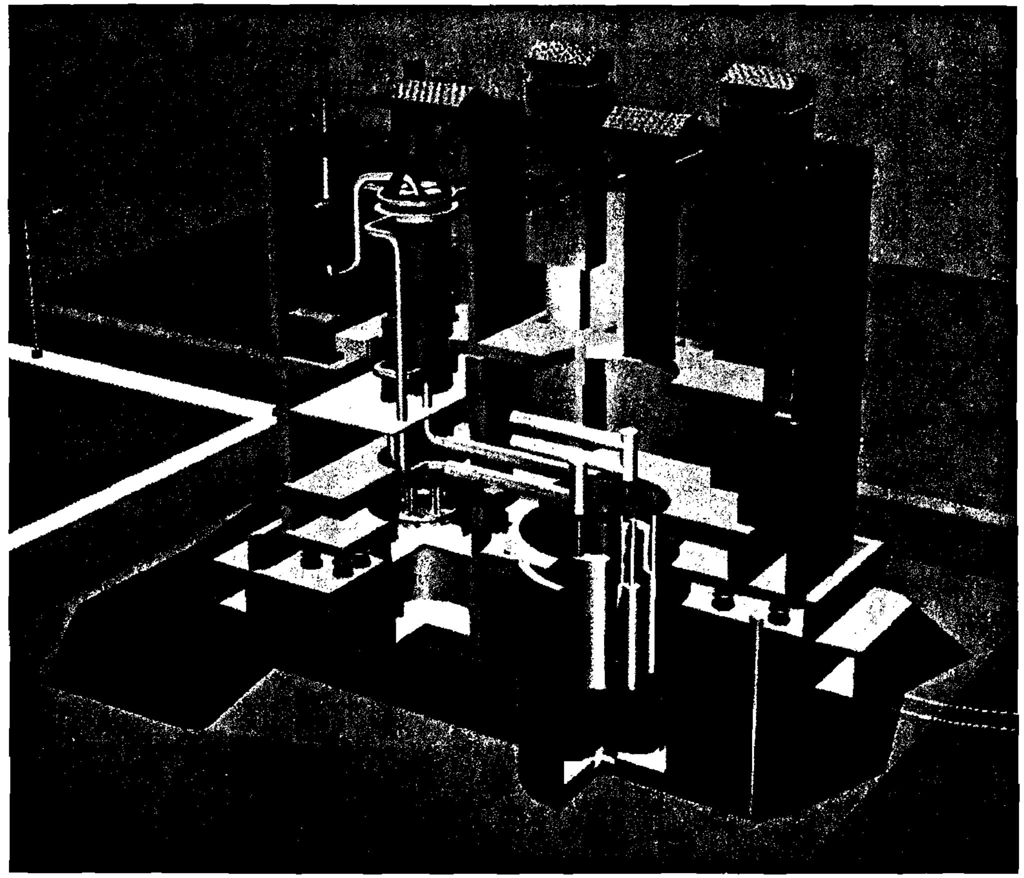
Shutdown Heat Removal Systems

S-PRISM - Principal Design Parameters

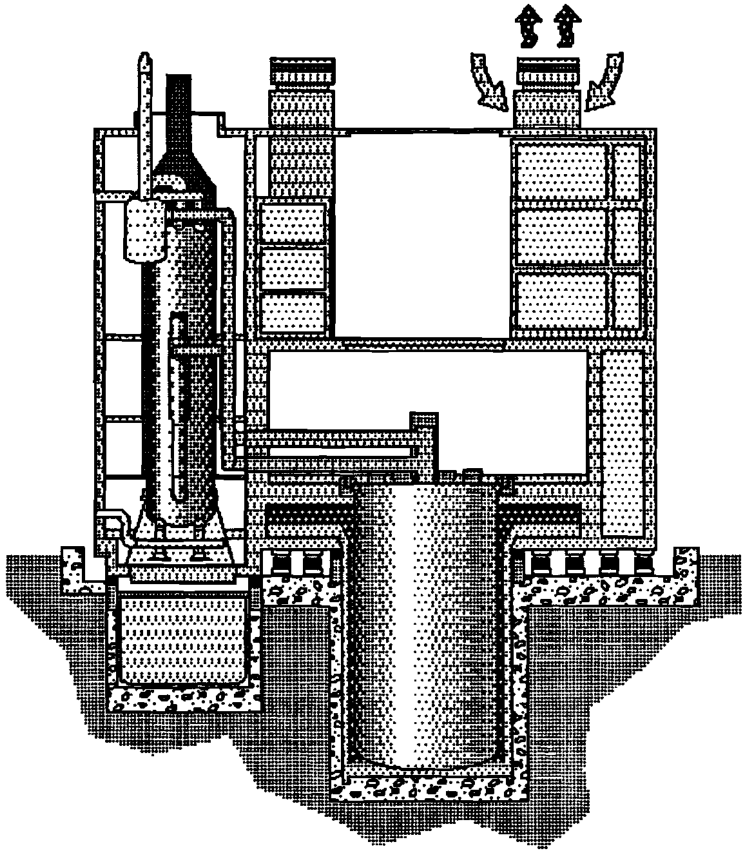
Reactor Module	
- Core Thermal Power, MWt	1,000
- Primary Inlet/Outlet Temp., C	363/510
- Secondary Inlet/Outlet Temp., C	321/496
Power Block	
- Number of Reactors Modules	2
- Gross/Net Electrical, MWe	825/760
- Type of Steam Generator	Helical Coil
- Turbine Type	TC-4F 3600 rpm
- Throttle Conditions, atg/C	171/468
- Feedwater Temperature, C	215
Overall Plant	
- Gross/Net Electrical, MWe	2475/2280
- Gross/Net Cycle Efficiency, %	41.2/38.0
- Number of Power Blocks	3
- Plant Availability, %	93

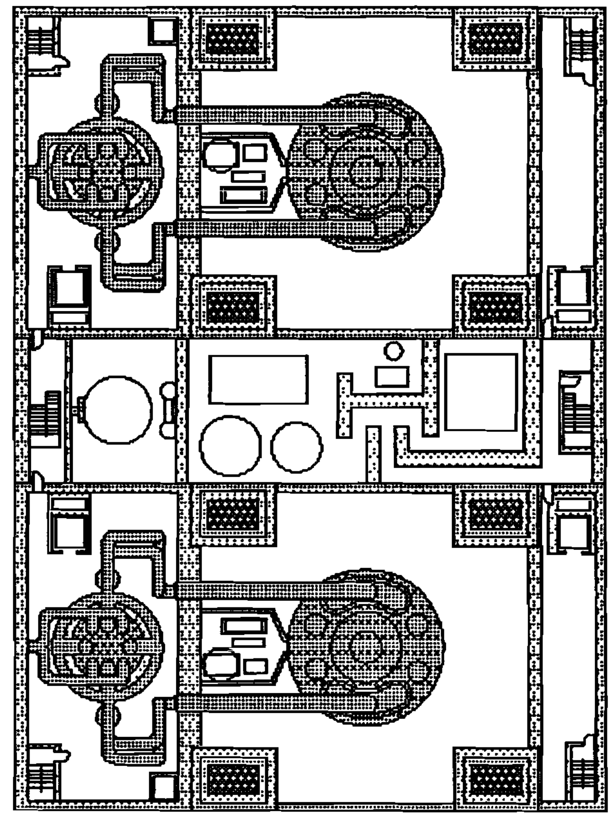
Super PRISM





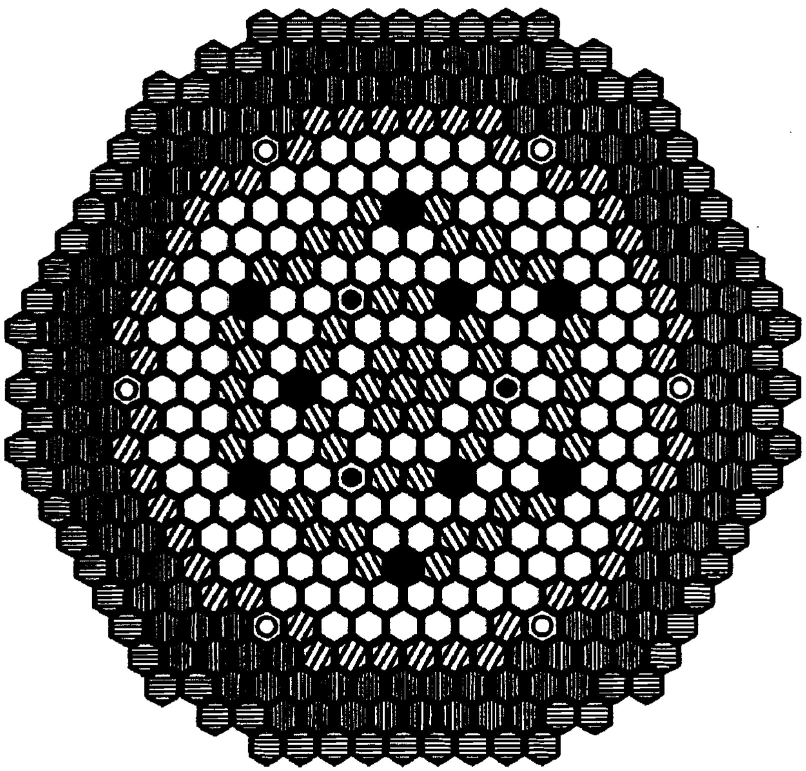
S-PRISM Power Block (760 MWe net)





Two 380 MWe NSSS per Power Block

Metal Core Layout



Number of Assemblies

Driver Fuel	138
Internal Blanket	49
Radial Blanket	48
Primary Control	9
Secondary Control	3
Gas Expansion Module	6
Reflector	126
Shield	72
Total	451

Fuel: 23 month x 3 cycles

Blkt: 23 month x 4 cycles

Oxide vs. Metal Fuel

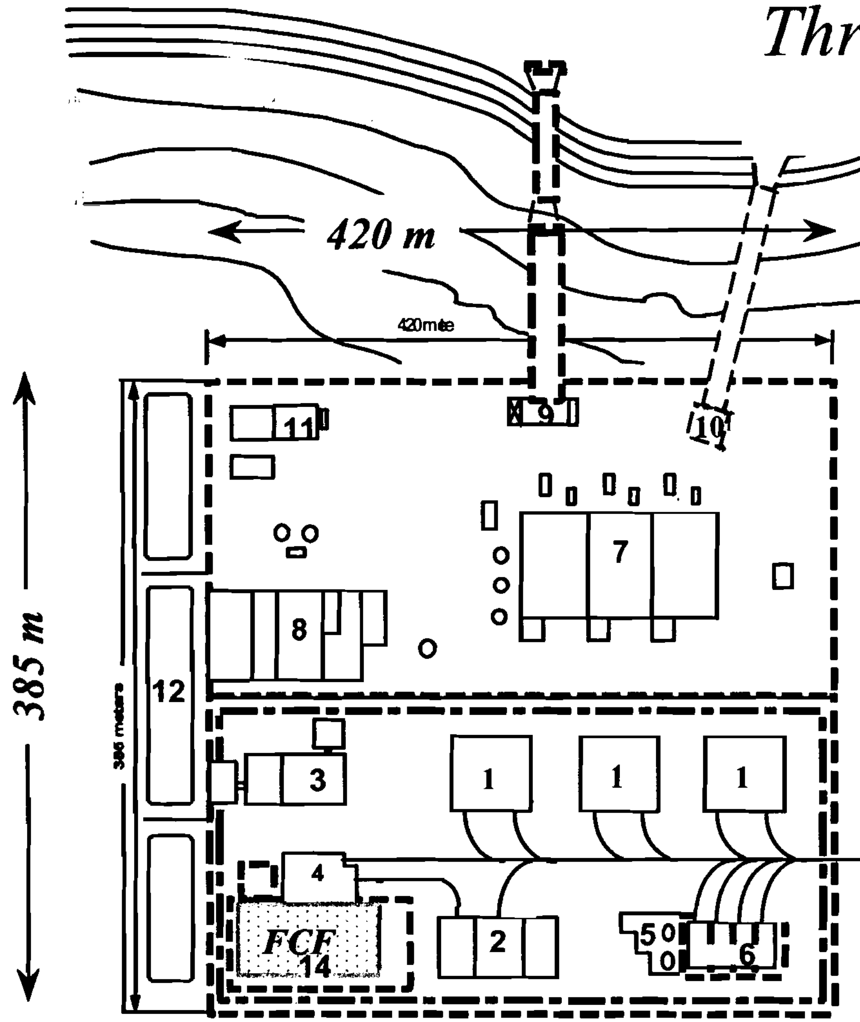
- *Attractive features of metal core include:*
  - *fuel is denser and has a harder neutron spectrum*
  - *compatible with coolant, RBCB demonstrated at EBR-II*
  - *axial blankets are not required for break even core*
  - *high thermal conductivity (low fuel temp.)*
  - *lower Doppler and harder spectrum reduce the need for GEMs for ULOF (6 versus 18)*
- *Metal fuel pyro-processing is diversion resistant, compact, less complex, and has fewer waste streams than conventional aqueous (PUREX) process*
- *However, an "advanced" aqueous process may be competitive and diversion resistant.*

S-PRISM can meet all requirements with either fuel type.

S-PRISM - Three Power Block Plot Plan

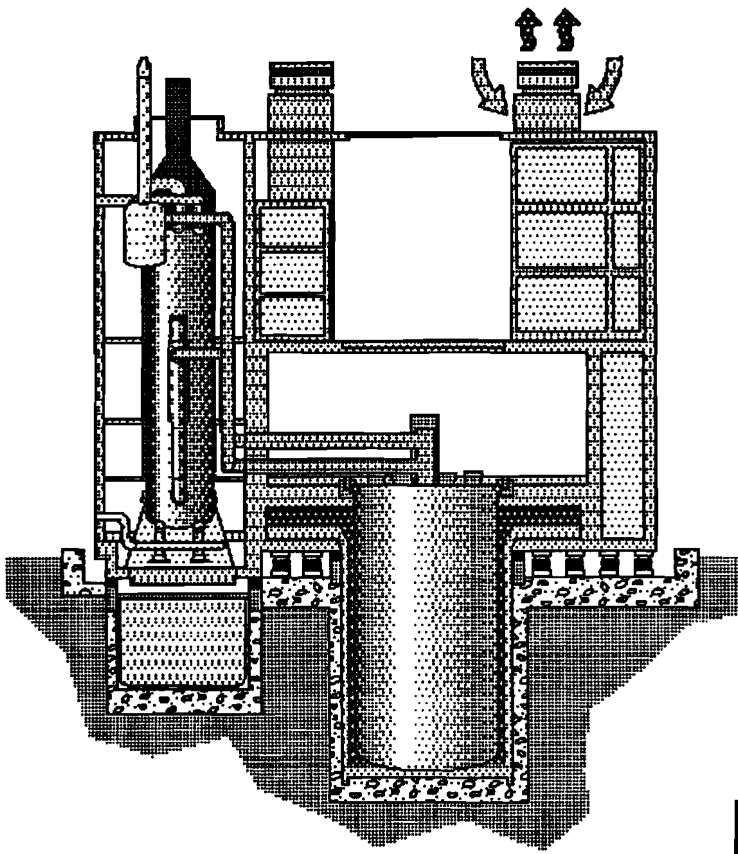
Three Power Block Plant

2475 MWe (2280 MWe net)



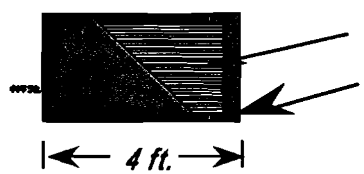
1 Reactor Building (2 NSSS/block)
2 Reactor Maintenance Facility
3 Control Facility
4 New and Spent Fuel Handling Facility
5 Assembly Facility
6 Cask Storage Facility
7 Turbine-Generator Facility
8 Maintenance Facility
9 Circulating Water Inlet Pump Station
10 Circulating Water Discharge
11 Waste Treatment
12 Parking Lot
13 Switch Yard
14 Fuel Cycle Facility

S-PRISM - Seismic Isolation System



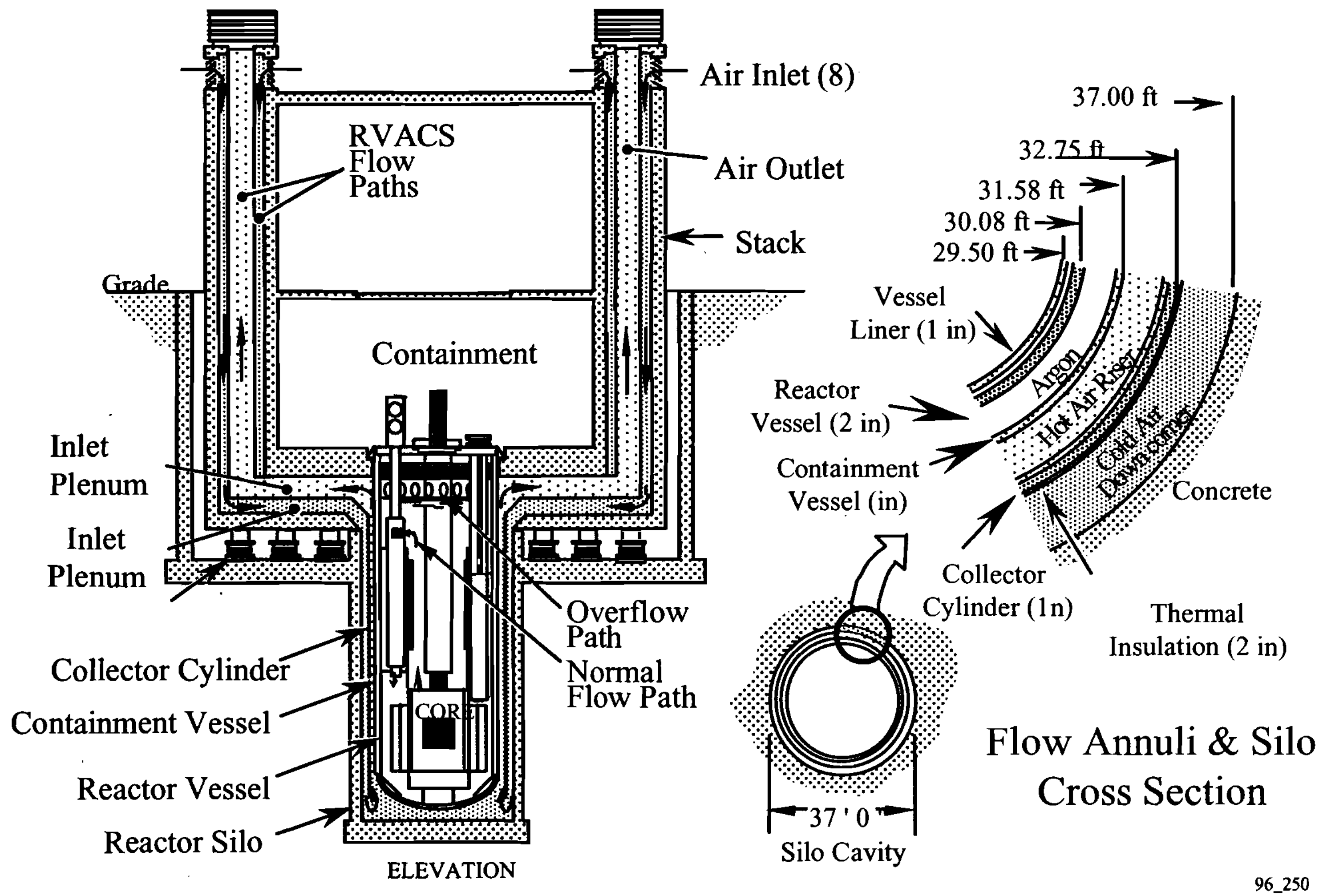
Characteristics of Seismic Isolation System

- Safe Shutdown Earthquake
  - Licensing Basis 0.3g (ZPA)
  - Design Requirement 0.5g
- Lateral Displacement
  - at 0.3g 7.5 inch.
  - Space Allowance
    - o Reactor Cavity 20 inch.
    - o Reactor Bldg. 28 inch.
- Natural Frequency
  - Horizontal 0.70 Hz
  - Vertical 21 Hz
- Lateral Load Reduction > 3

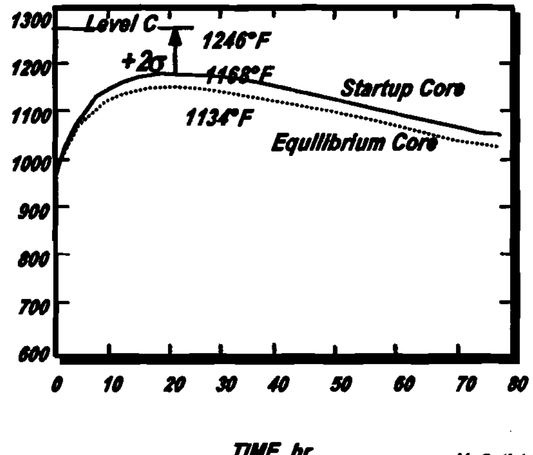


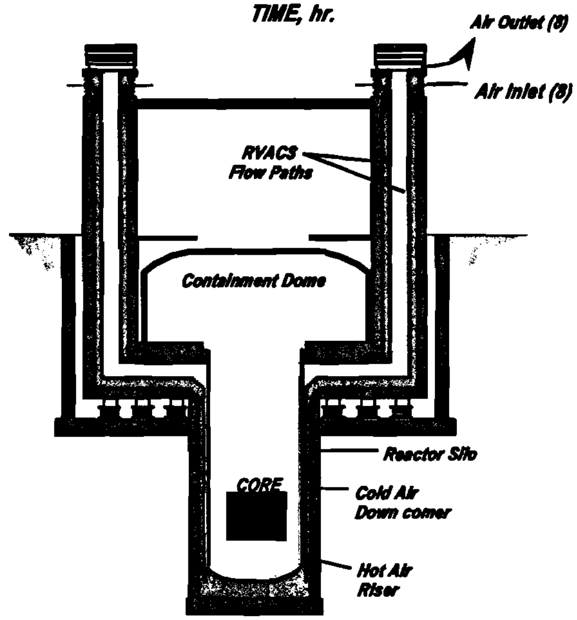
Seismic Isolators (66)

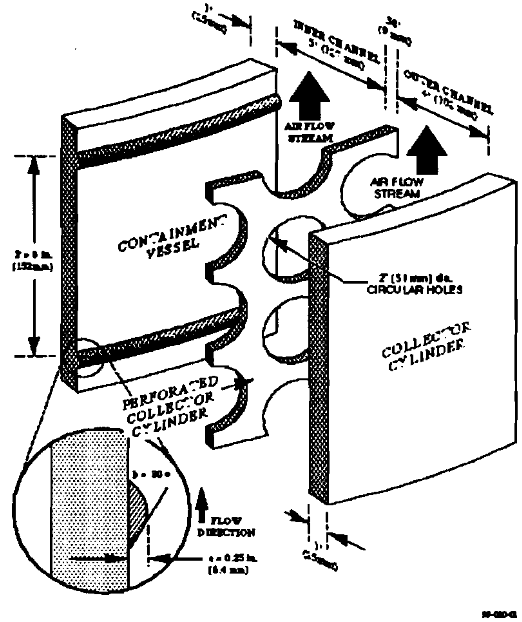
Reactor Vessel Auxiliary Cooling System (RVACS)



Passive Shutdown Heat Removal (RVACS)

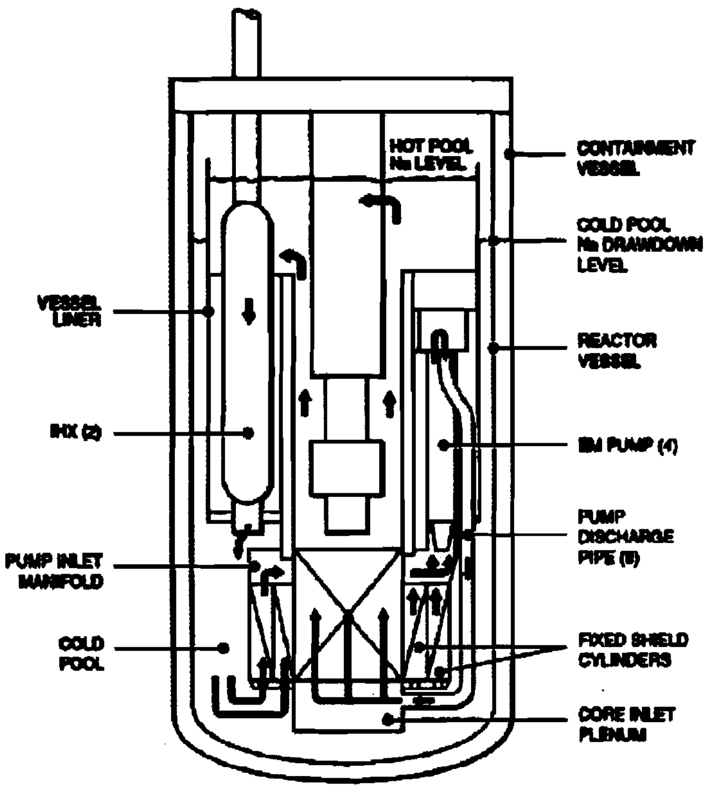




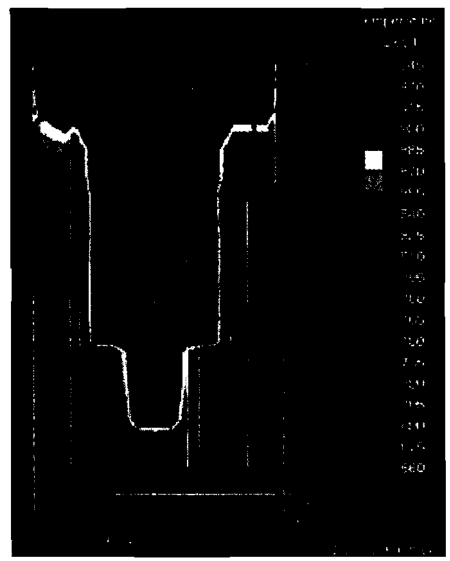


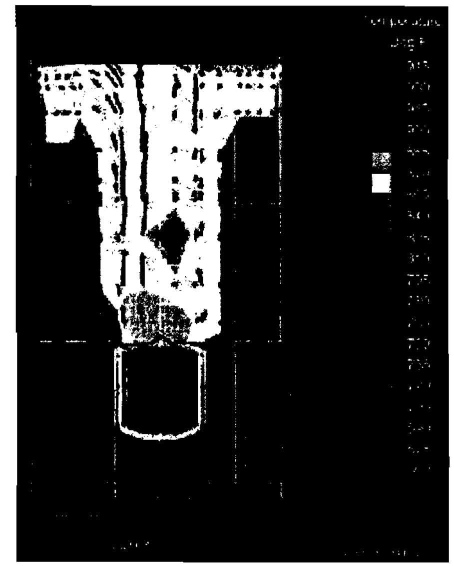
ENHANCED RVACS HOT AIR RISER WITH BOUNDARY LAYER TRIPS
AND PERFORATED COLLECTOR CYLINDER

Natural Circulation Confirmed by 3 Dimensional T/H Analysis



Normal Operation

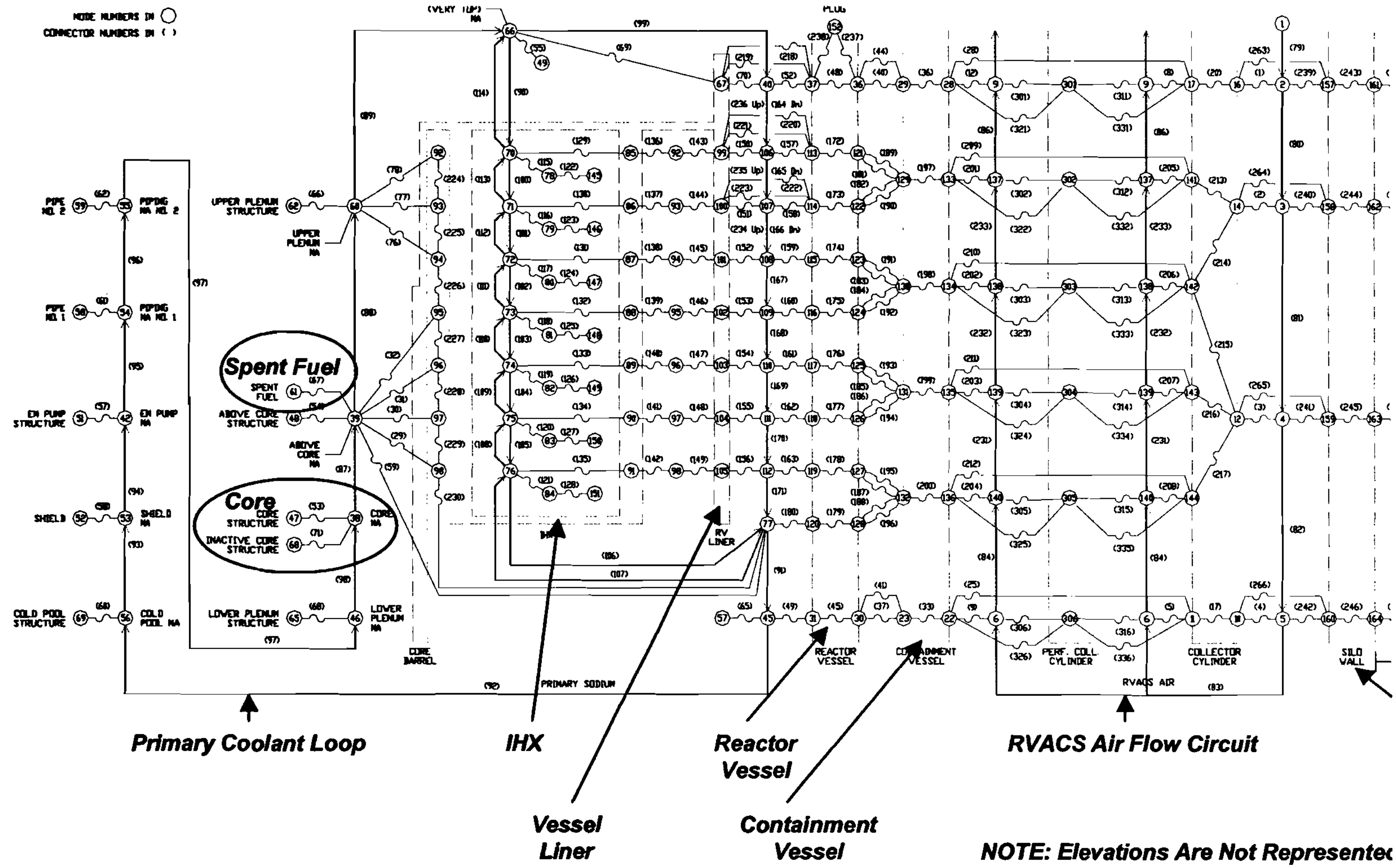




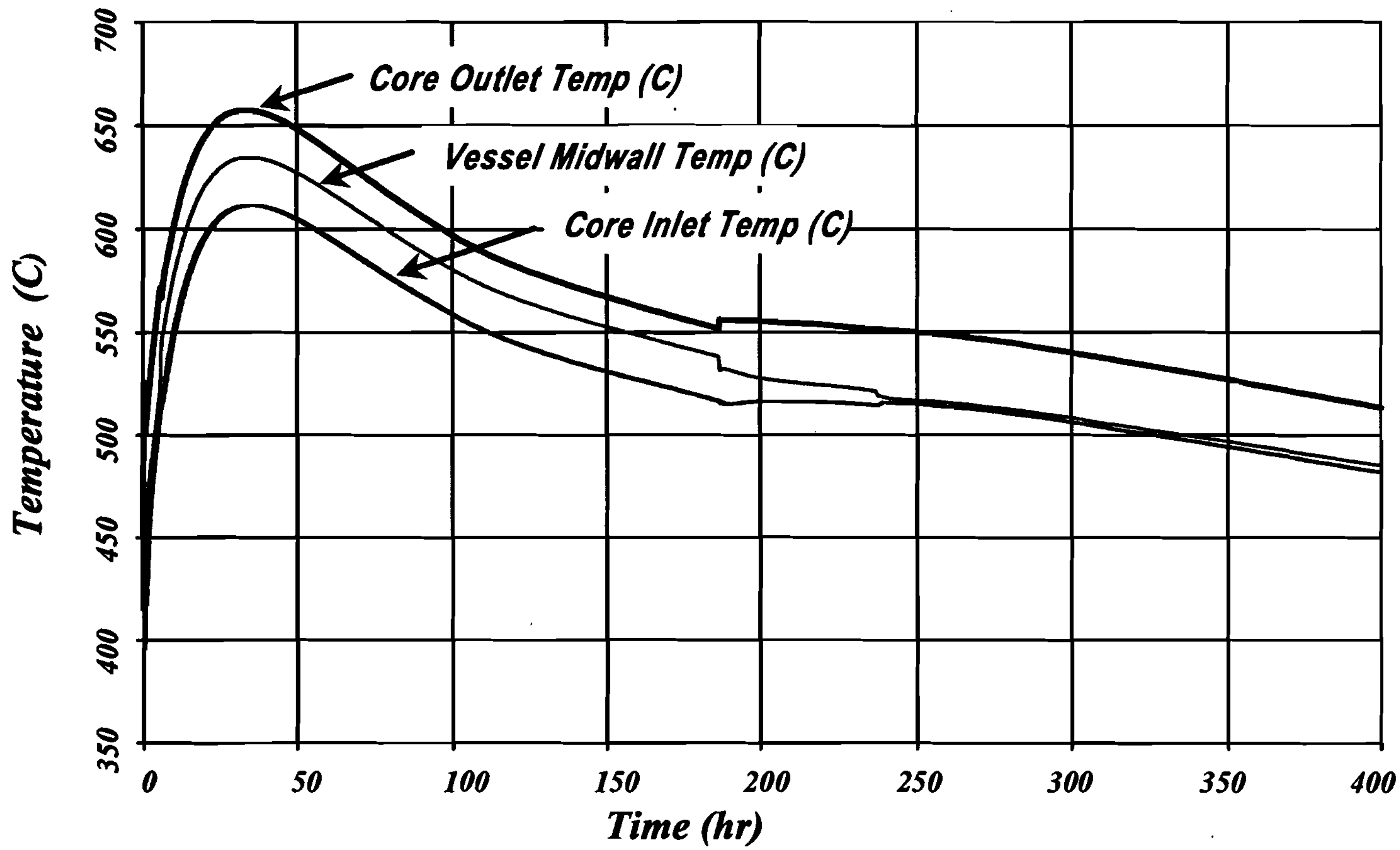
Examples

Temperature and velocity distribution at 4 and 20 minutes after loss of heat sink

Decay Heat Removal Analysis Model

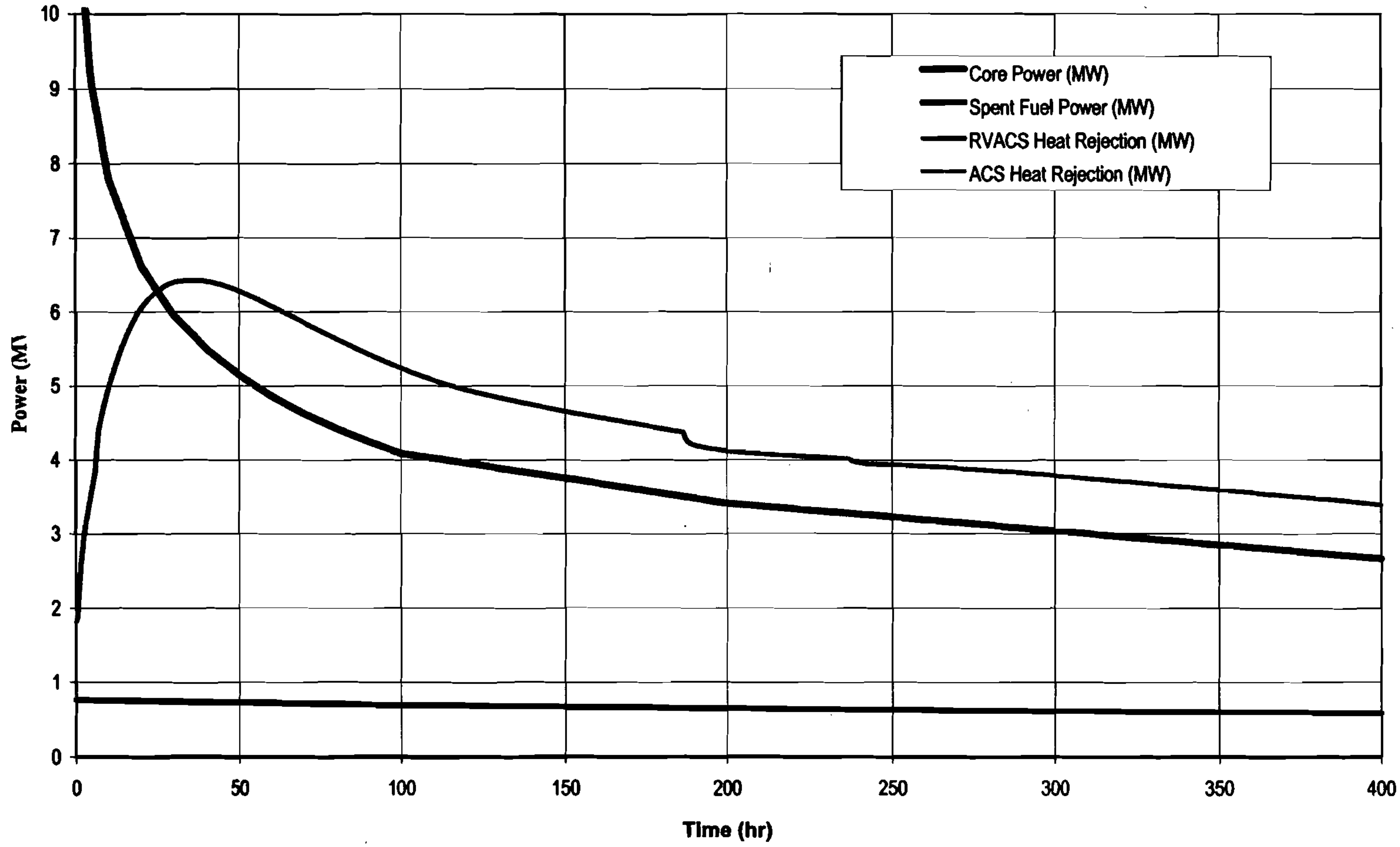


RVACS Cooling - Nominal System Temperatures

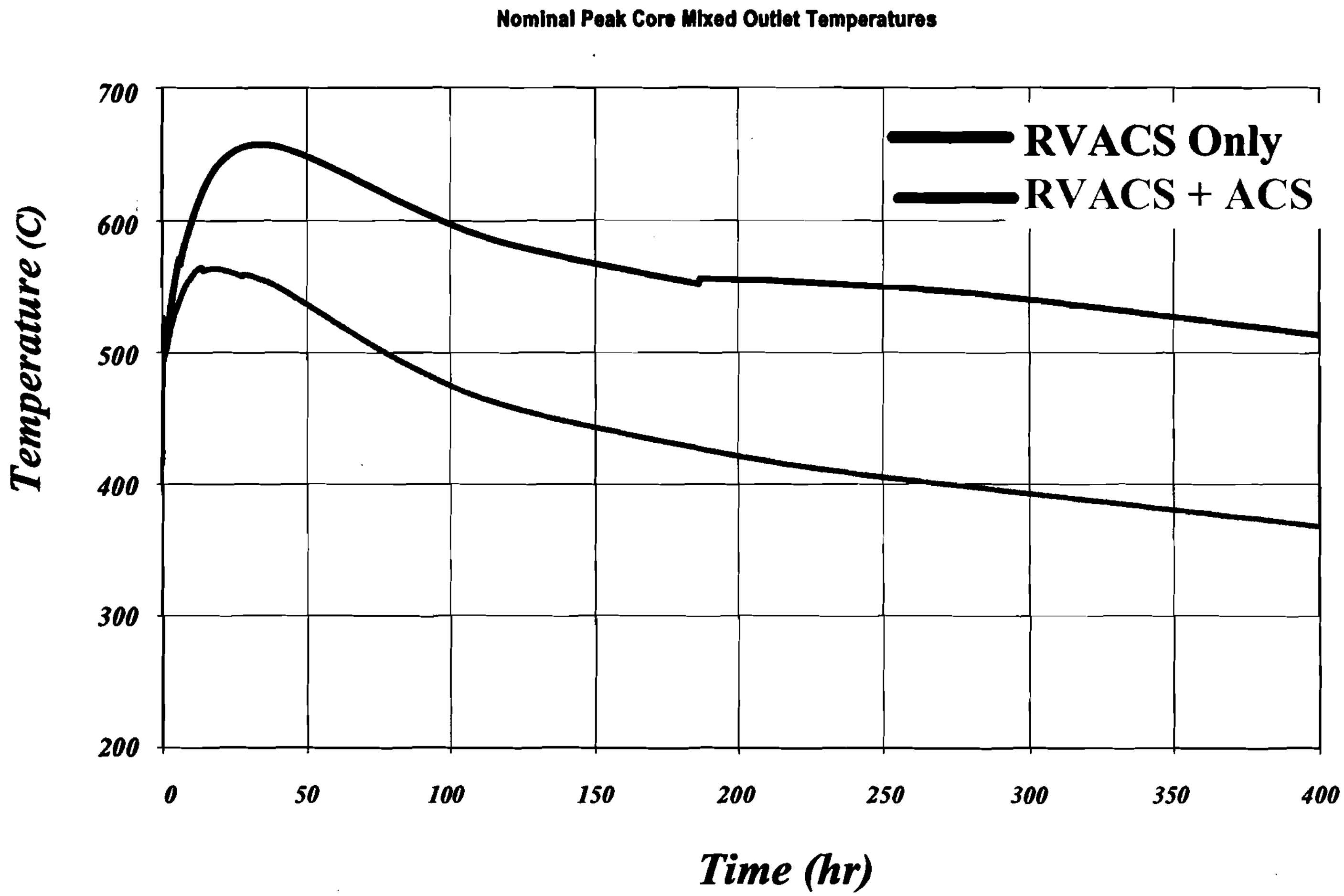


RVACS Transients Are Slow Quasi Steady State Events

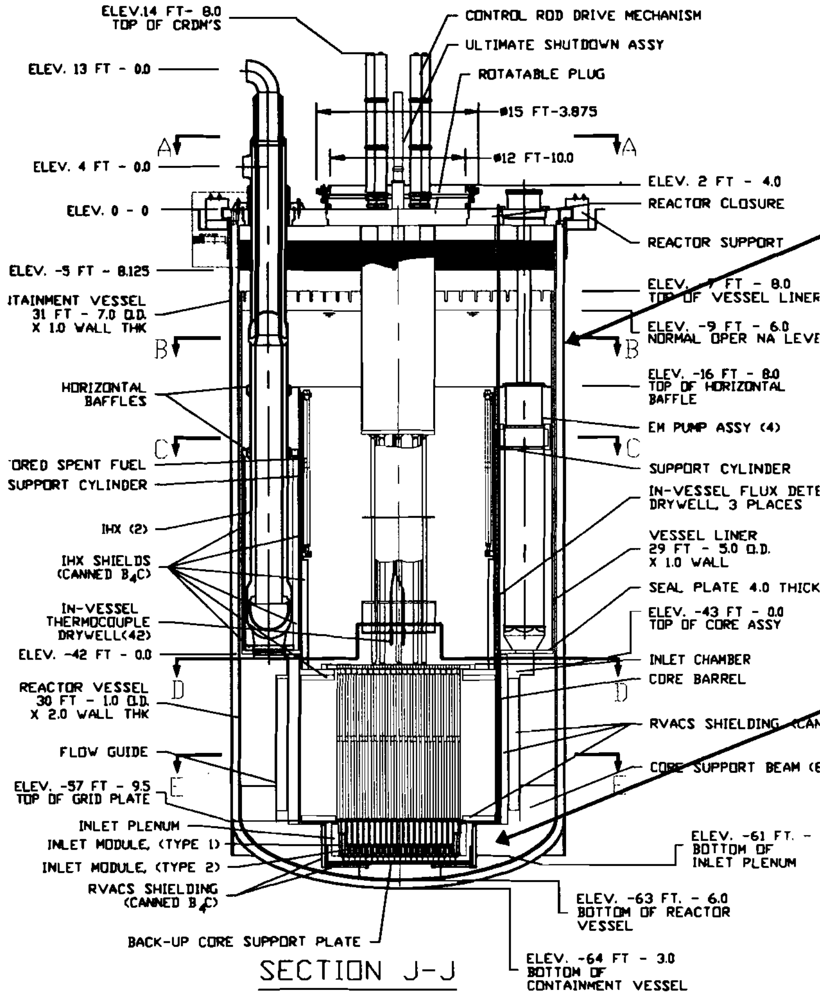
RVACS Heat Rejection and Heat Load versus Time



RVACS Cooling - Nominal Mixed Core Outlet Temperature



Damage Fraction from Six RVACS Transients



Peak Temperature & Damage Fraction at Vessel Mid Wall (nominal / 2-sigma)

Temperature °C	Damage Fraction
635 / 683	<0.002 / 0.002

Peak Temperature & Damage Fraction at Core Support (nominal / 2-sigma)

Temperature (°C)	Damage Fraction
612 / 658	<0.002 / 0.002

Damage from RVACS Transients Is Negligible

S-PRISM Approach to ATWS

Negative temperature coefficients of reactivity are used to accommodate ATWS events.

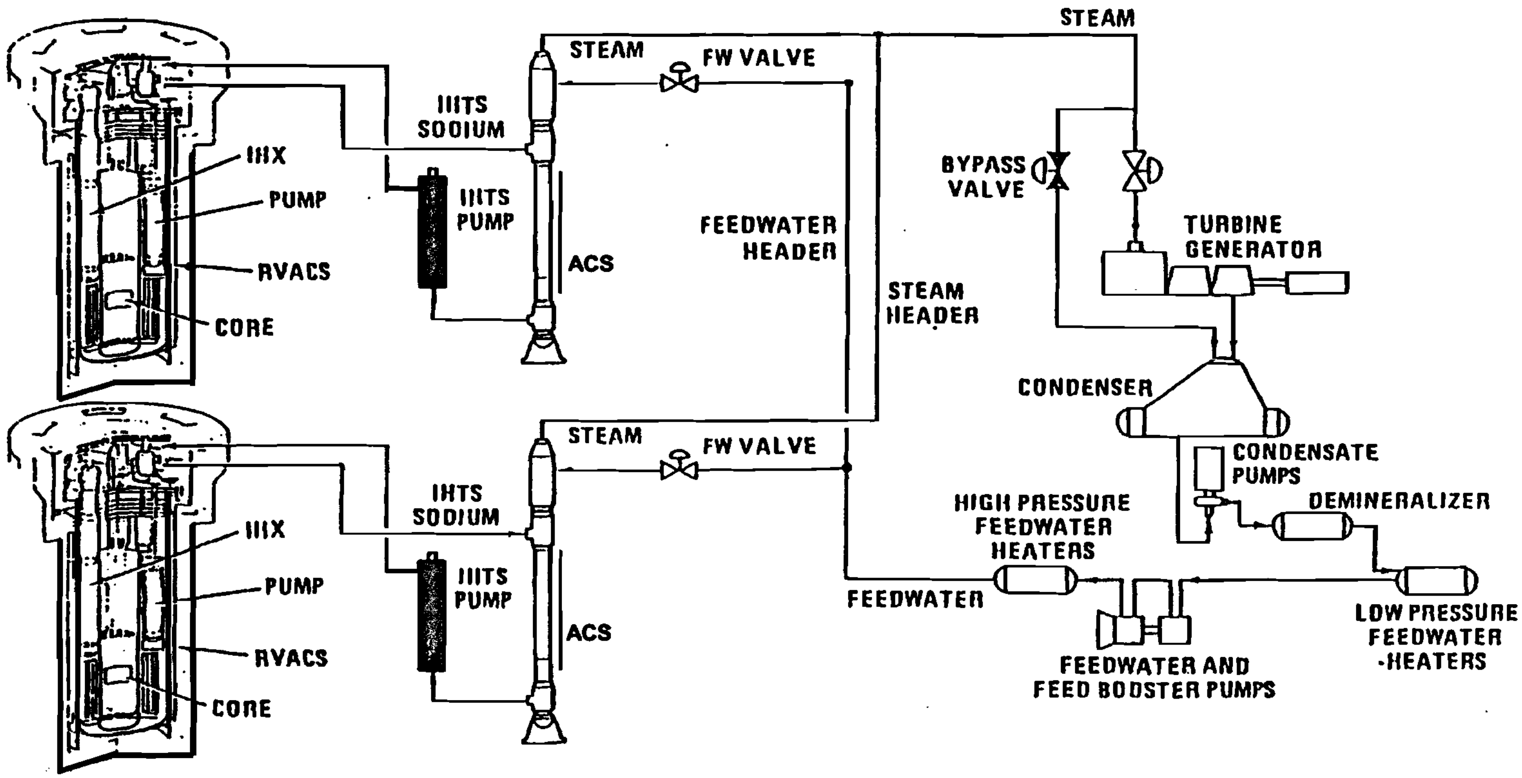
- *Loss of Normal Heat Sink*
- *Loss of Forced Flow*
- *Loss of Flow and Heat Sink*
- *Transient Overpower w/o Scram*

These events have, in priorLMR designs, led to rapid coolant boiling, fuel melting, and core disassembly.

S-PRISM Requirement:

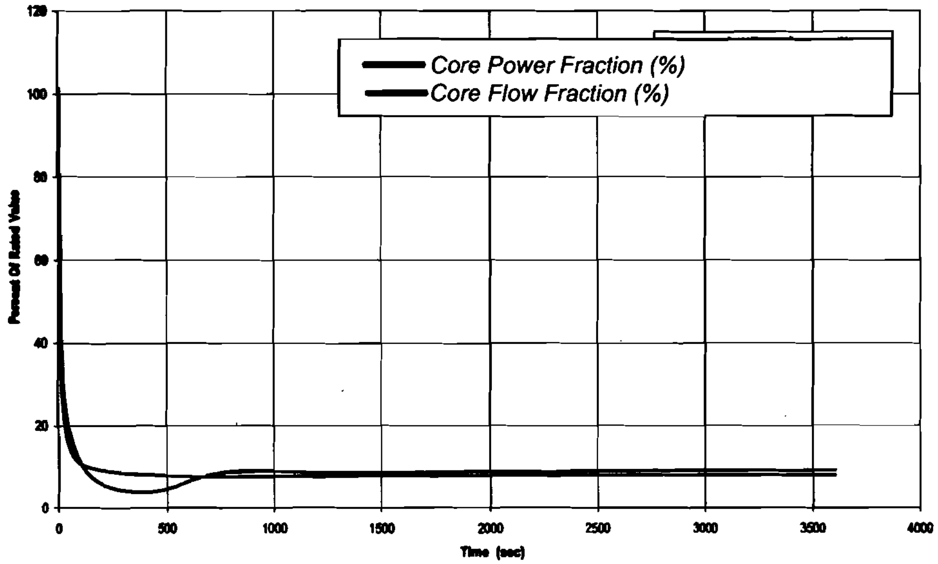
Accommodate the above subset of events w/o loss of reactor integrity or radiological release using passive or inherent natural processes. A loss of functionality or component life-termination is acceptable.

ARIES-P Power Block Transient Model



- *Two-Reactors Coupled to a Single TG*
- *One Group Prompt Jump Core Physics with Multi-Group Decay Heat*
- *RVACS/ACS*
- *Once-through Superheat*
- *Control Systems:*
  - *Plant control system (global and local controllers)*
  - *Reactivity control system (RCS)*
  - *Reactor protection system (RPS)*
  - *EM pump control system and synchronous machines*

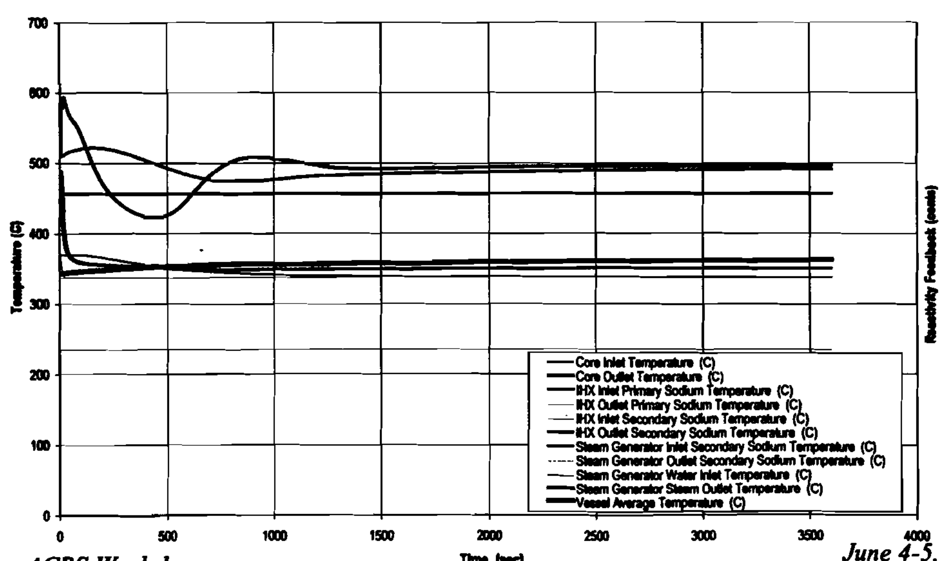
Example ATWS - Loss Of Flow Without Scram



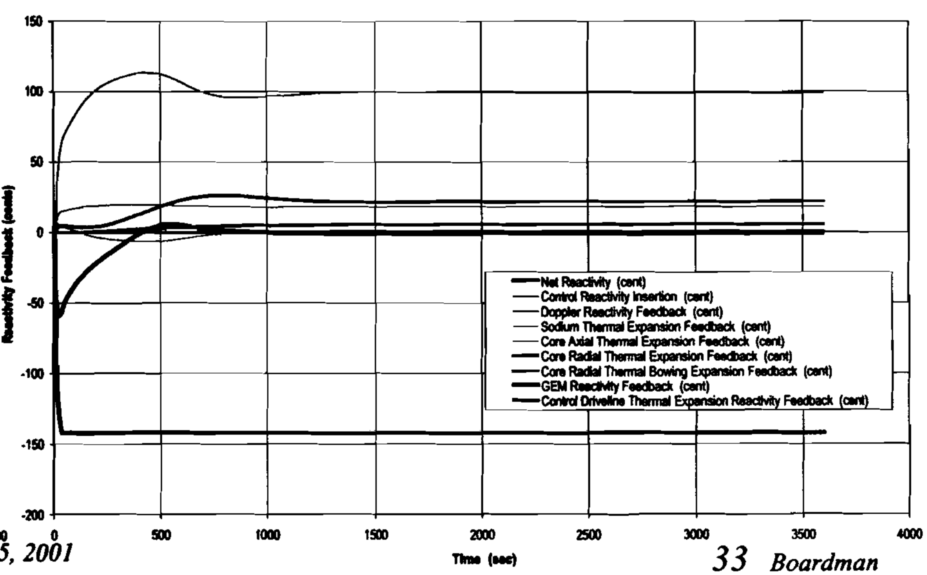
Loss of Primary Pump Power w/o Scram

- ***Loss of pump pressure allows GEM feedback and fission shutdown***
- ***Continuation of IHTS flow and feed water water enhance primary natural circulation to 10%***
- ***Excess cooling of core outlet shortens CR drivelines and pulls control rods slightly to balance fission power with heat removal***

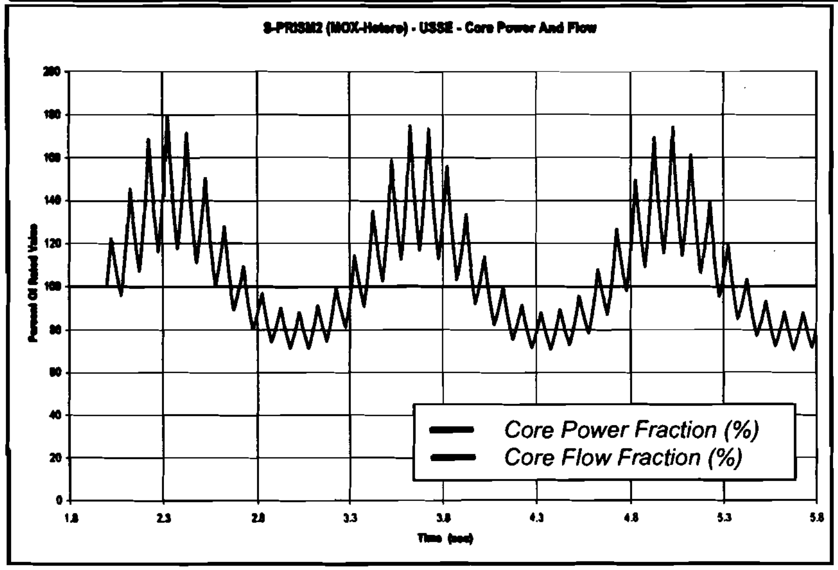
S-PRISM2 (MOX-Hetero) - ULOF - System Temperatures



S-PRISM2 (MOX-Hetero) - ULOF - Reactivity Feedback



Example - 0.5 g ZPA Seismic Event Without Scram

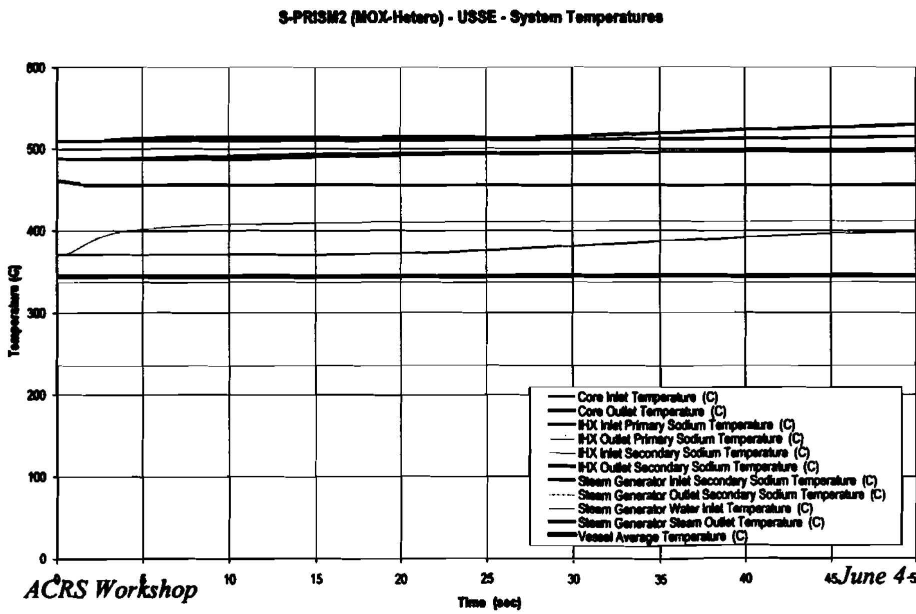


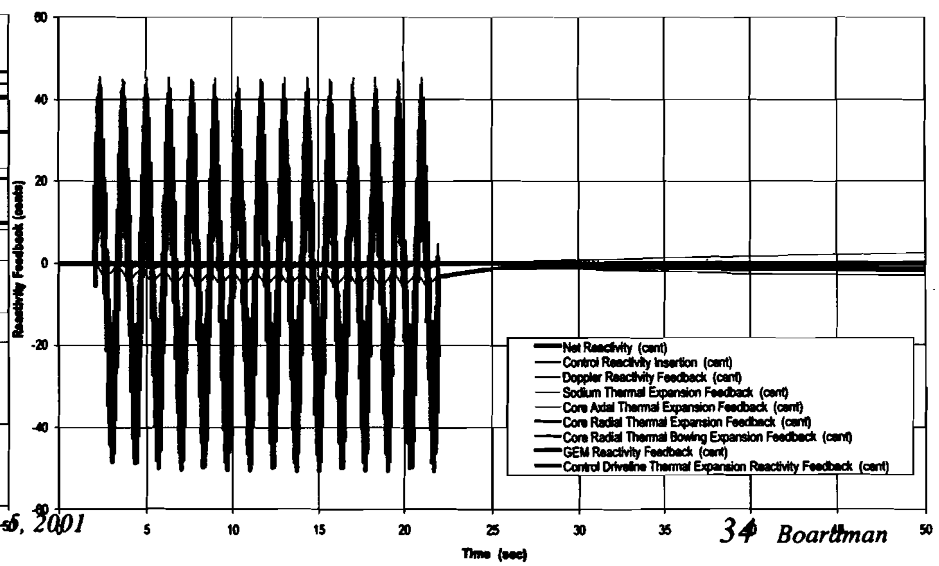
- ***Reactivity:***

  + - 0.30$ at 3/4 Hz (horizontal core compaction)

  + - 0.16$ at 10 Hz (vertical CR-core motion with opposite phases)

- ***Power oscillations to 180%, short duration, not supercritical***
- ***Fuel heat capacity absorbs power oscillation without melting***
- ***Fuel releases heat to structures slowly and gives small Doppler feedback to reduce power peaks***



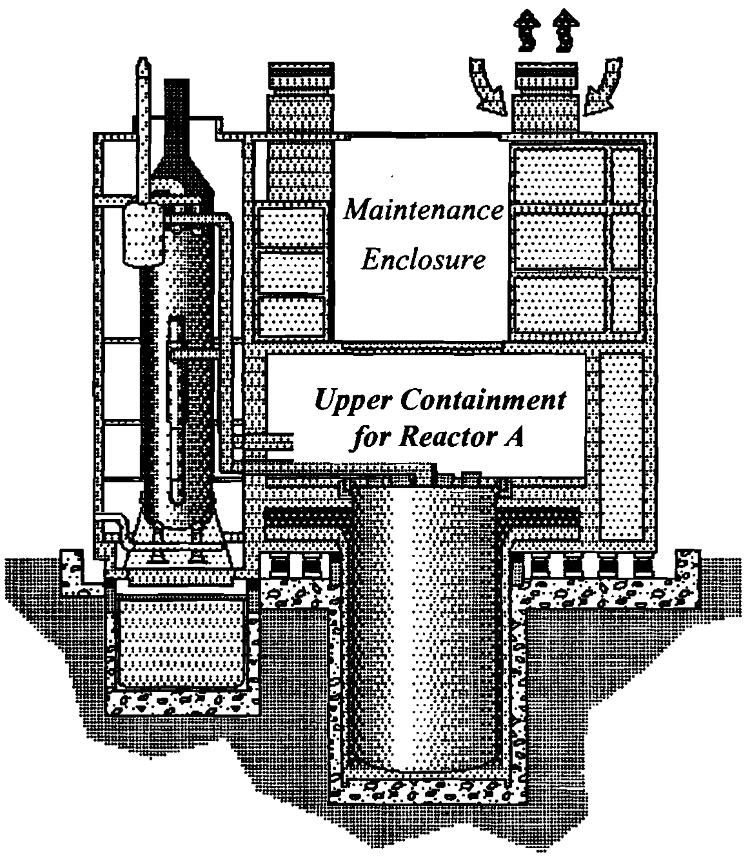


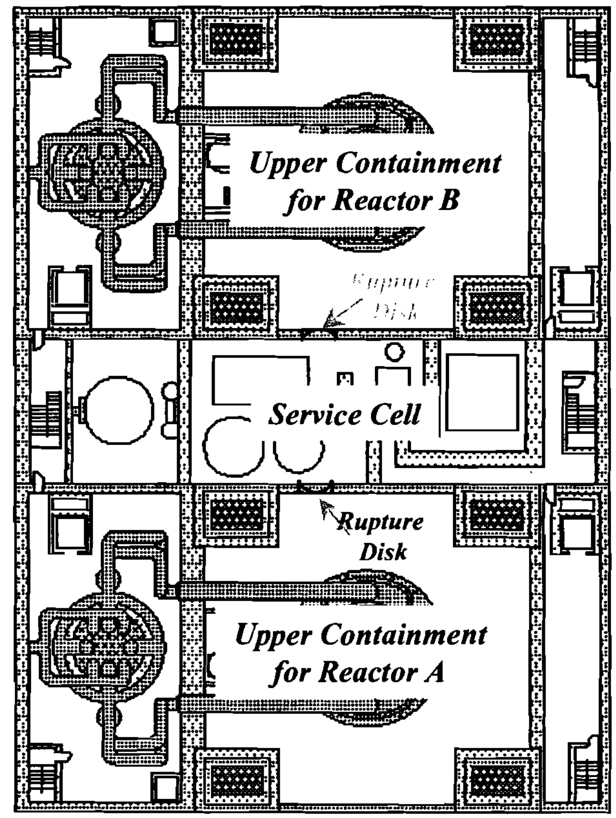
S-PRISM Transient Performance Conclusions

S-PRISM tolerates ATWS events within the safety performance limits

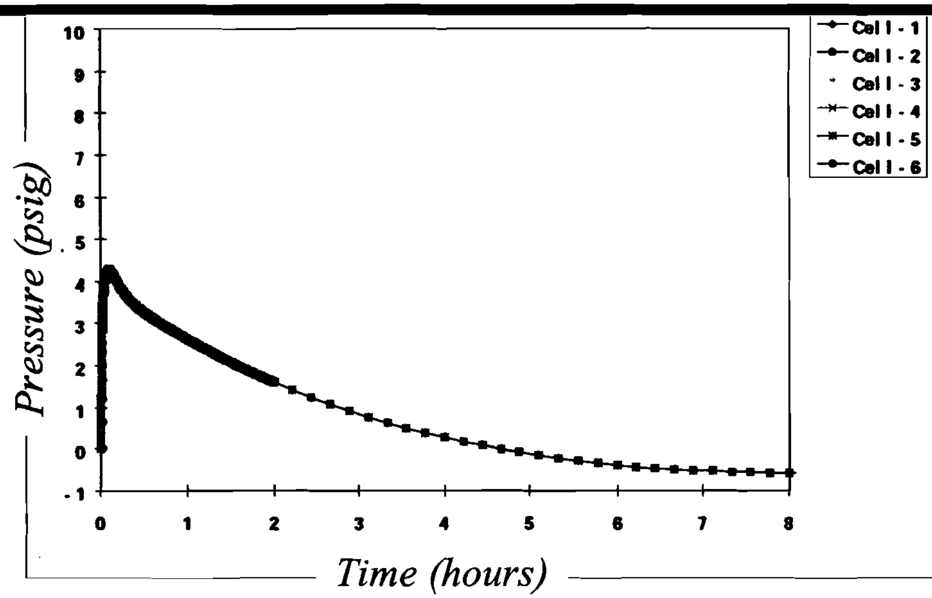
The passive safety performance of S-PRISM is consistent with the earlier ALMR program

S-PRISM Containment System





Example - Large Pool Fire



Beyond Design Basis (Residual Risk)
events have been used to assess containment margins

This event assumes that the reactor closure disappears at time zero initiating a large pool fire

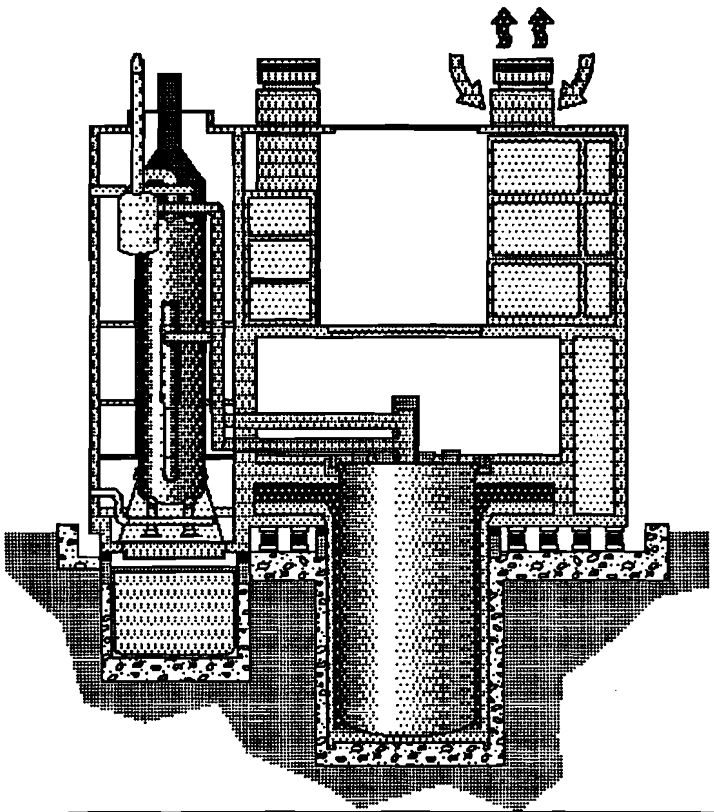
Note that the containment pressure peaks at less than 5 psig and drops below atmospheric pressure in less than 6 hours

Comparison of Emergency Power Requirements

Function	S-PRISM	Generation III LWRs
• Shutdown Heat Removal	Completely Passive	Redundant and Diverse Systems
• Post Accident Containment Cooling	Passive Air Cooling of Upper Containment	Redundant and Diverse Systems
• Coolant Injection/Core Flooding	N/A	Redundant and Diverse Systems
• Shutdown System	3/9 Primary or 2/3 Secondary Rods	Most Rods Must Function
	Self Actuated Scram on Secondary Rods	Boron injection
	Passive Accommodation of ATWS Events	N/A

Emergency AC Power	< 200 kWe from Batteries	~ 10,000 kWe

Layers of Defense



All Safety Grade Systems Are Located within the Reactor/NSSS Building

- ***Containment***
  (passive post accident heat removal)
- ***Coolant Boundary (Reactor Vessel***
  (simple vessel with no penetrations below the Na level)
- ***Passive Shutdown Heat Removal***
  (RVACS + ACS)
- ***Passive Core Shutdown***
  (inherent negative feedback's)
- ***RPS Scram of Scram Rods***
  (magnetic Self Actuaed Latch backs up RPS)
- ***RPS Scram of Control Rods***
  (RPS is independent and close coupled)
- ***Automatic Power Run Back***
  (by automated non safety grade Plant Control System

Increasing Challenge

Normal Operating Range

- ***Maintained by Fault Tolerant Tri-Redundant Control System***

Adjustments Since End of DOE Program In 1995

Parameter or Feature	1995 ALMR	S-PRISM
Core Power, MWt	840.	1000.
Core Outlet Temp, °C	499	510
Main Steam, °C / kg/cm^2	454/153	468/177
Net Electrical, MWe (two power blocks)	1243.	1520
Net Electrical, MWe (three power blocks)	1866	2280
Seismic Isolation	Yes. Each NSSS placed on a separate isolated platform	Yes. A single platform supports two NSSSs
Above Reactor Containment	Low leakage steel machinery dome	Low leakage steel lined compartments above the reactor closure

Topics

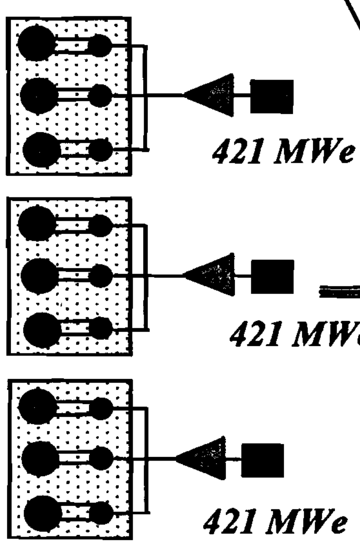
- *Incentive for developing S-PRISM*
- *Design and safety approach*
- *Design description and competitive potential*
- *Previous Licensing interactions*
- *Planned approach to Licensing S-PRISM*
- *What , if any, additional initiatives are needed?*

Optimizing the Plant Size

1988 PRISM → S-PRISM

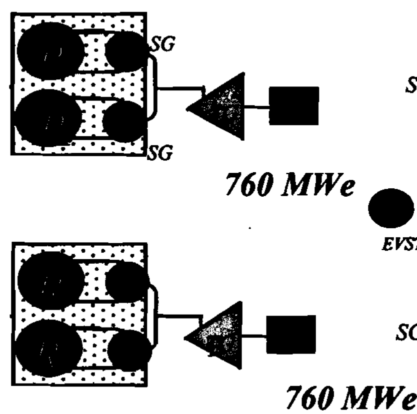
Large Commercial Design

1263 MWe (net) from 3 blocks
9 NSSS (425 MWt each)
3 421 MWe TG Units
9 primary Na containing vessels
9 SG units/eighteen IHTS loops

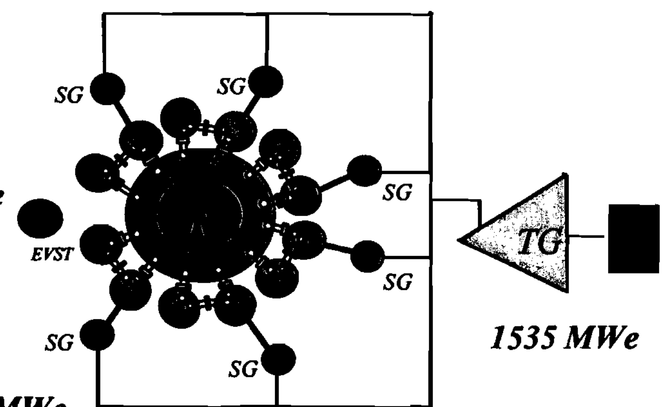


1,520 MWe (net) from two blocks
4 NSSS (1000 MWt each)
2 825 MWe (gross) TG Units
4 primary Na containing vessels
4 SG units and eight IHTS loops (1000/500 MWt each)

Larger module (1000 vs. 425 MWt)
Once through superheat steam cycle



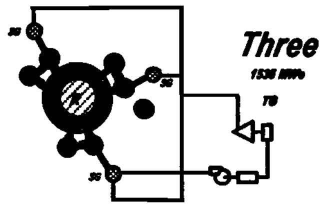
1,535 MWe Monolithic LMR
1 NSSS (4000 MWt)
1 1535 MWe TG Unit
14 primary Na containing vessels*
(12 primary component vessels, reactor, and EVST)
6 SG units and 6 IHTS loops (667 MWt each)
4 Shutdown Heat Removal Systems
(DHX/IHX units, pump, piping, and support systems)
- Redundant SHRS also required for EVST



Simplicity allows Reduction in Commodities and Building Size

Scale Up -- LWR versus Fast Reactor

1600 MWt Sodium Cooled Fast Reactor

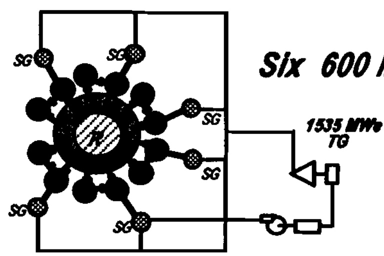


Three 533 MWt Loops

1600 MWt Light Water Cooled Reactor

Two 800 MWt Loops

3600 MWt FR

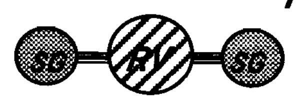


Six 600 MWt Loops

<u>Rating Limited by:</u>
IHTS Piping: < 1 m diameter

3600 MWt PWR

Two 1800 MWt Loops

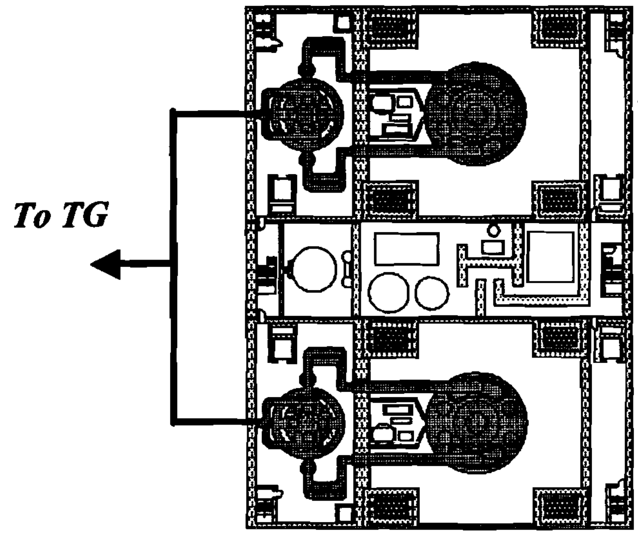


<u>Two Loops Viable Because:</u>
Specific heat of water 5 x sodium at operating temperatures

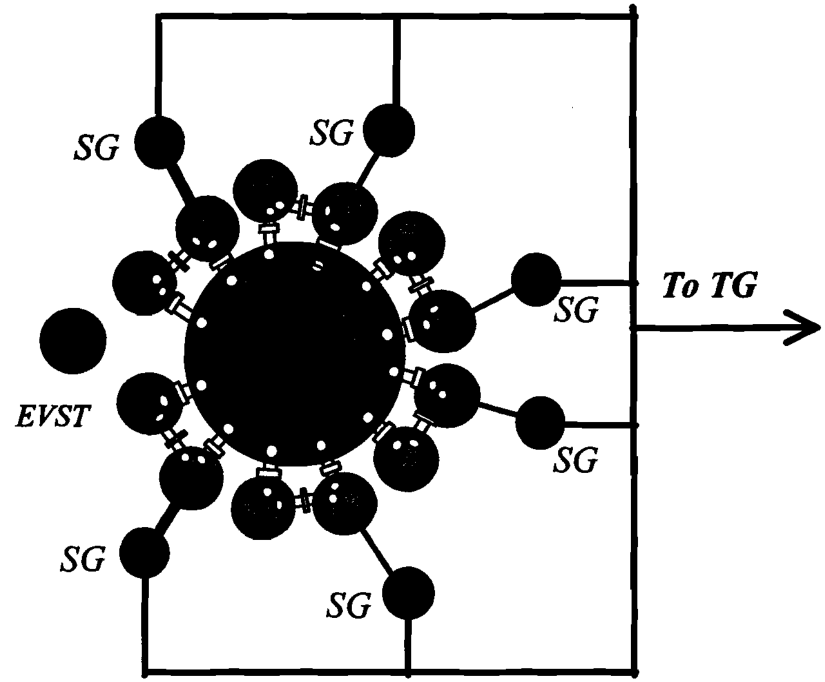
- ***The complexity and availability of a PWR is essentially constant with size***
- ***Due to the lower specific heat of sodium, six or more loops are required in a large FR.***

The Economy of Scale is Much Larger for LWRs then FBRs

Modular versus Monolithic *(Fast Reactors)*



Modular (S-PRISM)

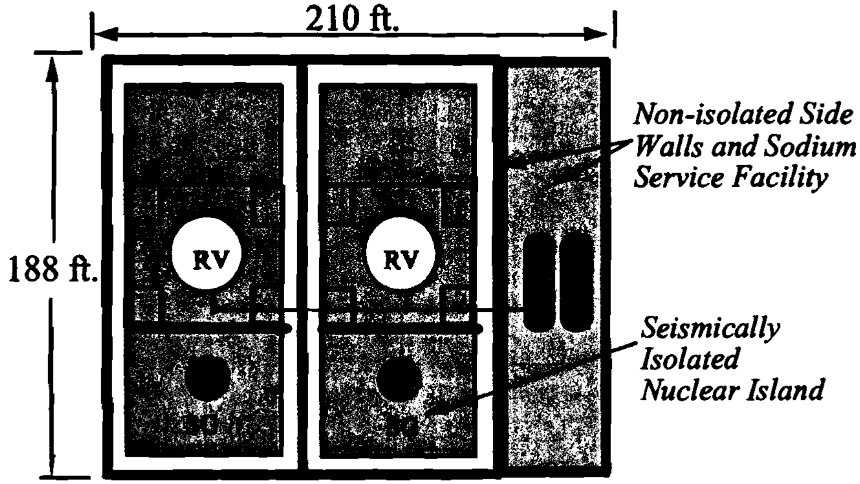


Monolithic Fast Reactor

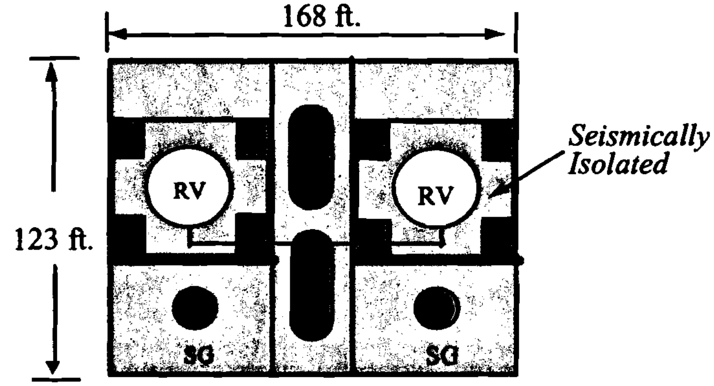
The one-on-one arrangement:

- *simplifies operation,*
- *minimizes the size of the reactor building*
- *improves the plant capacity factor*
- *reduced the need for backup spinning reserve*

NSSS Size, ALMR verses S-PRISM



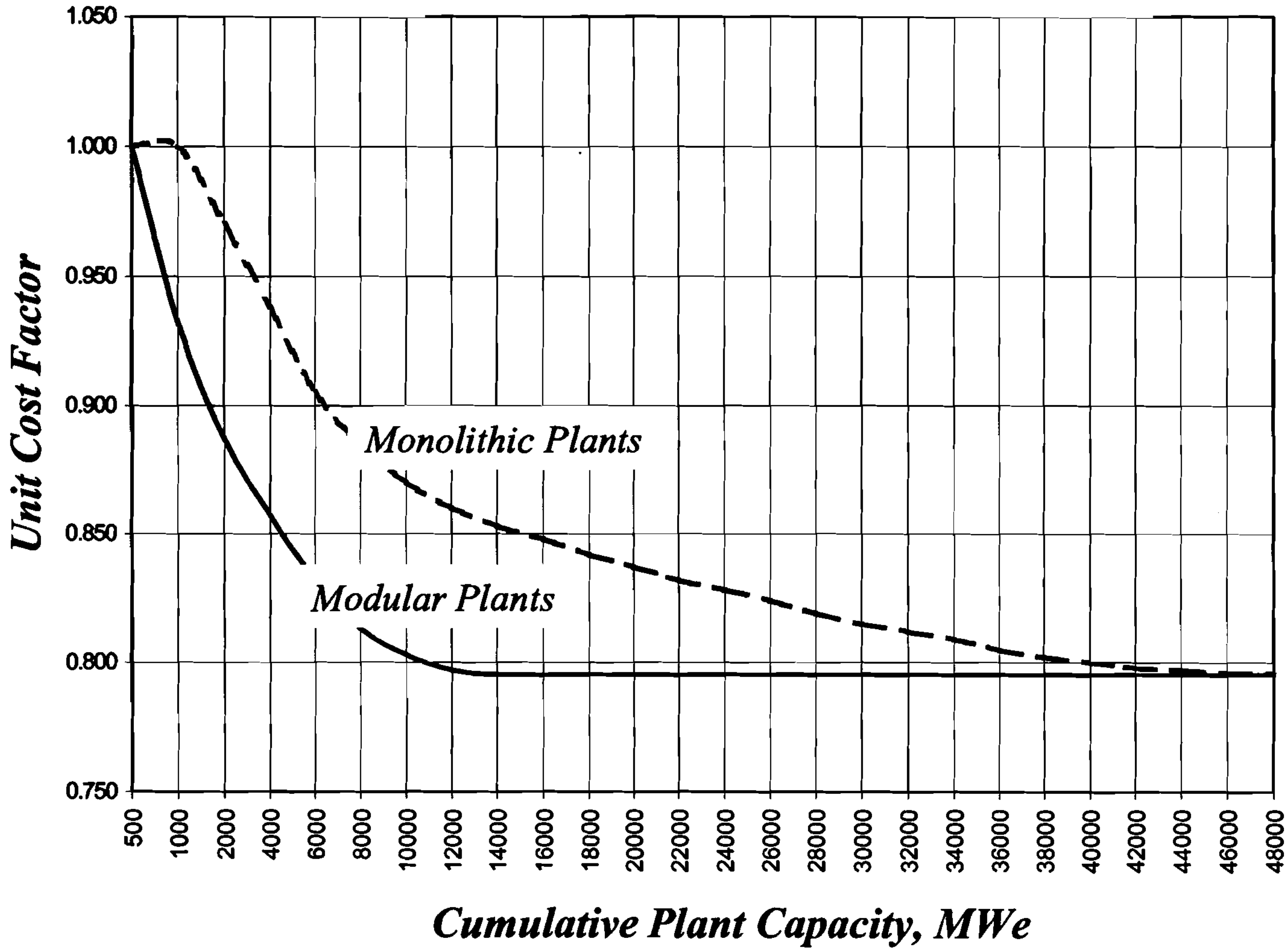
ALMR



S-PRISM

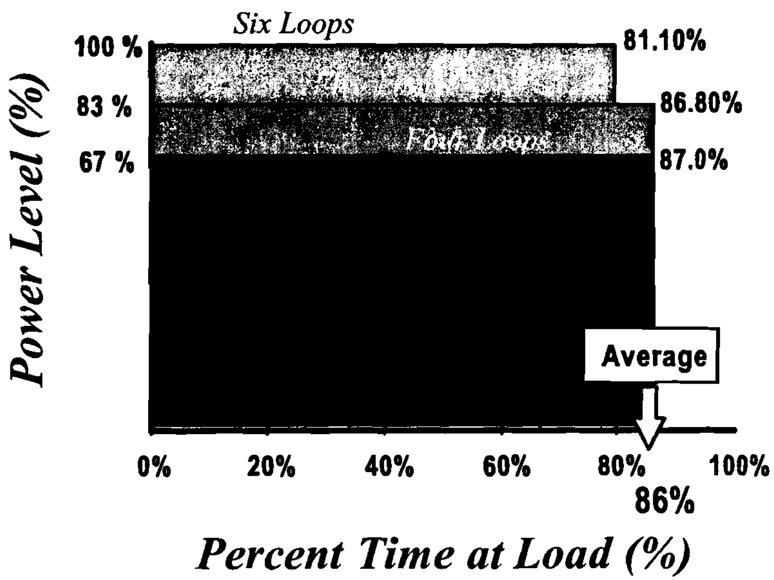
22 % More Power
from
Smaller NI

Learning Effect Favors Modular Plant Designs

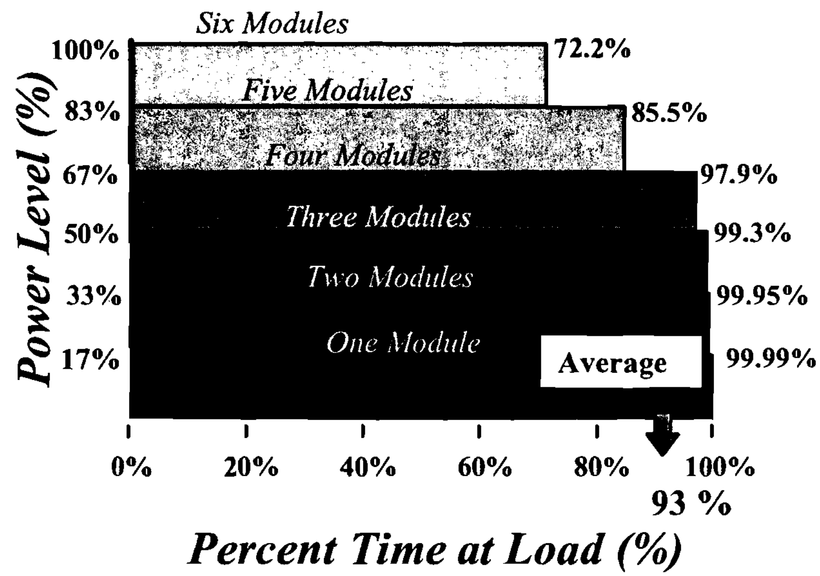


Modular vs. Monolithic Availability and Spinning Reserve

Monolithic Plant
6 Loops



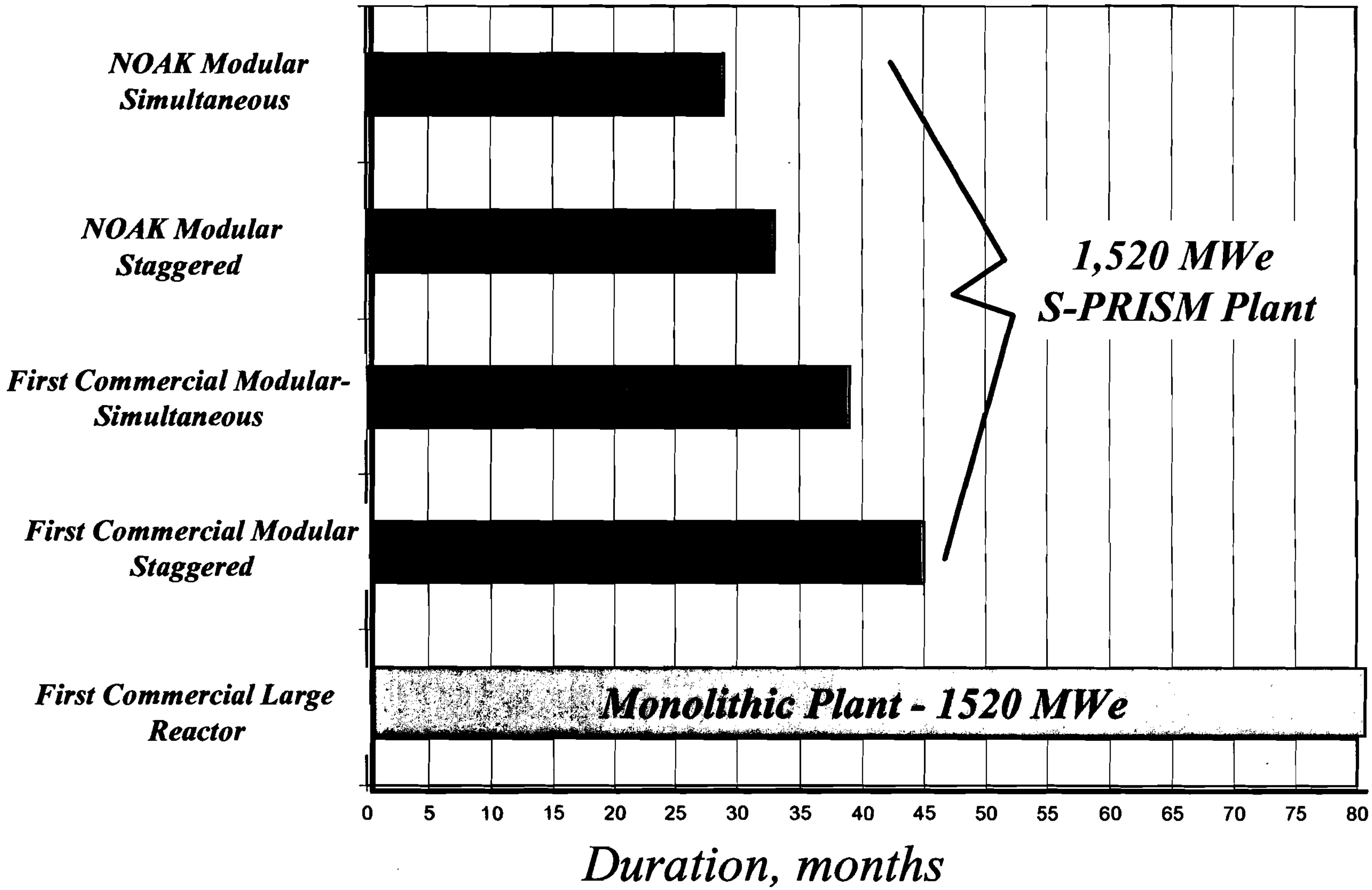
6 Module S-PRISM Plant



Seven point advantage caused by:

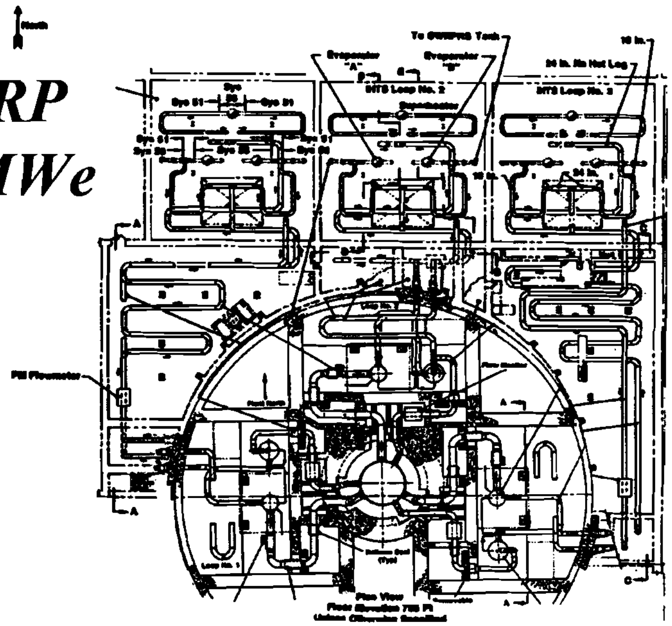
- *Relative simplicity of each NSSS (one SG System rather than 6)*
- *Ability to operate each NSSS independently of the others*

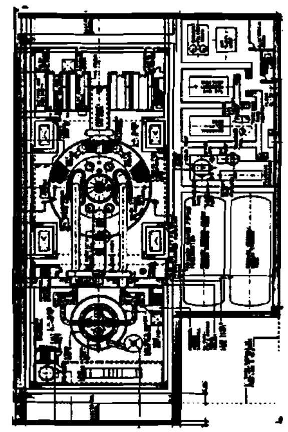
Comparison of Plant Construction Schedules



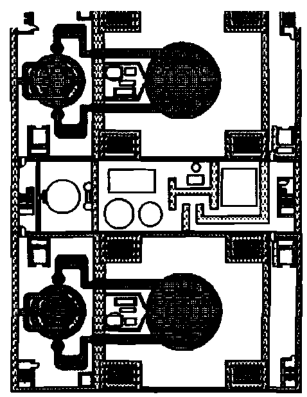
NSSS Size, CRBRP/ALMR /S-PRISM

CRBRP
350 MWe





ALMR
311 MWe



S-PRISM
760 MWe

Topics

- *Incentive for developing S-PRISM*
- *Design and safety approach*
- *Design description and competitive potential*
- *Previous licensing interactions*
- *Planned approach to licensing S-PRISM*
- *What , if any, additional initiatives are needed?*

ALMR Design and Licensing History

1981 -[redacted]84
G[redacted]SM
[redacted]rogram

GE Funded
Innovative Design Studies

1985 -[redacted]87
[redacted]M

- 30 $ M
Competition for
National Program

1988
PRDA

- $ 5 M
Continue Trade
Studies

1989 -[redacted]95
A[redacted]ROGRAM

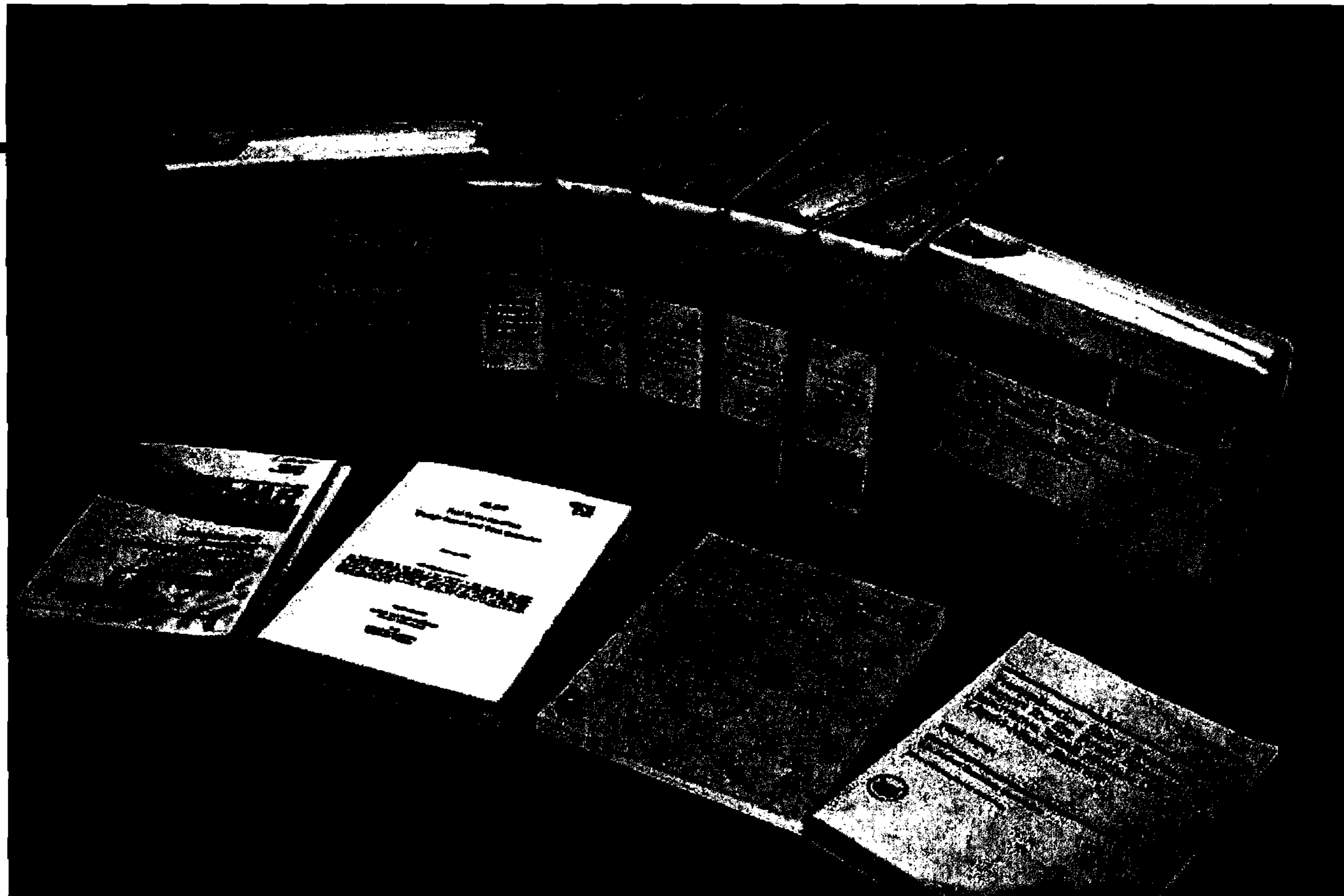
- $ 42 M
- Advanced. Conceptual
  & Preliminary Design
- ***Regulatory Review***
- Economic Reviews
- Commercialization Studies
- Technology Development
  ($107 M Additional)

$ 77 Million
DOE Program

199[redacted]
S-PRISM

GE Funded

S-PRISM is supported by a 100 million dollar Data Base



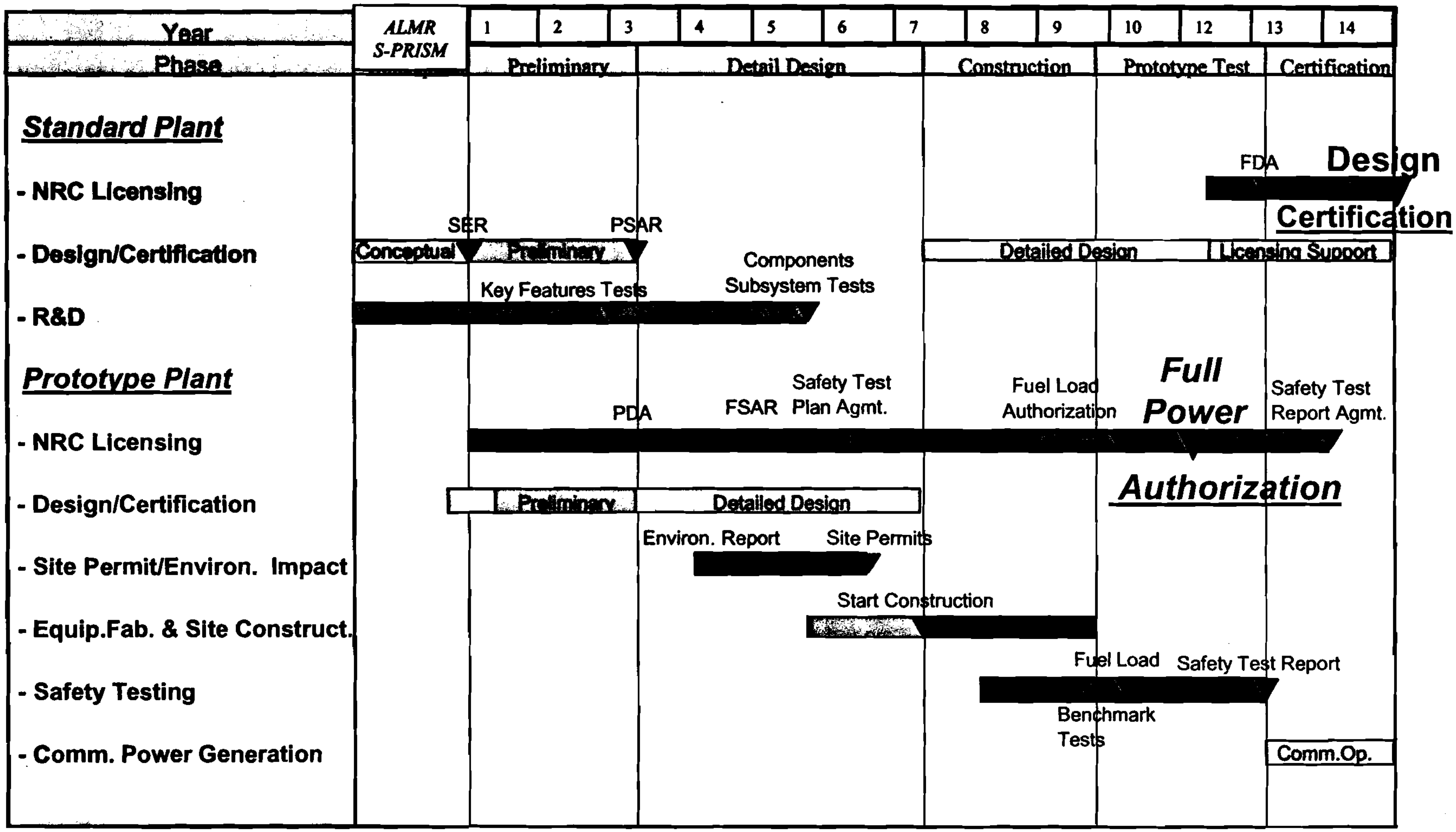
The NRC's Pre-application Safety Evaluation of the ALMR (NUREG-1368) concluded:

"the staff, with the ACRS in agreement, concludes that no obvious impediments to licensing the PRISM (ALMR) design have been identified."

Topics

- *Incentive for developing S-PRISM*
- *Design and safety approach*
- *Design description and competitive potential*
- *Previous Licensing interactions*
- *Planned approach to Licensing S-PRISM*
- *What , if any, additional initiatives are needed?*

Detailed Design, Construction, and Prototype Testing



Design Certification would be obtained through the construction and testing of a single 380 MWe module

Topics

- *Incentive for developing S-PRISM*
- *Design and safety approach*
- *Design description and competitive potential*
- *Previous Licensing interactions*
- *Planned approach to Licensing S-PRISM*
- *What, if any, additional initiatives are needed?*

Safety Review/Key Issues

Safety Methods

- *Containment*
- *Core energetic potential*
- *Analysis of Design Basis SG Leaks*
- *PRA*
- *Nuclear Methods*
- *T/H Methods*

Fuels

- *Validation of fuels data base (metal/oxide)*

Waste

- *Fission Product Treatment and Disposal*

NAME	LOCATION							
France								
Rapsodie	Cadarache							
Phenix	Marcoule							
SuperPhenix	Creys Malville							
INDIA								
FBTR	Kalpakkam							
ITALY								
PEC	Brasimone							
JAPAN								
Joyo	Oaral							
Monju	Ibarakl							
UK								
DFR	Dounreay							
PFR	Dounreay							
USA								
Clemetine	Los Alamos							
EBR-1	Idaho							
Lampre	Los Alamos							
EBR-2	Idaho							
Enrico Fermi	Michigan							
SEFOR	Arkansas							
FFTF	Richland							
Clinch River	Oak Ridge							
USSR								
BR-2	Obninsk	Research	1956	--	0.1	--	Pu	Hg
BR-5	Obninsk							
BOR-60	Melekess							
BN-350	Shevchenk							
BN-600	Beloyarsk							
BN-800	–							
BN-1600	–							
W. Germany								
KNK	Karlruhe							
SNR-300	Kalkar							
SNR-2	Kalkar	demonstration	--	--	3420	1460	U02/Pu02	Na

More than 20 Sodium cooled Fast Reactors have been built

Most have operated as expected (EBR-II and FFTF for example)

The next one must be commercially viable

Component Verification and Prototype Testing

Final component performance verification can be performed during a graduated prototype testing program.

Example: The performance of the passive decay heat removal system can be verified prior to start up by using the Electromagnetic Pumps that add a measurable amount of heat to the reactor system

Licensing through the testing of a prototypical reactor module should be an efficient approach to obtaining the data needed for design certification.

Defining the T/H and component tests needed to proceed with the the construction and testing of the prototype as well as defining the prototype test program will require considerable interaction with the NRC

NRC/NRR
GAMBERONI
GILES
KEYNON
BENNER
RAE

UNITED STATES NUCLEAR REGULATORY COMMISSION

ACRS WORKSHOP ON ADVANCED REACTORS
JUNE 4, 2001

NRR FUTURE LICENSING ACTIVITIES

INTRODUCTION: M. Gamberoni

FUTURE LICENSING AND INSPECTION READINESS: N. Gilles

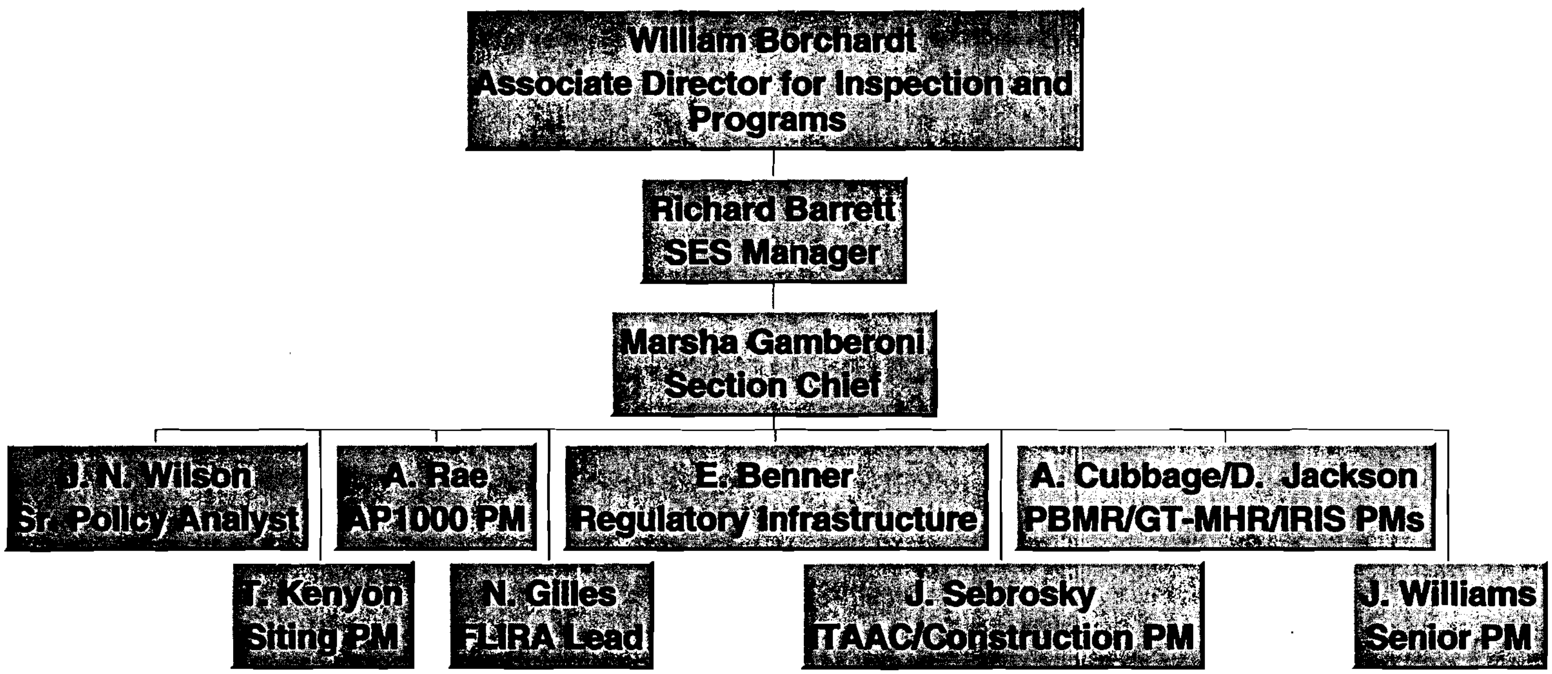
EARLY SITE PERMITS: T. Kenyon

ITAAC/CONSTRUCTION: T. Kenyon

AP1000: A. Rae

REGULATORY INFRASTRUCTURE: E. Benner

FUTURE LICENSING ORGANIZATION



FUTURE LICENSING AND INSPECTION READINESS ASSESSMENT (FLIRA)

- Evaluate Full Range of Licensing Scenarios
- Assess Readiness to Review Applications & Perform Inspections
  - Staff Capabilities
  - Schedule and Resources
  - External Support
  - Regulatory Infrastructure
- Recommendations:
  - Staffing
  - Training
  - Contractor Support
  - Schedules
  - Rulemakings & Guidance Documents
- Complete Assessment by September 28, 2001

EARLY SITE PERMITS

- Early Site Permits (ESP)
  - Site Safety
  - Environmental Protection
  - Emergency Planning
- 10 CFR Part 52, Subpart A
  - Regulatory Guides
  - Environmental SRP
  - Experience with Environmental Reviews on License Renewal
- Initial efforts
  - Coordinate Preparations for ESP Reviews
  - Interact with Stakeholders
  - Recent Meetings with NEI ESP Task Force
- Applications
  - One in 2002, Two in 2003, Three in 2004

ITAAC/CONSTRUCTION

- Construction Inspection Program Re-activation
  - Develop Guidance for Inspection of Critical Attributes
  - Include Inspections for Plant Components & Modules at Fabrication Site
  - Initiate Development of Training for Inspection Staff

- Reactivation of Construction Permit (WNP-1)

- Resolution of "Programmatic" ITAAC

AP1000 PRE-APPLICATION REVIEW

- Phase 1 Complete
  - July 27, 2000 Letter Identified 6 Issues that Could Impact Cost and Schedule of Design Certification
- Phase 2 Scope
  - Applicability of AP600 Test Program to AP1000 Design
  - Applicability of AP600 Analyses Codes to AP1000 Design
  - Acceptability of Design Acceptance Criteria in Selected Areas
  - Applicability of Exemptions Granted to AP600 Design
- Phase 2 Schedule
  - Receipt of Analyses Codes Will "Officially" Start Phase 2
  - Estimated Duration of Review - 9 Months
- Phase 3 - Westinghouse Application 2002?

REGULATORY INFRASTRUCTURE

Current Activities:

- Rulemaking to Update 10 CFR Part 52
  - Incorporate Previous Design Certification Rulemaking Experience
  - Update Licensing Processes to Prepare for Future Applications
  - Proposed Rule Package (9/01)

- Rulemaking on Alternative Site Reviews
  - Amend Requirements in 10 CFR Parts 51 and 52 for NEPA Review of Alternative Sites for New Power Plants
  - Initiation of Rulemaking - Mid-FY2002

- Rulemaking on 10 CFR Part 51, Tables S3 and S4
  - Amend Part 51 Tables S-3 & S-4 for Fuel Performance Considerations and Other Issues to Reflect Current and Emerging Conditions in the Various Stages of the Nuclear Fuel Cycle

REGULATORY INFRASTRUCTURE

- Financial-Related Regulations
  - NRC Antitrust Review Requirements
  - Decommissioning Funding Requirements
  - Modular Plant Requirements (Price-Anderson)

Future Activities:

- NEI Petition for Generic Regulatory Framework
  - NEI Intends to Propose Risk-Informed GDC, GOC and Regulations
  - Petition Anticipated in December 2001
  - NEI Proposal May Be Similar to Option 3 of RIP50
- Licensing of New Technologies
  - Short-Term: Address via Existing Regulations, License Conditions and Exemptions
  - Long-Term: Address via Rulemaking

NRC/RES
FLACK
RUBIN

United States
Nuclear Regulatory Commission

Office of Nuclear Regulatory Research
Advanced Reactors Activities
June 4, 2001

John H.Flack
Stuart D.Rubin

Introduction

- Historical role of RES in preapplication reviews
- Preapplication review of advanced reactors
- Current role of RES in advanced reactor reviews
- Advanced reactor group in Division of Systems Analysis and Regulatory Effectiveness (RES)

Advanced Reactor Activities

- Advanced reactors have greater reliance on new technology and safety features.
- Preapplication interactions and reviews will help NRC prepare for licensing application
- NRR has lead with RES support for LWR advanced reactor preapplication initiatives and licensing application reviews
- NMSS has lead for fuel cycle, transportation and safeguards
- RES has lead for non-LWR advanced reactor preapplication initiatives and longer-range new technology initiatives
- Recent industry requests for preapplication interactions:

  Westinghouse: AP1000 (5/4/00)
  Exelon: Pebble Bed Modular Reactor (12/5/00)
  General Atomics: Gas Turbine-Modular Helium Reactor (3/22/01)
  Westinghouse: International Reactor Innovative and Secure (4/06/01)

- NEI Risk-Informed framework for Advanced Reactor Licensing

RES Advanced Reactors Activities

- PBMR:

  - Request for pre-application interactions received from Exelon
  - NRC response
  - Plan developed (SECY-01-0070)
  - Pre-application work underway (FY2001-2002)
  - Objective - identify issues, infrastructure needs and framework for PBMR licensing
  - Develop nucleus of staff familiar with HTGR technology

- GT-MHR

  - Request for pre-application interactions received from General Atomic
  - NRC Response

RES Advanced Reactors Activities (cont.)

- IRIS
  - Developed under DOE-NERI program
  - Initial meeting on 05/07/01
- Generation IV
  - International activity coordinated by DOE
  - Longer term
  - NRC participating as an observer
- Generic Framework:
  - NEI developing proposal
  - Need for NRC to establish an effective and efficient risk-informed,and where appropriate, performance-based licensing framework

Significant Technology Issues:

- Unique, First of a Kind Major Components
- Fuel Design, Performance, Qualification, & Manufacture
- Source Term
- Thermal-Fluid Flow Design
- Hi-Temperature Performance
- Containment
- Fuel Cycle Safety & Safeguards
- Prototype Testing and Experiments
- Human Performance and I&C
- Probabilistic Risk Assessment Methodology and Data
- Emergency Planning
- Regulations Framework
    - design basis accident selection
    - safety classification
    - acceptance criteria
    - GDC,
    - use of PRA
    - Safety Goals

PBMR Pre-Application Review Objectives

- To develop guidance on the regulatory process, regulations framework and the technology-basis expectations for licensing a PBMR, including identifying significant technology, design, safety, licensing and policy issues that would need to be addressed in licensing a PBMR.

- To develop a core infrastructure of analytical tools, contractor support, staff training and NRC staff expertise needed for NRC to fully achieve the capacity and the capability to review a modular HTGR license application.

PBMR Pre-Application Review Guidance

- Commission Advanced Reactor Policy Statement
- NUREG-1226 on the Development And Utilization of the Policy Statement
- Previous Experience with MHTGR Pre-Application Review
- Identify Safety, Technology, Research, Regulatory & Policy Issues

PBMR Pre-Application Review Scope

Selected Design, Technology and Regulatory Review Areas:

- Fuel Design, Performance and Qualification
- Nuclear Design
- Thermal-Fluid Design
- Hi-Temp Materials Performance
- Source Term
- Containment Design
- PBMR Regulatory Framework
- Human Performance and Digital I&C
- Prototype Testing Program
- Probabilistic Risk Assessment
- Postulated Licensing-Basis Events
- Fuel Cycle Safety
- Emergency Planning
- SSC Safety Classifications

PBMR Pre-Application Review Process

- Conduct Periodic Public Meetings on Selected Topics:
  - Process Issues, Legal & Financial Issues, Regulatory Framework (4/30)
  - Fuel Performance and Qualification (6/12-13)
  - Traditional Engineering Design (e.g., Nuclear, Thermal-Fluid, Materials)
  - Fuel Cycle Safety Areas
  - PRA, SSC Safety Classification
  - PBMR Prototype Testing
- NRC Identifies Additional Information Following Topical Meetings
- Exelon/DOE Formally Documents and Submits Topical Information
- NRC Develops Preliminary Assessment and Drafts Documented Response
- Obtain Stakeholder Input and Comments at a Public Workshop
- Discuss Preliminary Assessments With ACRS and ACNW
- Commission Papers Provide Staff Positions and Recommend Policy Decisions
- Commission Provides Policy Guidance and Decisions
- NRC Staff Formally Responds to Exelon with Positions and Policy Decisions

PBMR Pre-Application Review Sources of Expertise

- RES, NRR, NMSS, OGC Technical Expertise and Regulatory Experience
- Contractor Support From National Labs and Design/Technology Experts
- Prior NRC Modular HTGR Pre-Application Review Experience
- Design, Operating and Safety Review Experience for Fort St. Vrain HTGR
- International HTGR Experience: IAEA, Japan, China, Germany, UK
- Exelon and DOE Design, Technology and Safety Assessments
- External Stakeholder Comments
- ACRS and ACNW Advice and Insights

PBMR Safety Significant Review Issues/Topics

- Fuel Performance and Qualification
- High Temperature Material Issues
- Passive Design and Safety Characteristics
- Accident Source Term and Basis*
- Postulated Licensing Basis Events*
- Prototype Testing Scope and Regulatory Credit
- Containment Functional Design Basis*
- Emergency Planning Basis*
- Risk-Informed Regulatory Framework*
- Probabilistic Risk Assessment

* Commission Policy Decision Likely Is Needed

PBMR Pre-Application Review Schedule

- About 18 months to Complete
- Monthly Public Meetings To Discuss Topics
- Feedback on Legal, Financial and Licensing Process Issues (~9/01)
- Feedback on Regulatory Framework (~12/01)
- Feedback on Design, Safety, Technology & Research Issues (~6/02)
- Feedback on Policy Issues (~10/02)

Regulatory Infrastructure Development Needs

- Staff Training Course for HTGR Technology
- Analytical Codes and Methods for Advanced Reactor Licensing Reviews
- Regulatory Framework for Advanced Reactor Licensing Reviews
- Core Staff Capabilities for Advanced Reactor Licensing Reviews
- Contractor Technical Support Capabilities
- Possible RES Confirmatory Testing and Experiments
- Possible Codes and Standards for Advanced Reactor Design and Technology

NEI
SIMARD

Licensing needs for future plants

ACRS workshop on Regulatory Challenges
for Future Nuclear Power Plants

Ron Simard
Senior Director, Business Services
Nuclear Energy Institute

June 5, 2001

NEI

New Nuclear Power Plants - New Momentum

- Growing electricity demand, need for new generating capacity
- Fossil fuel price volatility, clean air constraints
- Improving economics of new nuclear power plants
- Industry consolidation = companies large enough to undertake large capital projects
- Significant public and political support
- Potential for greater certainty in the licensing process

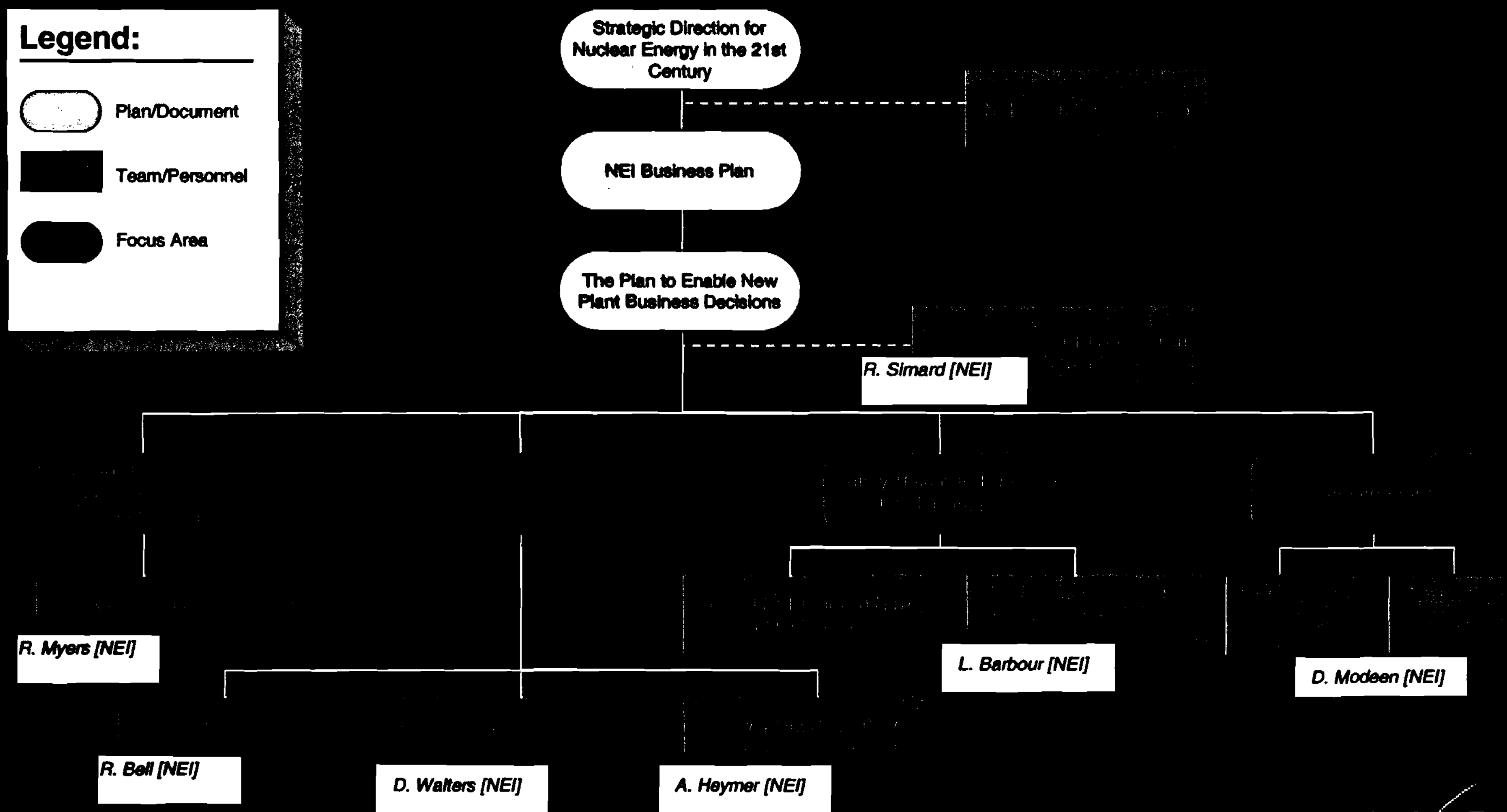
NEI

Focus of efforts to pave the way for new plants

- Policy, legislative, regulatory changes needed to support new approaches to ownership, risk sharing and project financing
- Policymaker support (Administration, Congress and others)
- Infrastructure (people, hardware, services) to support new and current plants
- Licensing, licensing, licensing

NEI

Activities in support of the plan to enable new plant business decisions



Licensing needs with respect to ...

- working out the Part 52 implementation details
- assuring safety and equitable application of regulations to new types of designs
- clarifying how financial related requirements apply in the new business environment

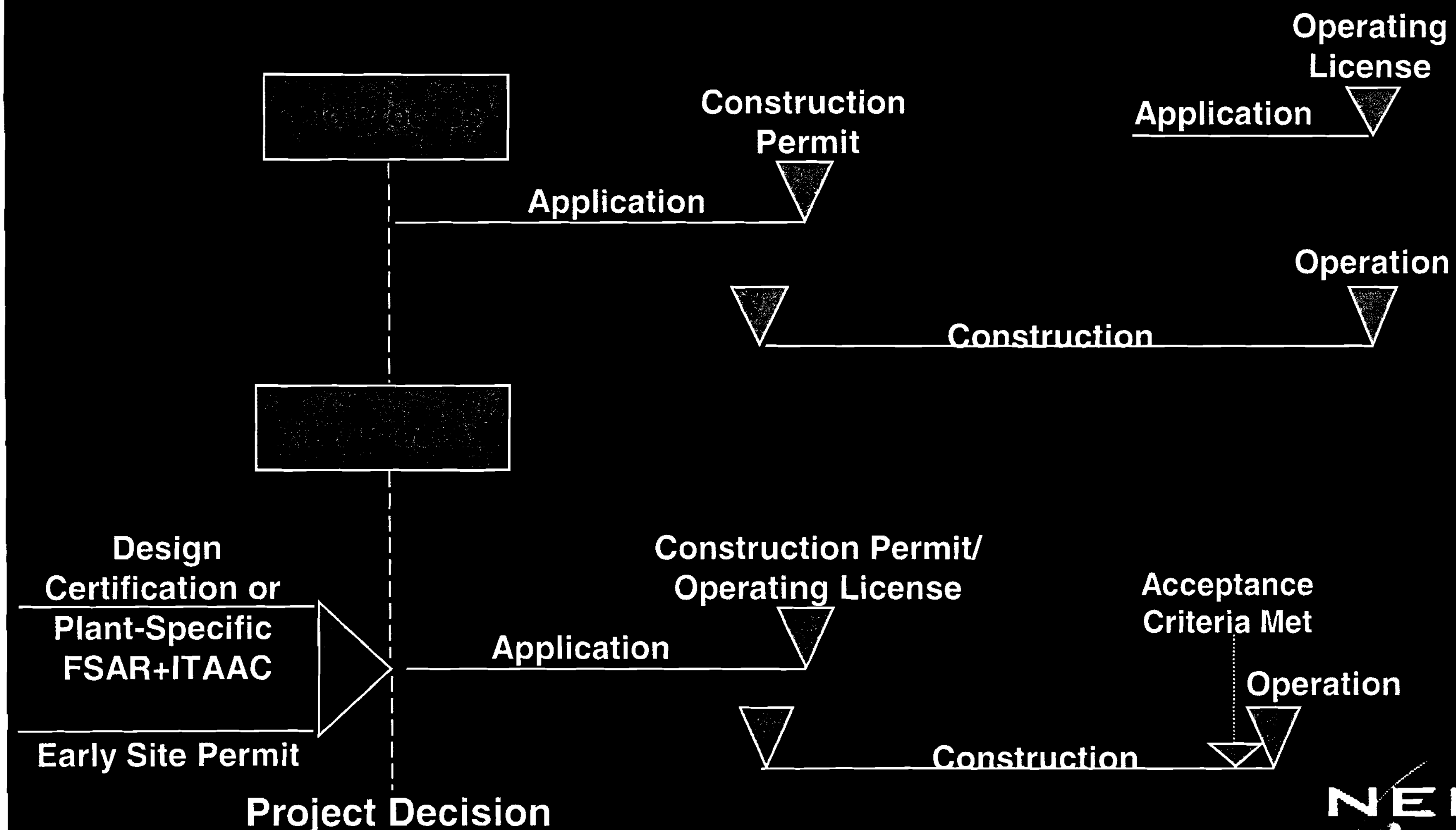
NEI

Examples of Part 52 licensing needs

- a timely and efficient ESP process (e.g., focusing on the incremental impacts of additional reactors at existing sites)
- a timely and efficient process for COL applications and reviews
- an efficient process for construction inspection and ITAAC verification

NEI

New Licensing Process Significantly Reduces Project Risk



NEI

"New design" licensing needs (in addition to safety determinations)

- For modular designs, clarification of
  - number of licenses per facility
  - application of Price Anderson requirements
  - basis for Part 171 annual fees
  - basis for control room staffing
- For gas cooled designs, clarification of
  - decommissioning funding levels
  - generic environmental impacts (Tables S-3, S-4)
  - basis for EP action levels, reporting requirements, implementation of NUREG-0654

NEI

Licensing needs for the new business environment

- Clarification of how financial related requirements apply to merchant nuclear plants
  - no need for an NRC antitrust review
  - nature of financial qualifications
  - appropriate mechanisms for decommissioning funding assurance

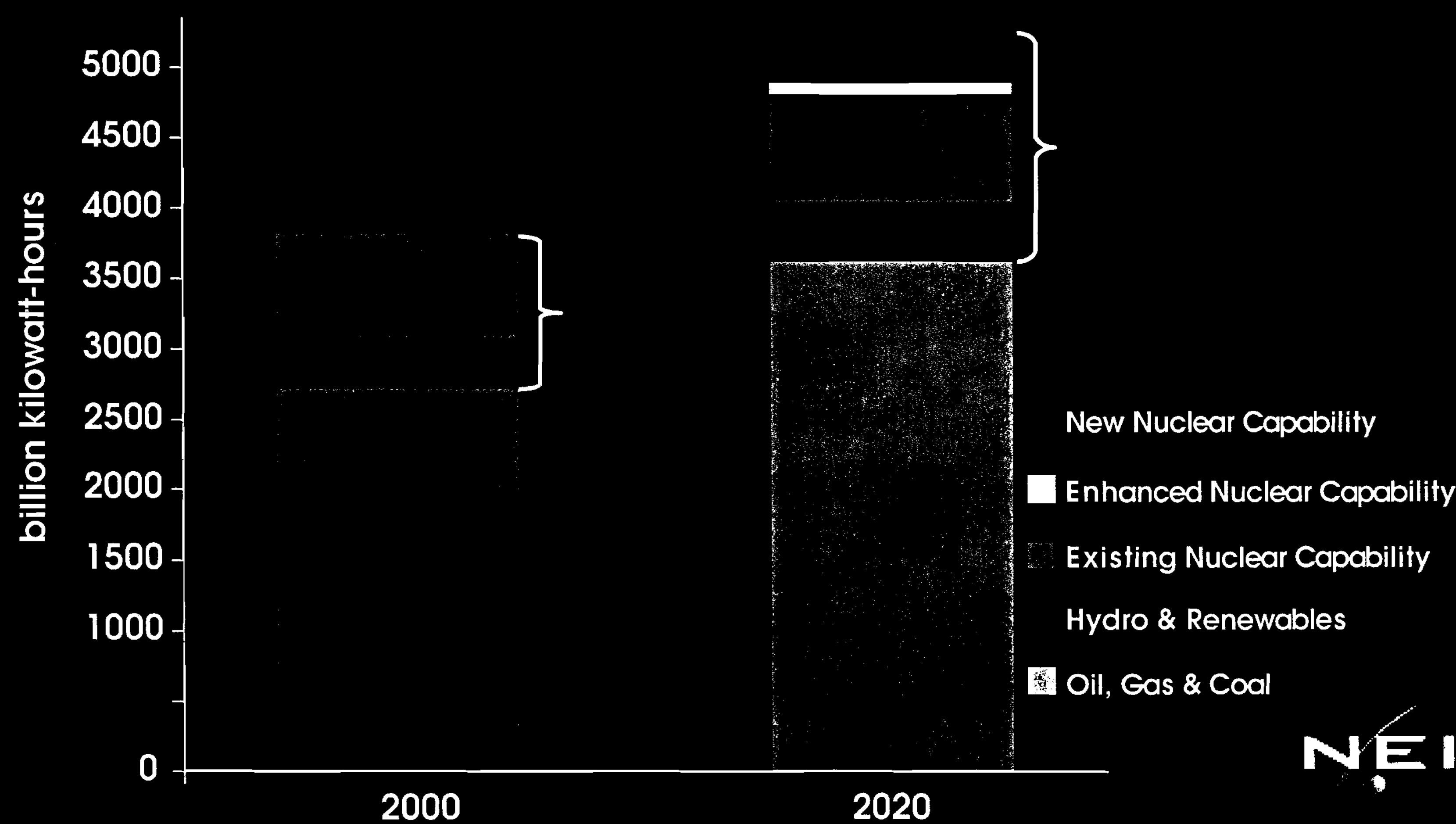
NEI

The nuclear energy imperative

- DOE projects 400,000 MW of additional capacity needed by 2020 (to replace existing plants that reach end of life and to meet new demand)
- 30% of our current generation is non emitting (nuclear, hydro, renewables)
- maintaining that contribution to clean air will require 50,000 Mwe of new nuclear

NEI

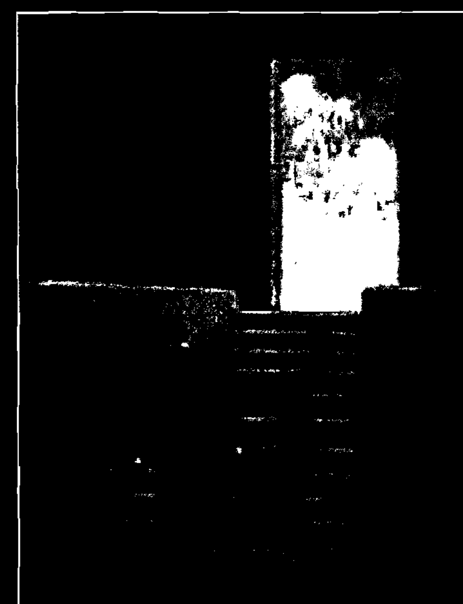
Vision 2020



billion kilowatt-hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
2000
2020
New Nuclear Capability
Enhanced Nuclear Capability
Existing Nuclear Capability
Hydro & Renewables
Oil, Gas & Coal

The Future isn't what it used to be because ...

- Electricity demand will continue to grow
- New nuclear generation is no longer an option
  - it is an imperative
- The business case for new nuclear plants will be clear
- The cost and schedule drivers must be known and manageable to much more certainty than in the past

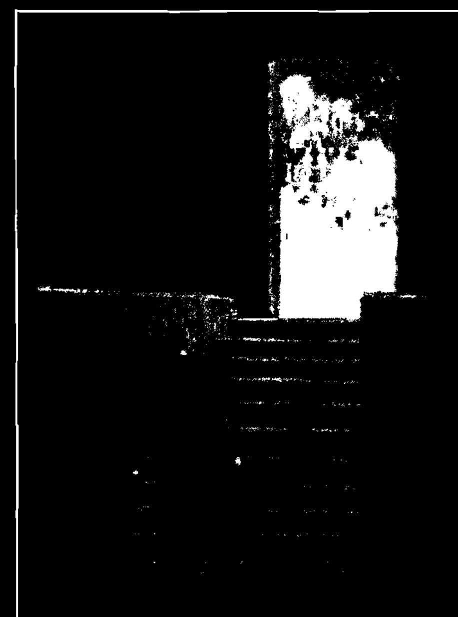


NEI

The Future isn't what it used to be because ...

NRC will be challenged to

- resolve Part 52 implementation issues in a timely manner
- establish efficient and predictable processes for siting, COL license applications, construction inspection
- respond to an increasing workload with new focus, discipline and efficiency



NEI

MIT
TODREAS

ACRS WORKSHOP
Regulatory Challenges for Future Nuclear Power Plants

Safety Goals for Future Nuclear Power Plants

Neil E. Todreas
KEPCO Professor of Nuclear Engineering
Massachusetts Institute of Technology

AM June 5, 2001

HOW TO MISCONSTRUE THIS TALK

I am not talking about:

- NRC Safety Goals - Quantitative Health Objectives - CDF and LERF.
- Suggested Regulatory Requirements for Future Power Plants.
- Soley about Future Power Reactors.
- Goals for Near Term Deployment* Plants (by 2010).

I am talking about:

- DOE and GIF Generation IV Technology Goals.
- Technology Goals formulated to
  - stimulate innovation.
  - suggest metrics for downselection which specifically are not to be construed as regulatory requirements.
- Nuclear Energy Systems Including
  - Fuel Cycles
- Goals for Systems to be Deployed from 2011 to 2030.

---

* Deployment: Manufacture, construction, and startup of certified plants ready to produce energy in their chosen market.

HOW TO MISCONSTRUE THE GOALS

- Assume that new nuclear energy systems must meet every new goal

  - Tradeoffs among goal parameters must be made for each design. Future markets may value different parameters.

    Desirable outcome is a spectrum of designs each best suiting different market conditions hence different goals.

  - Some goals presently appear unattainable (S+R 3).

  - Most goals are not overly specific because the social regulatory, economic and technological conditions of 2030 and beyond are uncertain.

HOW TO MISCONSTRUE THE GOALS (cont.)

- Assume that all safety considerations are encompassed in the Safety and Reliability Goal grouping (S+R 1, 2, +3)

  - Future designs will likely (but not necessarily) involve new fuel cycles and the capability to produce a broader range of energy products. For these reasons and to enhance the economic performance of electricity-only producing systems,
    I anticipate:
    - New Fuel Materials
    - Higher Burnups
    - Longer Operating Cycles
    - Higher Temperature Operation

  - These trends will be driven by the Sustainability (SU 1, 2, +3) and the Economic (EC 1+2) Goals.

SUSTAINABILITY

Sustainability is the ability to meet the needs of present generations while enhancing and not jeopardizing the ability of future generations to meet society's needs indefinitely into the future.

Sustainability–1.

Generation IV nuclear energy systems including fuel cycles will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilization for worldwide energy production.

Sustainability–2.

Generation IV nuclear energy systems including fuel cycles will minimize and manage **their nuclear waste and notably** reduce the long term stewardship **burden in the future, thereby improving protection for the public health and the environment.**

Sustainability–3. **Generation IV nuclear energy systems including fuel cycles will increase the assurance that they are a** very unattractive and least desirable **route for diversion or theft of weapons-usable materials.**

SAFETY AND RELIABILITY

Safety and reliability are essential priorities in the development and operation of nuclear energy systems.

Safety and Reliability –1.

Generation IV nuclear energy systems operations will excel in safety and reliability.

Safety and Reliability–2.

Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage.

Safety and Reliability–3.

Generation IV nuclear energy systems will eliminate the need for offsite emergency response.

Safety and Reliability –1. Generation IV nuclear energy systems operations will excel in safety and reliability.

This goal aims at increasing operational safety by reducing the number of events, equipment problems, and human performance issues that can initiate accidents or cause them to deteriorate into more severe accidents. It also aims at achieving increased nuclear energy systems reliability that will benefit their economics. Appropriate requirements and robust designs are needed to advance such operational objectives and to support the demonstration of safety that enhances public confidence.

During the last two decades, operating nuclear power plants have improved their safety levels significantly, as tracked by the World Association of Nuclear Power Operators (WANO). At the same time, design requirements have been developed to simplify their design, enhance their defense-in-depth in nuclear safety, and improve their constructability, operability, maintainability, and economics. Increased emphasis is being put on preventing abnormal events and on improving human performance by using advanced instrumentation and digital systems. Also, the demonstration of safety is being strengthened through prototype demonstration that is supported by validated analysis tools and testing, or by showing that the design relies on proven technology supported by ample analysis, testing, and research results. Radiation protection is being maintained over the total system lifetime by operating within the applicable standards and regulations. The concept of keeping radiation exposure as low as reasonably achievable (ALARA) is being successfully employed to lower radiation exposure.

Generation IV nuclear energy systems must continue to promote the highest levels of safety and reliability by adopting established principles and best practices developed by the industry and regulators to enhance public confidence, and by employing future technological advances. The continued and judicious pursuit of excellence in safety and reliability is important to improving economics.

Safety and Reliability–2. Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage.

This goal is vital to achieve investment protection for the owner/operators and to preserve the plant's ability to return to power. There has been a strong trend over the years to reduce the possibility of reactor core damage. Probabilistic risk assessment (PRA) identifies and helps prevent accident sequences that could result in core damage and off-site radiation releases and reduces the uncertainties associated with them. For example, the U.S. Advanced Light Water Reactor (ALWR) Utility Requirements Document requires the plant designer to demonstrate a core damage frequency of less than 10^{-5} per reactor year by PRA. This is a factor of about 10 lower in frequency by comparison to the previous generation of light water reactor energy systems. Additional means, such as passive features to provide cooling of the fuel and reducing the need for uninterrupted electrical power, have been valuable factors in establishing this trend. The evaluation of passive safety should be continued and passive safety features incorporated into Generation IV nuclear energy systems whenever appropriate.

Safety and Reliability–3. Generation IV nuclear energy systems will eliminate the need for offsite emergency response.

The intent of this goal is, through design and application of advanced technology, to eliminate the need for offsite emergency response. Although its demonstration may eventually prove to be unachievable, this goal is intended to stimulate innovation, leading to the development of designs that could meet it. The strategy is to identify severe accidents that lead to offsite radioactive releases, and then to evaluate the effectiveness and impact on economics of design features that eliminate the need for offsite emergency response.

The need for offsite emergency response has been interpreted as a safety weakness by the public and especially by people living near nuclear facilities. Hence, for Generation IV systems a design effort focused on elimination of the need for offsite emergency response is warranted. This effort is in addition to actions which will be taken to reduce the likelihood and degree of core damage required by the previous goal.

ECONOMICS

Economic competitiveness is a requirement of the marketplace and is essential for Generation IV nuclear energy systems.

Economics–1.

Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.

Economics–2.

Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.

CONCLUSIONS

- Future reactors fall in three categories - those which are:
  - Certified or derivatives of certified designs.
  - Designed to a reasonable extent and based on available technology.
  - In Conceptual form only with potential to most fully satisfy the GENIV goals.

  My focus has been on goals for the third category.

- It will be desirable to develop a range of design options in this third category to enable response to a range of marketing demands such as:
  - cheap versus expensive uranium.
  - small versus large power ratings.
  - significant reduction of greenhouse emissions.
  - new fuel cycles to achieve a significant response to the sustainability goals.

  Considerable R+D activity will be required to achieve these goals among which fuels, materials, and coolant corrosion research are the most intensive and long term.

- Consequently it is important that while an early dialogue between designers and regulators occur, the dialogue be framed to encourage & promote fundamental design directions which inherently promote safety. Development of a new regulatory process using risk-based principles is an important element of this dialogue. Interactions which frame the dialogue around the current regulatory framework can have the undesirable intent of discouraging the necessary and desirable exploration of technology and design alternatives.

MIT
KADAK

Licensing Approach for Generation IV Technologies

"License By Test"

Andrew C. Kadak
Massachusetts Institute of Technology

June 5, 2001

Challenges

Regulations focused on water

Knowledge of technology lacking

Regulatory System Rigid

Infrastructure to Support New Technology Not Developed

Changes in System take a long time

How to Introduce New Technology in Less than a Lifetime ?

- Go Back to Basic Safety Fundamentals
- Work Within Existing Regulatory High Level Objectives
- Use Risk Informed - Risk Based and Deterministic Analysis
- Assess Gaps in Knowledge
- Prioritize (risk assess)
- License by Test

Establish a Safety Basis

Use Public Health & Safety Goal

Define Plant Risks:

- Normal Operating Plant
- Transients
- Accident Scenarios

Identify Safety Margins

Quantify Risks

Show Defense in Depth

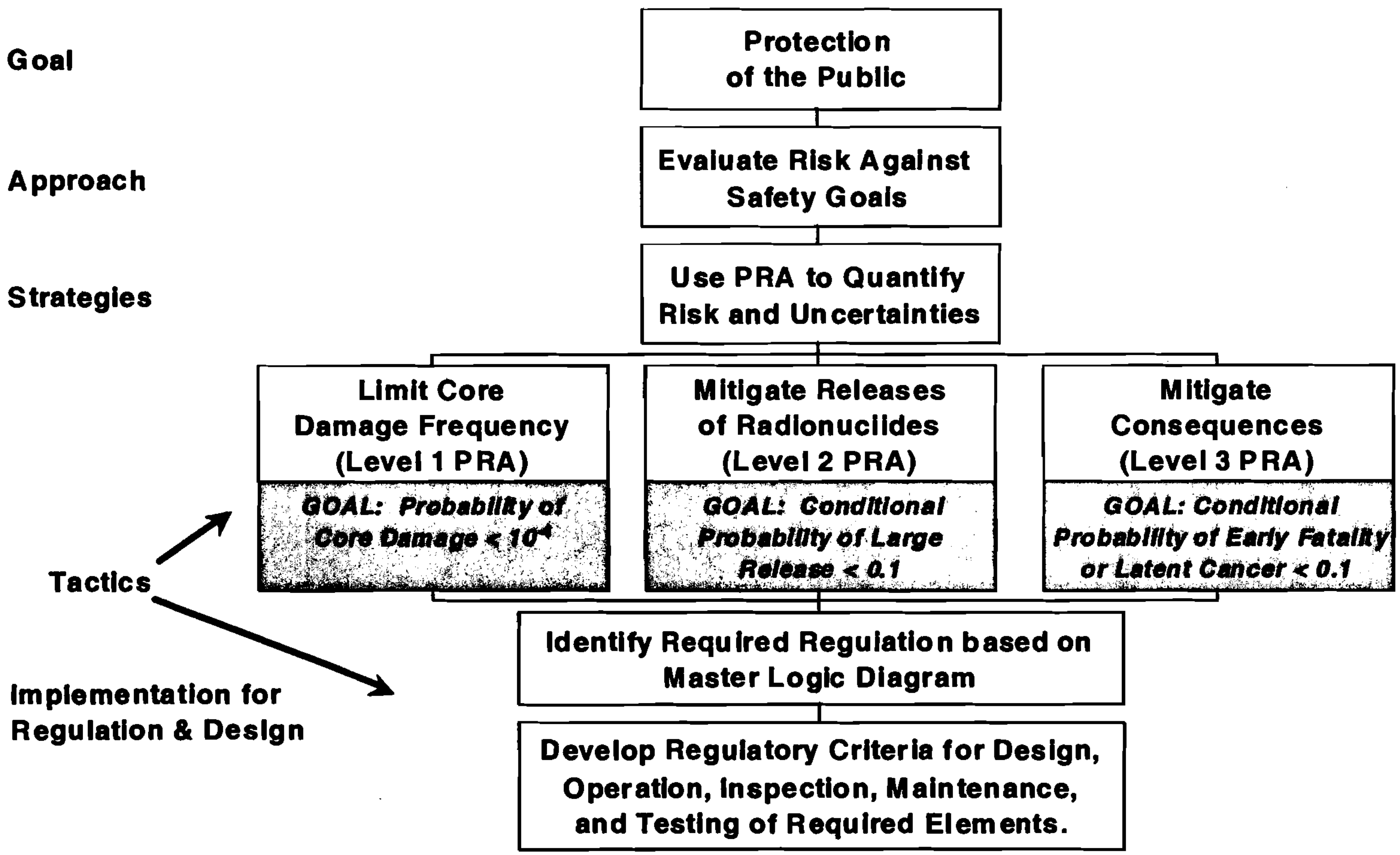
Risk Informed Approach

Establish a public health and safety goal

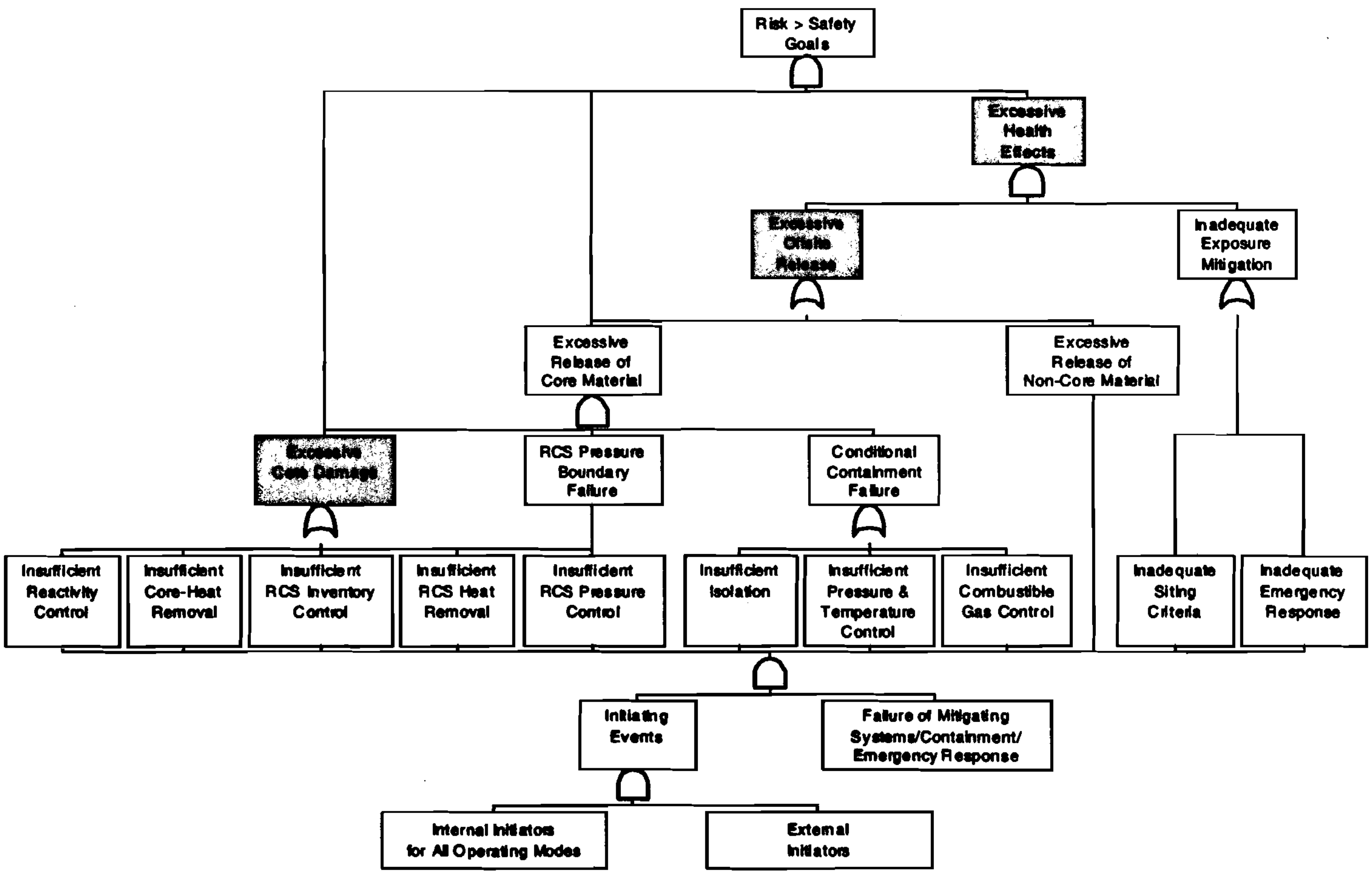
Demonstrate by a combination of deterministic and probabilistic techniques that the safety goal is met.

Using risk based techniques identify dominant accident scenarios, critical systems and components that need to be tested as a functional system

Risk Informed Approach



Master Logic Diagram for Water Reactors



Council for Nuclear Safety Licensing Approach
For the Pebble Bed Modular Reactor (PBMR)

	SAFETY REQUIREMENTS	EVENT FREQUENCY	SAFETY CRITERIA
a	The design shall be such to Ensure that under anticipated Conditions of normal operation There shall be no radiation hazard To the workforce and members of The public. This must be Demonstrated by conservative deterministic analysis.	Normal operational conditions shall be those which may occur with a frequency up to but not exceeding 10^{-2} per annum.	Individual radiation dose limits per annum of 20 mSv to workers and 250 μSv to members of the public shall not be exceeded. +ALARA+ Defense in depth criteria
b	Design to be such to prevent and mitigate potential equipment failure Or withstand externally or internally originating events which could give Rise to plant damage leading to Radiation hazards to workers or the public. This must be demonstrated By conservative deterministic Analysis.	Events with a frequency in the range 10^{-2} to 10^{-6} per annum shall be considered.	Radiation doses of 500 mSv to workers and 50 mSv to members of the public shall not be exceeded. +ALARA+ Defense in depth criteria
c	The design shall be demonstrated To respect the CNS risk criteria. This must be demonstrated by probabilistic risk assessment using Best estimate + uncertainty analysis.	Consideration shall be given to all possible event sequences.	CNS risk criteria apply. $5X10^{-6}$ individual risk 10^{-8} Population risk Bias against larger accidents. +ALARA

(CNS is the former name of the National Nuclear Regulator)

Review Existing Regulatory Structure for Gaps

Based on plant specific safety basis:

- Identify existing regulations that apply.
- Use risk based regulatory approach to fill in gaps for areas not covered.
- Develop implementation approach to General Design Criteria.

Develop Traditional Deterministic Regulatory Approach

- Establish Design Basis Accidents using risk based techniques
- Develop Defense in Depth Basis Using natural physical attributes of designs
- Establish confidence levels for analysis using risk assessment methods

License By Test

- Build Full Size Demonstration Plant
- Perform Critical Tests on components and systems identified using risk informed techniques
- If Successful, Certify Design

Why License By Test ?

Needs:

- To validate analyses
- To shorten time for paper reviews
- To "prove" what is debatable
- To reduce uncertainty
- Show Public and NRC that plant is safe

Tests Required

Traditional Performance tests of equipment still required for reliability

Use Risk Based Techniques to identify:

- Accident Scenarios of Importance
- Critical Systems
- Critical Components

Conduct Integrated System Tests

Examples of Tests

Loss of Coolant

Reactor Depressurization

Natural Circulation

Rod Withdrawal

Reactivity Shutdown Mechanisms

Reactor Cavity Heat Up and Removal

Selected Component Key Component Failures

Additional Tests

- Balance of Plant Failures - turbine overspeed, loss of heat sink, compressor failures, etc
- Control Rod Ejection (rapid withdrawal)
- Reactor Cavity Heat Up
- Validate Core Physics Models
- Validate Safety Analysis Codes and Methods
- Xenon Transients

Tests Leading Up to Demonstration Facility Tests

- Fuel Performance - Irradiation, post accident heat up, cycling
- Air Ingress - validate chimney model for air ingress potential
- Water Ingress - assess reactivity effect and fuel damage

Reactor Research Facility

- Pebble Bed Reactor as a prototype for this licensing approach.
- Built in Idaho - Full Size w/Containment
- Implement Structured Test Program
- Develop Regulatory Process as Part of Certification of Technology using RRF.
- Research Reactor Continues as facility to innovate and test new technologies for fleet of standard designs.

Will License By Test Be Able to Answer All Questions ?

No...

In combination of subtier component tests described and the risk informed analysis, it should provide high confidence of critical safety performance.

Will License by test instill public confidence ?

Yes,

By having the public and the media observe these tests, the confidence in the technology and the regulatory will be enhanced.

$10^{-\text{(pick a number)}}$ is not understandable or effective in safety discussions.

It will encourage development of naturally safe reactors.

Traditional Regulatory Approach

Ask General Atomics for MHTGR

Ask Canadians for Candu

Ask W about AP-600 - 1000

Costly - Time Consuming - Risky

Answers Not always possible to Satisfy NRC staff - Ask Licensees.

Need An Alternative to the "Bring me a Rock" Process.

This may be it...

Summary

For Non-traditional technologies, a new licensing approach is needed for timely deployment.

Risk Informed Techniques with Safety Goals Appear to meet the Need.

License By Test is the most direct means of answering difficult questions.

LBT should increase public confidence.

WESTINGHOUSE AND MIT
DAVIS AND GOLAY

ACRS Workshop on Regulatory Challenges for Future Nuclear Power Plants

NERI Project on Risk-Informed Regulation

June 5, 2001

Mr. George Davis - Westinghouse

Professor Michael Golay - MIT

Presentation Breakdown

- Mr. George Davis
  - Purpose and Overview
  - Expectations for the Future
- Professor Michael Golay
  - A New Risk-Informed Design and Regulatory Process
  - Example Problem

Westinghouse

INEEL

Massachusetts Institute of Technology

Duke Engineering & Services

A Duke Energy Company

Sandia National Laboratories

NC STATE UNIVERSITY

EGAN & ASSOCIATES, P.C.
Counselors at Law

Purpose of Presentation

- Describe our project and its vision of a new design and regulatory process
  - provide a "work-in-progress" illustrative example
- Explain the need for continuing the development of a new design and regulatory process
  - keep pace with the development and licensing of new reactor design concepts.

Substantial Reductions in Capital Costs and Schedule Will be Needed for New Plants

- Production costs (Fuel plus O&M) for operating plants approaching 1 cent/KW-hr
  - not much room for further improvement
- Future investors likely to require payback of capital costs within 20 years of operation, or less
- Capital costs must be reduced by 35% or more relative to large ALWRs
  - overnight capital cost below $1,000/KWe
  - construction schedule of about 3 years (or less)

Three NERI Proposals Aimed at New Processes to Lower Plant Capital Costs

Program	Basic Objective
Risk-Informed Assessment of Regulatory and Design Requirements	Development of methods for a new design and regulatory process.
"Smart" Equipment and Systems to Improve Reliability and Safety in Future Nuclear Power Plants	Development of methods for demonstrating improved component and system reliability; including on-line health monitoring systems.
Development of Advanced Technologies for Design, Fabrication, and Construction of Future Nuclear Power Plants	Development of methods and procedures for collaborative, internet-based engineering, integrated design analyses, and improved construction schedules.

Comparison of NRC and NERI Risk-Informed Regulatory Processes

The new design and regulatory process must be developed further to support new plant license applications - including Generation IV design concepts.

Risk-Informed Assessment - Interactions With Other Programs

- NERI framework development activities are being coordinated with NEI
  - NEI will emphasize the development of regulations
  - The NERI project will address the overall risk-informed design and regulatory process
  - Westinghouse will be an NEI Task Force member

- It is anticipated that a new risk-informed design and regulatory process will be an input to new plant license applications, including Generation IV reactor concepts.

A New Risk-Informed Design and Regulatory Process

Massachusetts Institute of Technology

George Apostolakis, Michael Golay

Sandia National Laboratories

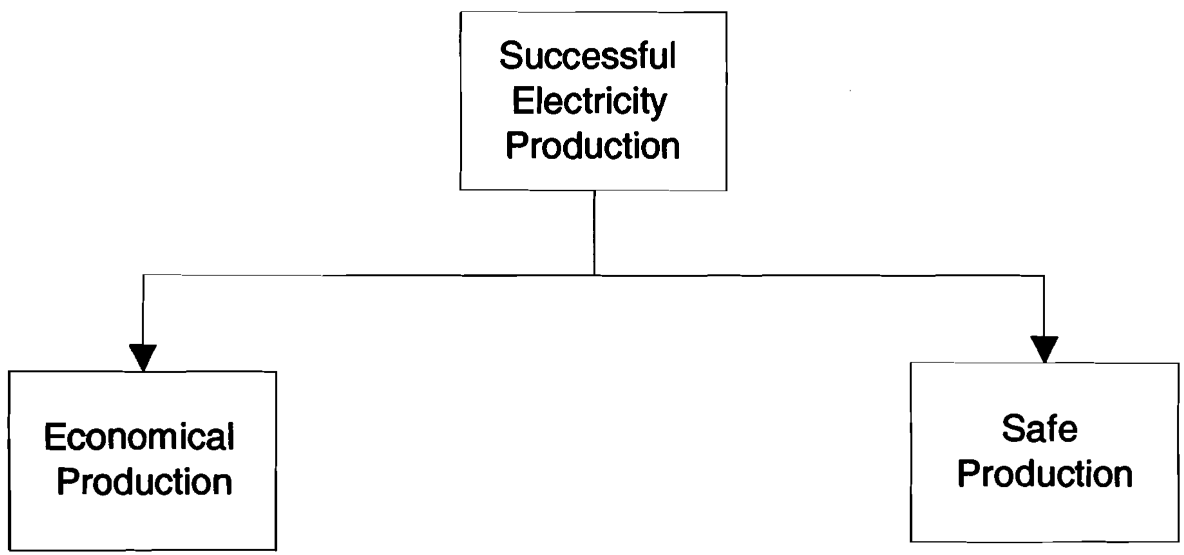
Allen Camp, Felicia Durán

Westinghouse Electric Company

David Finnicum, Stanley Ritterbusch

Overall Goal of Safety-Regulatory Reform

- Create methods to assure consistency of nuclear power plant applicant and regulator in performance/ goals for producing safe, economical power plants

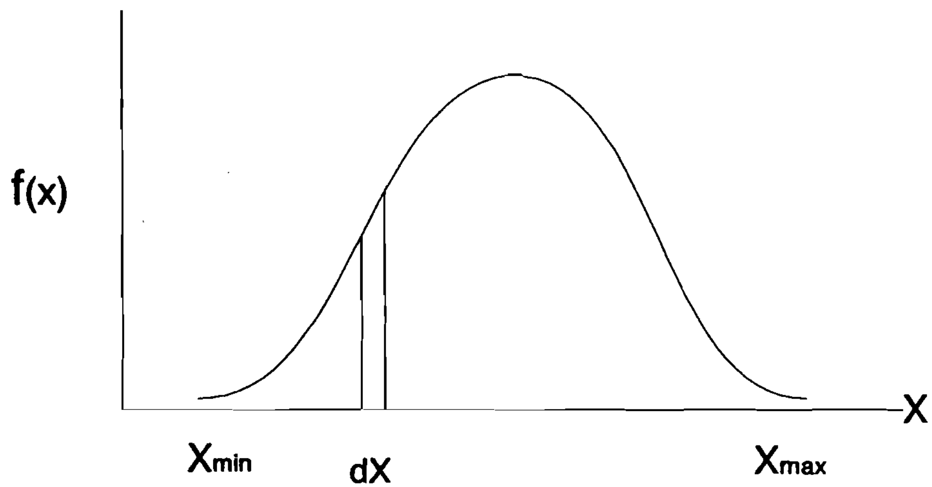


Major Elements:
- Acceptance Criteria
- Comprehensive, consistent assessment methods
- Designers, operators

Major Elements:
- Acceptance Criteria
- Comprehensive, consistent assessment methods
- Regulators, designers, operators

Risk-Informed Regulatory Approach - Fundamental Ideas

- Regulatory decisions are founded upon the informed beliefs of decision-makers.
- Any regulatory belief can and should be stated in a probabilistic format.

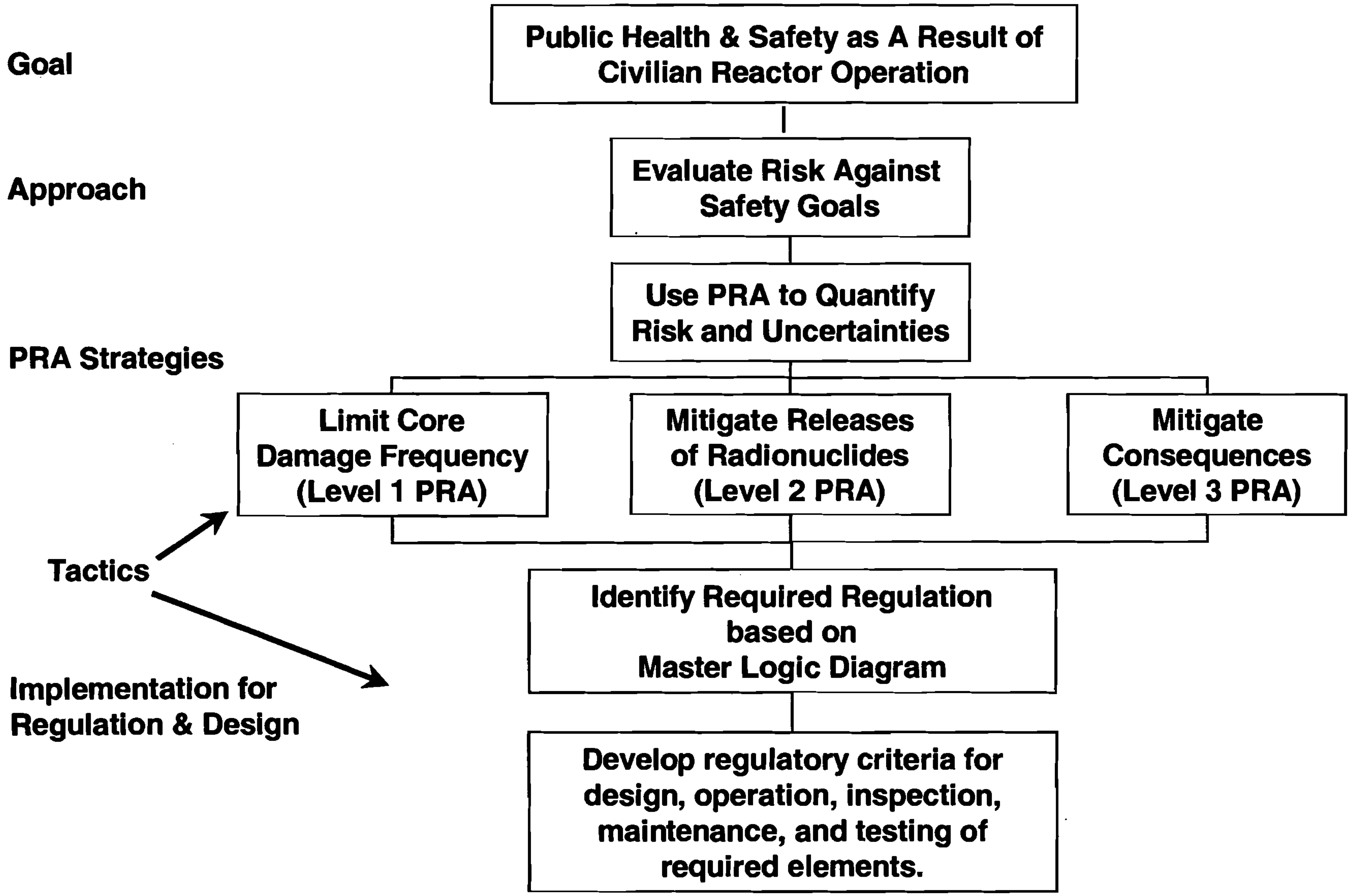


Probability $(x < X < x+dx) = f(x)dx$

- Regulatory acceptance criteria must reflect acceptable best-estimate performance expectations and uncertainties.

Risk-Informed Regulatory Approach - Fundamental Ideas....

- Regulatory questions and acceptance criteria should also be stated within a probabilistic framework.
- The probabilistic framework should be as comprehensive as possible:
  - utilize probabilistic and deterministic models and data where feasible - and use subjective treatments where not feasible,
  - state all subjective judgments probabilistically and incorporate into the PRA,
  - require both license applicant and regulatory staff to justify their decisions explicitly, and
  - initiate resolution process to resolve applicant-regulator disagreements.



Framework for Risk-Based Regulation and Design

Comparison of NRC and NERI Risk-Informed Regulatory Processes

Operating Plants (NRC/NEI)	Future Plants (NERI/New NEI Task Force)
Deterministic	**Probabilistic**
Traditional ("Structuralist") Approach	Risk-Based ("Rationalist") Approach

- Start with current designs and regulatory approvals.
- Justify risk-informed changes.
- Defense-in-depth remains as primary means of assuring safety.

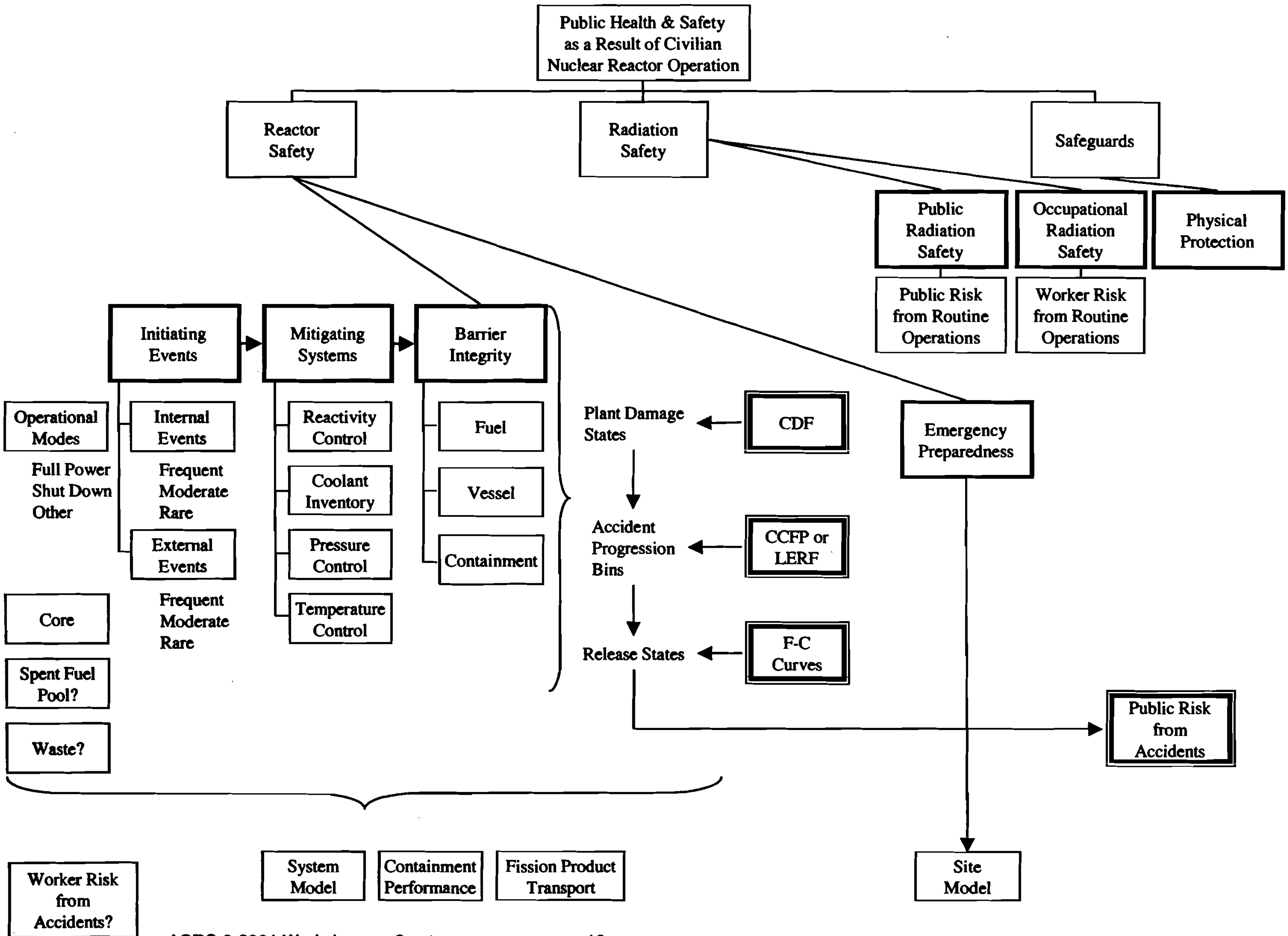
- Develop new design and regulatory process.
- Use firm probabilistic criteria to assure safety.
- Use defense-in-depth and safety margins as needed.

Risk-Informed Regulatory Approach....

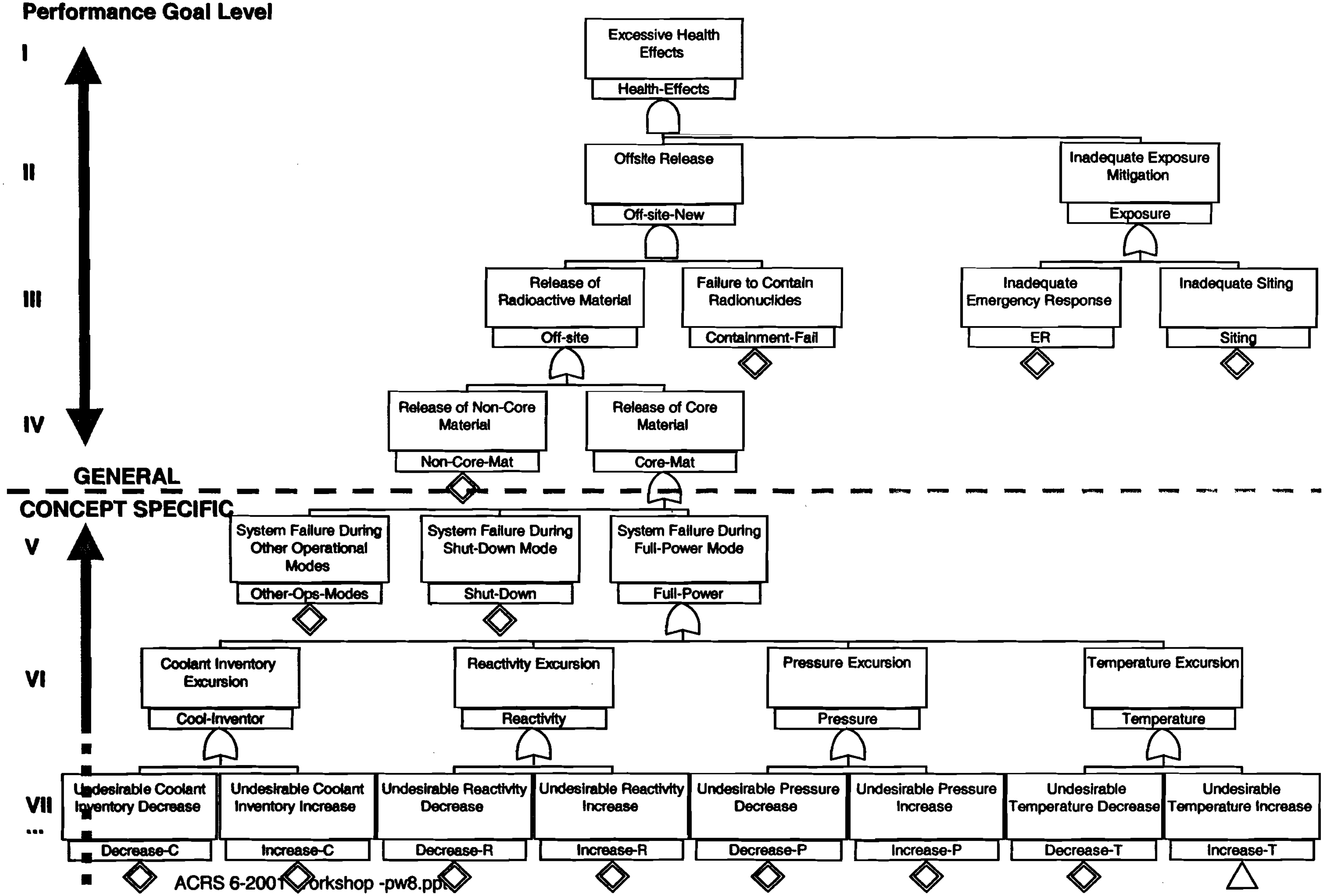
- At all conceptual stages of development, nuclear power plant evaluation is performed probabilistically and is supported by deterministic analyses, tests, experience, and judgements.
- Safety results of defense-in-depth, performance margins, best-estimate performance, and subjective judgements are all incorporated into a comprehensive PRA
  - PRA is used as a vehicle for stating evaluator beliefs concerning system performance
- The level of detail of acceptance criteria becomes finer as the level of concept development increases
  - many LWR-based regulatory constructs (e.g., DBAs, GDCs) are not applicable to less mature

Stages of Nuclear Power Plant Concept Development

Development Stage	Goals and Acceptance Criteria	Evaluation Tools	Relevant Evidence
Initial Concept	High level - qualitative	Qualitative, simple, deterministic	Experiences of other concepts, deterministic analyses
Initial detailed design	High level - quantitative	Quantitative – probabilistic, deterministic	Prior quantitative analyses
Final detailed design	Detailed – quantitative (design-specific subgoals)	Detailed – quantitative – probabilistic, deterministic	Prior quantitative analyses
N-th of a kind for a given plant type	Very detailed – quantitative (design specific criteria – DBAs, GDCs,....)	Very detailed – quantitative, probabilistic, deterministic, tests	Prior quantitative analyses, tests, field experience


Public Health & Safety as a Result of Civilian Nuclear Reactor Operation
Reactor Safety
Radiation Safety
Safeguards
Public Radiation Safety
Occupational Radiation Safety
Physical Protection
Public Risk from Routine Operations
Worker Risk from Routine Operations
Initiating Events
Mitigating Systems
Barrier Integrity
Operational Modes
Full Power
Shut Down
Other
Internal Events
Frequent
Moderate
Rare
External Events
Frequent
Moderate
Rare
Core
Spent Fuel Pool?
Waste?
Reactivity Control
Coolant Inventory
Pressure Control
Temperature Control
Fuel
Vessel
Containment
Plant Damage States
CDF
Accident Progression Bins
CCFP or LERF
Release States
F-C Curves
Emergency Preparedness
Public Risk from Accidents
System Model
Containment Performance
Fission Product Transport
Site Model
Worker Risk from Accidents?

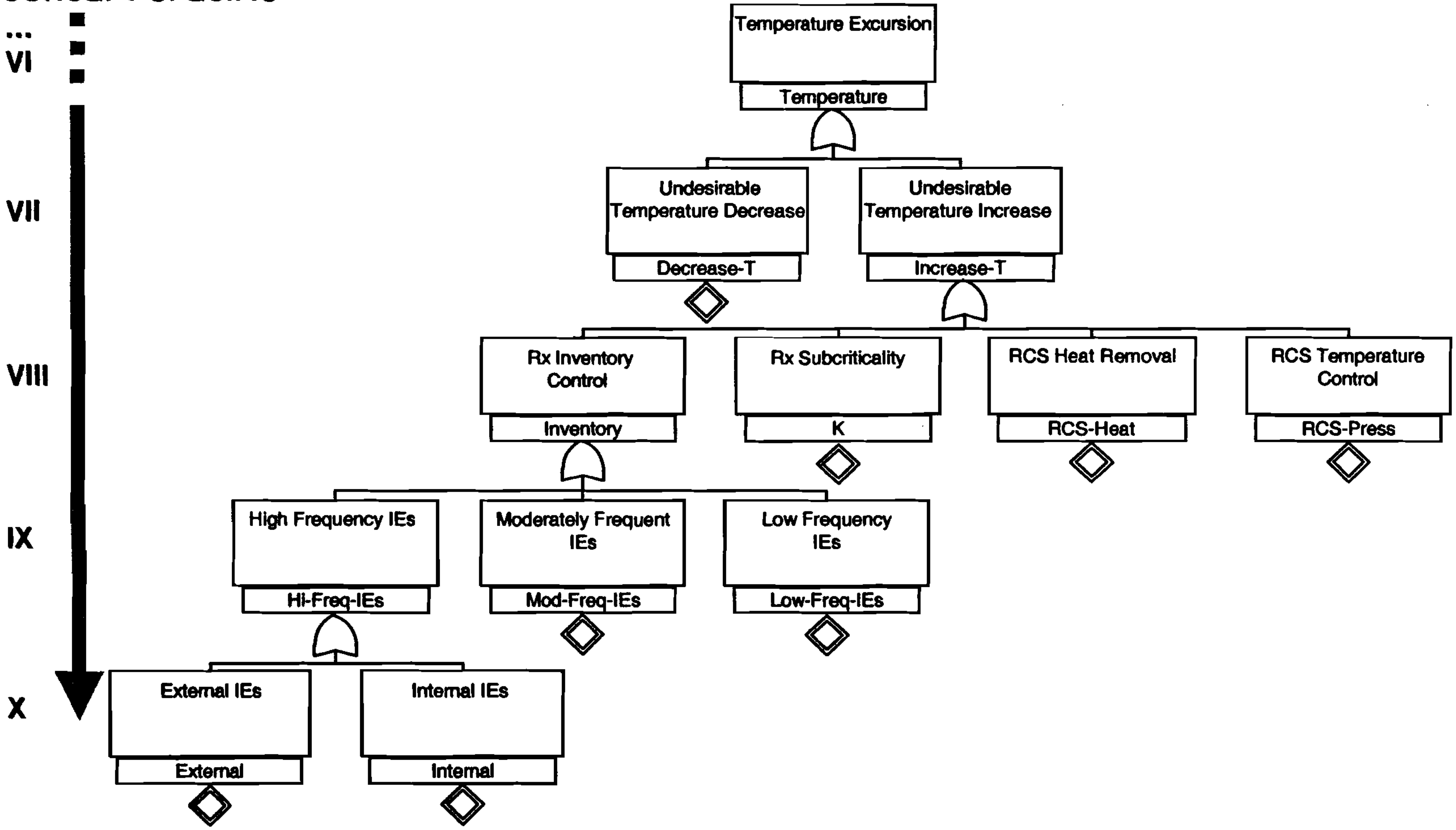
Master Logic Diagram



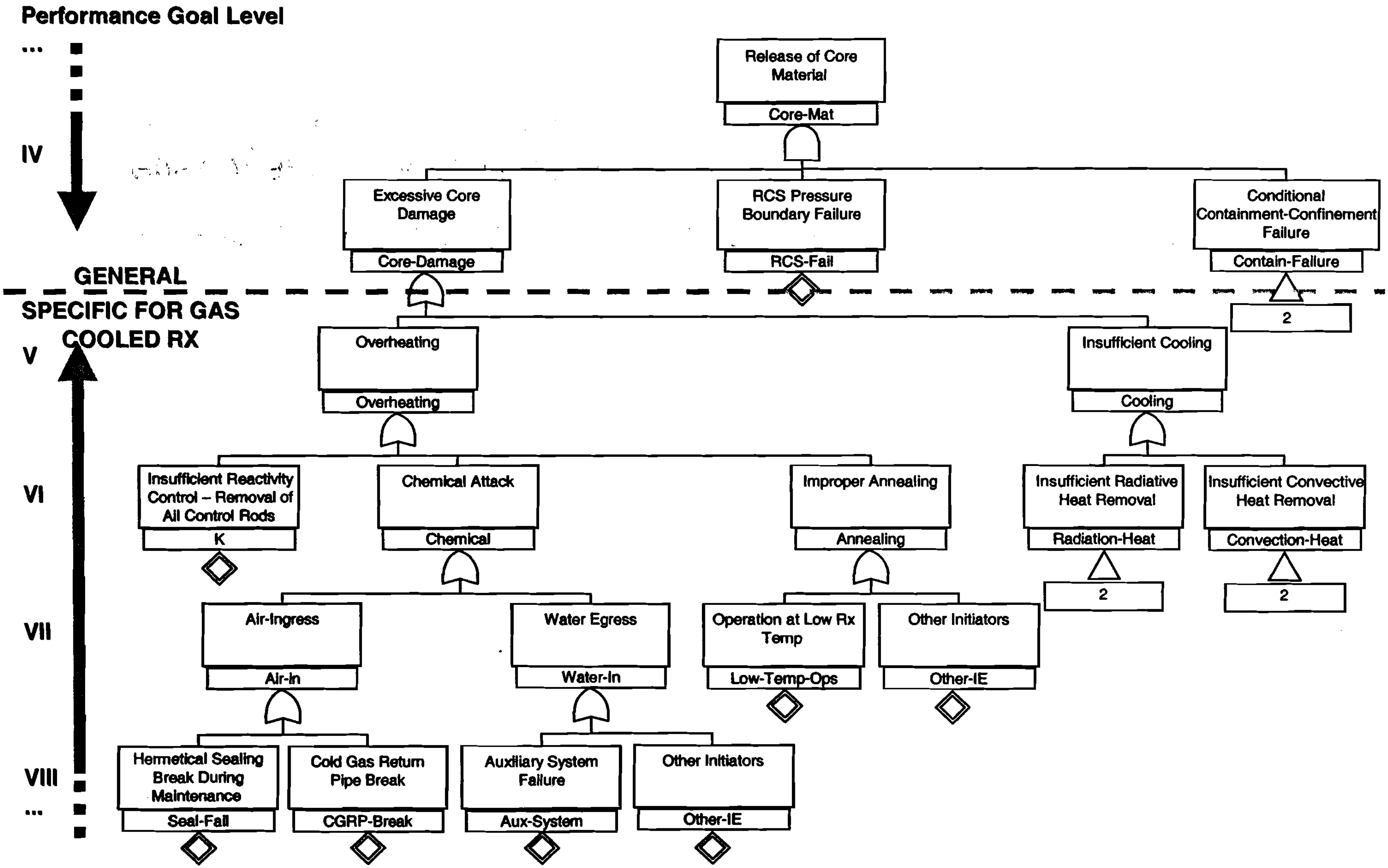
Master Logic Diagram

Performance Goal Level

CONCEPT SPECIFIC

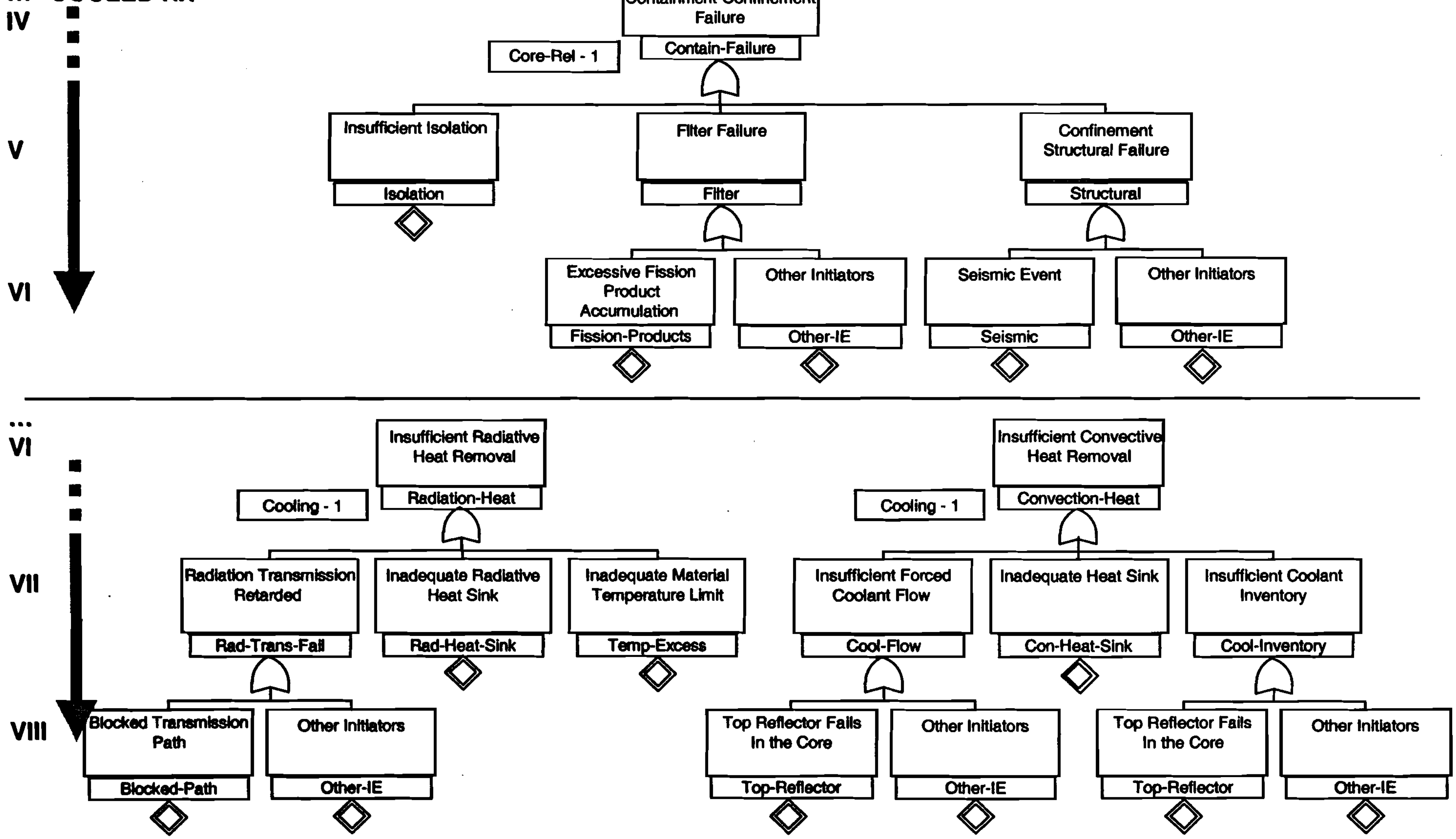


Concept-Specific Master Logic Diagram



Concept-Specific Master Logic Diagram

Performance Goal Level
SPECIFIC FOR GAS
... COOLED RX



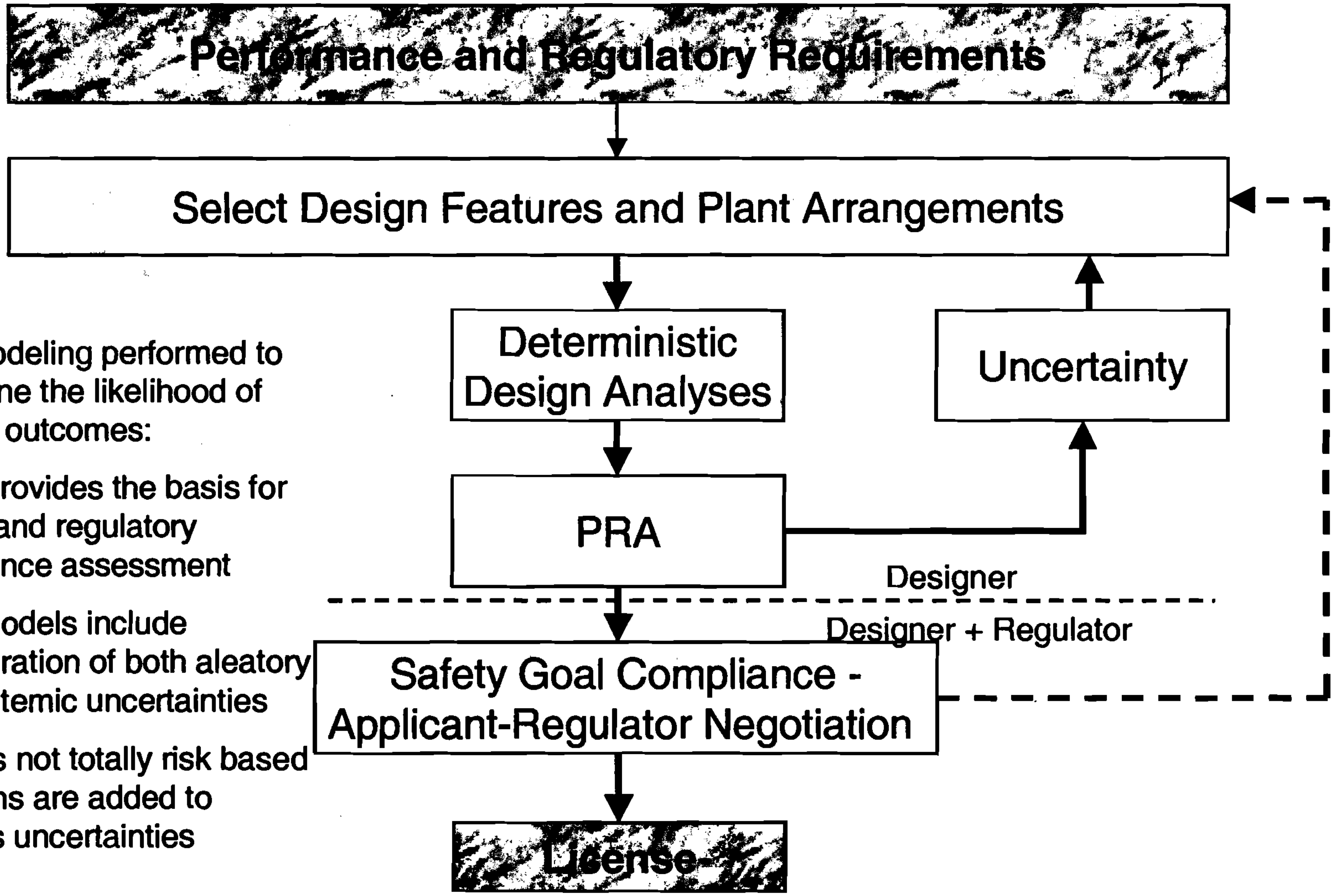
Fundamental Interactions Between License Applicant (or Licensee) and Regulator

- Should be formulated with probabilistic methods
- Acceptability negotiation for new license application or license revision
  - currently is deterministic
  - should be risk-based; completion of procedures, tools, and termination criteria is needed
- Plant construction oversight
  - can be deterministic, subject to risk-based oversight
- Plant operation oversight
  - can be deterministic, subject to risk-based oversight

Basic Design and Regulatory Process - Employed Traditionally, Remains Valid Today

- Designer develops a plant design that both produces power reliably and operates safely
  - responsible for plant safety, using high level regulatory criteria and policies as inputs
- Regulator reviews the design
- Designer and regulator engage in a dialog
  - specific safety features, their performance criteria, and methods of design and analysis
- Documentation is developed throughout the process
  - designer documents the design basis
  - regulator documents the safety evaluation, policies established, and criteria for future reviews (e.g., Reg. Guides and Standard Review Plans, and possibly regulations)

Risk-Informed Design and Regulatory Process - PRA Decision Making



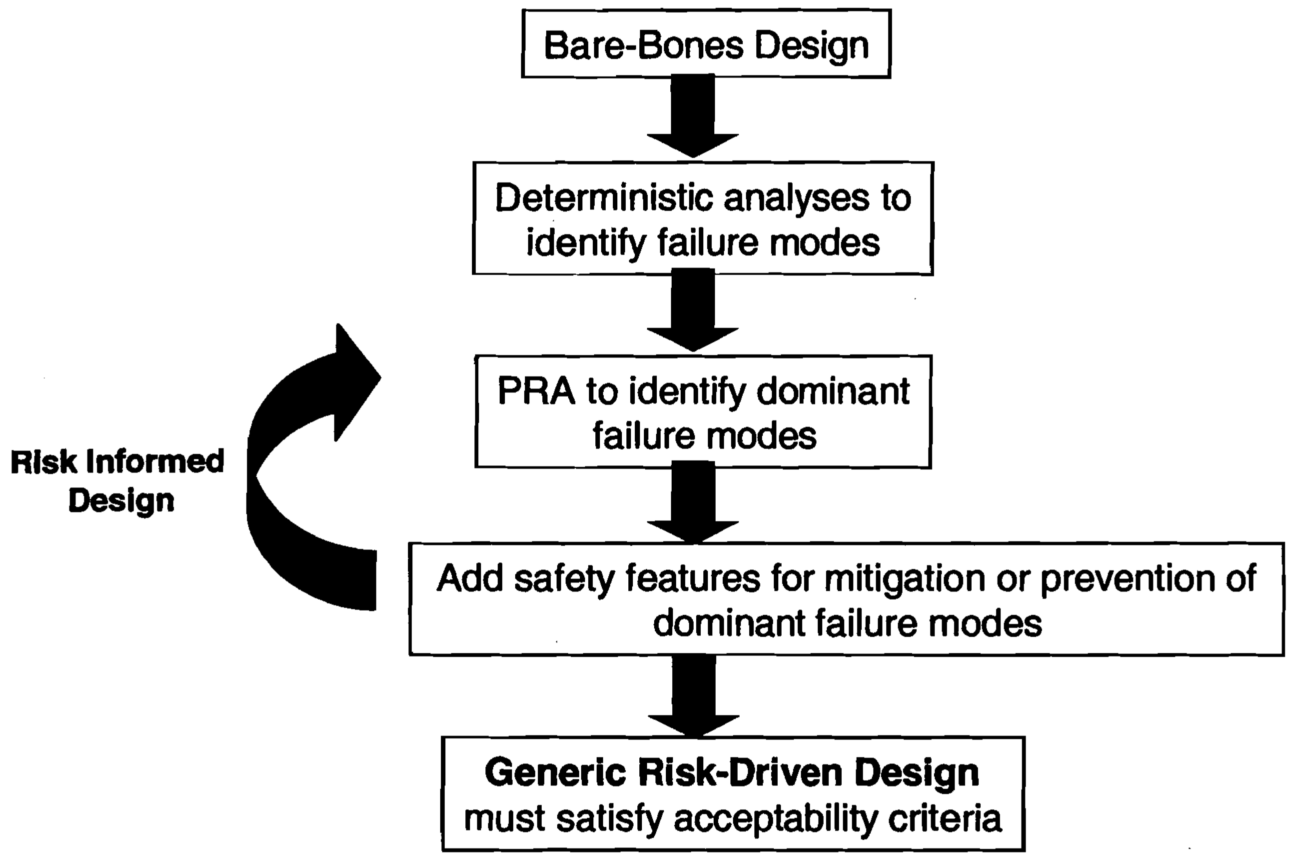
PSA Modeling performed to determine the likelihood of specific outcomes:

- PSA provides the basis for design and regulatory compliance assessment

-PSA models include consideration of both aleatory and systemic uncertainties

- PSA is not totally risk based
- margins are added to address uncertainties

Schematic Diagram of the Risk-Driven Generic Design - Builds Upon A Bare-Bones Design, Using an Iterative Process



Classification of Event Sequences Within the Risk-Informed DBA Approach

Classes

Response Required

Initial Sequences

Very Small Leak
Safety Relief Valve Stuck Open
Small Pipe Break LOCA
Pilot Operated Relief Valve Stuck Open
RC Pump Seal Failure
Medium Pipe Break LOCA
Large Pipe Break LOCA

Shared Functional Challenges

Insufficient RCS Inventory Control
Insufficient RCS Pressure Control
Insufficient RCS/Core Heat Removal

Classes	Response Required
Very Small Leak SRV Stuck Open	Normal Coolant Make-Up
Small Pipe Break LOCA PORV Stuck Open RC Pump Seal Failure	Emergency High Pressure Coolant Injection
Medium Pipe Break LOCA Large Pipe Break LOCA	Depressurization and Emergency Low Pressure Coolant Injection

Apportionment of a Performance Goal Into Subgoals

- Designer proposes apportionment - then negotiates with regulator
- Apportionment must reflect what is feasible in the design
- Example shows that the reliability/availability of mitigation systems reflects feasibility of the design

Initiating Event	Initiating Event Frequency	Mitigation Unavailability	Core Damage Frequency
Very Small LOCA	4E-3 /yr	1E-4	4E-7/yr
Small LOCA	2E-4 /yr	1E-3	2E-7/yr
Large LOCA	4E-5 /yr	1E-2	4E-7/yr
Example Acceptability Criterion: Achieved Total CDF due to LOCAs must be less than or equal to **2E-6 /yr**			Achieved Total CDF due to LOCAs: **1E-6 /yr**

Example of Designer's Initial Risk-Informed Submittal to the Regulator

- Two safety system divisions - each contains:
  - two active high-pressure injection trains
  - one active low-pressure injection train
  - cooling water (component cooling, service water, HVAC)
  - two diesel generators
  - DC (battery) power
- Shared support systems
  - chemical volume control system
  - off-site power
- PRA Includes:
  - deterministic analyses, data, models,
  - uncertainties, inter-dependencies, and common-cause failures
  - initiator data are from documented sources (NUREG/CR-5750)
  - component failure frequencies are estimated from existing PRA studies (for this LWR example problem)

Example of Negotiation Between Applicant and Regulator

Regulator disputes assumptions - requires new data

Result: Risk of failure to have adequate coolant levels too great

Cause: CDF due to high pressure LOCA is dominant contributor

Fix: Designer adds depressurization capability and revises PRA

Result: CDF due to LOCA still too high due to the high-pressure LOCA

Fix: Designer adds independent, redundant train of depressurization capability

Result: CDF remains too high due to support system common-cause failures (cooling water pump and diesel)

Example of Negotiation Between Applicant and Regulator....

Design is re-submitted to the regulator

Evaluation-1: Regulator reviews design and PRA with common-cause failure reduction. It is determined that further significant improvements in ensuring adequate core coolant levels cannot be accomplished at a reasonable cost or with an adequate degree of certainty - through use of a cost-benefit criterion.

Evaluation-2: The regulator compares the achieved level of function availability, including uncertainty, to a pre-determined standard to determine if the design is acceptable.

Result: Unavailability [illegible] has decreased by a factor greater than [illegible] acceptable).

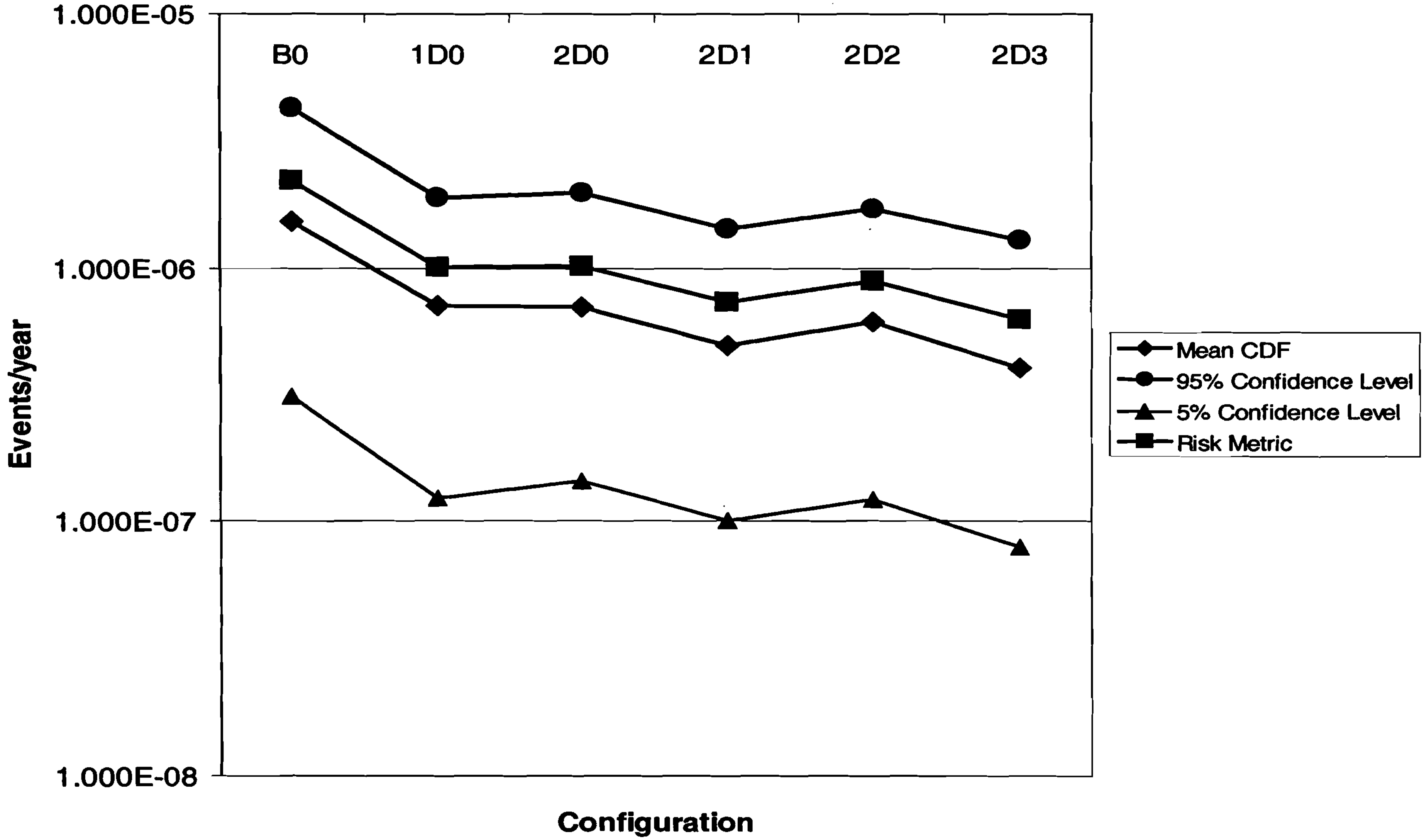
Following the Effects of Design Modifications Upon Important Risk Metric Values

Plant Configuration	Median-CDF	5% Conf.	95% Conf.	Risk Metric*
No Depressurization	*1.528E-06*	*3.093E-07*	*4.278E-06*	*2.216E-06*
One Division of Depressurization	*7.086E-07*	*1.226E-07*	*1.890E-06*	*1.004E-06*
Two Divisions of Depressurization	*7.055E-07*	*1.445E-07*	*1.980E-06*	*1.024E-06*
Depressurization and reduced CW CC Failure**	*4.970E-07*	*1.008E-07*	*1.432E-06*	*7.308E-07*
Depressurization and reduced Diesel CC Failure	*6.120E-07*	*1.211E-07*	*1.718E-06*	*8.885E-07*
Depress with reduced CW and Diesel CC Failure	*4.020E-07*	*7.960E-08*	*1.290E-06*	***6.24E-07***

* Risk metric selected = (0.75 * Median CDF) + (0.25 * 95% confidence CDF)

** CW = Cooling Water; CC = Common Cause

Effects of Design Modifications on CDF



Example Problem - Results & Questions

- Concerns about common cause failures and large uncertainties would lead designers and regulators to conservative design approaches
  - defense-in-depth, safety margins
- Guidelines are needed for consistently reflecting model weaknesses in the probabilistic database
- Consistent acceptance criteria are needed for negotiation guidance and termination
- Practical implementation requires more work
  - more trial examples
  - standardized models, methods, databases
  - methods for treatment of subjective judgements
  - replacements for:
    - GDCs
    - DBAs (risk-dominant event sequences)
    - Standard Review Plan

Summary

- The favored approach for a new design and regulatory process would:
  - use risk-based methods to the extent possible
  - use defense-in-depth when necessary to address model and data uncertainty.
- A new risk-informed design and regulatory process would:
  - provide a rational method for both design activities and applicant-regulator negotiations
  - provide a method for an integrated assessment of uncertainties in design and regulation
  - provide a process that is applicable to non-LWR technologies
- Development of a new design and regulatory process should be continued to support new reactor license applications.

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Advanced High-Temperature Reactor for Hydrogen and Electricity Production
(Joint ORNL–Sandia Activity)

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ACRS Workshop: Regulatory Challenges For Future Nuclear Power Plants
Advisory Committee on Reactor Safety
U.S. Nuclear Regulatory Commission
Washington D. C.
June 5, 2001

Outline

- Is a nuclear-based hydrogen economy in our future?
- The Advanced High-Temperature Reactor (AHTR)
  - An option for hydrogen production
  - An option for electric production
- Regulatory implications

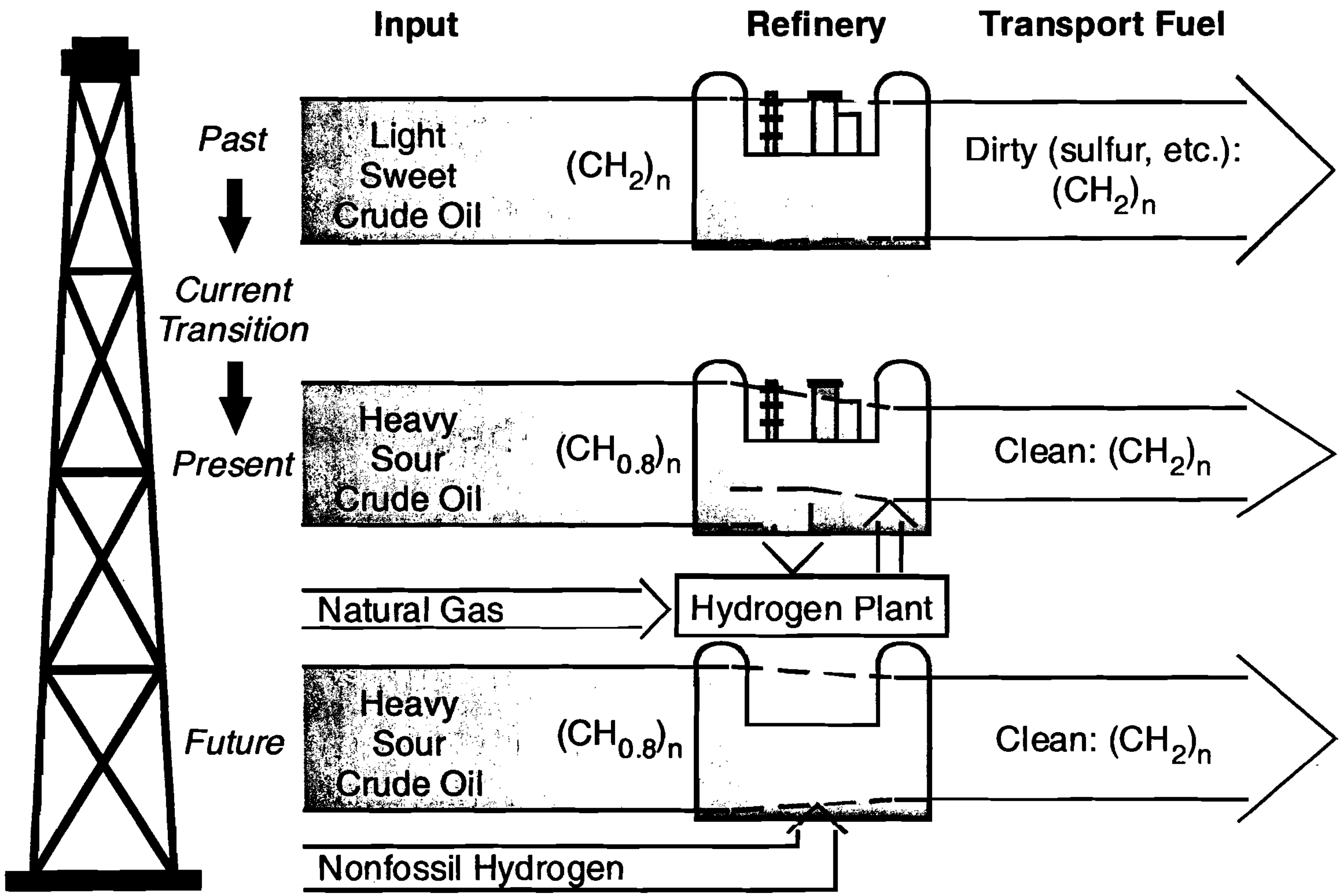
Is a Hydrogen Economy in our Future?

(It may already be here)

Rapid Growth Is Expected in Industrial Hydrogen (H_2) Demand

- Rapidly growing H_2 demand
  - Production uses 5% of U.S. natural gas plus refinery by-products
  - If projected rapid growth in H_2 consumption continues, the energy value of fuel used to produce H_2 will exceed the energy output of all nuclear power plants after 2010
- The chemical industry (NH_3 & CH_3OH) is a large consumer
- Changing refinery conditions are driving up the H_2 demand
  - More heavy crude oils (limited supplies of high-quality crude)
  - Demand for clean fuels (low sulfur, low nitrogen, non-toxic fuels)
  - Changing product demand (less heating oil and more gasoline)
- If nonfossil sources of hydrogen are used, lower-value refinery streams can be used to make gasoline rather than hydrogen—reduced oil imports

Increased Use of More Abundant Heavy Crude Oils Reduces Refinery Yields, Unless Nonfossil Hydrogen Is Used



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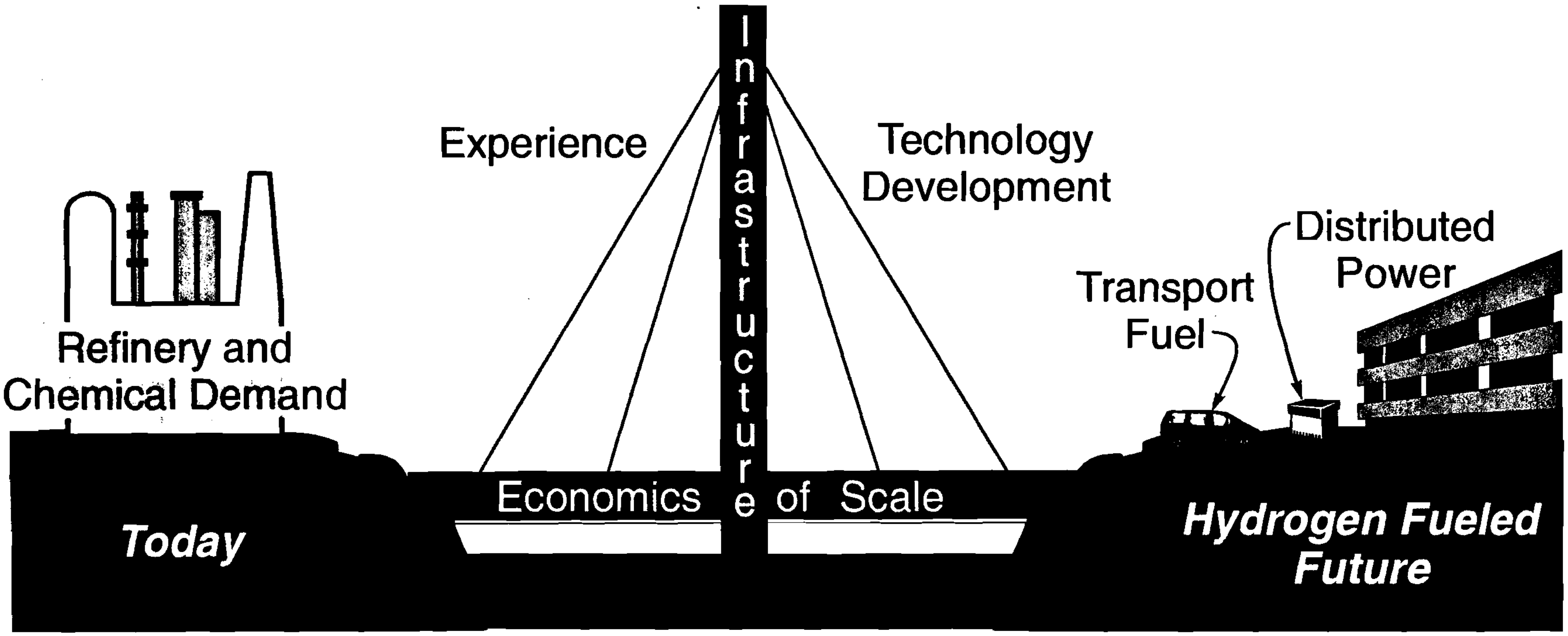
Multiple Benefits with Economic Nonfossil Sources of Hydrogen

- Increased transport fuel yields per barrel
  - Lower-value oil components converted to transport fuel rather than to hydrogen (current practice)
  - Reduced imports of crude oil and natural gas
- Greater use of heavy crude oils
  - More abundant with lower costs
  - Western Hemisphere suppliers (Venezuela, Canada, and the United States)
- Competitive chemical and refinery industry
  - Natural gas price increases are increasing H_2 costs
  - Risk of parts of the industry moving offshore
- Lower carbon dioxide emissions

The Growing Industrial Demand for Hydrogen Creates a Bridge to the Hydrogen Economy

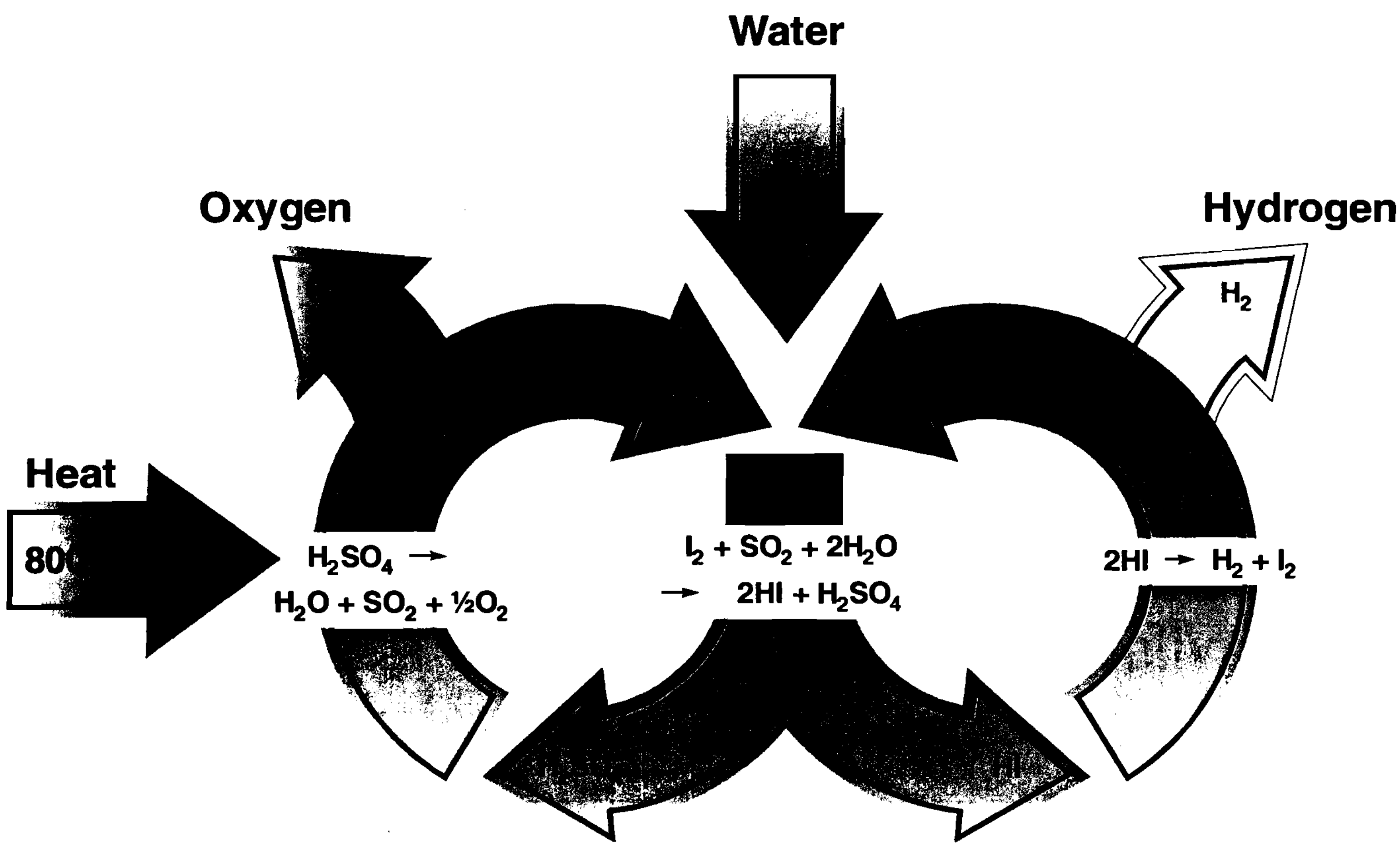


Hydrogen Can Be Produced with Heat from a Nuclear Reactor

- Heat + water $\Rrightarrow$ hydrogen (H_2) + oxygen (O_2)
- Nuclear energy would compete with natural gas for H_2 production
  - Rising natural gas prices
  - Constant (level load) H_2 demand matches nuclear output
- Characteristics of hydrogen from water
  - Projected efficiencies of >50%
  - High-temperature heat is required: 800 to 1000ºC
  - Existing commercial reactors can not produce heat at these high temperatures
  - An alternative reactor concept is required

Chemical Processes Convert High-Temperature Heat and Water to Hydrogen and Oxygen

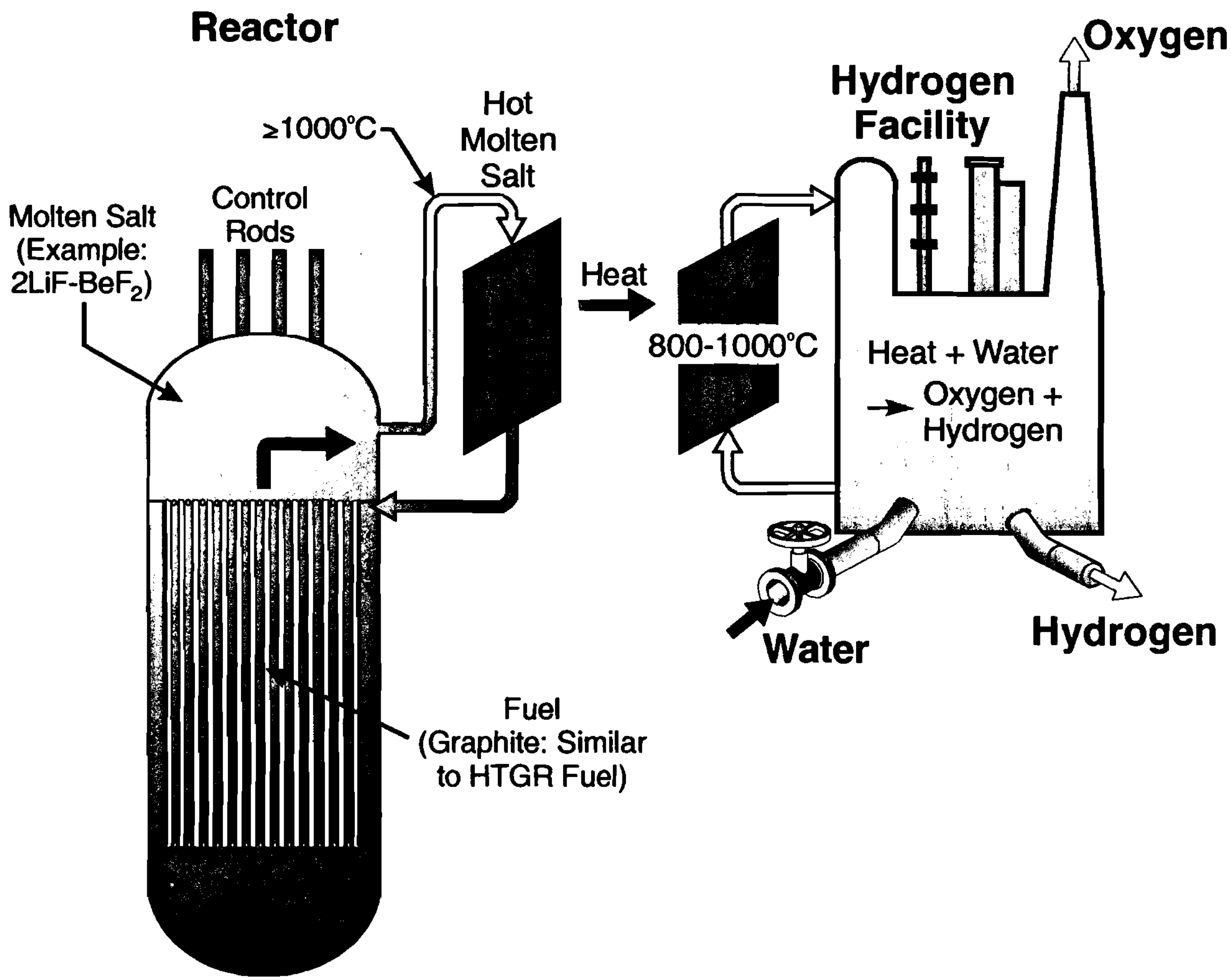
(Example: Iodine–Sulfur Process)



An Advanced High-Temperature Reactor (AHTR)—A Reactor Concept for Hydrogen Production

(Different products may require different reactors)

Advanced High Temperature Reactor Coupled to a Hydrogen Production Facility



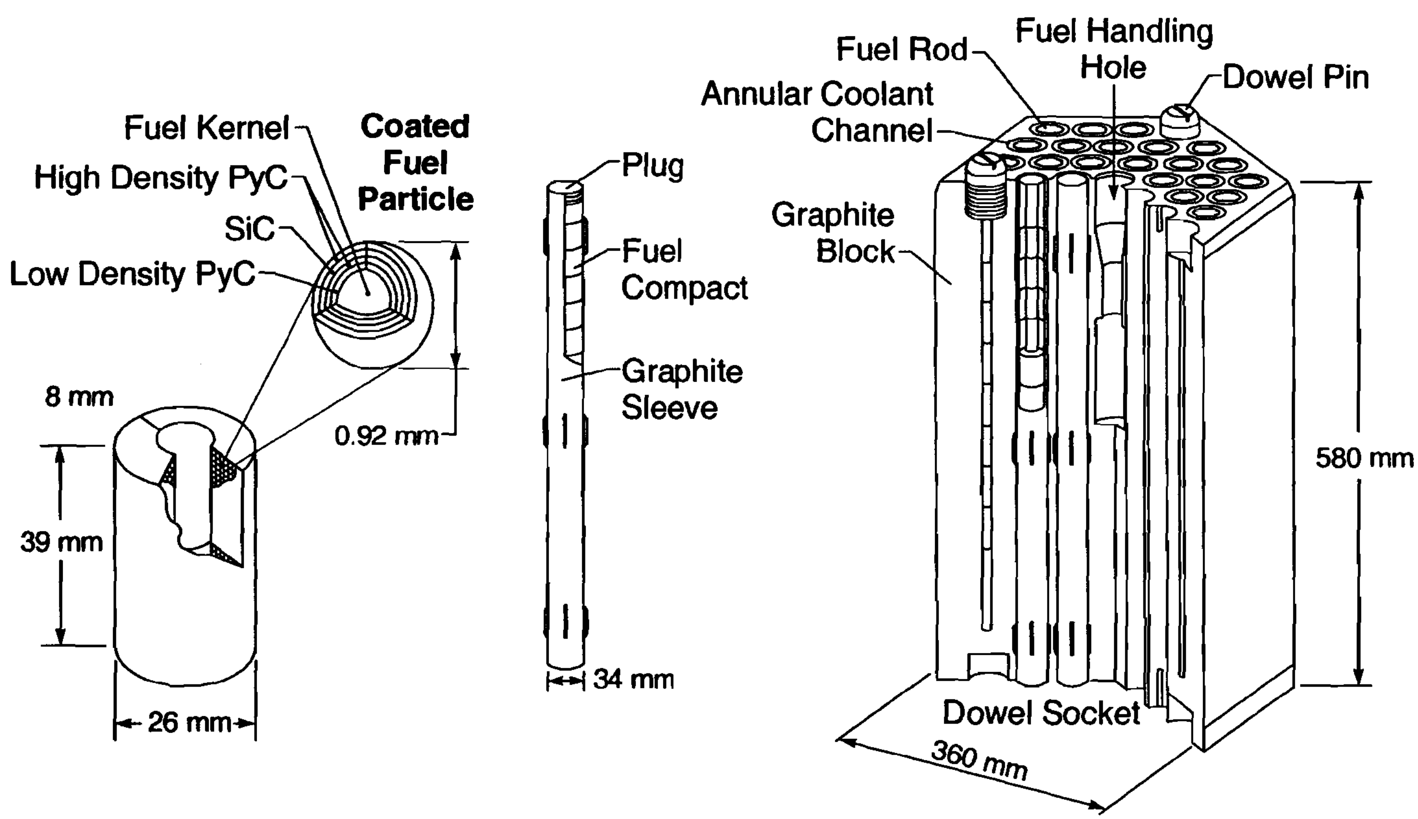
Desired Reactor Characteristics to Produce High-Temperature Heat

- Low-pressure system (atmospheric)
  - Metals become weaker at higher temperatures
  - Low pressures minimize strength requirements
  - Match chemical plant pressures (atmospheric)
- Efficient heat transfer
  - Need to minimize temperature drops between the nuclear fuel and application to deliver the highest-temperature heat
  - Liquid coolant

The AHTR Combines Two Different Technologies To Create an Advanced High-Temperature Reactor Option

- Graphite-matrix fuel
  - Demonstrated operation at an operating limit of ~1200ºC
  - Same fuel technology planned for modular high-temperature gas-cooled reactors
  - Fuel geometry/dimensions would be different for molten salt
- Molten salt coolant (2LiF-BeF_2)
  - Very low pressure (boils at ~1400ºC)
  - Efficient heat transfer (similar to that of water, except it works at high temperatures)
  - Proposed for fusion energy machines

Japanese High-Temperature Engineering Test Reactor Fuel for 950ºC Helium Exit Temperatures



Fuel Compact **Fuel Rod** **Fuel Block**

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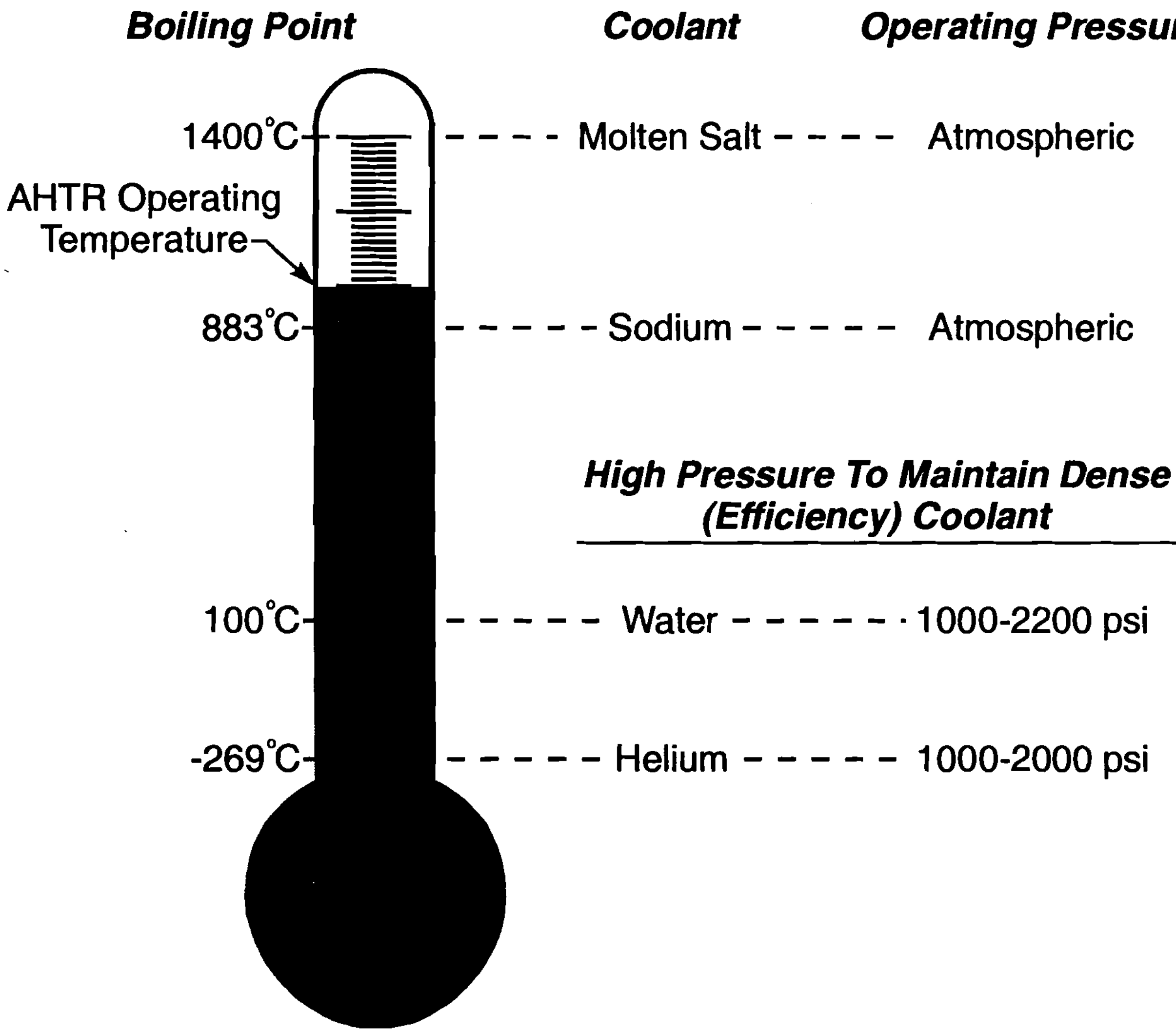
Molten Salt Coolants Allow Low-Pressure Operations at High Temperatures Compared With Traditional Reactor Coolants



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The Safety Case for the AHTR

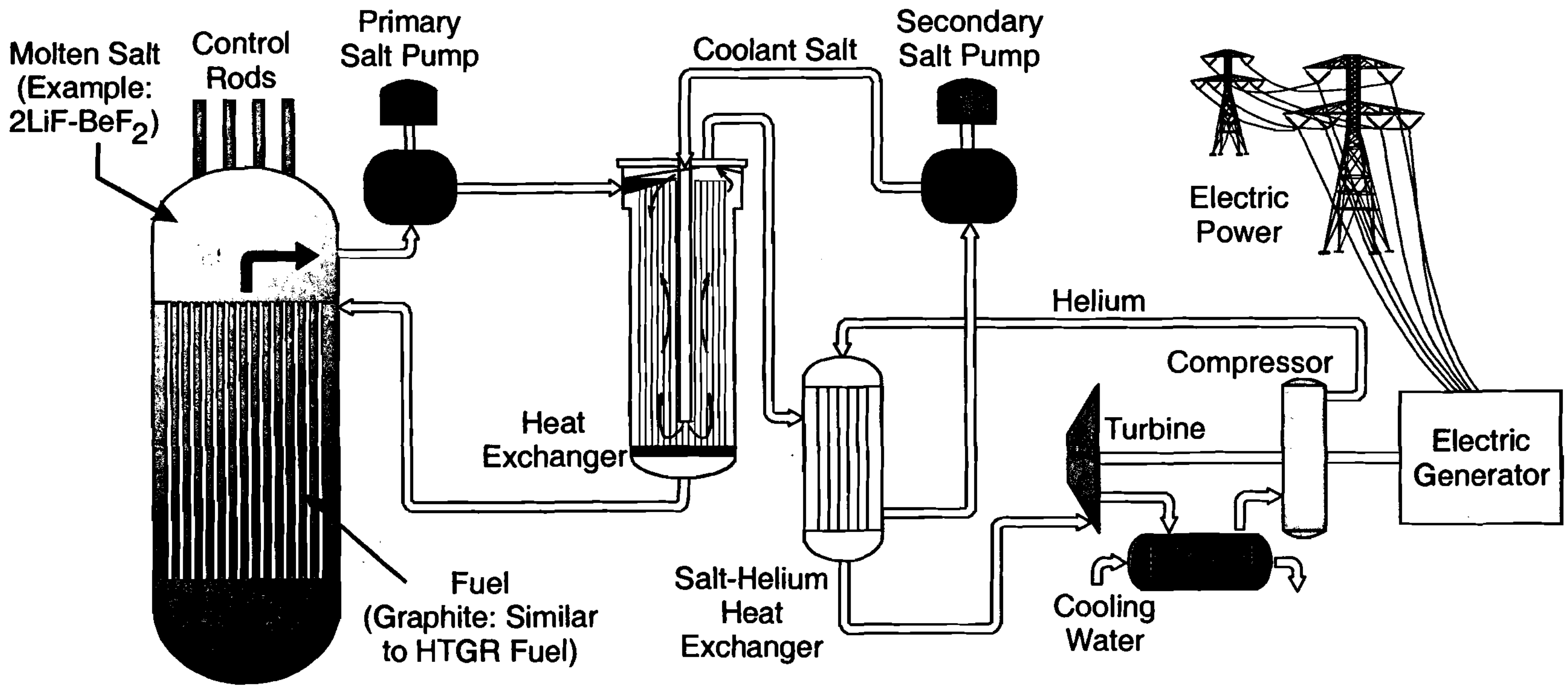
- Low-pressure (subatmospheric) coolant
  - Escaping pressurized fluids provide a mechanism for radioactivity to escape from a reactor during an accident
  - Low-pressure (<1 atm) salt coolant minimizes accident potential for radioactivity transport to the environment
  - Minimize chemical plant pressurization issues
- Good coolant characteristics provide added safety margins for many upset conditions
- Passive decay-heat-removal system similar to that proposed for other advanced reactors
  - Heat conducts outward from fuel to pressure vessel to passive vessel-cooling system
  - Power limited to ~600 MW(t)

High Temperatures Also Create New Options For Production of Electricity

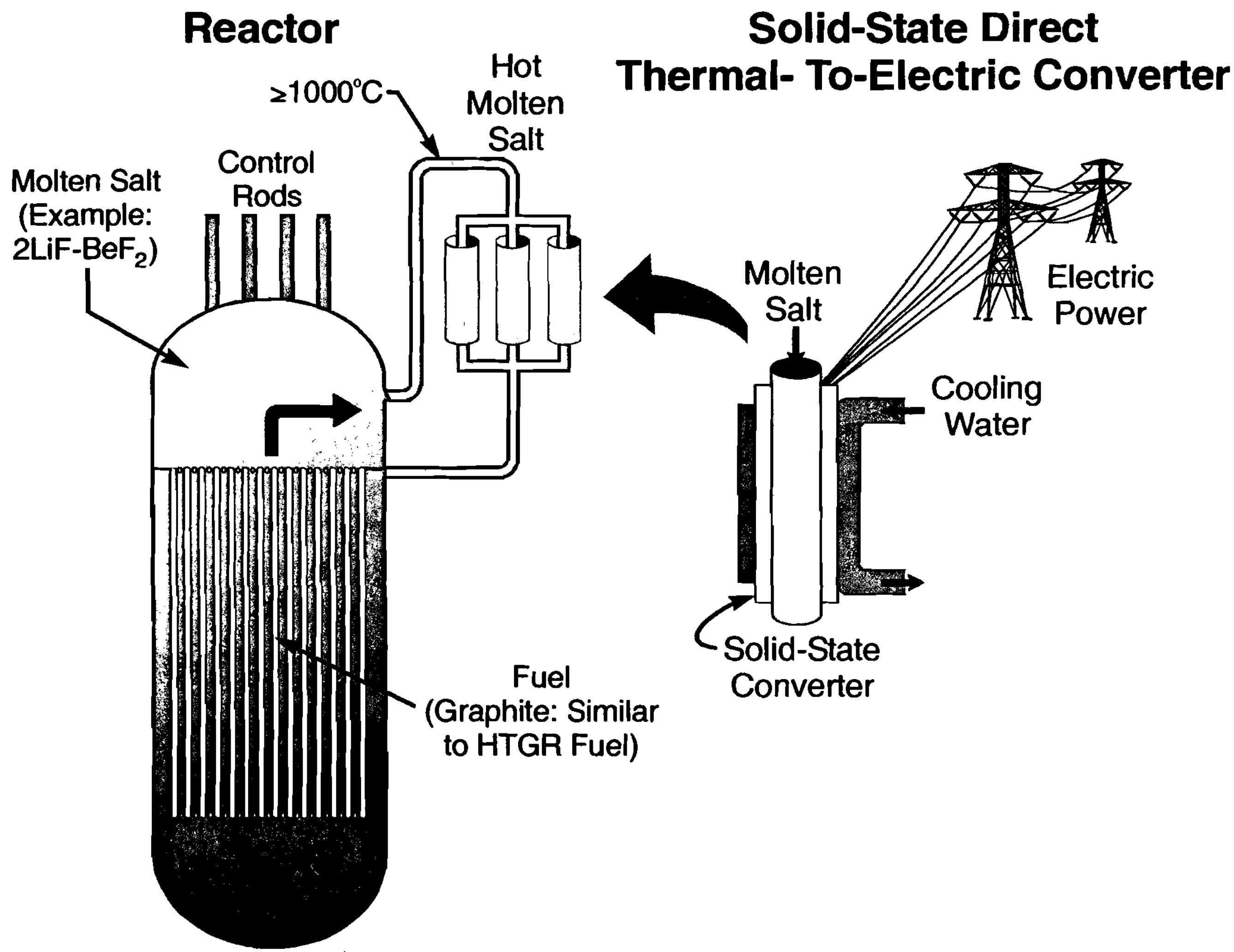
- **High-efficiency helium gas-turbine cycles**
  - Conversion efficiency >50% at 1000ºC
  - Provide isolation of power cycle from the reactor using low-temperature-drop heat exchangers
  - Use advanced gas-turbine technology
- **Direct thermal to electric production**
  - No moving parts (solid-state) methods to produce electricity from high-temperature heat
  - Radically simplified power plant
  - Potential for major cost reductions
  - Longer-term option—solid-state technology is in an earlier stage of development

Advanced High Temperature Reactor With Brayton Cycle For Electricity Production

Reactor **Heat Transfer Loop** **Electric Generation**



The AHTR May Enable the Longer-Term Option of Direct Conversion of Thermal Energy to Electricity



High Temperatures Create Development Challenges

- AHTR uses some demonstrated technologies
  - Fuels (modified HTGR fuel)
  - Coolant
- AHTR requires advanced technology
  - High-temperature materials of construction
  - Optimized system design
  - Heat exchangers
  - Hydrogen and energy conversion systems

Regulatory Implications of Hydrogen Production

- Different owners: oil & chemical companies
  - Larger than traditional utilities
  - Different perspectives
- Both chemical and nuclear safety must be considered (it is not clear where the primary hazard is)
  - Chemical plant must not impact nuclear plant
  - Nuclear plant must not impact chemical plant
- Non traditional (non-water, non-liquid-metal, non-gas) reactors may be preferred

Conclusions

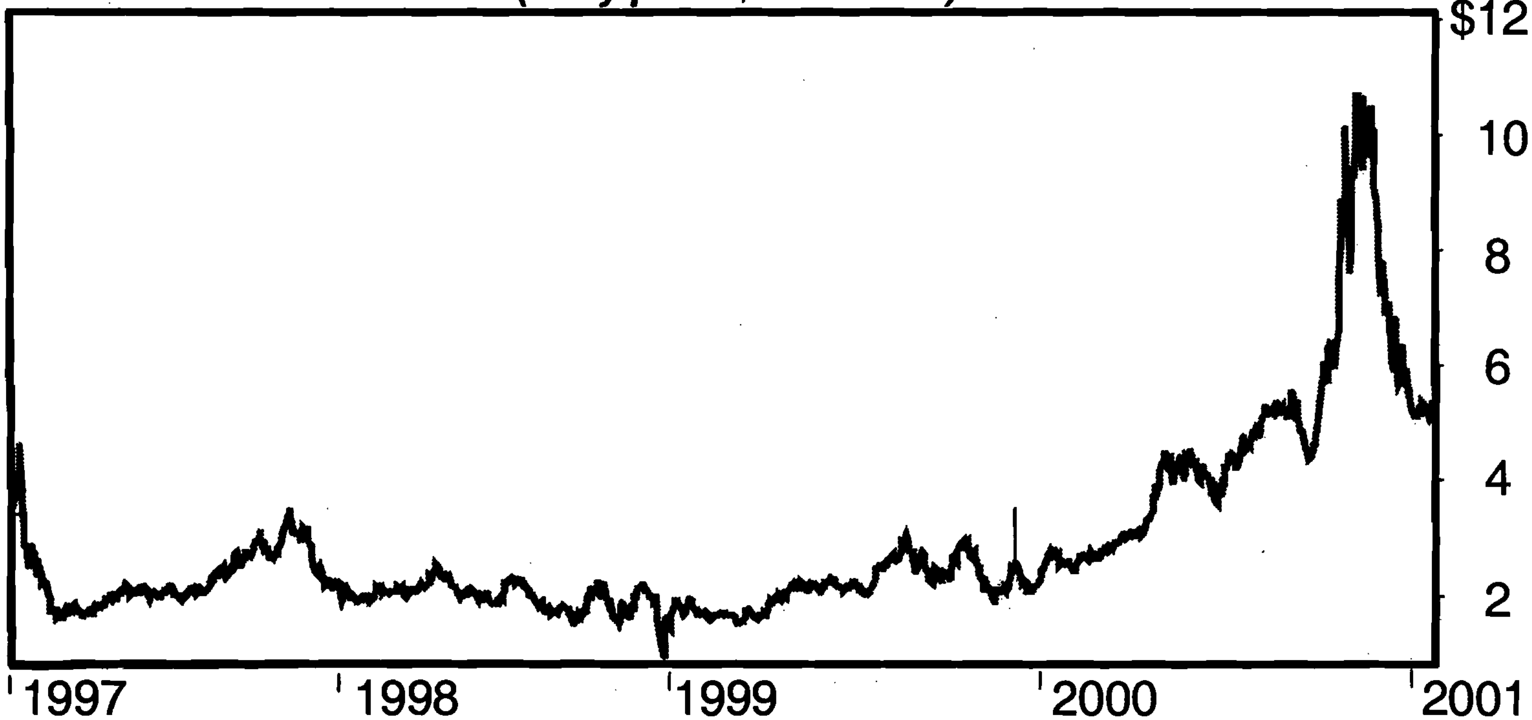
- **Economic methods to produce hydrogen from nuclear power may provide multiple benefits**
  - Increased gasoline and diesel fuel yields per barrel of crude oil with reduced dependence on foreign oil
  - Long-term pathway to a hydrogen economy
- **High-temperature heat allows for new, more-efficient methods to produce electricity**
- **Reactors with different characteristics may be preferred for such different uses**
  - Very high temperatures
  - Low pressures

Added Information

Hydrogen is Made From Natural Gas—If Gas Prices Remain High, a Significant Fraction of the Chemical and Refinery Industry May Move Offshore

U.S. Natural Gas Prices are Rising

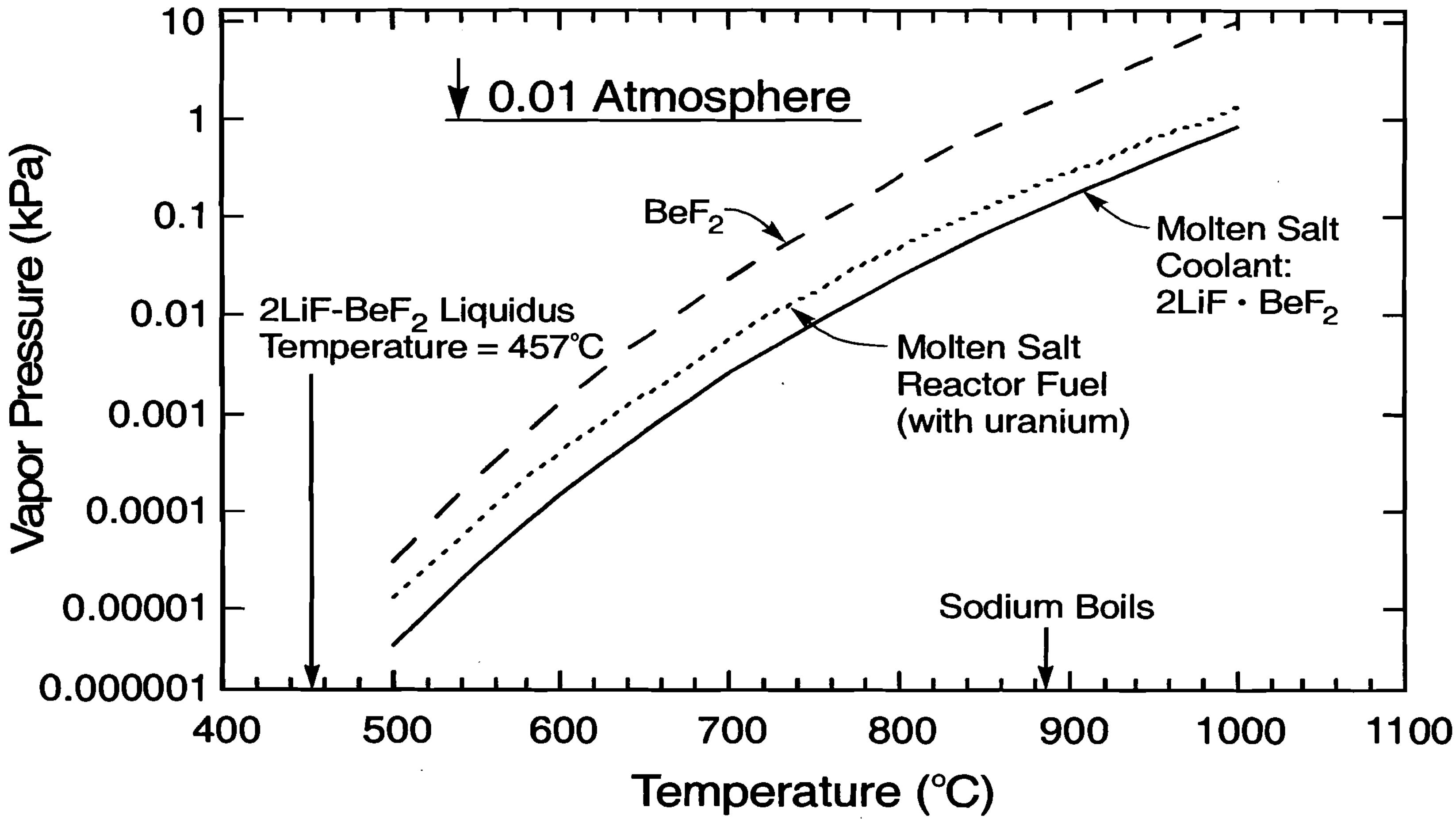
(daily price $/1000 cu ft)



There Has Been Extensive Development of Molten Salt Technologies For High-Temperature Nuclear Applications

- Initial development was for the Aircraft Nuclear Propulsion Program
  - Heat transferred from the solid-fueled reactor to the heat exchanger in the aircraft jet engine
  - Molten salts were chosen based on physical (pressure <1 atm.) and nuclear properties
- Molten salts are being considered for cooling fusion reactors (both types)
- Russian studies on molten-salt-cooled reactors

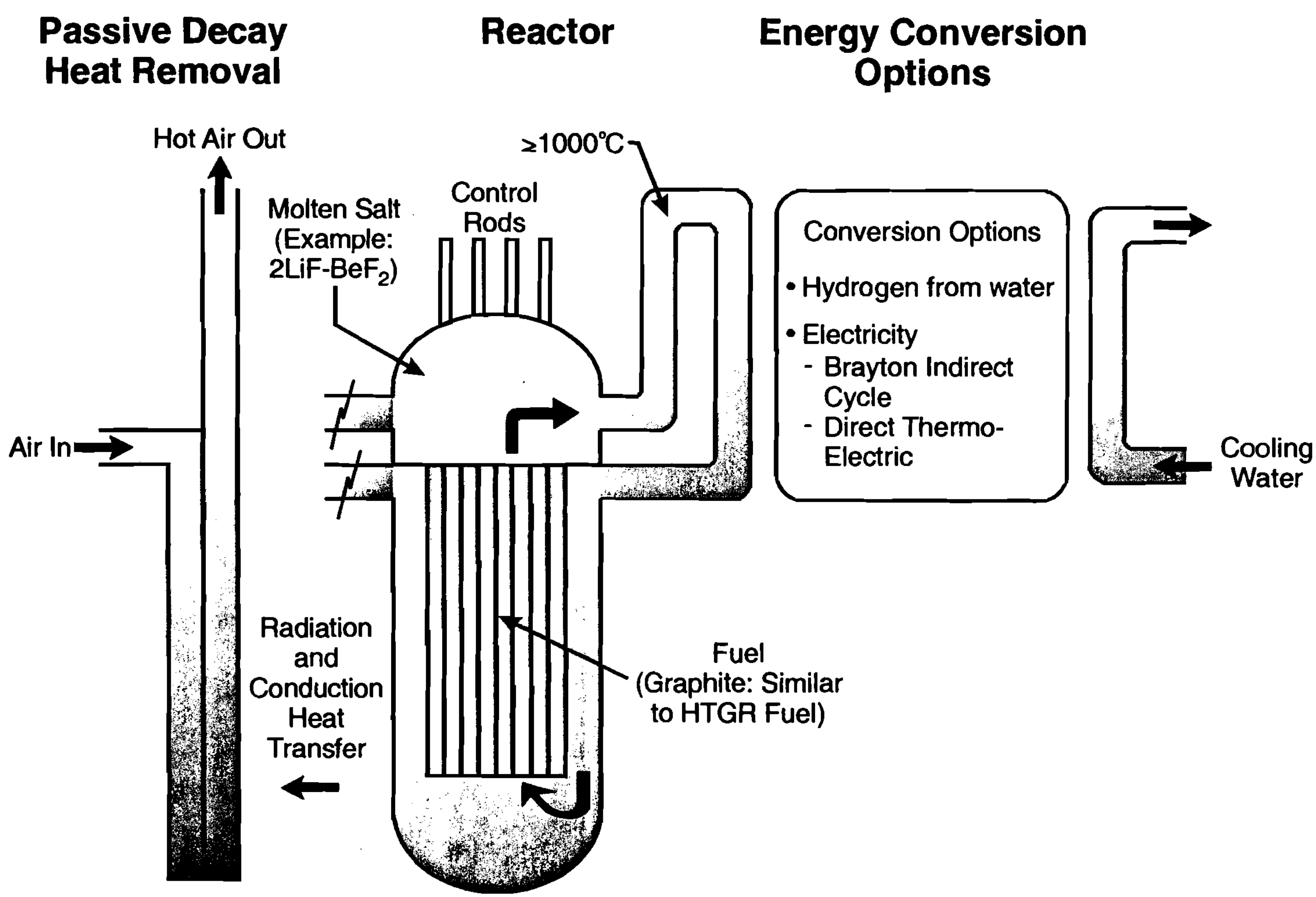
Vapor Pressure of $2LiF\text{-}BeF_2$ Is Low Compared To Other Reactor Coolants



Characteristics of Molten Salts

- For the proposed $2LiF\text{-}BeF_2$ salt, the temperature rise from the AHTR operating point to the boiling point is ~400ºC
- Several other fluoride salts could be used
- Natural circulation cooling is an option
- Fluoride salts dissolve most fission products and actinides (basis for molten salt fueled reactor)
- Freeze point is ~457ºC
- Large industrial experience with other fluoride salts (aluminum production)

Advanced High-Temperature Reactor



NEI
HEYMER

New Plant Regulatory Framework

NRC ACRS Workshop on Advanced Reactors

New Regulatory Framework

Adrian Heymer, NEI
(aph@nei.org, 202-739-8094)

NEI

Benefits of Establishing New Framework

- **Helps establish a new paradigm of thinking**
  - Not burdened by current requirements or interpretations
  - Provides a standard against which to set requirements
- **Provide a platform for agreement on principles and objectives**
  - Ensures issues are focused on safety and are tied to defined safety objectives

NEI

Benefits of Establishing New Framework

- **Provides basis for NRC & industry positions**
- **Improves regulatory consistency**
  - Aligns regulations and oversight process
- **Use Reactor Oversight Framework as basis for starting industry & regulatory interactions**
  - Avoids "re-invention" of framework already accepted by NRC
  - Cultural change burden eased

NEI

New Plant Regulatory Framework

- **Generic to all types of reactor**
- **Top-down approach based on NRC mission**
  - Adequate protection of public health & safety
- **Based on NRC oversight cornerstones**
- **New General Design Criteria**
- **Introduce General Operating Criteria**
- **Develop a new set of generic, risk-informed, performance-based regulations**
- **Develop design-specific and regulation specific regulatory guides**

NEI

Establishing a New Regulatory Framework for New Plants

- **Concept -- Risk-Informed, Performance-Based Licensing and Regulatory Regime**
- **Proof-of-concept application(s)**
  - Use License Renewal and Option 2 models
  - Minimizes hypothetical discussions
  - Definitive schedule to drive resolution process
- **Industry effort consolidates lessons learned from proof-of-concept activities**
  - Vehicle for supporting proof-of-concept positions

NEI

NRC's Mission to Provide Adequate Protection of Public Health & Safety

↑

Safety Areas

↑

Cornerstones & Attributes

↑

General Design and Operating Criteria

↑

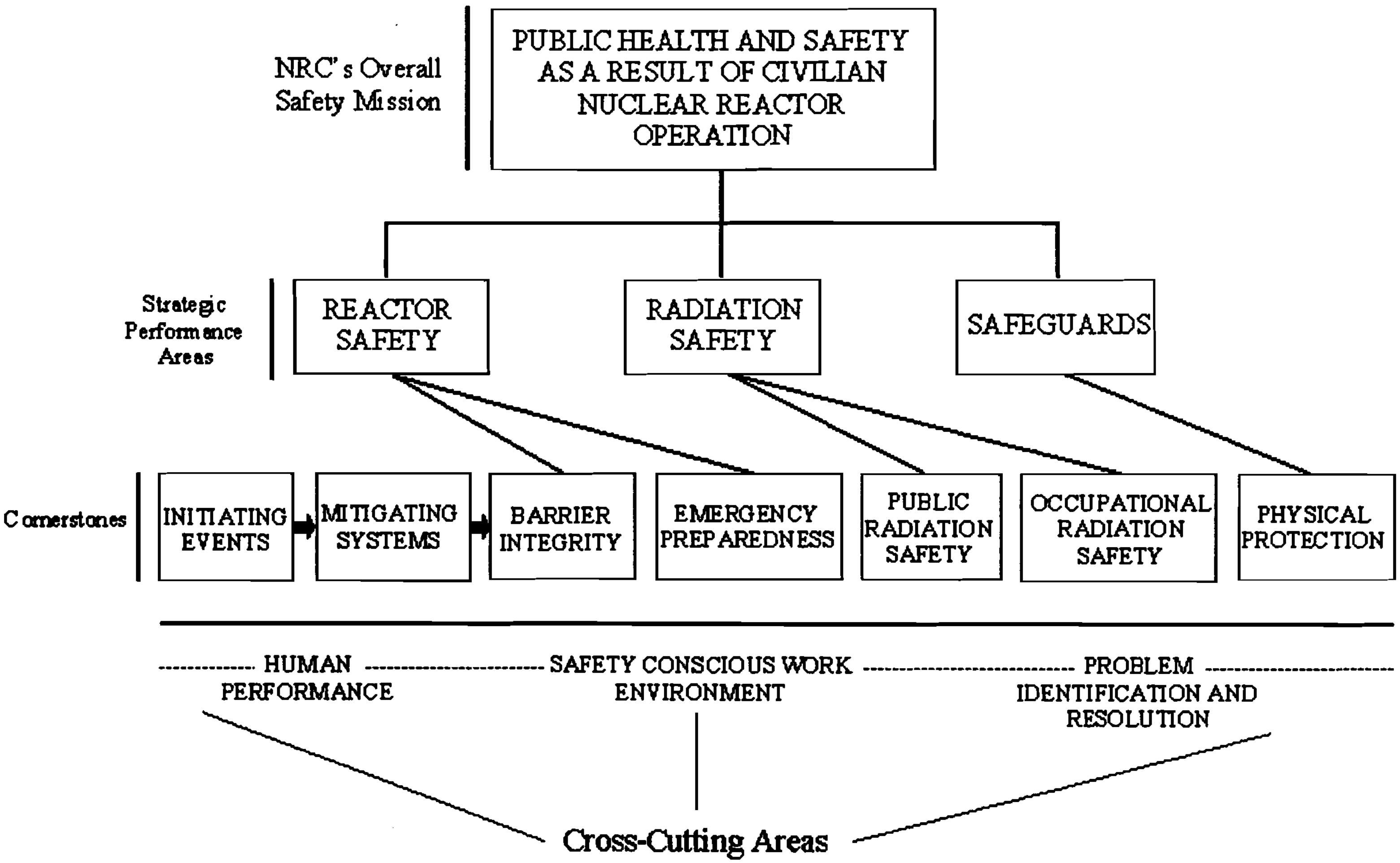
Risk-Informed, Performance-Based Regulations

↑

Design/Regulation Specific Regulatory Guides

DRAFT

REGULATORY OVERSIGHT FRAMEWORK



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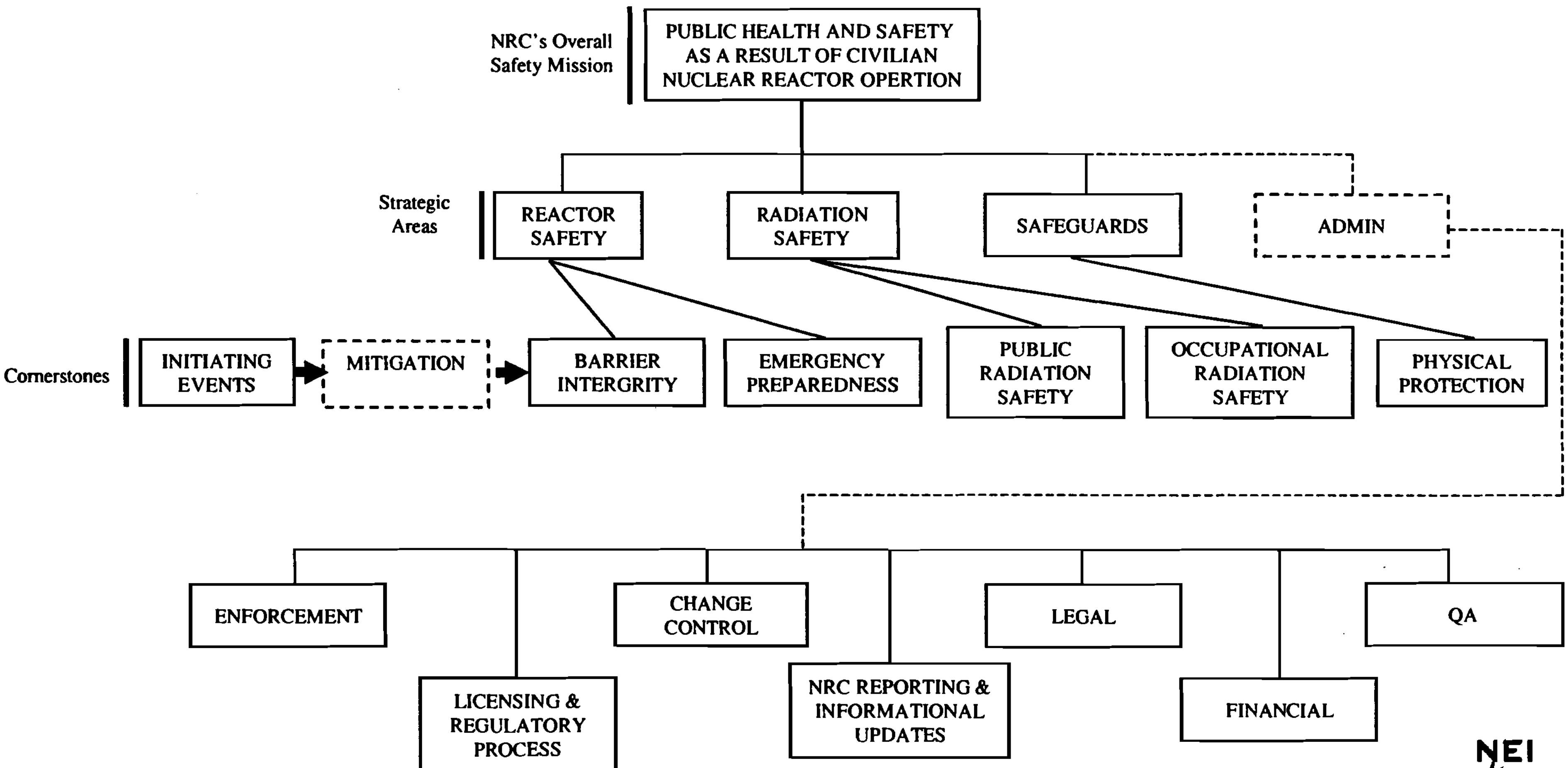
REGULATORY FRAMEWORK FOR NEW PLANTS



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Cornerstones
10 CFR Part 50

- **160 GDCs, Regulations & Appendices**
  - **Initiating Events -- 16**
  - **Mitigation (*Systems*) -- 46**
  - **Barriers -- 27**
  - **EP -- 3**
  - **Pub. Radiation Safety -- 9**
  - **Occupational Safety -- 4**
  - **Safeguards -- 4**
  - **Administrative -- 68**
  - **Financial -- 6**
  - *Operational* -- *23*

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Example of New Regulation

XX.63 Plant configuration management

Licensee shall assess and manage changes in risk that result from maintenance, modifications and operational activities that could degrade safety-significant functions.

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Example of New Design Criteria

Protection against natural phenomena

Safety-significant structures, systems, and components shall be designed to withstand, or be protected from the effects of natural phenomena, such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design and protective features shall reflect the most severe natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for uncertainty related to the limited accuracy, quantity, and period of time in which the data have been accumulated.

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ACRS WORKSHOP

Key Regulatory Challenges for Future Nuclear Power Plants

Neil E. Todreas
KEPCO Professor of Nuclear Engineering
Massachusetts Institute of Technology

PM June 5, 2001

CHALLENGES

FUEL AND CLAD MATERIALS - TAKEN TO HIGHER BURNUPS AND OPERATED AT HIGHER TEMPERATURES.

Drivers: **Longer Operating Cycles.**

Higher Temperature Primary Systems.

Particular Challenges:

1) Reductions in Waste Toxicity and Volume.

2) Understanding and Control of Coolant Corrosion, particularly role of coolant impurities.

★ **3) Qualification of Core Loads of Billions of Fuel Particles.**

★ **4) New Maintenance Practices.**

3) Questions Regarding Particle Fuel Qualification

- How many particles, if failed at the most limiting time in core life released, would be required to exceed the following conditions:
  - **Dose limits for plant workers?**
  - **The lowest condition on the IAEA scale of plant incidents?**
  - **Protective action guidelines for the general public?**

- If the fuel particle specification is product based:

  a. What are the individual particle attributes which are controlled by the specification, and for each, to what levels, and allowable variation to prevent particle failure?

  b. What is the allowable variation in related individual particle attributes which must be maintained to prevent particle failure?

- If the fuel particle specification is process based:

  a. What are the individual process variables which are controlled by the specification, and for each, to what levels, and allowable variation to prevent particle failure?

  b. What are the individual allowable variations in process variables which are sufficient to prevent particle failure?

  c. What is the allowable variation in related individual process variations which must be maintained to prevent particle failure?

Particle Fuel - Consequences of a Process Specification

- Critical Operator Actions now become located in the fuel fabrication facility. The fuel fabricator is the de facto control room operator.

- Innovation in particle fuel design & fabrication processing is likely more costly and hence inhibited.

4) Maintenance Practices

Driver: - Longer Operating Cycles

Frequencies - Extended

Plant Mode - More on-line.

Practice - Example: Relief Valve Testing

Why are these items Challenges?

- New Technologies - require development of
    - NRC staff expertise
    - NRC confirmatory research basis

- Design Solutions are aimed at precluding historic initiators
    - Establishment of a new risk-based regulatory framework will be needed.

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LYMAN

REGULATORY CHALLENGES FOR THE LICENSING OF FUTURE NUCLEAR PLANTS: A PUBLIC INTEREST PERSPECTIVE

Edwin S. Lyman
Scientific Director
Nuclear Control Institute

ACRS Advanced Reactor Workshop
June 5, 2001

REGULATORY CHALLENGES

- NRC licensing of advanced plants must ensure that these economic imperatives do not have adverse impacts on
  - Safety
  - Risk of radiological sabotage
  - Waste management and disposal
  - Non-proliferation
  - Full opportunity for public participation

EXAMPLE: PBMR

- PBMR characteristics **fundamental to its economic viability** represent significant deviation from traditional "defense-in-depth"
  - Lack of pressure containment
  - Significant reduction in safety-related SSCs
  - Reduction in EPZ radius by a factor of 40 (exploits regulatory exemption for HTGRs)
  - Greatly increased reliance on fuel integrity under accident conditions for protection of public health
- ACRS (1988): "unusually persuasive argument" required to justify "major safety tradeoff"

PBMR FUEL PERFORMANCE AND SAFETY GOALS

- Source terms must be accurately determined for a full range of potential accidents
  - Pebble performance very sensitive to initial conditions ---- relationship poorly understood
  - Robustness of PBMR fuel is being oversold --- significant fission product release (several % of Cs inventory) can occur at 1700-1800°C) --- hundreds of degrees below fuel degradation temperature
  - Quality control is paramount --- BNFL involvement in South African fuel fabrication plant suggests that a fuel quality control programmatic ITAAC is necessary

PBMR SAFETY GOALS

- Safety goals need to be reexamined for advanced reactors
  - Current goals not conservative enough --- could still be met by reactors today with containments removed!
  - "Large release fraction" if EPZs are reduced
- Accident frequencies that could result in LR must be accurately calculated
  - Design-basis LOCA --- safety margin may be too small
  - Air or water ingress
- System upgrades may be necessary to meet goals
  - secondary coolant system (MIT vs. Eskom)
  - advanced fuel coating materials (i.e. ZrC)

RADIOLOGICAL SABOTAGE --- THE "SHOW-STOPPER"?

- Providing adequate physical protection to defend plants against sabotage has proven to be a major challenge:
  - 50% of U.S. nuclear plants failed force-on-force (OSRE) testing of plant security in 2000
  - At Exelon's Quad Cities plant, "deficiencies in the licensee's protective strategy enabled the mock adversaries to challenge the … ability to maintain core cooling and containment" (NRC, October 18, 2000)

RADIOLOGICAL SABOTAGE (cont.)

- No nuclear system can be rendered "inherently safe" from radiological sabotage
  - Deliberate graphite fire in PBMR remains possible even if accidental fire is incredible
  - Reduction in security staffing requirements for PBMRs not technically justifiable
  - Systems with in-situ reprocessing plants (S-PRISM) would be especially attractive targets
- ACRS (1988) recommended that NRC develop guidance for incorporating sabotage resistance into advanced designs --- need early involvement of Reactor Safeguards staff

PBMR WASTE DISPOSAL

- Final waste disposal may be the single largest obstacle to nuclear power expansion
- Spent pebbles create a huge waste problem: per MWD, compared to spent LWR fuel:
  - Volume and weight are about 10 times greater– with proportionate increase in storage and transport requirements
  - Carbon-14 inventory is 10-20 times greater --- problem for unsaturated repository like Yucca Mountain

PUBLIC ACCEPTANCE

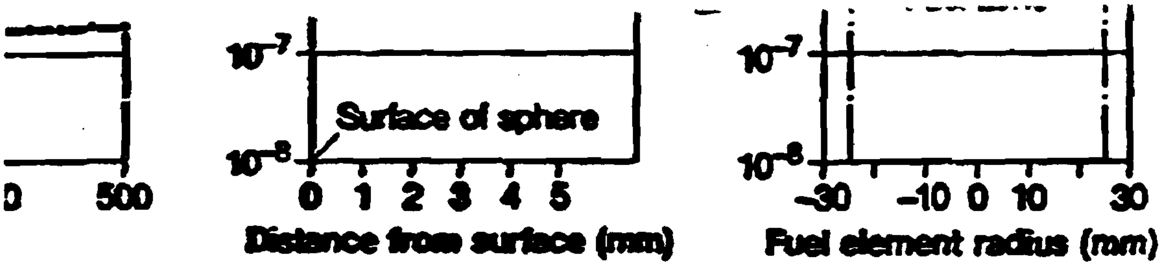
- New facility siting is a great challenge:
  - Favors new plants at existing sites in areas of broad public support
  - Trying to greatly increase number of nuclear plant sites is a losing strategy --- but there is little advantage in modularity if available sites remain highly limited
  - Favors minimization of transport of nuclear materials
- Public opposition may only be deterred with a clear commitment to maximize safety:
  - Favors "gold-plating" nuclear plants
  - Inconsistent with attempts to eliminate containment, reduce emergency planning, etc

PUBLIC ACCEPTANCE (cont.)

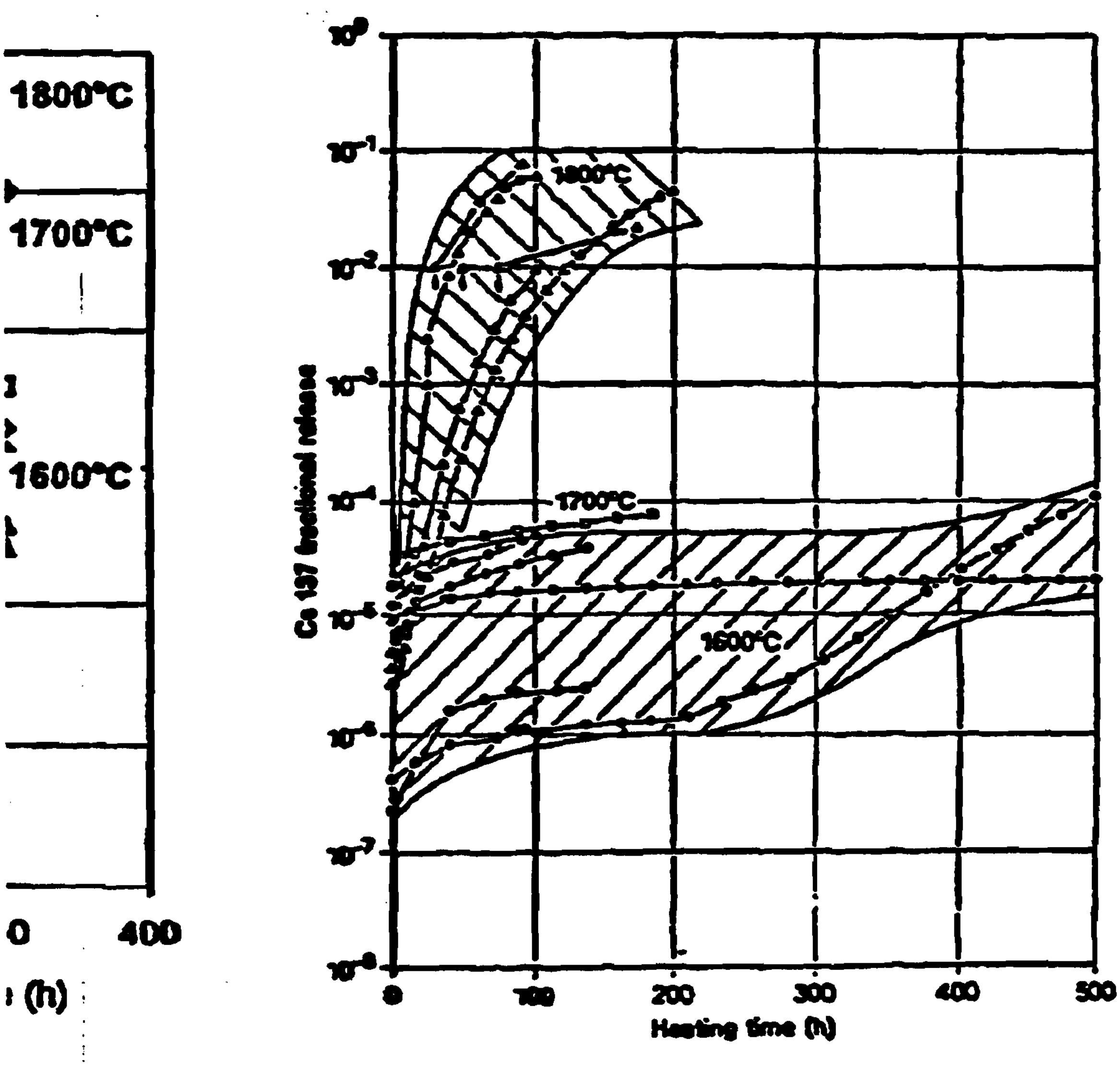
- Aggressive licensing schedule proposed by Exelon for PBMR (construction to begin in 2004, operation in 2007) will only antagonize antinuclear groups now mobilizing
- "License by test" is just a PR move --- unlikely to be adequate to resolve all safety issues to NRC satisfaction
- Better to proceed more cautiously and make sure that full resolution of all technical concerns is achieved

THE FUNDAMENTAL DILEMMA OF NUCLEAR POWER EXPANSION

- Without ratepayer or taxpayer subsidy, no new nuclear plants will be built unless they can successfully mimic the desirable economic features of gas turbines:
  - low capital cost
  - short construction time
  - modularity and ease of distribution
- Can this be done safely? Or is nuclear technology incompatible with these objectives?



release and distribution in sphere HFR-K3/1 after irradiation
or 359 days and 1600 °C heating



from fuel compacts (left) and fuel elements (right) with
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through the coating layers. The fractional release of ^{110m}Ag was higher than that of ^{137}Cs, which was consistent with the previous work.[10–13] Although the inventory is small, the release of ^{110m}Ag would be troublesome in mainte-

and ^{154}Eu were obtained in the individual coated fuel particles. To compare the irradiation performance of the individual particles, activity ratios, not activities, were used to account for variations in kernel size and to minimize

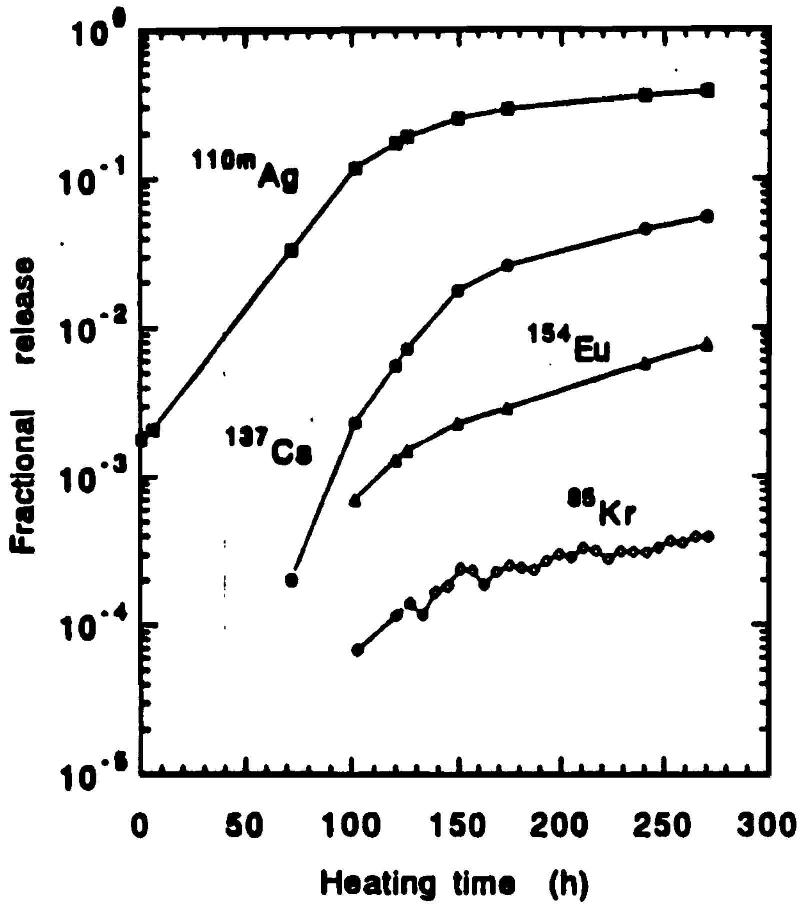

Fig. 2. Time-dependent fractional releases of fission products during the ACT3 heating test at 1700°C for 270 h, obtained by the on-line measurements of fission gas release and intermittent measurements of metallic fission product release.

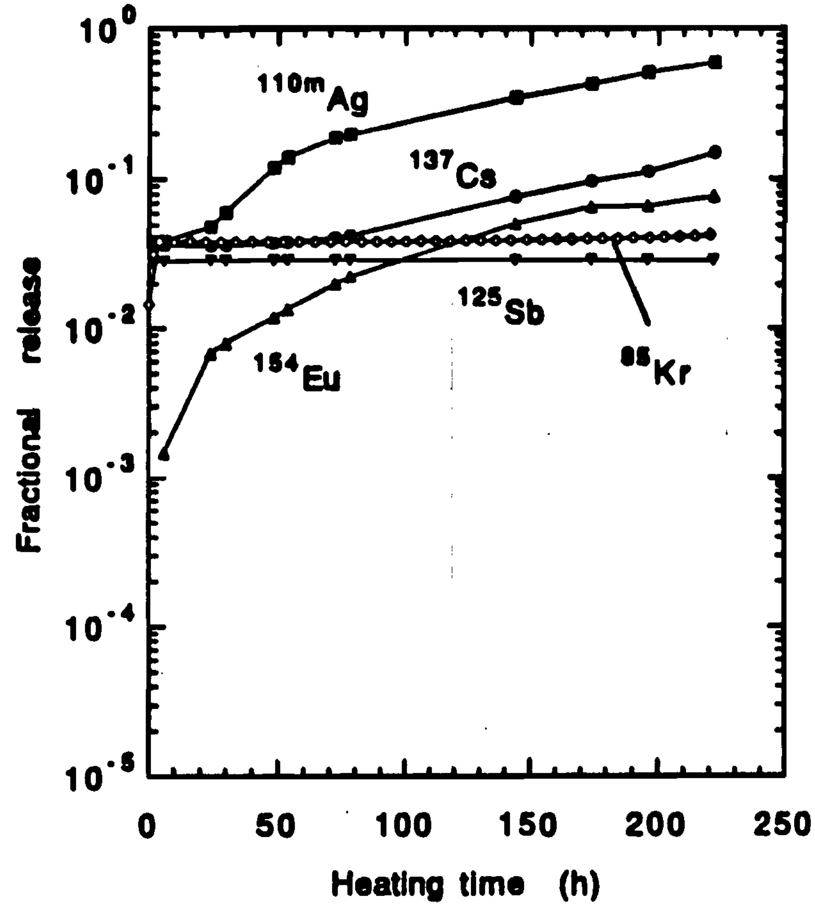

Fig. 3. Time-dependent fractional releases of fission products during the ACT4 heating test at 1800°C for 222 h, obtained by the on-line measurements of fission gas release and intermittent measurements of metallic fission product release.