U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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RC-5- Materials Research Pathway: Characterization and Modeling of the High Fluence Effect and Thermal Aging on Reactor Pressure Vessel Steels

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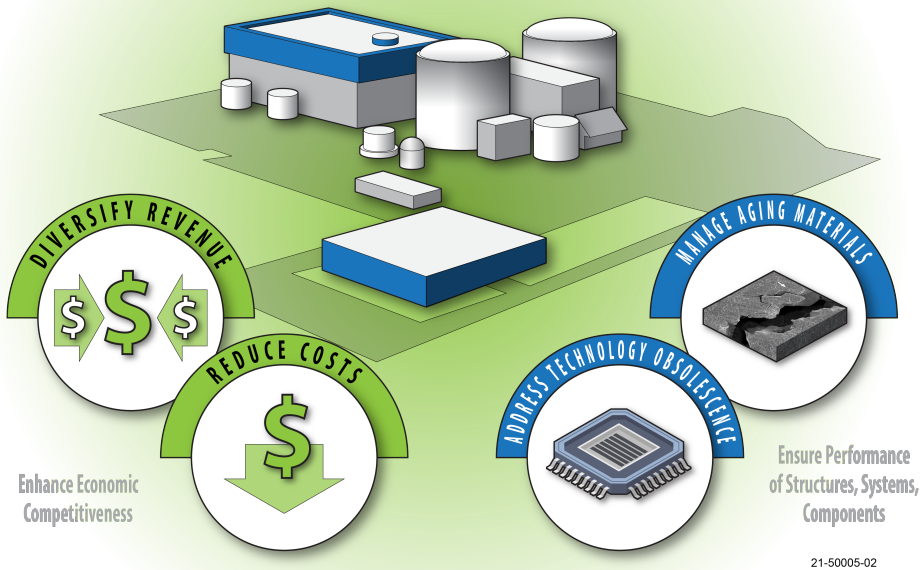
Office of Nuclear Energy
U.S. Department of Energy

Light Water Reactor Sustainability Program

- **Goal**
  - Enhance the safe, efficient, and economical performance of our nation's nuclear fleet and extend the operating lifetimes of this reliable source of electricity

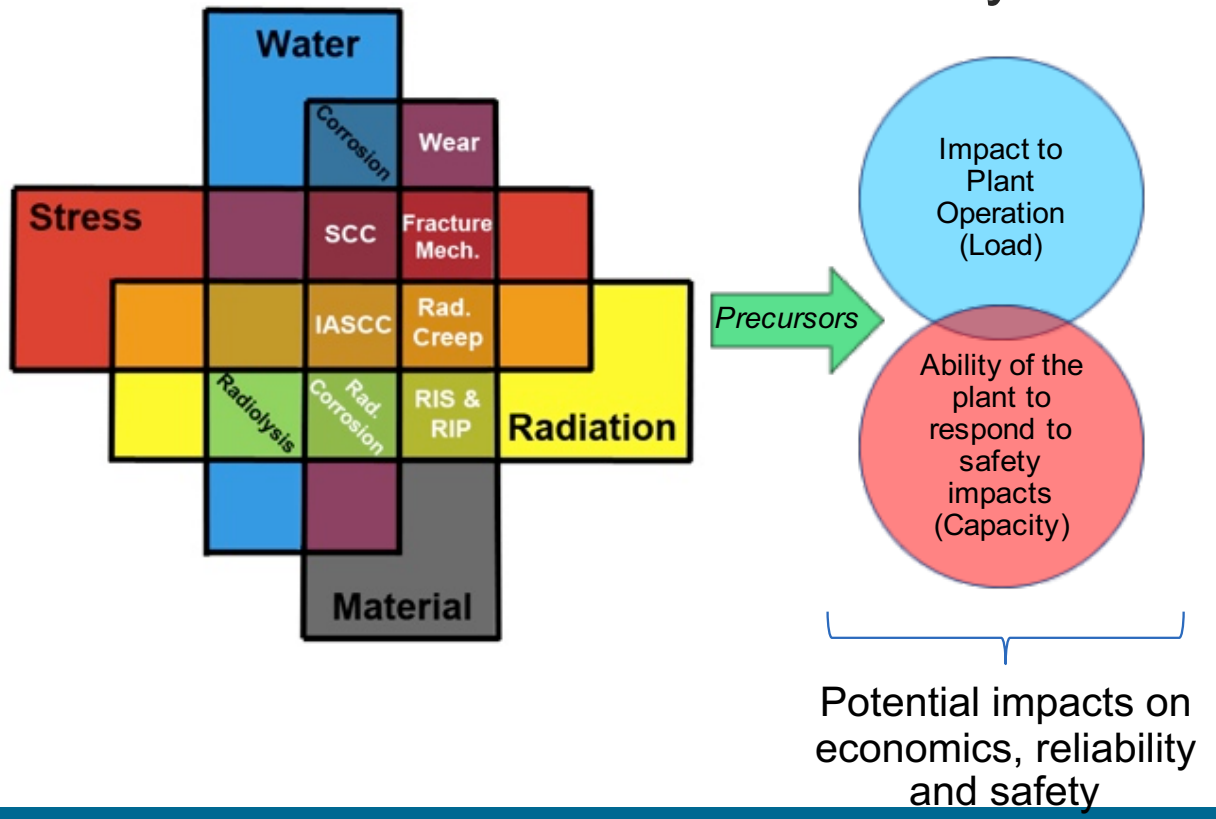
- **Objectives**
  - Enable long term operation of the existing nuclear power plants
  - Deploy innovative approaches to improve economics and economic competitiveness of LWRs in the near term and in future energy markets.
  - Sustain safety, improve reliability, enhance economics

- **Focus Areas**
  - Plant Modernization Research and Development
  - Flexible Plant Operation and Generation
  - Risk-Informed Systems Analysis
  - Materials Research
  - Physical Security

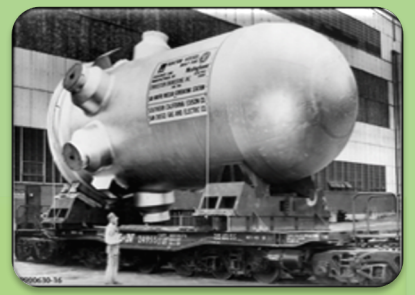


Materials Research: Goals and Objectives

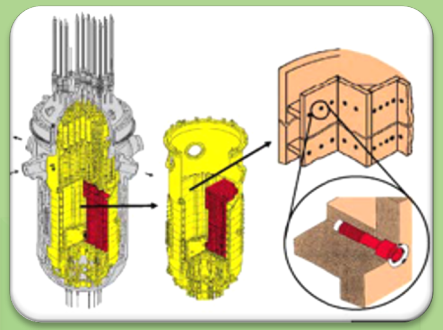
- Develop the scientific basis for understanding and predicting long-term environmental degradation behavior of materials in nuclear power plants
- Provide data and methods to assess the performance of systems, structures, and components essential for the safe and economically sustainable operation of the US NPP fleet.



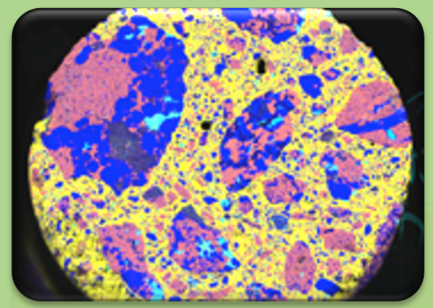
Materials Research Focus Areas



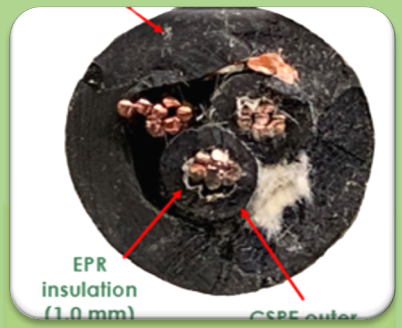
Reactor Pressure Vessel



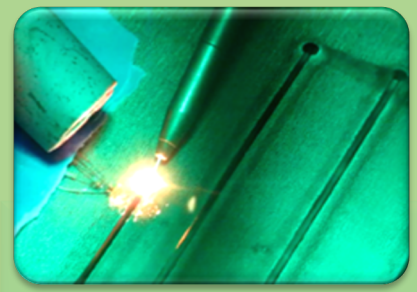
Internals, Pressure Boundaries and Piping



Concrete Degradation



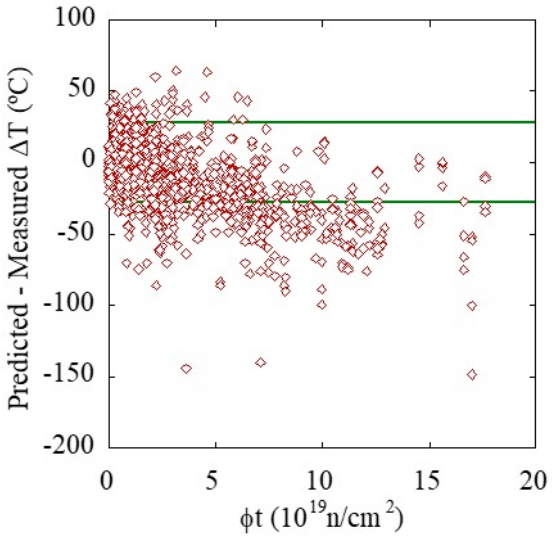
Cable Aging Degradation



Mitigation Methods

Materials Research Pathway: Characterization and **modeling of the effects of high fluence and thermal aging** on reactor pressure vessel (RPV) steels

- Proposals are sought to develop an enhanced understanding of the effects of high fluence on RPV steels **and potential for thermal aging** at extended LWR operations using advanced characterization and modeling techniques and methods
- RPV steels undergo significant changes in microstructure and associated mechanical properties, especially fracture toughness, when exposed to neutron irradiation and elevated temperatures
- High-fluence (φt), extended 80-year life embrittlement (ΔT) of RPV steels is under predicted due to late blooming MnNiSi phase precipitation hardening by current regulatory and code models. Recent reduced order model has demonstrated improvement with the existing US power reactor surveillance ΔT database
- Improving the treatment of some critical variables, especially flux (φ) effects at high fluence are expected to significantly reduce ΔT uncertainties and conservatism.
- Refined multiscale physics models emphasizing late blooming (MnNiSi) precipitation thermo-kinetics, dislocation evolution, and structure-property relations combined with machine learning are need.
- Proposals should include effects of irradiation, such as the fluence and flux effects, **potential for thermal aging at long term exposure,** and generation of models that could support life-extension licensing. Collaboration with industrial partners, national laboratories, or the NSUF materials library for accessing RPV steels at different irradiation conditions is **strongly** encouraged.

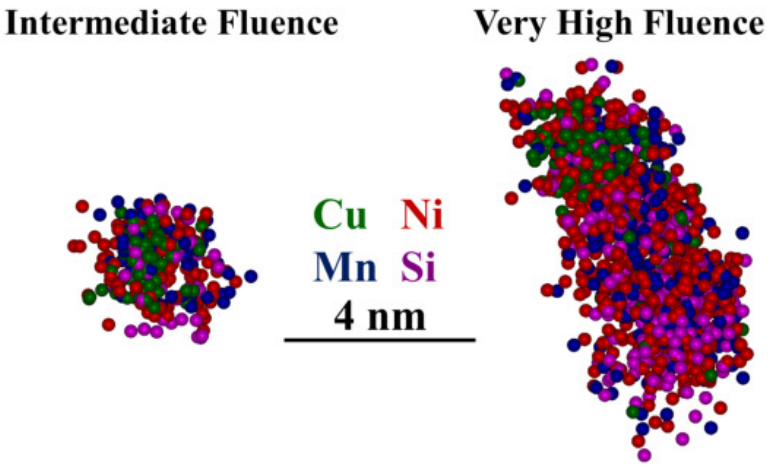


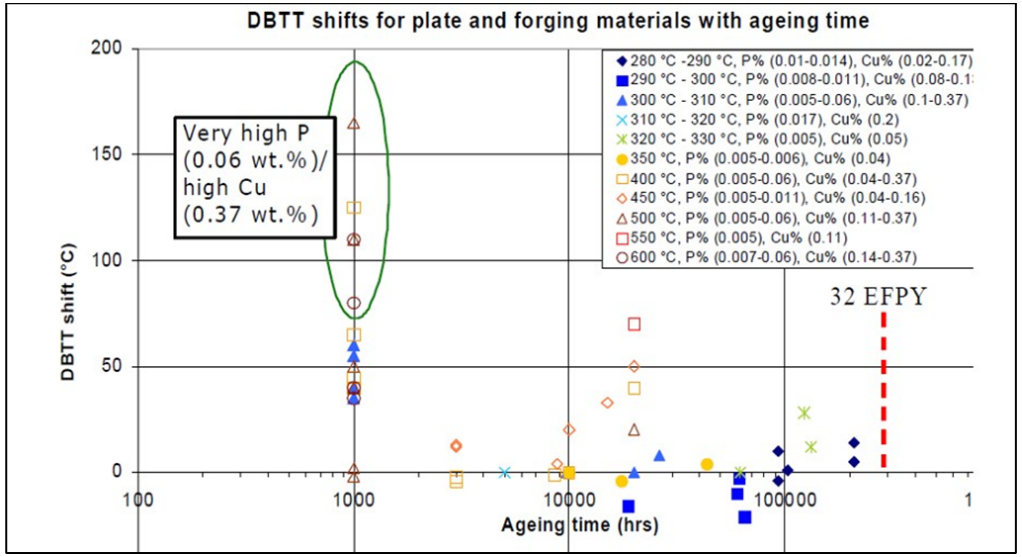
Current regulatory models under predict at high fluence

CINR Workscope: RC-7

The need for modeling of the effects of high fluence & thermal aging of RPV low alloys steels

- Cu-rich precipitates (CRP) quickly nucleate and grow up to matrix Cu depletion, a thin Mn, Ni and Si shell also appears in RPV low alloy steels (LAS).
- Mn-Ni-Si Precipitates (MNSP, or “Late Blooming Phases”) exhibit much slower nucleation and growth kinetics than CRP and become increasingly significant at high fluences.
  - For Cu-bearing steels, MNSP form as an appendages to CRP
  - For low Cu content steels, MNSP evolved from defect cluster complexes formed in displacement cascades
- Current models under predict embrittlement (ΔT) at high extended life fluence (φt) and, thus, need to be updated/improved to better account for Mn-Ni-Si “late blooming” phases and other embrittlement mechanisms that arise at high fluence, as well as to quantify neutron flux effects to adjust for accelerated test reactor irradiations to high-fluence, low-flux, service conditions.
- There is some evidence that thermal aging may present a potential concern for long-term operation. However, most research data are obtained from accelerated (high T) tests. The deficiency of sufficient data is due to the limited number of thermal aging surveillance capsules in US reactors. It should be noted that French and Russian reactors both have thermal aging capsules and both countries have regulatory provision to account for thermal embrittlement in their predictive equations.





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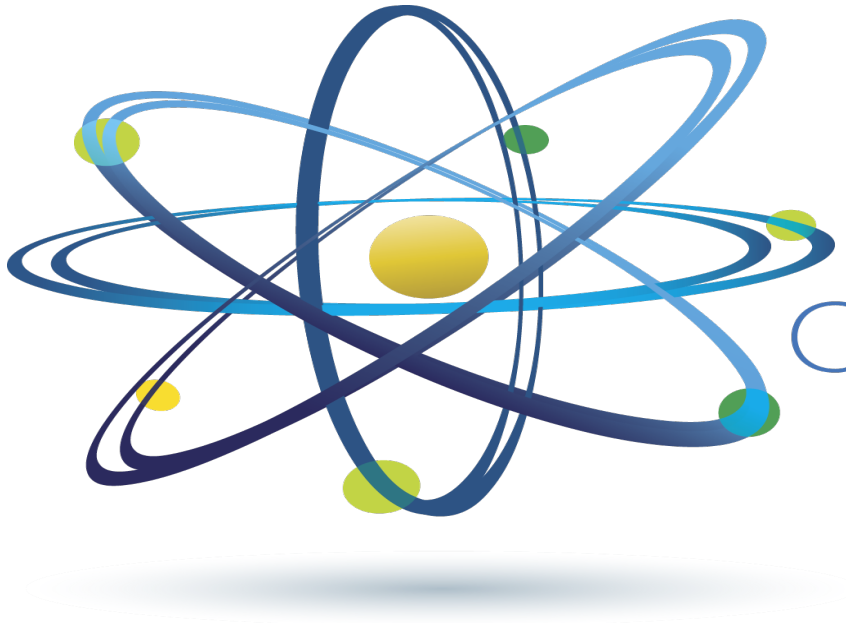
Questions



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