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Long-Time Operation of Light-Water Reactors – “Life After 60” Programs in the USA

**IAEA Regional Workshop on Structure, Systems
and Components Integrity**

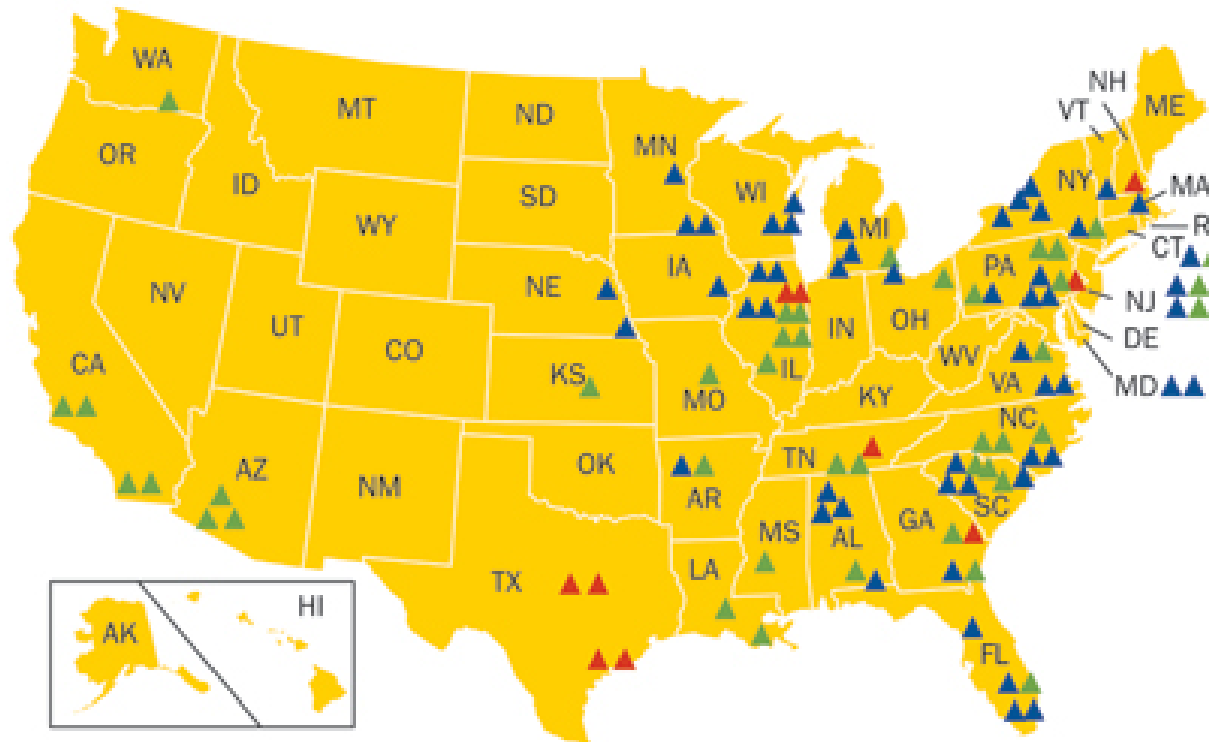
Centro de Desenvolvimento da Tecnologia Nuclear (CDTN)

Belo Horizonte, Brazil

23-26 June 2009

There Are 104 Nuclear Power Reactors Currently Operating in the USA

U.S. Commercial Nuclear Power Reactors—Years of Operation



Years of Commercial Operation

- △ 0-9
- ▲ 10-19
- ▲ 20-29
- ▲ 30-39

Number of Reactors

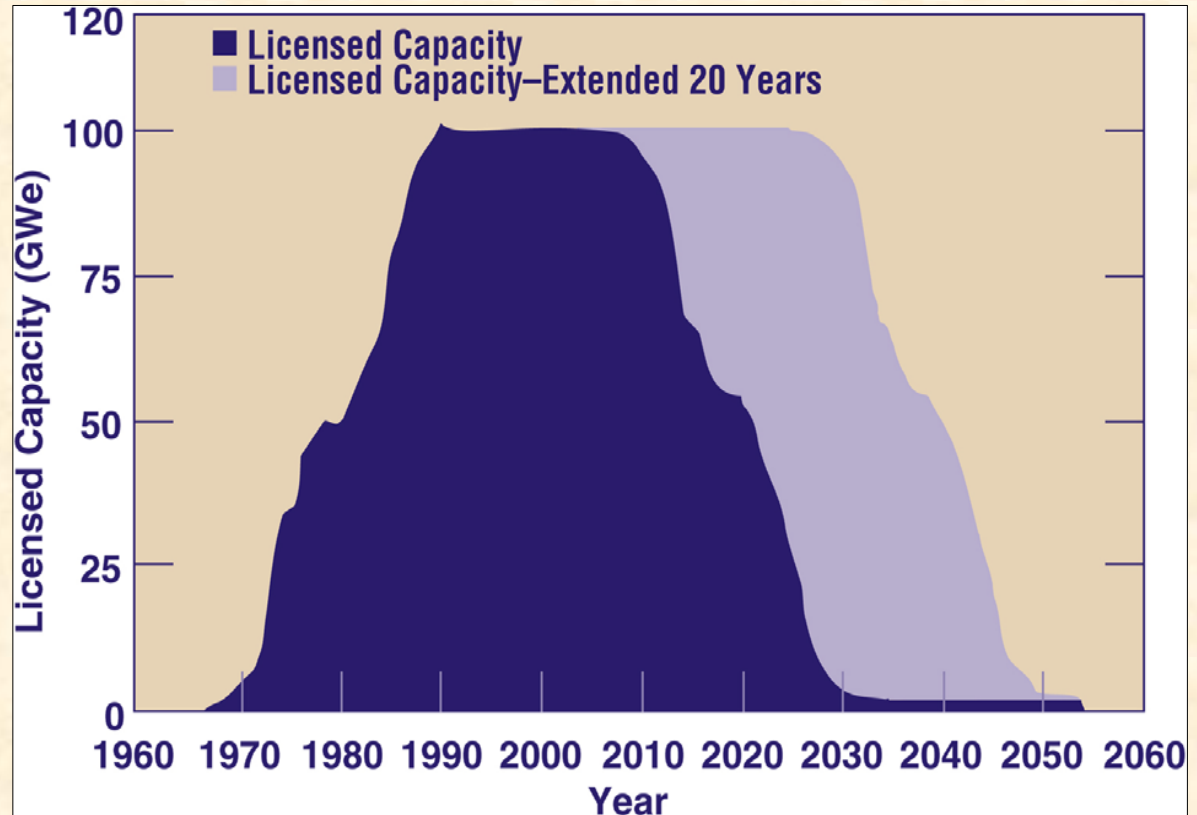
- 0
- 10
- 42
- 52

Source: U.S. Nuclear Regulatory Commission

WITHOUT LICENSE RENEWAL, EXPIRATIONS WILL OCCUR FOR MORE THAN 40 PERCENT OF U. S. NUCLEAR POWER PLANTS BY 2015

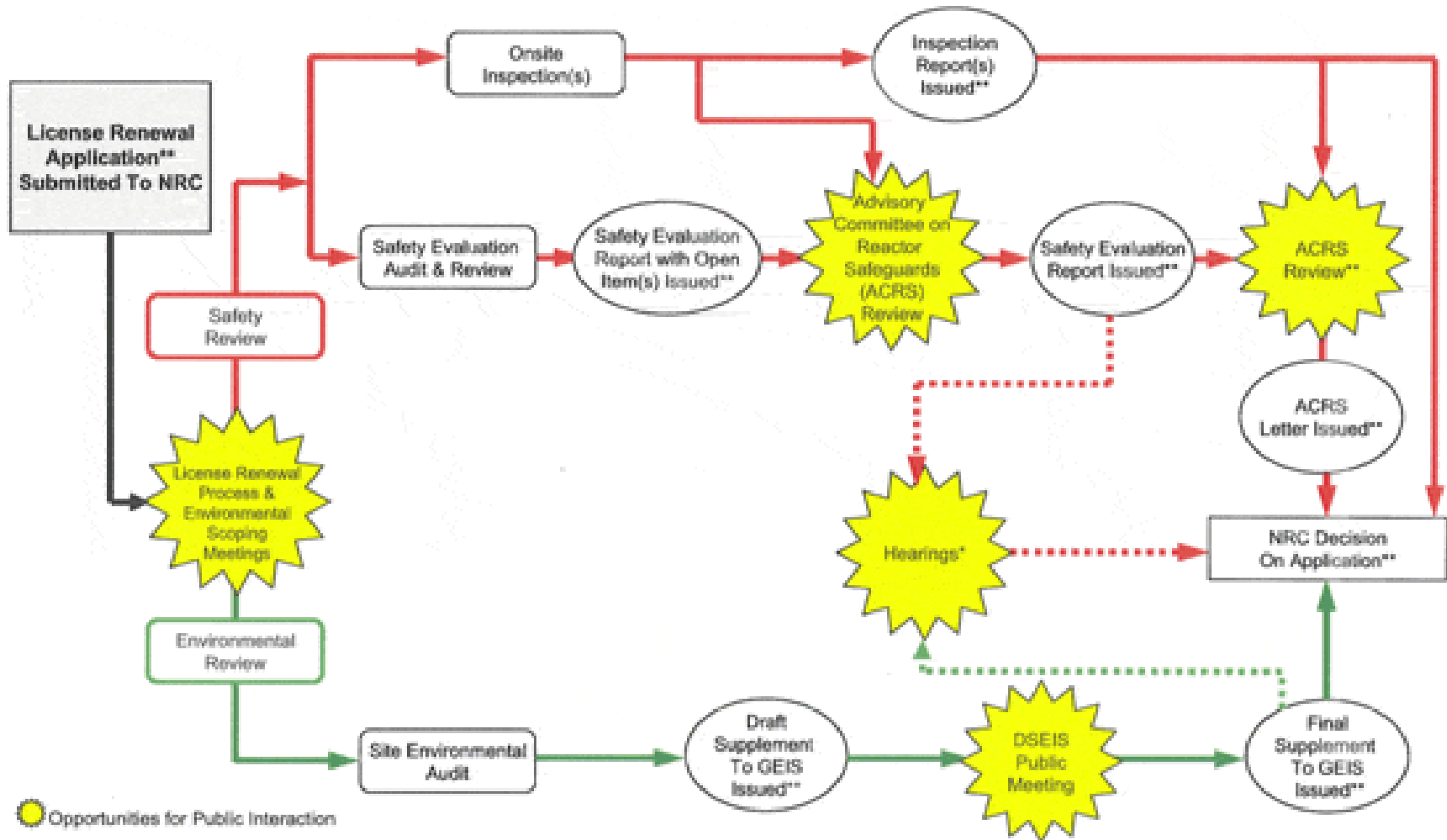
Current status of license extension applications:

- 49 completed
- 9 under review
- 26 letters of intent
- NEI: Replacement cost value of generation capacity under 2007-08 renewals = \$19.9 billion.



- *Extending license from 40 to 60 y will increase RPV neutron fluence nominally 50% and sufficient data at high fluences (irradiation doses) are not available.*

The U.S. Nuclear Regulatory Commission Has Implemented a License Renewal Process for Nuclear Power Plants



 Opportunities for Public Interaction

* If a Request for Hearing is Granted

** Available at www.nrc.gov

License renewal is expected to take about 30 months, including the time to conduct an adjudicatory hearing, if necessary, or 22 months without a hearing. In some cases, the process is completed on a plant-specific schedule agreed upon with the applicant. Upon receipt of a license renewal application, the review is conducted, in general, according to the steps in the following table:

Licensing Milestone	Months Elapse
Receive renewal application	0
Publish notice of opportunity for hearing	1.5
Conduct public meeting on license renewal process and scope of environmental impact statement	2.5
Opportunity for hearing closes	3.5
Pose environmental questions to applicant	5.5
Pose safety questions to applicant	6.0
Issue draft environmental impact statement for comment	11.0
Conduct public meeting on draft environmental impact statement	12.0
Issue safety evaluation report, identifying open items	13.0
Issue final environmental impact statement	18.0
Issue safety evaluation report	18.0
Complete Advisory Committee on Reactor Safety Review	20.0
Make decision on application (without hearing)	22.0
Complete hearing process (if needed)	--
Make decision on application (with hearing)	30.0

The National Interest

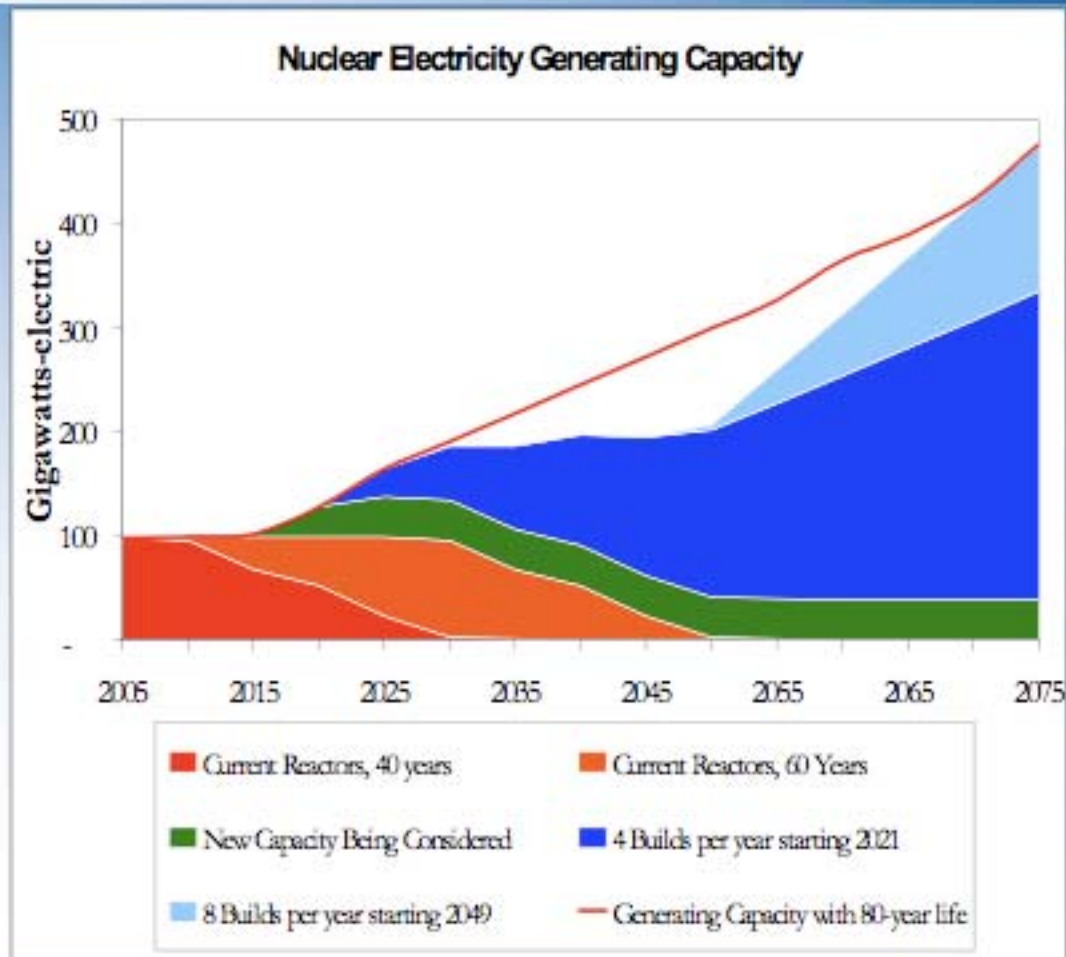
- By 2030, U.S. electricity demand expected to increase ~ 30%
- Nuclear generation is critical to U.S. efforts to:
 - Reduce greenhouse gases
 - Meet electricity demand
 - Ensure energy supply security and grid reliability
 - Curb increasing energy prices
- Cost to replace the current fleet exceeds \$500B in addition to the capacity that will be added as the U.S. builds new plants



It is in the national interest for the current fleet of nuclear power plants to be operated as long as possible

Reliance on existing plants

- 40+20 year licenses means current plants shut down starting 2030
- Steep reduction in generation if current fleet operations are not sustained
- Without today's nuclear plants, we lose:
 - 100 GWe of low-carbon generation over about 20 years – climate, air pollution concerns
 - Low-cost generation – economic concerns for businesses, homeowners



Extending operation of existing reactors will avoid ~12 billion metric tons CO₂ and provide enough electricity for 70 million homes during an additional 20 years of operations.

The NEI has also emphasized industry's growing commitment to the **next generation** of NPPs.

January 27, 2007 letter from NEI president (and Chief Officers for 12 NPP companies) to OMB:

- “...U.S. companies are moving toward construction of the next generation of nuclear power plants
- ... already more than \$2 billion has been committed to these new plant deployment activities...”
- “In 2007, we plan to file a minimum of nine applications for combined construction/operating licenses (COLs) ...
- as well as applications for certification for two reactor designs.
- In 2008, we expect to file an additional 10 applications for COLs.”

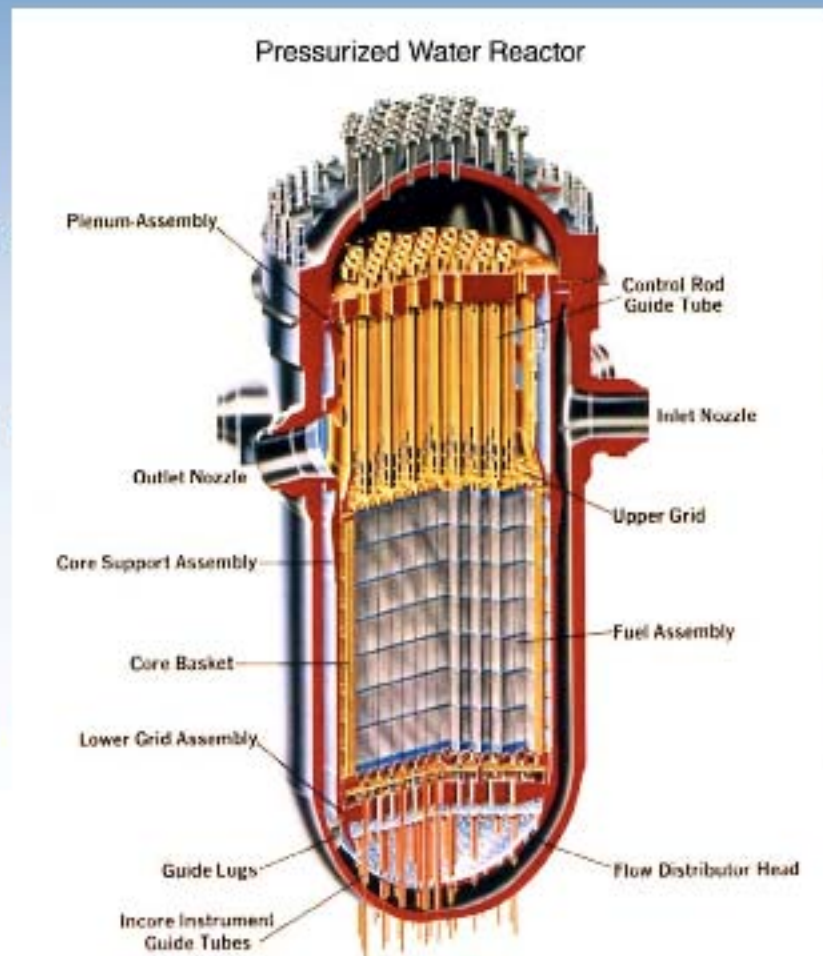
Program Vision and Goals

VISION

- ❑ Existing nuclear power plants will continue to safely provide clean and affordable electricity beyond current license periods

GOALS

- ❑ Develop the understanding, tools, and processes to ensure continued long term safe operation of existing nuclear power plants
- ❑ Develop technical and operational improvements that contribute to the economic viability of existing nuclear power plants



The U.S. Department of Energy (DOE) Has Implemented the Light-Water Reactor Sustainability Program – “Life After Sixty”

Collaborative R&D Program

Present Scope

- Nuclear Materials Aging and Degradation
- Advanced LWR Fuel Development
- Risk-Informed Safety Margin Characterization
- Advanced Instrumentation and Control Technologies

Funding

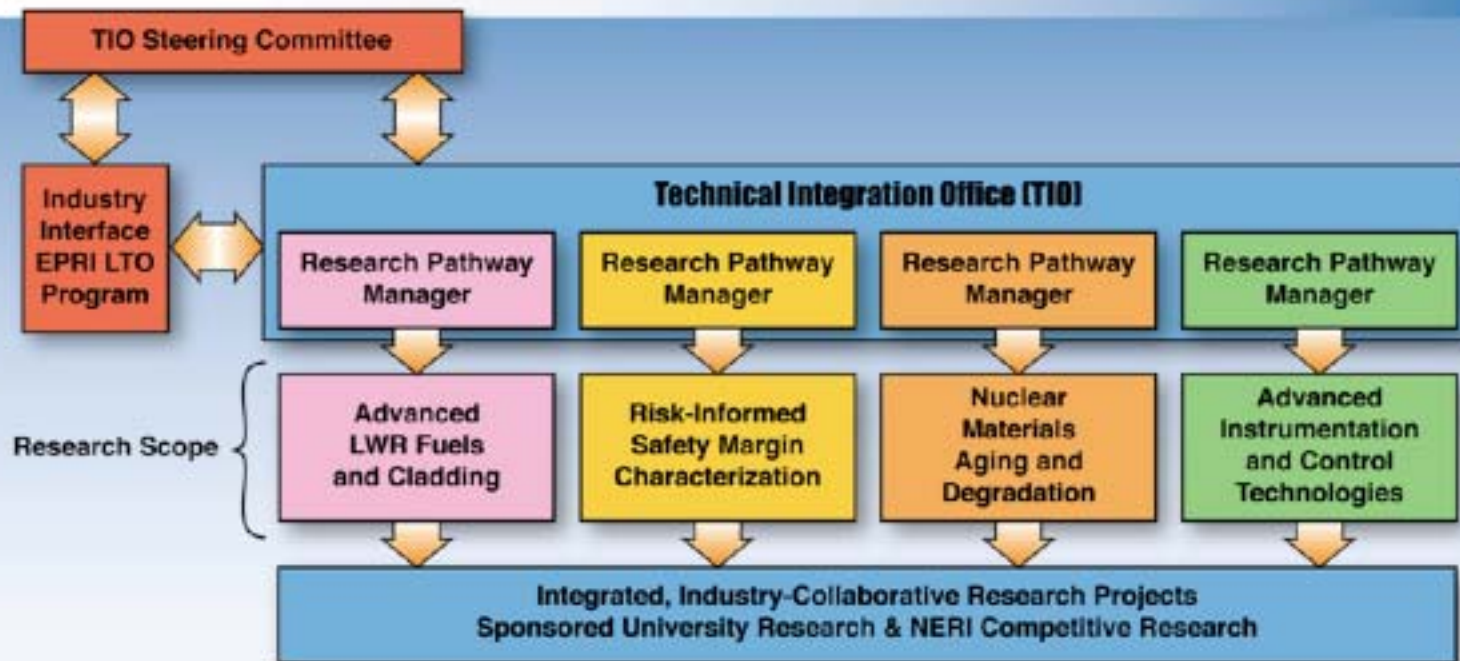
- FY2009 - \$9.75 Million
- Initial focus on *“component and material aging and degradation activities”*

R&D Implementation

- Coordinated by INL Technical Integration Office (TIO)
- Coordinated with EPRI and NRC-RES
- Implementation through broad-based Industry / National Laboratories / University collaboration / international partners



Success Requires the Right Kind of Partnerships

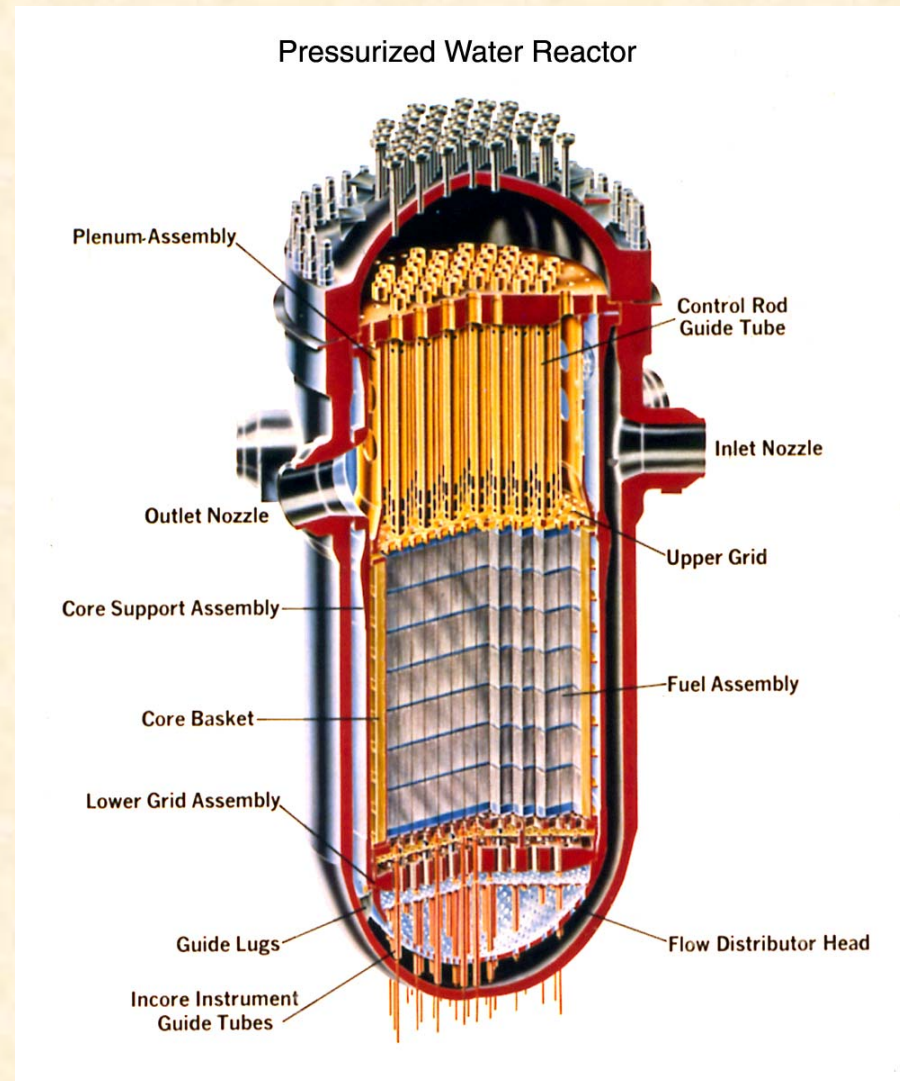


08-GAS0107-60

- Designed to facilitate industry and government decisions on long-term LWR operations
- Industry and government jointly define and fund R&D
- Provides access to expertise and facilities – leveraging the best experts on the right projects
- Includes cost sharing dependent on type of research and timescale
- Created with integrated collaboration among industry, government and universities
- Independent steering committee oversight

Materials degradation: Why do we care?

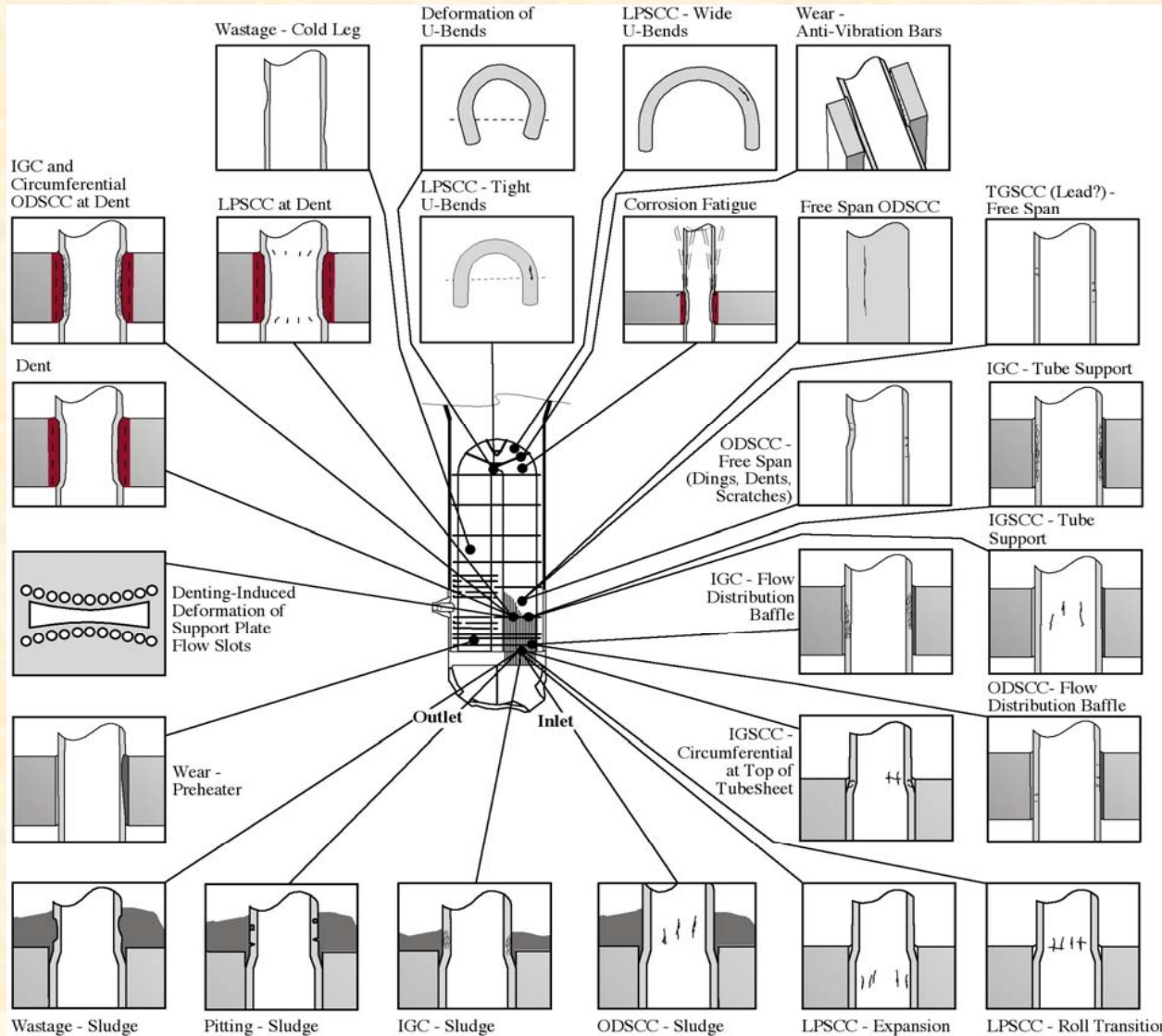
- **Materials are a common problem/concern in existing reactors/nuclear facilities**
- **Understanding the long-term behavior of materials in a nuclear reactor is critical for safe, reliable, reactor operation.**
- **Extending the life of any reactor will require comparing the known modes of materials degradation with the expected service life to identify possible problems.**



Materials issues are a key concern for the existing nuclear reactor fleet

- **Materials research is already a key need for the existing nuclear reactor fleet**
- **Materials degradation can lead to increased maintenance, increased downtime, and increased risk.**
- **Materials issues must be resolved for:**
 - **Reactor Pressure Vessels and Primary Piping**
 - **Core Internals**
 - **Secondary System**
 - **Weldments**
 - **Concrete**
 - **Cabling**
 - **Buried Piping**

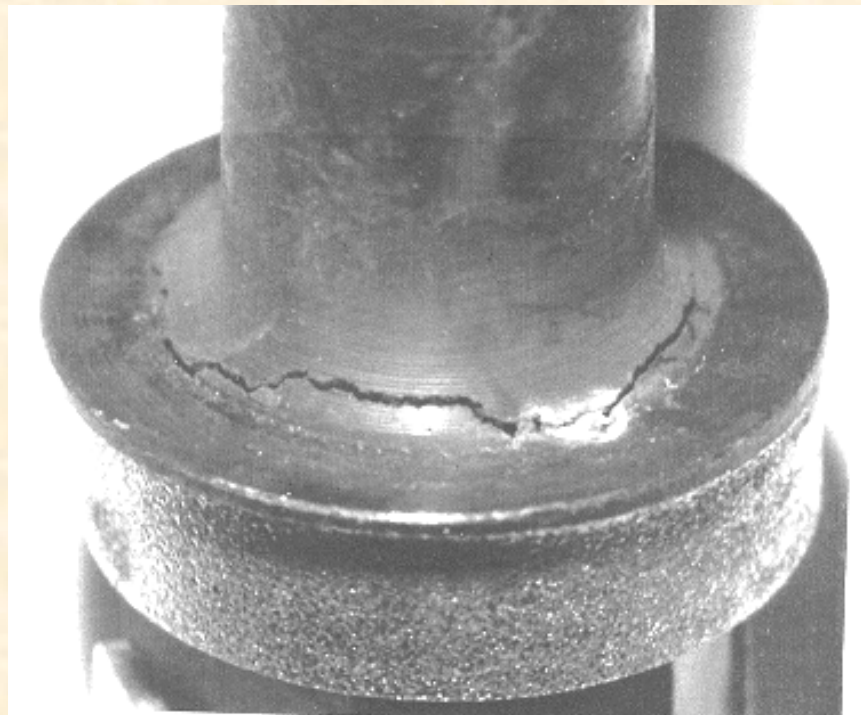
Materials degradation within subsystems and components is complex for today's reactors



25 different mode-location cases of corrosion have been identified in a SG with Alloy 600 tubes and drilled hole tube supports

Extension of service life may cause new challenges

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



Science-based analysis and mechanistic understanding will be a key component for success

- Traditional, experimental approaches can be expensive and slow in solving today's degradation issues.
- Modern materials science techniques should be utilized to provide faster and cheaper results
 - Improved analytical techniques
 - Improved predictive modeling
 - Improved knowledge integration
- Understanding degradation mechanisms via a science-based approach will allow for better lifetime performance predictions, risk management, and/or safety assessments.

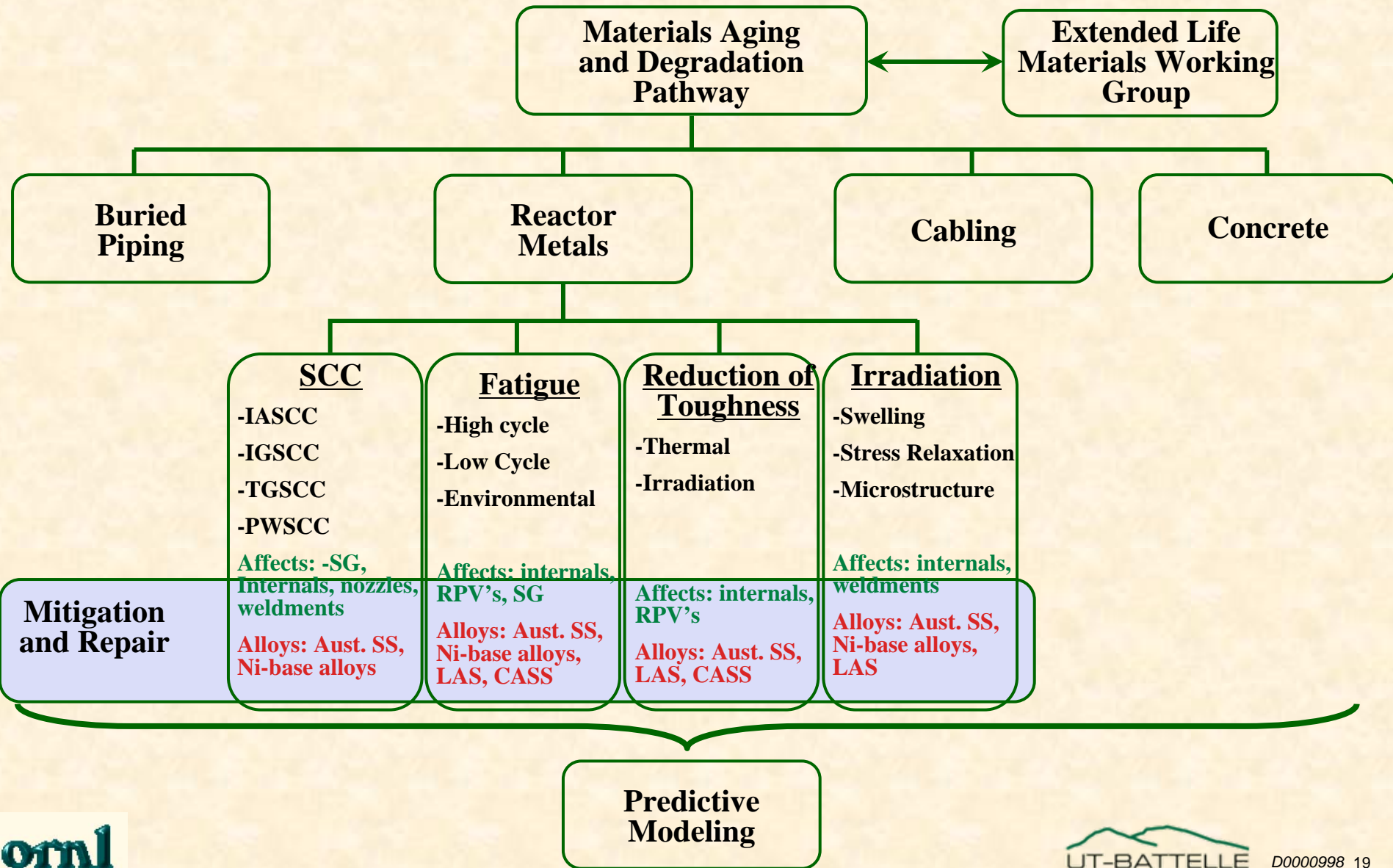
LWRSP must be inclusive of the leading experts and research around the world

- In order to be effective, materials support for LWRSP must be a broad-based program.
 - Provides a more comprehensive experimental capability.
 - Utilizes experts and facilities from across the nation
 - National laboratories
 - Universities
 - EPRI
 - NRC
 - Vendors (e.g. Areva, Westinghouse, and GE)
 - Utilities (directly or via EPRI)
 - International expertise should also be engaged to the fullest
 - International collaborations
 - Vendors and utilities
 - Universities
- To gain further support, we must have complementary programs and some early successes to build credibility.

Several areas were identified as key materials needs concerns at a recent expert workshop

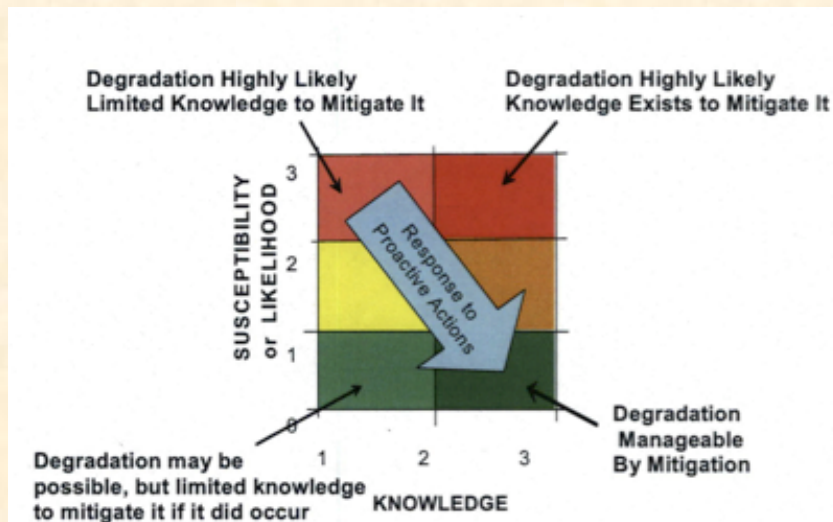
- A total of 13 “high” priority tasks were identified from a list of 38 possible tasks under consideration.
 - Irradiation-Assisted Stress Corrosion Cracking of core internals
 - Embrittlement of Reactor Pressure Vessels (two distinct tasks)
 - Stress-corrosion cracking of Ni-base alloys and stainless steel (two distinct tasks)
 - Irradiation-induced embrittlement of core internals at high fluences
 - Repair via advanced welding techniques
 - Concrete structures
 - Aging of cabling
- In addition, the Materials Pathway will support an ongoing survey task to identify and prioritize other forms of degradation not initially considered.

Organization Chart for Materials Aging and Degradation Pathway

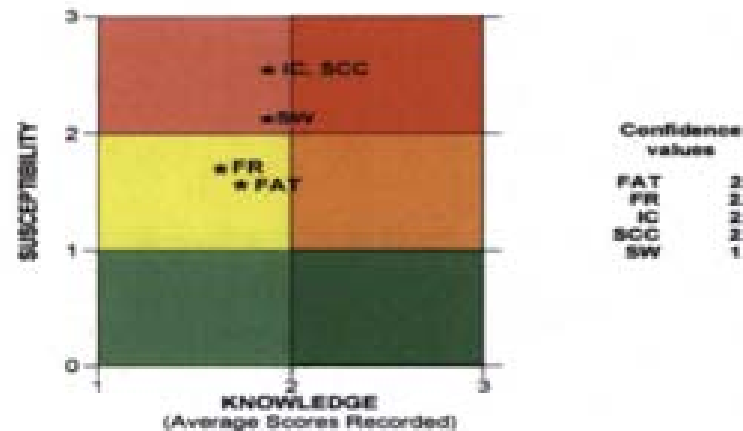


Proactive Materials Degradation Assessment and Materials Degradation Matrix provide a sound basis for initial extended operation evaluations

- EPRI maintains a series of Material Degradation Matrix for BWR and PWR issues
- In February 2007, the NRC published NUREG/CR-6923: Expert Panel Report on Materials Degradation Assessment.
- This detailed report examined and ranked materials degradation phenomena observed in the nuclear reactor fleet.
- Components and materials were ranked according to knowledge level, confidence level, and susceptibility for many different degradation mechanisms.
- This evaluation provides a basis for proactive management today.
- Both evaluations provide a sound basis for assessing materials degradation in extended service.



PMDA Matrix



PWR Internals, > 0.5 dpa

NUREG/CR-6923

Life extension may double the fluence to RPV steels and result in increased embrittlement

- Motivation: **Extending operation to 80y will result in a doubling of the neutron exposure and increased operating power level will further increase the fluence to RPV steels.**
- Objective: **Explore high fluence effects for pressure vessel steels, including “late blooming phases”, embrittlement, and data acquisition methods.**
- Other: **this work will leverage recent NRC work on RPV embrittlement mechanisms and provide an initial analysis of long-term needs for reactor pressure vessels.**

Task has been initiated.

Irradiation-assisted stress-corrosion cracking is a key concern for core internal components in BWR's and PWR's

- **Motivation: IASCC is has been observed in a number of different LWR components. This trend will continue with increasing fluence and lifetime. The mechanisms are poorly understood.**
- **Objective: Using specimens from past CIR/EPRI campaigns, evaluate IASCC response and mechanisms with single variable experiments. Determine the roles of key solute additions and microstructures on both crack initiation and crack growth. Develop a more complete understanding of IASCC by building on the CIR work**
- **Other: this work will build off previous CIR, EPRI, and NEER projects. This task may also be collaborative and complement current proposed work (NRC and EPRI funded) to test existing specimens.**

Task has been initiated.

Primary water stress-corrosion cracking is a problem in nickel-base alloys and will grow more severe with longer lifetimes

- Motivation: **PWSCC is poorly understood and of increasing concern for plant reliability. Possible mechanisms include slip-dissolution, internal oxidation, and oxide rupture, although the exact mechanism is unknown.**
- Objective: **examine PWSCC in common materials and weldments in a series of single-variable experiments designed to help identify mechanisms of PWSCC and crack initiation.**
- Other: **this work will build off previous CIR, EPRI, and NRC efforts using existing facilities and expertise at PNNL. This work will also be complementary to tasks proposed under the Materials Aging Institute.**

Task has been initiated.

Concrete can suffer undesirable changes with time due to environmental influences

- Motivation: **As concrete ages, changes in its properties will occur as a result of continuing microstructural changes (e.g., slow hydration, crystallization of amorphous constituents, and reactions between cement paste and aggregates), as well as environmental influences. A key need is quality performance data from which to create models and analyze long-term needs**
- Objective: **Collect, compile and analyze concrete performance in LWR applications**
- Other: **this work is complementary to current EPRI and NRC work. Further, this will also leverage the Advanced Cement-Based Materials Program.**

Task has been initiated.

A number of other tasks are being considered when additional funding becomes available

- High fluence effects on IASCC of core internals (FY09 start using ATR facility) [retired core shrouds? Weld metals/HAZ]
- Cabling degradation over extended service (FY09 start at TBD) [Gary Toman]
- Buried piping degradation (FY09 start at TBD) [Tim Eckert]
- Analysis of second-phase precipitation under high-fluence irradiation (FY09 start at ORNL)
- Analysis of potential swelling in high-fluence components during extended service (FY10 start at PNNL) [Anne Demma, MRP internals program]
- High-flux and surrogate material evaluation for RPV steels (FY09 start at ORNL/UCSB)
- Advanced welding and weld-repair techniques (FY10 start at INL/ORNL/TBD)
- Improved NDE and monitoring techniques (joint effort with I/C Pathway) (FY09 contribution at PNNL)
- SCC of X-750 components (FY10 contribution at INL)
- Mitigation techniques (post-irradiation annealing) (FY10 start at TBD)

Weld-repair techniques must be resistant to long-term degradation mechanisms

- **Motivation: Welding is already widely used for component repair. With extended lifetimes and increased repair frequency, these welds must be resistant to corrosion, irradiation, and other forms of degradation.**
- **Objective: Evaluate residual stress control and mitigation techniques for SCC and technologies to avoid He-induced cracking.**
- **Other: this work will build upon current and past experiences at ORNL, EPRI, and OSU. The Edison Welding Institute may also be a good partner.**

Industry and International Collaboration

- The LWRS Program has been designed to facilitate industry and government (DOE) decisions on long-term LWR operations
- Industry (EPRI-LTO) and DOE jointly define and fund R&D
- Independent steering committee oversight: NRC (MOU), EPRI, DOE, utilities, universities, industry experts
- Provides access to expertise and facilities – leveraging the best experts on the right projects
- Leverages expert knowledge through industry/international collaboration to maximize successful outcome
- Desired R&D collaboration with MAI/EdF, CEA, HRP, JAEA, KAERI, and others

Phase transformations in core components may cause embrittlement at higher fluences.

- **Motivation: radiation-induced segregation and steel impurities may lead to the formation of second-phases at higher fluences, which could in turn lead to embrittlement. Phases such as gamma-prime, G, and sigma have already been observed in 316 SS baffle bolts.**
- **Objective: Develop a model to predict phase transformations in stainless steel components and generate validation data on existing irradiated components and samples.**
- **Other: this predictive model will be extremely beneficial in predicting the long-term behavior of stainless steel components.**

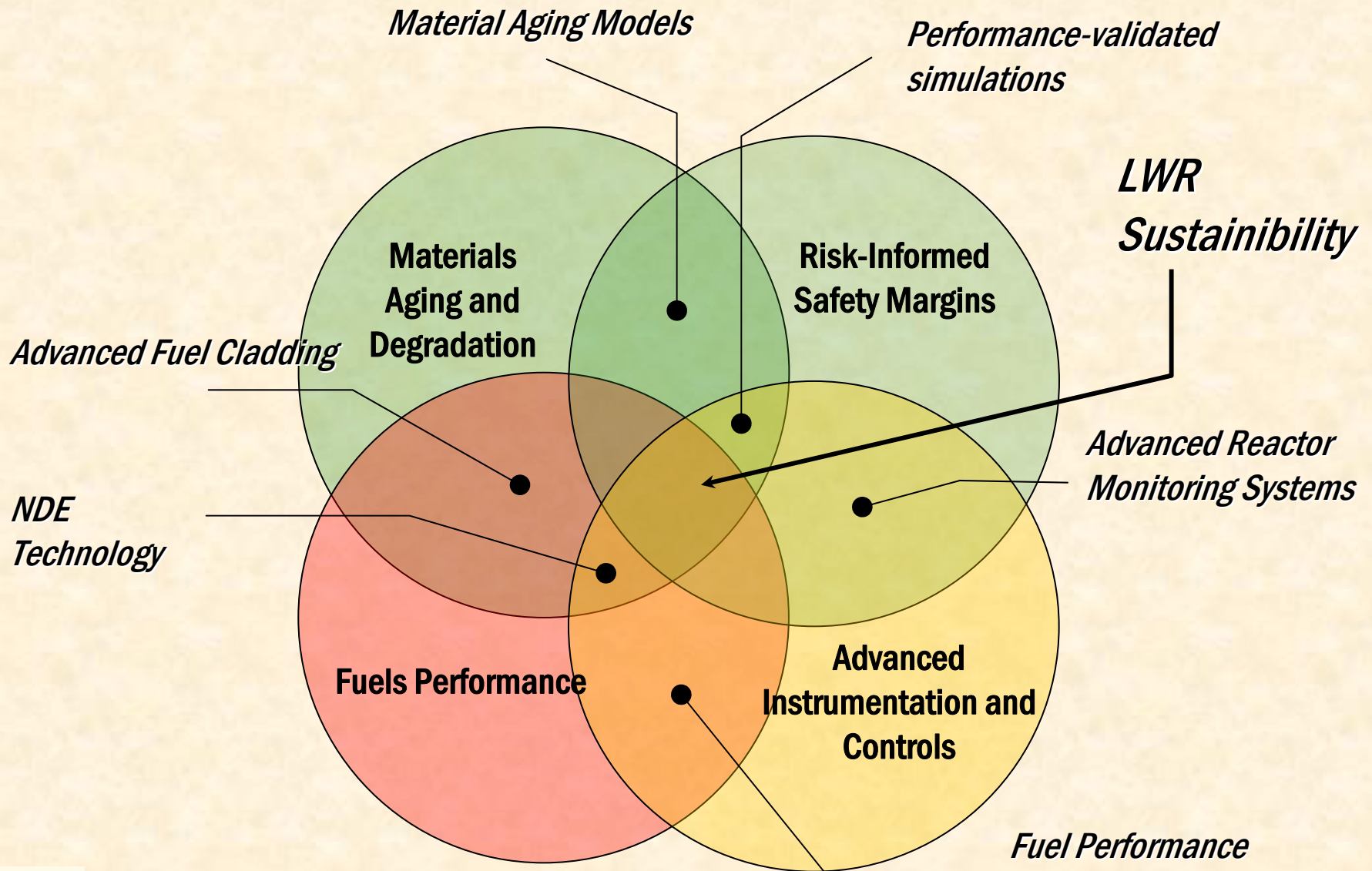
Swelling of stainless steel may become more prominent with increasing fluence

- **Motivation: Void swelling has recently been observed in PWR baffle bolts. With higher fluences expected over extended operations, the degree of swelling may increase in some components.**
- **Objective: Perform a comprehensive evaluation of the potential for swelling in LWR components over extended operations. Predictive modeling and experimental analysis will provide insight into magnitude of potential issue.**
- **Other: this work will extend previous work under EPRI, CIR, and other international programs.**

Extended lifetimes could impact cabling performance

- Motivation: **Degradation of low and medium voltage cables will increase over extended operating periods due to exposure to heat and water.**
- Objective: **Evaluate long-term aging effects on cabling due to extended wetting, heat, and ionizing radiation.**
- Other: **this work may help determine long-term replacement needs and drive other R/D for items such as fiber-optics and wireless technology.**

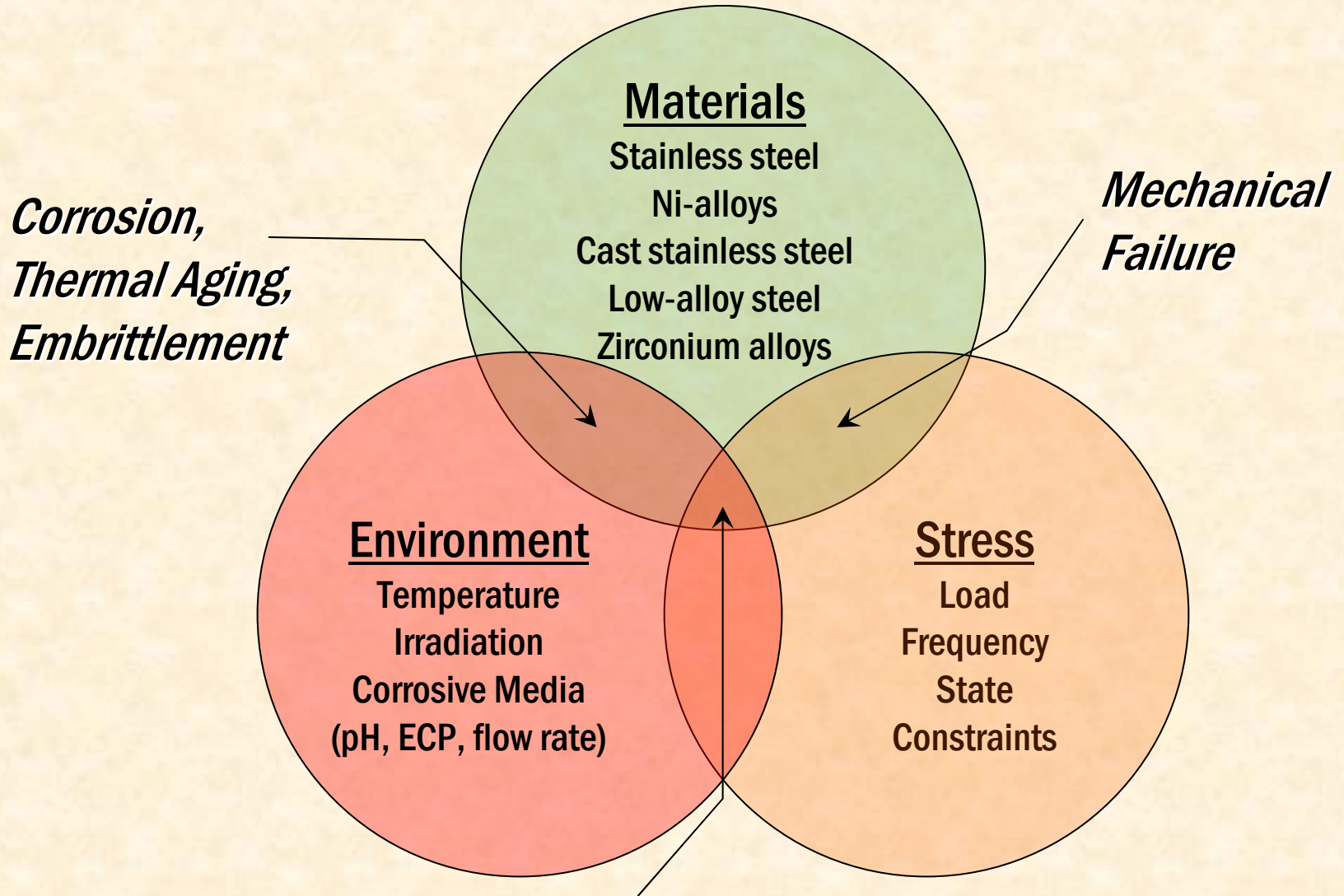
Integration and collaboration between research pathways is critical for success of LWRSP



The Materials Aging and Degradation Pathway supports the LWRSP strategic goals

- To support the LWRSP goals, the Materials Aging and Degradation Pathway will:
 - *Develop the scientific knowledge basis for understanding and predicting changes to key materials as a function of their use and the environment in nuclear power plants. Support development of methodologies used in accurately predicting lifetime performance of SSCs during extended plant operations.*
- This will be accomplished via a collaborative research effort using modern materials science, computation techniques, and partnerships

Materials aging and degradation in nuclear reactor systems is complex



Further detail on complexity....listing of variables in one material/environment system

- In crack growth, there are 20-40 variables and complex interactions. Purely empirical design of experiments would require $>10^{12}$ data points. –Peter Andresen/GE
- There is a need for
 - Development and critical testing of fundamental hypothesis
 - Sophisticated, very sensitive and critical experiments
 - Evaluation of well-characterized plant data
- “Issues continue to emerge and we should not be lulled into the wishful perspective that “we know enough.””

Science-based analysis and mechanistic understanding will be a key component for success

- **Traditional, experimental approaches can be expensive and slow in solving today's degradation issues.**
- **Modern materials science techniques should be utilized to provide faster and cheaper results**
 - Improved analytical techniques
 - Improved predictive modeling
 - Improved knowledge integration
- **Understanding degradation mechanisms via a science-based approach will allow for better lifetime performance predictions, risk management, and/or safety assessments.**

A science-based approach may be the only viable path to solve materials degradation problems for today and extended service

- **A successful science-based approach has several key requirements**
 - *Application of sound fundamentals and knowledge*
 - *Engaging leading experts in each field*
 - *Using new tools and techniques*
 - *Application of computational science advances*
- **All must (and will!) be applied for a successful and efficient research effort.**

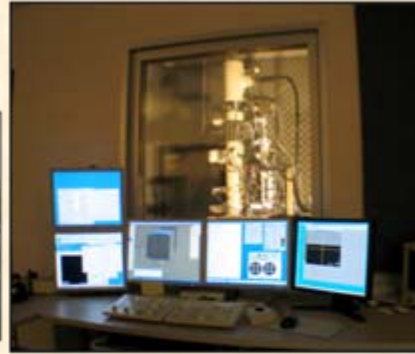
The tools available for detailed and fundamental sciences have made great jumps in the last decade



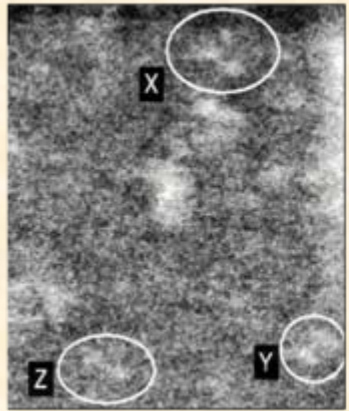
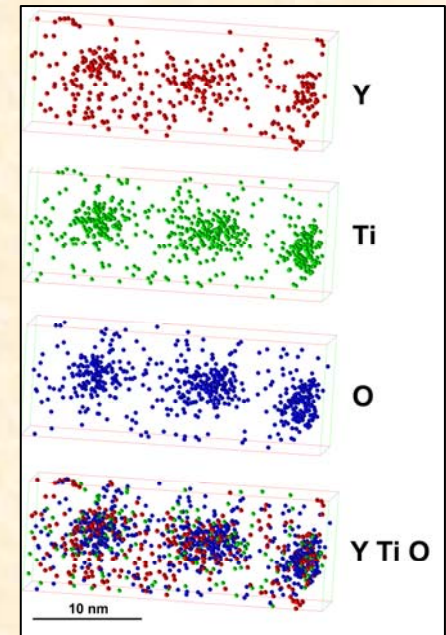
Historical approach: hands-on operation



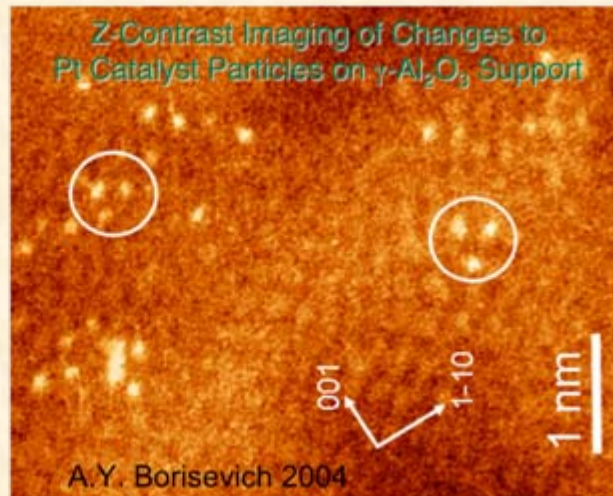
High-resolution approach: fully automated remote operation in room isolated from vibration, EM fields, ΔT and people



High resolution atom probe maps of Ti-, O-, Y-enriched NC



1 nm P.D. Nellist 1996

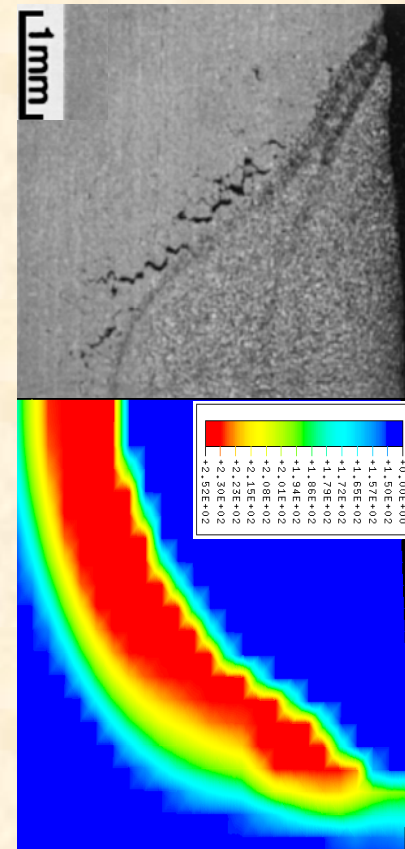


A.Y. Borisevich 2004

Electron Microscopy: Then and Now

Application of modern computational tools offer a path for mechanistic understanding

- Computational tools must be utilized (or developed) to enable more efficient advances in mechanistic understanding as well as predictive capabilities.
- Modeling and simulation must be based on physical models and theory.
- A key requirement for the application of computations in life prediction is adequate validation and verification with experimental results.



*Experiment
Observation*

*Model
Prediction*

Cracking in weld-repairs

Life prediction and mechanistic studies will be critical in ensuring safe and efficient operation

Predicting SCC in Hot Water

Perspective

- *60+ year life, nuclear safety and operating reliability puts a high demand on materials. Newest materials are 40+ yrs old.*
- *Issues continue to emerge, and we should not be lulled into the wishful perspective that “we know enough”.*
- *At its root is our inability to see the underlying, common characteristics of environmental effects on materials.*
- *Relying on no initiation in a thin skin of surface material in a large, complex, welded component has proven unwise.*
- *ASME codes avoid SCC by requiring immunity, and immunity from crack growth has mostly been disproven.*

Irradiation-assisted stress-corrosion cracking is a key concern for core internal components in BWR's and PWR's

- Motivation: **IASCC will become more severe and affects more materials and CSS's with increasing fluence and lifetime. The mechanisms are poorly understood.**
- Impact: **Improved mechanistic understanding, improved safety margins, greater safety, reduced replacement costs, improved plant reliability**
- Other: **Cooperative with EPRI, uses archive specimens.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Replacements/Reliability
Enhanced Operation	CSS Integrity and Margins	Replacement/Reliability
New Gen III+ Plants	Improved Margins	Replacement/Reliability
New Designs	Improved Margins	Replacement/Reliability

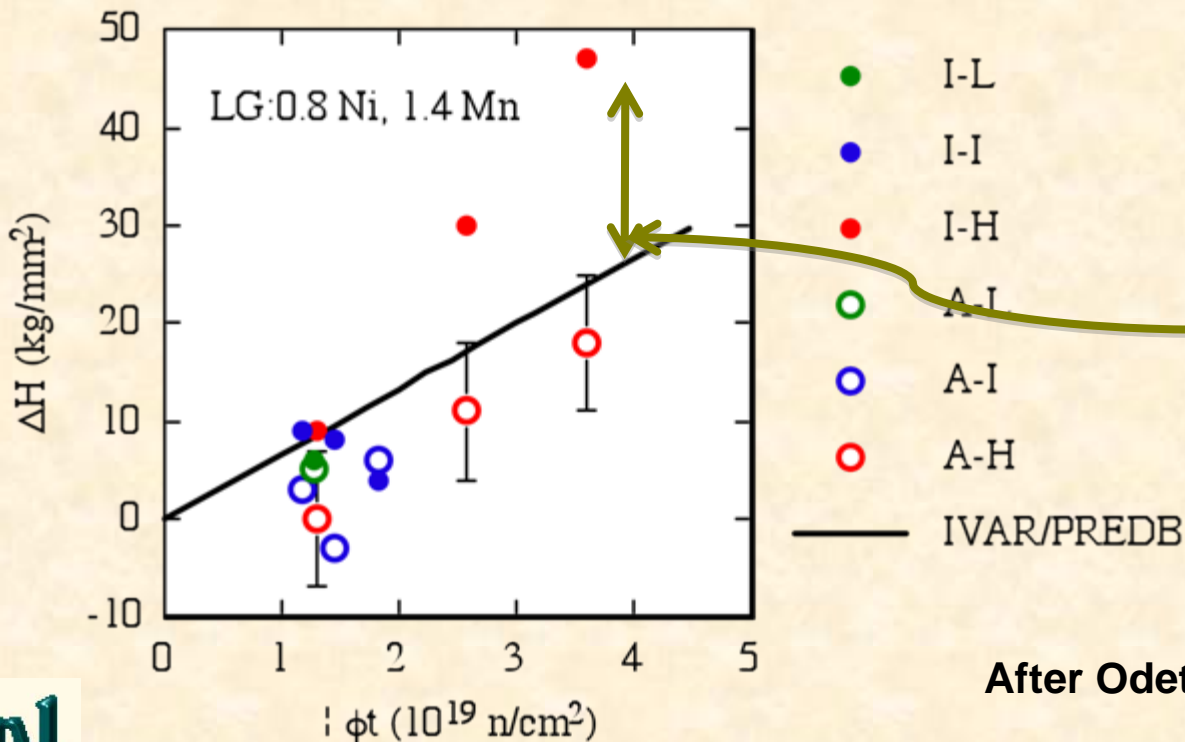
Life extension may double the fluence to RPV steels and result in increased embrittlement

- Motivation: **Extending operation to 80y will result in a doubling of the neutron exposure and increased operating power level will further increase the fluence to RPV steels.**
- Impact: **Evaluation of high fluence effects for pressure vessel steels, including “late blooming phases” and embrittlement**
- Other: **This effort is utilizing resources from past NRC campaigns.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	
Enhanced Operation	CSS Integrity and Margins	
New Gen III+ Plants	Improved Margins	
New Designs	Improved Margins	

The evaluation of RPV steels has provided the first experimental data for LWRSP

- Initial data on samples irradiated as part of previous NRC effort reveal greater hardening than expected using most advanced predictive models.
- Additional analysis is underway (small-angle neutron scattering and microstructure analysis).



Difference between IVAR prediction and experimental data indicates a new mechanism is at work. More data are required to fully evaluate these effects.

After Odette

Methodologies to study high fluence effects on RPV must also be validated.

- Motivation: **As reactor pressure vessels age, fewer and fewer surveillance specimens will be available although proper monitoring of RPV state is more critical. High fluxes and surrogate materials must be validated to obtain this data.**
- Impact: **This effort will provide monitoring strategies that can be utilized on current and future reactors.**
- Other: **This effort will be highly integrated with other RPV tasks and international efforts.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	
Enhanced Operation	CSS Integrity and Margins	
New Gen III+ Plants	Improved Margins	
New Designs	Improved Margins	

Primary water stress-corrosion cracking is a problem in nickel-base alloys and will grow more severe with longer lifetimes

- Motivation: **PWSCC is poorly understood and of increasing concern for plant reliability. Possible mechanisms include slip-dissolution, internal oxidation, and oxide rupture, although the exact mechanism is unknown.**
- Impact: **Use single variable experiments to identify mechanisms enabling effective prevention and mitigation strategies.**
- Other: **This effort is integrated with other EPRI and NRC tasks.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Replacements/Reliability
Enhanced Operation	CSS Integrity and Margins	Replacement/Reliability
New Gen III+ Plants	Improved Margins	Replacement/Reliability
New Designs	Improved Margins	Replacement/Reliability

Phase transformations in core components may cause embrittlement at higher fluences.

- Motivation: **radiation-induced segregation and steel impurities may lead to the formation of second-phases at higher fluences. Phases such as gamma-prime, G, and sigma have already been observed in 316 SS baffle bolts.**
- Impact: **Generate valuable experimental data and an integrated model predictions for extended service.**
- Other: **Experience from past and current fast-reactor efforts will be valuable**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Replacements/Reliability
Enhanced Operation	CSS Integrity and Margins	Replacement/Reliability
New Gen III+ Plants	Improved Margins	Replacement/Reliability
New Designs	Improved Margins	Replacement/Reliability

Swelling of stainless steel may become more prominent with increasing fluence

- Motivation: **Void swelling has recently been observed in PWR baffle bolts. With higher fluences expected over extended operations, the degree of swelling may increase in some components.**
- Impact: **Provides a critical analysis of potential for swelling issues using experiments and modeling.**
- Other: **Experience from past and current fast-reactor efforts will be valuable**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Replacements/Reliability
Enhanced Operation	CSS Integrity and Margins	Replacement/Reliability
New Gen III+ Plants	Improved Margins	Replacement/Reliability
New Designs	Improved Margins	Replacement/Reliability

Concrete can suffer undesirable changes with time due to environmental influences

- Motivation: **As concrete ages, changes in its properties will occur as a result of continuing microstructural and environmental influences. Quality performance is required.**
- Impact: **Provide quality data to provide a valuable assessment of concrete limitations and input for lifetime models.**
- Other: **This task is collaborative and coordinated with EPRI and MAI efforts.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	
Enhanced Operation	CSS Integrity and Margins	
New Gen III+ Plants	Improved Margins	
New Designs	Improved Margins	

The long-term performance of buried piping must be considered.

- Motivation: **Degradation of buried piping is expected to worsen through extended service, although quality data is needed.**
- Impact: **This task will provide valuable experimental data on the impact of aging on buried piping performance.**
- Other: **The results of this effort may help determine long-term replacement needs and inspection technologies.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Replacements/Reliability
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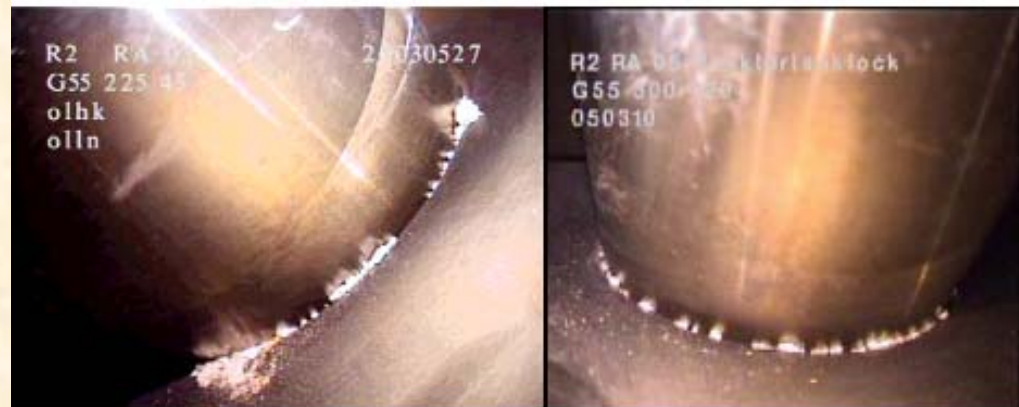
Extended lifetimes could impact cabling performance

- Motivation: **Degradation of low and medium voltage cables will increase over extended operating periods due to exposure to heat and water, although quality data is needed.**
- Impact: **This task will provide valuable experimental data on the impact of aging on cable performance.**
- Other: **may help determine long-term replacement needs and drive other R/D for items such as fiber-optics and wireless technology.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Replacements/Reliability
Enhanced Operation	CSS Integrity and Margins	Replacement/Reliability
New Gen III+ Plants	Improved Margins	Replacement/Reliability
New Designs	Improved Margins	Replacement/Reliability

Do we need to study degradation issues if replacement is an option?

- Component replacement does not always mean the end of degradation issues.
- For example, consider the RPV head replacement at Ringhals 2.
 - The head was replaced with modern materials in 2000
 - “boron popcorn” was observed by 2004.



B-precipitates found in 2004 and 2005

Weld-repair techniques must be resistant to long-term degradation mechanisms

- Motivation: **Welding is already widely used for component repair. With extended lifetimes and increased repair frequency, these welds must be resistant to corrosion, irradiation, and other forms of degradation.**
- Impact: **Develop new techniques for weldments, weld analysis, and weld repair**
- Other: **This task will be coordinated and collaborative with ongoing EPRI efforts in weld analysis and repair welding.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins, Repairs	Reliability and Repairs
Enhanced Operation	CSS Integrity and Margins, Repairs	Reliability and Repairs
New Gen III+ Plants	Improved Margins	Reliability and Repairs
New Designs	Improved Margins	Reliability and Repairs

Post-irradiation annealing may be one means of regaining performance without replacement.

- Motivation: **Reactor pressure vessel annealing has been demonstrated in Belgium and Russia, although not in the US. Additional data is required to establish the technical validity of this technique.**
- Impact: **Evaluate technical basis for application of post-irradiation annealing to RPV's and core internals.**
- Other: **This task provides a valuable and alternative strategy to replacement.**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Mitigation
Enhanced Operation	CSS Integrity and Margins	Mitigation
New Gen III+ Plants	Improved Margins	Mitigation
New Designs	Improved Margins	Mitigation

Advanced alloys and improved fabrication techniques may be used for new plants and replacement components

- Motivation: **Alternative and advanced materials may be used instead of traditional materials during component replacement.**
- Impact: **Advanced alloys may offer greater performance for new plants, increase safety margins and eliminate future replacements.**
- Other: **May build on other, recent DOE-NE efforts.**

	Safety & Licensing	Economics
Life Beyond 60	Increased Safety Margins	Replacement Components
Enhanced Operation	Increased Safety Margins	
New Gen III+ Plants	Improved Margins	Construction \$ Replacement/Reliability
New Designs	Improved Margins	Construction \$ Replacement/Reliability

Collaborations with the I/C Pathway may provide opportunities for innovation.

- Motivation: **A coordinated effort to develop new monitoring techniques will be required to monitor and mitigate degradation modes. Concrete and crack-initiation are two possible areas of collaboration.**
- Impact: **Evaluate and develop new monitoring and NDE techniques**
- Other: **Costs are shared with the I/C Pathway**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Reliability
Enhanced Operation	CSS Integrity and Margins	Reliability
New Gen III+ Plants	Improved Margins	Reliability
New Designs	Improved Margins	Reliability

Collaborations with the RISMC Pathway may provide improved methodologies

- Motivation: **Incorporating new data on degradation phenomena into safety margin characterization will be important. A case-study (on RPV degradation for example) will provide a demonstration of new methodologies.**
- Impact: **reduce uncertainty in safety margins and performance and increase efficiency in testing.**
- Other: **Costs are shared with the RISMC Pathway**

	Safety & Licensing	Economics
Life Beyond 60	CSS Integrity and Margins	Reliability
Enhanced Operation	CSS Integrity and Margins	Reliability
New Gen III+ Plants	Improved Margins	Reliability
New Designs	Improved Margins	Reliability

The Materials Aging and Degradation Pathway Tasks encompass all aspects of LWRSP

	Life Beyond 60	Enhanced Operation	New Gen III+ Plants	New Designs
Safety & Licensing	IASCC, PWSCC, HF IASCC, X-750 RPV, HF RPV, Phases, Swelling Concrete Cabling Buried Piping Weldments, PIA Advanced Alloys IC, RISMIC	IASCC, PWSCC, HF IASCC, X-750 RPV, HF RPV, Phases, Swelling Concrete Cabling Buried Piping Weldments, PIA Advanced Alloys IC, RISMIC	IASCC, PWSCC, HF IASCC, X-750 RPV, HF RPV, Phases, Swelling Concrete Cabling Buried Piping Weldments, PIA Advanced Alloys IC, RISMIC	IASCC, PWSCC, HF IASCC, X-750 RPV, HF RPV, Phases, Swelling Concrete Cabling Buried Piping Weldments, PIA Advanced Alloys IC, RISMIC
Economics	IASCC, PWSCC, HF IASCC, X-750 RPV, Phases, Swelling Cabling Buried Piping Weldments, PIA Advanced Alloys IC, RISMIC	IASCC, PWSCC, HF IASCC, X-750 RPV, Phases, Swelling Cabling Buried Piping Weldments, PIA Advanced Alloy IC, RISMIC	IASCC, PWSCC, HF IASCC, X-750 RPV, Phases, Swelling Cabling Buried Piping Weldments, PIA Advanced Alloys IC, RISMIC	IASCC, PWSCC, HF IASCC, X-750 RPV, Phases, Swelling Cabling Buried Piping Weldments, PIA Advanced Alloys IC, RISMIC

Summary

- The Materials Aging and Degradation Pathway will support licensing decisions by providing *the scientific knowledge basis for understanding and predicting changes to key materials as a function of their use and the environment in nuclear power plants.*
- An integrated and collaborative program using modern materials science has been initiated.
- A number of research tasks have been initiated and more are in the planning phases.
- These tasks will provide valuable data insights, mechanistic understandings, mitigation strategies, and new technologies to achieve sustainable nuclear power.