Planning for Pre-application Focus Topic: Selection of Licensing Basis Events & PRA

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Discussion Outline

- Issue Definition & Objective Outcomes
- Issue Details for Planning
- Communication Information
- Suggested Sequence of Activities
- References

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Issue Definition

- **Background**
  - Licensing Basis Event determination for non-LWRs is not well established in current regulatory practice or requirements.
  - The use of PRA to better understand plant design and performance in normal, abnormal, design basis and beyond design basis events is an essential element of modern safety assessments and encouraged by NRC Policy.

- **Issue**
  - Establish the mechanisms and approaches to determining Licensing Basis Events for the PBMR design using a combination of probabilistic and deterministic methods

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Outcome Objectives

- **Agreement on selection method:**
  - Use of PRA to select a comprehensive set of event sequences
    - *Inclusion of multiple and common cause failures*
    - *Treatment of events affecting more than one reactor module*
    - *Inclusion of external events and shutdown events*
    - *Inclusion of statistically-combined uncertainties in frequencies and consequences*
    - *Highlight defense-in-depth by explicitly considering all SSCs capable of performing a safety function*
  - Based on the mean frequencies of event sequences per plant year
  - Event sequences < TBD/plant year need not be considered

- **Agreement on the role of defense-in-depth in LBE selection**

- **Agreement that the PBMR process is consistent with the Staff's technology-neutral licensing framework**

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Blend of Probabilistic & Deterministic Methods

- Probabilistic methods include fault trees and event trees and statistical treatment of uncertainties
- Deterministic methods include initiating events and traditional assumptions in terms of which SSCs respond and the use of the single failure criterion
- Postulation of bounding events are also a deterministic tool.

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Licensing Basis Events

- **LBEs are all the events considered in the licensing basis and include:**
  - Anticipated Operational Occurrences (AOOs)
  - Design Basis Events (DBEs)
  - Beyond Design Basis Events (BDBEs)
- **LBEs are evaluated collectively to show compliance with Quantitative Health Objectives (QHOs) of Safety Goals.**
- **LBEs define *when* the TLRC must be met**

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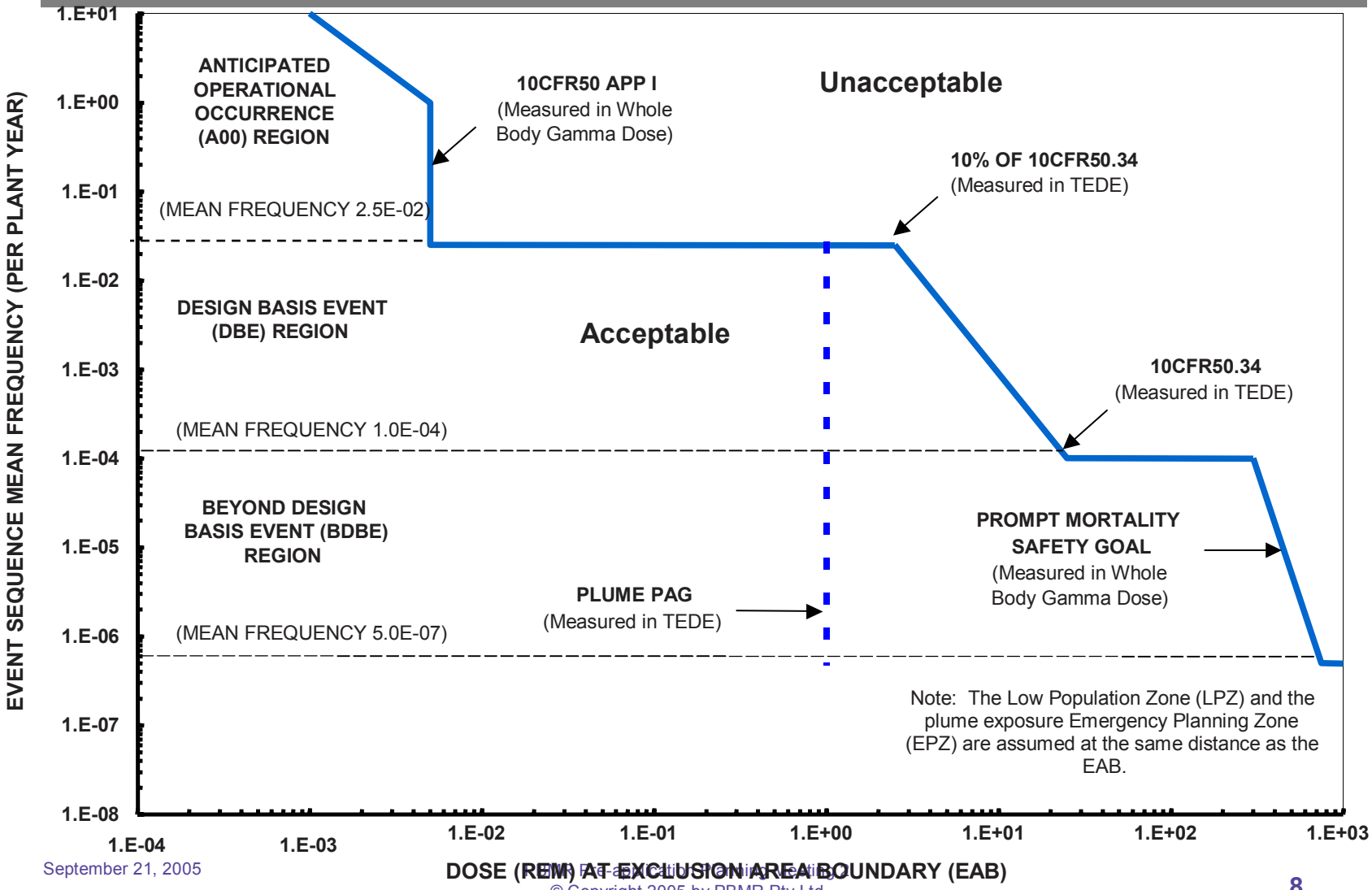
Example Frequency-Consequence Chart with Top Level Regulatory Criteria



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Ref: Exelon letter dated March 15, 2002, "Revision of Exelon Generation Company's Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States," Section 4.

Anticipated Operational Occurrences

- **Events expected once or more in the plant lifetime**
  - plant defined as having up to 8 reactors
  - a plant lifetime of 60 years assumed
  - lower frequency of 0.01/plant year
- **Identified as families of events that could exceed criteria in 10 CFR 50, Appendix I, *if certain equipment or design features had not been selected***
- **Consequences realistically analyzed for compliance with 10 CFR 50, Appendix I**
- **Used as basis for operational limits, such as tech specs**

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Preliminary PBMR AOOs

AOO Designation	Anticipated Operational Occurrence
AOO-1a	Loss of Power Conversion Unit with SBS forced cooling
AOO-1b	Loss of Power Conversion Unit with CCS forced cooling
AOO-2a	Control rod group withdrawal with SBS forced cooling
AOO-5a	Heat Exchanger tube break, manually isolated with CCS forced cooling

Ref: Exelon letter dated March 15, 2002, "Revision of Exelon Generation Company's Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States," Section 4. AOO's were associated with the 268MWt design

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Design Basis Events

- **Design Basis Events (DBEs) are events of lower frequency than AOOs, not expected to occur in the lifetime of the plant**
  - lower boundary frequency of 10^{-4}/plant year
  - events at 10^{-4}/plant year have less than 1% chance of occurring
- **Identified as families of event sequences with similar initiating events and safety function responses that could exceed 10 CFR 50.34 dose criteria *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 10 CFR 50.34 including safety margin**
- **Used as basis for design, such as SSC classification and for establishing actions for events that exceed EPA Protective Action Guidelines (PAGs)**

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Preliminary PBMR DBEs

DBE Designation	Design Basis Event
DBE-1c	Loss of PCU w/ core conduction cooling to RCCS
DBE-2b	Control rod withdrawal w/ CCS forced cooling
DBE-3a	Small, auto isolated HPB break w/ SBS forced cooling
DBE-3b	Small, manually isolated HPB break w/ CCS cooling
DBE-4a	Small, unisolated HPB break w/ pumpdown w/ RCCS cooling
DBE-4b	Small, unisolated HPB break w/o pumpdown w/ RCCS cooling
DBE-5b	HX tube break, manually isolated w/ RCCS cooling

Ref: Exelon letter dated March 15, 2002, "Revision of Exelon Generation Company's Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States," Section 4. DBE's were associated with the 268MWt design

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Preliminary PBMR DBEs (Cont'd)

DBE-6a	HX tube break unisolated w/ pumpdown w/ RCCS cooling w/ filterered release
DBE-6b	HX tube break unisolated w/ pumpdown w/ RCCS cooling w/ unfiltered release
DBE-6c	HX tube break unisolated w/o pumpdown w/ RCCS cooling w/ filtered release
DBE-6d	HX tube break unisolated w/o pumpdown w/ RCCS cooling w/ unfiltered release
DBE-7a	Medium, auto isolated HPB break w/ SBS cooling
DBE-7b	Medium, isolated HPB break w/ CCS cooling
DBE-11a	Safe shutdown earthquake w/ SBS cooling
DBE-11b	Safe shutdown earthquake w/ CCS cooling

Ref: Exelon letter dated March 15, 2002, "Revision of Exelon Generation Company's Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States," Section 4. DBE's were associated with the 268MWt design

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Lower Frequency of Design Basis Region

- **The frequency of an event in the design basis region should not be expected in the lifetime of a plant:**
  - Lower boundary frequency @10^{-4}/plant yr, < 1% chance
- **PBMR plant has up to 8 modules (with ~1/8th the inventory):**
  - Equivalent to ~10^{-5}/reactor yr for independent events
- **Comparison to requirement important:**
  - To account for uncertainties, if the assessed upper bound of the mean frequency of the event sequence is >10^{-4}/plant year, the event is a DBE.
- **10^{-4}/plant yr is consistent with regulatory practice:**
  - Core damage events for LWRs are beyond design basis events.
  - RG 1.174 establishes an acceptance guideline of 10^{-4}/reactor yr for CDF, events beyond the design basis.
- **10^{-4}/plant yr is reasonable and sufficient:**
  - A lower frequency (e.g., 10^{-5}/plant yr) would establish unduly conservative and possibly prohibitive design requirements.
  - Adequate safety for events less than 10^{-4}/plant yr is ensured by requiring conformance with Safety Goals.

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Beyond Design Basis Events

- **Called Emergency Planning Basis Events (EPBEs) in DOE MHTGR and Exelon PBMR preapplication interactions**
- **Events that are not expected to occur during the lifetime of a fleet of plants**
  - lower frequency of 5×10^{-7}/plant yr
  - necessary meet prompt fatality safety goal QHO
- **Consequences realistically evaluated for compliance with EPA Protective Action Guidelines (PAGs) dose limits**
- **Used as basis for rare event analysis for establishing actions for events that exceed EPA PAGs**
- **Some of the BDBEs will be included in the selection of Design Basis Accidents as discussed later**

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Preliminary PBMR BDBEs

BDBE Designation	Beyond Design Basis Events
EPBE-3c	Small, isolated HPB break w/ core conduction cooling to RCCS
EPBE-7c	Medium, isolated HPB break w/ RCCS cooling
EPBE-8a	Medium, unisolated HPB break w/ RCCS cooling w/ filtered release
EPBE-8b	Medium, unisolated HPB break w/ RCCS cooling w/ unfiltered release
EPBE-9a	Large, isolated HPB break w/ forced cooling
EPBE-10b	Large, unisolated HPB break w/ RCCS cooling w/ unfiltered release

Ref: Exelon letter dated March 15, 2002, "Revision of Exelon Generation Company's Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States," Section 4. BDBE's were associated with the 268MWt design

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Lower Frequency of LBE Regions

- The frequency of an event in the beyond design basis region should not be expected in the lifetimes of a fleet of plants: @ $5x10^{-7}$/plant year, <1% for >200 plants with 60year lifetimes

- Proposal consistent with meeting the prompt fatality Safety Goal: events with frequency $<5x10^{-7}$/yr automatically meet individual risk goal

- Open to other proposals for a de minimus threshold, but must have a lower frequency below which events are no longer the basis for the license

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Full Scope All-Mode PRA

- Includes single and multiple failures within a system and within systems performing common functions
- Considers common cause failures in initiating events and in responding events
- Includes events impacting one or more modules
- Considers internal and external events
- Includes events from full and part power and shutdown
- Includes reactor and non-reactor sources
- Based on mean values of frequency and consequences with explicit treatment of uncertainties

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PBMR PRA Scope Requirements

- Comprehensive treatment of initiating events, sequences, and end states
- Includes operating experience from power industry including Light Water Reactors (LWRs), Magnox, Advanced Gas Reactors (AGRs), and High Temperature Gas Reactors (HTGRs)
- PBMR PRA will address all modes of operation including shutdown, and internal / external events
- PBMR design characteristics support use of integrated event tree structure from initiating events to end states for accident family consequences and frequencies, including uncertainties

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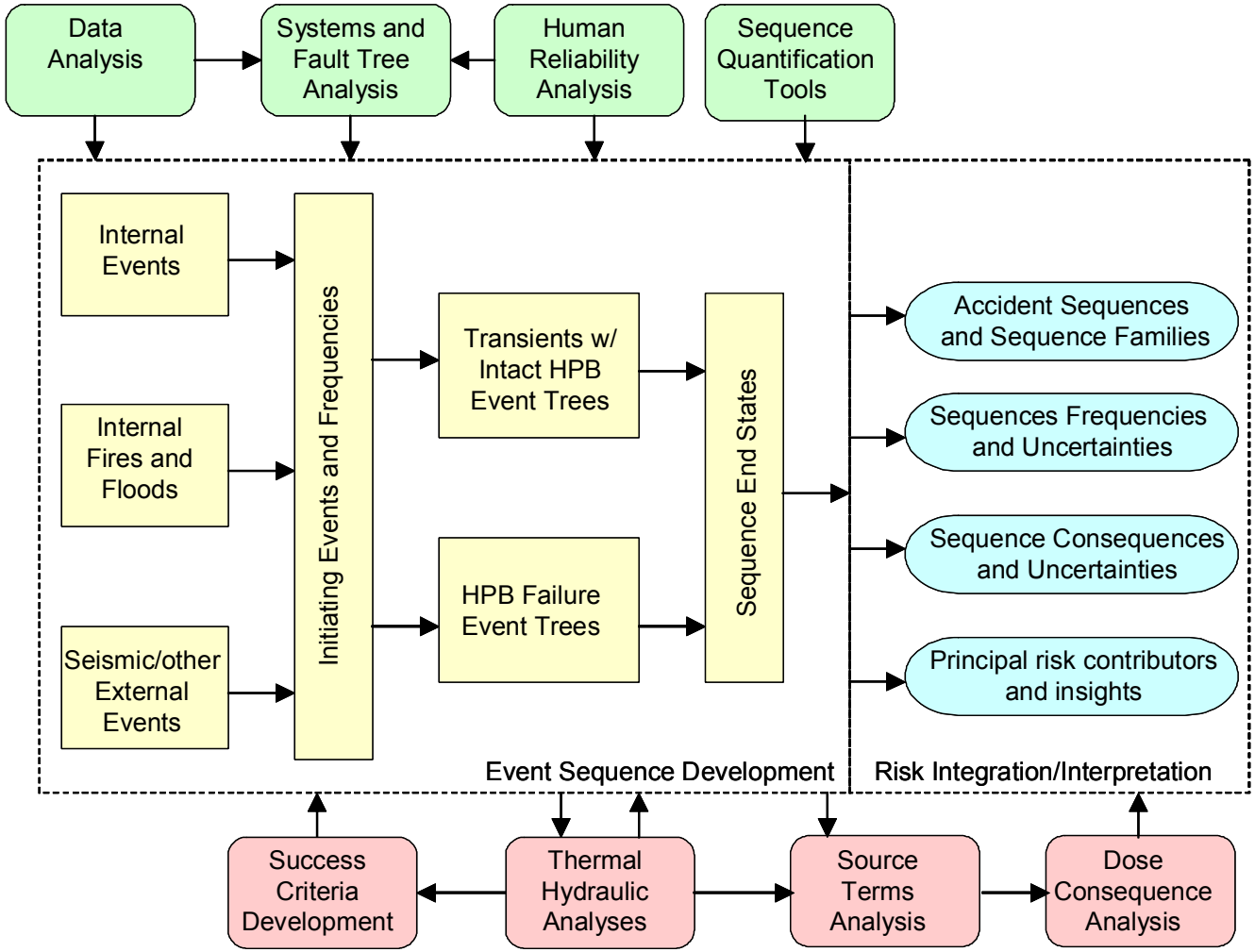
Planned Activities in the PBMR PRA



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Usage of Terms

- **Initiating event** is a frequency either in terms of per reactor year or per plant year depending on the type of event and the likelihood of a common cause.

  NB: results from common events and independent events are summed to show all results on a per plant basis

- **Plant responses** to the initiating event are probabilities (zero to one with no units).

- **Event sequence** includes the initiating event and the plant responses and is a frequency.

- **Event sequence families** sum similar plant responses in the event tree for a given initiating event (e.g., successful isolation automatically and by operator action) and is a frequency.

- **Release categories** sum the event sequence families with similar offsite consequences (e.g., release of circulating activity from several initiating events) and is a frequency.

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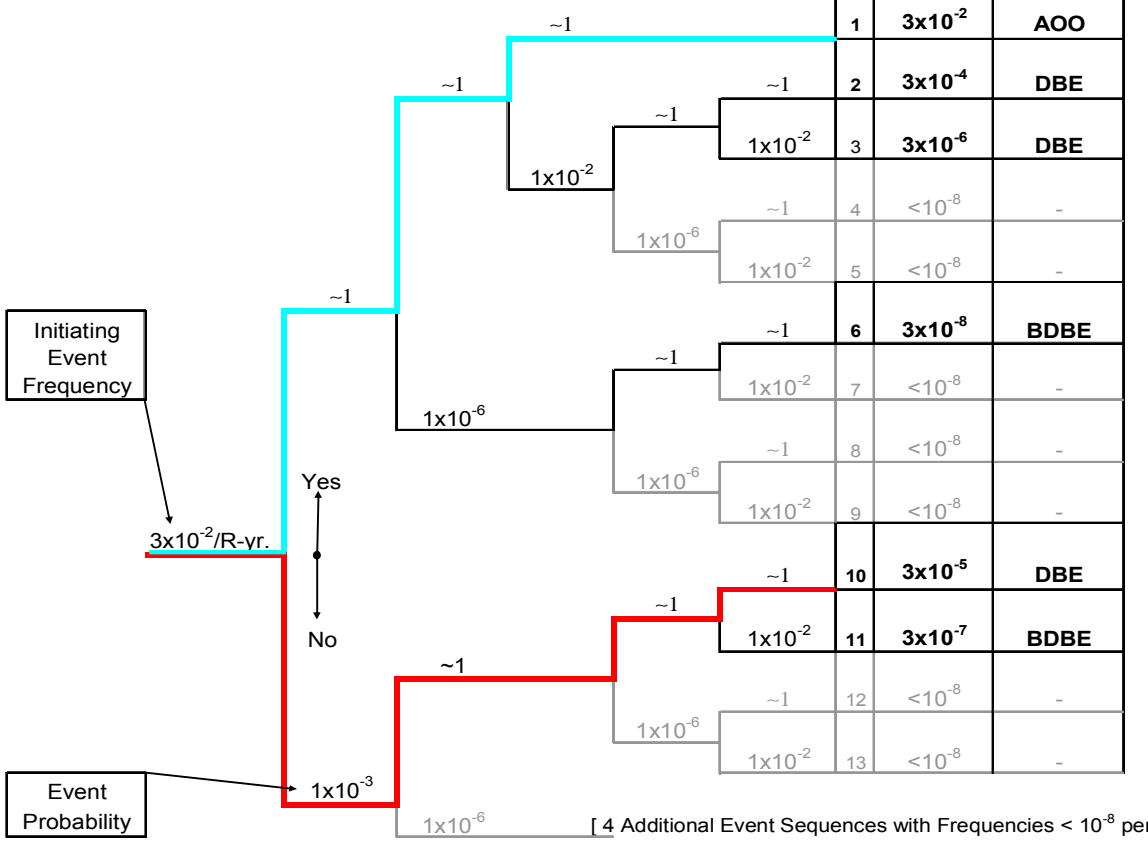
Example Abbreviated Event Tree with Initiating Event & Event Sequence Families



Initiating Event: MPS HX Tube Break	Break Isolation via Maint. Valve	Reactor Trip via RCS/RSS	Core Heat Removal via CCS	Core Heat Removal via RCCS	Release Filtration via HVAC	Sequence No.	Event Sequence Frequency per R-yr.	LBE Type
			~1			1	$3x10^{-2}$	AOO
		~1			~1	2	$3x10^{-4}$	DBE
			1x10-2	~1	1x10-2	3	$3x10^{-6}$	DBE
				1x10-6	~1	4	$<10^{-8}$	-
					1x10-2	5	$<10^{-8}$	-
	~1	1x10-6		~1	~1	6	$3x10^{-8}$	BDBE
				1x10-6	1x10-2	7	$<10^{-8}$	-
					~1	8	$<10^{-8}$	-
					1x10-2	9	$<10^{-8}$	-
	1x10-3	~1		~1	~1	10	$3x10^{-5}$	DBE
					1x10-2	11	$3x10^{-7}$	BDBE
				1x10-6	~1	12	$<10^{-8}$	-
					1x10-2	13	$<10^{-8}$	-

[4 Additional Event Sequences with Frequencies < 10^{-8} per reactor year]

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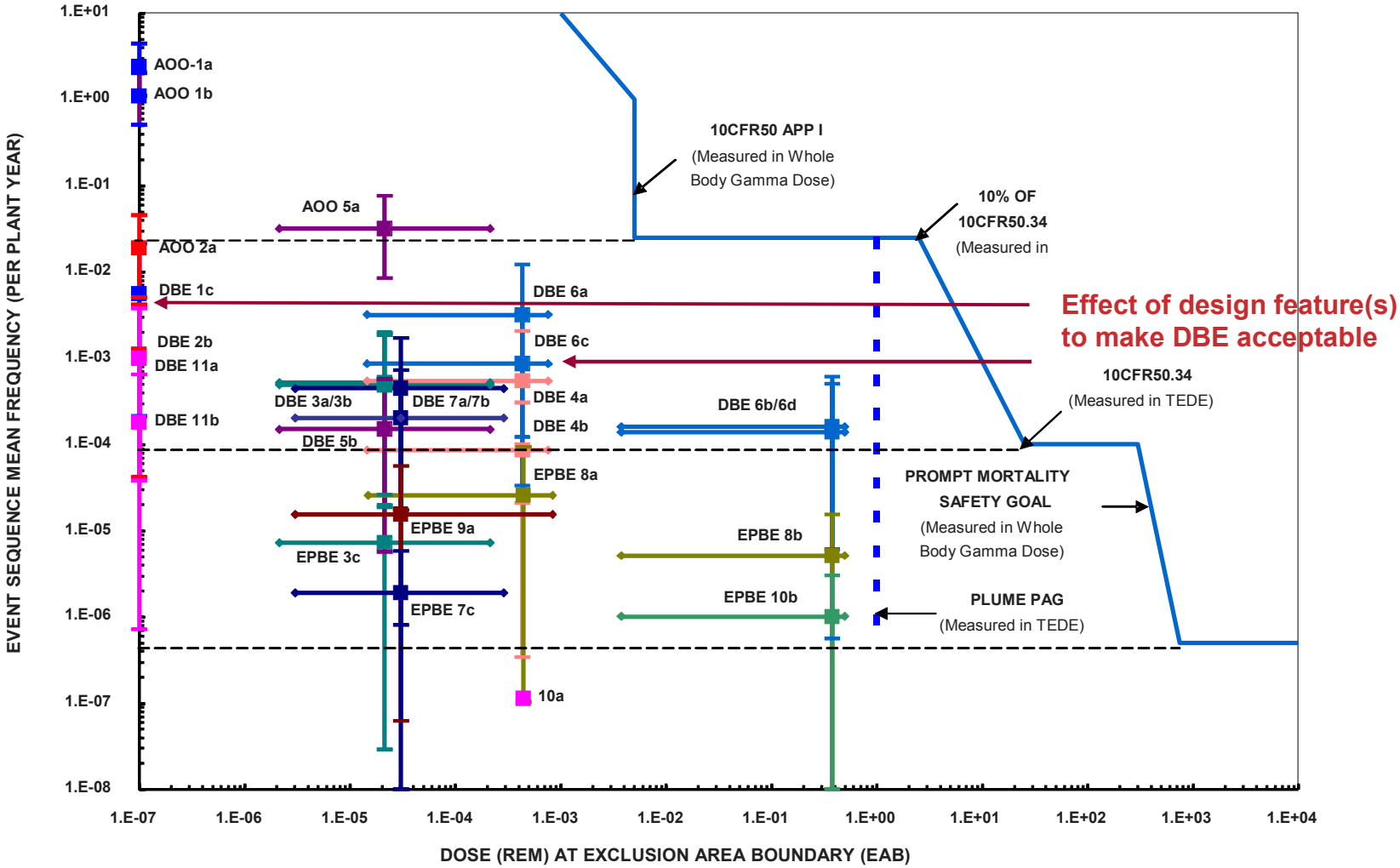
Example of Selection of DBE



Effect of design feature(s) to make DBE acceptable

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Treatment Of Rare Events Of Very Low Frequency

- Postulated events assessed for first order approximation of frequency
- Scoping calculation of realistic consequences performed
- Risk compared to NRC Safety Goals to assure low residual risk
- Example of process implemented by DOE-NRC preapplication interactions on MHTGR with Bounding Event Sequences

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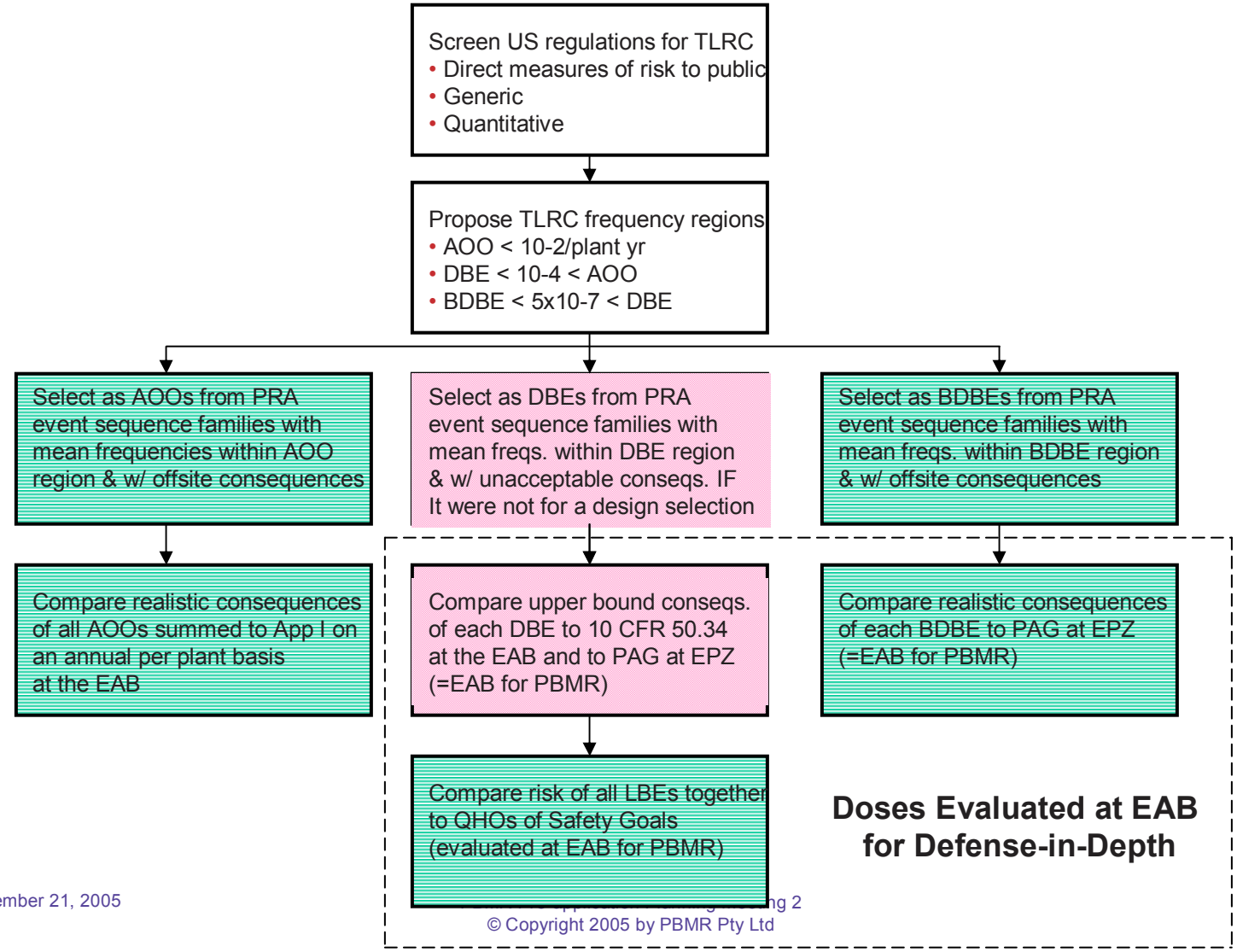
Summary of Selection and Evaluation of LBEs



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Issue Focus

- **Issues with LBE selection include**
  - Use of PRA risk insights to select a comprehensive set of risk-informed event sequences
  - Extent of inclusion of multiple and common cause failures
  - Extent of inclusion of events affecting more than one reactor module
  - Extent of inclusion of external events and shutdown events
  - Best means to account for uncertainties in frequency and consequences
  - Events to use for operational limits, events for design, events for emergency planning, and events for meeting safety goals
  - Rare events that are sufficiently low in frequency that they need not be considered
  - Best means to harmonize PBMR process with the Staff's technology neutral framework development

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Typical Terms and Definitions

- Initiating event
- Master logic diagram
- Event sequence
- Event sequence family
- Release category
- Common cause failure
- Dependent failure
- Independent failure
- Frequency – Consequence Chart
- Complementary Cumulative Distribution Function Curve
- Exclusion Area Boundary
- Emergency Planning Zone

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Example Terms Not Used

- Loss of Coolant Accident
- Core Damage Frequency
- Severe Accident
- Large Early Release Frequency
- Credit for
- Core Melt
- Postulated Initiating Events

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Exelon RAIs

Area of Review	Timing	Pre-application Work Item(s)
White Papers		
PBMR Operational Modes and States		
RAI 7.1.1	**1**	
Licensing Approach		
RAIs 1-9	**1**	

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Proposed Strategy

- Develop an LBE and PRA white paper with PBMR examples
- Workshop to discuss the white paper and outcomes; propose DCA specification on this topic
- NRC review and provide RAIs
- Revise the white paper and resubmit for NRC final consideration
- Confirm DCA content specification

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References

- **Exelon pre-application interactions**
  - Exelon letter dated March 15, 2002, “Revision of Exelon Generation Company’s Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States,” Section 4.
  - Exelon presentation to ACRS, “Proposed Licensing Approach for the Pebble Bed Modular Reactor in the United States,” October 2001.

- **DOE submittal to NRC, “Preliminary Safety Information Document for the Standard MHTGR,” Volume 1, Section 3, August 1992, Amend 11.**

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