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Use of Advanced PSA Technologies in Regulatory Applications by the United States Nuclear Regulatory Commission

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US NRC's Strategic Plan enables our Vision: We make SAFE use of Nuclear Technology POSSIBLE!

The NRC's overall responsibility is to protect public health and safety in the civilian uses of radioactive materials. It has the following main regulatory functions:

- Establish standards and regulations.
- Issue licenses, certificates, and permits.
- Ensure compliance with established standards and regulations.
- Conducts research, adjudication, risk and performance assessments to support regulatory decisions.

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Some excerpts from the US NRC PRA Policy

This statement presents the policy that the Nuclear Regulatory Commission (NRC) will follow in the use of probabilistic risk assessment (PRA) methods in nuclear regulatory matters. The Commission believes that an overall policy on the use of PRA methods in nuclear regulatory activities should be established so that the many potential applications of PRA can be implemented in a consistent and predictable manner that would promote regulatory stability and efficiency.

In addition, the Commission believes that the ***use of PRA technology in NRC regulatory activities should be increased to the extent supported by the state-of the-art in PRA methods and data*** *and in a manner that complements the NRC's deterministic approach.*

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Three categories of reactors must be considered to determine near-term and longer-term significance of Advanced PSA methods .

Light Water Reactors:

There are 95 reactors operating at 57 sites in USA

- Regulations do not require these reactors to have PRA models.
- However, reactors possess peer-reviewed Level 1 internal event PRAs.
- Majority of reactors maintain peer-reviewed PRA models for internal events and fires because they use these models to implement risk informed initiatives.

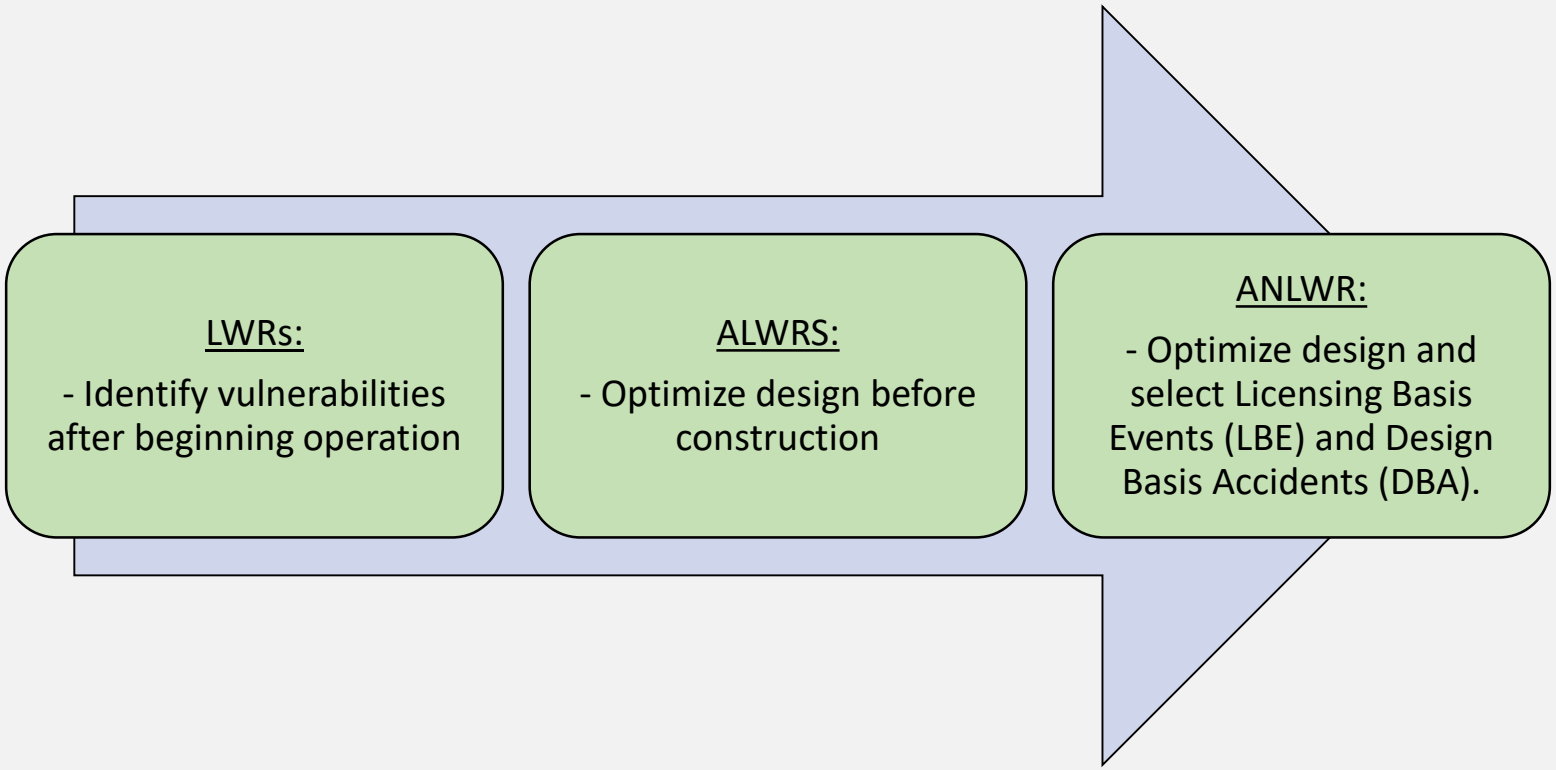
Advanced Light Water Reactors (ALWRs):

- Several designs of ALWRs have been approved {AP600, AP1000, ESBWR, APR1400, NUSCALE (FSER issued)}.
- Two AP1000 units, (Vogtle 3 and Vogtle 4) are undergoing construction.
- Regulations require applicants to develop and update PRAs.

Advanced Non Light Water Reactors:

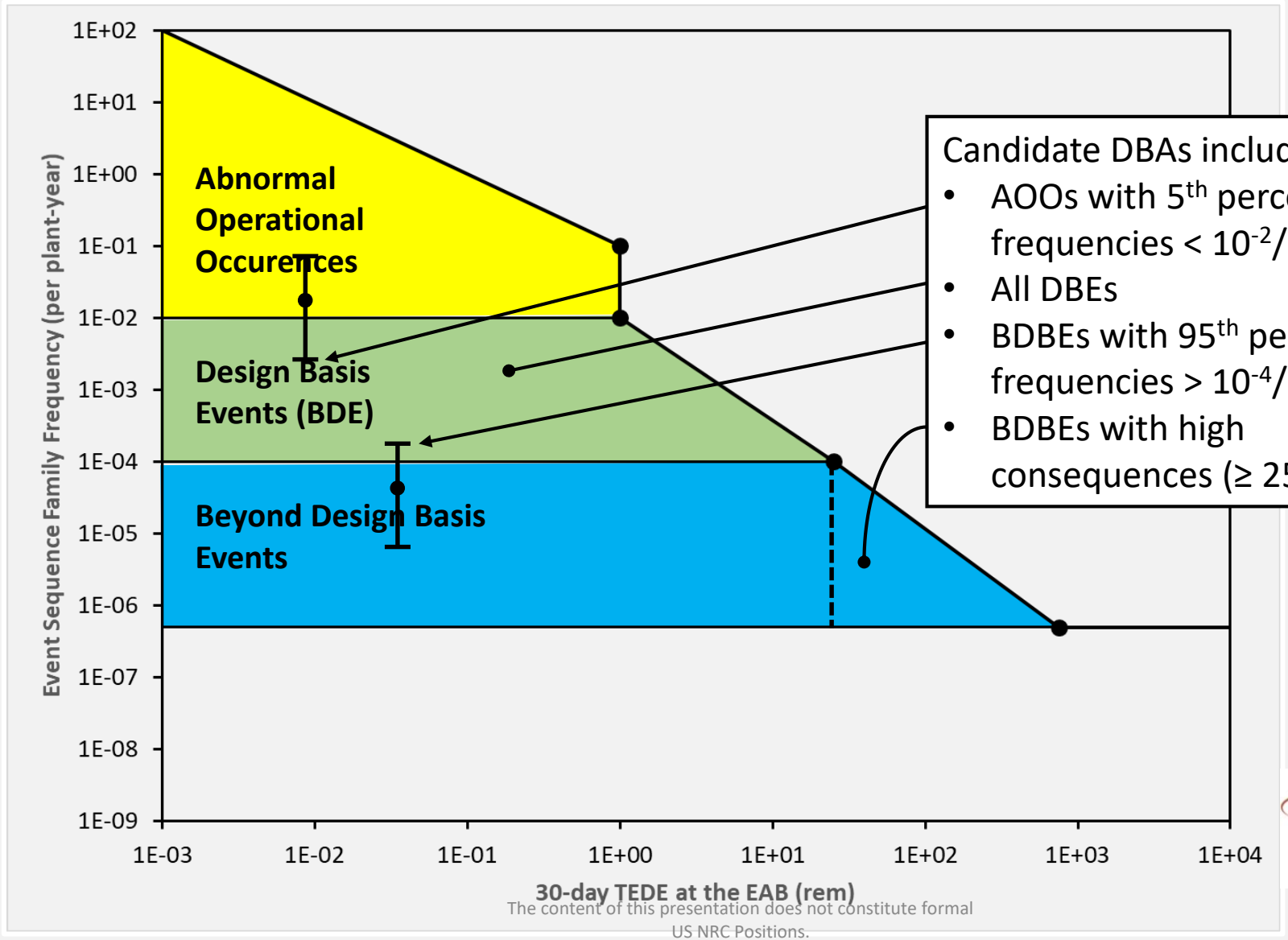
- NRC has received several applications and\or pre-applications (e.g., Oklo-Compact fast micro reactor, Kairos-Fluoride salt cooled high temperature reactor, Terrestrial- Molten salt reactor).
- Regulations require applicants to develop and update PRAs.

In USA, use of PSA in support of siting, design, licensing, and operating reactors are continuing to increase.



As reflected by the Licensing Modernization Project (LMP)(ADAMS Accession No. ML18271A172), use of PSAs in support of designing, licensing, and oversight of reactors is increasing.

Example: Selecting Candidate Design Basis Accidents (DBAs) using Level 3 PSAs



Candidate DBAs include:

- AOOs with 5th percentile frequencies < 10^{-2}/py
- All DBEs
- BDBEs with 95th percentile frequencies > 10^{-4}/py
- BDBEs with high consequences (≥ 25 rem)

Relative Significance of Advanced PSA Methods

All topics proposed are significant to advance PSA Technology and use it in risk-informed decision making..

A subset of them are more important than other because of the immediacy of their need and gap between current state-of-the-art and desired state-of-the art.

- Modeling of portable equipment
- Modeling Software and Digital I&C
- Modelling Passive Systems
- Ageing aspects of passive systems
- Level 3 PSA

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Modeling Portable Equipment: Fukushima Related Safety Enhancements: FLEX - Mitigating Strategies

NRC required a three-phase approach for maintaining or restoring core cooling, containment, and spent fuel cooling.

Phase	Licensee may use
Initial	Installed equipment
Transition	+ Portable, onsite equipment
Final	+ Resources obtained from offsite

Fundamental cornerstone of United States approach

Modeling Portable Equipment

Why is it important?

- US LWR operators secured a large number of portable equipment in response to US NRC orders following Fukushima Daiichi event (March 11, 2011).
- These equipment and associated procedures must be appropriately incorporated into PRA models to enhance PRA realism and enhance. RIDM.

What is state-of-practice/experience?

- ASME\ANS PSA Standard provides guidance to enable incorporation of portable equipment to PRA models.
- US NRC has been modifying its processes to enable licensees to receive “regulatory credit” for enhanced safety associated with portable equipment in its licensing and oversight activities.

Modeling Portable Equipment (Continued)

What are challenges and open issues?

- Availability of data on equipment reliability or failure probabilities remains a challenge.
- Need for Human Reliability Analysis techniques and data to credit operator manual actions implemented outside of the control room poses a challenge.

Actions taken to address challenges

- US industry efforts and NRC involvement to establish a database for reliability of portable equipment is reflected in an NRC Audit report summary (ADAMS Accession No. ML20155K827).
- Staff efforts to advance HRA methods is described in RIL-2002-02 entitled "Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA)," ADAMS Accession No. ML20016A481.
- Planned update to RG 1.200 further clarifies peer review requirements (ADAMS Accession No. ML19308B636.

Modeling Software and Digital I & C

Why is it important?

- Operating LWRs requests approval to replace traditional analog systems to digital systems.
- Advanced reactor designers' requests to consider autonomous and remote operations in review of those designs prompts a need to assess the influences of Artificial Intelligence and Cybersecurity on software reliability

What is the state-of-practice?

- Research has resulted in number of publications {NUREG/CR-6962 (2008), NUREG/CR-6997 (2009), EPRI 1025278 (2012)}
- Chapter 19.0 of US NRC Standard Review Plan (NUREG 0800) provides detailed guidance to review PRA related aspect of DI&C and Software Reliability.
- Planned update to IAEA SSG-3 "Development and Application of Level 1 PSA for Nuclear Power Plants," addresses the issue at an appropriate level of detail.

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Modeling Software and Digital I&C (Continued)

- What are the challenges and open issues (that inhibits state-of-practice in modeling)?
  - Qualitative guidance and requirements have been used to identify and minimize risk. Some examples provided below:
    - Appendix D to NEI-96-07, "Supplemental Guidance for Application of 10 CFR 50.59 to Digital Modifications" (ADAMS Accession No. ML18235A165).
    - BTP 7-19, "Guidance for Evaluating Diversity and Defense-in-Depth Computer-Based I&C System Review Responsibilities" (ADAMS Accession No. ML16019A344).
  - State-of-practice has not matured (i.e., lack of wide spread modeling of DI&C and Software in PSA Models in light water reactor PRAs).

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Modeling Passive Systems

Why is it important?

- Advanced reactor designs have increased reliance on passive systems.
- Passive systems are not inherently safe; Therefore, PSA modeling requires data on reliability via operating experience, experiments, tests, or other means.
- Some categories of passive systems rely on new technologies with limited operating experience.

What is the state-of-practice?

- Chapter 19.0 of NRC's Standard Review Plan (NUREG-0800).
- Planned ASME\ANS PSA Guidance for Advanced Non Light Water Reactors.
- Planned update to IAEA SSG-3, "Development and Application of Level 1 PSA for Nuclear Power Plants," addresses the issue at an appropriate level of detail.
- IAEA-TECDOC-626 (1991), "Safety-Related Terms for Advanced Nuclear Plants," 1991.
- IAEA-TECDOC-1752 (2014), "Progress in Methodologies for the Assessment of Passive Safety System Reliabilities in Advanced Reactors."

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Modeling Passive Systems (continued)

- What are the challenges and open issues (that inhibits state-of-practice in modeling)?
  - State-of-the-art methods and information to generate reliabilities needs enhancement and alignment among PSA community.
  - State-of-practice is maturing.

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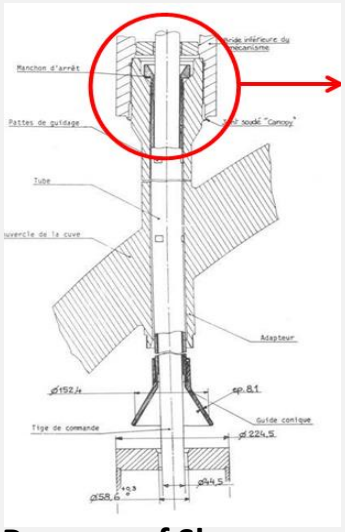
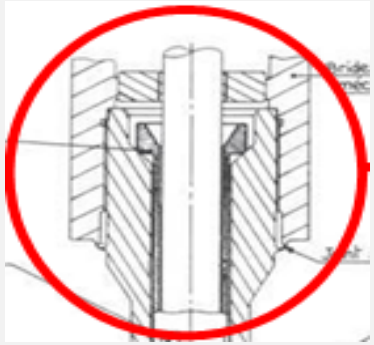
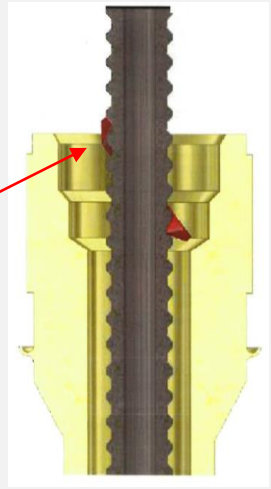
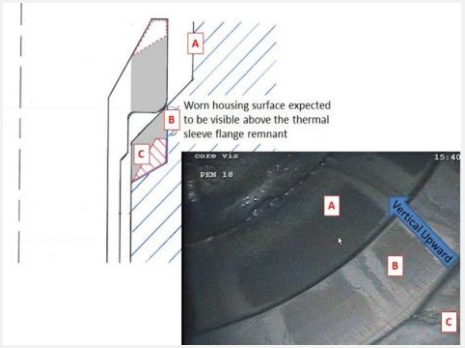
Modeling Ageing Aspects
Example: CRDM Thermal Sleeve Flange Wear: Example to illustrate significance









Purpose of Sleeve:

- **Guides rod cluster control assembly (RCCA) drive rods into the head penetration tubes during reactor vessel head installation**
- **Provide thermal shielding of the head penetration tubes**

Wear remnant can cause control rod to stick

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Modeling Ageing aspects in PRA

Why is it important?

- Almost all operating LWRs have received approval to operate up to 60 years.
- US NRC has begun receiving, reviewing\approving requests by some licensees to operate up to 80 years.

Why is it important (Continued)?

- Recent emergent issues (issues that emerge as a result of national or international operating experiences) have periodically identified potentially risk significant issues that are difficult to model using PRA models.
  - Control Rod Drive Mechanism Thermal Sleeve Wear (ADAMS Accession No. ML18249A081).
  - Degradation of Baffle-Former Bolts (ADAMS Accession No. ML16225A341).

What is the state-of-practice?

- US NRC uses its collaborations with US and International entities to early identify ageing aspects of passive components.
- US NRC provides focus attention on licensees' ageing management procedures before approving life extension.
- Bounding analysis and performance monitoring is used to monitor and manage risks to assure reasonable assurance od adequate protection of public health and safety.

Modeling ageing aspects in PSA Passive Systems (continued)

- What are the challenges and open issues that inhibit advancement of state-of-practice in modeling?
  - Ageing aspects are not a priority for ALWRs and ANLWRs.
  - Ability to use bounding analyses and performance monitoring to manage issues reduces incentive to invest in advancing the state-of-the-art and state-of-practice in spite of the following negatives.
    - Imposes additional burdens on performance monitoring.
    - Upper bound estimates may miscommunicate risk significance.

Level 3 PSA

Why is it important?

- Insights from Level 3 PSAs are essential for risk-informed decision making in some situations (does not imply that site specific Level 3 PSAs are essential to support risk-informed decision making).

What is the state-of- practice?

- US NRC uses insights from past Level 3 PSAs to support risk-unformed decision making.
- US NRC is in the process of completing state-of-the art Level 3 PSA that considers all modes and all sources.
- Insights from that study will enhance NRC's ability to more accurately consider consequences from accidents in risk-informed decision making.

IN Conclusion,

US NRC continues to increase use of PSA in Risk-Informed Decision Making in support of its currently operating light water reactors, advanced light water reactors, and advanced non-light water reactors.

There is a need to continue to advance the state-of-the-art and state-of-practice of PSA methods in all areas.

From a near-term perspective, advancements in some area are more critical than others.

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