NGNP Next Generation Nuclear Plant

Implementation of a Risk Informed Licensing Approach

NGNP Project
December 11, 2008
Rockville, Maryland

Meeting Agenda

- NGNP Licensing Strategy Overview
- Proposed NGNP Risk-Informed Performance-Based Approach
- Selection of Licensing Basis Events
- Summary of Previous Licensing Activities

Meeting Purpose

- Per the Licensing Strategy, a focused 3 year pre-application period commences in 2010
  - Key pre-application documents to be developed in 2009
  - Establish a clear & common understanding of the Licensing Strategy implementation options
- Provide a summary description of the methods being developed
- Obtain NRC Staff insights & feedback on the specific topics discussed

Attendees

- An integrated contract team is being managed by INL on behalf of DOE in support of NGNP. The team includes:
  - The three gas-cooled reactor suppliers
  - Experienced LWR owner-operator
  - Experienced architect-engineers
  - R&D inputs from multiple labs, universities, and members of the gas-cooled reactor community

Approach to Addressing Issues With NRC

Establish Areas of Initial Focus

- Support development and implementation of updated guidance for HTGR compliance with existing regulations, while minimizing the need for new or revised regulations and rulemaking
- Agree on pre-application issues with NRC
  - Those that could have significant impact on preparation of a successful licensing application
  - NGNP Team submits white papers or topical reports
  - Conduct workshop with NRC and stakeholders
  - NRC issues Requests for Additional Information (RAIs)
  - NGNP Team responds to RAIs and updates submittals, as needed
  - NRC documents its conclusions and identifies remaining issues to be addressed in the application

Meeting Objectives

- *Confirm common understanding of definition and objectives of Option 2 in NGNP Licensing Strategy Report to Congress*
- *Provide overview of risk-informed performance-based (RIPB) process for NGNP Option 2*
- *Define preapplication activities to set the stage for a successful RIPB design and licensing review*
- *Determine next steps to achieve preapplication objectives*

Preapplication Objectives

Reach agreement that:

- *RIPB approach adequately addresses objectives of NRC Policy Statements with respect to Advanced Reactors, Risk, and Safety Goals and aligns with the NGNP Licensing Strategy*
- *The scope and use of NGNP deterministic and probabilistic analyses are reasonable for the intended uses in design and licensing*
- *RIPB approach accounts for uncertainties in a conservative and bounding manner to provide assurance that the LBEs and DBAs derived from the design and PRA are appropriate for as-built and as-operated plants*

Preapplication Objectives
(cont)

- *The NGNP definition of defense-in-depth is appropriate*
- *Sufficient information on the NGNP approach to defense-in-depth required to support licensing of the NGNP design will be included in the COL*
- *The NGNP RIPB licensing approach will provide a well defined regulatory framework for the development and deployment of subsequent commercial HTGRs*

Overview of Development & Content of the NGNP Licensing Strategy

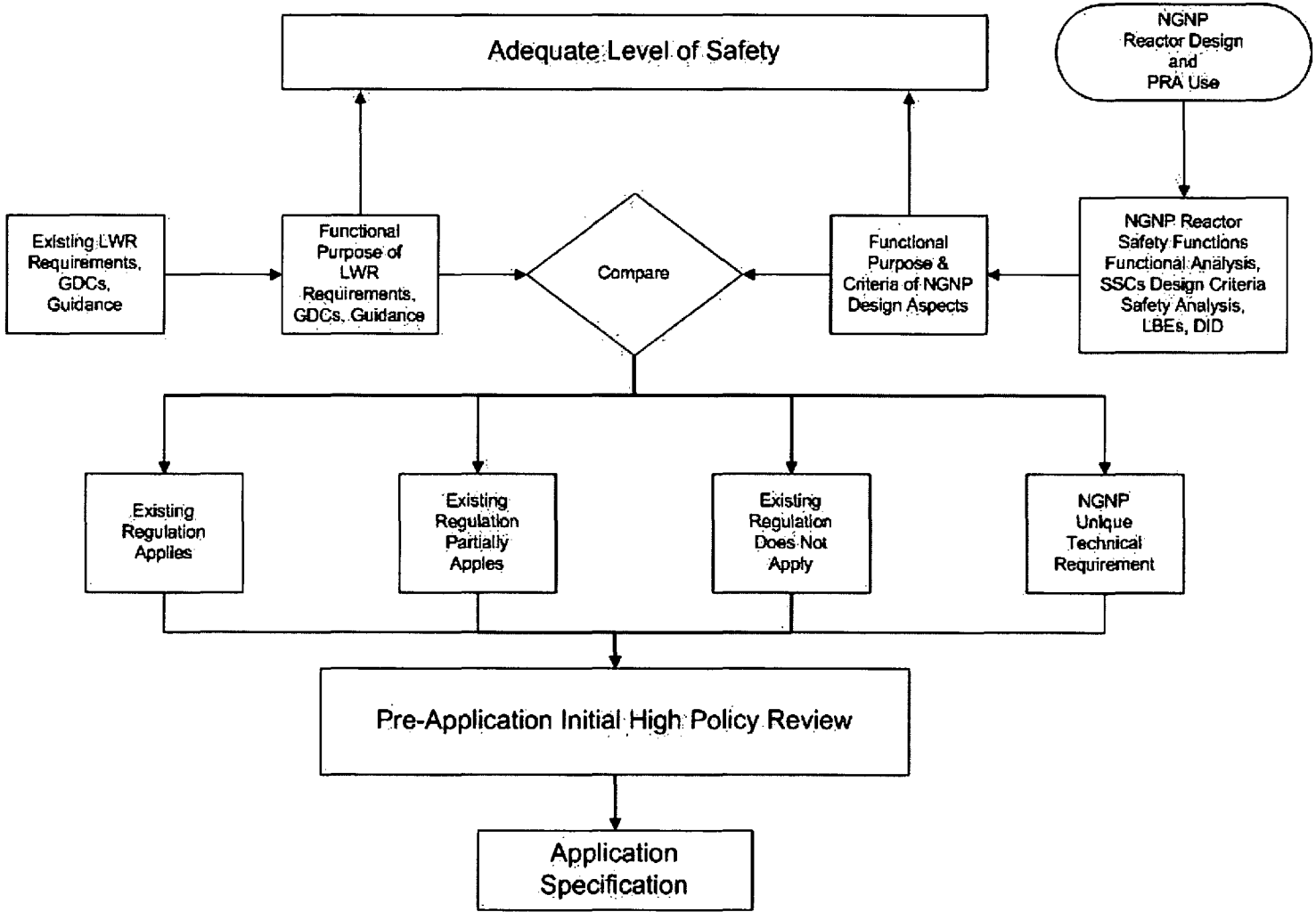
Presentation Outline

- NGNP Licensing Strategy Report to Congress
- LWR Requirements Evaluation Process
- Options for Adapting LWR Requirements
- NGNP Implementation Approach

NGNP Licensing Strategy Report to Congress

- Recommends 10 CFR Part 52 licensing approach
  - Submit Combined Operating License application that contains final safety system design information sufficient for application review
- Modify existing LWR rules using a methodology consistent with Option 2
  - Option 2: Deterministic judgment and analysis complemented by probabilistic insights

LWR Requirements Evaluation Process



LWR Requirements Evaluation Process

- Starts with design information supported by a PRA
- LBEs determine design functions and capabilities needed for prevention and mitigation of LBEs
- RIPB insights affect applicability and adaptability of LWR requirements, and determination of needed additional technical requirements
- Design functions and capabilities are compared to LWR regulatory requirements and criteria
- Levels of applicability are determined, including need for new technical requirements unique to NGNP

Options for Adapting LWR Requirements

- Option 1 – Deterministic
- Option 2 – Deterministic complemented by Probabilistic
- Option 3 – Probabilistic complemented by Deterministic
- Option 4 – New risk-informed regulatory framework

Option 2

- *Risk-Informed Performance-Based*
  - *Uses deterministic engineering judgment and analysis, complemented by design-specific PRA information*
  - *<u>Less</u> emphasis on use of the PRA than Options 3 and 4*
  - *The ability to use PRA information will be a function of the PRA quality and completeness*

Option 2 Details

- *Event categories include:*
  - *Frequent events (normal operations & anticipated operational occurrences)*
  - *Infrequent events (design basis events), and*
  - *Rare events (beyond design basis events)*
- *Conservative deterministic engineering judgment (based on experience) is used to select bounding LBEs in each event category*
- *Bounding event selection would consider probabilistic insights*
- *PRA used to directly select LBEs in each event category to complement the bounding LBEs*

NGNP Licensing Implementation Approach

- *Meet the expectations of the NGNP Licensing Strategy Report to Congress*
  - *Utilize 10 CFR Part 52 licensing process, through development of a COL application*
  - *Using RIPB approach consistent with Option 2*
- *Objectives:*
  - *Ensure adequate public safety*
  - *Maximize the probability of establishing a comprehensive safety basis*
  - *Acknowledge the safety characteristics provided by gas-cooled reactor designs*
  - *Build a well defined regulatory framework for future gas-cooled reactor applications*

Approach Basis

- *Current regulations are not fully applicable to a non-LWR*
- *Option 2 relies (in part) on deterministic licensing experience that is limited for gas reactors, complimented by RIPB safety design basis knowledge*
- *NGNP will use RIPB approach to provide rigor while utilizing deterministic measures to address uncertainties or completeness issues about regulatory requirements*

NGNP RISK-INFORMED PERFORMANCE-BASED SAFETY DESIGN APPROACH

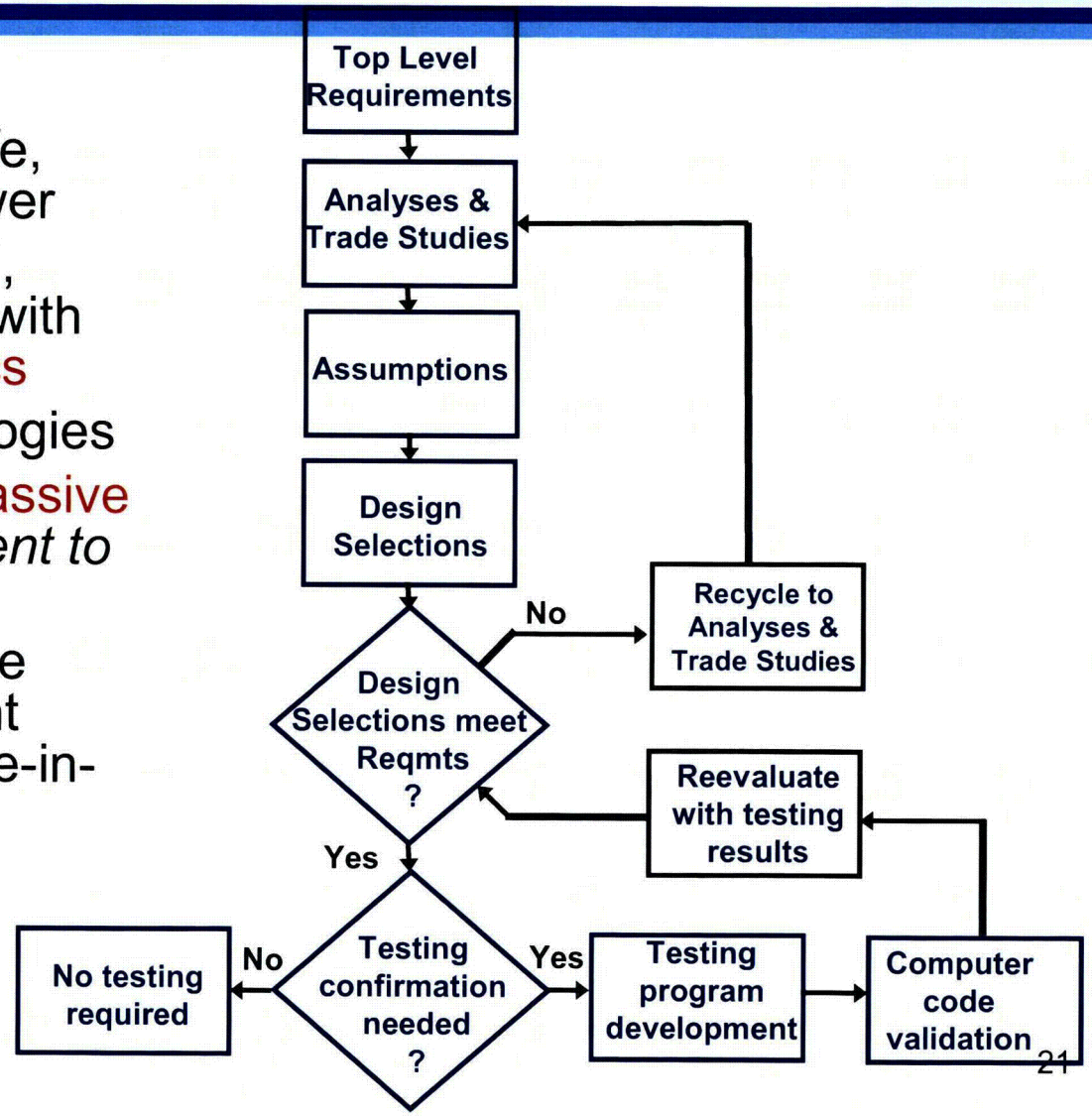
Evolution of RIPB Safety Design Approach

- NGNP RIPB Safety Design Approach incorporates lessons learned from:
  - MHTGR pre-licensing review including NUREG-1338
  - Exelon PBMR licensing approach and NRC RAIs
  - Experience gained from risk informing LWR regulations and implementing 10 CFR Part 52
  - PBMR US Design Certification White Papers and NRC RAIs
  - NRC Technology Neutral Framework (NUREG-1860)
- Enhancements to approach include:
  - Adopted Top Level Safety Criteria (TLSC) vs. TLRC
  - Modified TLSC in AOO region
  - Explicitly addresses cumulative risk relative to QHOs
  - Safety Related Design Conditions now described as deterministic Design Basis Accidents (DBAs)
  - Use of three vs. two SSC safety categories with prevention/mitigation linked to reliability/capability and special treatment requirements
  - Clarified approach to defense-in-depth and integrated it with other elements of the licensing approach

NGNP Design Basics

Iterative Design Approach

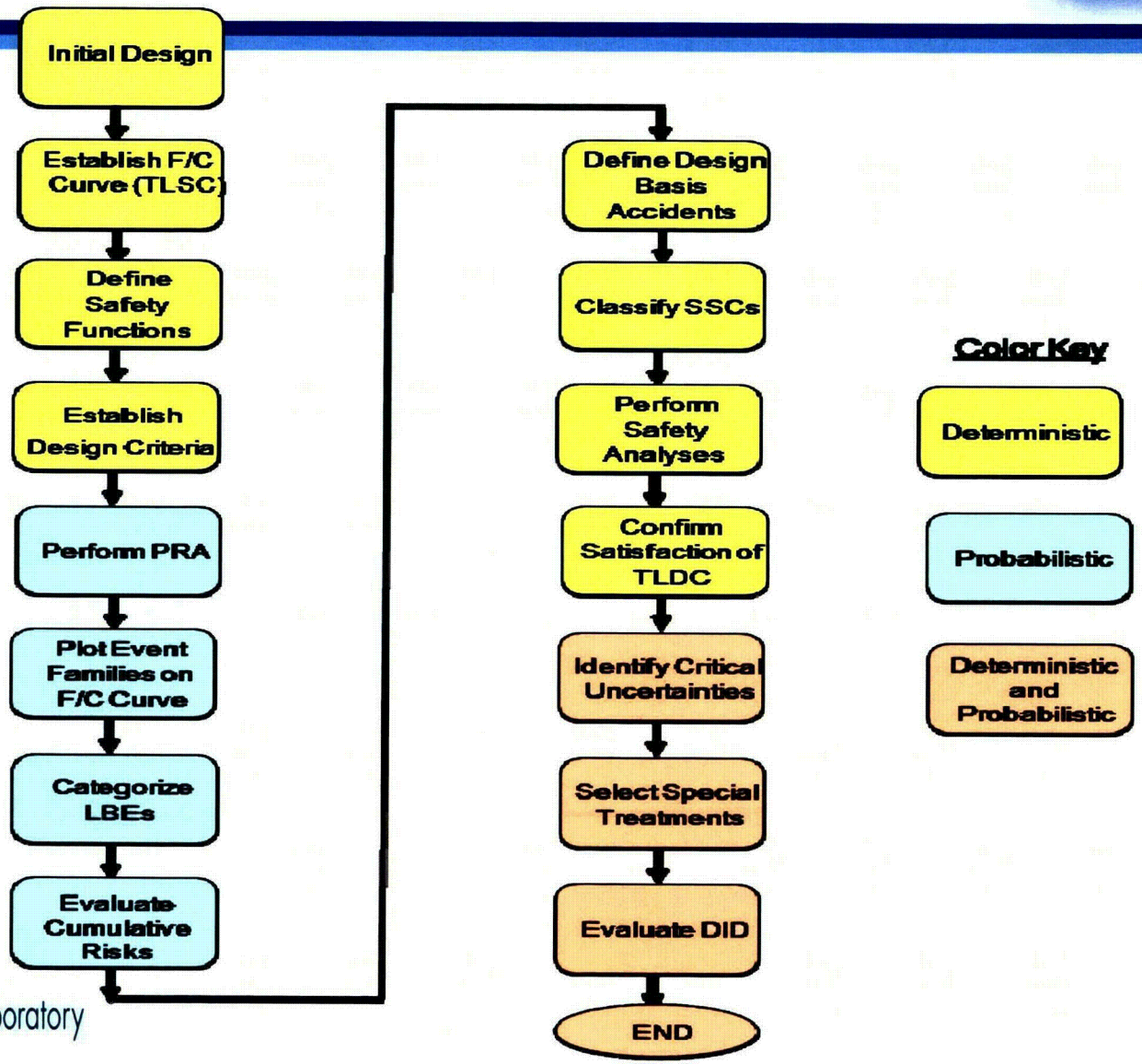
- Objective: Provide safe, economic reliable power
- Select compatible fuel, moderator, & coolant with inherent characteristics
- Utilize proven technologies
- Design reactor with passive safety features *sufficient to protect the public*
- Supplement with active features for investment protection and defense-in-depth



Idaho National Laboratory

NGNP Safety Design Process

(adapted from draft ANS 53.1)

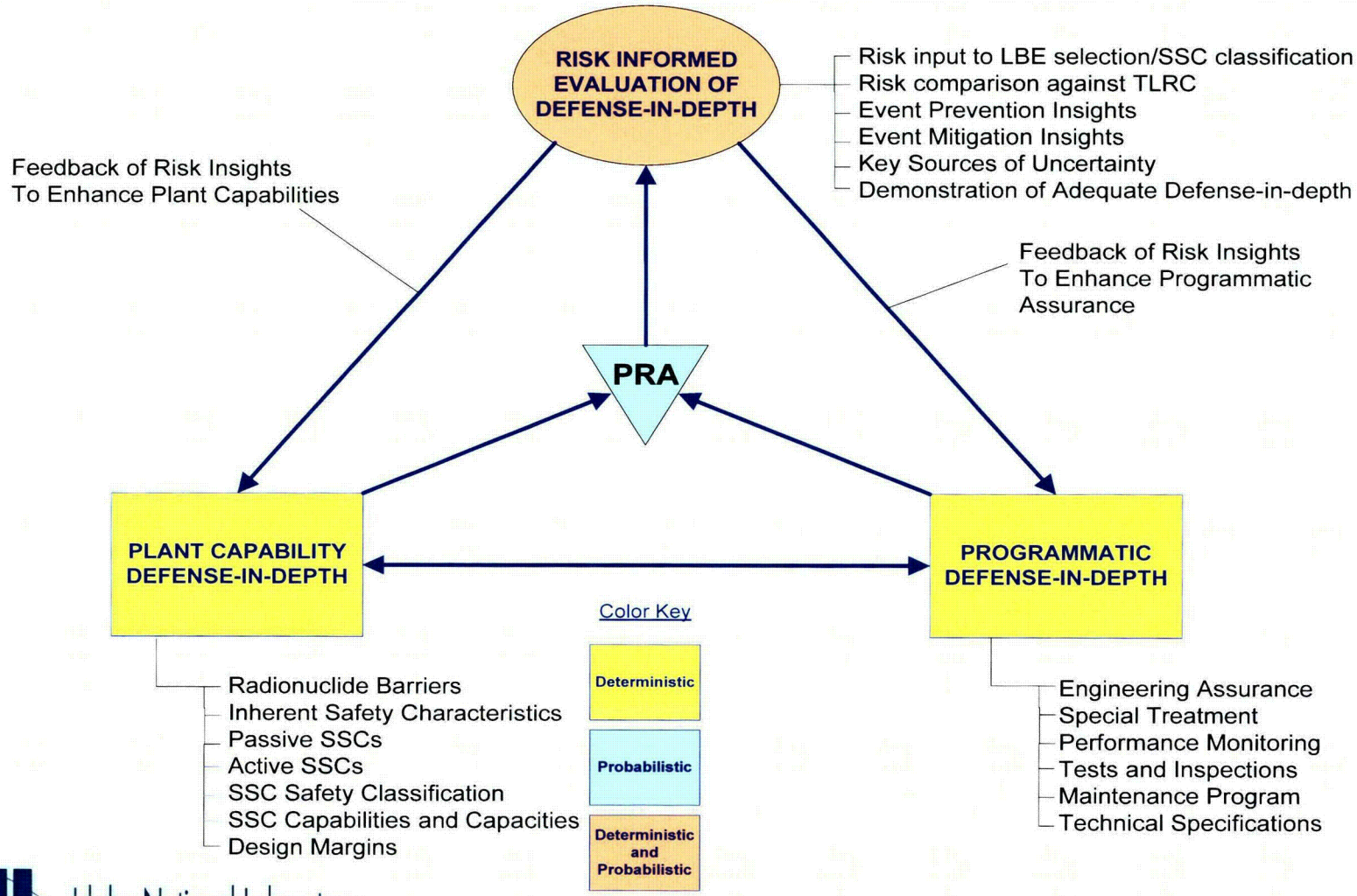


Idaho National Laboratory

Purpose of Each Element of Approach

Elements of Approach	Purpose
• Top Level Safety Criteria (TLSC)	• Establish what level of safety must be achieved in terms of the frequencies and radiological doses of event sequences
• Licensing Basis Events (LBEs)	• Define when and under what conditions the TLSC must be met based on event sequences selected from the PRA
• Reactor Specific Safety Functions • Safety Classification of SSCs • Top Level Design Criteria	• Establish how it will be assured that the TLSC are met
• Deterministically Selected Design Basis Accidents (DBAs) • Special Treatment Requirements • Plant Capability Defense-in-Depth • Programmatic Defense-in-Depth	• Provide assurance as to how well the TLSC are met by satisfying deterministic requirements to reduce uncertainties in the probabilistic results

Defense-in-Depth: An Integral Part of the Approach



Idaho National Laboratory

NGNP Next Generation Nuclear Plant

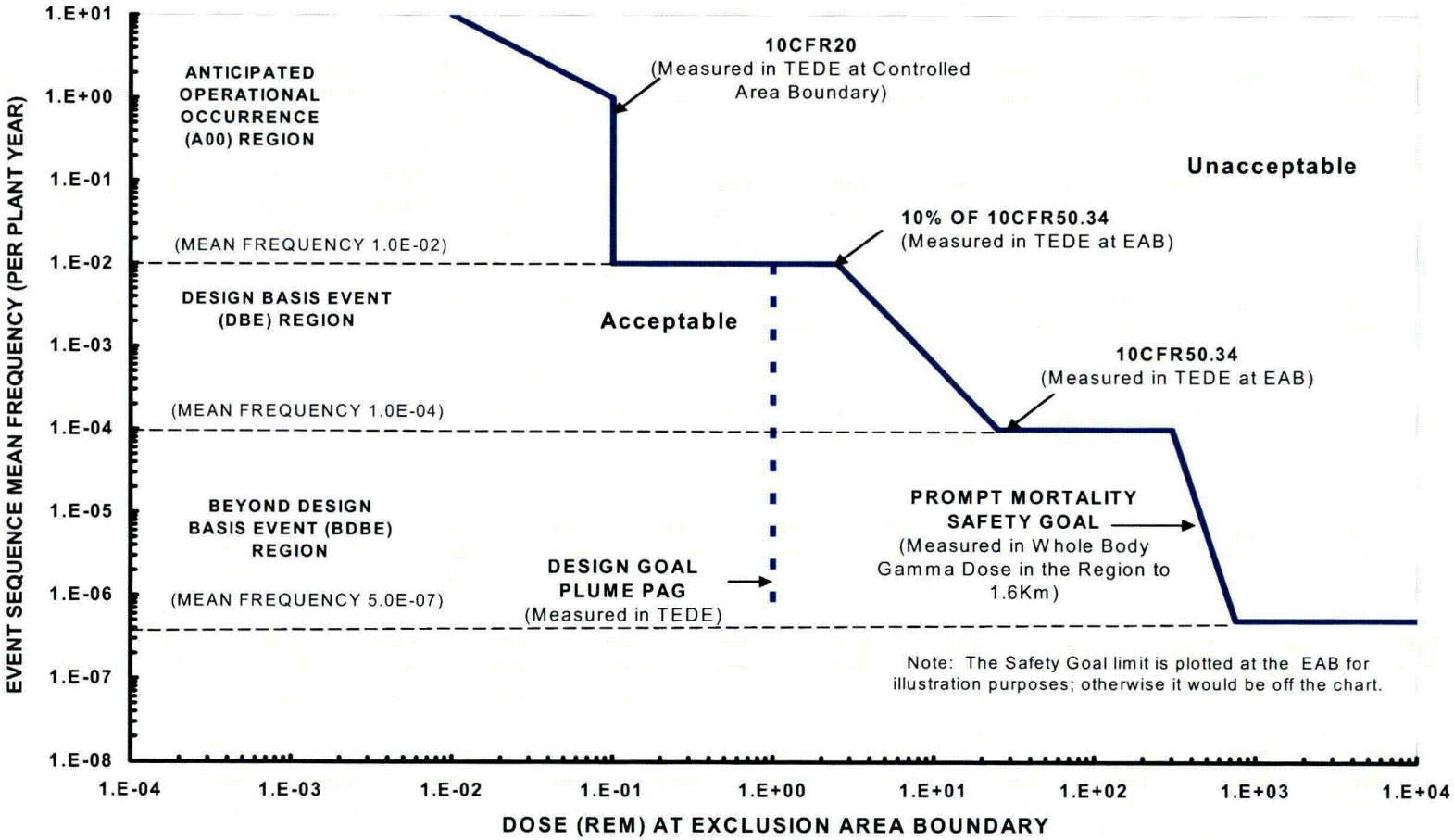
Top Level Safety Criteria (TLSC)

Idaho National Laboratory

Regulatory Foundation for TLSC

- Reactor Safety Goal Policy Statement (51 FR 28044)
- 10 CFR Part 20, 'Standards for Protection against Radiation (Subpart D, Radiation Dose Limits for Individual Members of the Public)'
- 10 CFR Part 50, Appendix I, 'Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low as is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents'
- 40 CFR Part 190, 'Environmental Radiation Protection Standards for Nuclear Power Operations'
- 10 CFR Part 100, 'Reactor Site Criteria (Subpart B, Evaluation Factors for Stationary Power Reactor Site Applications on or After January 10, 1997)'
- 10 CFR §50.34(a)(ii)(D), 'Contents of Applications: Technical Information (Radiological Dose Consequences)'
- Similar logic used in NUREG-1860 to develop a similar set of frequency vs. dose criteria

Frequency-Consequence Chart with Top Level Safety Criteria



Idaho National Laboratory

NGNP Next Generation Nuclear Plant

Licensing Basis Events (LBEs)

Idaho National Laboratory

Licensing Basis Events

- LBEs define *when* the TLSC must be met
- Each LBE represents a family of event sequences with similar challenges to barriers, response of SSCs that perform safety functions, and common end state
- LBEs are all the event sequences considered in the licensing basis and include:
  - LBEs derived from the PRA
    - Anticipated Operational Occurrences (AOOs)
    - Design Basis Events (DBEs)
    - Beyond Design Basis Events (BDBEs)
  - Deterministically Selected Design Basis Accidents (DBAs)
  - Other design basis threats (e.g., evaluating physical security)
- LBEs are evaluated <u>individually</u> against the TLSC and <u>collectively</u> to show compliance with Quantitative Health Objectives (QHOs) of Safety Goals.

Rationale for Use of PRA

- LBEs for existing designs may not apply or adequately reflect reactor specific and unique characteristics
- Logical and structured approach to safety evaluation that incorporates deterministic evaluations such as: FMEA, HAZOPs, success criteria development, as well as deterministic evaluation of plant response to events and mechanistic source terms
- Systematic and exhaustive enumeration of event sequences, including multiple failures
- Capability to identify reactor specific and unique scenarios, dependencies, and interactions within a holistic plant perspective
- Rational approach to identifying, understanding and addressing uncertainties while anchoring assessments on realistic assumptions
- Capability to confirm that new plant designs meet the safety goal QHOs

Deterministic Elements Shape the Definition of Event Sequences

- Initial design specifications and user requirements
- Selection of the safety design approach
- Definition of safety functions
- Allocation of safety functions to inherent characteristics, passive and active SSCs
- Initial assumptions regarding SSC safety classification
- Specifications for the reliability and capability of SSCs to prevent and mitigate accidents

Deterministic Elements Shape the Definition of Event Sequences (cont)

- Systematic search for initiating events via FMEA, HAZOPS, Master Logic Diagrams
- Definition of safe stable end states for reactor response to events
- Systematic enumeration of event sequences via event trees and fault trees
- Deterministic engineering evaluations of the plant response to events, success criteria, and mechanistic source terms
- Development of the accident management philosophy and emergency operating procedures

Elements of an LBE

- Initial Plant Conditions
- Initiating Events
- Plant Response to Initiating Events
- Plant Functional Response
- Plant Response to SSC Successes and Failures
- Consequence Assessment

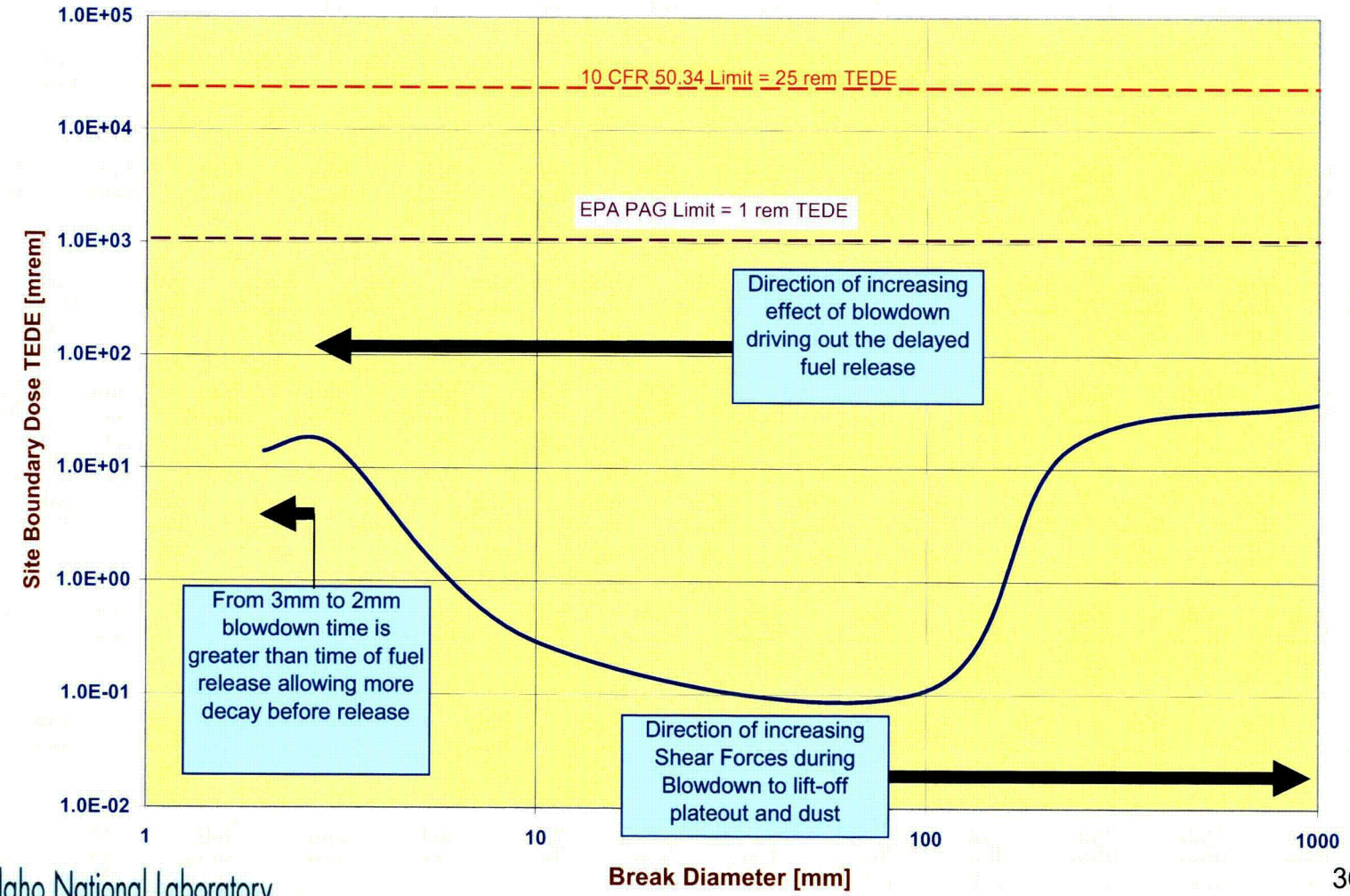
Initiating Event Examples

- Transients with intact Helium Pressure Boundary (HPB) examples
  - Heat Transport System (HTS) and Shutdown Cooling System (SCS) still capable of forced cooling operation
  - HTS failed, SCS still capable of operation
  - HTS and SCS not capable of operation
- Transients with intact HPB and reactivity addition examples
  - Control rod or group withdrawal
  - Overcooling transients
- HPB Leaks and Breaks (excl. HPB HX failures) examples
  - Range of break sizes from small leaks up to complete breaks of HTS piping
  - Range of break locations with different potential for HTS retention, air ingress, and pressure and temperature loads on reactor building
- HPB Heat Exchanger Failures
  - IHX failures
  - SCS heat exchanger failure
- Initiating events specific to radionuclide sources outside the HTS boundary including spent fuel, Helium purification, gas waste, etc.
- Functional initiating events may be caused by internal events, internal plant hazards, or external events including seismic events and process hazards

Helium Pressure Boundary Leaks and Breaks

- HPB breach required for radioactive material release
- Different than an LWR LOCA
- Presents unique characteristics to safety design approach
  - Chemically inert
  - Non-condensible gas
  - Pressure and temperature loads on building
  - Pressure driving force for delayed fuel releases from small breaks
  - Shear force from large breaks releases plate-out and dust
  - Consequences are a function of both break size and location
  - Important considerations for reactor building design requirements
- RIPB approach provides a systematic process for evaluating the whole spectrum of events

Dose Behavior vs. Break Size for Unfiltered Vented RB (example)



Idaho National Laboratory

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 public consequence criteria in 10CFR20 *if certain equipment or design features had not been selected*
- Consequences realistically analyzed for compliance with 10CFR20 100mRem TEDE at the controlled area boundary

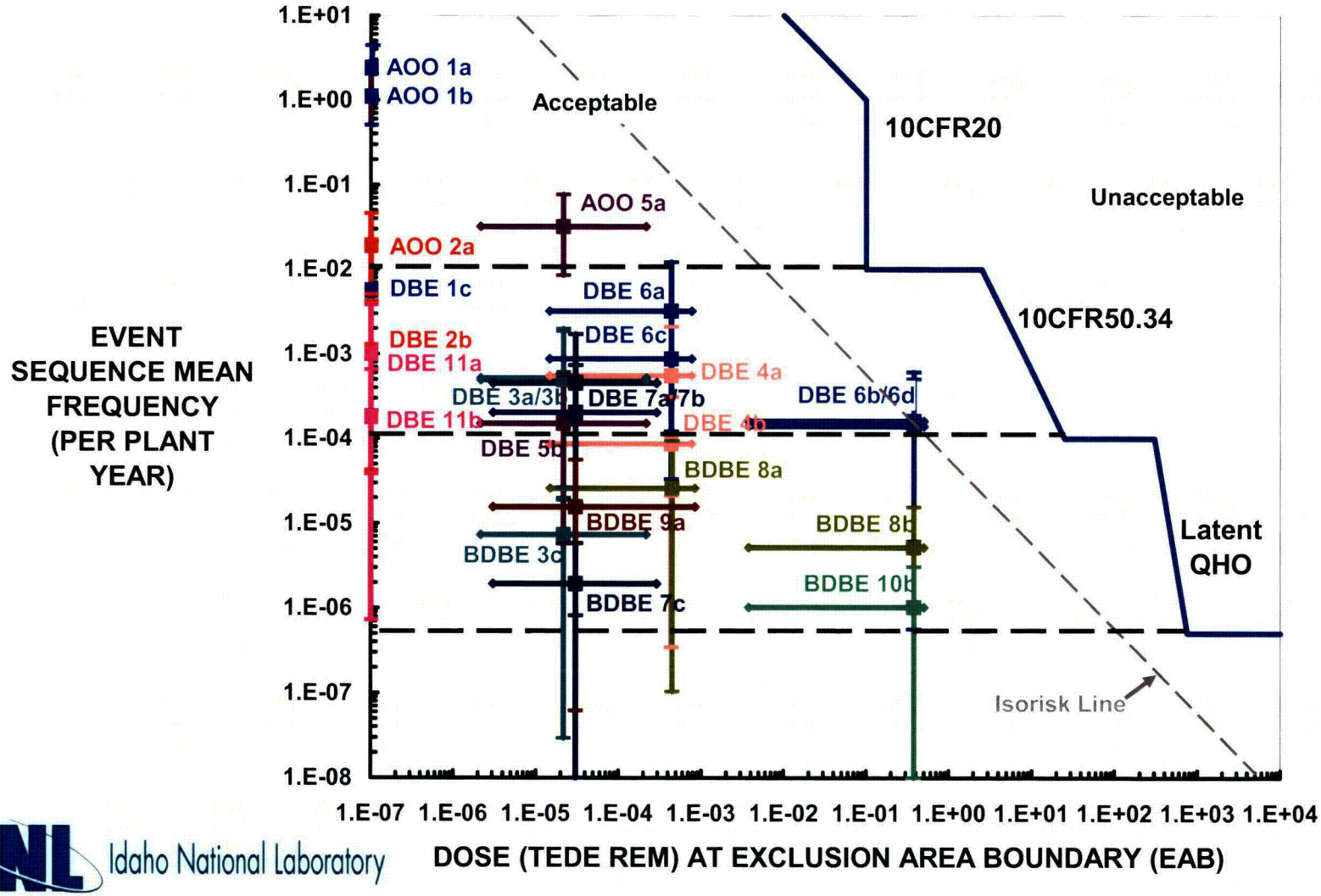
Design Basis Events

- 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 10CFR50.34 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 10CFR50.34 including safety margins
- Used as basis for design, such as SSC classification and for establishing emergency planning for events that exceed EPA Protective Action Guidelines (PAGs)

Beyond Design Basis Events

- Events that are not expected to occur during the lifetime of a fleet of plants
  - lower frequency of 5×10^{-7}/plant yr
  - necessary to meet prompt fatality safety goal QHO
- Consequences realistically evaluated for compliance together with other LBEs with the NRC Safety Goal Quantitative Health Objectives
- Used as basis for rare event analysis for establishing emergency planning for events that exceed EPA Protective Action Guidelines (PAGs)

Frequencies and Consequences of RIPB LBEs



Idaho National Laboratory

Cumulative Risk Model for Latent Cancer Fatality QHO

$$R_{LCF} = \sum_j F_{RCj} \sum_k p_k \sum_l d_{jkl} n_l r_{LCFd}$$

R_{LCF} = *Individual risk of latent cancer*

F_{RCj} = *Frequency of release category j*

p_k = *Probability of weather conditions k*

d_{jkl} = *Dose for release category j given weather condition k in sector l*

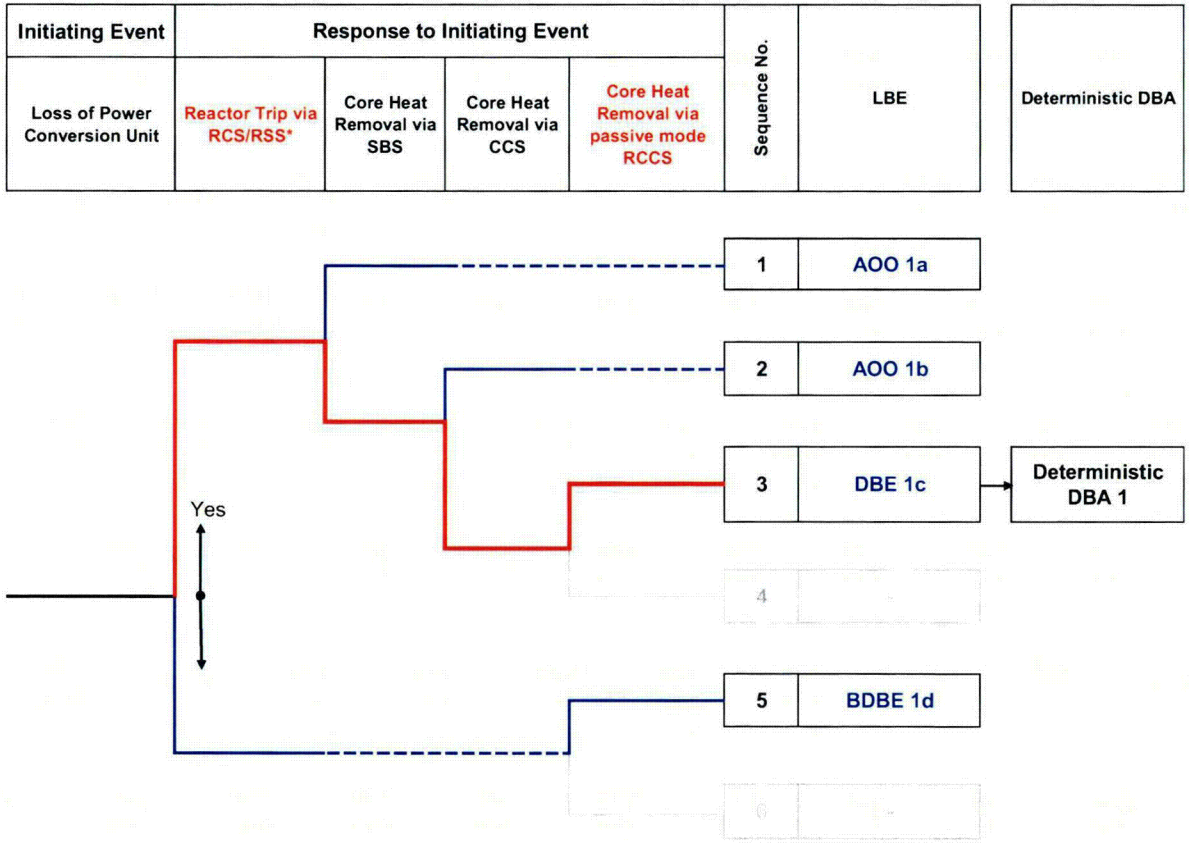
n_l = *Number of people in sector l*

r_{LCFd} = *Individual probability of Latent cancer given dose d*

Deterministic Design Basis Accidents

- Design Basis Accidents (DBA) provide deterministic confirmation that the safety-related SSC can alone mitigate the consequences of the selected DBEs
- Deterministic DBAs are used to develop the limiting parameter values i.e., temperatures, stresses, heat loads, etc., that safety-related SSCs must be able to meet in order to fulfill its mission for each DBE
- Deterministic DBAs are used to establish conservative operating conditions

Deterministic DBAs Rely Only on Safety Related SSCs

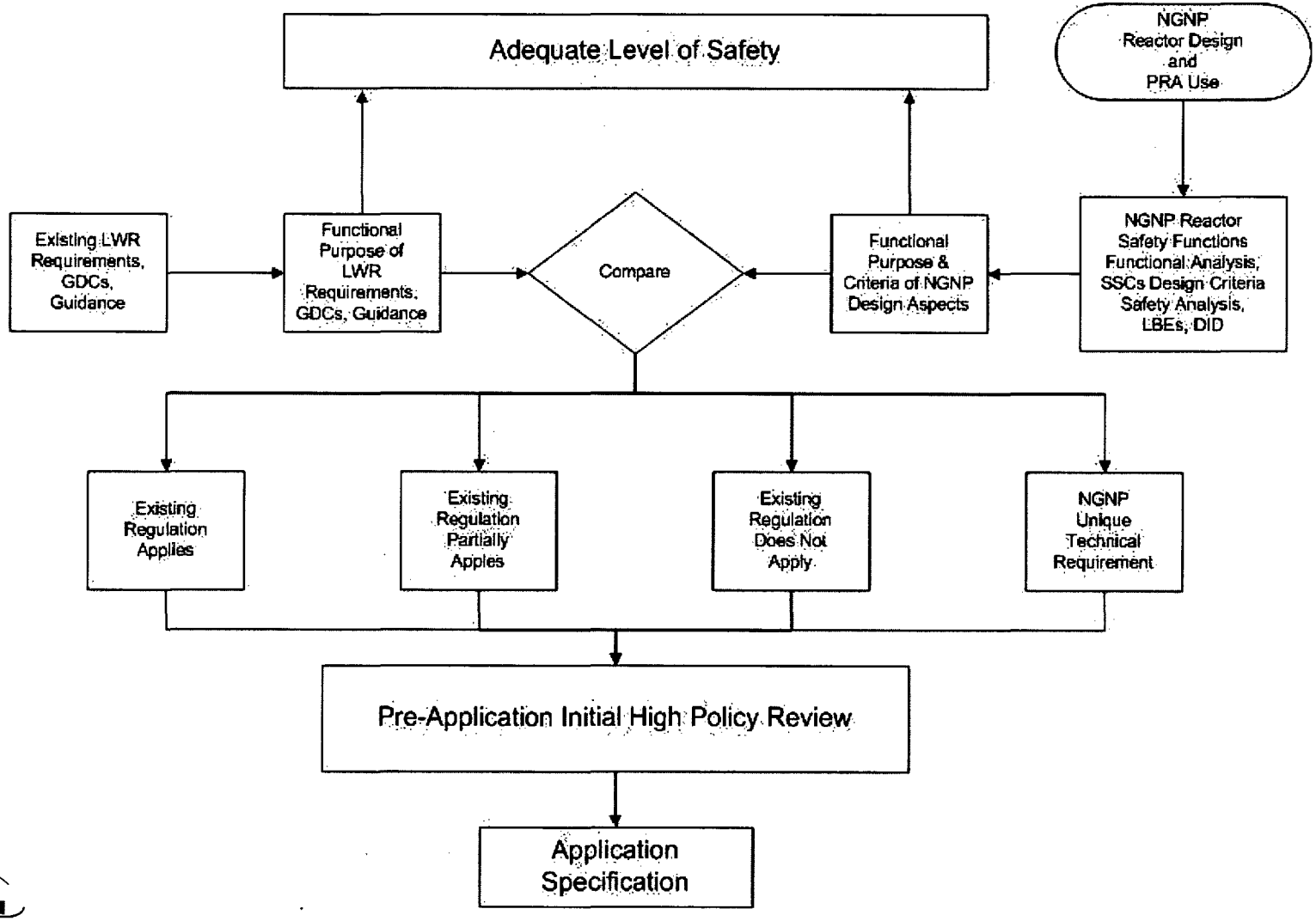


* safety-related SSCs shown in red font

PBMR Example DBEs and Deterministic DBAs

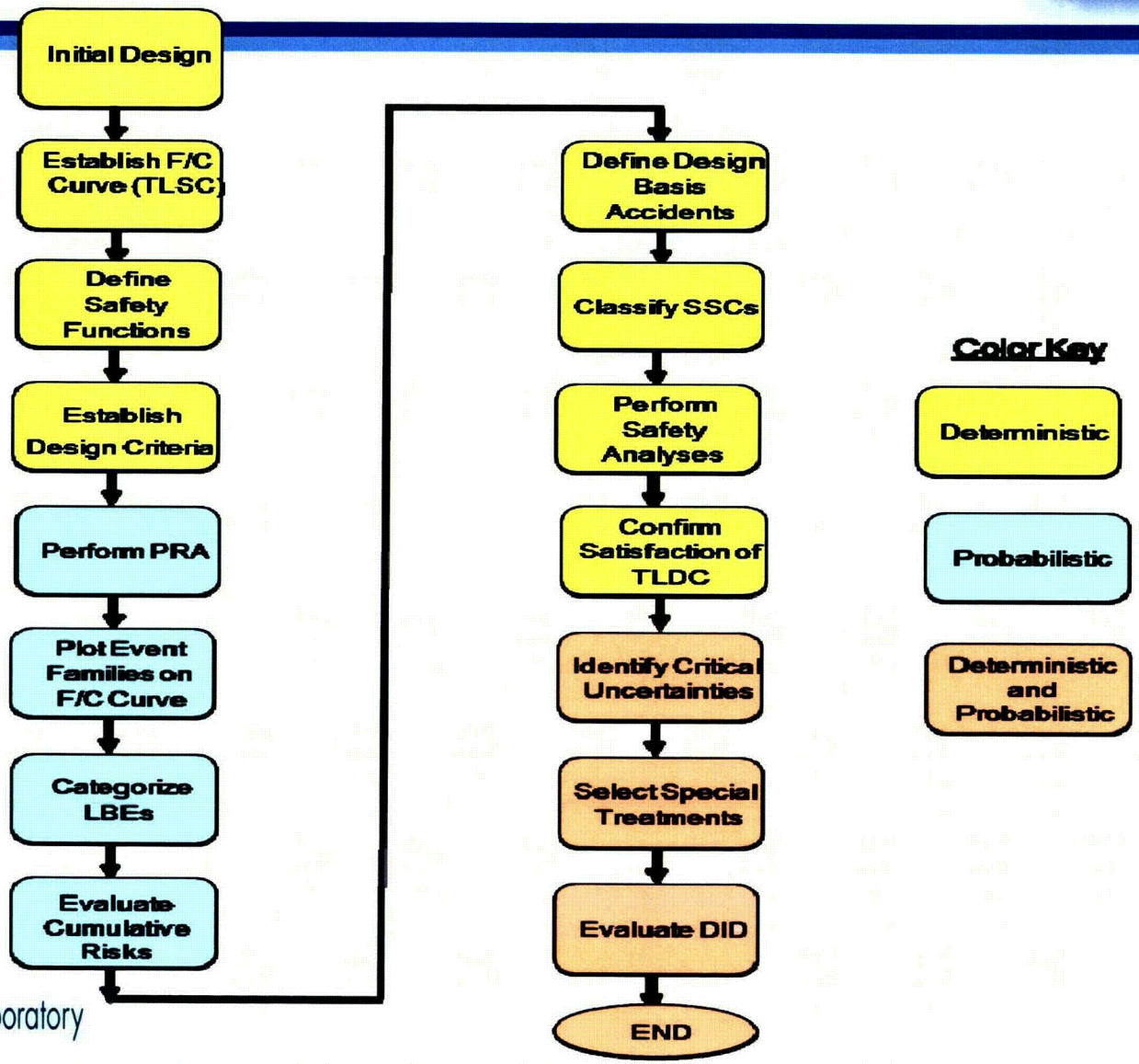
DBE Designation	Design Basis Event	Deterministic DBA Designation	Deterministic Design Basis Accident
DBE-5b	HX tube break, manually isolated w/RCCS cooling	Deterministic DBA-6	HX tube break, unisolated w/core conduction cooling to passive mode of RCCS w/unfiltered release
DBE-6a	HX tube break unisolated w/pumpdown w/RCCS cooling w/filtered 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	Deterministic DBA-7	Medium, unisolated HPB break w/core conduction cooling to passive mode of RCCS
DBE-7b	Medium, isolated HPB break w/CCS cooling		
DBE-11a	Safe shutdown earthquake w/SBS cooling	Deterministic DBA-11	Safe shutdown earthquake w/core conduction cooling to passive mode of RCCS
DBE-11b	Safe shutdown earthquake w/CCS cooling		

LWR Requirements Evaluation Process



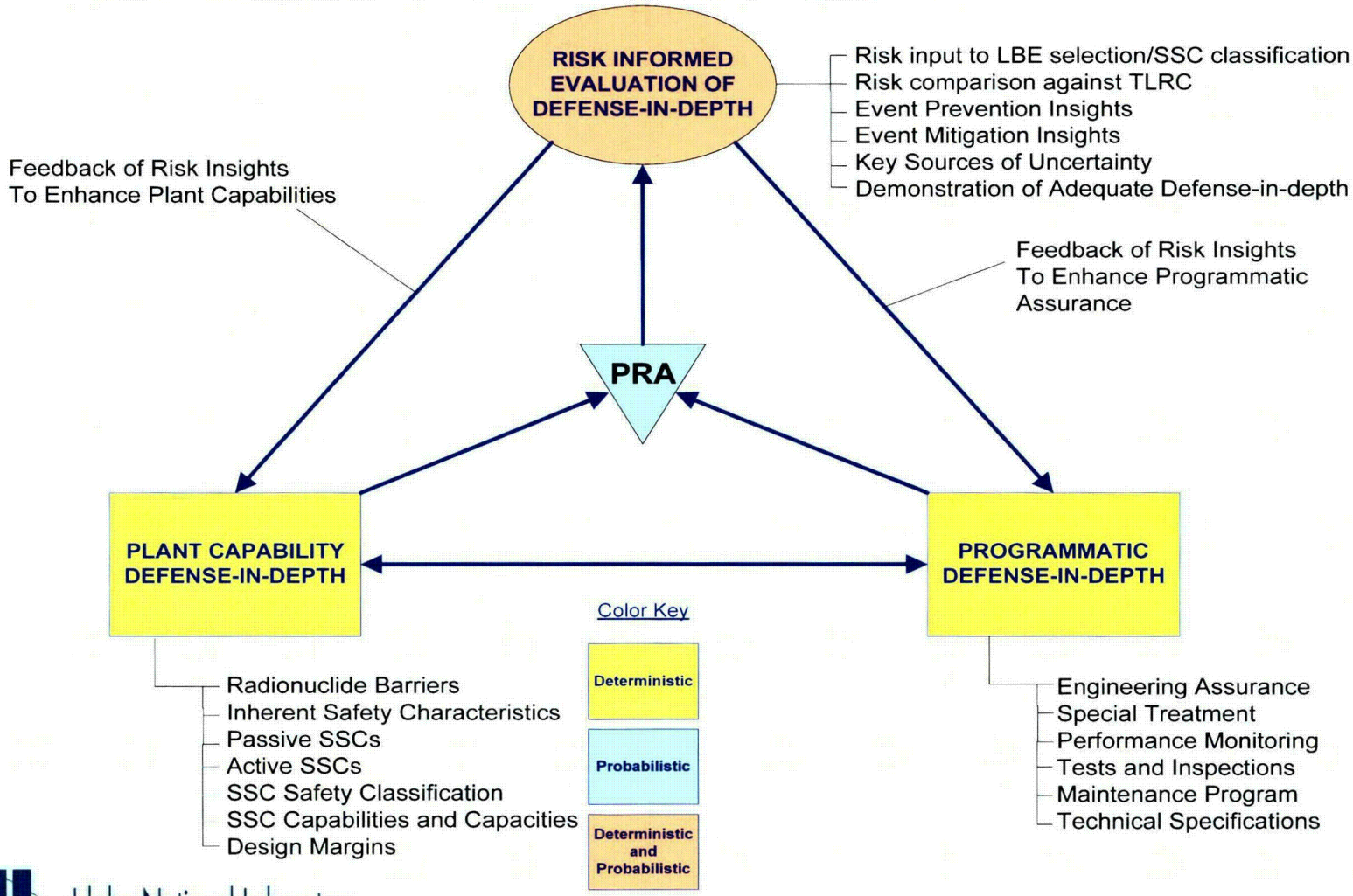
NGNP Safety Design Process

(adapted from draft ANS 53.1)



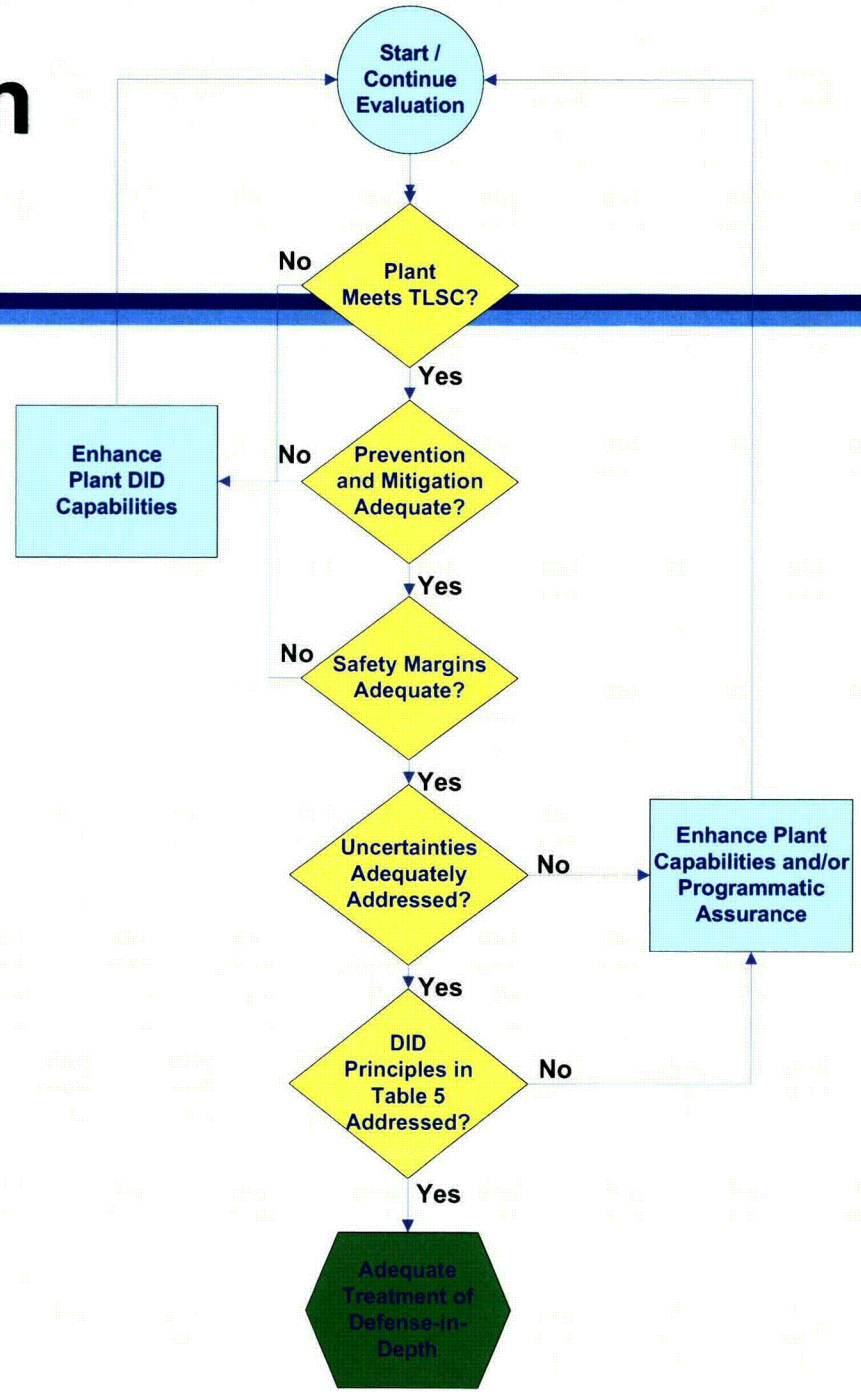
Idaho National Laboratory

Defense-in-Depth: An Integral Part of the Approach



Idaho National Laboratory

RI Evaluation of DID



Idaho National Laboratory

Summary

- NGNP proposes a generic RIPB safety design approach
- Selection of LBEs is a key element of the approach
- Other elements flow from LBEs (e.g., SSC safety classification)
- RIPB LBE process builds on deterministic design framework
- Advantages of LBE selection approach
  - Systematic search for initiating events and event sequences specific and unique to the NGNP design
  - Clear delineation of the role of each SSC in support of NGNP-specific safety functions and in the prevention and mitigation of accidents
  - Includes common cause events, multiple failures, and events involving more than one reactor module in integrated risk framework
  - Explicit delineation and evaluation of uncertainties
  - Greater understanding of expected plant performance and margins in licensing analysis
  - Robust foundation for SSC design requirements and operational requirements that have a common basis of understanding
- Extensive use of deterministic methods in definition of candidate LBEs
- Defense-in-depth is integral to the approach

Brief Licensing History of High Temperature Gas-Cooled Reactors

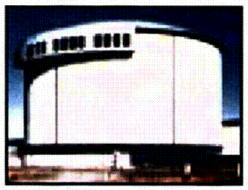
Idaho National Laboratory

December 11, 2008

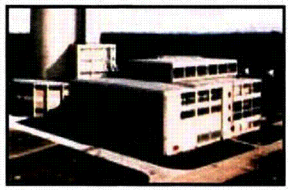
U.S. AND EUROPEAN TECHNOLOGY BASES FOR MODULAR HELIUM REACTORS

BROAD FOUNDATION OF HELIUM REACTOR TECHNOLOGY

EXPERIMENTAL REACTORS



DRAGON
(U.K.)
1963 - 76

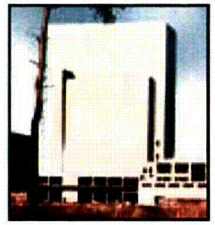


AVR
(FRG)
1967 - 1988

DEMONSTRATION OF BASIC HTGR TECHNOLOGY

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

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

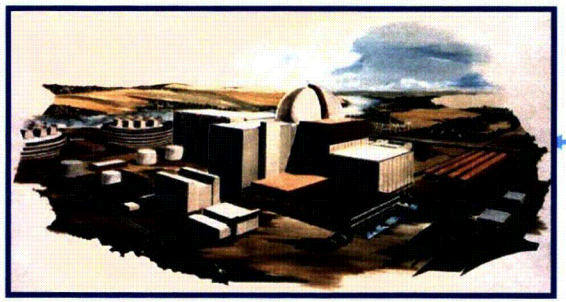


THTR
(FRG)
1986 - 1989

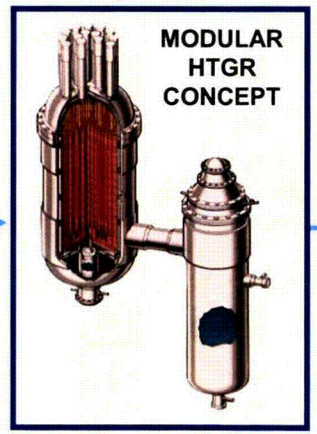
HTGR TECHNOLOGY PROGRAM

- MATERIALS
- COMPONENTS
- FUEL
- CORE
- PLANT TECHNOLOGY

LARGE HTGR PLANTS

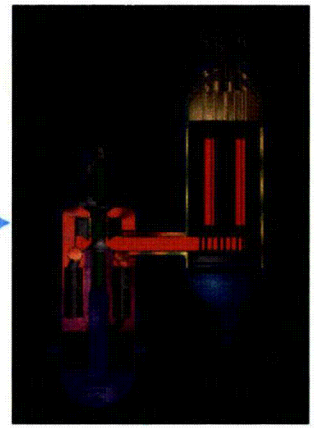


MHTGR



Steam Cycle

GT-MHR



Gas Turbine Cycle

Idaho National Laboratory

U.S. Licensing Experience Prior to End of 1970's

Utilities	Power Level
Delmarva P&L	2 x 770
Philadelphia Electric	2 x 1160
Ohio Edison	2 x 1160
Louisiana P&L	2 x 1160
Southern Cal. Edison	2 x 770

	MW(e)	Status
Peach Bottom 1	40	Lic/Built/Decom.
Fort St. Vrain	330	Lic/Built/Decom.
Summit 1 & 2	770 ea.	Lic. to Const. Permit
Fulton 1 & 2	1160 ea.	Lic. to Const. Permit
GASSAR	1160 ea.	Submitted

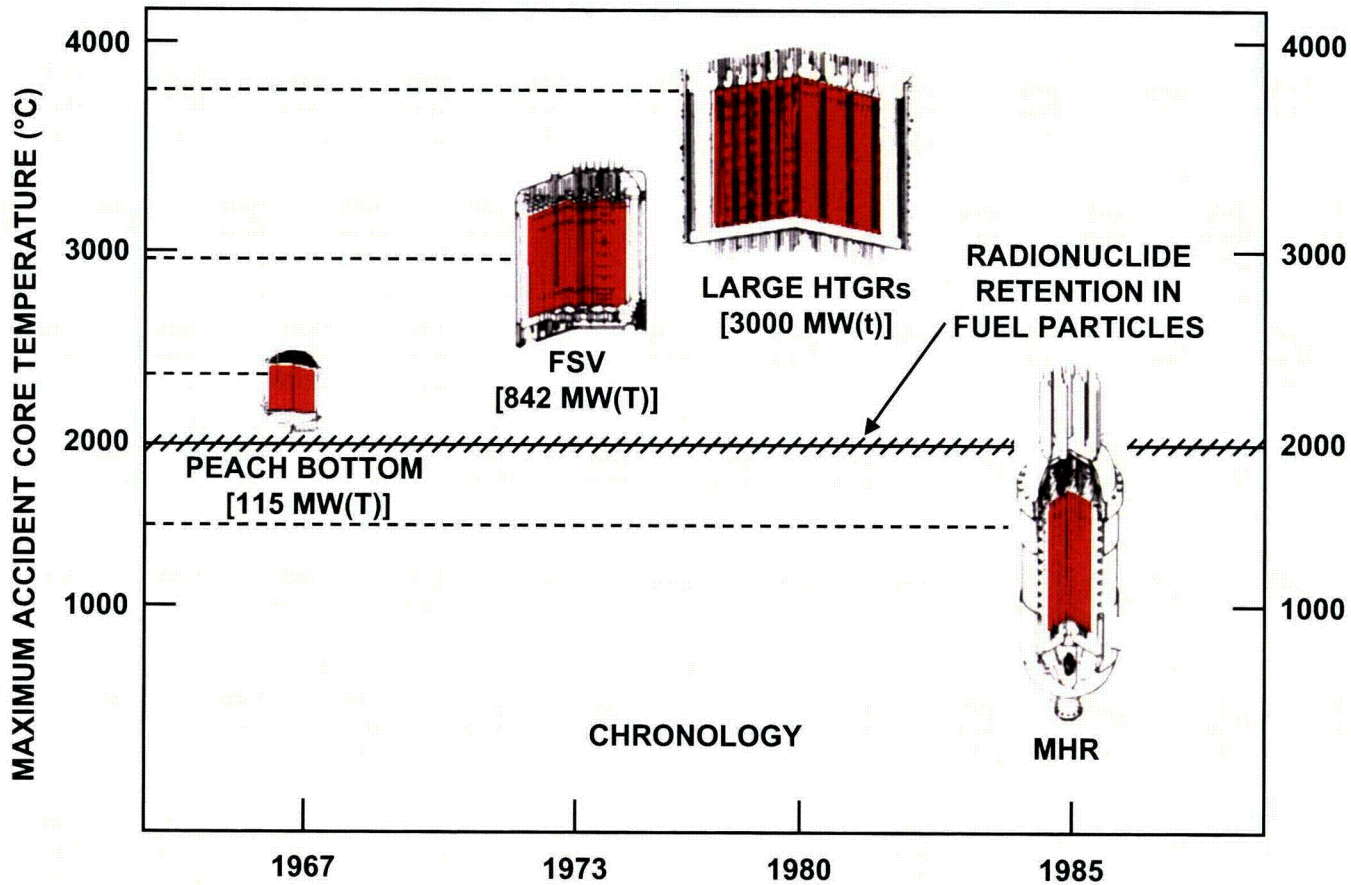
Fort St. Vrain Licensing Experience

- Two Design Basis Accidents (with offsite dose)
  - Rapid Depressurization
  - Loss of All Forced Cooling
- Delayed (Time-Dependent) Fission Product Release
- Low-Pressure Confinement Building in Combination with PCRV
  - Early pressure pulse vented through louvers
  - Later releases with much more fission products filtered through charcoal

Modular Concept

- Modular concept brought to the attention of NRC chairman Joseph Hendrie in 1980 by Germans from Jülich and Siemens.
- Concept was based on the AVR modified to achieve passive emergency cooling.
  - Called the HTR Modul, it had a power of 80 MW(e).
- Concept of MHTGR pursued in early 80's under DOE sponsorship

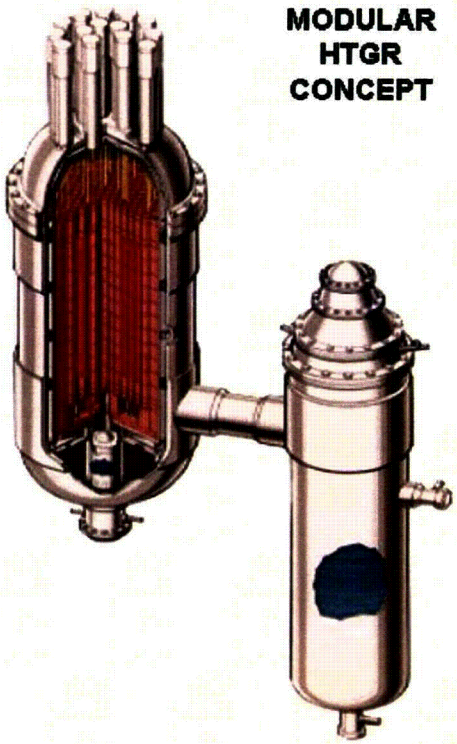
MODULAR HELIUM REACTOR REPRESENTS A FUNDAMENTAL CHANGE IN REACTOR DESIGN AND SAFETY PHILOSOPHY



...SIZED AND CONFIGURED TO TOLERATE EVEN A SEVERE ACCIDENT WITHOUT ACTIVE COOLING

Preapplication Review of MHTGR

- MHTGR - revised application of HTGR technology
  - 350 MW(t) steam cycle
  - 4 modules to standard plant
  - Low pressure, vented reactor building
  - Below grade siting
- Purpose of preapplication review by NRC
  - First reactor application to propose a risk-informed design and licensing approach
  - Licensability statement
  - Feedback on licensing and approach to safety design



PRA Central to Preapplication Review of MHTGR

- Used to quantify the frequency and consequences of a broad range of accidents
- Identified scenarios unique to MHTGR steam cycle designs
- Confirmed compliance to the QHOs
- Used to identify LBEs
- Provided input to SSC safety classification
- Underlies system logic establishing "deterministic" Safety Related Design Conditions (i.e., DBAs)
- Supplemented by Bounding Event Sequences deterministically selected by NRC to address PRA uncertainties

MHTGR Preapplication Review

- First technical briefing of US concept made to NRC staff on MHTGR, June 1984.
- DOE transmits Preliminary Safety Information Document (PSID) to NRC-RES, September 30, 1986 - February 1989.
  - 6 volumes, plus 10 amendments
  - Utilizes unique PRA based approach to selecting licensing bases
- Review began formally on October 1, 1986. Many supplementary documents submitted including
  - 2 volume Probabilistic Risk Assessment (PRA)
  - Technology Development Plan.
- NRC publishes NUREG 1338, *Draft Preapplication Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor*, in March 1989.

CONCLUSIONS FROM MHTGR LICENSING REVIEW

- MHTGR meets the advanced safety-enhancement objective of the Advanced Reactor Policy Statement
- Independent analysis by ORNL and BNL confirmed transient and accident assessments
- Both NRC and ACRS
  - Open to proposed containment approach
  - Final approval would require further fuel and fission product transport testing
- Both NRC and ACRS supported prototype testing before design certification

Subsequent Events

- NRR did not complete MHTGR review due to project cancellation in 1993-94
- Subsequent HTGR (2000 & on) work:
  - Exelon
  - PBMR Pty Ltd
  - ANS standards development committee
  - All build on licensing approach of MHTGR
- Experience gained from technology-neutral regulatory framework development for non-LWRs

Discussion and Next Steps

Idaho National Laboratory

Meeting Objectives

- *Confirm common understanding of definition and objectives of Option 2 in NGNP Licensing Strategy Report to Congress*
- *Provide overview of risk-informed performance-based (RIPB) process for NGNP Option 2*
- *Define preapplication activities to set the stage for a successful RIPB design and licensing review*
- *Determine next steps to achieve preapplication objectives*