August 1, 2001

MEMORANDUM TO: Ashok C. Thadani, Director
Office of Nuclear Regulatory Research

FROM: Thomas L. King, Directork **/RA/**
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Office of Nuclear Regulatory Research

SUBJECT: MEETING WITH THE EXELON GENERATION COMPANY, THE DEPARTMENT OF ENERGY, AND OTHER INTERESTED STAKEHOLDERS REGARDING THE PEBBLE BED MODULAR REACTOR

On July 17 and 18, 2001, the Nuclear Regulatory Commission (NRC) staff held a day-and-half meeting with the representatives of the Exelon Generation Company, the Department of Energy (DOE), and other interested stakeholders to discuss topics associated with the Pebble Bed Modular Reactor (PBMR) pre-application review. This meeting was the third in a series of planned monthly topical meetings that are being conducted between the NRC staff, Exelon and DOE during the course of the review.

Attachment 1 contains the meeting agenda. Attachment 2-a and 2-b contain a list of attendees for each day. The Exelon presentation material is included in Attachments 3-a through 3-e. The Working Draft A of a discussion paper titled, “Selection of Licensing Basis for the Pebble Bed Modular Reactor in the United States,” submitted by Exelon, is included as Attachment 4. Additionally, another submittal, “PBMR Response to NRC Questions From June 13, 2001 Meeting,” is included as Attachment 5. NRC presentation material is included as Attachment 6. On the second day, in a closed session, Exelon discussed proprietary information with D. Lee, N. Broom, K. Smit, J. Van derWesthuizn, K. Van Rensburg, I. Drodskie, A. George, J. Venter (all of PBMR Pty.) and J. Hufnagel participated via teleconference. The presentation material used in this session is not being released to the public

On July 17th, in his opening remarks, Stuart Rubin (NRC) stated that the main objective of the PBMR pre-application review process is to develop and feedback to Exelon NRC guidance concerning the resolution of significant issues related to the siting, construction, and licensing of a PBMR in the US. At this meeting, discussions on PBMR licensing approach as well as fuel performance and qualification continued from the June meeting, and a new discussion topic – codes and standards – was introduced.

Kevin Borton (Exelon) led the discussion on the planned scope of PBMR technical reviews and discussed the schedule for presenting information at the monthly meetings. Attachment 3-a contains the presentation material. Exelon’s objectives were to get an agreement on the licensing approach and the Part 52 licensing process. Format content and resolution process for license application will be a topic of discussion at the August meeting.

Joseph Sebrosky et al. (NRR) requested information on the schedule for fabrication of major components as part of PBMR construction to support the staff's readiness review for new plant construction (Attachment 6). Diane Jackson et al. discussed the status of open items related to the nine white papers that were submitted by Exelon in May 2001, and were addressed at length at the June meeting with Exelon. There were additional brief discussions led by the following: Edward Wallace (Exelon) on the fuel cycle impacts in reference to 10 CFR Part 51; James Turdici (OCIO) on the requirements on annual fees in 10 CFR Part 171; Michael Dusaniwskyj and Norman St. Amour on antitrust review under 10 CFR 50.33a; and Norman St. Amour on financial protection requirements. As noted previously in other meetings with Exelon, resolution of various issues will require Commission policy decisions. Finally, there was a re-cap of the open items identified in the June meeting and due dates for various submittals by Exelon and responses by NRC were re-affirmed. The staff also stressed the importance of timely submittals of revised documentation from Exelon on various topics discussed at the meeting.

The discussion on the proposed PBMR licensing approach continued in the afternoon of July 17, with Kevin Borton (Exelon) leading the discussion. Edward Wallace (Exelon) and Fred Silady (Exelon consultant) made individual presentations and K. Fleming (Exelon consultant) participated via teleconference. F. Silady discussed in detail the integrated process for selection of licensing basis events (LBE) for the PBMR using the top level regulatory criteria (Attachment 3-b). The proposed LBE selection process is risk-informed. The method for initial screening of regulations for applicability to the PBMR was illustrated by using examples from the application of a similar process in the 80's for the modular high temperature gas reactor (MHTGR). The PBMR probabilistic risk assessment scope was outlined and also discussed was applicability of the established probabilistic risk assessment standards for light-water reactors to the PBMR. Exelon sought out staff comments and feedback on the LBE selection process and agreement on the use of risk-informed LBE as a foundation of the licensing approach. Edward Wallace discussed the PBMR licensing approach by preliminary screening of current NRC regulations, including the General Design Criteria (GDC), for applicability to PBMR (Attachment 3-c). Since PBMR will use both a probabilistic and deterministic approach, he also discussed plans for a pilot project to deterministically evaluate "regulatory applicability." The key elements of this decision-making process were depicted in a logic diagram that will be used to determine applicability (complete or partial) or inapplicability to the existing regulations or the intent of regulations, including the GDC. Exelon had assembled a seven-member expert panel, comprising a variety of technical and legal expertise, to look at a sample of existing regulations, to determine their applicability to PBMR.

On July 18, Robert Calabro (Exelon consultant) discussed the PBMR fuel irradiation program (Attachment 3-d). The objectives of the PBMR fuel irradiation program are (1) to confirm performance of the PBMR fuel (manufactured at the Pelindaba plant) to be within the envelope of the German-measured irradiation data, and (2) to provide irradiation data for the steady state and transient operating conditions as closely possible to those expected in the demonstration plant. He described the program plan and schedule, irradiation measurements to be taken, and the PBMR proposed joint international irradiation program. He presented the proprietary-blocked-out information related to the proposed test programs which are planned to be conducted at the Safari reactor in the Republic of South Africa, and in the Russian IVV-2M reactor. The proprietary information was later discussed in a closed session.

Vijay Nilekani (Exelon), with Dr. Johan Venter and others via teleconferencing, presented an overview of the selected areas of codes and standards applicable to the PBMR design seeking staff's comments and feedback (Attachment 3-e). The areas covered were: civil, structural and seismic; reactor pressure vessel and the primary pressure boundary; electrical and instrumentation & control; and fire protection. Dr. Joseph Muscara (NRC) led the staff's discussion. During exchange at this meeting and various comments from the staff, several areas were identified where NRC endorsements of the industry standards or specific code cases would be required. Further discussion on the Codes and Standards, which will continue at the August and September meetings, will give staff a feel for the required lead time for various review and endorsement activities.

The dates for the future 2-day topical meetings are: (1) August 15 and 16 (revised) to continue discussions on licensing approach, fuel performance, and qualification as well as the Codes and Standards to be used, and to provide an overview of analytical codes to be used; and (2) September 19 and 20 to close out discussions on licensing approach and fuel performance, and to continue discussion of Codes and Standards. The staff will coordinate the meeting schedule with Exelon and the final dates will be announced in a formal meeting notice.

The meeting adjourned at 1:30 p.m. on July 18th. Any questions regarding this meeting should be addressed to Stuart Rubin (SDR1@nrc.gov), (301) 415-7480.

Attachments: As stated

ADAMS PACKAGE NO. ML012140060

cc w/o attachments: See attached list

SUBJECT: MEETING WITH THE EXELON GENERATION COMPANY, THE DEPARTMENT OF ENERGY, AND OTHER INTERESTED STAKEHOLDERS REGARDING THE PEBBLE BED MODULAR REACTOR

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Agenda
Meeting with Exelon and the Department of Energy
on Pebble Bed Modular Reactor
July 17, 2001 9:00 a.m.–3:15 p.m.

Tuesday, July 17, 2001

9:00 a.m.–9:10 a.m.	Introductory Remarks – NRC (S. Rubin) • PBMR Pre-Application Review Goals, Meeting Purpose and Process, and Review Status • Administrative Items • Meeting Agenda
9:10 a.m.–9:40 a.m.	Overview of PBMR Pre-Application review Technical Topics, Objectives and Schedule – Exelon (K. Borton)
9:40 a.m.–9:45 a.m.	PBMR Construction: Schedule for Fabrication of Major Components – NRC (J. Sebrosky)
9:45 a.m.–10:30 a.m.	Exelon White Papers Additional Exelon Information, Preliminary Staff Views/Comments, and NRC/Exelon Discussion on: • Fuel Cycle Impacts in 10 CFR Part 51 – Exelon/All (E. Wallace) • Requirements on Annual Fees in 10 CFR Part 171 – NRC/All (J. Turdici) • Number of Licensees–Status – NRC/All • Requirements for Antitrust Review Under 10 CFR 50.33a – NRC/All (M. Dusaniwskyj; N. St. Amour) • Financial Protection Requirements in 10 CFR 140 – NRC/All (N. St. Amour)
10:30 a.m.–10:45 a.m.	Break
10:45 a.m.–12:15 p.m.	Proposed PBMR Licensing Approach – Exelon (K. Borton; E. Wallace, F. Silady; Exelon Consultant, K. Fleming via Teleconference) • Background • PRA • Process for Selection of Licensing Basis Events
12:15 p.m.–12:30 p.m.	Stakeholder Comments
12:30 p.m.–1:30 p.m.	Lunch Break
1:30 p.m.–3:00 p.m.	Proposed PBMR Licensing Approach– Exelon (Continued) • Preliminary Screening of Regulations
3:00 p.m.–3:15 p.m.	Stakeholder Comments

Agenda
Meeting with Exelon and the Department of Energy
on Pebble Bed Modular Reactor
July 18, 2001, 9:00 a.m.–3:15 p.m.

Wednesday, July 18, 2001

9:00 a.m.–10:00 a.m. PBMR Codes and Standards – Exelon (V. Nilekani, D. Lee, N. Broom, K. Smit, J. Van derWesthuizen, K. Van Rensburg, I. Drodski, J. Hufnagel via teleconference); PBMR, Pty. (A. George)

- Discussion of PBMR Codes and Standards
- Requested Objective for Codes and Standards Pre-Application Review

10:00 a.m.–10:15 a.m. Break

10:15 a.m.–10:45 a.m. PBMR Fuel Irradiation Program – *Non-proprietary* – *Open to the Public* – Exelon (V. Nilekani, J. Hufnagel via teleconference, R. Calabro [Exelon consultant]), PBMR, Pty. (A. George, J. Venter)

- Discussion of PBMR Fuel Irradiation Program
- Requested Objective for Fuel Irradiation Program Pre-Application Review

10:45 a.m.–11:15 a.m. Stakeholder Comments

11:15 a.m.–12:45 p.m. PBMR Fuel Irradiation Program – *Proprietary* – *Closed to Public* – Exelon (V. Nilekani, J. Hufnagel via teleconference, R. Calabro [Exelon consultant]), PBMR, Pty. (A. George, J. Venter)

- Review of Proprietary Answers to Questions from July 13 meeting
- Discussion of PBMR Fuel Irradiation Program

12:45 p.m.–1:00 p.m. Closing Remarks and Future Meeting Schedule – NRC/Exelon

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July 17, 2001

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Attachment 2-a

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Exelon

PBMR Pre-Application Meeting

Presented to the U.S. Nuclear Regulatory Commission

July 17-18, 2001

Kevin Borton
Manager, Licensing
Exelon Generation

Pre-Application Issues – NRC Staff Schedules

- Licensing Approach
  - **September, 2001**: Staff recommendations
  - **October, 2001**: ACRS recommendations
  - **December, 2001**: Commission Paper
- Technical
  - **December, 2001**: Staff recommendations
  - **January, 2002**: ACRS recommendations
  - **April, 2002**: Commission Paper
- Policy
  - **June, 2002**: Staff recommendations
  - **July, 2002**: ACRS recommendations
  - **September, 2002**: Commission Paper

Pre-Application Objectives -
Exelon Licensing Approach Introductions

- ✓ Licensing Approach
  - Agreement on approach - Commission Paper
- ✓ Part 52 Process
  - Agreement on process and schedule – Commission Paper
- ✓ 9 White Papers
  - Staff positions and initiation of actions
- August 2001 - License Application
  - Agreement on format, content, resolution process

Pre-Application Objectives – Exelon Technical Topic Introductions

Common understanding of design; Identification of the level of information necessary in order to obtain license; Early identification of additional or unique requirements

✓ **June, 2001** - Fuel

✓ **July, 2001** - Codes and standards

August, 2001 - Analytical codes
- Core Design (steady/transients)
- Shut-down cooling and shut-down capability

September, 2001
- Confirmatory test program / ITAAC
- High temperature material
- Fuel handing system
- Source term

October, 2001 – Graphite chemical attack
- Security / safeguards
- Control room design / habitability

November, 2001 - Waste characteristics
- Brayton Cycle / Power conversion unit

December, 2001 - Open

Pre-Application Objectives - Exelon Policy Topic Introductions

- Review of Current Commission Policies
  - No changes, or
  - Changes noted and staff recommendations

January, 2002	- Containment
	- Control room habitability / staffing
February, 2002	- Emergency preparedness
	- Defense-in-depth
March, 2002	- Human factors
	- Shutdown Margin
	- Others

Process for Selection of Licensing Basis Events for the PBMR

Fred Silady, PhD
Consultant for
Exelon Generation

Presentation Purpose

- To describe the risk-informed process for selection of licensing bases events
- To illustrate the method with examples from the application of the similar process utilized for the MHTGR in the mid-80's
- To provide insights for regulatory document review

Presentation Outline

- Use of Top Level Regulatory Criteria
- Use of PRA
- Process for Selection of Licensing Basis Events
  - Anticipated Operational Occurrences (AOO)
  - Design Basis Events (DBE)
  - Emergency Planning Basis Events (EPBE)
- Risk Insights for Regulatory Document Review

Relation of Risk-Informed Licensing Bases

- Top Level Regulatory Criteria (TLRC) provide *what* must be achieved
- Licensing Basis Events (LBE) provide *when* the TLRC must be met
- Regulatory design criteria (RDC) and equipment safety-related classification provide *how* it will be assured that the TLRC are met
- Requirements (special treatment) for the safety-related Systems, Structures, and Components (SSC) provide *how well* the TLRC are assured

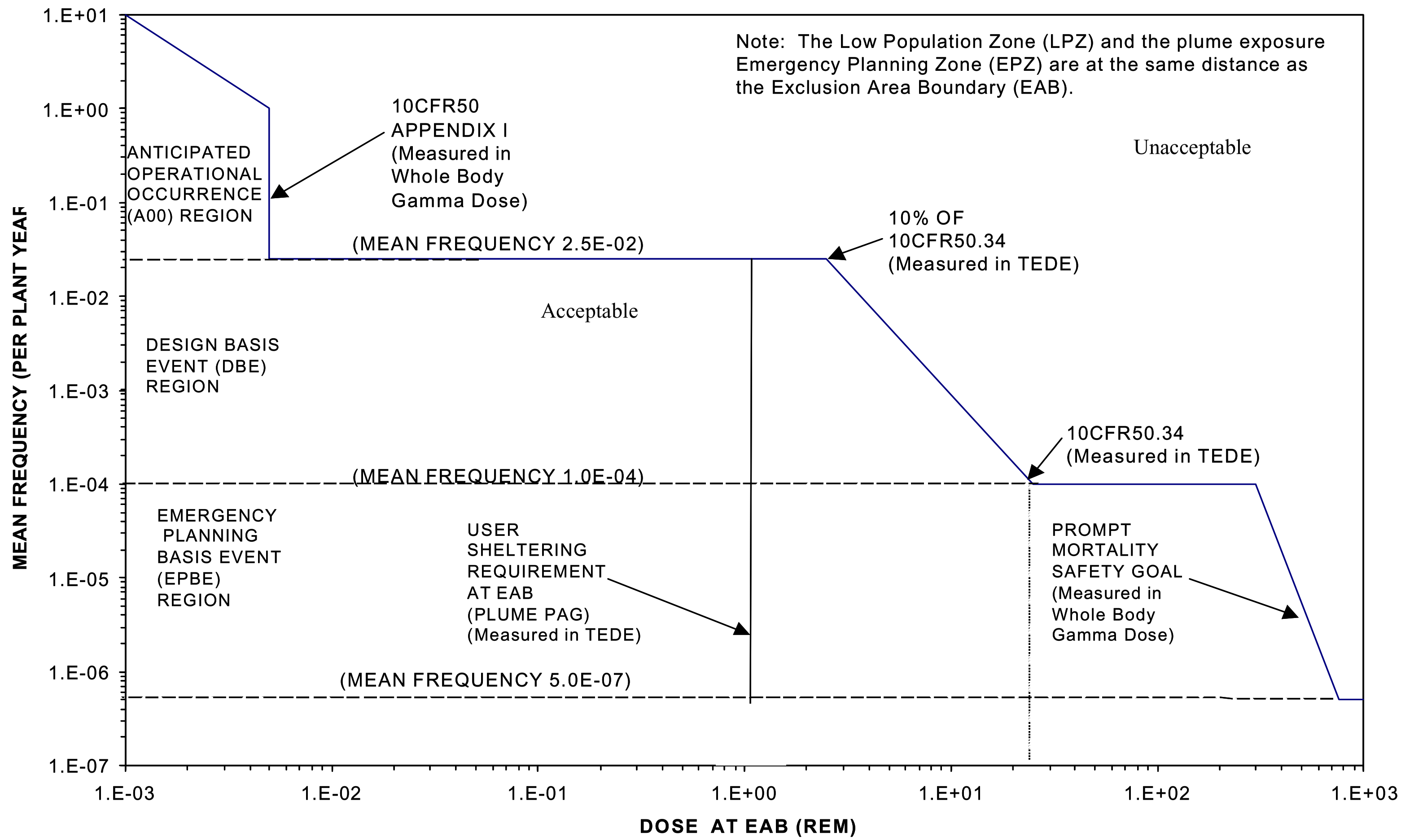
Bases for Top Level Regulatory Criteria

- Direct statements of acceptable health and safety as measured by risks of radiological consequences to the public or the environment
- Quantifiable
- Independent of reactor type and site

Top Level Regulatory Criteria for the PBMR

- 10CFR50 Appendix I annualized offsite dose guidelines
  - 5 mrem/yr whole body
- 10CFR100/50.34 accident offsite doses
  - 25 rem total effective dose equivalent
- EPA-400-R-92-001 protective action guideline doses
  - 1 rem total effective dose equivalent
- 51FR130 individual acute and latent fatality risks
  - $5x10^{-7}$/yr and $2x10^{-6}$/yr, respectively

PBMR Risk Criteria Chart with Top Level Regulatory Criteria



PBMR PRA Objectives

- Confirm design meets the TLRC
- Support identification of LBE
- Provide insights and a basis for development of RDC

PBMR PRA Scope Requirements

- Comprehensive treatment of end states and initiating events for robust risk assessment
- PBMR design characteristics support use of single event tree structure from initiating events to end states for accident family consequences and frequencies with uncertainties
- PBMR PRA needs to address all modes of operation and shutdown and internal and external events
- Includes operating experience from power industry including LWR, Magnox, AGR, and HTGR
- Provides framework for evaluation of deterministically selected events

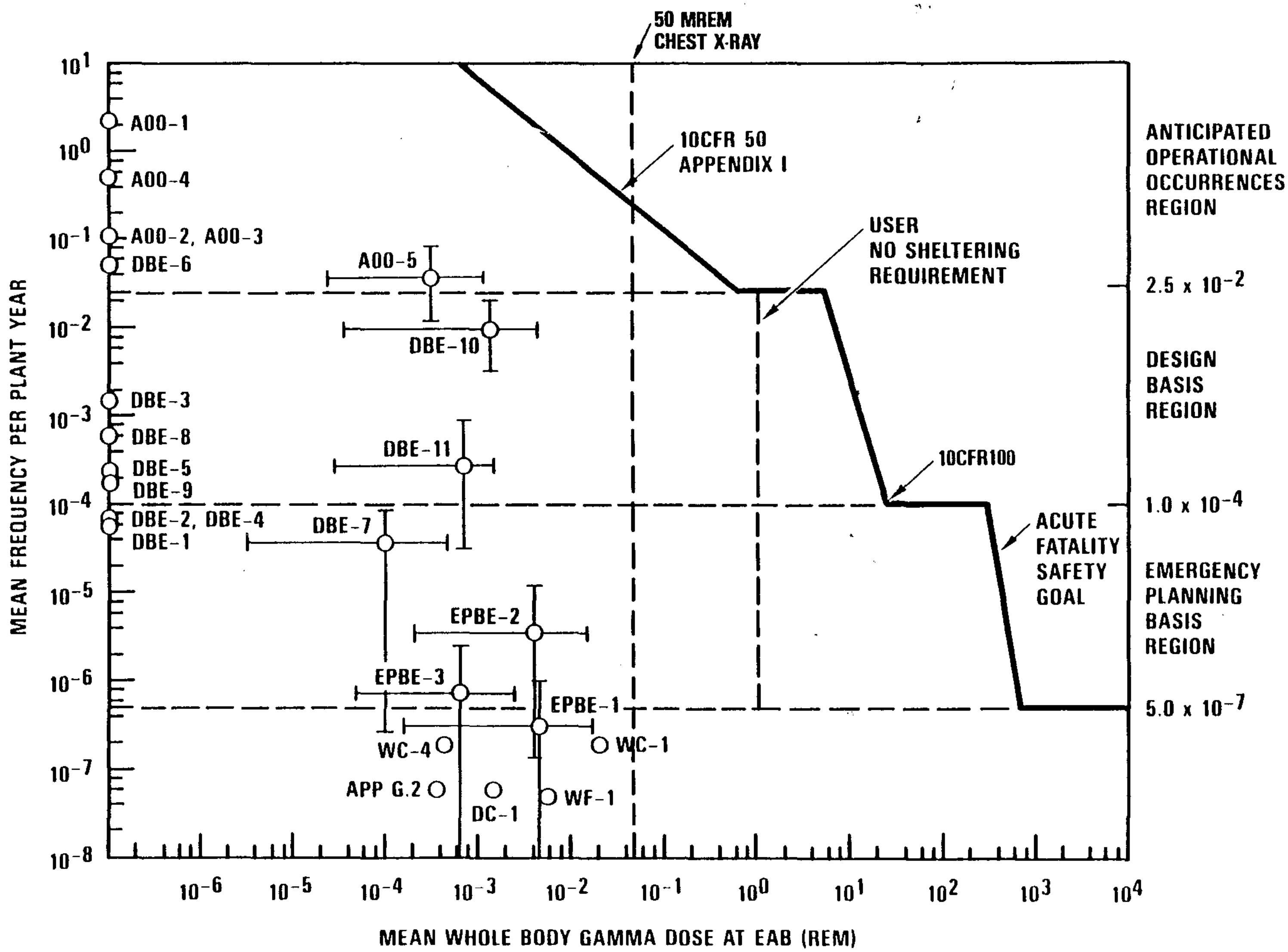
Applicability of LWR PRA Standards

- General principles of LWR PRA standards applicable to PBMR
- LWR risk metrics such as CDF and LERF will be replaced by representative set of PBMR accident family consequences and frequencies
- Slow evolution of PBMR transients results in time-dependent source terms and potential for mitigative actions
- Tools and method for physics, thermal hydraulics, and fission product transport must be specific to PBMR conditions
- Need to address multiple modules and sites with LWRs

Licensing Basis Events

- Off-normal or accident events used for demonstrating design compliance with the Top Level Regulatory Criteria
- Collectively, analyzed in PRA for demonstrating compliance with the safety goal
- Encompass following event categories
  - Anticipated Operational Occurrences
  - Design Basis Events
  - Emergency Planning Basis Events
- Example of selection process provided for MHTGR pre-application submittals

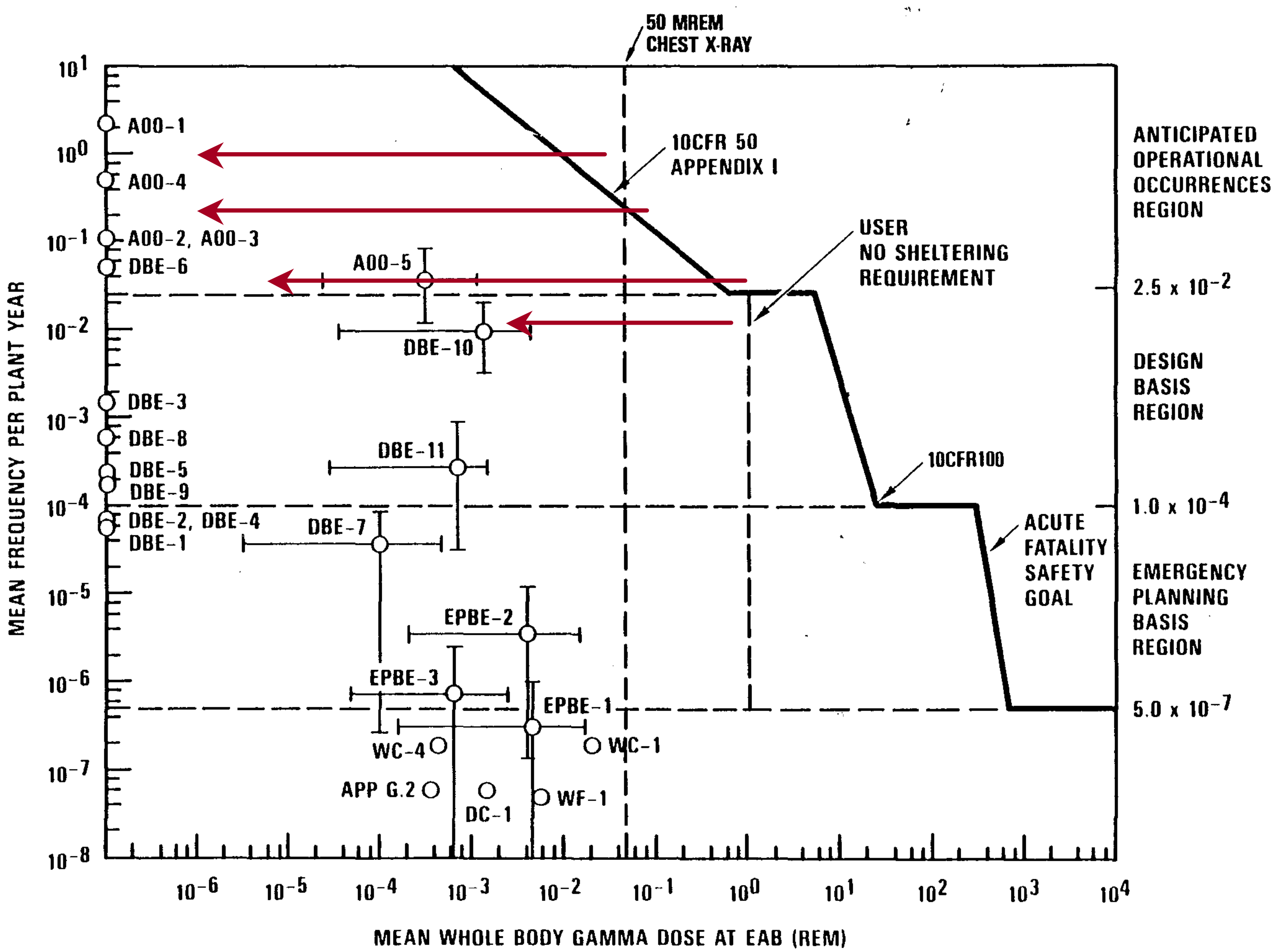
MHTGR Licensing Basis Events



Anticipated Operational Occurrences

- Events expected once or more in the plant lifetime
  - a plant lifetime of 40 years assumed
  - lower frequency of .025/plant year ($\leq$10 modules for PBMR)
- Identified as families of events in AOO region that could exceed Appendix I of 10CFR50 *if certain equipment or design features had not been selected*
- Consequences realistically analyzed for compliance with 10CFR50 Appendix I

MHTGR Example for Selection of AOO



AOO Examples from MHTGR

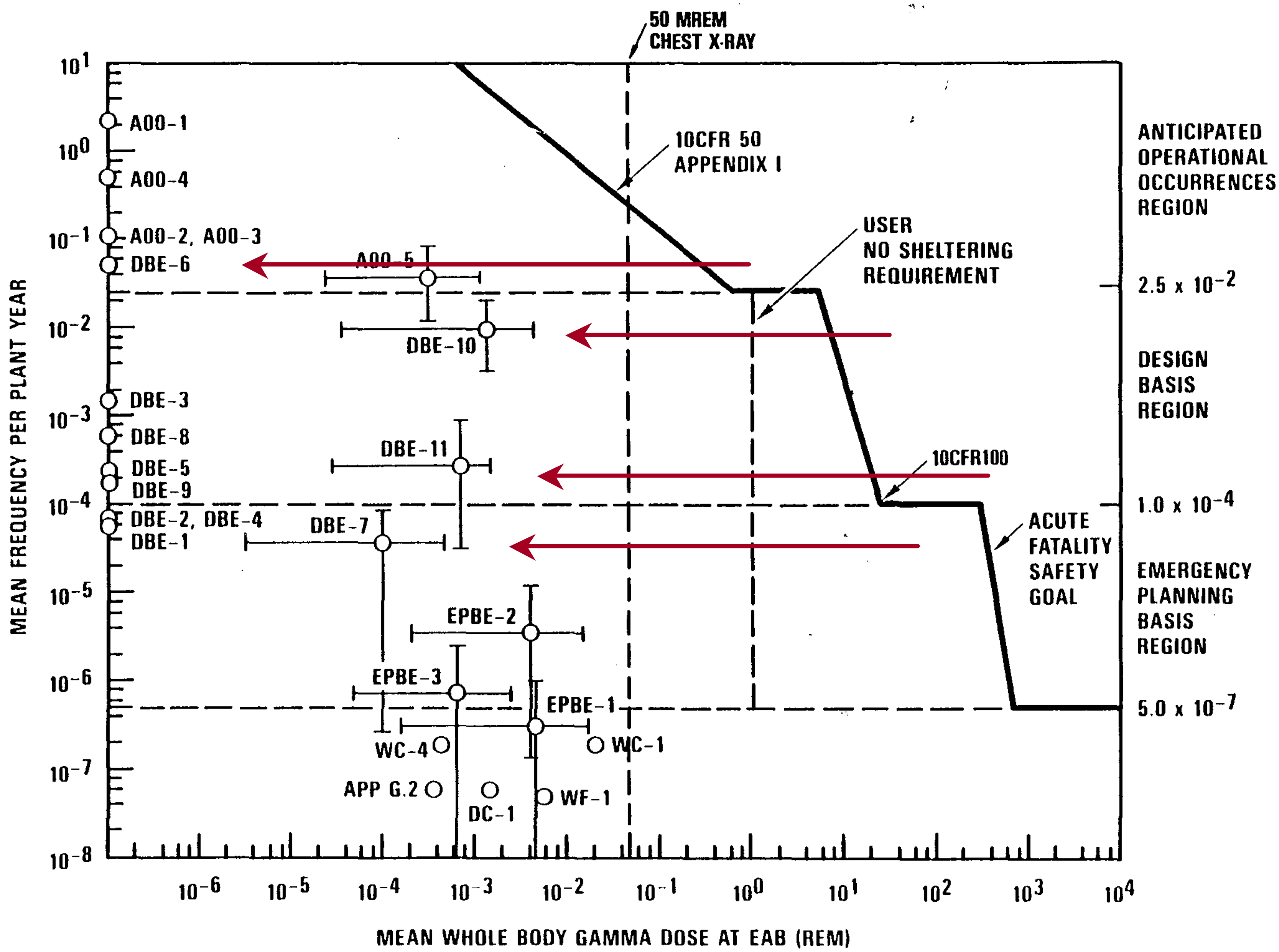
AOO Designation	Anticipated Operational Occurrences
AOO-1	Main loop transient with forced cooling
AOO-2	Loss of main and shutdown cooling loops
AOO-3	Control rod group withdrawal w/ control rod trip
AOO-4	Small steam generator leak
AOO-5	Small primary coolant leak

Shaded LBE not expected for PBMR

Design Basis Events

- Events of lower frequency than AOOs, not expected to occur in the lifetime of the plant
  - for a plant lifetime of 40 years, less than 1% chance
  - lower frequency of 10^{-4}/plant year
- Identified as families of events in (or close to) DBE region that could exceed 10CFR100 *if certain equipment or design features had not been selected*
- Mean values and uncertainty range of consequences are evaluated to provide high confidence of compliance with and safety margin to 10CFR100

MHTGR Example for Selection of DBE

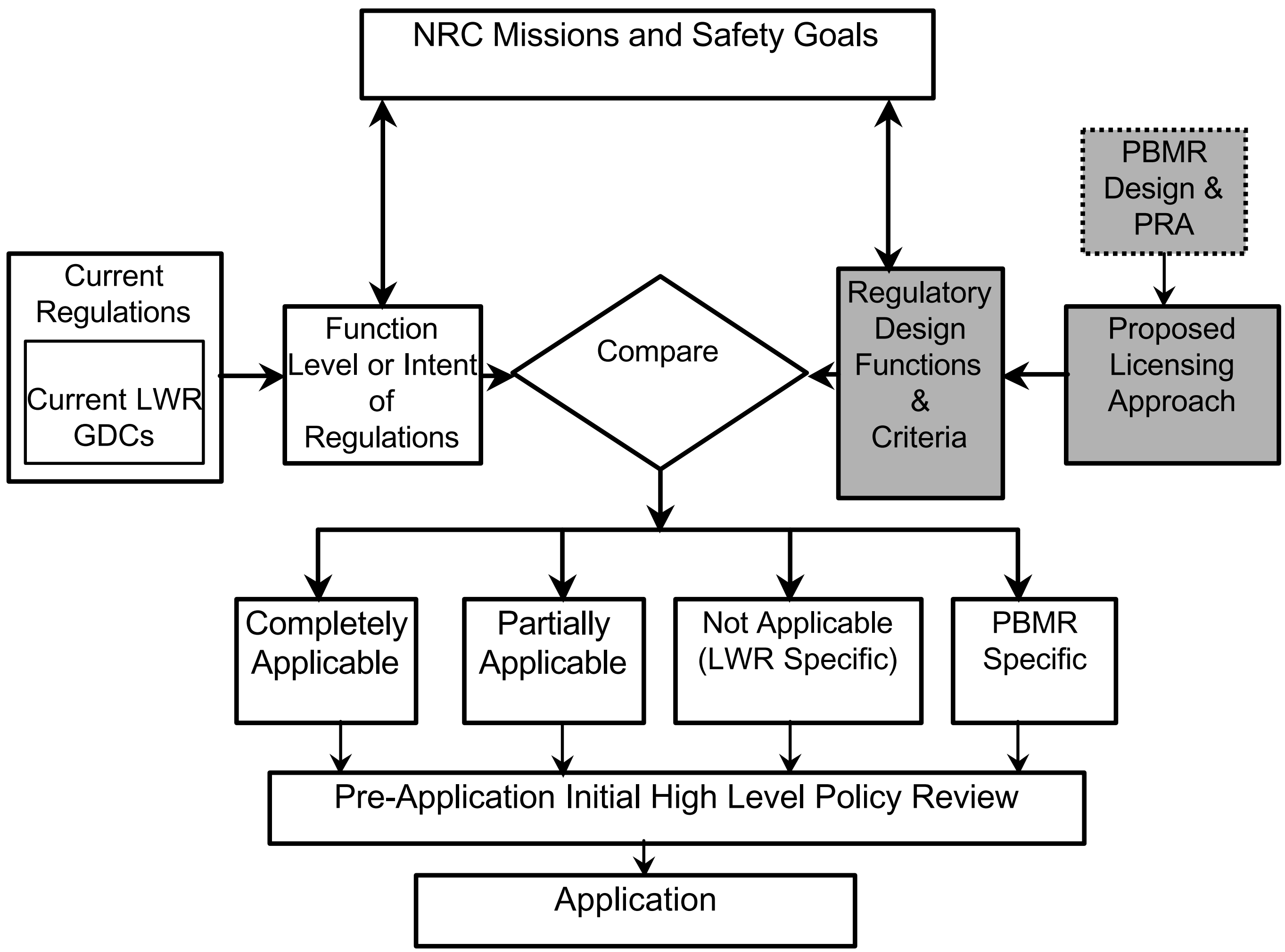


DBE Examples from MHTGR

Designation	Design Basis Events
DBE-1	Loss of main loop and shutdown forced cooling
DBE-2	Main loop transient w/o control rod trip
DBE-3	Control rod withdrawal w/o main loop cooling
DBE-4	Control rod withdrawal w/o forced cooling
DBE-5	Earthquake
DBE-6	Moisture inleakage
DBE-7	Moisture inleakage without forced cooling
DBE-8	Moisture inleakage with moisture monitor failure
DBE-9	Moisture inleakage w/ steam generator dump failure
DBE-10	Moderate primary coolant leak w/o forced cooling
DBE-11	Small primary coolant leak w/o forced cooling

Shaded LBE not expected for PBMR

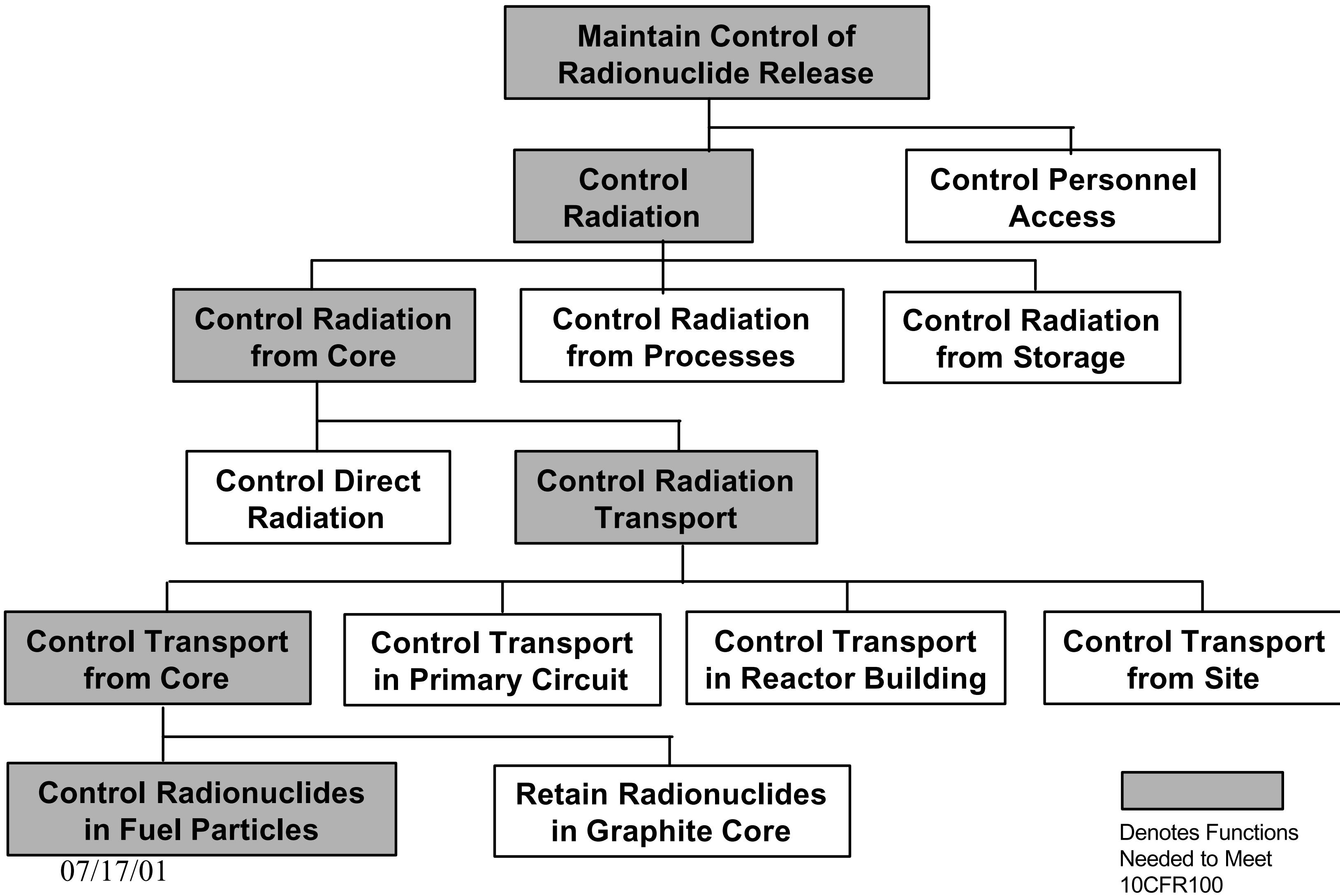
Use of PRA Insights for Regulatory Document Review



Required Safety Functions

- Required safety functions developed from review of LBE versus TLRC
- PBMR required safety functions will be similar to those for the MHTGR
  - For compliance with 10CFR100/50.34:
    - radionuclide retention within fuel particles
      - control of heat generation
      - core heat removal
      - control of chemical attack
- Defense-in-depth provided in both process and barrier sense for radionuclide retention and sub-functions

MHTGR Example of Radionuclide Retention Functions



Unique PBMR Characteristics Relative to LWR

- PBMR primary pressure boundary provides following safety functions
  - Retain radionuclides
  - Maintain core geometry (by reactor vessel for core heat removal and control of heat generation)
- The following functions are NOT required
  - Prevent core melt---ceramic particles and graphite do not melt
  - Prevent loss of coolant----can't lose coolant, always there to some extent, thus, LOCA does not apply
  - Prevent fuel failure----core materials and geometry selected for heat transfer by conduction and radiation, convection not required
- Other differences include no need for containment heat removal---low enthalpy of helium

MHTGR Example of Design Criteria

Conduct Heat from Core to Vessel Wall:

The reactor core design and configuration shall ensure sufficient heat transfer by conduction, radiation, and convection to the reactor vessel wall to maintain fuel temperatures within acceptable limits following a loss of forced cooling. The materials which transfer the heat shall be chosen to withstand the elevated temperatures experienced during this passive mode of heat removal. This criterion shall be met with the primary coolant system both pressurized and depressurized.

Linkages to Other PBMR Licensing Bases

- Required safety functions during DBE help shape RDC and review of existing regulatory documents
- Method for classification and requirements for safety related SSC is the subject of the next meeting.

Outcome Objectives from NRC to Exelon

- Comments and feedback on the process for selection of the LBE
- Agreement on the use of risk-informed LBE as key foundation of licensing approach

Exelon[SM]

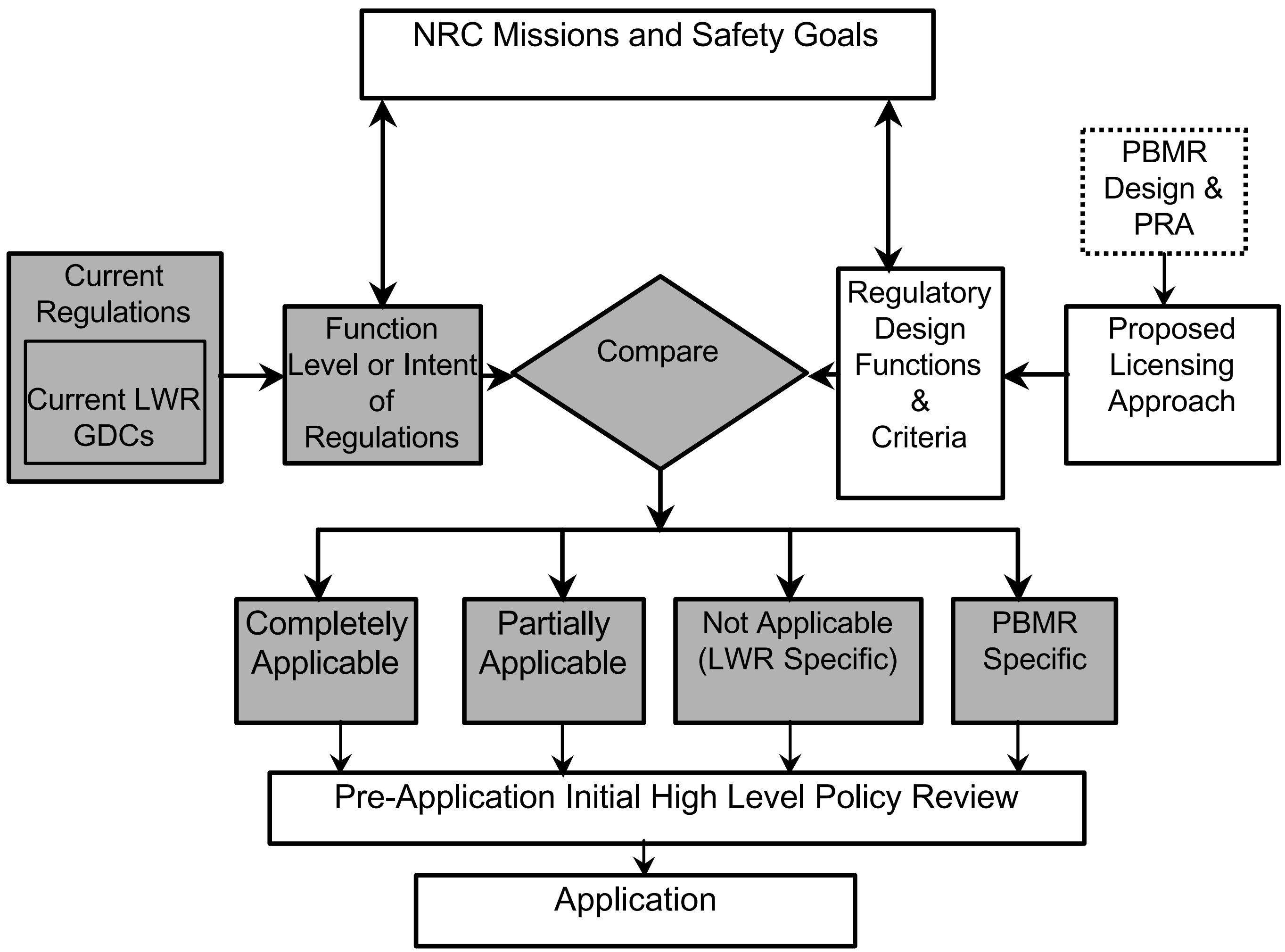
Preliminary Screening of Regulations

Ed Wallace

Project Manager

Exelon Generation

Licensing Approach



Deterministic Evaluation of Regulatory Applicability

Purpose:

- To conduct a pilot project that will develop an initial categorization of a large sample of regulations that apply to the licensing of the PBMR in the US.

- Also provide: A greater sense of the number of exemptions that could be required in the process of reviewing the PBMR design;

- A greater sense of what the key questions and logic for making decisions regarding applicability of current regulatory guidance documents,

- A beginning point for applying risk-informed insights to help shape the changes or interpretations that will be needed to address partially applicable regulations, and

- Confidence that a logical, repeatable, reliable and defendable decision process can be defined for addressing the remaining set of regulatory guidance in existence today.

Expert Panel Process

- Panel Members
  - Seven participants
  - Owner, regulator, designer, legal perspectives included
  - Backgrounds include experience in LWR design, operations, maintenance, construction, licensing, reactor regulation, risk assessment, and gas reactor design
- >180 years of nuclear industry experience total

Expert Panel Process (continued)

- Sample Set Selection
  - 10CFR50 including Appendices plus selected other regulations
  - 163 total regulations / GDCs reviewed
- Process
  - Vote types
    - Applies; Partially Applies; Not Applicable
  - Process Definitions
    - Specific meaning for rules / regulations developed that differ from guidance documents
      - Literal reading for rules / regulations
      - Intentions or purpose for guidance
  - Technical Definitions

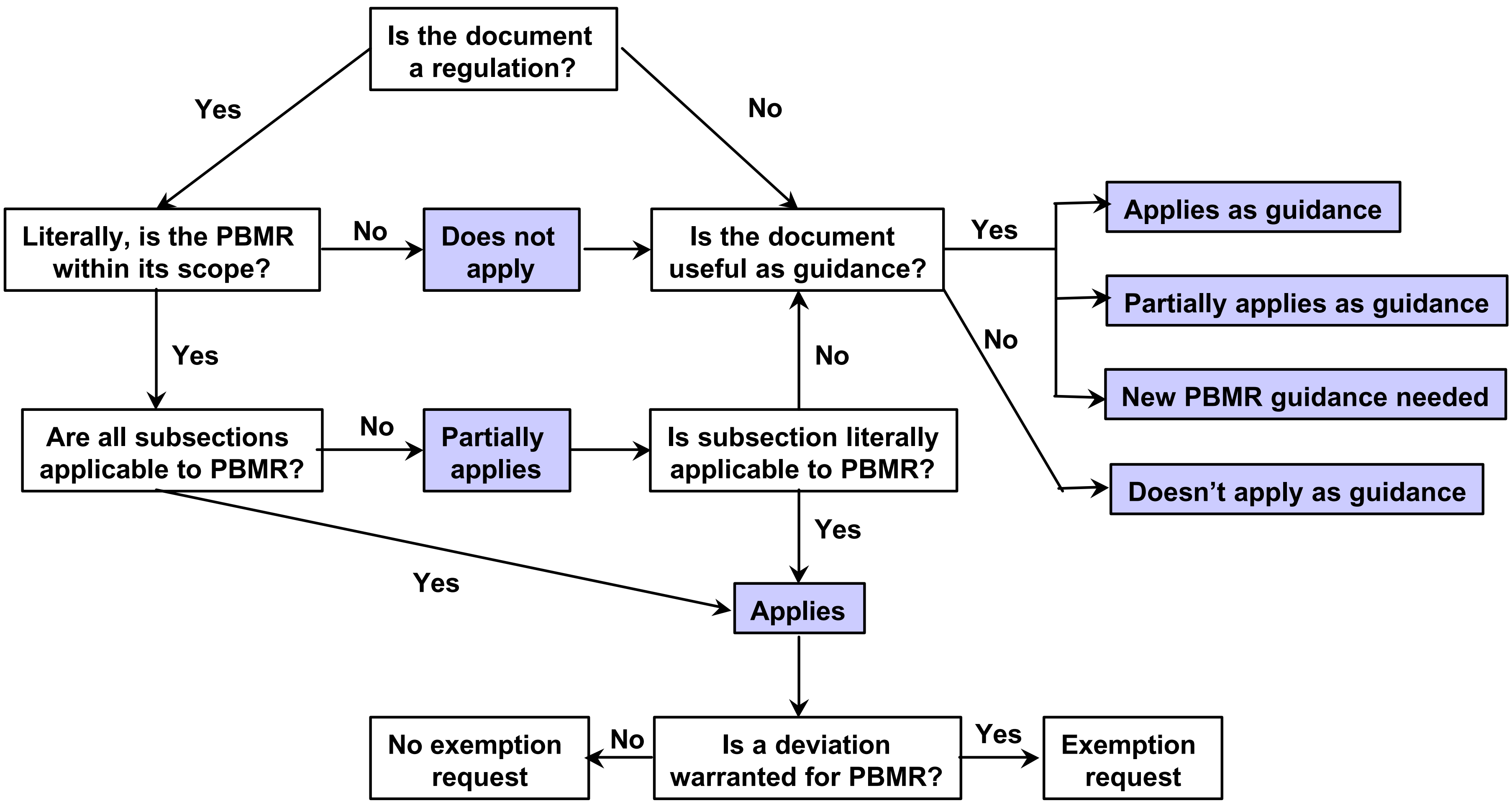
Technical Definitions

- Primary Pressure Boundary
  - Use in lieu of Reactor Coolant Pressure Boundary
  - Fission Product Retention
  - Core Geometry for Residual Heat Removal
- LOCA
  - Evaluation models and other regulatory requirements only when needed to support PBMR specific LBE and Safety Outcomes
- Containment
  - One of defense-in-depth barriers in PBMR design
  - PBMR design requirements appropriate for advanced gas reactor
    - Performance parameters driven by LBE scenarios
    - Performance parameters risk-informed
- Merchant Plant
- Modular Reactor

Results Summary

- Developed logic diagram reflecting the consensus decision-making process
- 114 Apply
- 23 Partially Apply
- 26 Not Applicable
- Key process observations
  - Common definitions of both plain English terms and key technical terms needed to reach consensus
  - Considerations of actual design and PRA insights important

Logic Chart for Regulatory Document Review



Use of Design Type and PRA Insights in Determining Applicability of Regulatory Documents

- Based on current knowledge of PBMR design
- Used early risk insights to determine LBEs
- Based on knowledge of LBEs, concluded what functional capabilities are necessary
- Compared the functional capabilities against regulatory criteria to determine level of applicability

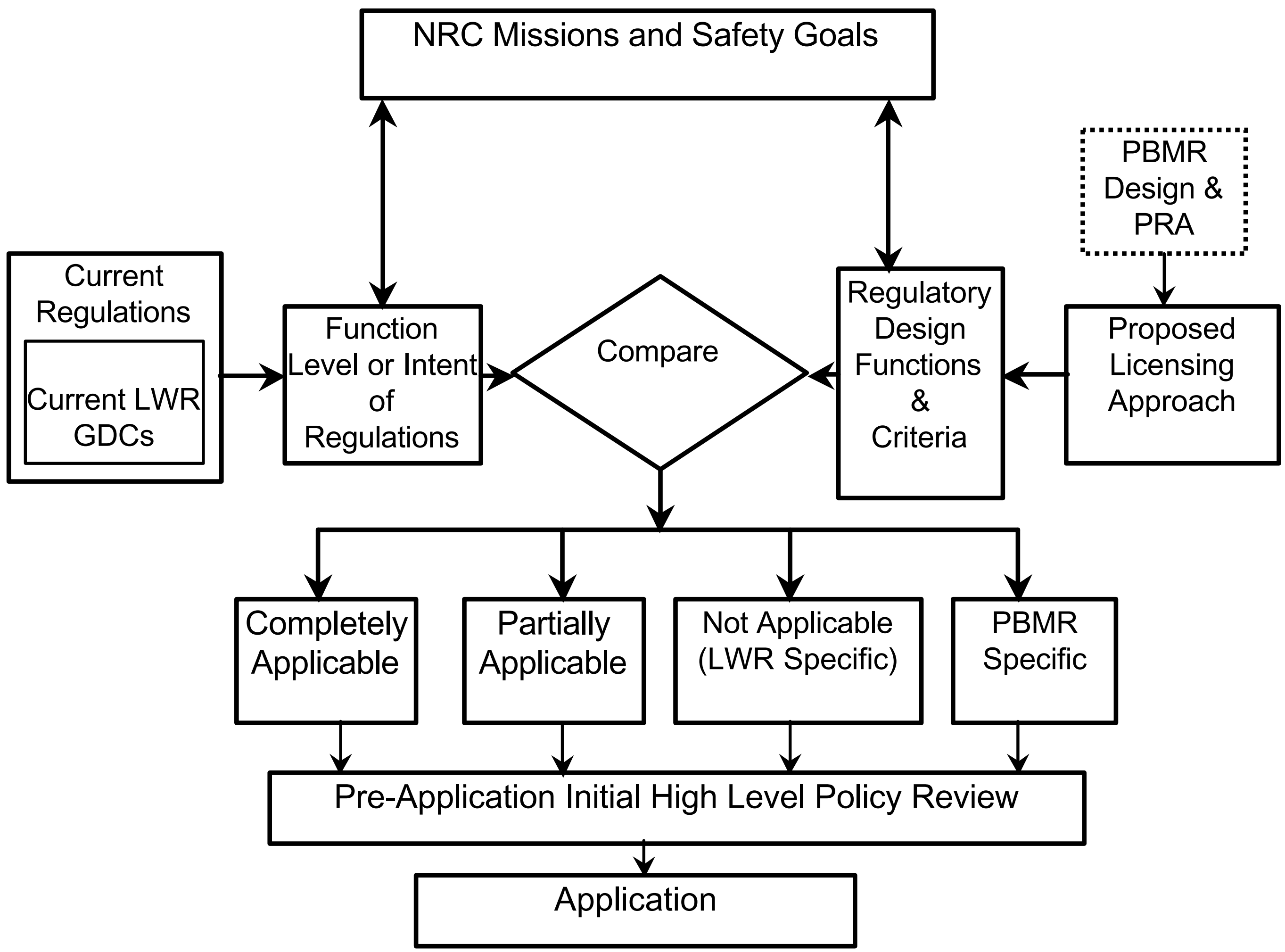
Process Example Demonstrations

- Regulations / Rules
  - Straight Forward
    - applies [50.59 “changes, tests, and experiments”]
    - partially applies [50.54(o) “primary rector containments”]
    - does not apply [50.44 “standards for combustible gas”]
  - Requires Judgement and Insight
    - applies [50.75 “recordkeeping for decommissioning”]
    - partially applies [50.49 “environmental qualification for electric equipment important to safety”]
    - does not apply [50.46 “criteria for emergency core cooling systems”]

Process Example Demonstrations

- Guidance
  - Applies [GDC 13 “Instrumentation and control”]
  - Partially Applies [Appendix A preamble; GDC 30 “Quality of reactor coolant pressure boundary”]
  - Not Applicable [GDC 55 “Reactor coolant pressure boundary penetrating containment”]

Licensing Approach



Looking Forward

- Screen the entire set of NRC regulations, not just sample
- Continue to validate the logic chart
- Begin application of PBMR specific risk-insights to applicable or partially applicable regulations
- Iterate the assessment of applicability
- Expand the effort to non-regulation regulatory documents (i.e., Regulatory Guides, Standard Review Plans)
- Provide results to NRC on on-going basis and achieve outcomes

Outcome Objectives from NRC to Exelon

- Comments and feedback on “left side” portion of approach for developing regulatory set of requirement and guidance documents
- Agreement on using the logic process developed as a decision tool for preliminary screening of the regulatory set
- Agreement on the development of key definitions for the purposes of regulatory screening effort
- Early agreement on the set of “not applicable” regulations
- Agreement on the plan for use of the screening process for the lower-tier regulatory documents.
- Development of the complete set of regulatory documents that will drive the application content during the pre-application period using this licensing approach.

Exelon[SM]

PBMR
Fuel Irradiation Program

July 18, 2001

Robert R.Calabro
Consultant

PBMR Fuel Irradiation Program

- Purpose of presentation
  - Define the purpose of the PBMR fuel irradiation program
  - Describe the program plan and schedule
  - Describe the irradiation measurements to be taken
  - Describe the PBMR proposed joint international irradiation program

Purpose of PBMR Fuel Irradiation Program

- To confirm that the PBMR fuel, manufactured at the Pelindaba plant with modern processes and equipment to German specifications and quality control standards, will perform within the envelope of German measured irradiation data.

- To provide irradiation data for the steady state and transient operating conditions, as closely as possible, to those expected in the Demonstration Plant.

PBMR Irradiation Program

- Test Program in the RSA Safari Reactor
- Test Program in Russian IVV-2M Reactor

Fuel Baseline Program

Proprietary information not shown

Fuel Baseline Program

Proprietary information not shown

Proposed Test Program in the Safari Reactor

- Phase I

Proprietary information not shown

Proposed Test Program in the Safari Reactor, Cont’d

- Phase II

Proprietary information not shown

Proposed Test Program in Russian IVV-2M Reactor

- Test Process

Proprietary information not shown

- Coated Fuel Particle Tests

Proprietary information not shown

Proposed Test Program in Russian IVV-2M Reactor, Cont’d

- Fuel Element Tests

Proprietary information not shown

Proposed Test Program in Russian IVV-2M Reactor, Cont'd

Proprietary information not shown

Proposed Joint International Irradiation Program

Proposal

Irradiate PBMR fuel prior to completing the Pelindaba plant, using fuel from current manufacturing plants in different countries in the US. Advanced Test Reactor (ATR) in Idaho.

Advantages

USNRC will more easily participate in the Irradiation program.

Will establish further confidence in modern HTR fuel elements.

Develop in the US capability for HTR fuel irradiation testing.

Extend HTR database by irradiating fuel from different manufacturers Provide additional data for model development.

Provide opportunity for RSA and USA scientists collaboration.

Program

Three spherical and one cylindrical fuel element irradiated from each manufacturer. RSA would add 12 elements when Pelindaba was complete.

Target burnups of 80-90,000 MWD/Mtu. Tests will include pre and post characterizations, PIE examinations and heating tests for measurement of fission product release.

Conclusion

RSA Safari and Russian IVV-2M tests will confirm that fuel manufactured at Pelindaba will perform as successfully as previously tested German fuel under PBMR reactor conditions.

PBMR Design Codes And Standards

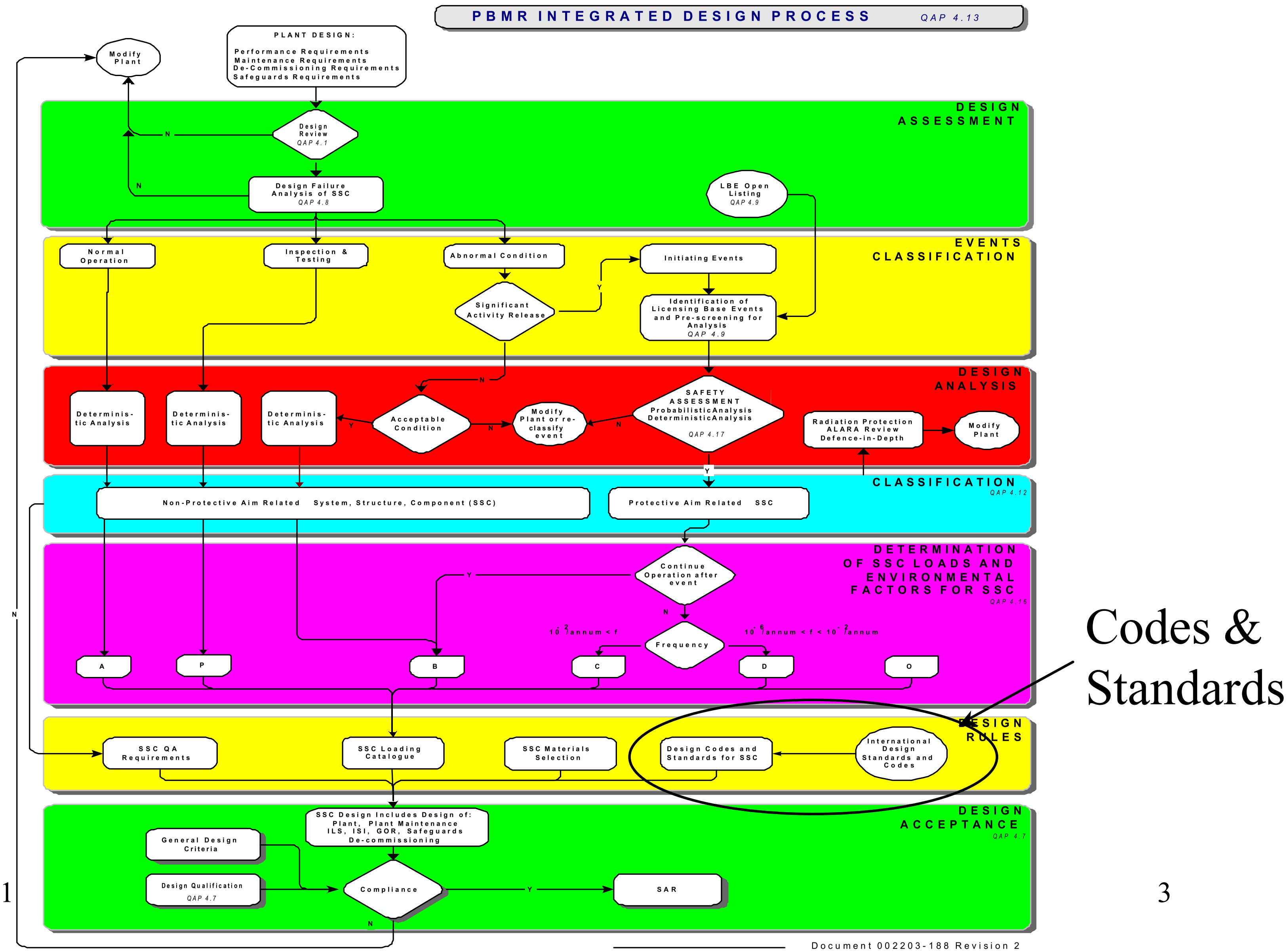
July 18, 2001

Vijay Nilekani
Manager, Technology Transfer
Exelon Generation

PBMR Design Codes & Standards
Scope Of Presentation

- PBMR Integrated Design Process/Codes & Standards
- Civil, Structural and Seismic
- RPV, Primary Pressure Boundary
- Electrical and Instrumentation & Control
- Fire Protection

PBMR Integrated Design Process Codes & Standards



PBMR Integrated Design Process
Codes & Standards, Cont'd

Codes and Standards selection philosophy

- Established internationally recognized design and construction rules will be followed
- Applicability is demonstrated
- Compatible with the PBMR design and safety requirements
- Differing requirements will be resolved by following the most conservative requirement

Civil, Structural and Seismic

- Civil
  - Primary code used is ACI 349-97

    “Code Requirements for Nuclear Safety

    Related Concrete Structures”

    Subsidiary reference codes also used
  - Guidance – Draft Reg Guide DG-1098

    “Safety-Related Concrete Structures for Nuclear Power Plants (other than reactor vessels and containments)”

- Structural
  - Primary code used is ANSI/AISC N690 – 1994

    “American National Standard Specification for the Design, Fabrication and Erection of Steel Safety- Related Structures for Nuclear Facilities”

Civil, Structural and Seismic Cont'd

- ASME Code Section III 1998 is also used

  "Boiler and Pressure Vessel Code, Div 1, Subsection NF, Supports"
- The following Reference Codes are used for determining Design Envelope Loadings
  - ASCE 7-8, "Minimum Design Loads for Buildings and Other Structures"
  - US DOE STD-1020-94, "Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities"
  - SABS 0160 – 1989, "South African Standard, Code of Practice: General Procedures and Loads to be adopted in the design of Buildings"

Civil, Structural and Seismic Cont'd

- Seismic
  - US NRC guidance (NUREG 0800, RG's 1.122, 1.165, 1.60, etc.)
  - US DOE guidance (DOE STD 1020-94, etc.)
  - IAEA guidance (50-SG-S2, etc.)
  - Design for tornado and other natural hazards as well as protection from missiles, aircraft crashes, etc. are addressed in some of the guidance above.

RPV, Primary Pressure Boundary

- RPV
  - ASME Section III Class 1, Sub-Section NB 1998
  - ASME approved Code Case N-499 (1994) has been used to address higher temperatures experienced during Pressurized Loss of Forced Coolant (PLOFC) and Depressurized Loss of Forced Coolant (DLOFC) DBE's (420 deg. C and 480 deg. C). The code case permits temperatures up to 538 deg. C for certain pressures and for a certain time that envelope the PBMR DBE's

    This code case needs NRC review and approval.

RPV, Primary Pressure Boundary Cont'd

- RPV Internal Core Barrel
  - Designed to ASME Section III, Division 1, Sub-section NG 1998
  - ASME approved Code Case N-201 (1994) has been used to address higher temperatures experienced during PLOFC and DLOFC DBE's (720 deg. C). The code case permits temperatures up to 816 deg. C for certain levels of stress and for a certain time that envelope the PBMR DBE's

    This code case needs NRC review and approval.

RPV, Primary Pressure Boundary Cont’d

- Primary Pressure Boundary
  - ASME Section III, Division 1, Sub-Section NC 1998
  - ASME Section XI guidance will be used for the Inservice Inspection Program. Inspectability is one of the design considerations

Electrical and Instrumentation & Control

- Nuclear Safety Related Systems
  - Reactor Protection System (RPS), Post-Event Instrumentation (PEI), Associated Neutronic Instrumentation, RPS & PEI Human Machine Interfaces (HMI)
    - IEEE Std 603 1998 and IEEE Std 7-4.3.2 1993 are the primary standards
    - Applicable IEEE sub references of the above (e.g. IEEE 308, IEEE 344, IEEE 577, IEEE 1023 only for RPS/PEI HMI)
    - NUREG 0800, Chapter 7

Electrical and Instrumentation & Control Cont’d

- Non-Safety Related I & C Systems
  - Equipment Protection System
    - ANSI/ISA S84.01 1996
  - Operational Control Systems
    - IEC Standards are being used. (International Electrotechnical Commission, based in Geneva, Switzerland. IEC is affiliated with ISO and endorsed by 14 countries, including the US, UK, Germany.)

Electrical and Instrumentation & Control Cont’d

- HMI in the Control Room (excluding RPS & PEI HMI)
  - Detailed design is in preliminary stage
  - NUREG 0800, Chapters 13 and 18
  - NUREG 0700, “Human System Interface Review Guidelines” is the primary input to the HMI and control room design. NUREG 0700 refers to:
    - NUREG 0711, “Human Factor Engineering Program Review Model”
    - NUREG CR 5908, “Advanced Human System Interface Design Review Guidelines”
    - NUREG CR 6105, “Human Factors Engineering Guidance for the Review of Advanced Alarm Systems”
    - NUREG CR 6146, “Local Control Station: Human Engineering Issues and Insights”

Electrical and Instrumentation & Control Cont’d

- Radiological Monitoring System, Seismic Monitoring System, etc. are in preliminary design stage.
    - Appropriate Regulatory guidance (e.g. NUREG 0737) will be used.
- Electrical Systems
    - IEC Standards is being used for “50 Hz design”
    - IEEE Standards will be used for “60 Hz design”

Fire Protection

- The design of this is in preliminary design stage
- Guidance from the following sources is under consideration
  - NFPA, (e.g. NFPA 80, Fire Doors; NFPA 101, Life Safety)
  - NUREG 0800, Section 9.5.1, Fire Protection Program
  - USNRC (Appropriate Secy's, RG's, and other guidance documents)
  - IAEA Safety Standard Series

WORKING DRAFT A

SELECTION OF LICENSING BASIS EVENTS

FOR THE

PEBBLE BED MODULAR REACTOR

IN THE UNITED STATES

JULY 2001

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1 INTRODUCTION

The purpose of this document is to describe the risk-informed process for selection of Licensing Basis Events (LBE) in support of planned efforts directed toward the licensing of the Pebble Bed Modular Reactor (PBMR). The process is based on the method (Reference 1) developed in the mid-80s for the Modular High Temperature Gas Cooled Reactors (MHTGR) and modified to reflect the advances that have been made since then in risk informed regulation.

Licensing Basis Events are used to demonstrate compliance with the Top Level Regulatory Criteria (Reference 2) for a spectrum of normal and off-normal plant conditions. Additionally, selection and evaluation of the LBE provide the insights that specify/confirm the functions required for compliance. These required functions lead to the development of the regulatory design criteria and to the selection of equipment and associated performance criteria relied on for compliance.

This report on the selection of LBE is the second in the series of documents describing the PBMR risk-informed licensing process. It builds on and utilizes the subject of the first report, Top Level Regulatory Criteria, which states ***what*** must be satisfied (Reference 2). The LBE describe ***when*** the criteria must be met. Subsequent reports in the series will describe the process for specifying the regulatory design criteriariteria, the ***how***, and for selecting and specifying the special treatment for Equipment Classification, the ***how well***.

Section 2 recaps the Top Level Regulatory Criteria in the risk chart format to be used in the LBE selection process. The characteristics of the PRA that are needed for the selection of the LBE are discussed in Section 3. Section 4 presents the step-by-step selection process for each type of LBE. Examples of the process are provided utilizing the DOE MHTGR preapplication submittals.

2 USE OF TOP LEVEL REGULATORY CRITERIA

Reference 2 provides the identification of the TLRC for the PBMR. Bases for the selection of the TLRC are identified to:

1) be a necessary and sufficient set of direct statements of acceptable health and safety as measured by the risks of radiological consequences to individuals and the environment.
2) be independent of reactor type and site.
3) utilize well defined and quantifiable risk metrics.

As presented in Reference 1 the spectrum of potential accidental radioactive releases from a plant are divided in the following three regions in a scenario frequency vs. consequence chart:

- Anticipated Operational Occurrences (AOO)
- Design Basis Events (DBE)
- Emergency Planning Basis Events (EPBE)

An examination of the entire frequency range and the identification of one or more of the TLRC as being applicable for each Region provide assurance that the selected criteria are adequately established. A summary of the TLRC and their applicable frequency ranges are provided in Table 3-1.

Anticipated Operational Occurrences are those conditions of normal operation which are expected to occur at least once during the life of the plant. Assuming a licensing basis design lifetime of 40 years yields a lower boundary for the AOO region of 2.5×10^{-2} per plant year. For this Region, 10CFR50, Appendix I has been chosen as the applicable criteria as it specifies the numerical guidance to assure that releases of radioactive material to unrestricted areas during normal reactor operations, including AOOs, are maintained As Low As Reasonably Achievable (ALARA).

The dose criteria are expressed in terms of the expected annual dose at the site boundary along the plume centerline for each event to be plotted against the criteria. Hence, for an event expected to occur twice per year the total dose from two events is compared to the Appendix I annual limit. This is used to derive an equivalent allowable dose for each event. For frequent events occurring more than once a year, this results in the sloped risk line shown in Figure 4-1. For less frequent events within the plant lifetime, no single event may exceed the allowable dose as indicated by the vertical dose line in the figure. Appendix I is the most limiting requirement of those identified for normal operation and anticipated operational occurrences.

The **Design Basis Event** region encompasses scenarios that are not expected to occur during the lifetime of one nuclear power plant. The frequency range covers events that are expected to occur during the lifetime of a population (several hundred) of nuclear power plants; and therefore a lower limit of 10^{-4} per plant year is chosen. This frequency is consistent with the existing LWR design basis region even though LWR design basis accidents were not determined from a quantitative assessment of frequency. Estimates of LWR core damage accidents, which exceed the design basis, have been in the range of $1x10^{-5}$ to greater than $1x10^{-4}$. For this region, 10CFR100 and 10CFR50.34 (a)(1) provide the quantitative dose guidance for accidental releases for siting a nuclear power plant to ensure that the surrounding population is adequately protected.

In the design basis region, acknowledgement that relatively more frequently occurring events should meet more stringent criteria leads to the sloping dose criteria line. At the lower end (i.e. 10^{-4} per plant year), the criteria are 100% of the limit dose. The criteria linearly decrease to the upper end where 10% of the limit is used. This is consistent with the NRC's qualitative criterion, as reflected in the Standard Review Plan guidance, that the dose limitations from more frequent accidents be a fraction of the dose guidelines. The dose criteria are expressed in TEDE at the site exclusion area boundary (EAB). The 10CFR100 / 50.34.(a) (1) criteria are more limiting than the Reactor Safety Goals.

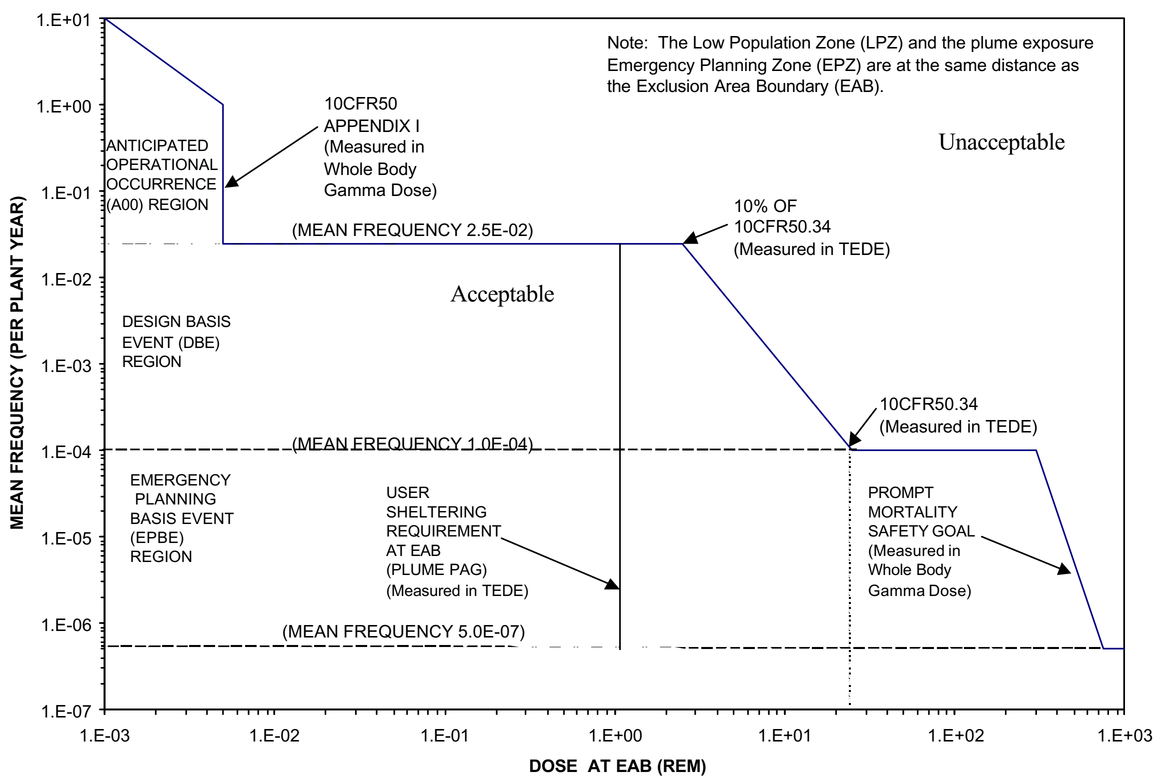
The **Emergency Planning Basis Event** region considers improbable events that are not expected to occur during the lifetime of several hundred nuclear power plants. This is to assure that adequate emergency planning is developed to protect the public from undesirable exposure to radiation for improbable events. The frequency cutoff implicit in the acute fatality risk goal in NUREG-0880 is taken as the lower frequency boundary of the EPBE Region. NUREG-0880 notes that the individual mortality risk of prompt fatality in the U. S. is about 5×10^{-4} per year for all accidental causes of death. The prompt mortality risk design objective limits the increase in an individual's annual risk of accidental death to 0.1% of 5×10^{-4}, or an incremental increase of no more than 5×10^{-7} per year. If the frequency of a scenario or set of scenarios is at or below this value, it can be assured that the individual risk contributions from these scenarios would still be within the safety goal independent of the magnitude of consequences. Therefore this value is used as the lower frequency bound for the EPBE Region.

The incremental mortality cancer risk allowed by the safety goal is 5×10^{-7} fatalities per year. The illustration of the prompt mortality risk curve displayed in Figure 2-1 is approximated and presented in terms of whole body dose in rem. The prompt mortality risk is more limiting than the latent fatality risk. The use of the safety goals to draw the criteria line in this region is very conservative when applied to the dose at the site boundary along the plume centerline as a person at this point would be located at the point of maximum risk over the area within 1-mile of the site boundary in which the average individual risk must meet the safety goal. When the individual risk at this point meets the safety goal, the average individual risk within 1-mile of the site boundary would be much less than $5x10^{-7}$ per year value.

The Protective Action Guidelines (PAG) from EPA-400-R-92-001 are shown as a dose limit as expressed in TEDE at the emergency planning zone (EPZ). The PAG apply to the design and emergency planning basis regions. Depending on the size of the EPZ, the

PAG can be the most limiting criteria. The PBMR will be designed with the option to preclude the need for offsite sheltering, that is, the EPZ would be at the EAB.

FIGURE 2-1
PBMR RISK CRITERIA CHART



3 USE OF PROBABILISTIC RISK ASSESSMENT (PRA)

The purpose of this section is to define the objectives, scope, level of detail, treatment of uncertainties, and conformance with relevant industry standards for the PBMR PRA that will be needed to support the proposed risk informed licensing approach for U.S. sited PBMR plants.

3.1 Rationale for Use of PRA

Probabilistic Risk Assessment provides a logical and structured method to evaluate the overall safety characteristics of the PBMR plant. This is accomplished by systematically enumerating a reasonably complete set of accident scenarios and by assessing the frequencies and consequences of the scenarios individually and in the aggregation of results to predict the overall risk profile. It is the only available safety analysis method that captures the dependencies and interactions among systems, structures, components, human operators and the internal and external plant hazards that may perturb the operation of the plant that could produce an accident. The quantification of both frequencies and consequences must address uncertainties because it is understood that the risk is determined by the potential occurrence of rare events. These quantifications provide an objective means of comparing the likelihoods and consequences of different scenarios and of comparing the assessed level of safety against the TLRC.
PRA is selected because for the following objectives

- Provide a systematic examination of dependencies and interactions and the role that each SSC and operator action plays in the development of each accident scenario; this is referred to in the PRA community as the capability to display the cause and effect relationships between the plant characteristics and the resulting risk levels.
- Provide quantitative estimates of accident frequencies and consequences under the most realistic set of assumptions that can be supported by available evidence.
- Address uncertainties through full quantification of the impact of identifiable sources of uncertainty on the results and by appropriate structured sensitivity studies to understand the risk significance of key issues.
- Apply conservatism only through the examination of explicit percentiles of uncertainty distributions and not by inappropriate combinations of non-physical conservative assumptions.
- Provide a reasonable degree of completeness in treatment of appropriate combinations of failure modes; including multiple failures necessary to determine risk levels

I t is important that all key assumptions that are used to develop success criteria, to develop and apply probability and consequence models, and to select elements for incorporation into the models are clearly documented and are scrutible. Uncertainties in the collective state of knowledge are not introduced by PRA but rather are systematically exposed by the rigorous set of questions that are addressed in the development of the PRA models and results. PRA provides a means of decomposing the general problem of uncertainty and the limitations of our state of knowledge that challenge any attempt to assess the adequacy of safety into a structured set of questions about the scope, completeness, and dependencies within and among each element of the PRA.

3.2 Objectives of PBMR PRA

In order to determine the scope and necessary characteristics of the PRA that will be required for the development of licensing bases for the PBMR it is important to list the objectives of the evaluation. The objectives include:

- To confirm that the Top Level Regulatory Criteria, including that the safety goal Quantitative Health Objectives for individual and societal risks are met at a U.S. site or sites
- To support the identification of licensing basis events
- To provide a primary technical basis for the development of regulatory design criteria for the plant
- To support the determination of safety classification and special treatment requirements of systems, structures, and components (SSCs).
- To support the identification of emergency planning specifications including the location of the site boundary.
- To support the development of technical specifications

3.3 Elements of the PBMR PRA

In the case of LWR PRAs, the scope of a PRA is defined in two dimensions, with one dimension used to define the scope of the accident sequence end state and the other for the scope of initiating events and plant initial states to consider. The different treatment of end states is expressed in terms of three PRA Levels. The Level 1 PRA is used to describe the part of the PRA needed to characterize the core damage frequency (CDF); Level 2 is used to describe the aspects of the scenarios involving releases of radioactive material from the containment including the frequencies of different release states and estimates of the source terms for the releases; and Level 3 is used to characterize the aspects of the scenarios involving transport of radioactive material from the site to the ultimate determination of consequences to public safety, health, and the environment so that the frequency of different consequence magnitudes is quantified.

LWR accident initiating events are normally placed into two major categories, one for internal events and the other to capture external events such as seismic events and transportation accidents. (Internal plant flooding events are normally included as part of the internal events scope, but internal plant fires are normally included within the external events scope.) Due to the combination of inherent LWR characteristics and the fact that major changes to thermal hydraulic configuration occur during shutdown, the expansion of scope to include shutdown and low power conditions usually requires a completely different set of initiating events and event sequence models compared with the PRA models for full power initial conditions.

The scope of the PBMR PRA needed to support this risk-informed approach to PBMR licensing will be as comprehensive and reasonably complete as would be covered in a full scope, all modes, Level 3 PRA covering a full set of internal and external events. However, the inherent features of the PBMR tend to simplify the number of different elements that need to be assembled to accomplish a comparably scoped PRA in relation to an LWR.

The first observation in defining the PBMR PRA elements is that the traditional Level 1-2- 3 model of an LWR PRA that was originally defined in NUREG/CR-2300 and still used today does not fit the unique characteristics of the PBMR. Since there is no counterpart for the LWR core damage end-state, the splitting up of event sequences involving releases into Level 1 and Level 2 segments does not apply to the PBMR. The elements of the PBMR PRA are integrated around a single, event sequence model framework that starts with initiating events and ends in PBMR specific end states for which radionuclide source terms and offsite consequences are calculated. The integral PBMR PRA encompasses the functions of a full scope Level 1-2- 3 PRA.

Another distinction in the definition of PBMR PRA elements is in the treatment of initial operating states such as full power, low power and shutdown modes. In the LWR case, the early PRA work was focused on the full power-state as intuitively representing the most limiting potential for producing risk significant sequences. In the late 1980's to early 1990's it was realized that accidents initiated during shutdown were even more risk significant until controls were applied to better manage safety functions during plant activities at shutdown. Importantly, PRAs for shutdown conditions in LWRs were much more complex than for full power as there were many plant configurations to deal with and many different time frames during an outage that created a need to develop separate PRA models for each unique configuration. By contrast, the different configurations of the PBMR do not have so many different applications of the safety functions and therefore lend themselves to a single integrated PRA that accounts for all operating and shutdown states. Furthermore, the on-line refueling aspect and specifications for maintenance on the large rotating machinery (i.e., the turbo units and power turbine generator) mean that the fraction of time the plant is shutdown is expected to be an order of magnitude less than current LWRs. Hence for each PBMR PRA element, it is necessary to address applicable sequences in all modes of operation and this can be accomplished without the need for separate models for each mode of operation.

The modular aspect of the PBMR creates the potential for anywhere from one to as many as 10 reactors located at the same site. The PRA needs to account for the risk of multiple modules, which is comparable to the LWR PRA case of a multiunit site. The existence of multiple modules increases the likelihood of scenarios that impact a single module independently, and creates the potential for scenarios that may dependently involve two or more modules.

The elements of the PBMR PRA, which comprise a full scope treatment of initiating events and end states, include:

1. Initiating Events Analysis
2. Event Sequence Development
3. Success Criteria Development
4. Thermal Hydraulics Analysis
5. Systems Analysis
6. Data Analysis
7. Human Reliability Analysis
8. Internal Flooding Analysis
9. Internal Fire Analysis
10. Seismic Risk Analysis
11. Other External Events Analysis
12. Event Sequence Quantification (includes full uncertainty quantification)
13. Source Term Analysis
14. Consequence Analysis (includes full uncertainty quantification)
15. Risk Integration and Interpretation of Results
16. Peer Review

As emphasized in the current LWR PRA standards, the PBMR PRA must be capable of a thorough treatment of dependent failures including the comprehensive treatment of common cause initiating events, functional dependencies, human dependencies, physical dependencies, and common cause failures impacting redundant and diverse components and systems.

The ASME PRA standard includes both High Level and Supporting Criteria for dependency treatment that arises in essentially all of the above elements. In general, the PBMR PRA will conform tothe ASME PRA standard for PRA Capability Category III, a full quantification of uncertainties is required that must reflect the iterative nature of the PRA as the PBMR evolves from conceptual design, completion of construction, and eventual commissioning. Quantification of uncertainties provides the capability to determine the mean frequencies and consequences of each accident family to be compared against the TLRC, to compare specific percentiles of the uncertainty distributions against the criteria, and to compute the probability that specific criteria are met.

In order to support the evaluation of regulatory design criteria, the PRA will be capable of evaluating the cause and effect relationships between design characteristics and risk as well as be able to support a structured evaluation of sensitivities to examine the risk impact of adding and removing selected design characteristics.

3.4 Applicability of LWR PRA Practices and Standards

The increased use of PRA in the risk-informed regulatory process has led to a number of initiatives to address and improve PRA quality. These initiatives include an industry PRA peer review program (Reference 3) and efforts to develop PRA standards by the ASME (Reference 4), ANS (References 5 and 6) and NFPA (Reference 7). The concepts and principles that are being developed in these initiatives address both fundamental aspects of PRA technology and certain aspects that are rooted in characteristics of LWRs that are not shared by the PBMR. While the fundamental aspects are applicable, the following aspects of these quality initiatives will be modified to apply to a PBMR PRA.

- The current quality initiatives are focused on PRAs that are used to calculate CDF and LERF. If one replaces CDF and LERF with the PBMR task of providing estimates of each characteristic PBMR accident family, which is defined by appropriate combinations of PBMR specific initiating events and end-states, then the associated high level and supporting requirements can be viewed as directly applicable to the PBMR.
- As noted in the previous section it is not appropriate to fit a PBMR PRA into the mold of the Level 1 -2 -3 framework.Instead an integrated PRA that develops sequences from initiating events all the way to source terms and consequences is developed.
- As noted in the previous section, it is not necessary to perform a completely different set of PRA models for full power vs. low power and shutdown, such that the PBMR lends itself to an integrated treatment of accident sequences that cover all operating and shutdown modes.
- Unlike the current LWR applications in which it is rarely necessary to extend the PRA to Level 3, the initial PBMR applications will need to include off-site dose consequences to demonstrate the safety case and to meet licensing framework objectives.
- In view of the applications envisioned for the PBMR PRA, a full scope treatment of internal and external events is anticipated.

With these adjustments it is reasonable to apply the applicable LWR PRA standards and peer review process to assessing PBMR PRA quality until such time as PBMR specific standards and peer review processes are developed. A proposal for application of these standards to each PBMR PRA element is provided in Table 3-1. Note that the ASME standard proposes three Capability Categories to address PRA requirements for different applications. The applications envisioned for the PBMR are assumed in this PRA plan to use ASME PRA Capability Category III. This is a reasonable assumption because of the expectation that the PRA will be integral to the licensing basis of the reactor. These are the standards assumed for defining the scope, level of detail, and capability levels needed to support the risk informed approach to licensing the PBMR.

Table 3-1 Comparison of PBMR PRA Technical Elements and Applicable PRA Standards

PBMR PRA Technical Elements	Applicable PRA Standards	Comments
1. Initiating Events Analysis	• ASME PRA Standard Initiating Events Analysis • ANS shutdown PRA standard for low power and shutdown states	• PBMR and LWR PRAs essentially equivalent for this element; separate shutdown PRAs not needed for PBMR
2. Accident Sequence Definition	• ASME PRA Standard Accident Sequence Analysis • ANS shutdown PRA standard for accident sequence analysis in low power and shutdown states	• Replace LWR focus on CDF and LERF with focus on major PBMR accident classes; separate shutdown PRAs not needed for PBMR
3. Success Criteria Development	• ASME PRA Standard Success Criteria and Supporting Engineering Analysis	• Use of PRA to support licensing basis will make it easier to delineate realistic vs. conservative success criteria relative to LWRs
4. Thermal Hydraulics Analysis	• ASME PRA Standard Success Criteria and Supporting Engineering Analysis	• Computer codes to support this developed in Germany and being installed at PBMR; Existing LWR codes are not applicable to PBMR conditions
5. Systems Analysis	• ASME PRA Standard Systems Analysis	• PBMR and LWR PRAs essentially equivalent for this element except that PBMR has fewer systems to analyze
6. Human Reliability Analysis	• ASME PRA Standard Human Reliability Analysis	• PBMR and LWR PRAs essentially equivalent for this element
7. Data Analysis	• ASME PRA Standard Data Analysis	• PBMR and LWR PRAs essentially equivalent for this element
8. Internal Flooding Analysis	• ASME PRA Standard Internal Flooding Analysis	• PBMR and LWR PRAs essentially equivalent for this element
9. Internal Fires Analysis	• NFPLA Standard for Internal Fires Analysis	• PBMR and LWR PRAs essentially equivalent for this element
10. Seismic Analysis	• ANS PRA Standard External Events Analysis	• PBMR and LWR PRAs essentially equivalent for this element
11. Other External Events Analysis	• ANS PRA Standard External Events Analysis	• PBMR and LWR PRAs essentially equivalent for this element
12. Accident Sequence Quantification	• ASME PRA Standard Quantification	• LWR separation of accident sequences into Level 1-2-3 not appropriate for PBMR; scope of accident sequences includes doses at the site boundary; risk importance measures to be developed and analyzed for each major PBMR accident class
13. Source Term Analysis	• No corresponding standard	• This task is similar to the T/H and source terms analysis in an LWR Level 2 PRA which is not currently covered in LWR PRA standards
14. Accident Consequence Analysis	• No corresponding standard	• This task is similar to the consequence analysis in an LWR PRA which is not currently covered in LWR PRA standards
15. Risk Integration and Interpretation	• No corresponding standard	• This task is needed to integrate the frequency and consequence information into a frequency-consequence format and to interpret the results compared to TLRC
Not applicable	• ASME PRA Standard Level 2/LERF	• The treatment of physical and chemical

Table 3-1 Comparison of PBMR PRA Technical Elements and Applicable PRA Standards

PBMR PRA Technical Elements	Applicable PRA Standards	Comments
	Analysis	processes that impact source terms are reflected as an integral process into the PBMR accident event trees and fault trees; there is no segregation into Level 1-2-3 as in LWR PRA
16. Peer Review	• ASME PRA Standard for full power internal events, ANS external events and low power and shutdown sections on peer review; NEI guide for industry PRA Certification Peer Review process	• A peer review can be performed for each site specific PBMR PRA that reflects the PRA scope and uses applicable aspects of the NEI PRA Certification Peer Process.

4 SELECTION OF LICENSING BASIS EVENTS

With a PBMR PRA as outlined above, the selection of LBE proceeds by comparing the risk results with the three frequency-consequence regions defined on the PBMR risk criteria chart of Figure 2-1. This section describes the selection process for each of the three subsets of LBE, namely for the Anticipated Operational Occurrences, the Design Basis Events, and the Emergency Planning Basis Events. The process is utilized as the design detail and technology development proceed so that the PRA certainty advances and a final set of LBE are selected.

4.1 Anticipated Operational Occurrences

Anticipated Operational Occurrences (AOO) are selected from those families of events whose mean frequency falls within the AOO region, as shown on the risk criteria chart, and that would exceed the 10CFR50 Appendix I criteria on a mean value basis were it not for design selections that control radionuclide release. Those that meet this condition, or a bounding set of these, are designated AOO.

Families of events may have significant uncertainties in the estimate of their frequencies. The consideration of these uncertainties is necessary to ensure that all events will be assessed against the appropriate criteria. The mean value of frequency, which involves an integral over the complete uncertainty spectrum, is the selected parameter for accounting for frequency uncertainties. An additional factor (2 at the early stage of the design) is placed on the mean frequency to assure that event families falling just above or below a region are evaluated in the most stringent manner.

AOO typically have associated with them relatively small consequences. Furthermore, the uncertainties in the consequences of AOO are relatively small, and are monitored and reduced during the life of the plant. Therefore, although the PRA assessment provides the entire consequence distribution, including the mean, and upper and lower bound doses, it is appropriate that the consequences of AOO meet 10CFR50 Appendix I criteria on a mean-value basis. The mean-value represents a first order consideration of uncertainty. This consideration of uncertainty is consistent with LWR precedent for AOO.

An example of the AOO selection process utilizing comparison of a PRA with TLRC is taken from the MHTGR preapplication licensing as shown in Figure 4-1. Table 4-1 from Reference 8 provides the list of the five families of events designated as AOO in the figure. AOO-5, a small primary coolant leak in one of the MHTGR modules, is the only event with an offsite consequence. Both frequency and consequence uncertainty bands are explicitly shown in the figure.

While the other four AOO do not involve an offsite release, each involves a source sufficiently large that could exceed 10CFR50 Appendix I limits if it were not for a design feature, e.g., protection of the primary coolant boundary or isolation of the steam generator.

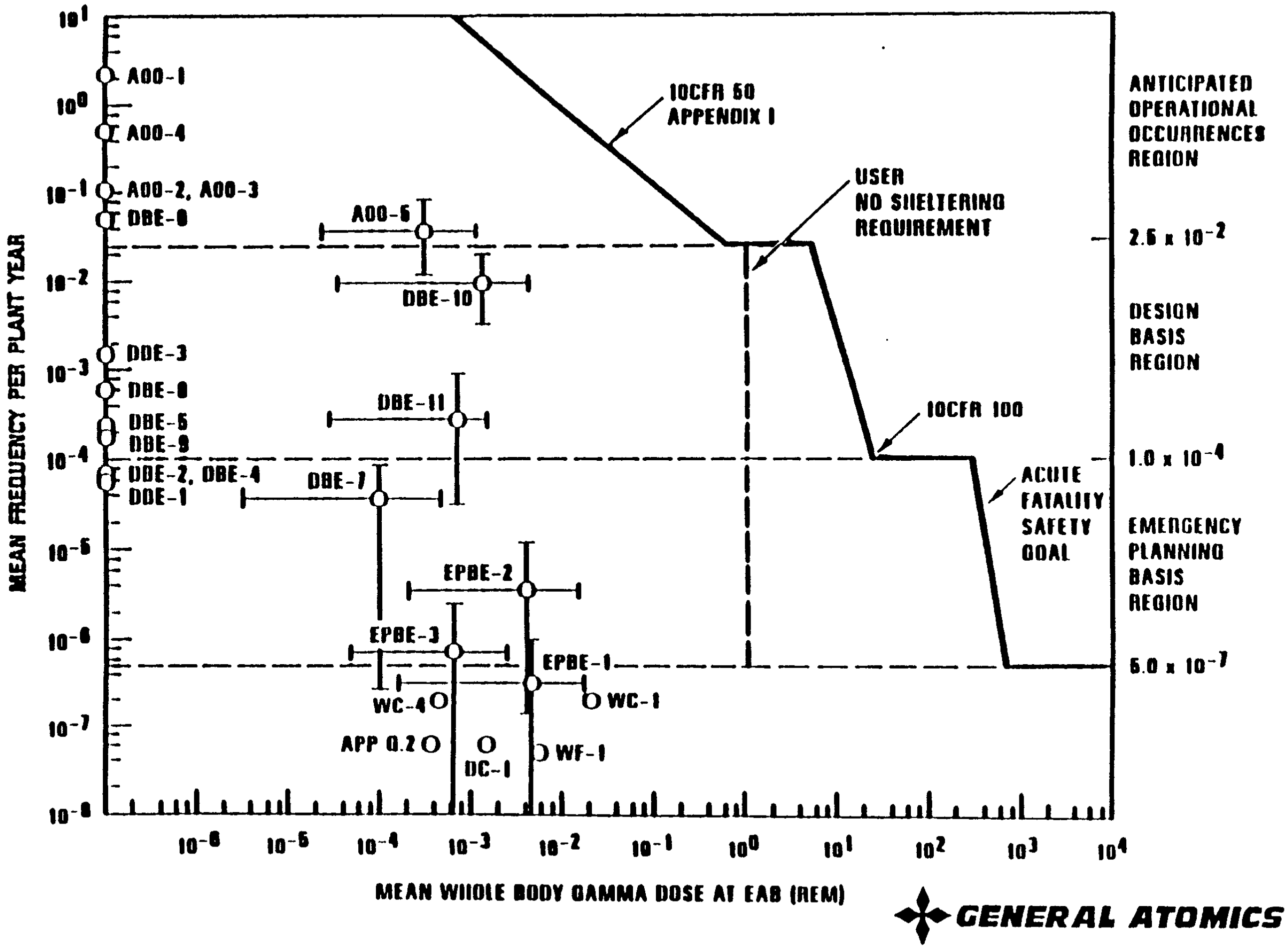


Figure 4-1 Comparison of MHTGR PRA Event Families with the MHTGR Top Level Regulatory Criteria

Table 4-1 Identification of MHTGR Anticipated Operational Occurrences (Reference 8)

AOO Designation	Anticipated Operational Occurrence
AOO-1	Main loop transient with forced core cooling
AOO-2	Loss of main and shutdown cooling loops
AOO-3	Control rod group withdrawal with control rod trip
AOO-4	Small steam generator leak
AOO-5	Small primary coolant leak

4.2 Design Basis Events

Design Basis Events are selected from those families of events whose mean frequency falls within (or within a factor of) the DBE region as shown on the risk criteria chart and that would exceed the 10CFR50.34 criteria on a mean value basis were it not for design selections that control radionuclide release. Those that meet this condition are designated DBE.

Figure 4-1 again provides an example from the MHTGR. Table 4-2 from Reference 8 provides the list of the eleven families of events designated as DBE in the figure for the MHTGR. These are lower frequency events that oftentimes involve multiple failures, both dependent and independent. An external event is included as DBE-5, which is the 0.3g SSE. Five of the eleven events have mean frequencies outside the DBE region, but were included because of their large uncertainties.

Three of the DBE have offsite doses and the mean and upper and lower bound doses are shown. Within the DBE region the both the mean values and upper bound (95% confidence) doses are compared to the criteria. The mean values provide a more consistent comparison of the doses in this region to those in the other two regions, and the upper bounds are used to be consistent with the traditional use of conservative assumptions in performance of design basis accident safety analyses for LWRs.

The PBMR would be expected to have many of these same events, albeit with different frequencies and consequence values. However, since the PBMR does not have a high pressure source of water in steam generators, water inleakage is expected to have less risk significance.

4.3 Emergency Planning Basis Events

Emergency Planning Basis Events are selected from those families of events whose mean frequency falls within (or within a factor of) the EPBE region as shown on the risk criteria chart. Those that meet this condition are designated EPBE.

Figure 4-1 again provides an example from the MHTGR. Table 4-3 from Reference 8 provides the list of the three families of events designated as EPBE in the figure for the MHTGR. These are lower frequency events that involve multiple failures, both dependent and independent. An event is included as EPBE-5, which involves all of the plant's four modules. One of the events has a mean frequency outside the EPBE region, but was included because of its large uncertainty.

All EPBE have offsite doses and the mean and upper and lower bound doses are shown. The EPBE and DBE mean doses are compared to the PAG and the EPBE mean doses together with those of the DBE and the AOO are summed over their entire frequency distribution and compared to the safety goal QHO.

Events below the EPBE region are examined to assure that the residual risk is negligible with respect to the latent mortality safety goal and to provide general assurance that there is no "cliff" in which a high consequence event goes unnoticed. The five low frequency events in Figure 4-1 below the EPBE region without an LBE number (e.g., WC-1) are examples for the MHTGR.

The PBMR would be expected to have similar events to EPBE-3 involving more than one module and still lower frequency events beyond the licensing basis would be examined to assure low residual risk.

Table 4-2 Identification of MHTGR Design Basis Events
(Reference 8)

DBE Designation	Design Basis Event
DBE-1	Loss of HTS and SCS cooling
DBE-2	HTS transient without control rod trip
DBE-3	Control rod withdrawal without HTS cooling
DBE-4	Control rod withdrawal without HTS and SCS cooling
DBE-5	Earthquake
DBE-6	Moisture inleakage
DBE-7	Moisture inleakage without SCS cooling
DBE-8	Moisture inleakage with moisture monitor failure
DBE-9	Moisture inleakage with steam generator dump failure
DBE-10	Primary coolant leak
DBE-11	Primary coolant leak without HTS and SCS cooling

Table 4-3 Identification of MHTGR Emergency Planning Basis Events
(Reference 8)

EPBE Designation	Emergency Planning Basis Events
EPBE-1	Moisture inleakage with delayed steam generator isolation and without forced cooling
EPBE -2	Moisture inleakage with delayed steam generator isolation
EPBE -3	Primary coolant leak in all four modules with neither forced cooling nor HPS pumpdown

5 REFERENCES

1. "Licensing Basis Events for the Standard MHTGR," Department of Energy Report, DOE-HTGR-86-034, Revision 1, February 1987.

2. "Top-Level Regulatory Criteria for the Standard MHTGR," Department of Energy Report, DOE-HTGR-85002, Revision 3, September 1989.

3. NEI-0002, Industry PRA Certification Peer Review Process

4. ASME PRA Standard, Draft 14, May 2001.

5. ANS PRA Standard for Low Power and Shutdown PRA

6. ANS PRA Standard for External Events

7. NFPLA Standard for Fire PRA

8. "Preliminary Safety Information Document for the Standard MHTGR," Department of Energy, DOE-HTGR-86-024, Volume 1, September 1988

PBMR Response to NRC Questions
From June 13, 2001 Meeting

Note: Proprietary information has been deleted as indicated by blank or ellipsis.

1. How do the fuel packing fractions compare – German vs. RSA?
The PBMR packing is particles per sphere, the same as the German proof test of spheres manufactured and tested in 1988. The packing fraction is well within the envelope of all the fuel the Germans tested successfully, which ranged from particles per sphere to particles per sphere.

2. Do you look for damage to the kernels during the "packing" portion of the fuel manufacturing process?
Yes.
Each uranium dioxide kernel is coated with four layers:
(1) a porous carbon buffer
(2) a pyrolytic carbon layer
(3) a silicon carbide layer and
(4) a final pyrolytic carbon layer.
After coating, they are now referred to as coated particles.
The coated particles … lot.

3. Referencing the graph showing free uranium content in fuel, what drove the improvements for the HTR-10 fuel (Chinese experience)?
As far as we know the Chinese used a similar process to that used in Germany. The improvement after initial batches with higher free uranium fraction is due to a learning process of mainly the pressing step in the manufacturing process. The same is expected to happen with the PBMR process during the production of initial fuel batches.

4. What are the reasons for the differences in the maximum fuel temperatures between PBMR and the Germans Phase I and AVR fuel temperatures?
PBMR will inquire whether any reports on the matter of the unexpected high temperatures encountered in the AVR are available in Germany. (OPEN ITEM)

5. How many pebbles do you load before seeing coolant activity?
Coolant activity is not expected until operation at power is sustained.

6. Will radial variations in coolant temperature be able to be monitored?
PBMR is not planning to place any thermocouples inside the reactor core. PBMR is considering placing thermo-couples and neutron detectors in the demonstration plant's graphite reflectors. This will detect radial (azimuthal) imbalances in power distribution.

7. With regard to pebble flow experiments, how were temperature effects accounted for?
As far as we know no tests were performed with helium at operating temperature. The Germans did perform many flow experiments with spherical balls of different materials having different friction factors. PBMR will review the German records. (OPEN ITEM)

8. Did the Germans ever find higher burn-up levels than predicted by modeling?
During operation, the burnup of each sphere is measured as it is removed from the core, prior to re-insertion. Fuel spheres that would exceed the limit if re-inserted for an additional cycle were permanently discharged. PBMR will inquire whether there was any fuel that exceeded the burnup limit, including fuel that was in the reactor at the time the AVR was shut down. However, fuel has been irradiated to burnups higher than planned for PBMR. (OPEN ITEM)

9. What confidence do you have that pebbles don't actually get "hung up" in the core? Any insights from AVR?
The Germans had some fuel spheres restrained from movement by the graphite reflector. PBMR is reviewing this issue with the Germans although it has a different graphite reflector design based on this experience. (OPEN ITEM)

10. It was noted that the presentation had been focused on German experience. What are the plans for this (PBMR) fuel?
PBMR fuel plans will be presented to NRC on July 18, 2001. (OPEN ITEM)

11. NRC noted the need for Quality and Acceptance Testing details.
In the proprietary session following the public session PBMR presented the fuel product specifications, source of fuel materials and characteristics to be measured for QC checks.

12. Did AVR testing simulate load following (temperature/power transient issue)?
Not that we are currently aware of.

13. NRC questioned the appropriateness of using the Poisson distribution for modeling (failure fraction vs. temperature).
The heading of the slide on page 28 of the presentation on June 13, 2001 was in error. The slide in fact shows results using a binomial distribution and not a Poisson distribution.

14. Referencing page 32 of handout, if the test results are for various fuel batches (rather than for the reference AVR 21-2 fuel), what is the significance of the results?
This slide demonstrates that….

15. Will the burn-up measurement system be digital?

Yes.
The system will measure Cesium-137 activity. Major components of the system are its collimator, Germanium detector and amplifier/signal processor/computer assembly. The burn-up measurement system operates in an automated manner. Controls to the system and measurement results from the system are interfaced to the Fuel Handling and Storage System operational control system via input and output signals. A local operator interface display and keypad panel is provided at the system's electronic enclosure for calibration, troubleshooting and maintenance activities. Testing, validation and proving the equipment performance are planned.

16. What is the asterisk on the anisotropy values?
It refers to the fact that ….

17. How does the drop strength test height (   ) compare with actual drop height?
The actual drop….

18. How does the number of drops in test (   ) compare with expected number of drops in operation?
A fuel sphere is expected to be recycled in the core….

19. What is the source of the corrosion limit   ?
It came from German material graphite standard.

20. On page 17 with regard to these QC checks, were these German tests or will they be the QC checks done for PBMR?
They were the tests done in Germany and will be the QC checks for PBMR.

21. On page 20, are the methods specified new, or the same as the Germans?
The same as the Germans.

22. On page 26, within the test designation numbers, what do K and P mean?
K refers to a sphere, P to a particle.

23. On Page 27, what was method of heat-up?
Heat-up was done via oven testing. Zero failures observed**.**

24. What is definition of failure fraction?
PBMR distinguishes fuel anomalies as:

1. Fuel manufacturing defects as measured by the free uranium fraction which includes tramp uranium (failed particle fraction – the fraction of coated particles that have been damaged in manufacture).
2. Fuel mechanical failures as measured by broken or cracked spheres as a result of drops, handling damage etc.
3. Fuel failures in the reactor is measured by Krypton-85 level in the coolant above the level than can be expected from manufacturing defects.

25. On Page 32, how is a fast neutron defined?
Neutrons with energies greater than 0.1 Mev.

26. NRC noted that it would need to help establish acceptance criteria – Safety Limits, Operating limits, etc.
Another meeting will be planned with the NRC discussing Safety analysis, Design basis accidents, operating limits, etc., at the appropriate time.

27. What are PBMR's nuclear material control and accountability plans?
PBMR has developed a conceptual plan that has been endorsed by IAEA. The issue of material accountability will be addressed at a future meeting. (OPEN ITEM)

28. NRC requested more detail about source term projections, analysis, testing plans, etc. Expected release in terms of time and temperature and the uncertainty related to the release projection.
A separate presentation to the NRC will be made on the radiological effects during steady state, transient and accident conditions at the appropriate time.
(OPEN ITEM)

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PBMR CONSTRUCTION SCHEDULE

July 17, 2001

Joe Sebrosky, NRR Future Licensing Organization

PBMR Construction Schedule

- 5/25/01 Exelon letter provides a proposed schedule for PBMR construction
  - Proposes COL issuance of 4/15/05
  - Proposes ITAAC satisfied for first module 12/01/06
- Compressed construction schedule from previous designs
- Staff needs to know details of pre-COL construction activities (e.g., schedule for fabrication of major components)
  - Attached is a composite construction schedule from “The Revised Construction Inspection Program,” dated October 1996 (Table W)
  - Composite construction schedule provides an example of information that is of interest for the construction inspection program