Process for Selection of Licensing Basis Events for the PBMR

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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

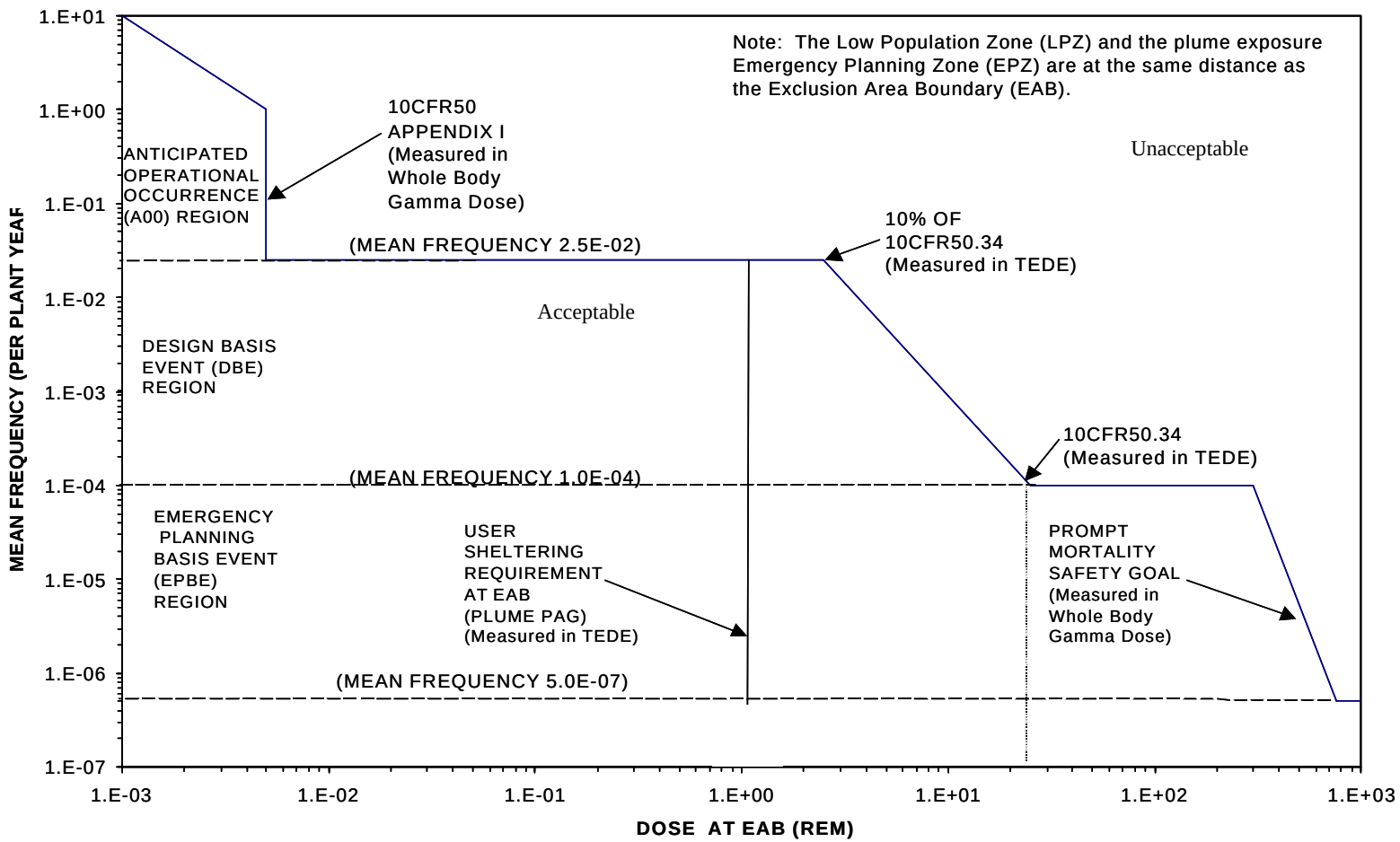
Bases for
Top Level Regulatory Criteria

- 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

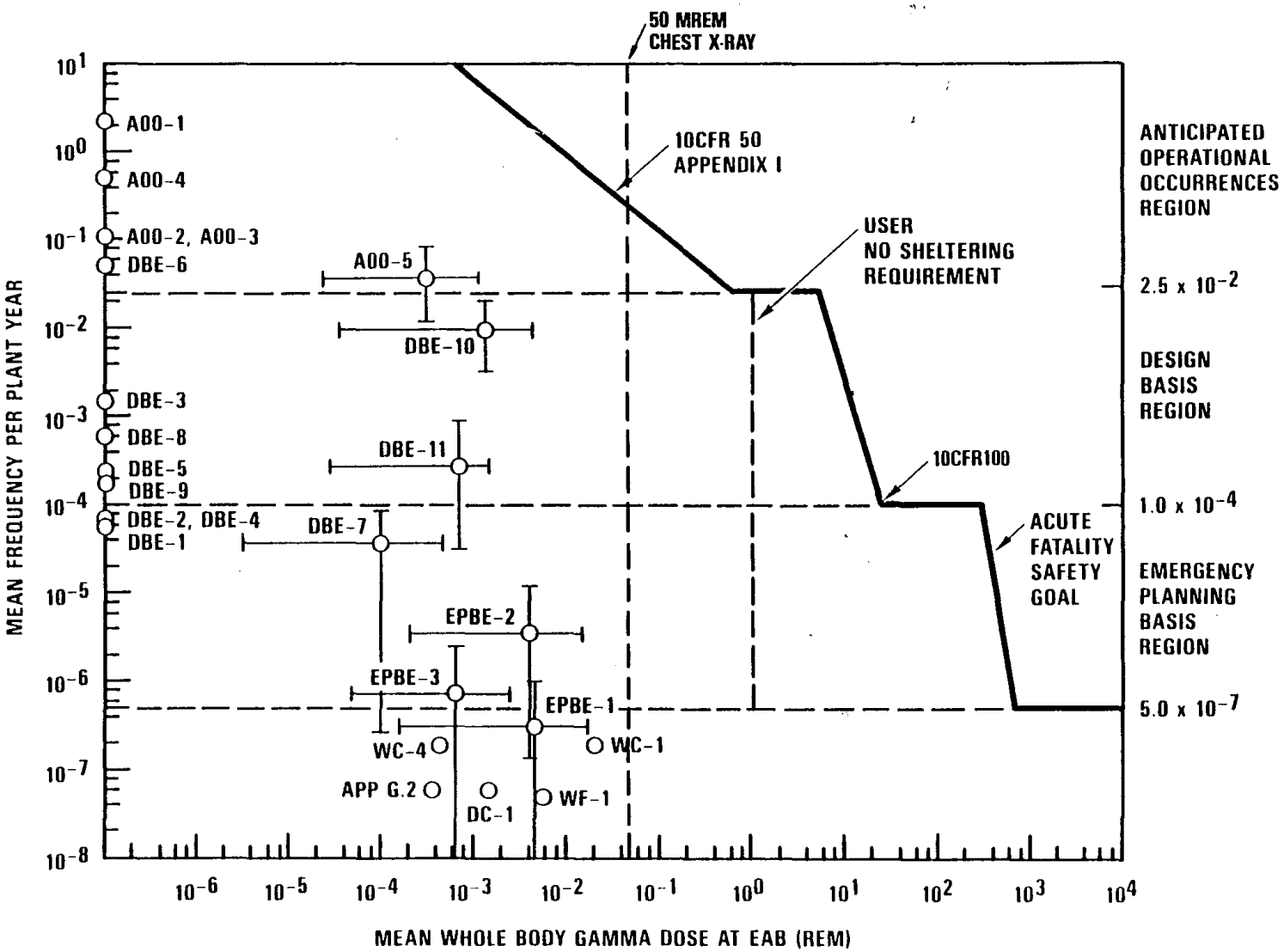
Applicability of LWR PRA Standards

- 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

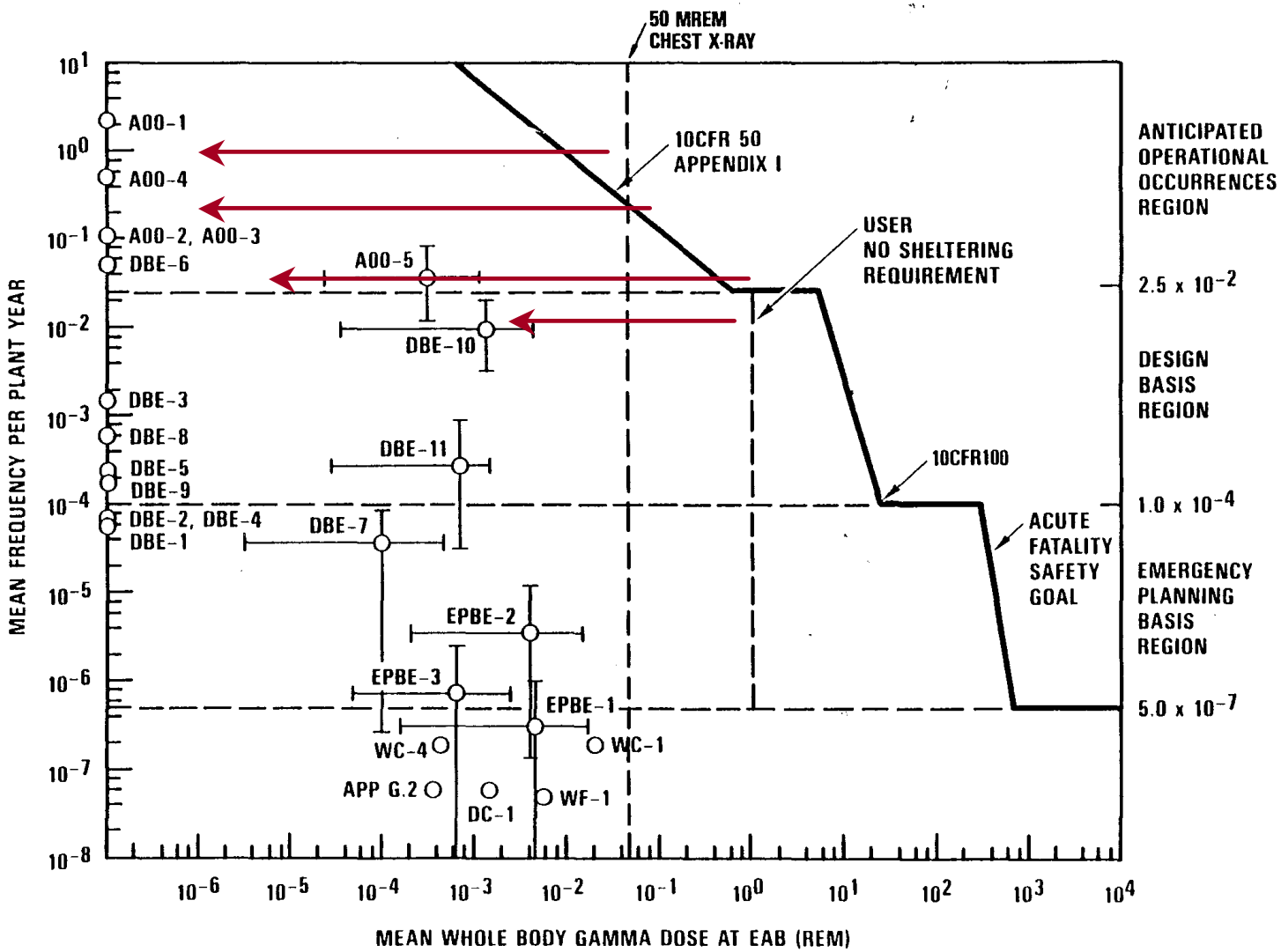
MHTGR Licensing Basis Events



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

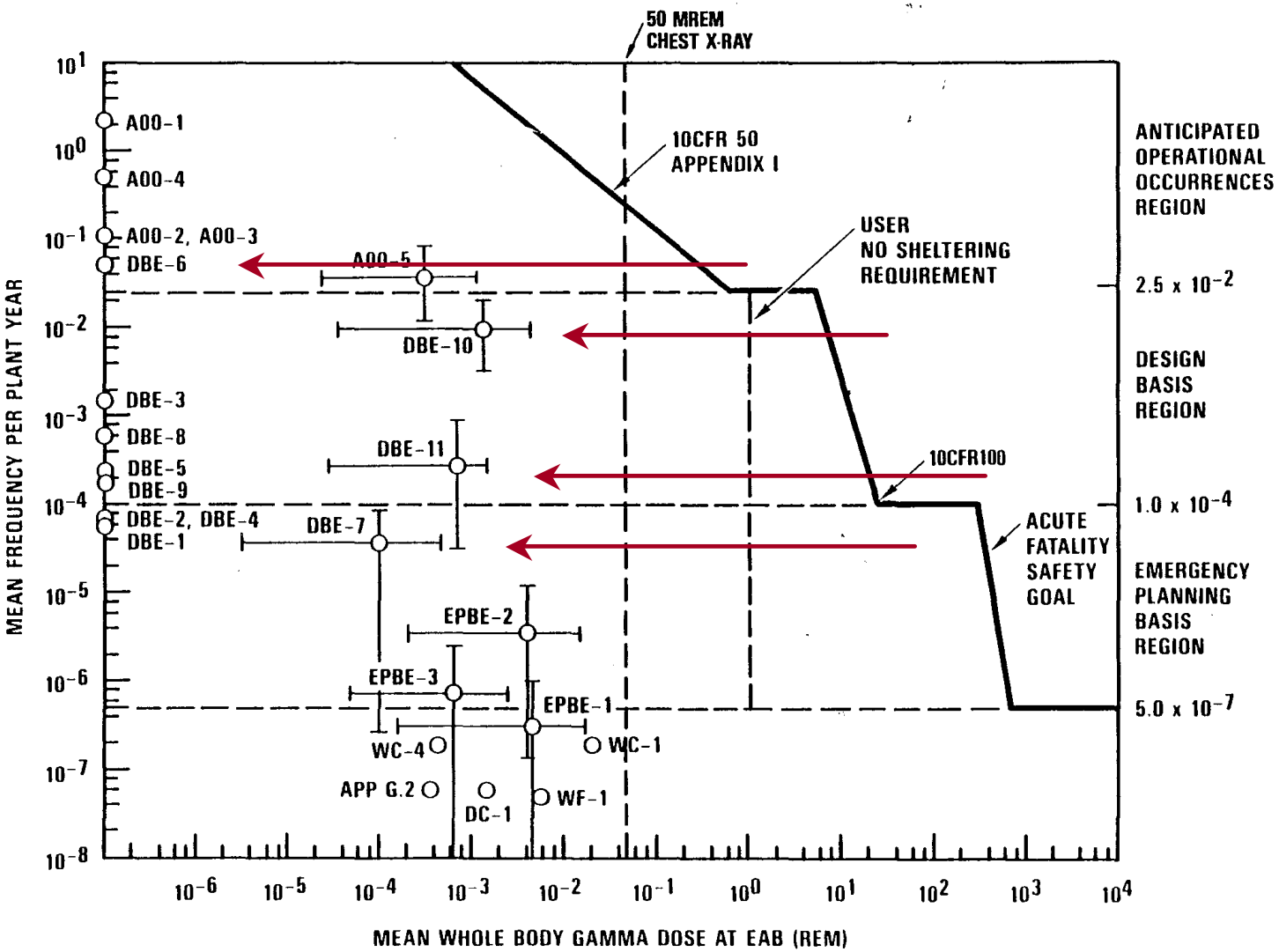
AOO Designation	Anticipated Operational Occurrences
AOO-1	Main loop transient with forced cooling
AOO-2	Loss of main and shutdown cooling loops
AOO-3	Control rod group withdrawal w/ control rod trip
AOO-4	Small steam generator leak
AOO-5	Small primary coolant leak

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

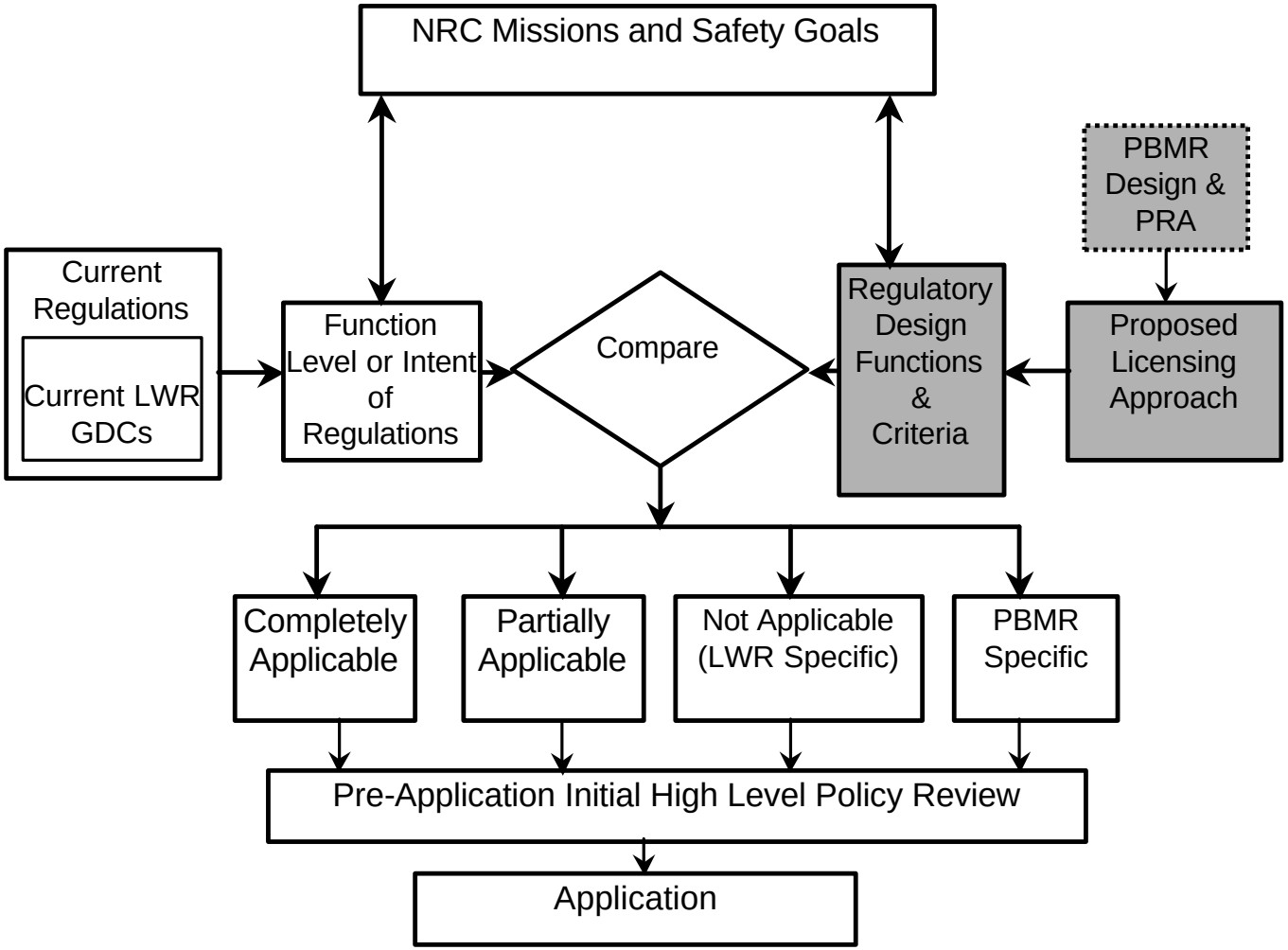


DBE Examples from MHTGR

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

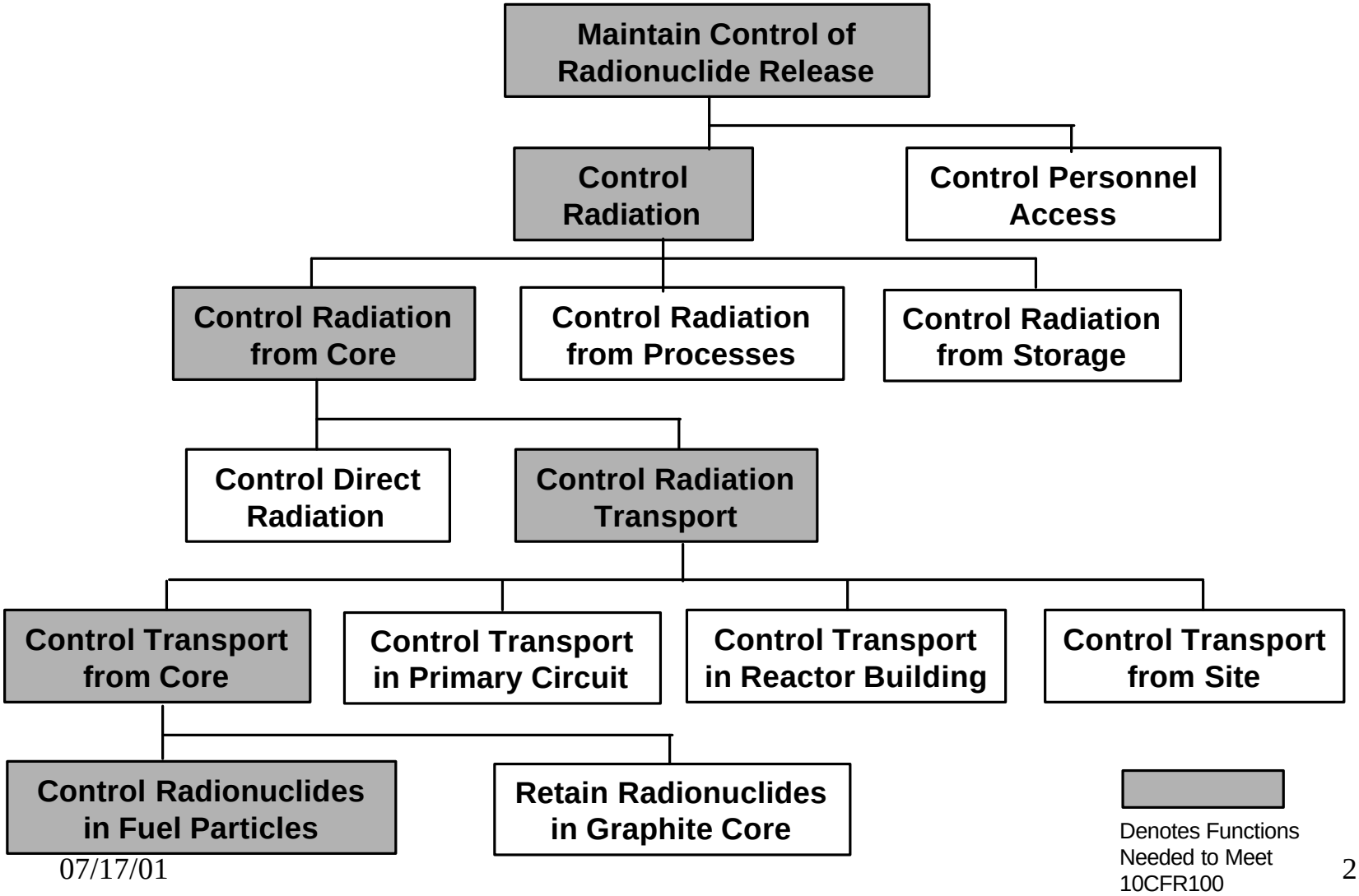
Use of PRA Insights for Regulatory Document Review



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