International Materials Research

Program Update

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Program Manager

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Agenda

- EPRI Contacts
- Introduction
- Research Areas
  - Fundamental Research
  - Reactor Sustainability
  - Advanced Reactors
  - International Reactors

International Materials Research (IMR) – EPRI Team

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IMR Program Strategy

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Irradiated Materials Research

Environmentally Assisted Fatigue

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Fundamental Research

MRFAs 3, 4, and 8

Environmentally-Assisted Cracking

Irradiated Materials Testing

Atom Probe Tomography

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Reactor Sustainability

MRFAs 2, 6, and 9

Materials Harvesting

Advanced Manufacturing

KOH Qualification

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Advanced Reactors

MRFAs 2, 10, and 12

Advanced Material Characterizations

Nuclear Fuel Materials

Advanced Reactor Materials

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IMR Program Support

Communications

Meeting Coordination

International Materials Research (IMR) Program Objectives

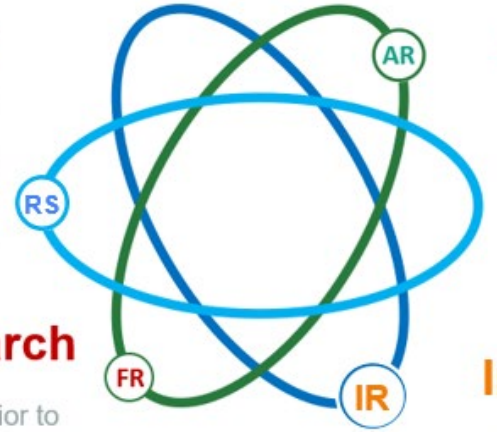
- The IMR Program enhances the understanding of the damage mechanisms in materials used in light and heavy water reactors. Research results lead to improved predictive models, more radiation-resistant materials, and potential countermeasures that contribute to the safe, continued operation of plant components.

Reactor Sustainability

Study age-dependent degradation mechanisms such as fatigue and wear. Advanced manufactured components for repair and replacement must be evaluated for degradation in LWR (and AR) environments.

Fundamental Research

Connecting microstructural behavior to mechanical properties for long-term operation.



Advanced Reactors

Utilities considering advanced reactors and/or SMRs can closely follow the EPRI Advanced Reactor Materials Strategy projects.

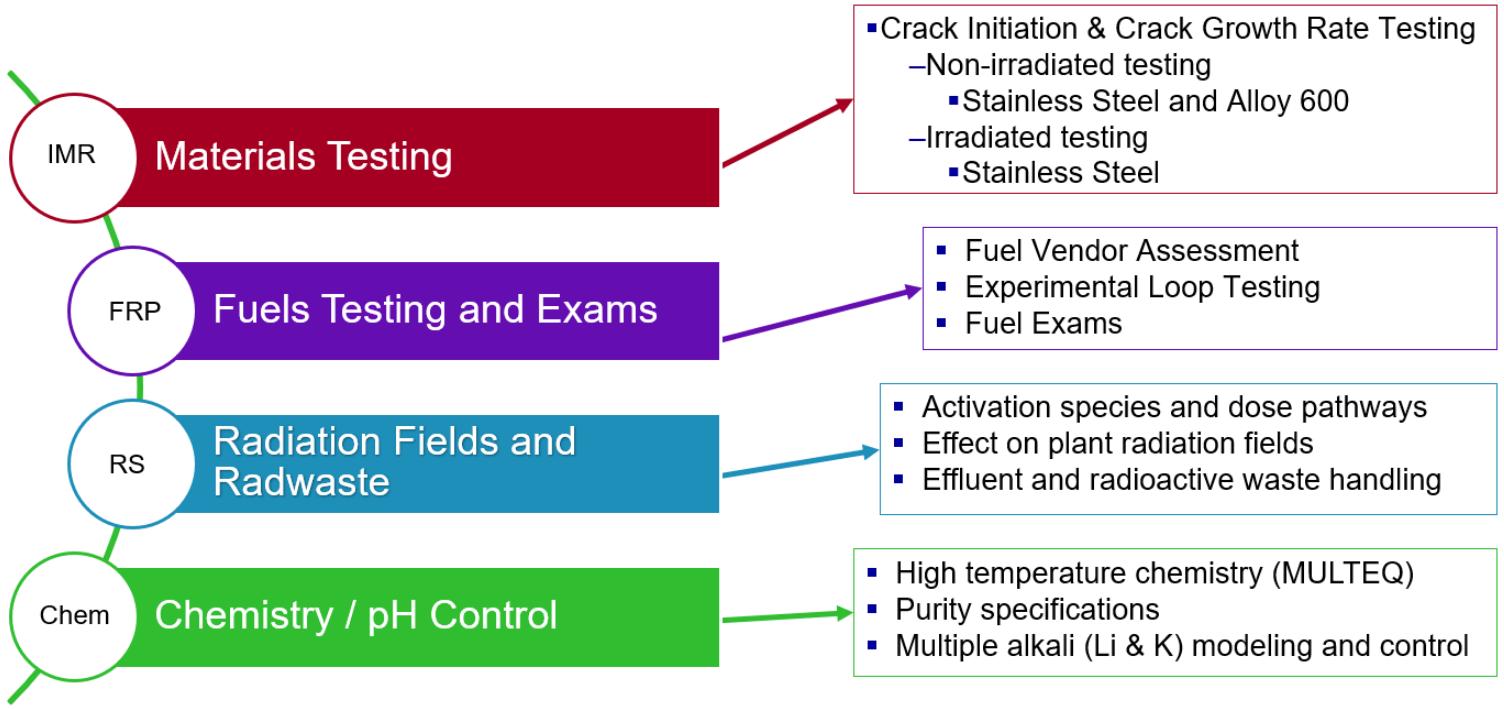
International Reactors

Using the newly-developed VVER IMTs and the functionality analysis & screening approach used by PWRs, develop reactor internals inspection and evaluation guidelines for aging management.

- IMR collaborates with other EPRI materials-related research programs, the Materials Aging Institute (MAI) at EDF, the U.S. Department of Energy (DOE), the U.S. Nuclear Regulatory Commission (US NRC), and international organizations to ensure that research projects and results reflect a wide range of nuclear technologies, operating conditions, and service environments.
- IMR is also actively involved in internal and external programs that support the identification and qualification of materials for advanced reactors, including non-light-water reactors.

IMR: Fundamental Research – KOH Materials Qualification

- Crack initiation and crack growth rates under same test parameters, in particular pH(T)
  - Absolute rates are not the key results because tests will be accelerated
- Test prototypical Fe-Ni-Cr alloys (Alloy 600, austenitic stainless steels 304/304L and 316/316L) rather than all Fe-Ni-Cr alloys used in PWR service
  - If no significant differences in test results of selected materials in KOH and LiOH pH-balanced environments → infer also no differences for other, related, Fe-based and Ni-based Fe-Ni-Cr alloys
- Crack initiation and crack growth rate studies have been performed in several classes of materials to compare material behavior in KOH environments to LiOH environments



- *No statistical difference in crack initiation times or crack growth rates were observed in the two environments*
  - Retest of non-irradiated stainless steel in hydrogenated crevice chemistry environments underway

Key question: Do the cations K^+ and Li^+ influence crack initiation and crack growth rates differently?

IMR: Reactor Sustainability – Materials Harvesting

Problem

- All LWRs need to address aging management of stainless steel reactor internals components, RPVs, and other structural materials.
- Harvested materials are the most representative source for characterizing the mechanical properties of reactor internals components; however, they are difficult and expensive to obtain.
- The EPRI-led Zorita Internals Research Project set the precedent for industry efforts in materials harvesting.

Action

- IMR staff are leading the Materials Department projects on materials harvesting and are actively involved with US NRC and DOE projects.
- IMR staff will participate in the US NRC public meeting on harvesting in June and will support the International Harvesting Workshop in November.

Ongoing Projects

- MRP and BWRVIP are supporting the Studsvik Material Integrity Life Extension (SMILE) project.
- Pressurizer materials are being harvested from Indian Point and from Ringhals 2 and 4.
- In addition, NDE of Indian Point thermal shield support block bolts and thermal shield flexures are being planned.

Outcomes

- The results of the harvested materials testing programs will go into the materials database that forms the technical bases for the materials models. Many PWR/BWR/VVER Issue Management Table (IMT) assessment gaps we be addressed by these programs.
- Strengthening the technical basis of the materials models alleviates the need for excessive conservatisms in developing aging management strategies. Optimization of the frequency and scope of aging-related inspections is the desired outcome of irradiated materials harvesting and testing.

IMR: Reactor Sustainability – Materials Harvesting Spreadsheet Inputs

- IMR is leading a renewed effort to solicit inputs for the decommissioned plant materials data spreadsheet
- Data Collection
  - Listing of plants with known end-of-life dates
  - Includes key design and operating parameters, structural materials and expected neutron dose levels
  - Identify “best choice materials” to address harvesting objectives and priorities
  - Also need to consider operating experience (OE events)
  - Potentially identify opportunities for collaboration
- Update to be provided at public meeting in June and international workshop in November

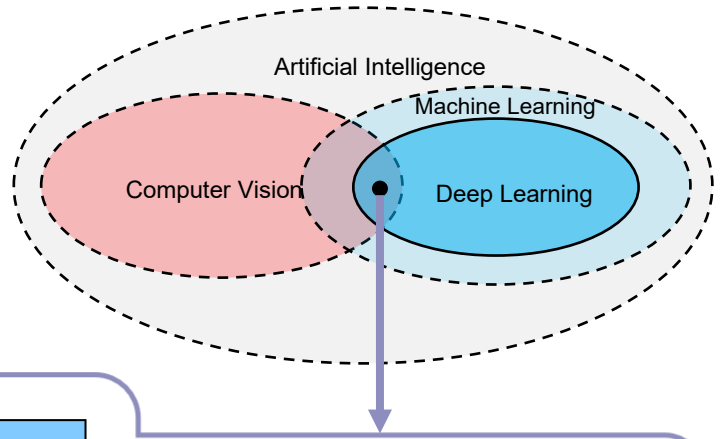
Plant Information	• Location • Utility • Design • Size (MWe) • Years operation (and EFPY) • Shutdown date • Decommissioning Timeline • Core inlet/outlet temperature	
Potential Components	• RPV Beltline • PWR RPV Head Penetrations • BWR Instrumentation Penetrations • Baffle Plate • Internals Bolts • Core Shroud/Barrel Welds • Lower Support Column (if CASS) • SG Tubes/Plugs • RCS Piping/Welds/Elbows • PZR Surge Line	<u>Information needed for each component:</u> • Material (alloy & fabrication method) • Environment (dose, temperature, water chemistry • OE or other information (peened or other mitigative actions, high fatigue usage location, etc.)

IMR: Advanced Reactors

Rapid Quantification of Irradiation-Induced Microstructures by Deep Learning

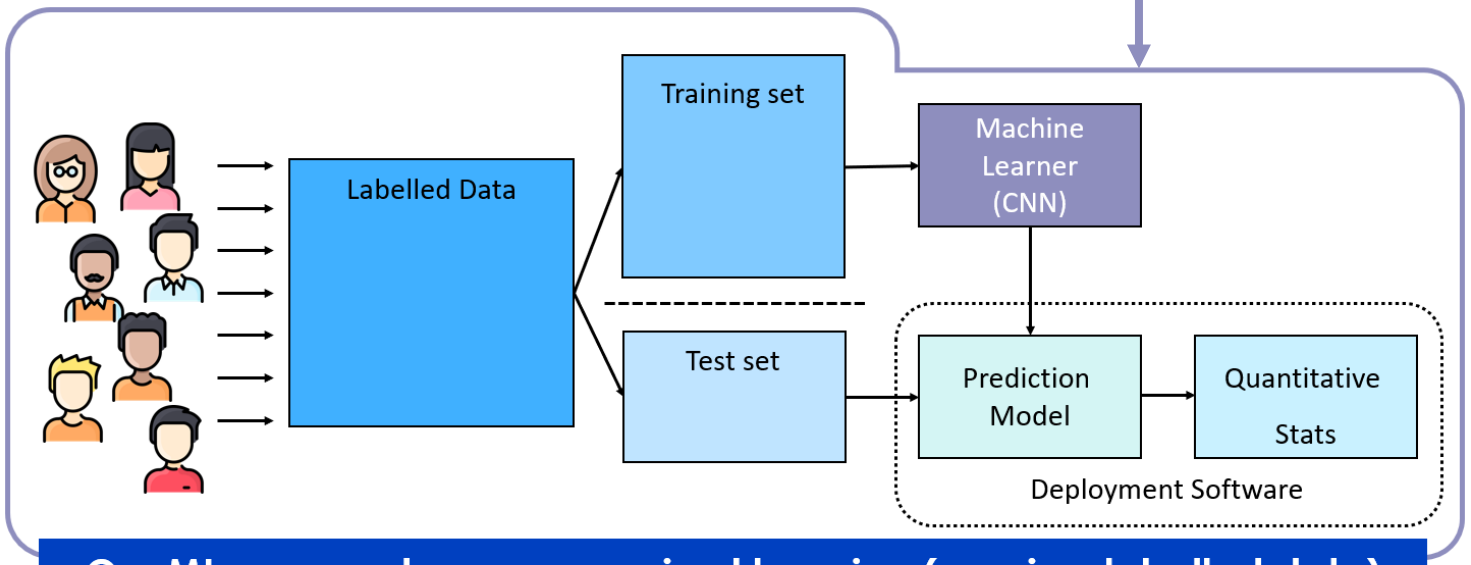
Background

- Irradiation-induced microstructural changes such as phase transformations, second-phase formation, and defect clusters can lead to the degradation of mechanical properties.
- Electron microscopy techniques are widely used to identify defects in materials.
- Key challenge is to determine the number density and size distribution of each defect type.



Objectives:

- To employ machine/deep learning methods to develop a standardized approach to quantify irradiation-induced microstructural evolution of nuclear materials in an extremely rapid and standardized routine.
- Main objective is to develop a combined framework for automatic detection and analysis of nanocavities and estimate void swelling accurately.



IMR: International Reactors – MDM and IMTs

EPRI Materials Programs use a strategic approach to assess and update research results and plant operating experience to identify key knowledge gaps.

The continuous Aging Management Issue Assessment Cycle (shown below) uses the EPRI Materials Degradation Matrix (MDM) and Issue Management Tables (IMTs) to identify high-priority research needs.

EPRI Materials Programs develop projects to advance the state of knowledge of degradation mechanisms, quantify the effects of plant operating conditions on material integrity, and to develop models to support plant aging strategies.

Optimize Inspection Requirements

Increased confidence in aging management strategies leads to optimal inspection requirements.

Characterize Margins

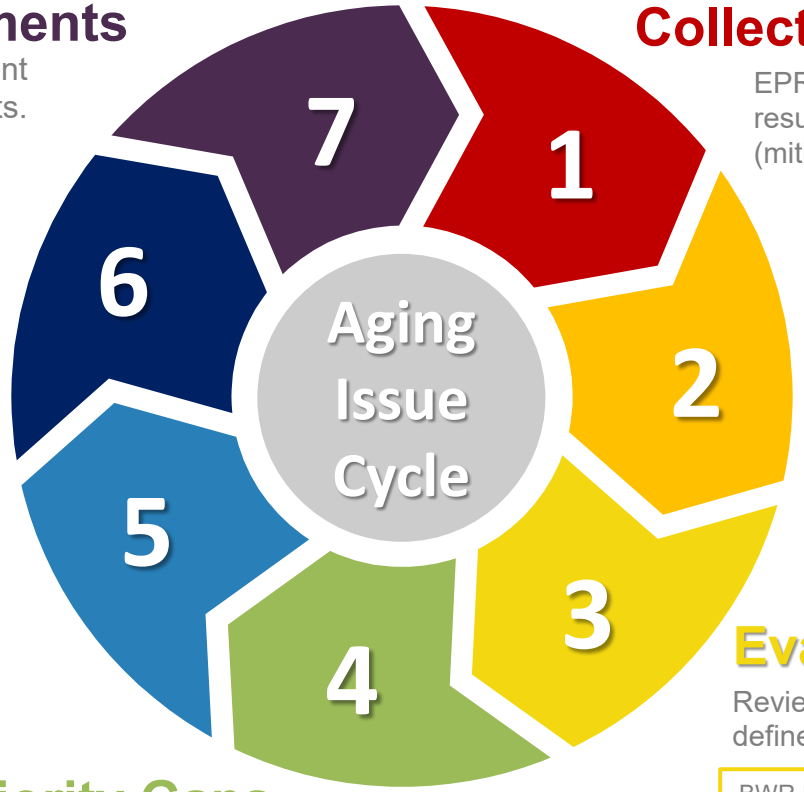
Better models lead to more accurate predictions of long-term irradiation effects thereby reducing the conservatism applied in the development of aging management strategies.

Enhance Materials Models

Improve accuracy and technical robustness of database that serves as a basis to the materials models used in the reactor internals functionality analyses.

Address High-Priority Gaps

Conduct research on representative materials, perform simulations, develop new models to address high-priority assessment and degradation mechanism gaps.



Collect Operating Experience

EPRI SMEs collect data from field reports and inspections results and assess the efficacy of the corrective actions (mitigation, repair, replacement).

Review Research Results

Updated research results from EPRI programs, technical literature, and conferences are reviewed by EPRI SMEs.

Materials Degradation Matrix (MDM) Revision 4 (3002013781; May 2018)

Evaluate Technical Gaps

Review gaps from previous IMT revision (close, keep open, re-rank); define new gaps based on OE; utility members prioritize gaps.

BWR Issue Management Tables BWRVIP-167 Rev. 4 (3002018319; June 2020)
PWR Issue Management Tables MRP-205 Rev. 4 (3002018255; September 2020)
VVER Issue Management Tables MRP-471 (3002021033; September 2021)

IMR: International Reactors
VVER Materials Testing Support + CANDU IMTs

- Many research programs conducted by International Materials Research and Materials Reliability Program have direct applicability to VVERs.
- Research on VVER materials has focused on IASCC and void swelling → High-priority IMT Gaps
- New projects specific to VVERs are being proposed in the context of the IMTs and a timeline of research needs and opportunities for conducting research is being outlined.
- Research applicable to all PWR designs includes reactor pressure vessels, EAF, and primary water effects.
- Fundamental research on degradation mechanisms in PWR materials can be used as the technical basis for materials ageing management in VVERs.

- Materials Degradation Matrix (MDM) Revision 4 (3002013781; May 2018) includes both VVER and CANDU degradation mechanisms and materials.
- Using the lessons learned from the development of the VVER IMTs, work will begin using the same process to develop IMTs for CANDU reactors.
- EPRI members in Canada, China, and South Korea operate CANDUs