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U.S. NRC Activities Related to Aging PSA

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Agenda

- Introduction
- Standardized Plant Analysis Risk Models
- License Renewal
- Probabilistic Fracture Mechanics
- Life Beyond 60 Program
- Final Thoughts
- Resources

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Standardized Plant Analysis Risk (SPAR) Models

- The NRC develops and maintains 77 unique nuclear power plant PSA models to support a variety of risk-informed regulatory initiatives
- Scope generally limited to Level 1 internal events
  - Some models also include Level 2, LPSD, and certain external events

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Age-Related Degradation in SPAR Models

- The SPAR models do not explicitly model aging, but do include certain dependencies among equipment within a common cause component group
  - α-factor model accounts for a variety of dependencies, including aging effects
- Models are periodically updated to reflect plant modifications, improved modeling practices, and updated parameters

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Data Collection and Analysis Activities

- NRC has several operating experience data collection and analysis programs
  - Equipment Performance and Information Exchange (EPIX)
  - Mitigating System Performance Index (MSPI)
  - Licensee Event Reports and Emergency Notifications
  - Common cause failure database and insight reports

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Data Evaluation & Trending

- Special system and component studies
  - System and component studies involve a risk-based data analysis to estimate reliability and include an engineering analysis of trends and patterns
  - System studies documented in NUREG/CR-5500 and include ECCS, emergency power, reactor protection, AFW, and isolation condenser
  - Component studies documented in NUREG-1715 and include EDGs, MOVs, AOVs, MDPs, and TDPs
- Generic Safety Issue Program
- Operating Experience Clearinghouse

Underlying assumption is that significant unmitigated aging mechanisms would be identified through these data analysis and trending efforts

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License Renewal

- Commercial nuclear plant operating licenses initially issued for no more than a 40 year term (10 CFR 50.51).
  - License term based on economic and antitrust considerations -- not on limitations of nuclear technology
- Operating license may be extended in 20 year increments in accordance with 10 CFR 54.

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License Renewal Regulatory Principles

- The regulatory process is adequate to ensure that the licensing bases provides and maintains an adequate level of safety as long as age-related degradation is appropriately managed
  - The detrimental effects of aging is the only generically applicable safety issue for license renewal
- Licensing bases for the plant must be maintained in the same manner during the extended license term as during the original term
  - This principle is addressed, in part, through a program of age-related degradation management (i.e. aging management programs) for SSCs within the scope of the license renewal rule

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License Renewal - GALL

- Generic Aging Lessons Learned Report (NUREG-1801) is a compilation of plant aging information
- The GALL Report identifies aging management programs (AMP), which were determined to be acceptable programs to manage the aging effects of systems, structures and components (SSC) in the scope of license renewal
  - Contains the NRC technical basis for determining which existing programs are adequate and which programs should be augmented for license renewal
  - The GALL does not have AMPs for some areas – in these cases the licensees must develop acceptable programs

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License Renewal
SSC Scope

- License renewal scope include safety-related SSCs, nonsafety SSCs whose failure could prevent a SR SSC from functioning, and SSCs needed to meet certain regulatory requirements (i.e., fire, EQ, PTS, ATWS, and SBO)
- Rule assumes that existing monitoring programs (e.g., TS surveillance, maintenance rule) would detect detrimental changes due to aging of active SSCs
  - However, SSCs that perform a function without moving parts or a change in configuration properties cannot be readily monitored
- Therefore, aging management review focuses on passive SSCs that are not subject to planned replacement. Therefore. the following types of SSCs are not subject to aging management:
  - SSCs that perform active functions
  - SSCs that are replaced based on a qualified life or specified time period

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PRA in License Renewal

- License renewal SSC scope is consistent with the deterministically based licensing basis for the operating reactor population.
  - NRC concluded that PRA has very limited use for SSC scoping without the necessary regulatory requirements and controls for plant-specific PRAs.
- The NRC noted that PRA insights could be used to assess relative importance of SSCs and draw attention to specific vulnerabilities, but PRAs cannot be used to demonstrate that aging is adequately controlled
- Some concern articulated that PRA insights might be used to reduce the scope of aging management programs.
  - The statements of consideration for the rule state that the "PRA will not be used to justify poor performance in aging management or to reduce regulatory or programmatic requirements…"

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PRA in License Renewal

- PRA is used to support the evaluation of Severe Accident Mitigation Alternatives (SAMAs) for the license renewal environment impact review
- SAMAs are additional features or actions which would prevent or mitigate the consequences of serious accidents
- SAMA analysis includes consideration of:
  - hardware or procedure changes
  - core damage prevention or consequence mitigation
  - full scope of accidents (e.g., internal and external events)

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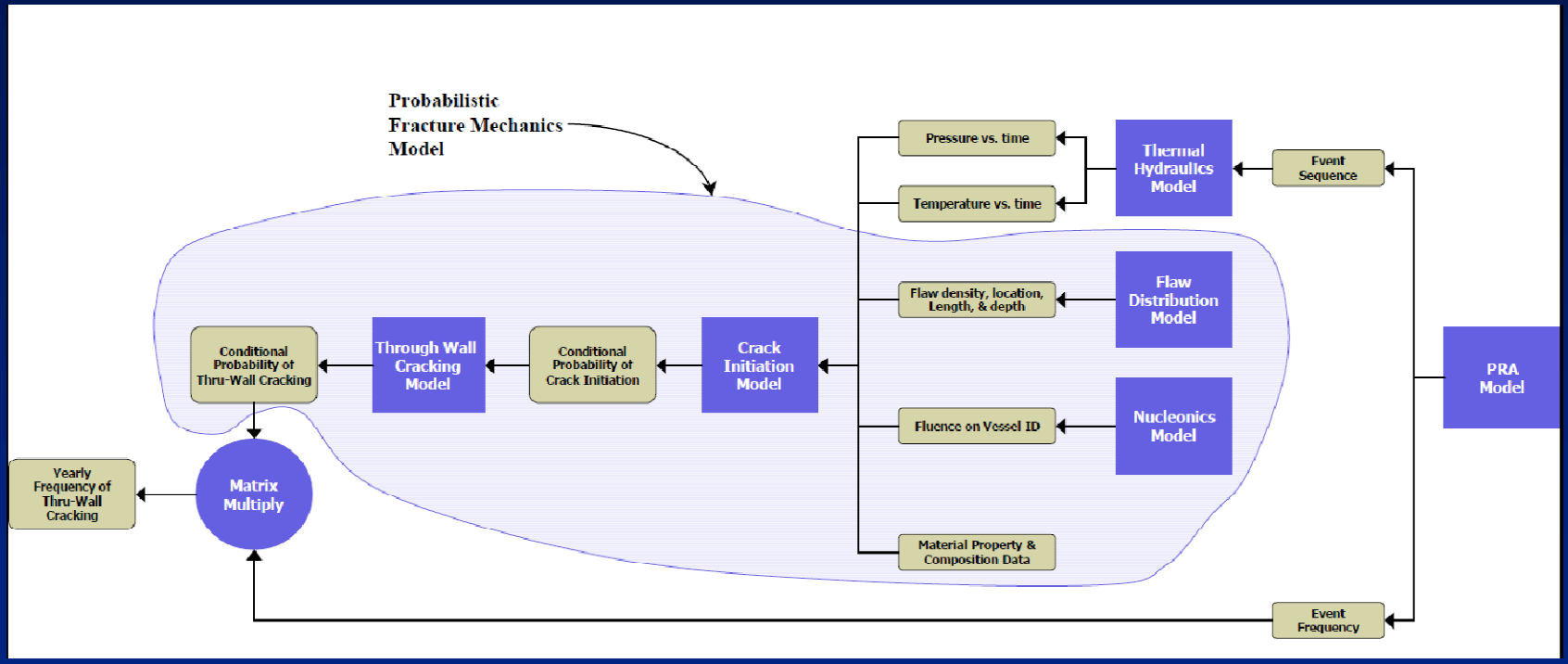
Pressurized Thermal Shock

- NRC's Office of Nuclear Regulatory Research undertook a project in 1999 to develop a technical basis to support a risk-informed revision of the existing PTS Rule, set forth in Title 10, Section 50.61, of the Code of Federal Regulations (10 CFR 50.61) to provide the technical basis that the staff will consider in a potential revision of 10 CFR 50.61
- The risk from PTS was determined from the integrated results of the Fifth Version of the Reactor Excursion Leak Analysis Program (RELAP5) thermal-hydraulic analyses, fracture mechanics analyses, and probabilistic risk assessment.

PTS Analysis Approach



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PTS Evaluation - Results

- These calculations demonstrate that, even through the period of license extension, the likelihood of vessel failure attributable to PTS is extremely low (NUREG-1874)
  - At the end of 40 years of operation – or 32 Effective Full Power Years (EFPY) – the 95th percentile through-wall cracking frequency (TWCF) does not exceed ~2E-07/ry.
  - At the end of license extension (60 operational years, or 48 EFPY at an 80% capacity factor) the 95th percentile TWCF estimated does not exceed ~4.3E-7/ry.
- Considering that the reference plant RPVs (Beaver Valley and Palisades) were constructed from some of the most irradiation-sensitive materials in commercial reactor service today, these results suggest that, provided operating practices do not change dramatically in the future, the operating reactor fleet is in little danger of exceeding the TWCF acceptance criterion (1E-6/ry) even after license extension.

PTS Evaluation - Results

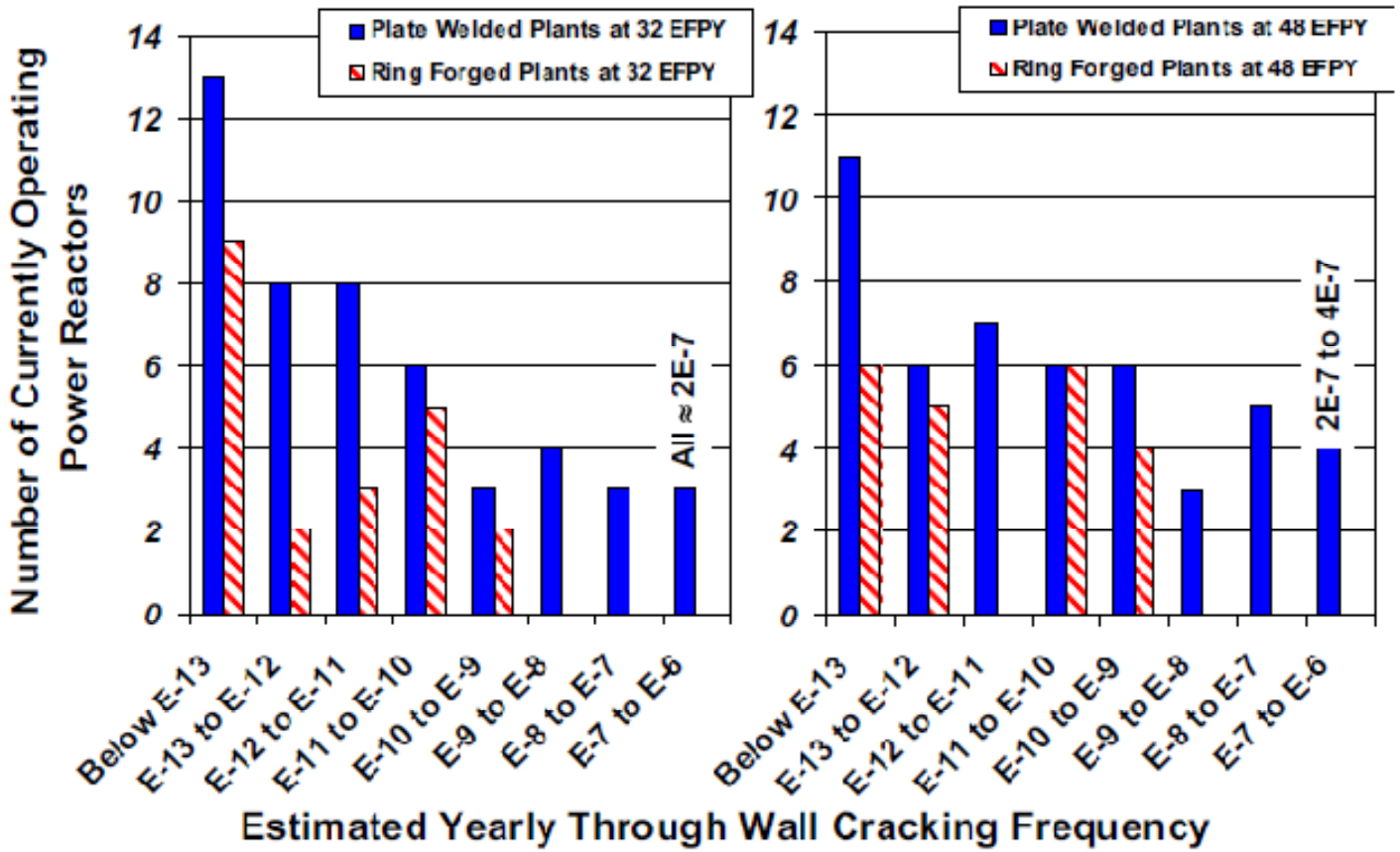

Figure 3.11. Estimated distribution of TWCF for currently operating PWRs using the procedure detailed in Section 3.5.1

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LOCA Frequency Estimation

- Objective of study was the estimate of LOCA frequencies as a function of break size.
  - Separate BWR and PWR piping and non-piping passive system LOCA frequency estimates were developed
  - Estimates were based on an expert elicitation process which consolidated operating experience and insights from probabilistic fracture mechanics studies with knowledge of plant design, operation, and material performance.
- A number of potential aging mechanisms were considered:
  - Low Cycle Thermal Fatigue
  - High Cycle Mechanical Fatigue
  - Stress Corrosion Cracking
  - Corrosion (localized and general)
  - Fretting
  - Material aging
  - Fabrication Defects and Repair
  - Hydrogen embrittlement
  - Flow assisted corrosion
  - Unanticipaited

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LOCA Frequency Estimation

- BWR Insights: Most participants identified thermal fatigue, FAC, IGSCC, and mechanical fatigue as the important degradation mechanisms to consider in BWR piping.
- PWR Insights: Most participants identified thermal fatigue, mechanical fatigue, and PWSCC, as the important degradation mechanisms to consider in PWR piping

Work is documented in NUREG-1829

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LOCA Frequency Estimation

- Many panelists thought that aging may have the greatest effect on intermediate diameter (i.e., 6 to 14-inch nominal diameter) piping systems
  - large number of components within this size range, and
  - the fact that this piping generally receives less attention than the larger diameter piping and is harder to replace than the more degradation-prone smaller diameter piping.
- Panelists' consensus is that mitigation procedures are in place, or will be implemented in a timely manner, to alleviate significant increases in future LOCA frequencies for existing degradation mechanisms.
- Increases expected beyond the next 15 years are largely due to uncertainty about the future and the concern that new degradation mechanisms could arise in the operating fleet after this time

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LWR Sustainability Program

- Research and development (R&D) program sponsored by the U.S. Department of Energy (DOE), performed in close collaboration with industry, to provide the technical foundations for licensing and managing the long-term, safe and economical operation of current nuclear power plants
- Program focus is on the longer term and higher risk/reward research that contributes to the national policy objectives of energy security and reduction of carbon dioxide (CO2) emissions.

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LWR Sustainability Program

- **Nuclear Materials Aging and Degradation**
  - Provide data and methods to assess performance of systems, structures, and components essential to safe and sustained nuclear power plant operation.
- Advanced LWR Nuclear Fuel Development
  - Improve the scientific knowledge basis for understanding and predicting fundamental nuclear fuel and cladding performance in nuclear power plants.
- Advanced Instrumentation, Control, and Information Systems Technologies
  - Establish advanced condition monitoring and prognostics technologies for use in understanding the aging of systems, structures and components of nuclear power plants. Develop and demonstrate information system technology enhancements for knowledge migration and regulatory compliance.
- **Risk-Informed Safety Margin Characterization**
  - Bring together risk-informed, performance-based methodologies with fundamental scientific understanding of critical phenomenological conditions and deterministic predictions of nuclear plant performance, leading to an integrated characterization of public safety margins in an optimization of nuclear safety, plant performance, and long-term asset management.
- Economics and Efficiency
  - Develop methodologies and scientific basis to enable more extended power uprates or ultra high power uprates and improve thermal efficiency.

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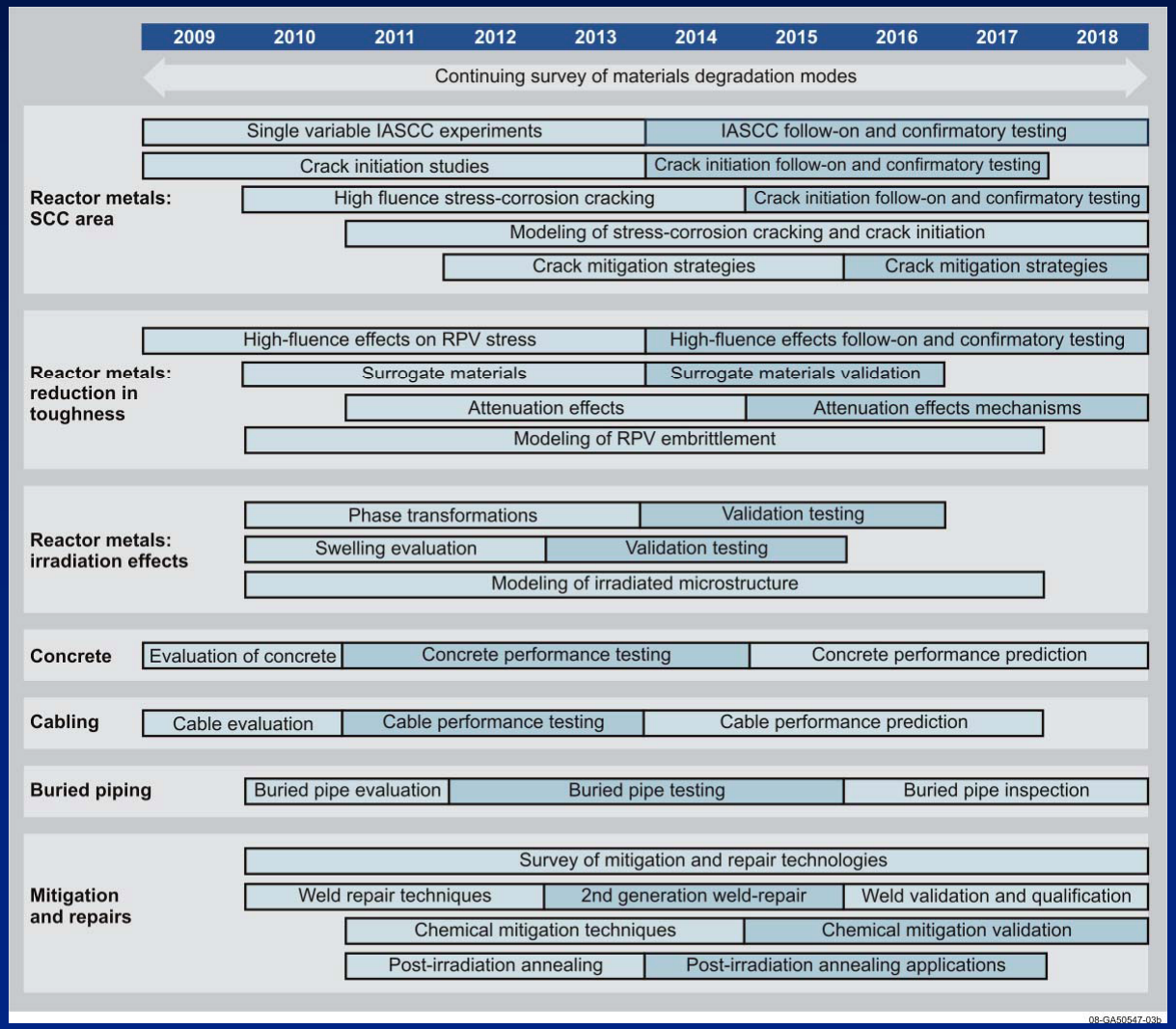
LWR Sustainability – Materials Research



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LWR Sustainability - Risk

- Risk Informed Safety Margin Characterization (RISMC) Research and Development
  - Objective is to bring together risk-informed, performance-based methodologies with fundamental scientific understanding of critical phenomenological conditions and deterministic predictions of nuclear plant performance, leading to an integrated characterization of public safety margins in an optimization of nuclear safety, plant performance, and long-term asset management.

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LWR Sustainability - Risk

Three interrelated project areas are considered:

- Integrated Risk Modeling (IRM)
  - comprehensive and transparent methodology to define and subsequently quantify safety margins in the risk-informed framework and determine how these could change over the long operating lifetimes of nuclear power plants is established; in other words, to quantify uncertainties in loads and capacities
- Enhanced Technology Integration (ETI)
  - using real plant analysis, issues, and examples to scrutinize methodological and framework aspects developed in the IRM research
- RISMC-Enabling Methods and Tools (M&T)
  - new generation production codes will be built on their existing capabilities while capitalizing on the advances in computing power and computational science (including computational fluid dynamics, neutron diffusion/transport, and fluid-structure interactions) that have been achieved over of the past decades.
  - A conceptual vision of this integration tool, called Phoenix, has been developed by EPRI. As a platform for safety margin measurement and trending, Phoenix interfaces with the materials degradation matrix, real time I&C and equipment monitoring to update the input information, and produce recommendations for acceptance limits, risk trends, and priorities.

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Final Thoughts

- NRC does not explicitly consider aging in PSAs
- License renewal does not require that an aging PSA be developed
- Data collection and trending programs are expected to identify significant age-related failure mechanisms
- A number of previous NRC studies have explicitly considered age-related degradation mechanisms (e.g., PTS, LOCA evaluation)

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Resources

- NRC Operating Experience Database Webpage http://nrcoe.inel.gov/results/index.cfm
- NUREG/CR-5612," Degradation Modeling with Application-to Aging and Maintenance Effectiveness Evaluations"
- NUREG/CR-5750, "Rates of Initiating Events at U.S. Nuclear Power Plants"
- NUREG/CR-6514, "Applications of Reliability Degradation Analysis"
- NUREG-1715, "Component Performance Study"
- NUREG/CR-6819, "Common Cause Failure Event Insights"
- NUREG-1801, "Generic Aging Lessons Learned (GALL) Report", Revision 1

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Resources (con't)

- NUREG-1806, "Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10 CFR 50.61)"
- NUREG-1874, "Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening
- Limit in the PTS Rule (10 CFR 50.61): Final Report"
- NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process"
- NUREG/CR-5500, Reliability Studies (multi-volume)
- NRC License Renewal Webpage:
  http://www.nrc.gov/reactors/operating/licensing/renewal.html
- Light Water Reactor Sustainability Program Webpage:
  http://nuclear.energy.gov/LWRSP/overview.html