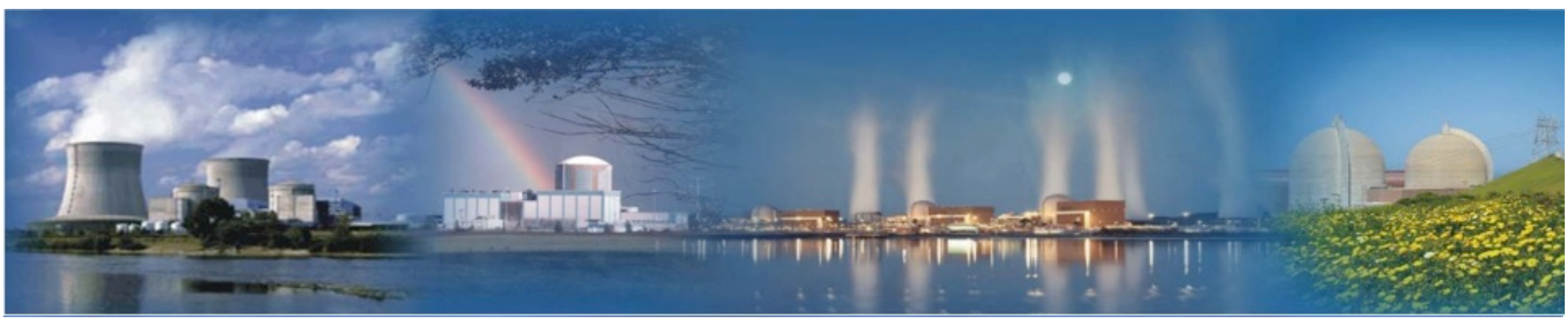
Overview of DOE-NE LWRS Materials and Aging Degradation Pathway

DOE-NE Materials Program Crosscutting Coordination Webinar

July 30, 2013

Light Water Reactor Sustainability R&D Program



Outline of presentation

- Motivation and Overview of LWRS Program
- Key activities within Materials Aging and Degradation portion of LWRS
- Partnerships
- Examples of research
  - Concrete
  - Cabling
  - Metals

Extending the lifetimes of today's reactors: A sustainable energy solution

Most of U.S. nuclear power plant (NPP) fleet is scheduled to retire between 2029 and 2056

- Original licenses: 40 years
- 20 year license renewals now being granted or considered for most of US fleet

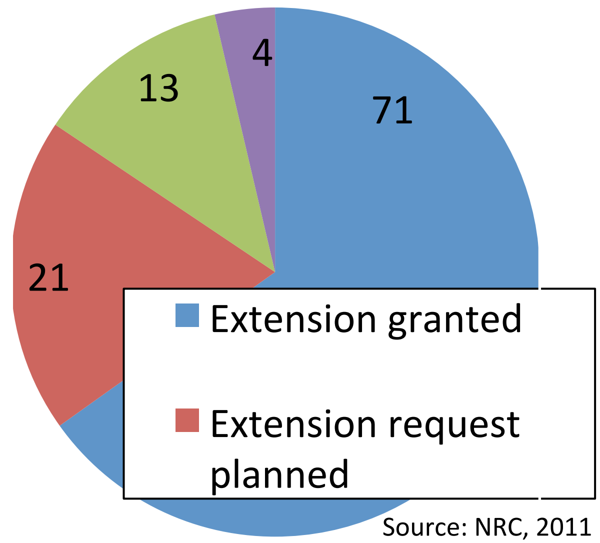
Extending NPP lifetimes to 80 years or more would provide multiple benefits

- Reducing greenhouse gas emissions
- Meeting electricity demand
- Ensuring energy supply security and grid reliability
- Stabilizing energy prices

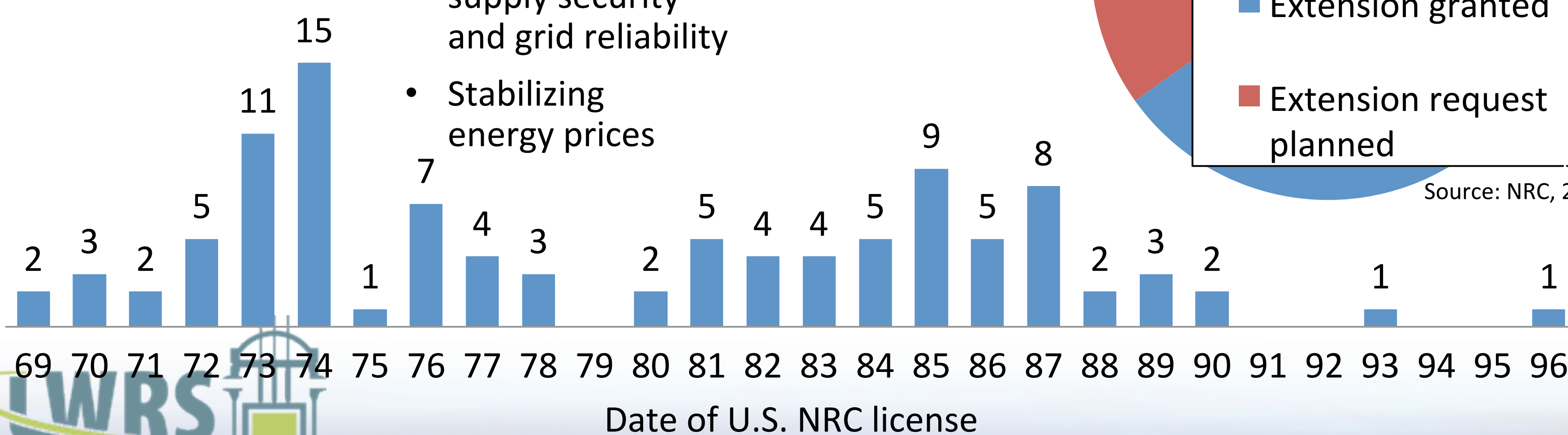
Subsequent license renewal makes economic sense

- Building a new NPP: $8B
- Extending lifetime to 80 years: $800M

R&D is needed to provide the technical basis for subsequent lifetime extension



Source: NRC, 2011



Light Water Reactor Sustainability

The DOE-NE Light Water Reactor Sustainability Program is supporting subsequent license extension decisions

Vision

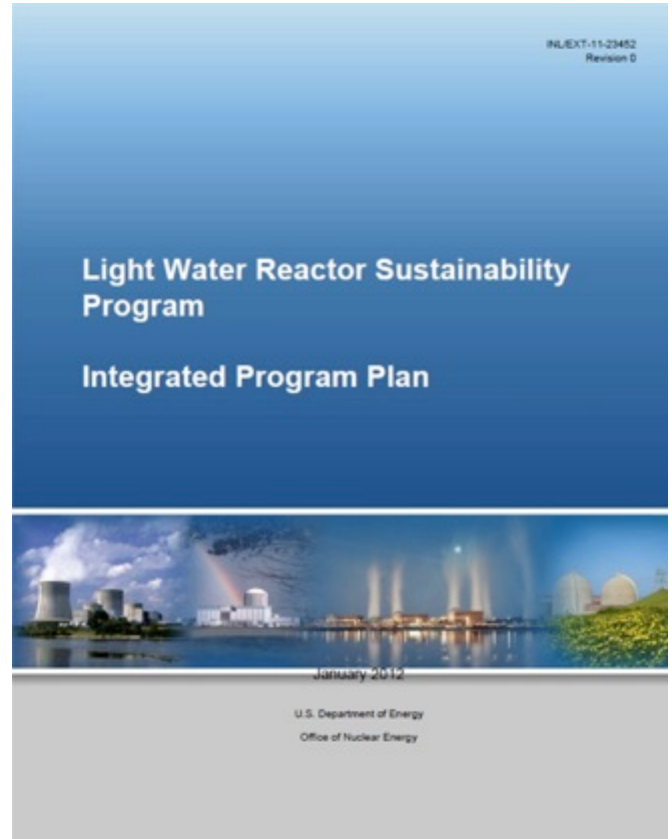
- *Enable existing nuclear power plants to safely provide clean and affordable electricity beyond current license periods (beyond 60 years)*

Program Goals

- Develop fundamental scientific basis to understand, predict, and measure changes in materials as they age in reactor environments
- Apply this knowledge to develop methods and technologies that support safe and economical long-term operation of existing plants
- Research new technologies that enhance plant performance, economics, and safety

Scope

- Materials Aging and Degradation
- Advanced Instrumentation and Controls
- Risk-Informed Safety Margin Characterization
- Advanced Fuels Development


INL/EXT-11-23452
Revision 0

Light Water Reactor Sustainability Program

Integrated Program Plan

January 2012

U.S. Department of Energy
Office of Nuclear Energy

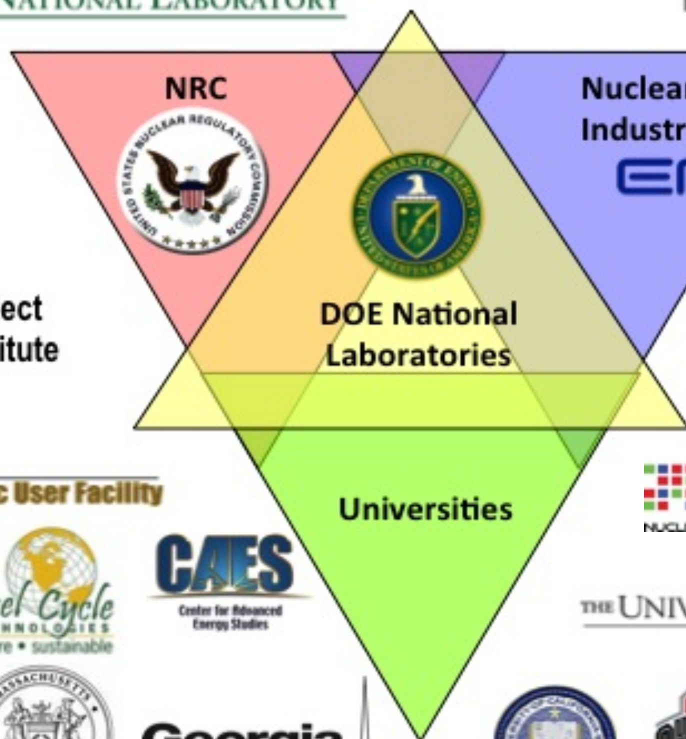
LWRS Integrated Program Plan (INL/EXT-11-23452, Rev. 0) Available on www.inl.gov/lwrs

LWRS Light Water Reactor Sustainability

The LWRS program has a diverse set of partners

- MOU with NRC

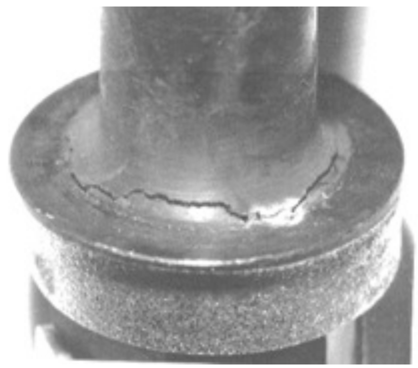
- International Partners
  - Halden Reactor Project
  - Materials Aging Institute



- MOU with EPRI
- Joint R&D Plan
- Industry pilot projects

Materials aging and degradation is a key need for subsequent license renewal

- Increased lifetime leads to increased exposures
  - Time at temperature
  - Stress
  - Coolant
  - Neutrons
- Extending reactor life to 60, 80 years or beyond may increase susceptibility and severity of known forms of degradation
- New mechanisms of materials degradation are possible



- 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 to safe and sustained NPP operations
- Develop means to detect and characterize aging degradation processes
- Develop technologies for mitigation of key forms of degradation

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Materials Aging and Degradation tasks provide results in several ways

- ***Measurements of degradation****:* High quality data will provide key information for mechanistic studies, but has value to regulators and industry on its own.
- ***Mechanisms of degradation*****:** Basic research to understand the underlying mechanisms of selected degradation modes will lead to better prediction and mitigation.
- ***Modeling and simulation*****:** Improved modeling and simulation efforts have great potential in reducing the experimental burden for life extension studies. These methods can help interpolate and extrapolate data trends for extended life.
- ***Monitoring*****:** While understanding and predicting failures are extremely valuable tools for the management of reactor components, non-destructive monitoring must also be utilized.
- ***Mitigation strategies*****:** While some forms of degradation have been well-researched, there are few options in mitigating their effects. New technologies may overcome limits of degradation in key components and systems.

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LWRS Materials Aging and Degradation research encompasses the entire plant

Concrete Degradation & Non-Destructive Evaluation(NDE)

Repair welding

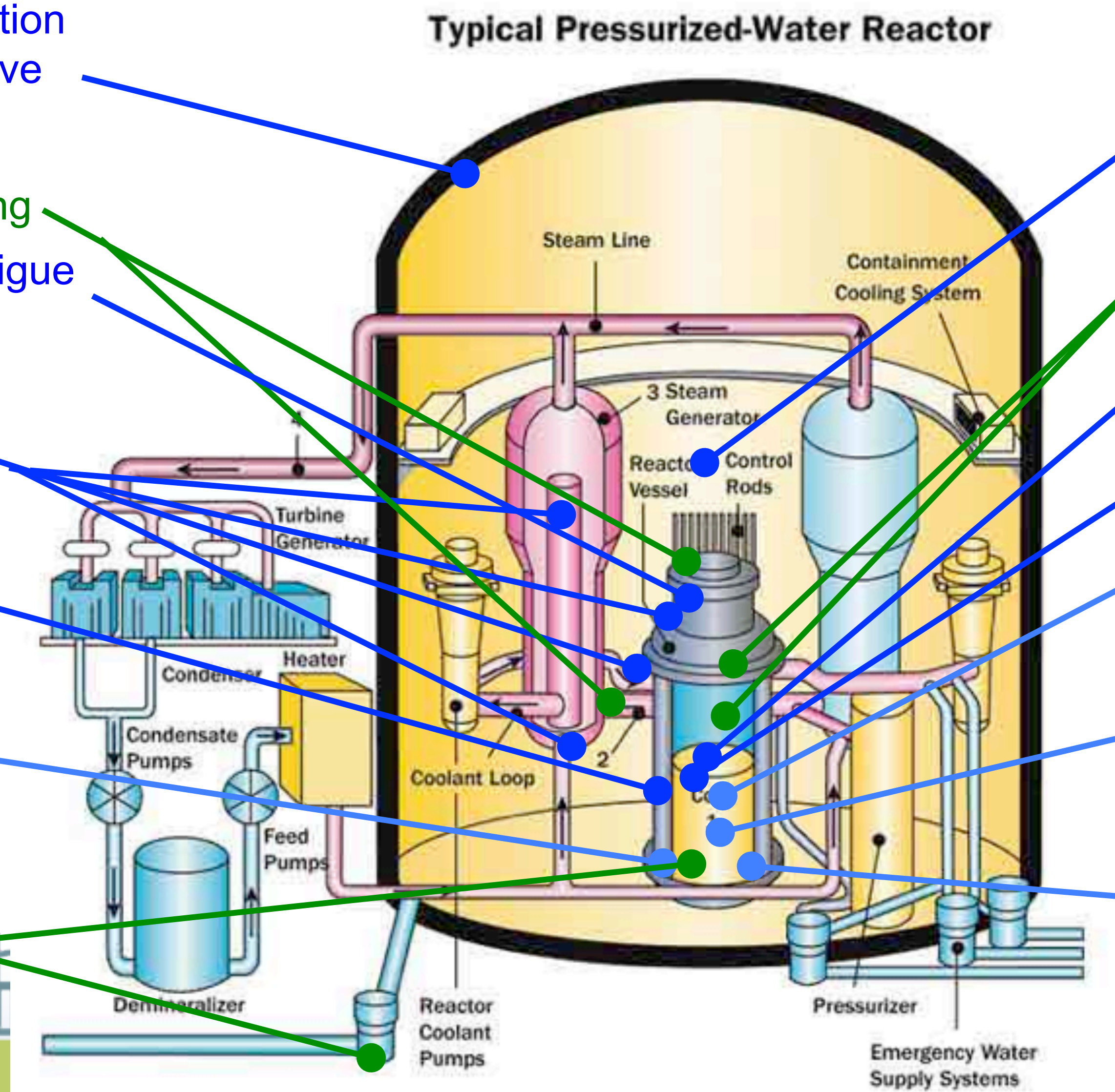
Environmental Fatigue & NDE

Crack initiation in Ni-base alloys & NDE

High Fluence effects on RPV & NDE

Surrogate materials and attenuation

Advanced replacement alloys



Analysis of cable degradation & NDE

Thermal annealing

Mechanisms of IASCC

High Fluence IASCC

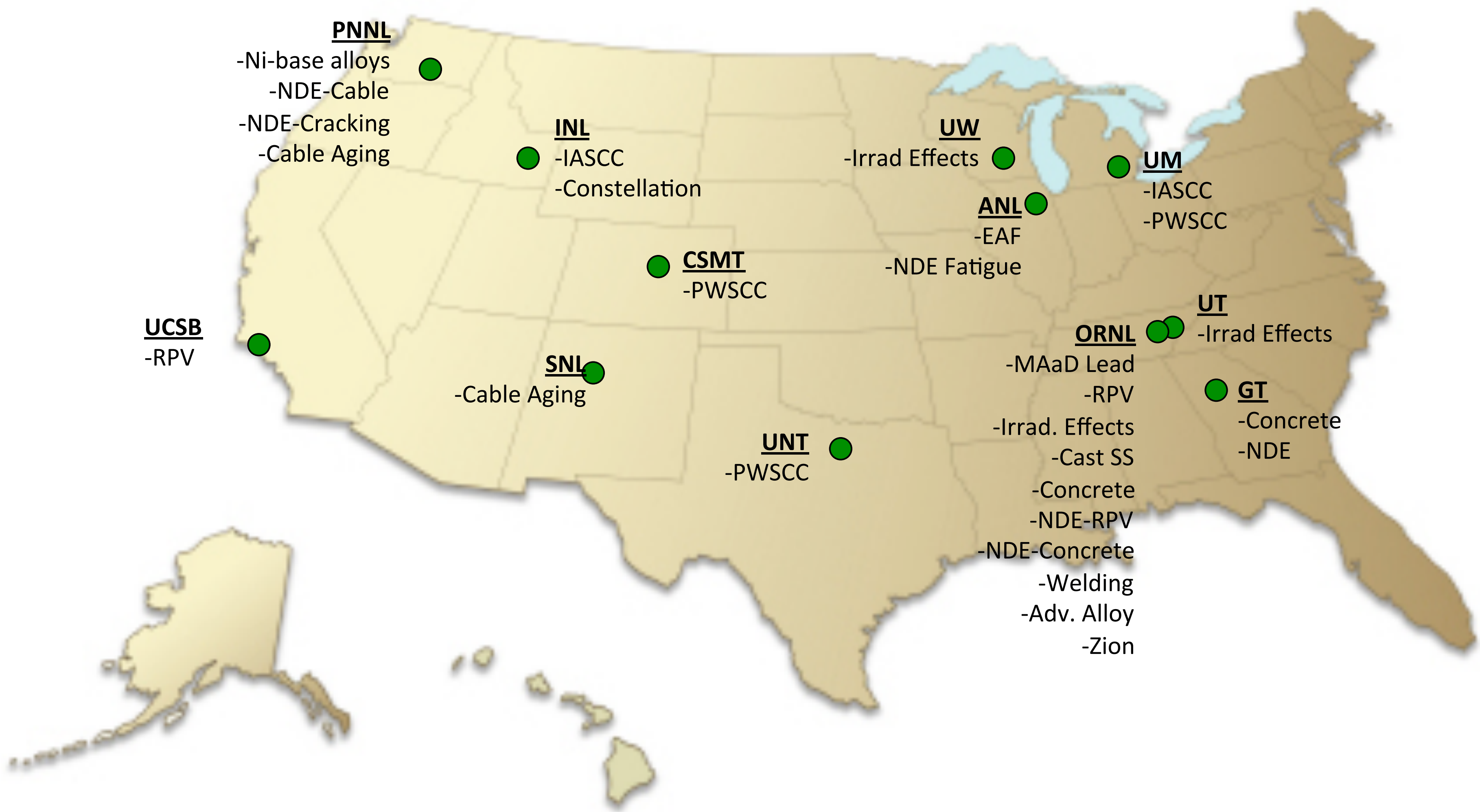
Swelling of core internals

High fluence phase transformations

Cast Stainless Aging

Light Water Reactor Sustainability

MAaD includes a diverse materials research effort team



LWRS Materials Aging and Degradation research is collaborative

Green: interactions strong, joint funding
Blue: coordinated or collaborative research
Orange: supported and collaboration developing
Red: collaboration unlikely

Concrete Degradation (EPRI and MAI)

Repair welding (EPRI)

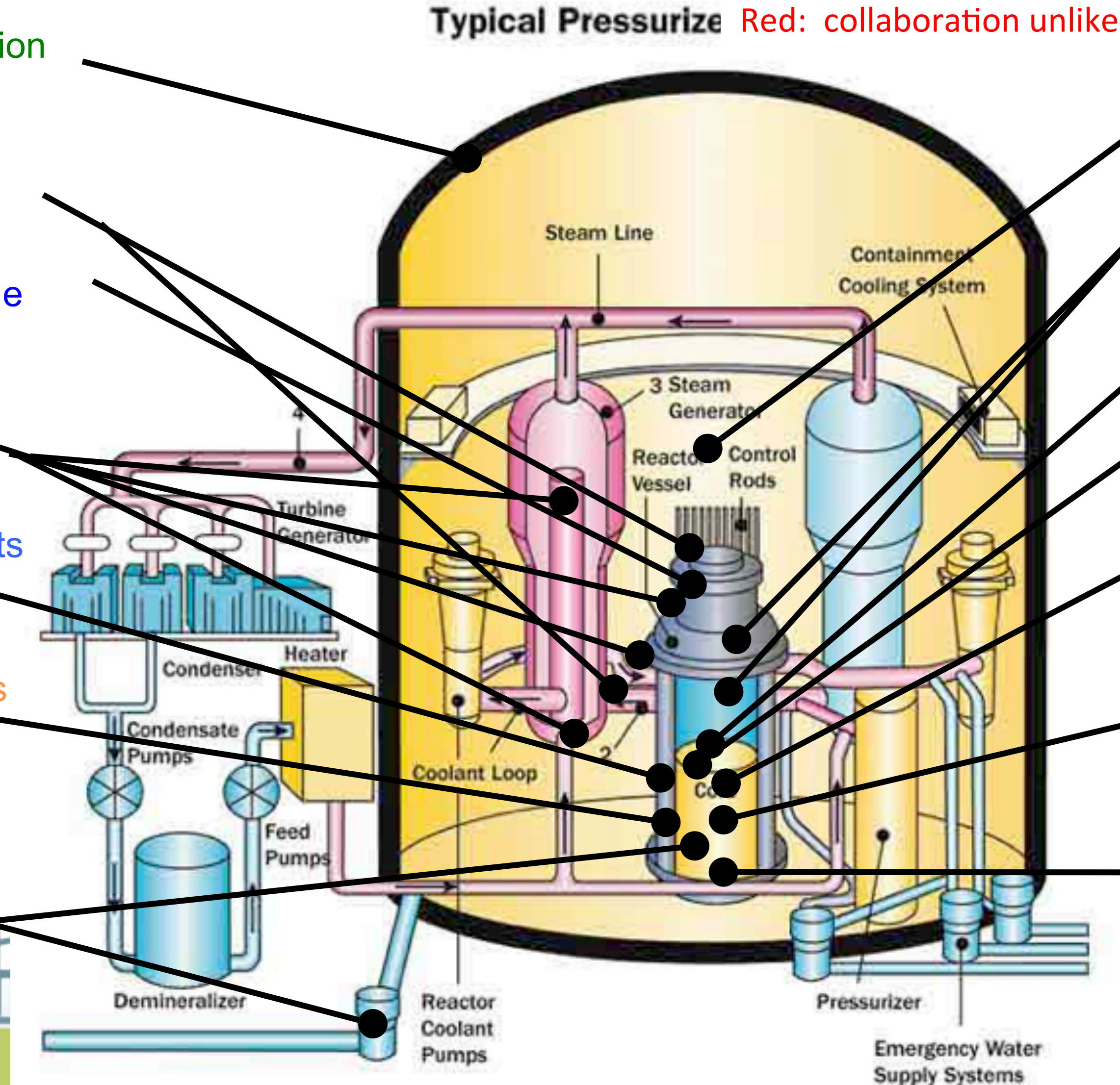
Environmental Fatigue (EPRI)

Crack initiation in Ni-base alloys (EPRI)

High Fluence effects on RPV (NRC and industry)

Surrogate materials and attenuation

Advanced replacement alloys (EPRI)



Analysis of cable degradation (EPRI)

Thermal annealing

Mechanisms of IASCC (EPRI)

High Fluence IASCC

Swelling of core internals (EPRI, Areva,)

High fluence phase transformations (EPRI, Areva,)

NDE

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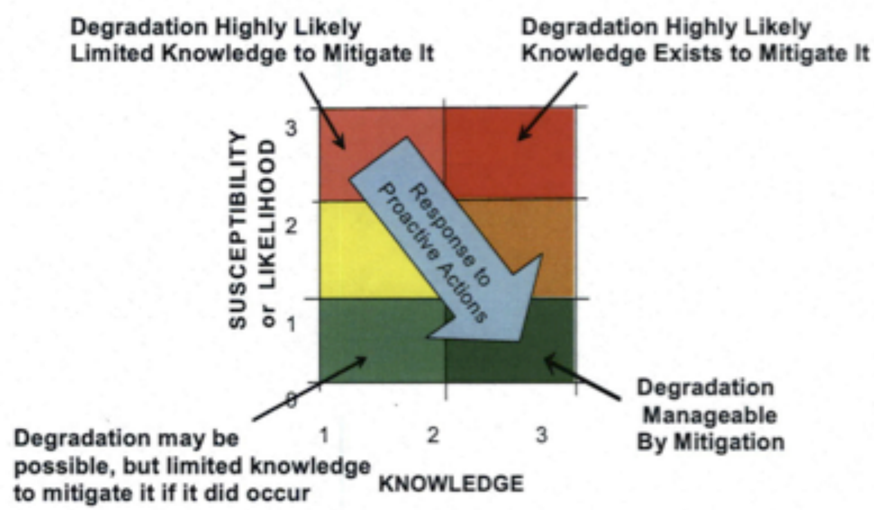
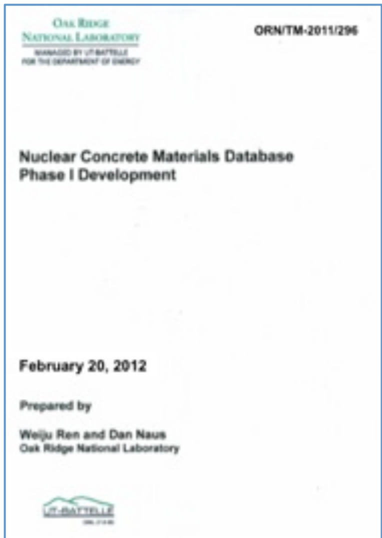
In addition to expert panel, other or new topics must be identified before they become life-limiting

- "Knowing the unknowns" is a difficult problem that must be addressed.
- This is a particularly difficult issue for such a complex and varied material/environment system.
- An organized approach similar to the US NRC's Proactive Materials Degradation Assessment (PMDA) (*NUREG/CR-6923* .
- Together with the U.S. NRC, the LWRS Program is working to expand the initial PMDA activity to systems and longer
  - Core internals and primary piping
  - Pressure Vessel
  - Concrete
  - Cabling



Proactive **M**aterials **D**egradation **A**ssessment Matrix

Nuclear Concrete Materials Database (NCMDB)


Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

ORN/TM-2011/296

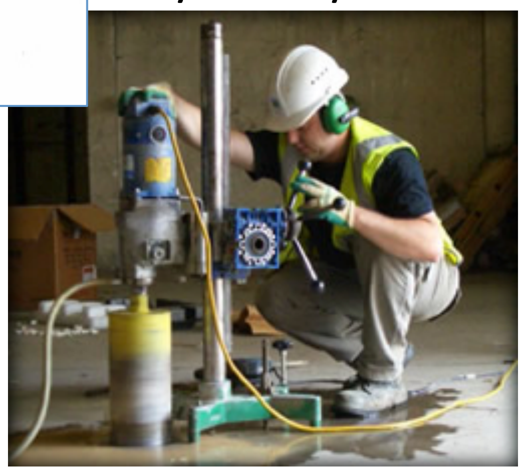
Nuclear Concrete Materials Database
Phase I Development

February 20, 2012

Prepared by

Weiju Ren and Dan Naus
Oak Ridge National Laboratory

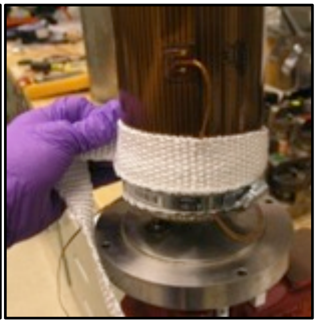
ORNL/TM-2011/296

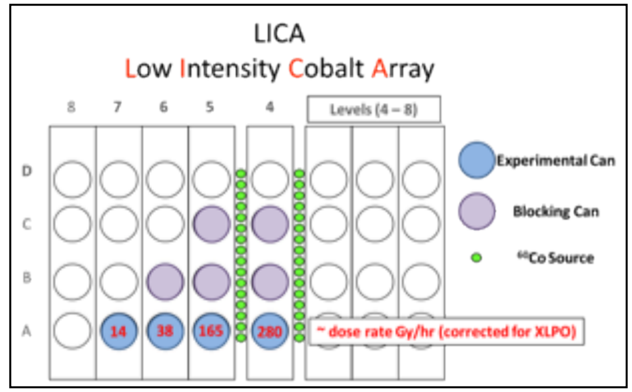


Concrete coring to obtain samples for evaluating effects of aging and environmental stressors

- Phase I of NCMDB has been completed and is on an internal server
- Data and information for populating the NCMDB are provided from literature sources and obtaining and testing samples from aged facilities
  - Aging
  - Elevated temperature
  - Irradiation
  - Migration of hostile species (e.g., Cl^-, SO_4, CO_2)
- Concrete irradiation damage working group formed
  - Development of protocols related to removal and testing of irradiated concrete cores
  - Identification of potential sources of irradiated concrete cores

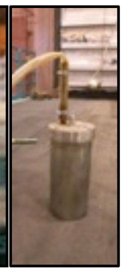
Cable aging research has focused on both service and lab materials





Finalized LICA Facility Updates

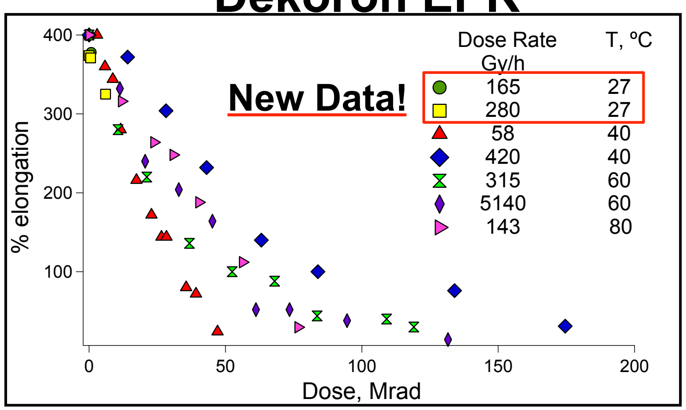
Performed Dosimetry and Updated Experimental Plan



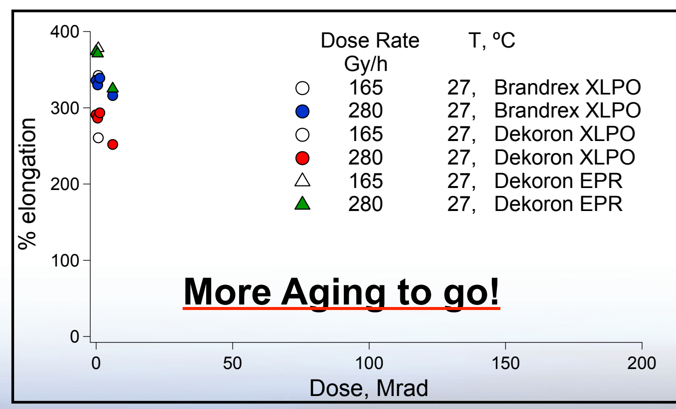
Initiated Long-Term Aging Experiments

Tensile Tested Virgin and Aged Specimens

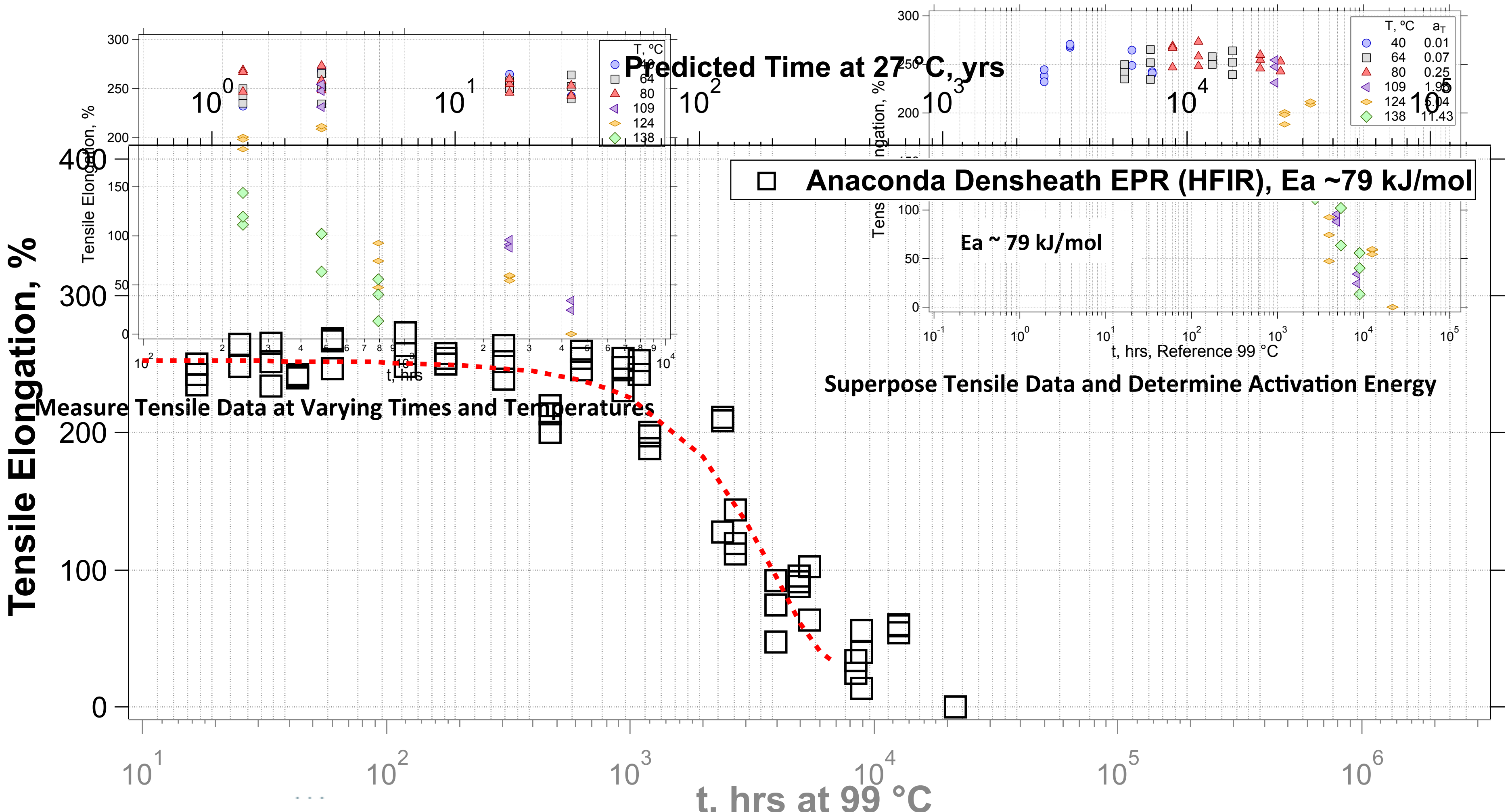
Dekoron EPR



Analyzed Aging Data



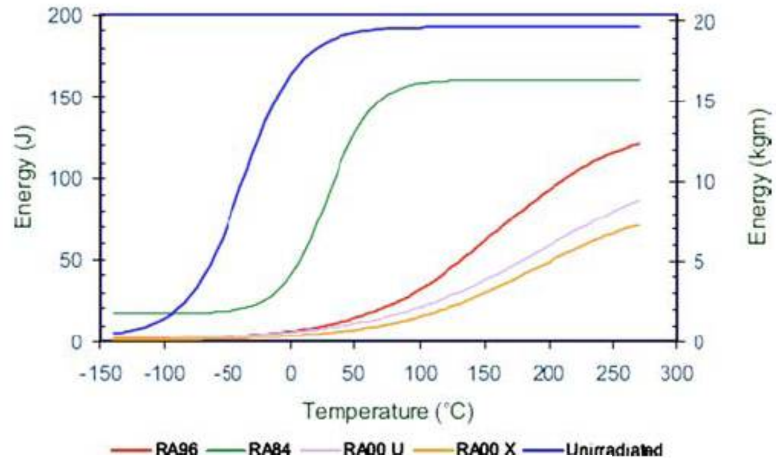
Accelerated aging has continued on service cable materials

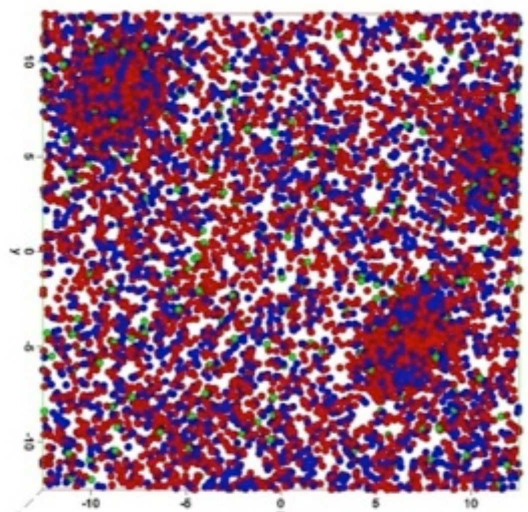


Anaconda Densheath EPR cables returned from service at HFIR at ORNL (~45 yrs of age, T_{avg} ~27 °C, RH ~70%). These cables were subjected to further thermal aging to elucidate their remaining tensile properties.

"Late Blooming Phases" have been the focus of one key materials research area

- Classical embrittlement of the reactor pressure vessel has been driven by rapid Cu-rich precipitate hardening
- Modern RPV steels have low-residual Cu-levels to mitigate this concern
- However, early models (Odette et al.) predicted that irradiation may drive phase transformations in even low Cu alloys
  - Mn-Ni(-Si-Cu) LBP that can reach large volume fractions and contribute to embrittlement
  - Could be important in low Cu steels thought to have little sensitivity to embrittlement
- RPV materials and surveillance specimens from the Ginna Nuclear Plant and from the Zion Nuclear Plants for material examination, APT, SANS, PAS





Low-copper (0.05 wt%) weld shifts 162°C at 6×10^{19}, clusters primarily of Ni-Mn-Si, very little copper.

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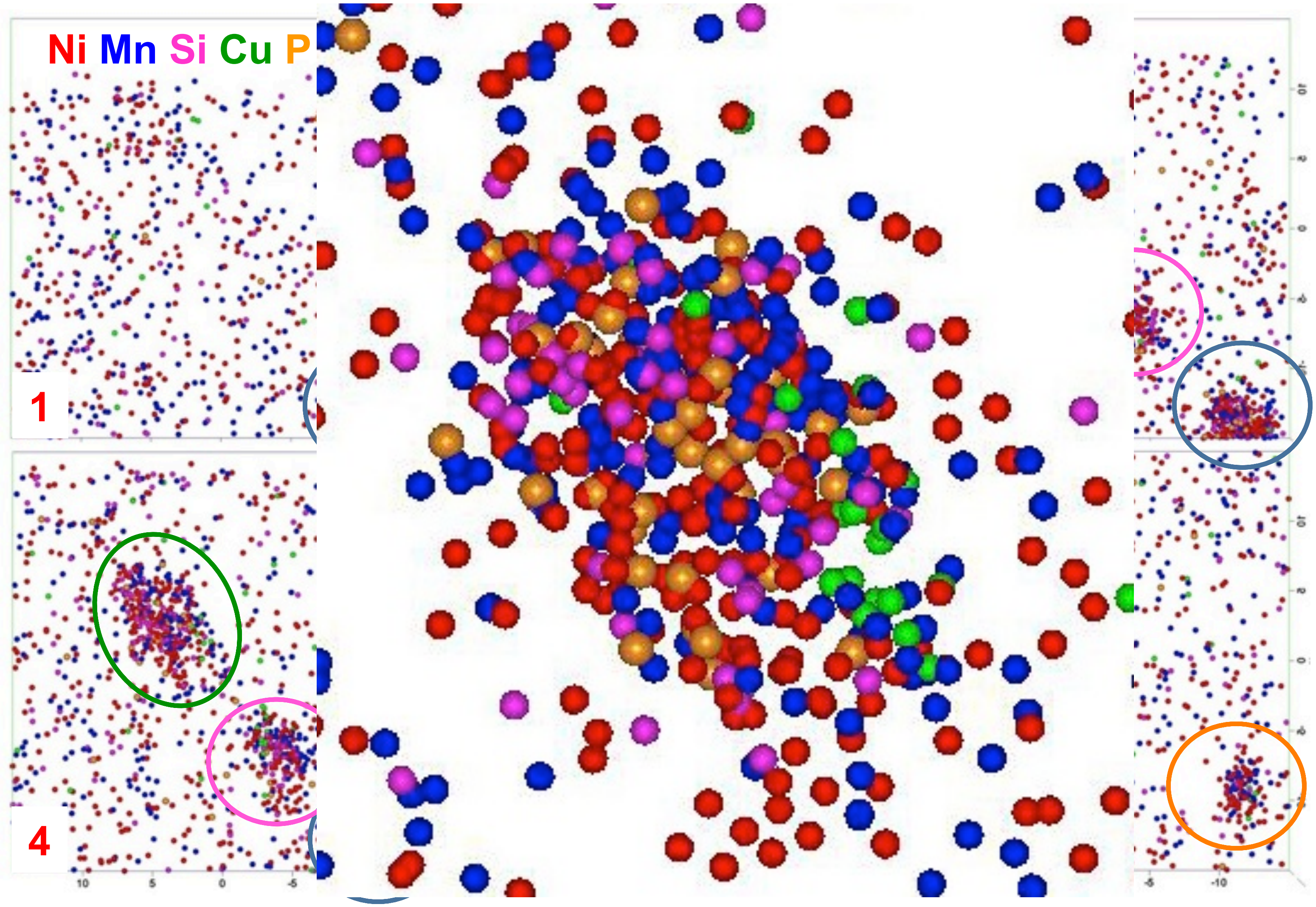
E6 surveillance weld: Atom maps - 1 nm slices



Fe (wt%)
0.08 Cu
1.58 Ni
1.46 Mn
0.54 Mo
0.21 Si
0.07 Cr
0.009 P
0.052 C

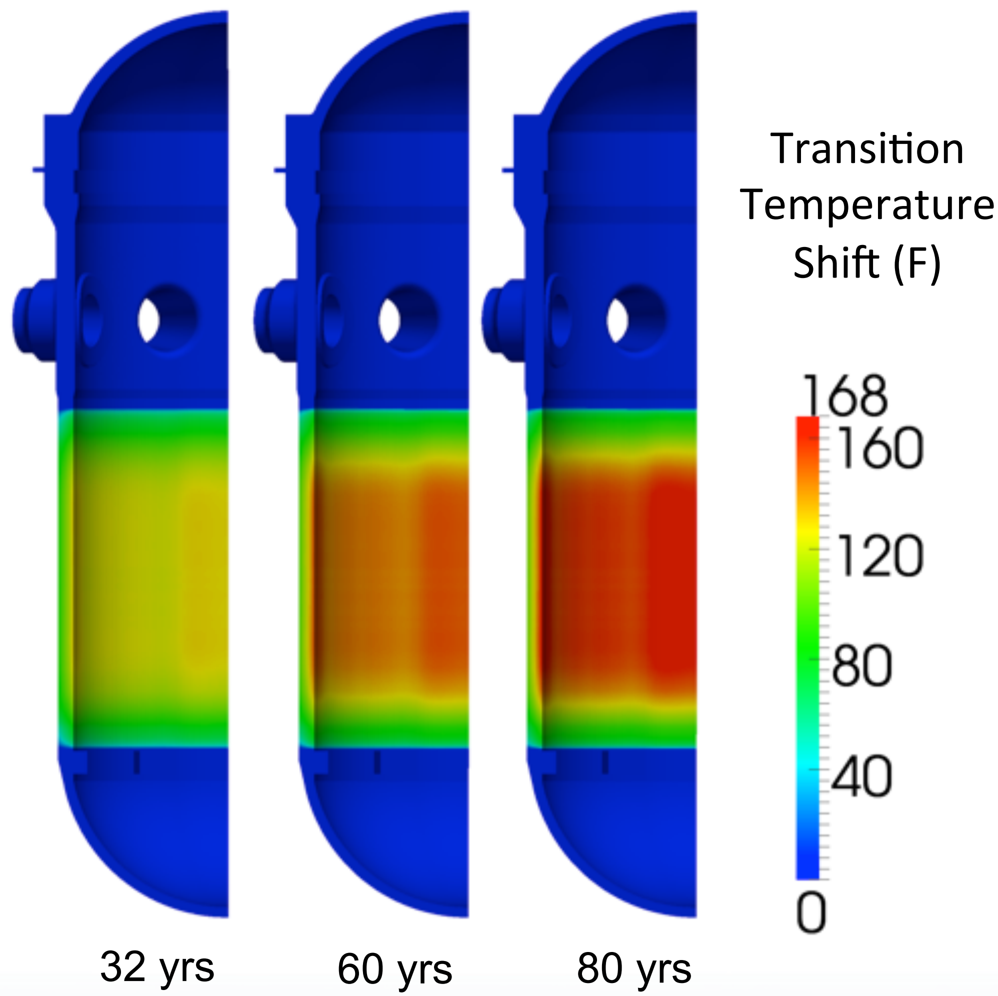
13.8 effective full power years

Atom map slices through 2-nm-diameter precipitates showing the solute distributions of Cu, Ni, Mn, P and Si within the precipitates.

High 0.08%Cu, high fluence: 6.4 x10^{19} n cm^{-2}

A new modeling tool is being developed to predict RPV degradation

- EONY model has been implemented on 3-D model of an RPV in Grizzly, calculates change in temperature transition shift over time and location.
- Application beyond 40 years is currently an extrapolation of experimental data and will be updated for extended service with new mechanisms and data in coming year
- In coming year, model will incorporate weldments, heat affected zones, spatial variations in chemistry, and vessel cladding.
- This task has provided additional opportunities for collaboration between research tasks.



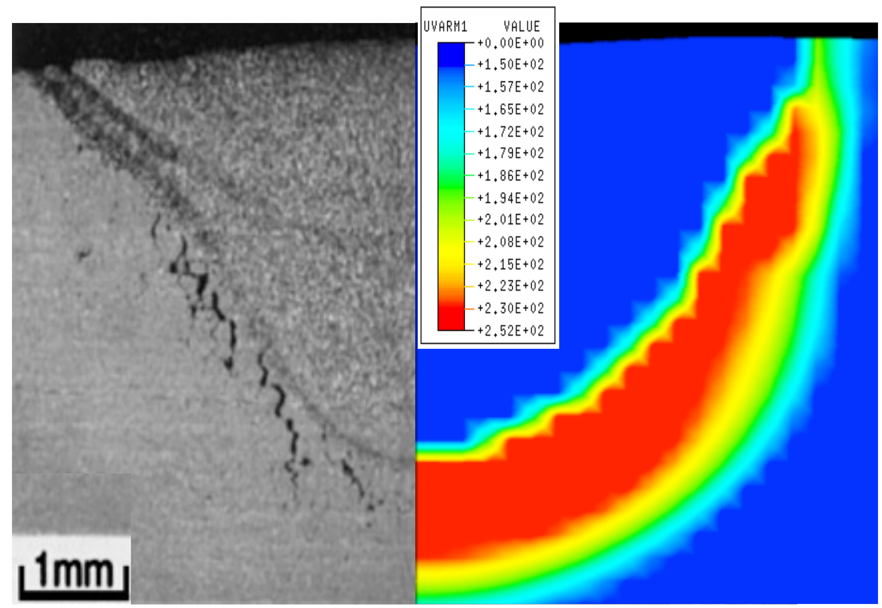
INL/ORNL/UT collaboration

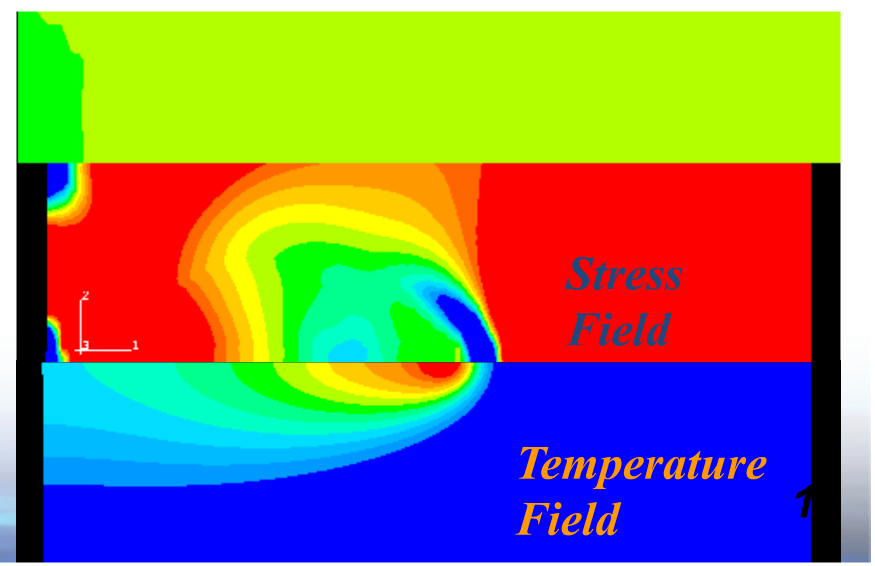
Analysis of irradiation-embrittlement in Ni-base alloys as part of the LWRS/Areva/EPRI partnership has continued

Light Water Reactor Sustainability

Advanced welding R&D may provide solutions to long-standing areas of concern

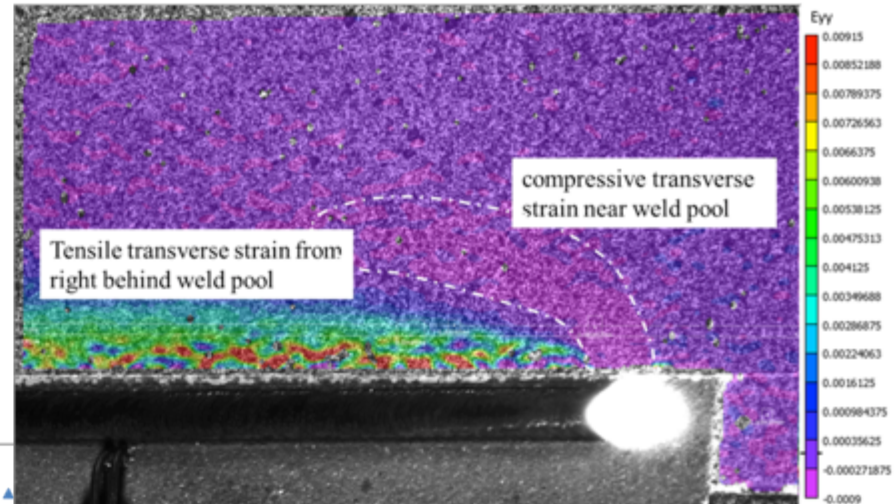
- Residual stress-modeling provides insights into long-term performance and cracking resistance
- Current research in advanced weldments is jointly funded by DOE and EPRI
  - Survey of present art of hybrid welding processes
  - Development of advanced computational model for hybrid welding processes
  - Develop a science-based hybrid laser weld processing model to optimize the weldability of irradiated materials
  - Develop experiment methodology for direct measurement of transient high-temperature temperature and stress history during welding
- Technology is being developed with the direct expectation of transfer to industry in the near term

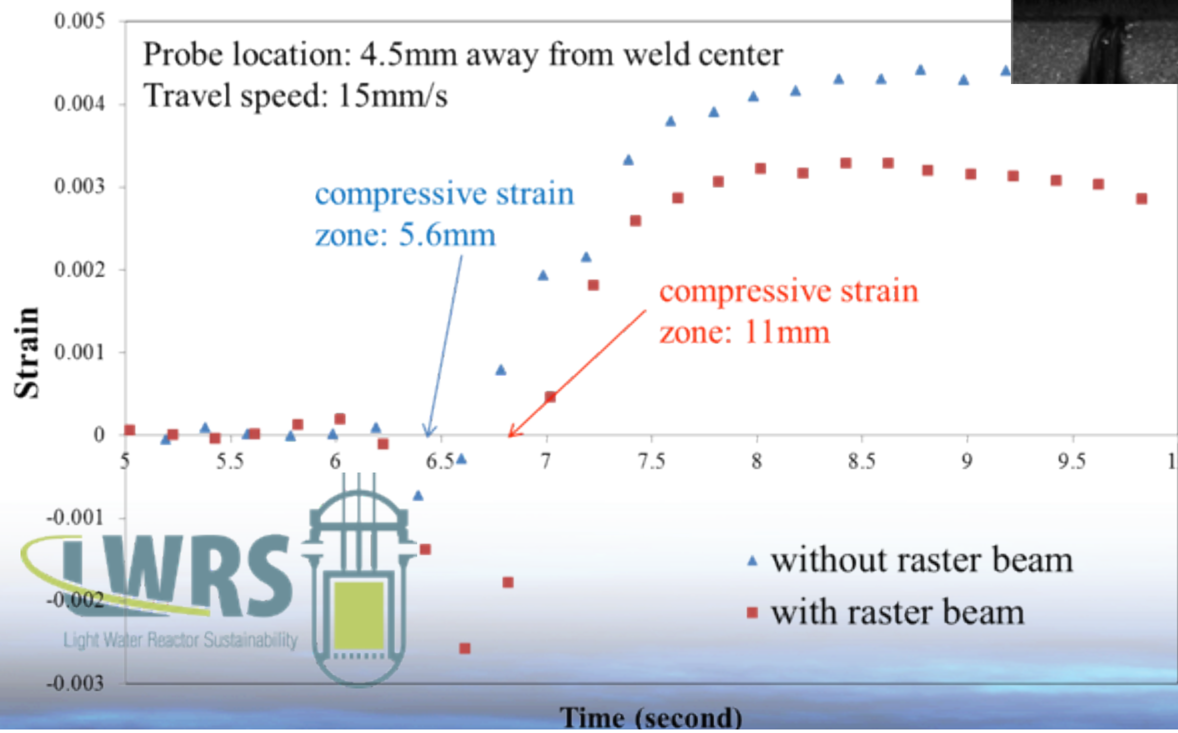




Pro-active Weld Stress Management by means of hybrid laser welding (patent pending)

Developed an in-situ strain field measurement technique based on digital image correlation (DIC) to experimentally capture and confirm the compressive strain fields near the weld region by means of hybrid laser welding





LWRS
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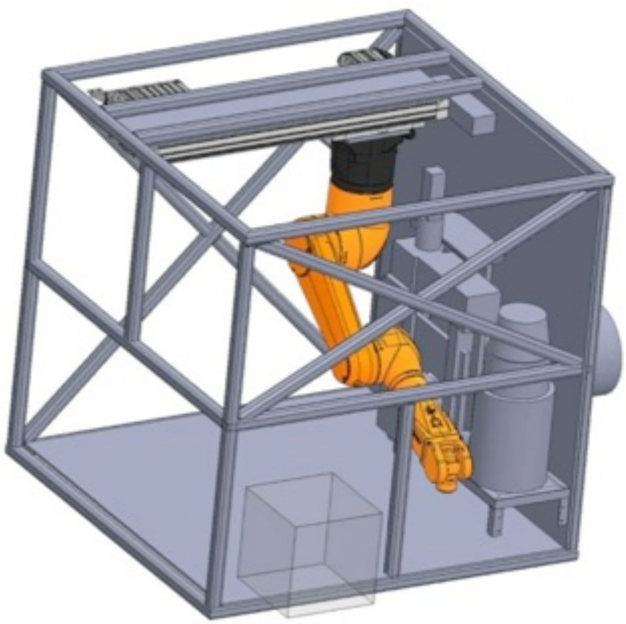
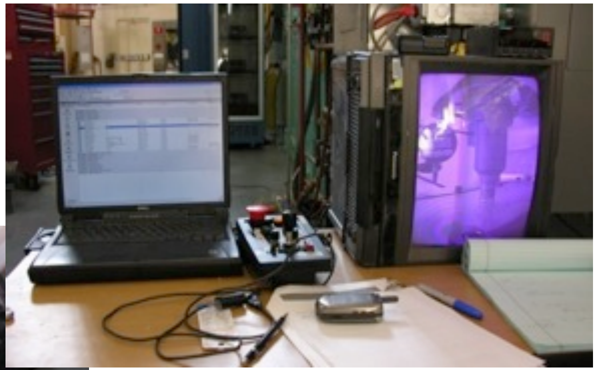
Design and Construction of A Dedicated Welding Hot Cell:

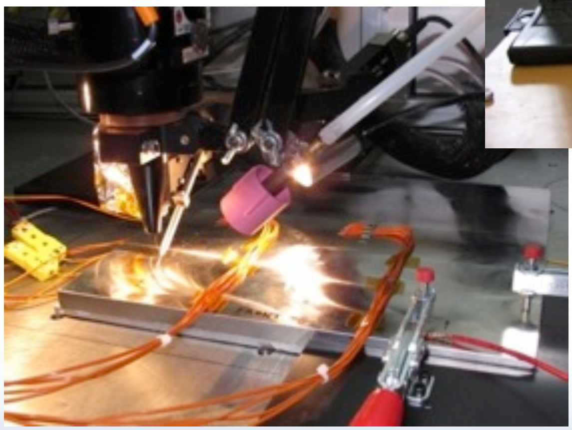
- First of its kind in the US. Part of an "one-stop" facility for R&D on irradiated materials to support DOE NE programs and industry's needs.
- Cost-shared with EPRI
- Switchable between different welding processes: laser welding, arc welding, and friction stir welding systems. Both LW and FSW can be remotely operated to reduce contamination issues of welding equipment
- In-situ temperature and stress measurement capability through remote optical system and unique measurement techniques
- System design has been completed. Individual hardware are being procured and tested



Exposed view of concept design of welding hot cell with robotic manipulators and friction stir welding system



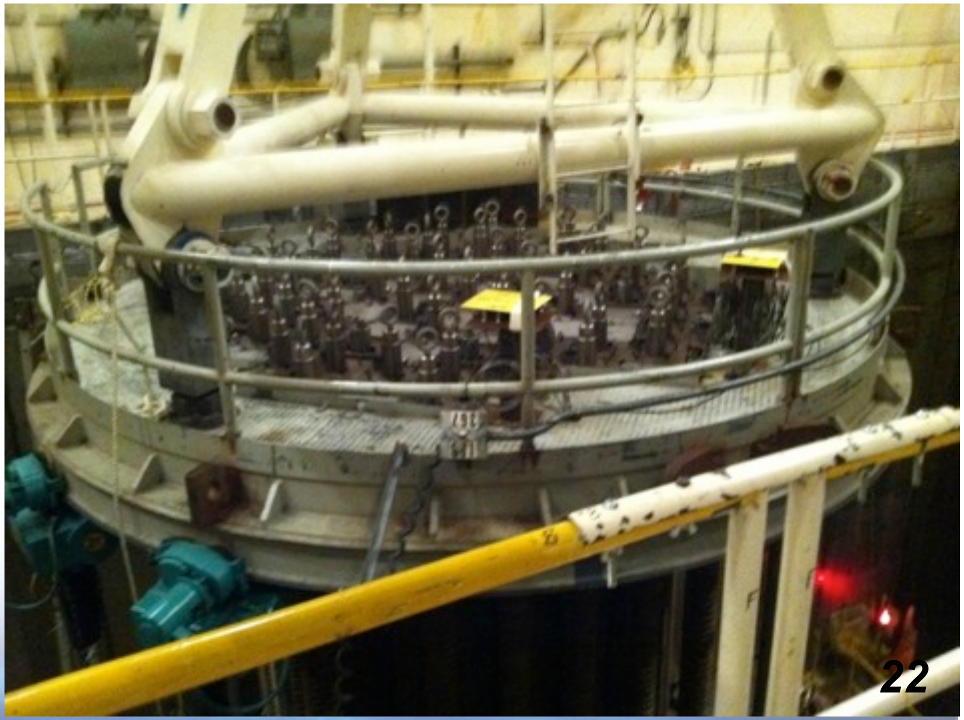
Remotely operated FSW system to be integrated in the hot cell



Laser welding system under testing and to be integrated in the hot cell

The Decommissioning of the Zion Unit 1&2 NPPs Provides a Timely Opportunity to Examine Service-Aged Materials Degradation

- In support of extended service (and current operations), ORNL is coordinating and contracting activities with Zion Solutions.
- In collaboration with the US NRC, EPRI, and others, a list of materials for "harvesting" has been compiled and feasibility examined.
- Structures and components of interest:
  - Thru-wall RPV sections
  - Cabling
  - Concrete bore samples



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The Zion RPV's may provide invaluable material

- The Zion material could prove to be valuable for a number of key RPV issues.
- Composition can be evaluated through out thickness of weldments to assess Cu and other element variability
- CVN, tensile, and KJc testing could be performed through thickness to evaluate attenuation effects.
- Previously tested and untested surveillance specimens will be tested and examined with atom probe tomography and small-angle neutron scattering to compare irradiated microstructures with those from high flux irradiations.
- Specimens reserved for future testing and possible transfer to ATR User Facility

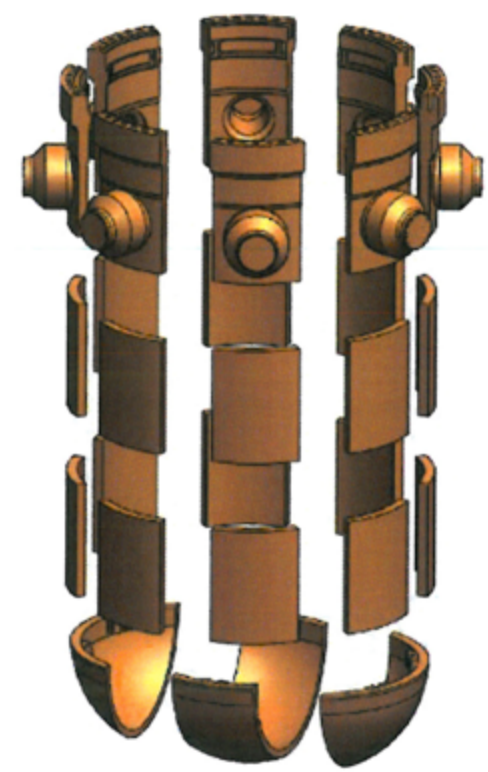

Figure 30 - Proposed Segmentation Plan

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Summary

- The DOE LWRS R&D program has initiated a national materials research effort to help provide fundamental and mechanistic knowledge to support extended reactor service.
  - IASCC
  - RPV issues
  - Concrete
  - Cabling
  - Ni-base alloys
  - NDE
  - Mitigation strategies
- Research is collaborative and well coordinated with partners around the world.
- LWRS is providing key leadership and technical contributions.

Discussion?

LWRS

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