From: Reister, Richard
To: Hiser, Matthew
Subject: [External_Sender] RE: Ex-plant Materials Harvesting Workshop Presentations
Date: Thursday, March 2, 2017 2:58:18 PM
Attachments: NRC_MATERIALS_HARVESTING_WORKSHOP - Reister.pdf

Note to requester: The attachment to this email is immediately following. The March 1, 2017 email from M. Hiser was released in full in a previous interim response.

Matt:
Attached are my slides in pdf format. Let me know if you need them in ppt format.
I know it's a little long at 14 slides, but I plan to go through them very quickly and stay within my time limit.
Thanks, Rich

From: Hiser, Matthew [mailto:Matthew.Hiser@nrc.gov]
Sent: Wednesday, March 01, 2017 9:45 AM
To: 'Bernhoft, Sherry (sbernhoft@epri.com)' <sbernhoft@epri.com>; 'Dyle, Robin' <rdyle@epri.com>; 'Jean Smith (jmsmith@epri.com)' <jmsmith@epri.com>; 'Ahluwalia, Kawaljit' <kahluwal@epri.com>; Reister, Richard <Richard.Reister@nuclear.energy.gov>; 'leonardk@ornl.gov' <leonardk@ornl.gov>; 'Rosseel, Thomas M.' <rosseeltm@ornl.gov>; 'William F Zipp (Generation - 4)' <william.f.zipp@dom.com>; 'Gerard P. Van Noordennen' <gpvannoordennen@energysolutions.com>; Ramuhalli, Pradeep <pradeep.ramuhalli@pnnl.gov>; 'daniel.tello@canada.ca' <daniel.tello@canada.ca>; 'Uwe.Jendrich@grs.de' <Uwe.Jendrich@grs.de>; 'rachid.chaouadi@sckcen.be' <rachid.chaouadi@sckcen.be>; 'arait@criepi.denken.or.jp' <arait@criepi.denken.or.jp>; 'alpanfa@westinghouse.com' <alpanfa@westinghouse.com>; Jackson, John Howard <john.jackson@inl.gov>
Cc: Tregoning, Robert <Robert.Tregoning@nrc.gov>; Purtscher, Patrick <Patrick.Purtscher@nrc.gov>
Subject: RE: Ex-plant Materials Harvesting Workshop Presentations
Dear Presenters:
Thank you for sending presentation titles. I have all but a couple at this point and have attached the updated agenda.
I know many of you are working on finalizing your slides for the workshop (I already have 2 submitted as of today!). Please provide slides by Friday if at all possible. It will be very challenging to load presentations onto the computer via thumb drive the day of the workshop due to NRC computer security restrictions, so sending them in advance is greatly preferred. Again, best options for sending are either email or upload to Google Drive: https://drive.google.com/drive/folders/0B5DWMLch5YSXcnpZZ0JOS055QUU?usp=sharing.
I am looking forward to a productive workshop next week and appreciate your participation. Please let me know if you have any questions or suggestions for the workshop.
Thanks!
Matt

From: Hiser, Matthew
Sent: Thursday, February 23, 2017 9:07 AM
To: Bernhoft, Sherry (sbernhoft@epri.com) <sbernhoft@epri.com>; Dyle, Robin <rdyle@epri.com>; Jean Smith (jmsmith@epri.com) <jmsmith@epri.com>; Ahluwalia, Kawaljit <kahluwal@epri.com>; Richard Reister (Richard.Reister@nuclear.energy.gov) <Richard.Reister@nuclear.energy.gov>; 'leonardk@ornl.gov' <leonardk@ornl.gov>; 'Rosseel, Thomas M.' <rosseeltm@ornl.gov>; 'William F Zipp (Generation - 4)' <william.f.zipp@dom.com>; 'Gerard P. Van Noordennen' <gpvannoordennen@energysolutions.com>; Ramuhalli, Pradeep (Pradeep.Ramuhalli@pnnl.gov)

<Pradeep.Ramuhalli@pnnl.gov>; 'daniel.tello@canada.ca' <daniel.tello@canada.ca>; 'Uwe.Jendrich@grs.de' <Uwe.Jendrich@grs.de>; 'rachid.chaouadi@sckcen.be' <rachid.chaouadi@sckcen.be>; 'arait@criepi.denken.or.jp' <arait@criepi.denken.or.jp>; 'alpanfa@westinghouse.com' <alpanfa@westinghouse.com>; Jackson, John Howard <john.jackson@inl.gov>; desire.ndomba@canada.ca
Cc: Tregoning, Robert <Robert.Tregoning@nrc.gov>; Purtscher, Patrick <Patrick.Purtscher@nrc.gov>
Subject: RE: Ex-plant Materials Harvesting Workshop Presentations

Dear Presenters:

Friendly reminders:

- Please provide presentation title by February 28.
- Please send me your slides (either via email or upload to Google Drive: https://drive.google.com/drive/folders/0B5DWMLch5YSXcnpZZ0JOS055QUU?usp=sharing) by March 3.

I have attached the workshop agenda to this email. Please let me know if you have any questions or corrections.

Thanks!

Matt

From: Hiser, Matthew
Sent: Wednesday, February 15, 2017 10:47 AM
To: Bernhoft, Sherry (sbernhoft@epri.com) <sbernhoft@epri.com>; Dyle, Robin <rdyle@epri.com>; Jean Smith (jmsmith@epri.com) <jmsmith@epri.com>; Ahluwalia, Kawaljit <kahluwal@epri.com>; Richard Reister (Richard.Reister@nuclear.energy.gov) <Richard.Reister@nuclear.energy.gov>; 'leonardk@ornl.gov' <leonardk@ornl.gov>; 'Rosseel, Thomas M.' <rosseeltm@ornl.gov>; 'William F Zipp (Generation - 4)' <william.f.zipp@dom.com>; 'Gerard P. Van Noordennen' <gpvannoordennen@energysolutions.com>; Ramuhalli, Pradeep (Pradeep.Ramuhalli@pnnl.gov) <Pradeep.Ramuhalli@pnnl.gov>; 'daniel.tello@canada.ca' <daniel.tello@canada.ca>; 'Uwe.Jendrich@grs.de' <Uwe.Jendrich@grs.de>; 'rachid.chaouadi@sckcen.be' <rachid.chaouadi@sckcen.be>; 'arait@criepi.denken.or.jp' <arait@criepi.denken.or.jp>; 'alpanfa@westinghouse.com' <alpanfa@westinghouse.com>
Cc: Tregoning, Robert <Robert.Tregoning@nrc.gov>; Purtscher, Patrick <Patrick.Purtscher@nrc.gov>
Subject: Ex-plant Materials Harvesting Workshop Presentations

Dear Harvesting Workshop Presenters:

If you are receiving this email, then I have you down on the agenda to present at the upcoming Ex-plant Materials Harvesting Workshop on March 7-8. I have attached the workshop introduction slides that have been shared with most, if not all, of you. These slides cover meeting logistics, motivation, approach, expected outcome, and session expectations. We are hoping these slides provide a common vision for the workshop that will allow for a focused, productive discussion. Please take a look at these slides and try to tailor your presentation to the focus and length of the respective session.

There are two actions I request from presenters:

1. I have attached the confirmed list of speakers in an Excel document. Please take a look at this list to confirm you are presenting in the session you expected and if I have made any mistakes in the list of speakers. If you have not already done so, please provide me with a presentation title.
2. Please send me your slides (either via email or upload to Google Drive:

https://drive.google.com/drive/folders/0B5DWMLch5YSXcnpZZ0JOS055QUU?usp=sharing) by the end of February if possible.

Thank you for your participation in the workshop. We are looking forward to the discussion and engagement and appreciate your contribution to a productive and interesting meeting!

Thanks!

Matt

Matthew Hiser

Materials Engineer

US Nuclear Regulatory Commission | Office of Nuclear Regulatory Research

Division of Engineering | Corrosion and Metallurgy Branch

Phone: 301-415-2454 | *Office: TWFN 10D62*

Matthew.Hiser@nrc.gov

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Light Water Reactor Sustainability (LWRS) Program – Perspectives on Material Harvesting

Ex-Plant Materials Harvesting Workshop

Richard Reister
Office of Light Water Reactor Deployment
Office of Nuclear Energy
U.S. Department of Energy

March 7-8, 2017

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Light Water Reactor Sustainability (LWRS) Program

LWRS Program Goal

- Develop fundamental scientific basis to allow continued long-term safe operation of existing LWRs (beyond 60 years) and their long-term economic viability

LWRS program is developing technologies and other solutions to

- Enable long term operation of the existing nuclear power plants
- Improve reliability
- Sustain safety

LWRS focus areas

- Materials Aging and Degradation
- Advanced Instrumentation and Controls
- Risk-Informed Safety Margin Characterization
- Reactor Safety Technologies

Nine Mile Point ~ Courtesy Constellation Energy

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Materials Aging and Degradation

- **Metals: including Reactor Pressure Vessels, core internals, steam generators, and balance of plant**
  - Irradiation-Assisted Stress Corrosion Cracking
  - High-fluence phase transformations and swelling of core internals
  - High-fluence effects on RPV steel
  - Crack initiation in Nickel based alloys
  - Thermal Aging of Cast Austenitic Stainless Steels
  - Environmentally Assisted Fatigue
- **Concrete: Joint research plan with EPRI focused on radiation effects (supports and biological shield) and monitoring tools**
- **Cables: Joint research plan with EPRI and NRC to better predict and monitor cable aging**
- **Mitigation, repair, and replacement technologies: Weld repair techniques; Post irradiation annealing; Advanced replacement alloys; and Advanced Non-Destructive Examination techniques**

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Advantages of service-aged materials

- Fills knowledge gaps when there is limited operational data or experience
- Informs current degradation models

The LWRS Program has ongoing or potential activities at:

- Zion
- Ginna and Nine Mile Point Plants
- Crystal River 3: EPRI led effort in collaboration with LWRS and NRC (Cables)
- Zorita: NRC led effort to obtain concrete cores from the biological shield. Testing at ORNL with possible LWRS support

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Difficulties and Limitations

- **High cost**
- **High costs lead to multiparty cooperation to spread costs which adds to complexities**
- **Scheduling difficulties (both with decommissioning companies and operating plants)**
- **Getting sufficient material pedigree**
- **Potentially limited research value (cost/benefit)**
- **Limited opportunities**
- **Potential negative results could impact operating plants**
- **Difficult logistics**
  - Contracting
  - Final disposition and disposal
  - Liability
  - Shipping

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Zion Coordination

- In support of extended service (and current operations), ORNL coordinated and contracted activities with Zion Solutions (Energy 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
  - Access to stored fuel containment

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Zion Unit 1 Containment Cables acquired in the Spring 2012

- Harvested 6 sets of cables, ~ 25' in length, and each containing two cable types - CRDM DC power and position indicator. Also harvested 8 thermocouple cables identified during 2011 containment tour.
- The LWRS Program and NRC are studying cables harvested from Zion to understand and predict cable degradation at extended lifetimes.

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Zion Records Harvested from Vault 2013

Zion Records: **The acquisition of key records provides critical information about the initial materials properties, in service inspection, and operational history necessary to evaluate the degradation of materials.**

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Zion Harvesting 2013: Electrical Components for the US NRC

Zion Electrical Components: During February 25, 2013, site visit, the NRC identified an L shaped bus bar that was harvested in 2013 for fire protection testing.

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Zion Cables Part 2 (2013-2017)

- **Harvested Zion Unit 2 low and medium voltage cables in collaboration with the NRC**
  - **Accumulator Discharge MOV Cabling**
  - **Instrumentation Cables**
  - **Air-Operated Valve Cabling**
  - **Cables in Electrical Penetrations**

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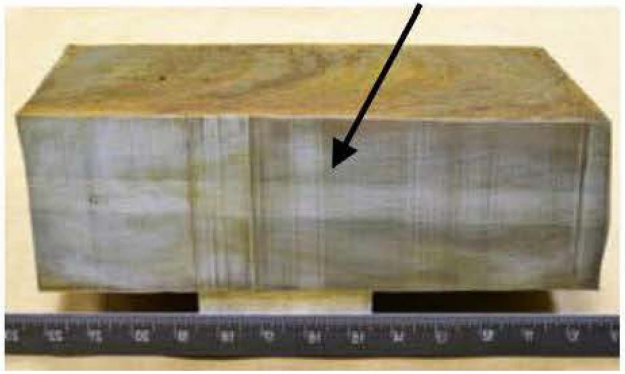
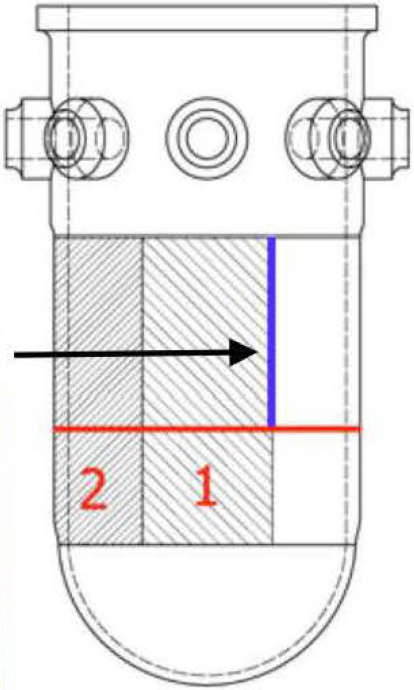
Zion Unit-1 RPV Harvesting 2014-2017

- **Two panel sections, ~14 tons each, were harvested in November 2015, cut into blocks and are now in the process of being machined into >1,000 individual test specimens**
- **Goal of research:**
  - Evaluation of radiation damage models
  - Comparison to surveillance and high flux reactor experiments
  - Attenuation and through wall variation in base and weld metal.
  - Mitigation techniques - annealing / re-irradiation studies.





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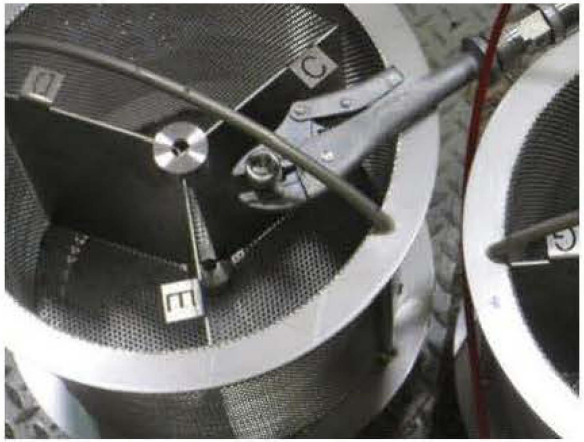
Ginna Baffle Former Bolts

- Retrieval of bolts end of August 2016
- Post-service/irradiation evaluation of high fluence bolts that were withdrawn from service in 2011 from R.E. Ginna (2-loop down flow).
- Alloy 347, irradiation profiles spanning 15 to 42 dpa (variation of fluence along bolts with overlap between the two bolts - same fluence, different temperatures).
- Fracture toughness / fatigue crack growth testing, microstructural examinations, and Stress Corrosion Cracking (SCC) testing.



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I&C cables from Crystal River and Zion

- Harvested I&C cables play a critical role in developing models to quantify the influence of environmental degradation and develop practical NDE techniques
- In collaboration with EPRI & NRC in 2016, over 5,000 feet of I&C cable *outside of containment* from Zion and Crystal River have been harvested and environmental degradation studies on highest priority materials has begun

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Zorita Concrete

Harvesting concrete cores from reactor cavities of plants undergoing decommissioning will yield material that has experienced typical LWR radiation fields

- **NRC led effort**
- **ORNL as contractor**
- **Possible DOE support for sample storage and further examinations**

Jose Cabrera (Zorita) NPS

Note to requester: This presentation was scanned from the paper copy provided to the NRC FOIA team by SECY. We provided the best quality available.

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Light Water Reactor Sustainability (LWRS) Program
Materials Research to Support Long-term Operations

US NRC
Regulatory Information Conference

Richard Reister
Office of Light Water Reactor Technologies
Office of Nuclear Energy
U.S. Department of Energy

March 9, 2016

Light Water Reactor Sustainability (LWRS) Program

- **LWRS Program Goal**
  - Develop fundamental scientific basis to allow continued long-term safe operation of existing LWRs (beyond 60 years) and their long-term economic viability
- **LWRS program is developing technologies and other solutions to**
  - Enable long term operation of the existing nuclear power plants
  - Improve reliability
  - Sustain safety
- **LWRS focus areas**
  - Materials Aging and Degradation
  - Advanced Instrumentation and Controls
  - Risk-Informed Safety Margin Characterization
  - Reactor Safety Technologies

Nine Mile Point
** Courtesy Constellation Energy

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Materials Aging and Degradation Activities

- **Metals: including Reactor Pressure Vessels, core internals, steam generators, and balance of plant**
  - Mechanisms of Irradiation-Assisted Stress Corrosion Cracking
  - High-fluence phase transformations and swelling of core internals
  - High-fluence effects on RPV steel
  - Crack initiation in Nickel based alloys
  - Thermal Aging of Cast Austenitic Stainless Steels
  - Environmentally Assisted Fatigue
- **Concrete: Joint research plan with EPRI (supports and biological shield) - irradiation effects, Alkali-Silica Reactions, modeling.**
- **Cables: Joint research plan with EPRI and NRC - predict and monitor cable aging**
- **Mitigation, repair, and replacement technologies: Weld repair techniques; Post irradiation annealing; Advanced replacement alloys; and Advanced Non-Destructive Examination techniques.**

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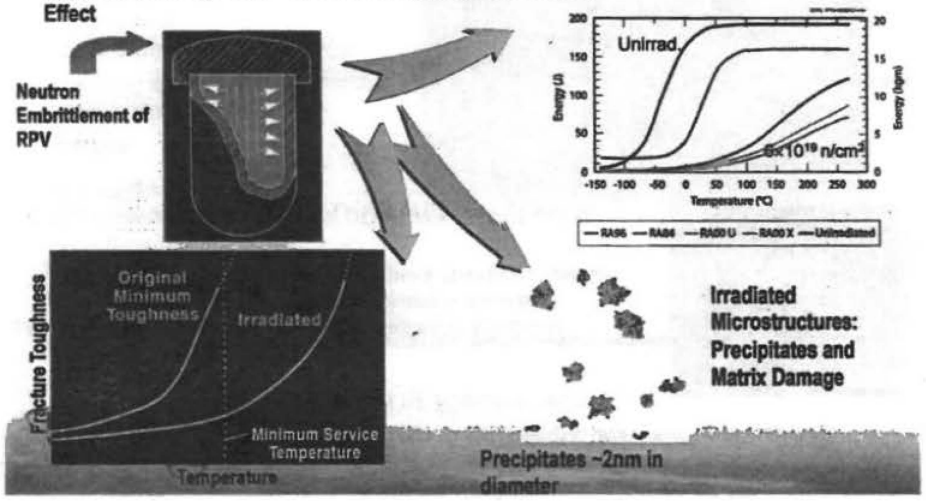
Materials Aging and Degradation

- ***Measurements of degradation:*** Collect high quality data
- ***Mechanisms of degradation*:** Understand the underlying mechanisms for better prediction and mitigation
- ***Modeling and simulation*:** Use mechanistic models to explore data trends for extended life
- ***Monitoring*:** Monitor and validate predicted degradation
- ***Mitigation strategies*:** Develop technologies to reduce the rate of degradation, facilitate economic repair, and potentially replace with advanced materials that are less susceptible

Reactor Vessel Integrity Assessments Must Account for Potential Degrading Effects of Neutron Irradiation

Irradiation Causes Ductile/Brittle Transition Temperature Shift and Upper Shelf Energy Loss — Copper, Nickel, etc. Increase The Effect



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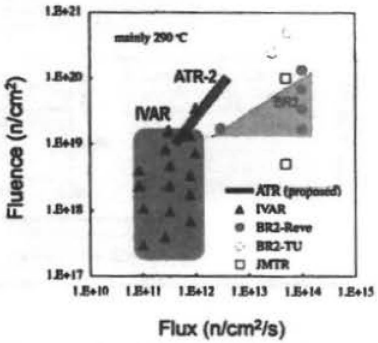
Developing High Fluence Model Predictions

- Current RPV embrittlement models under-predict the transition temperature shift in high fluence irradiations.
- Need for more high fluence data from both experimental reactor irradiations and power reactor surveillance or harvested material.
- The ATR-2 experiment is to examine radiation effects over four temperature zones and up to 10^{20} n/cm². This is intended to bridge experimental conditions of earlier studies.
- Total of ≈ 180 RPV steel alloys (~ 1600 specimens)
- Properties are defined by the microstructures developed and understanding the mechanisms and kinetics for Cu-rich and Mn-Ni-Si precipitation development has also been an important part of the LWRS work.



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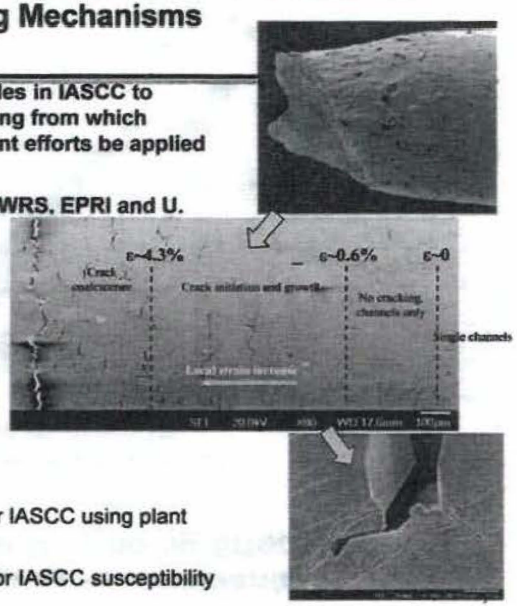
Irradiation Assisted Stress Corrosion Cracking Mechanisms

- **Analysis of key contributing variables in IASCC to develop a mechanistic understanding from which mitigation or controlled management efforts be applied for long-term operations.**
- **Coordinated effort between: DOE/LWRS, EPRI and U. of Michigan.**
- Activities
  - ✓ Materials procurement and IASCC susceptibility evaluation
  - ✓ Mechanistic testing of IASCC conditions
  - ✓ Initiate modeling and theoretical studies to develop predictive capability
  - ➢ 2017: Initiate benchmark testing for IASCC using plant component materials
  - ➢ 2019: Predictive model capability for IASCC susceptibility



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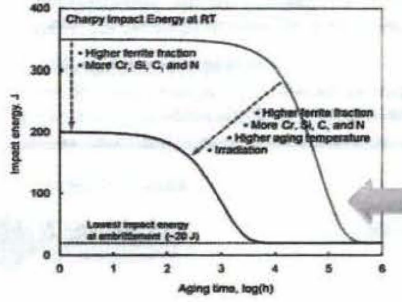
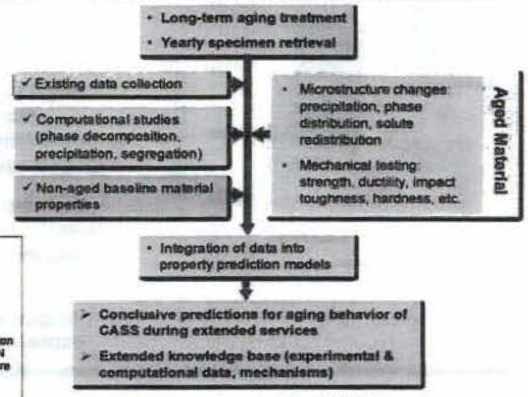
Cast Austenitic Stainless Steel (CASS)

- **Addresses DOE/NRC EMDA and EPRI MDM concerns regarding lack of long term data on CASS for 60 yrs and beyond.**
- **Aim: to systematically build a scientific knowledge base for the thermal aging behavior within a limited time of five years.**





Long-term aging under LWR conditions result in precipitate phase development and changes in mechanical properties.

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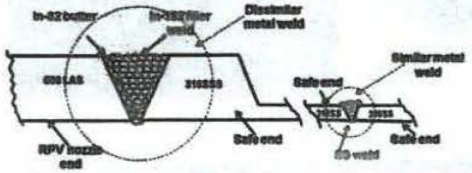
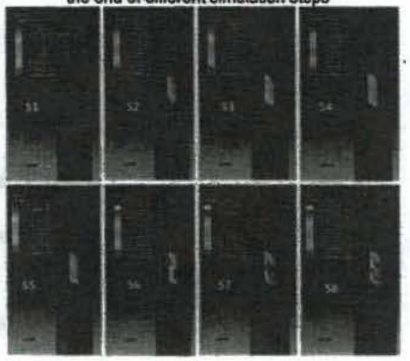
Modeling of Environmental Assisted Fatigue (EAF)



FE simulated accumulated plastic strain profile at the end of different simulation steps



- Model EAF mechanisms through mechanistic based approach supported by experimental studies to identify key variables.
- The aim is to develop finite element based fatigue modeling capability.
- Current work (right) on FE simulated fatigue test component will be developed further into component level fatigue analysis.

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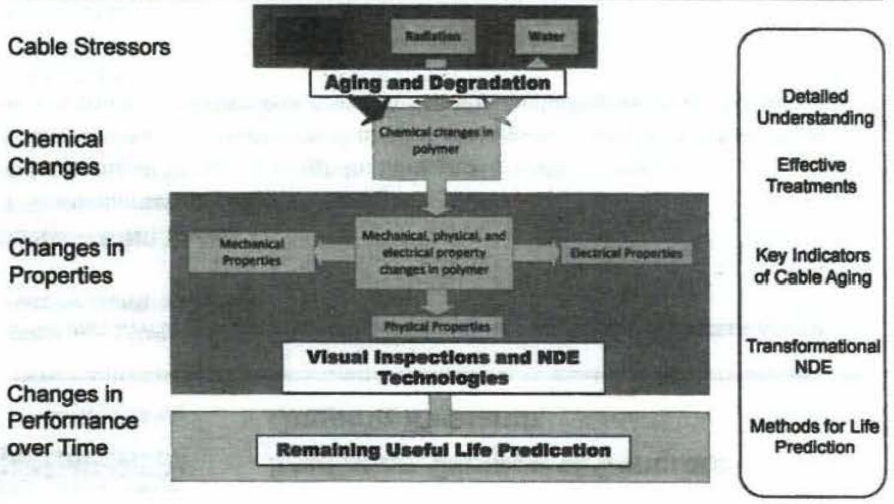
Cable Aging and Degradation



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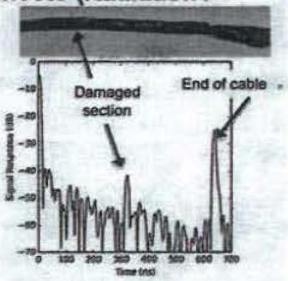
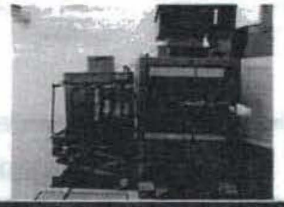
Separate and Synergistic Effects (Radiation / Thermal)

Method / Approach

- **Coordinated, accelerated aging of cable insulation and jacket materials representative of current NPP systems - compare with harvested materials**
- **Electrical and mechanical characterization to determine key factors in cable aging**
- **Short and long length segment testing**
- **Condition monitoring of exposed cables through NDE**



Frequency Domain Reflectometry spectrum showing thermally age damaged section.



Combined thermal and irradiation exposure testing at PNNL

Data collected from variations in dose rate, thermal aging, accumulated dose; all provide fundamental information for model development

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Irradiation Damage of Concrete – Ongoing Research

EPRI and LWRS have partnered to study the effects of radiation damage on reactor cavity concrete

LWRS – ORNL Tasks

- **Fundamentals of radiation damage**
- **Modeling of fluence through the biological shield *(complete)***
- **Neutron and ion irradiation of mineral analogues to characterize swelling**
- **Structural significance of radiation damage including swelling due to irradiation**

EPRI Tasks

- **Estimation of bounding fluence *(complete)***
- **Structural significance of radiation damage including swelling due to irradiation**

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Effect of Radiation on Concrete Properties

RIVE of silicate minerals

⇩

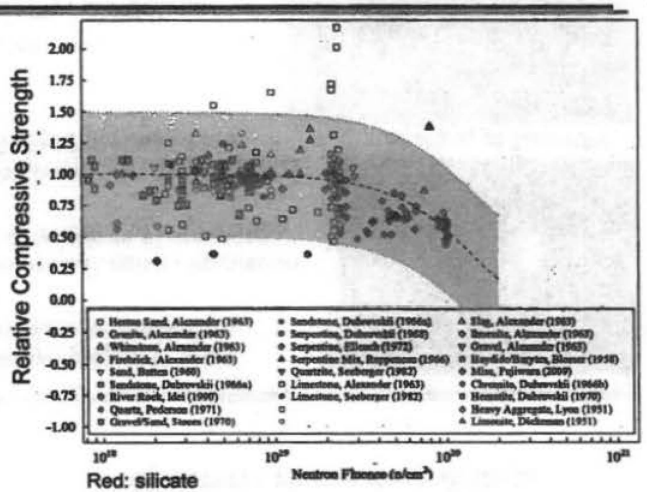
Expansion of aggregate

⇩

Damage/cracking of the cement paste

⇩

Loss of mechanical properties



Red: silicate
Blue: limestone
Green: miscellaneous and heavy aggregate

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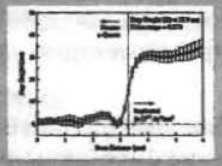
Irradiated Concrete Modeling Strategy

Aggregate Simulation

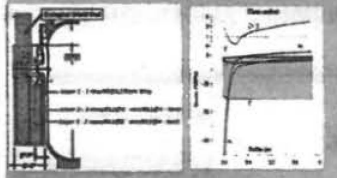
Irradiated Minerals Properties



Optical microscopy image in cross polarized light of a natural olivine polycrystal (Oman mylonite). Credit: S. Demouchy, Montpellier

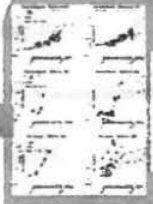
(left) Periodic microstructure of an olivine polycrystal and (right) intragranular distribution of equivalent stress (normalized) during a creep test. UMET- Univ. Lille, ESRF, Grenoble

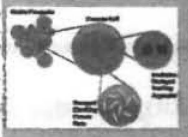
Structural Simulation



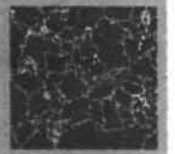
Stress profile in bio-shield

Concrete Simulation





Swelling of aggregate and concrete (random medium homogenization) Le Pape et al. (2015)



ASR induced cracking. Giorla (2013) EPFL Ph.D.

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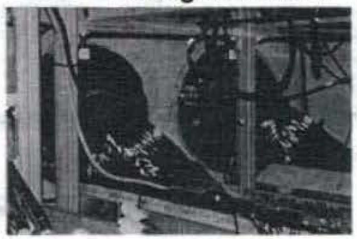
Materials Harvesting Efforts

- **The collection of metal, concrete and cable materials from in-service power reactors is critically important.**
- **Needed to validate accelerated aging / irradiation testing and computer simulations of degradation mechanisms.**
- **Service aged materials can also be used in further accelerated aging tests to predict end-of-life conditions.**
- **Current projects:**
  - RPV steel from the Zion Unit 1
  - Cable harvesting from Zion and Calloway
  - Baffle former bolts from R.E. Ginna
  - Potential concrete harvesting projects being evaluated with NRC and EPRI partners

Cutting of Zion RPV



Zion, Unit 2 cables

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Zion Unit 1 RPV Harvesting

- **Sections 1 and 2 containing belt-line weld (Linde 80, WF-70 weld).**
- **Peak fluence = 0.75×10^{19} n/cm^2 (>1MeV). Anticipated temperature transition shift is 145°F.**
- **RPV sections have been cut and shipped by railcar to Energy Solutions for further machining.**
- **Over 1000 samples of Charpy, fracture toughness, tensile and test coupons will be available for analysis and testing.**