Light Water Reactor Sustainability

July 27-28, 2010

FY2011
NEUP Workshop
Breakout Sessions

LWRS

Light Water Reactor Sustainability

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Light Water Reactor Sustainability

R&D Objective 1: Extend Life, Improve Performance, and Maintain Safety of the Current Fleet

Science-Based R&D to Extend Nuclear Plant Operation

July 2010

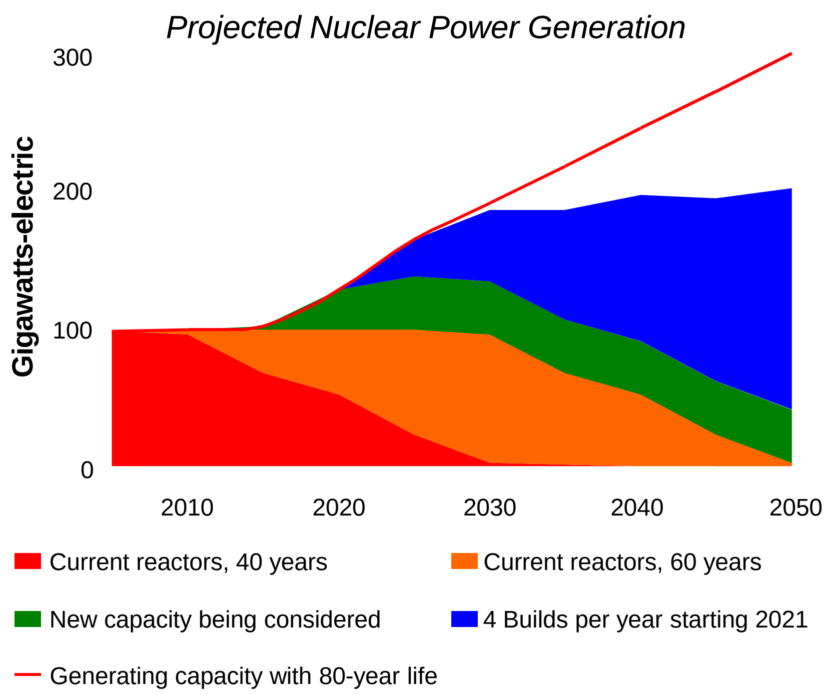
Maximizing the Use of Existing Nuclear Plants

- Currently, 104 operating nuclear plants provide 100 GWe of capacity which is about 20% of U.S. electric generation and over 70% of emission-free generation
- License Renewal – originally licensed for 40 years
  - 54 license renewals approved to operate to 60 years
  - 21 license renewal applications in NRC review
  - 20 license renewal applications anticipated
  - 9 unannounced

- Fleet maintaining greater than 90% average capacity factors
- Power up-rates continue
- Since 1977 5,640 MWe added
  - 595 MWe currently in NRC review
  - 2,894 MWe additional up-rate capacity expected between 2009 – 2013
- Utilities exercising options to use prior nuclear investments
  - Browns Ferry Unit 1 (Alabama) resumed operation
  - Watts Bar Unit 2 (Tennessee) restarted construction
  - Consideration being given for Bellefonte 1&2 (Alabama) construction restart

The National Interest

- EIA AEO 2009 reference case has U.S. electricity demand expected to increase ~24% by 2030
  - Annual CO_2 emissions projected to increase by 296 million metric tons to a total of 2,729
- Nuclear generation is critical to:
  - Reduce greenhouse gases
  - Meet electricity demand
  - Ensure energy supply security and grid reliability
  - Stabilize energy prices
- Current nuclear plants retire between 2029 – 2056
  - New nuclear build rate will not replace plant retirements
  - Cost to replace the current fleet exceeds $600B
  - Steep reduction in emission-free generation
- Existing reactors reduce burden of new clean electricity that will need to come online



R&D Objective 1: The LWR Sustainability (LWRS) R&D Program

Vision

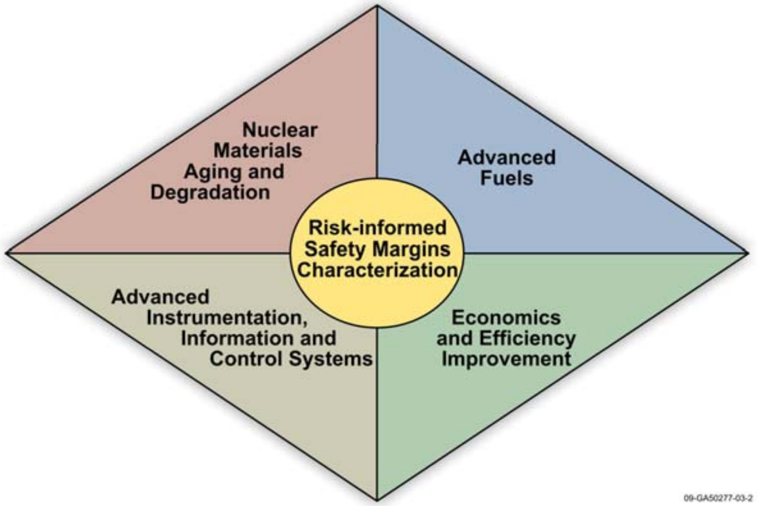
- Enable existing nuclear power plants to **safely** provide **clean** and **affordable** electricity beyond current license periods (beyond 60 years)

Program Goals

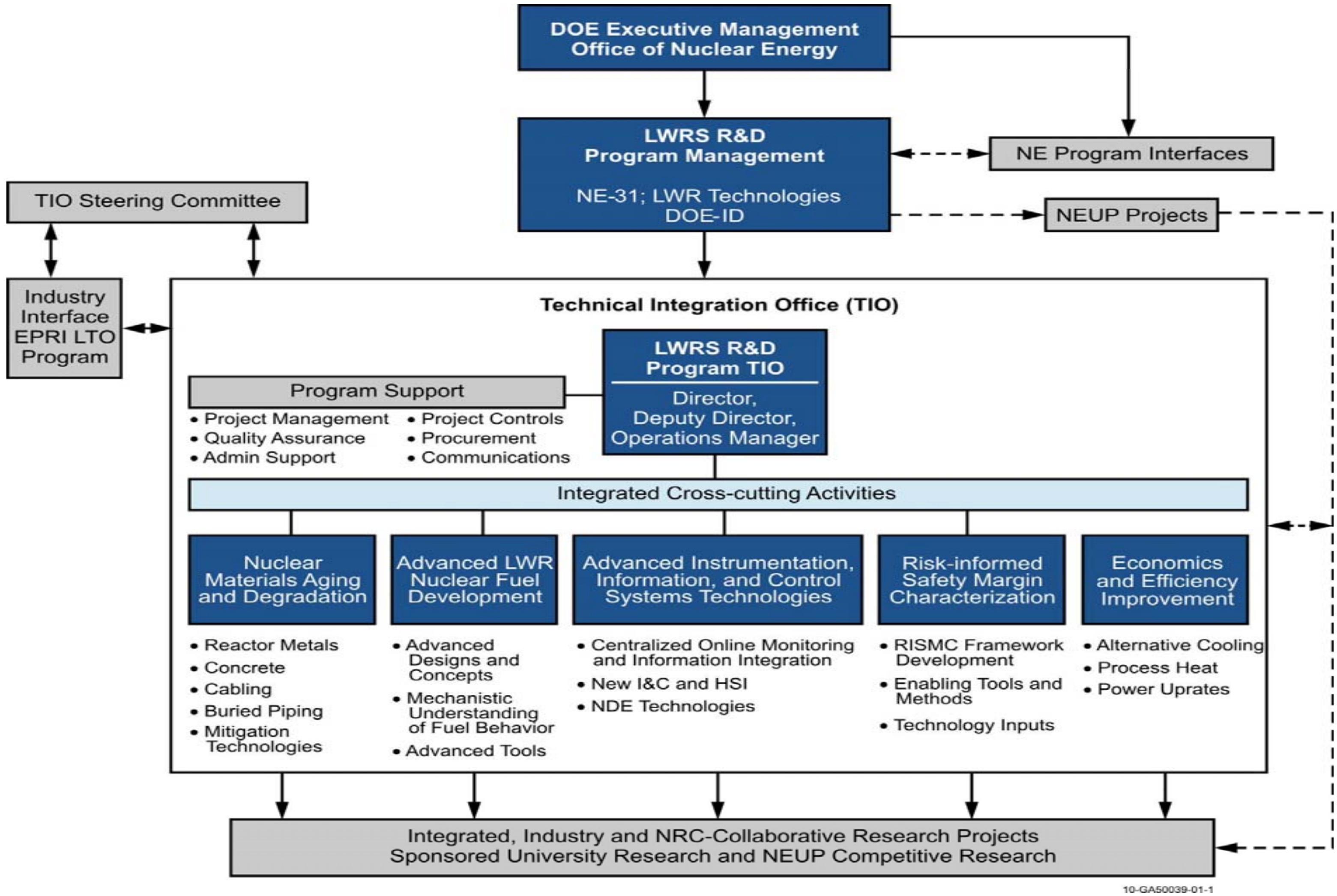
- Develop fundamental **scientific** basis to allow continued **safe long-term** operation of **existing** LWRs
- Develop technical and operational improvements that contribute to long-term **economic** viability of existing nuclear power plants

Scope

- Materials Aging and Degradation
- Advanced Instrumentation and Controls
- Risk-Informed Safety Margin Characterization
- Advanced Fuel Development
- Economics and Efficiency Improvements



R&D Objective 1: Organization



LWRS Leadership (1/2)

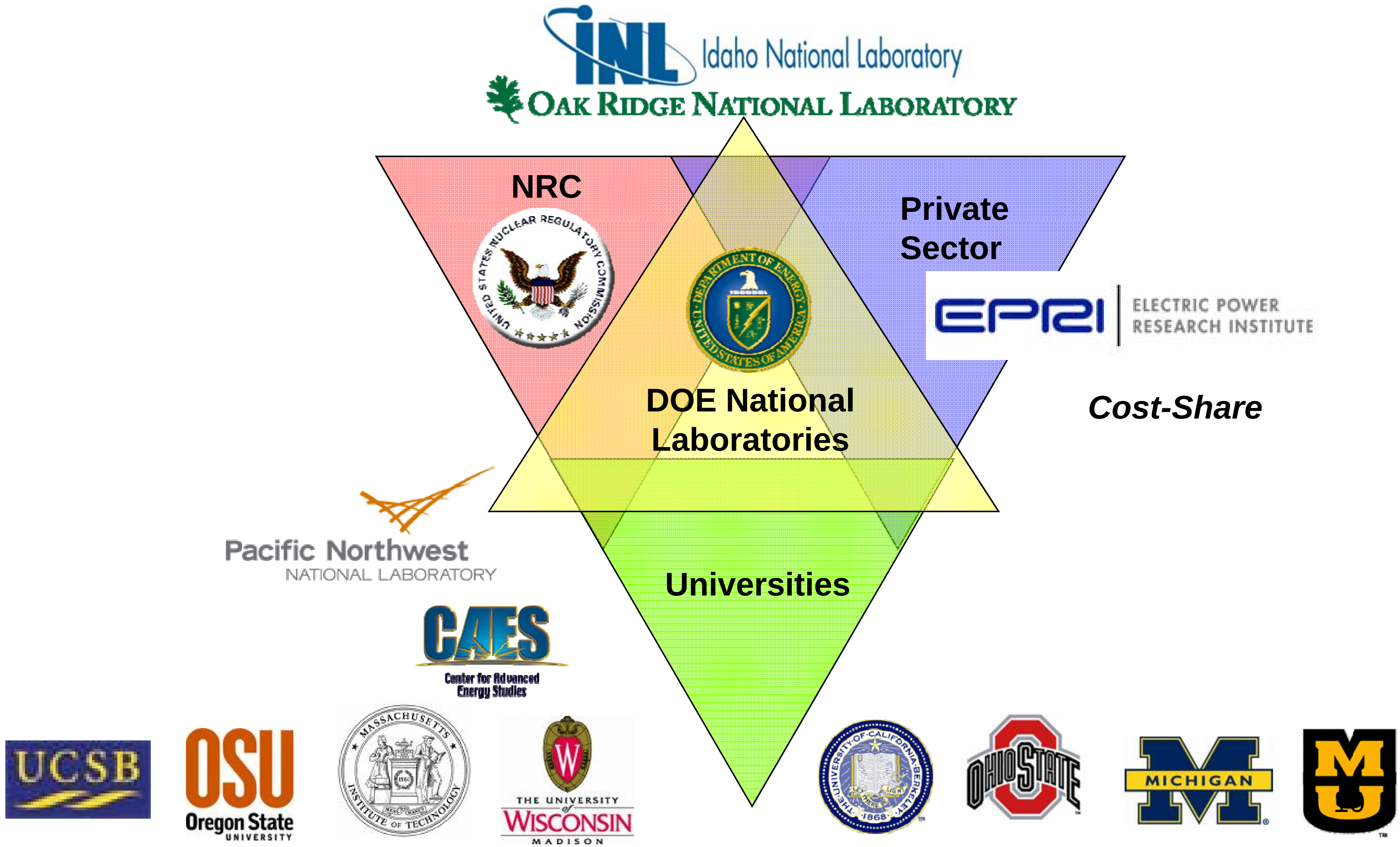
- ***DOE – Office of Nuclear Energy***
  - ***Richard Reister, Federal Project Director***
  - ***301-903-0234, richard.reister@nuclear.energy.gov***
- ***LWRS Technical Integration Office (TIO), http://www.inl.gov/lwrs***
  - ***Ronaldo Szilard, LWRS Director***
    - ***INL, 208-526-8376, ronaldo.szilard@inl.gov***
  - ***Don Williams, LWRS Deputy Director***
    - ***ORNL, 865-574-8710, williamsdljr@ornl.gov***
  - ***Cathy Barnard, LWRS Operations Manager***
    - ***INL, 208-536-0382, cathy.barnard@inl.gov***
  - ***John Gaertner, EPRI TIO Representative***
    - ***704-595-2169, jgaertner@epri.com***

LWRS Leadership (2/2)

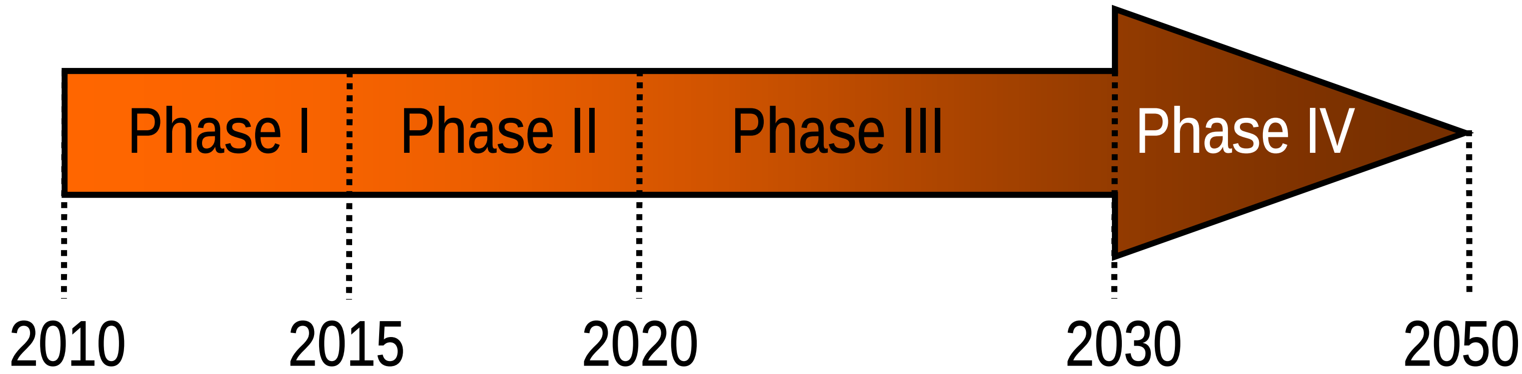
<u>TECHNICAL PATHWAYS</u>

- ***Nuclear Materials Aging and Degradation***
  - ***Jeremy Busby, ORNL, 865-241-4622, busbyjt@ornl.gov***
- ***Advanced I&C and Information Systems Technologies***
  - ***Bruce Hallbert, INL, 208-526-9867, bruce.hallbert@inl.gov***
- ***Risk-Informed Safety Margin Characterization***
  - ***Robert Youngblood, INL, 208-526-7092, robert.youngblood@inl.gov***
- ***Advanced LWR Nuclear Fuel Development***
  - ***George Griffith, INL, 208-526-8026, george.griffith@inl.gov***
- ***Economics and Efficiency Improvement***
  - ***Hongbin Zhang, INL, 208-526-9511, hongbin.zhang@inl.gov***

LWRS: An Integrated Collaborative R&D Program



LWRS Program R&D Investment



Build Confidence in Life Extension with Data and Tools

Enable Industry Decision to Invest and License for License Extension

Acceptance of Advanced Tools, Methods and Technologies

Fleet Operation Beyond 60-year Life

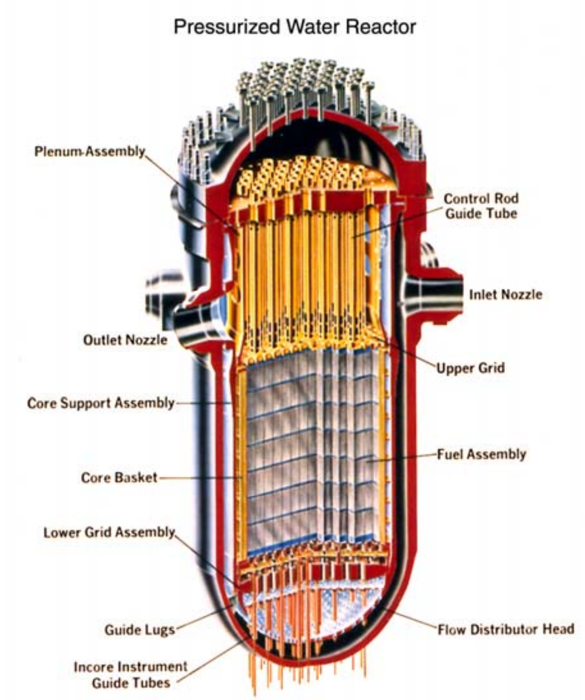
$10M
(FY 2010 university funding: $1.3M)

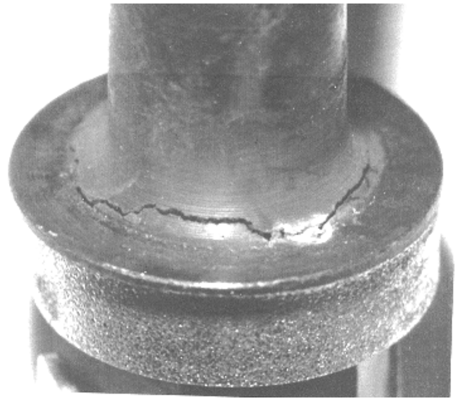
$100M

Large Payoff: Moderate R&D Cost Leveraging High Capital Investments

Extending the service life of today's LWR fleet may create new material challenges

- Extending reactor life to beyond 60 years will likely increase susceptibility and severity of known forms of materials degradation and potentially introduce new forms of degradation
- The LWRS R&D effort seeks to provide the scientific basis for understanding and predicting materials aging and degradation within components, systems, and structures
  - Reactor metals (RPV's, internals, steam generators, balance of plant, and weldments)
  - Concrete
  - Buried piping
  - Cabling
  - Mitigation, repair, and replacement technologies
- A new working group has been formed to integrate the materials efforts within DOE's LWRS, EPRI's LTO, and NRC's LB60 programs





LWRS Light Water Reactor Sustainability

Modern materials science 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
  - Leading expertise from around the country
  - 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

Idaho National Laboratory

Oak Ridge National Laboratory
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Pacific Northwest NATIONAL LABORATORY

EPRI ELECTRIC POWER RESEARCH INSTITUTE

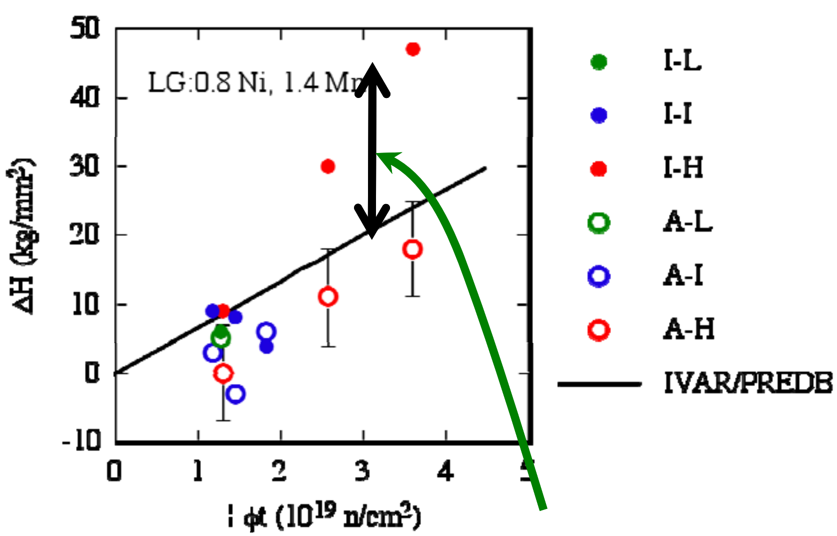
THE UNIVERSITY of WISCONSIN MADISON

MICHIGAN

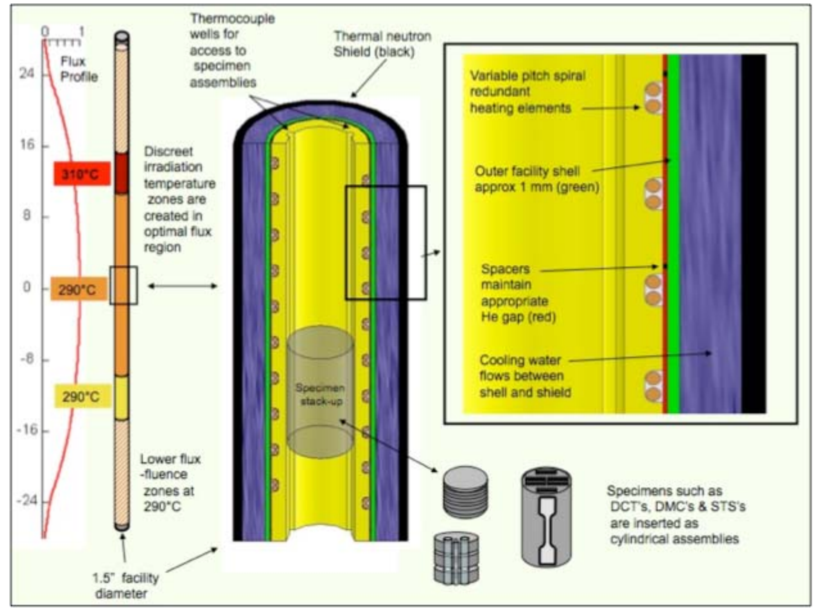
UCSB

Analysis of high-fluence RPV steels has provided the first experimental data for LWRS R&D

- Initial data on samples irradiated as part of previous NRC effort reveal greater hardening than expected using most advanced predictive models, based on decades of research.



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



- Additional work has been initiated using the ATR NSUF to generate new specimens irradiated over a wide range of flux and fluence.
- High value specimens in the Palisades NPP are also being investigated

LWRS Light Water Reactor Sustainability

Advanced Information, Instrumentation, & Controls (IIC) R&D

- Current technology for IIC is not sustainable –will become a limiting factor for continued operation
- Recent replacements and modernizations using digital technologies are perceived as unsuccessful.
- Regulatory uncertainty and a risk-averse industry reinforce the status quo of outdated and antiquated analog I&C.
- ALWR licensing will not change current IIC limitations.
- Asset owners and vendors recognize that the needed change is not occurring and is not likely to occur without substantial federal involvement.

From this…

…to this!

- The commercial nuclear power industry will undertake modernization as a result of this program.
- Confidence will be created in the process of developing and deploying technology through this program to support utility and regulatory decisions.
- A federally funded and supported IIC Laboratory will form the basis for multi-party agreements used for research, development, demonstration, test & evaluation.

Pacific Northwest NATIONAL LABORATORY

United States Nuclear Regulatory Commission

ornl

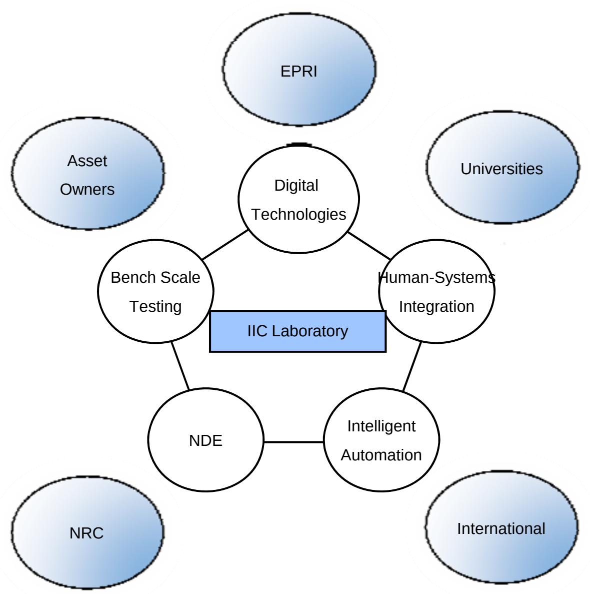
HRP

Ohio State

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Industry Supports a Strong R&D Program

- Data generation & use in future operations concepts
- Real-time performance data from active and passive systems
- Diagnostics & prognostics
- Fleet-wide implementation
- Dedicated facilities for R&D



Formulate a new perspective of IIC technologies for long term operation and asset management

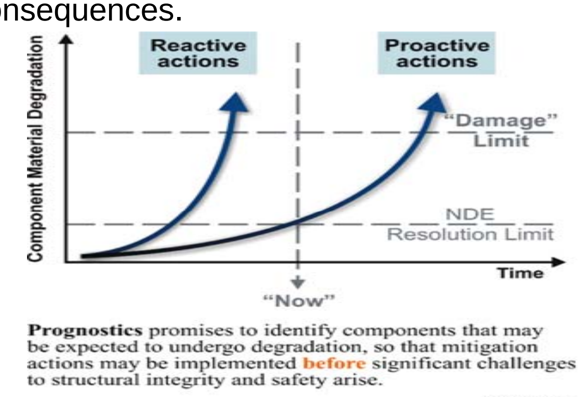
Design & test HSI to improve information access, situation awareness, and decision-making

Improve automation to amplify human capabilities

New NDE technologies to improve characterization of change due to material aging and degradation

On-line monitoring and diagnostics to better estimate the margins between operating parameters and design parameters

Eventual prognostic technologies to more accurately predict failure mechanisms and consequences.



Characterization of safety margin is central to decision making in plant operational performance, power uprate, and life extension

Aging of Structures, Systems and Components (SSC) has potential

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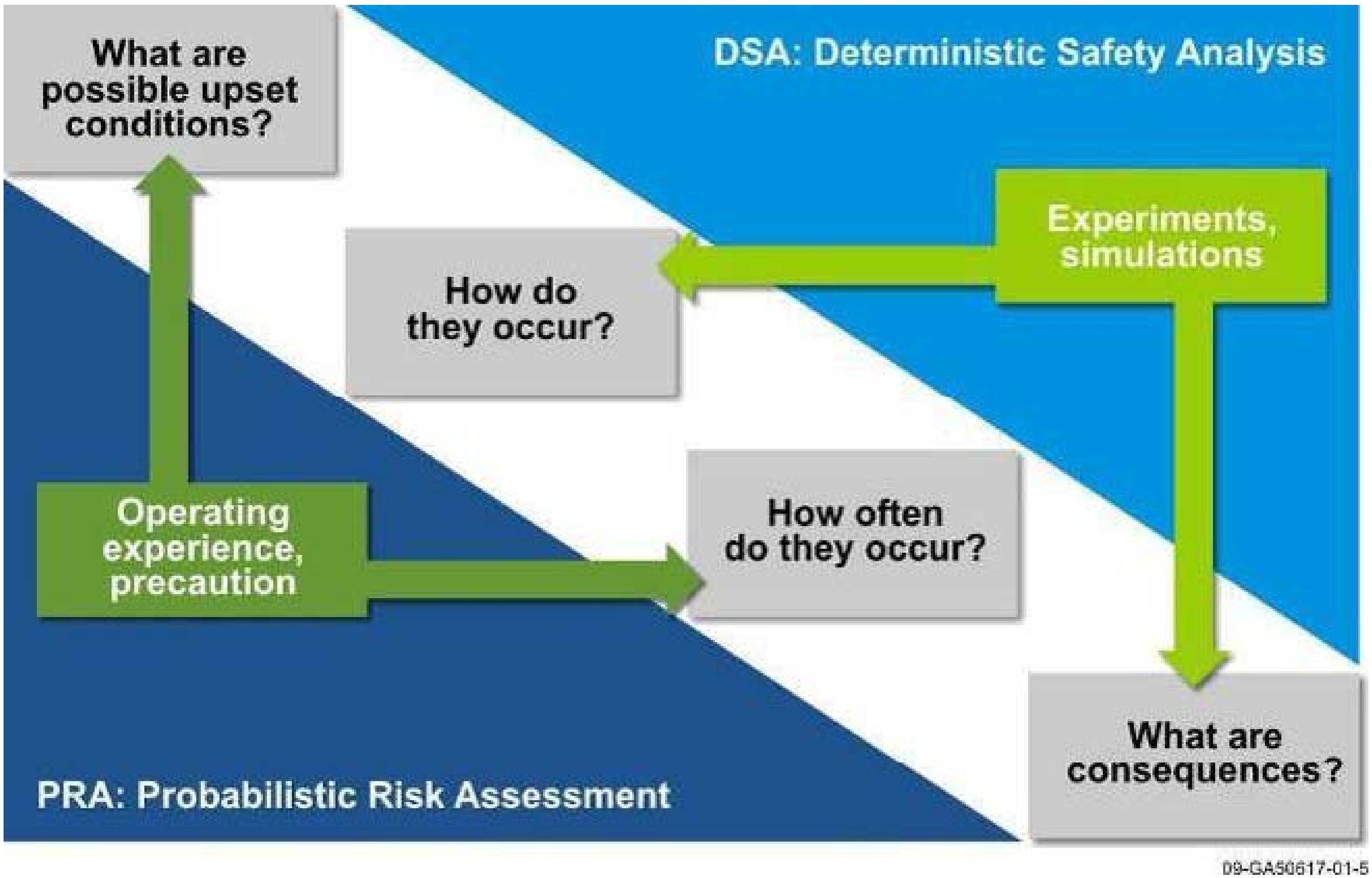
- to increase frequency of initiating events of certain safety transients;
- to create new and more complex transient sequences associated with previously-not-considered SSC failures; and
- to increase severity of safety transients due to cascading failures of SSCs.

Quantification of the effect of SSC aging on plant safety is hindered by

- deficient data and models required to predict behaviors of the aging SSCs in a broad range of plant operating, upset and accident conditions;
- large uncertainties in using the existing M&S tools to analyze the plant system dynamics in scenarios involving aging-induced SSC failures; and
- lack of a risk assessment methodology that takes into account (reliability of) passive SSCs and passive safety features.

→ *New Methods, Tools and Data are Needed to Meet High Demands in LWR Safety Decision Making*

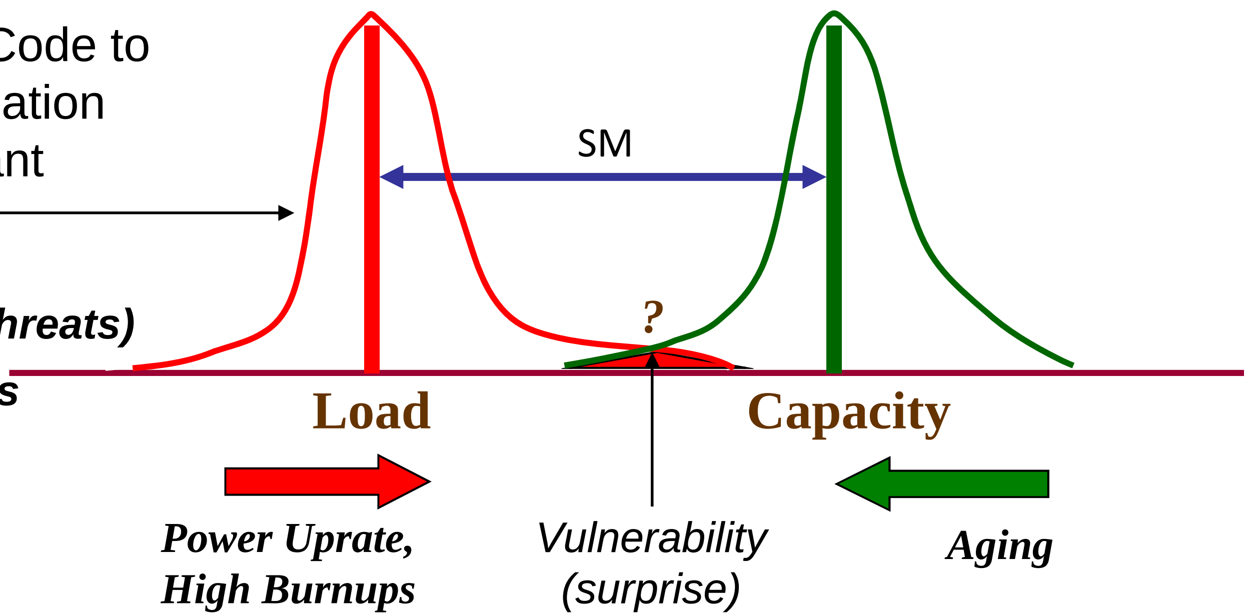
Characterization of safety margin is central to decision making in plant operational performance, power uprate, and life extension



Risk-Informed Safety Margin Characterization (RISMC)

Combining Probabilistic and Mechanistic Modeling to provide Integrated Quantification of Aleatory and Epistemic Uncertainty

Area 1: Develop RELAP7 Code to Enable Plant System Simulation and Computation of the Plant Probabilistic Loads



- ✓ ***System analysis (multiple threats)***
- ✓ ***Tightly couple multi-physics***
- ✓ ***Coverage of scenarios***
- ✓ ***Computational efficiency***
- ✓ ***Appropriate model fidelity***

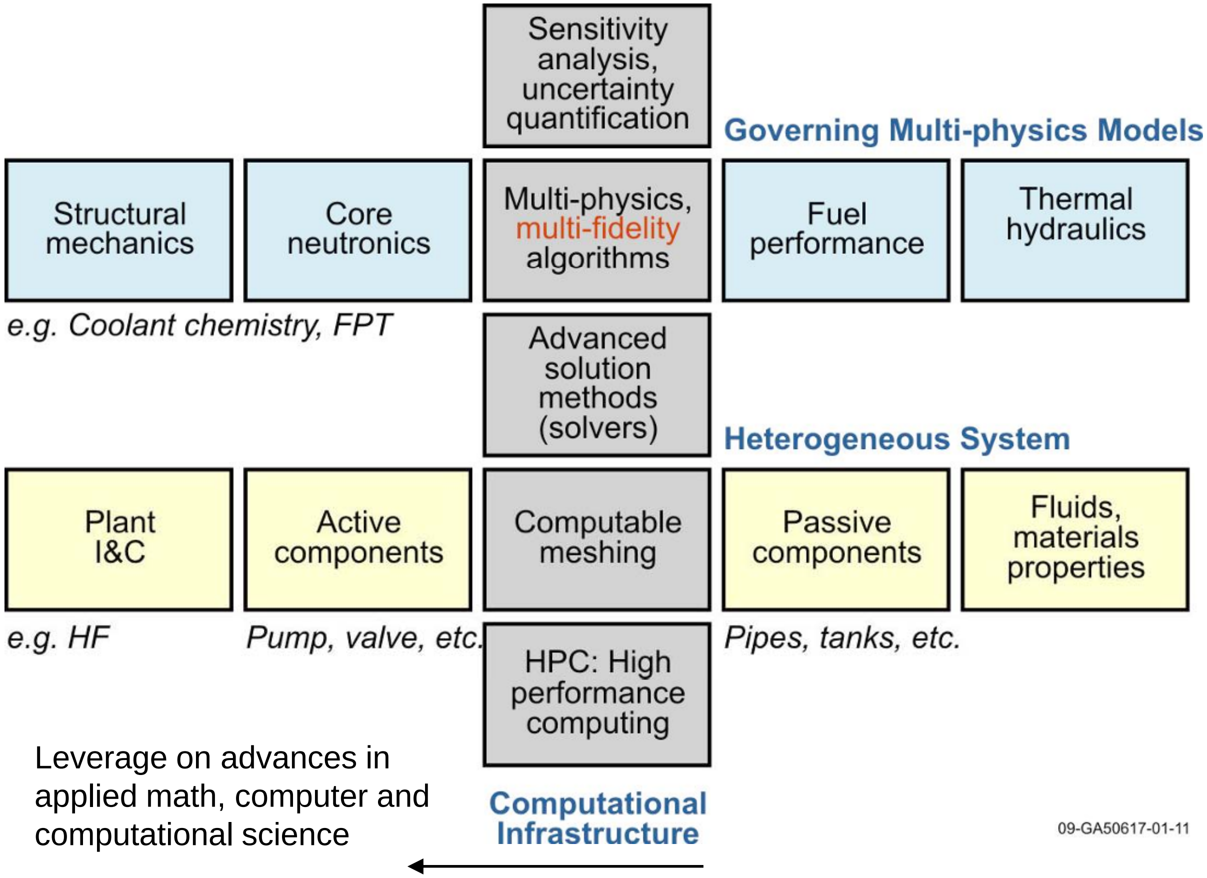
Area 2: Develop a risk-informed margin-based framework for construction of LWR plant life extension "safety case"

Area 3: Incorporate (aging) SSCs into a Plant Risk Model. Integrate RISMC with Materials Aging R&D

RELAP7 Code: a Next Generation of System Analysis Code to Support Risk-Informed Safety Decision Making

→ **Go beyond the current technology manifested by legacy codes (RELAP5, SAPHIRE) developed at INL and used broadly by the industry and regulatory evaluation**

❖ **The RELAP7 Project is a community effort, to develop new safety analysis methods, cultivate new safety culture and train new generation of nuclear engineers**



Overcome limitations of 1970s' "divide and conquer" paradigm

Push envelop of M&S in all physical processes involved in plant safety

FY10-FY11 Goals:

Develop R7 code architecture and test version engine

Analyze a plant safety issue of importance for life extension

Demonstrate viability of using the R7 capability to construct the RISMC "safety case" on the selected life extension issue

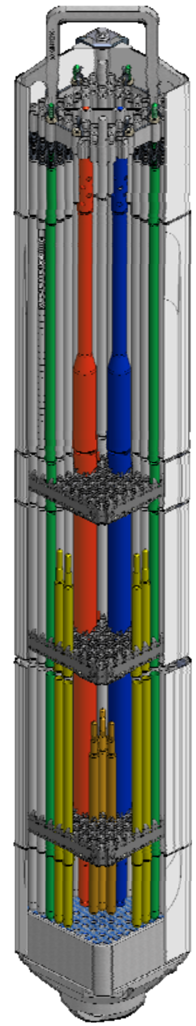
Advanced Nuclear Fuels

Goals:

- Improve the **fundamental scientific understanding** and **prediction** of the behavior of nuclear fuel pellets, cladding, and the fuel-coolant system under extended burn-ups for normal and transient conditions
- In **public-private** collaborations apply this information developing and demonstrating very advanced fuels with **improved safety margins**, and potential for **higher fuel** burn-ups and **performance**
- Develop **predictive** tools for advanced nuclear fuel performance
- **Speed implementation** of new fuel technologies to industrial application

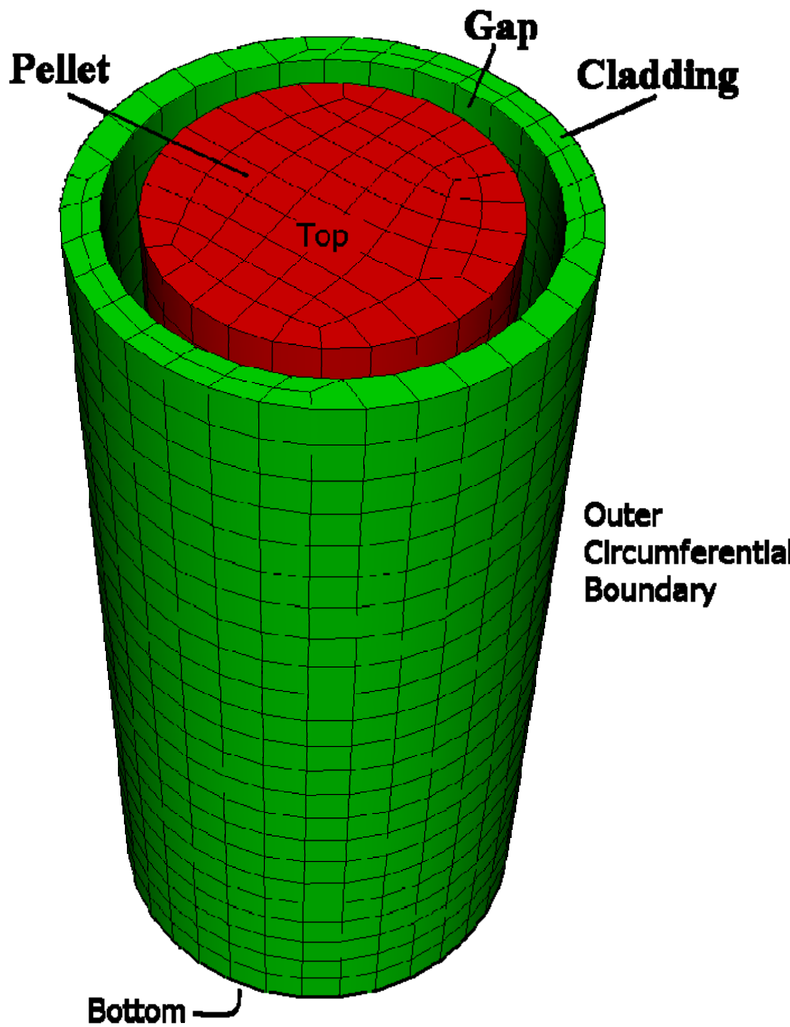
Specific planned activities:

- Begin the development of new long-life fuel designs with **advanced fuel** and **cladding** materials
- Develop **predictive tools** of advanced nuclear fuel performance
- Develop a **model for fuel cracking** at the mesoscale level with sufficient understanding to develop a predictive model for fission gas release



Advanced Fuel Designs & R&D Concepts

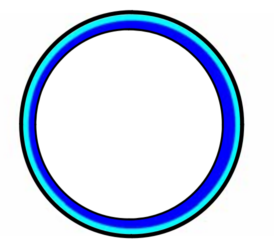
- Advanced fuels
  - UOX variants (additive fuels, >5% U-235, enriched gadolinium)
  - Alternate fuels (UN, UC, hydride)
  - Novel designs (annular fuel, innovative shapes, liquid metal bond)
  - Dopants for PCI, thermal conductivity
- Advanced Cladding
  - optimized next generation zirconium alloys
  - SiC
- Modeling and Simulation
  - Address fuel performance issues through basic scientific understanding
  - Accelerate design to implementation



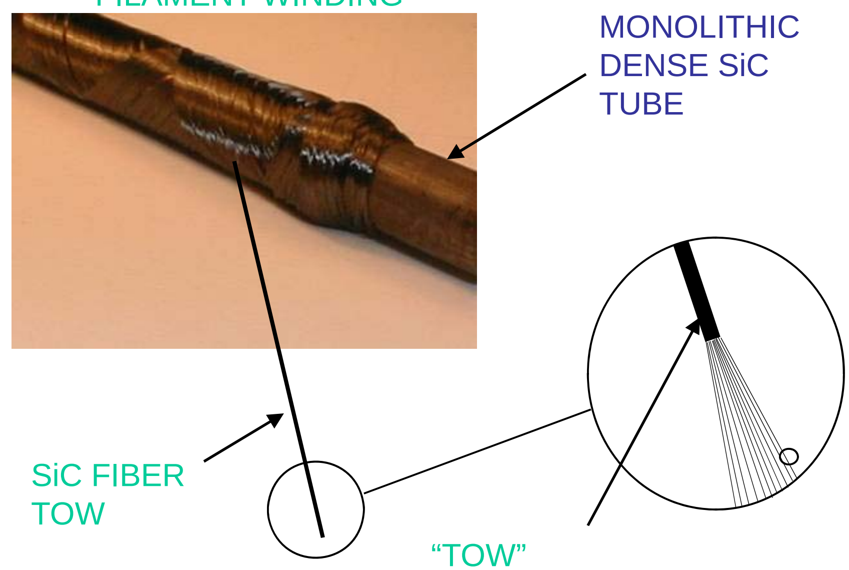
SiC Cladding Development

- Develop high performance, high burnup nuclear fuels with improved safety, clad integrity, and fuel cycle economics
- Design, develop and test a multilayered SiC clad fuel that significantly increases fuel performance. Key characteristics include:
  - strength retention to at least 1500°C, appears to be DNB proof, and therefore can facilitate power uprates of 30% or more.
  - minimal exothermic water reaction or H_2 release during LOCA's,
  - fully retains fission gases – no creep and FG retention to at least 5000 psi
  - composite layer solves ceramic "brittleness" problem
  - Can operate in LWR coolant for over 10 years with no appreciable corrosion
    - Zirc alloys embrittle after 5 years operation and are therefore limited by regulation to 62 gwd/t
  - When coupled with increased U235 loading, can double the burnup to 100 gwd/t
  - Very hard, resists fretting and debris failure, further reduction in operational failures

SiC TRIPLEX CLADDING



FILAMENT WINDING



Efficiency Improvement IP Schedule

	Phase I	Phase II	Phase III
Alternative Cooling Technology	Preserve once-through technology	Cost reduction and efficiency improvement for dry and hybrid cooling technology	Application of advanced cooling technologies
	Development of water conservation technology for wet cooling tower		
Non-electirc Applications	Technology and economics viability	Interface design	Applications
Power Uprate	Collaborate with other pathways to enable 10 GWe extra capacity addition through power uprates, with a stretch goal of 20 GWe		

09-GA50277-05f

Planned FY 2011 Program Accomplishments (1/2)

- ***Address high-fluence neutron irradiation effects on reactor metals, including the reactor pressure vessels and core internals (stainless steels and high strength alloys), radiation-induced swelling effects, and phase transformation of core internals***
- ***Evaluate long-term aging of concrete structures***
- ***Investigate crack initiation in nickel-based alloys (steam generator tubing)***
- ***Examine advanced mitigation techniques such as welding and weld repair techniques, post-irradiation annealing and modern replacement alloys***
- ***Develop a risk-informed simulation-driven methodology to guide safety system analysis and uncertainty quantification***
- ***Enhance the deterministic safety analysis capability to simulate plant dynamics and compute safety margin***

Planned FY 2011 Program Accomplishments (2/2)

- ***Incorporate passive structures, systems and components into a probabilistic safety analysis at one plant type***
- ***Develop alternative and new cooling technologies that can be applied (near term) to reactors impacted by inadequate cooling water supplies and innovative technologies to lessen environmental impacts from removing large volumes of cooling water from naturally occurring sources***
- ***Develop plant control and monitoring systems to improve plant efficiency, facilitate power up-rates, and enable remote monitoring and support***
- ***Develop a model for fuel cracking at the mesoscale level with sufficient understanding to develop a predictive model for fission gas release***
- ***Begin the development of new long-life fuel designs with advanced fuel and cladding materials***

Risk-Informed Safety Margin Characterization

Risk-informed safety margin characterization research is focused on developing methodologies for assessing safety margins in a way that supports plant decision-making regarding sustainability: what the key margins are that affect the sustainability decisions (including refurbishment investments), which margins are reducing due to uncertainty about SSC status, which ones are degrading, and so on. This places very stringent demands on analysis capability, and also promises to help prioritize plant modifications. Key university research needs are related to the development of improved approaches for modeling plant behavior, and better understanding of the response of plant structures and components to aging and to loads imposed by operational transients. R&D should address the Risk-Informed Safety Margin Characterization (RISMC) methodology.

NEUP Workscope Descriptions (2/7)

Risk-Informed Safety Margin Characterization (continued)

Areas of high priority include advanced modeling and simulation methods to support the development, verification, and validation of next-generation system safety codes that enable the nuclear power industry to perform analysis of a nuclear power plant's transients and accidents. An especially important need in this analysis is a very clear understanding of the real uncertainties in the analysis. This requires not just propagation of parameter uncertainty via sampling techniques, but also meaningful quantification of the underlying distributions, addressing not only epistemic uncertainty but also variability in phenomena, including variability in component behavior (variability in stroke times, pump head curves, heat transfer coefficients, and so on). Universities performing this research will be expected to produce results that integrate multiple mechanistic processes.

NEUP Workscope Descriptions (3/7)

Economics and Efficiency Improvement

Economics and Efficiency Improvement research is focused on (1) developing methodologies and scientific basis to enable more extended power uprates or even ultra high power uprates; (2) improving the thermal efficiency by developing advanced cooling technologies to minimize the water usage; and (3) studying the feasibility of expanding the current fleet into non-electric applications.

NEUP Workscope Descriptions (4/7)

Nuclear Materials Aging and Degradation

Nuclear materials aging and degradation research develops the scientific basis for understanding and predicting long-term environmental degradation behavior and performance of materials in nuclear power plants. Key university research needs in this area include developing advanced mitigation strategies and techniques. Advanced mitigation strategies and techniques. Extended operating periods may reduce operating limits and safety margins of key components and systems. While component replacement is one option to overcome materials degradation, other methods (e.g. thermal annealing or water chemistry modification) may also be developed and utilized to ensure safe, long-term operation. Validation and/or development of techniques to reduce, mitigate, or overcome materials degradation of key LWR components are sought. Mitigation strategies for pressure vessel steels, core internals, weldments, or concrete are encouraged. Universities engaging in this effort will be expected to produce concepts, supporting data and/or model predictions demonstrating the viability of mitigation strategies for key LWR components.

Advanced I&C/Information Systems Technologies

Advanced Instrumentation, Information, and Control Systems Technologies research is focused on addressing long-term aging and obsolescence of instrumentation and control technologies, development and testing of new information and control technologies. Addressing long term issues for advanced instrumentation, information, and control (II&C) system technologies, development of technical bases and practices for ensuring their safety, and establishment of a strategy to implement long-term modernization of II&C systems. Development of advanced condition monitoring technologies for more automated and reliable plant operation, and improved understanding of physical methods of degradation and the means to detect and characterize them.

Advanced I&C/Information Systems Technologies (cont)

Key university research needs are identified as the development of digital instrumentation and control technologies for improved monitoring and reliability. Digital instrumentation and control technologies for highly integrated control and display, improved monitoring and reliability. Research is needed to improve upon available methods for online monitoring of active and passive components to reduce demands for unnecessary surveillance, testing, and inspection and to minimize forced outages and to provide monitoring of physical performance of critical SSCs. In addition, methods are needed to analyze the reliability of integrated hardware/software technologies that comprise digital systems.

NEUP Workscope Descriptions (7/7)

Advanced I&C/Information Systems Technologies (cont)

Research should investigate NDE technologies to characterize the performance of physical systems in order to monitor and manage the effects of aging on SSCs. High priority research areas include the following: 1) methods and technologies that can be deployed for monitoring nuclear plant systems, structures, and components, and that can be demonstrated in test bed environments representative of nuclear plant applications; and 2) methods for analyzing the dynamic reliability of digital systems, including hardware and software systems based on formal methods that can be demonstrated on systems that are proposed or representative of systems proposed for nuclear plant control and automation. This research is expected to support the development of methods and technologies to support digital instrumentation and control integration for monitoring and control as well as for noting areas of improved reliability and areas requiring further information and research. Universities performing this research will be expected to produce results that integrate multiple mechanistic processes.

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