Advanced Test Reactor NSUF Program Update

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TRTR-IGORR Joint Meeting
September 2010

Idaho National Laboratory

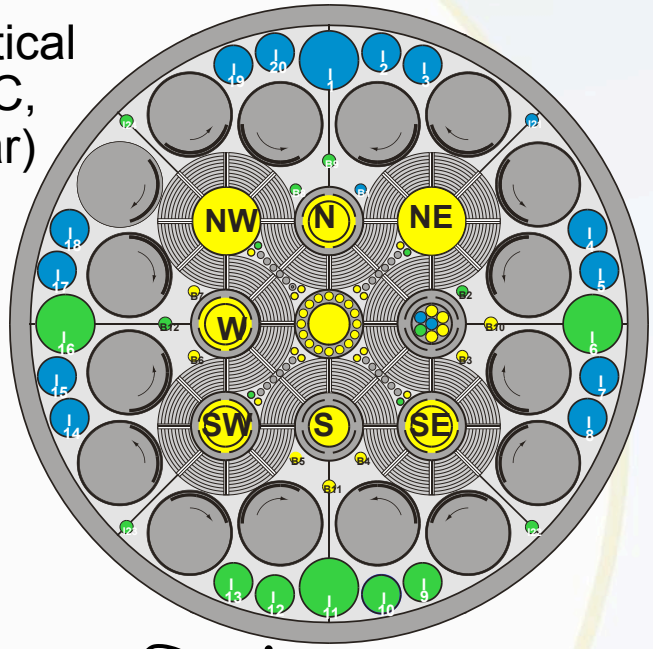
ATR
National Scientific User Facility

What is the ATR NSUF?

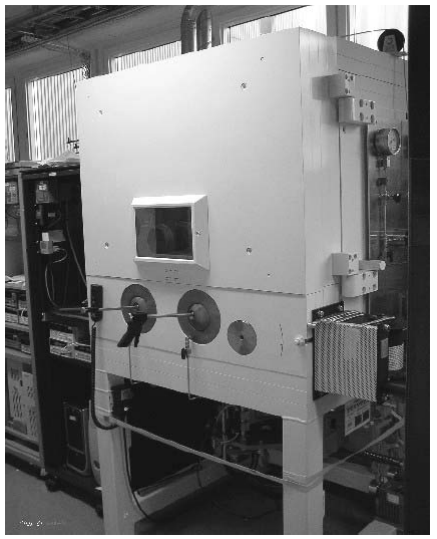
ATR National Scientific User Facility

A means to provide the research community access to national capability to conduct cutting edge nuclear technology research and development

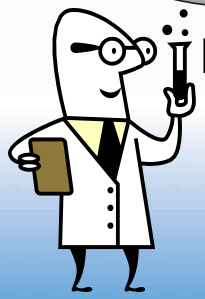
Test Reactors and Critical Facilities (ATR, ATRC, NRAD, MITR, Pulstar)



Examination Facilities (INL MFC, UNLV, NCSU, Michigan, Wisconsin)



Other National User Facilities (APS, SHaRE)



Ideas from Smart People

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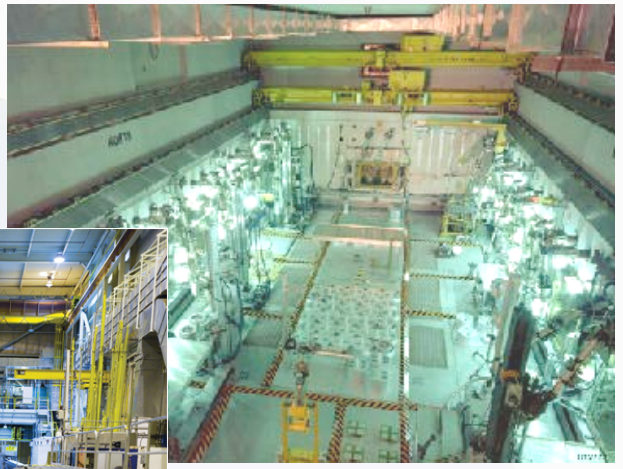
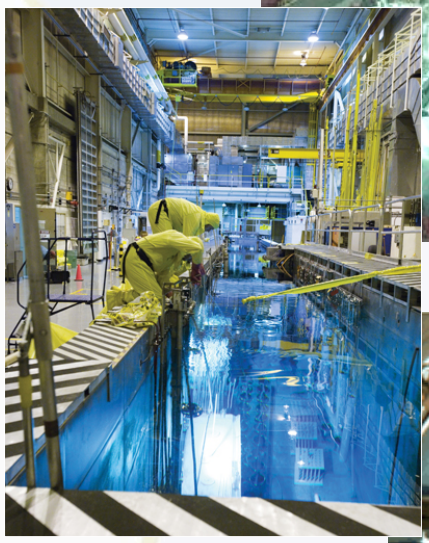
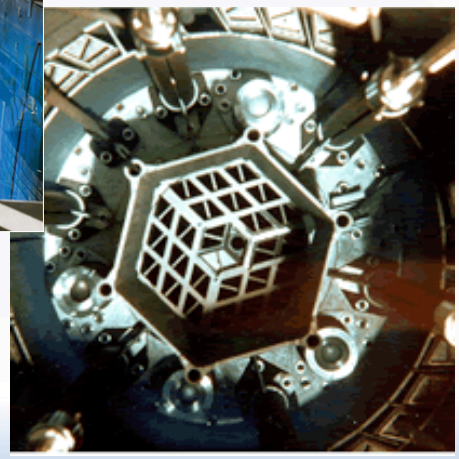
What's New in the ATR NSUF?

- Experiment Solicitation Changes
- ATR Capability Enhancements
  - Reactivation of Loop 2A
  - Hydraulic Shuttle Irradiation System (HSIS)
  - Test Train Assembly Facility
  - Dry Transfer Cubicle
  - Boiling Water Reactor Loop
  - Software and Modeling Upgrades
- Instrumentation Development
- Post-irradiation Examination Capability Additions
- Education Programs
- Partner Facilities





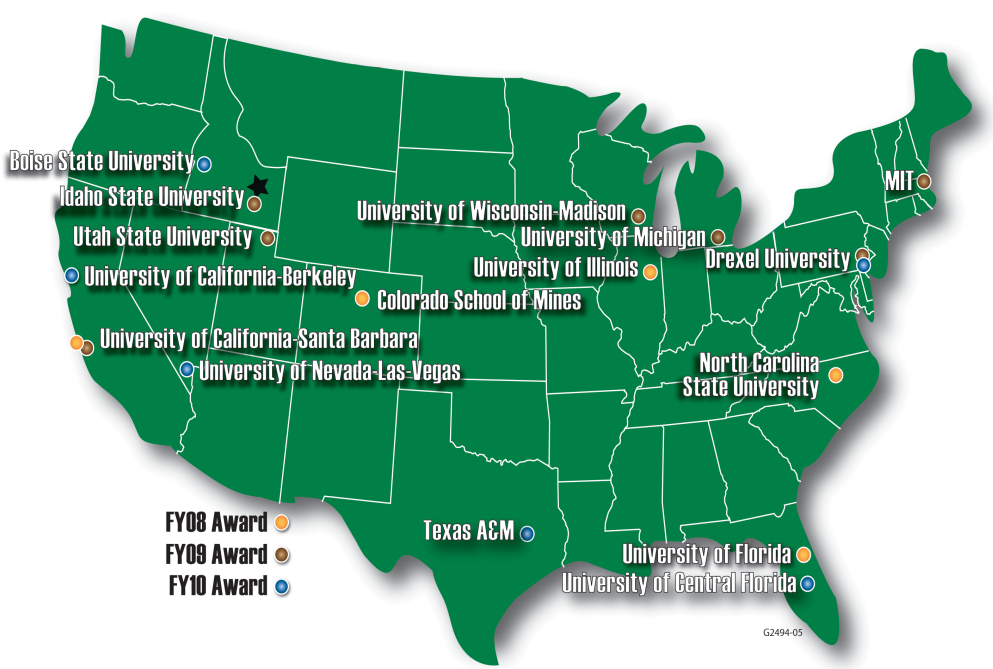


Experiment Offerings

- Irradiation Experiments, at ATR or Partner Facilities
- PIE-only, at INL or Partner Facilities
- Use of INL Pre-Irradiation Sample Library
- ATR Critical Facility, for Model Validation or Instrument Testing
- Rapid Turnaround Experiment
  - At partner facilities
  - Can be completed in < 2 months, and funding limited
- New User Experiment - Expand knowledge base of university PIs and proposers
  - Collaboration between multiple universities and INL for single experiment
  - Several research topics identified by INL Director
    - Irradiation Assisted Stress Corrosion Cracking (IASCC)
    - Radiation Resistant Alloys
    - Radiation Resistant Ceramics
  - Simple static capsule configuration

Experiment Awards

- Proposal Process Initiated in 2008, Web-based
  - Annual or Semi-annual solicitation (proposals accepted any time)
  - University led
  - Peer review
  - Program relevance review by DOE-NE
  - Open call – accepting proposals any time
- First Irradiation Project Initiated PIE in 2010
- First Partner Facility Project initiated in 2009
- RTE and New User Experiment Initiated in 2010



University Experiments

Seventy-five project proposals submitted as part of the first five solicitations, 27 projects

Projects Performed at INL

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Institution	Objective	Status
Wisconsin	Material properties for several structural materials for Generation IV reactor development	In ATR, PIE
UCSB	Development of a library of irradiated alloys to address various questions about the characteristics of irradiation materials	In ATR, PIE
NCSU	Study of neutron irradiation effects on nanostructured metals and alloys, nanograined metals and oxide-disperson strengthened alloys	PIE Initiated
Illinois	Assessment of radiation performance of FeCr alloys to establish the basis for materials and materials modeling development. Additional HSIS experiment planned	In ATR, PIE
Florida	Investigation of irradiation effects of spinel composites as inert matrix materials and characterization of the microstructure of the materials	PIE Initiated
UCSB	Assessment of high fluence embrittlement of RPV steels	In Design
Utah St.	Investigation of thermophysical properties of Hf_3Al-Al composite	In Design
Idaho St.	Study of fission detectors (collaboration with CEA) utilizing ATR-C	Testing in ATRC
Drexel	Assessment of structural ceramic damage tolerance. Additional HSIS experiment planned	In Design
Idaho St.	Measurement of actinide neutronic transmutation rates, accelerator mass spectroscopy, with ANL	In Design
UNLV	Neutron modeling code development, validation tests in ATR-C	In Design
Boise State	High temperature nuclear fuel testing on uranium silicide (U3Si2)with collaborators from Westinghouse and the University of Wisconsin	Initiated
Central FL	Analysis of new metallic fuels under development , to include modeling of the fuel performance, in collaboration with Ga Tech, INL, ANL, OSU	Initiated
Texas A&M	Irradiation Behavior and Performance of a Uranium-Zirconium Metal Alloy Fuel, w/ Lightbridge Corp.	Initiated
Michigan	PIE only. Radiation-induced Segregation/Depletion at Grain Boundaries in Neutron Irradiated 304SS at Low Dose Rates, using hex blocks irradiated in the INL EBR-II fast reactor, w/ TechSource, Inc. , INL	Initiated
Drexel	PIE only. Use of the ATR Pre-Irradiated Sample Library to perform a multi-scale analysis on effect of specific grain boundary character distributions on mechanical behavior of steel alloys in LWRs	Initiated

Partner Facility Projects

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Institution	Objective	Status
CSM	Use of silicon doping techniques to develop non-destructive aging assessment technology	MIT - Completed
MIT	Behavior of triplex SiC/Sic tubing at PWR conditions	MIT
Wisconsin	PIE only - Analysis of TEM samples of irradiated ZrC, ZrN, TiC, TiN	Wisconsin
UCB	Investigation of feasibility of incorporation of hydride fuels in LWRs	MIT - November
ANL	Analysis of irradiated HT9	APS – Completed
IIT	Analysis of Samples of irradiated ZrC, ZrN, TiC, TiN	APS – Completed
INL	Measurements of spatially resolved strain fields in nuclear fuel plates	APS – Completed
LANL	Investigation of the thermodynamics of plutonium/iron solubility in brines	APS – Completed
ORNL	Developing a Mechanistic Understanding of Radiation Tolerant Materials	Michigan, November
Wisconsin	Microstructural and Irradiation Effects on Ag and Cs Diffusion in DVC-SiC	Michigan – Completed
INL	Radiation Effects on Ceramic Coating of Advanced Cladding for Fast Reactors	Michigan - Completed

Hydraulic Shuttle Irradiation System

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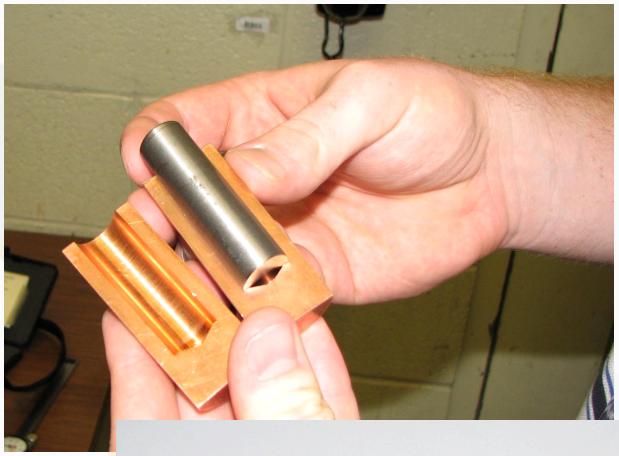
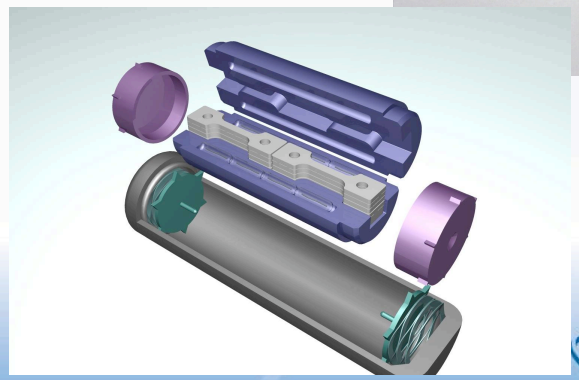
- 14 shuttle capsules
- In the ATR B-7 Position
- Flux, at 110 MW:
  - Thermal: 2.5E14 n/cm^2-s
  - Fast (>1MeV): 8.1E13 n/cm^2-s
- ~35 gm contents per capsule
- Drexel University
  - MAX ceramic alloys
  - Tensile, TEM, resistivity
- University of Illinois
  - Fe-Cr alloy
  - Tensile specimens





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Test Train Assembly Facility

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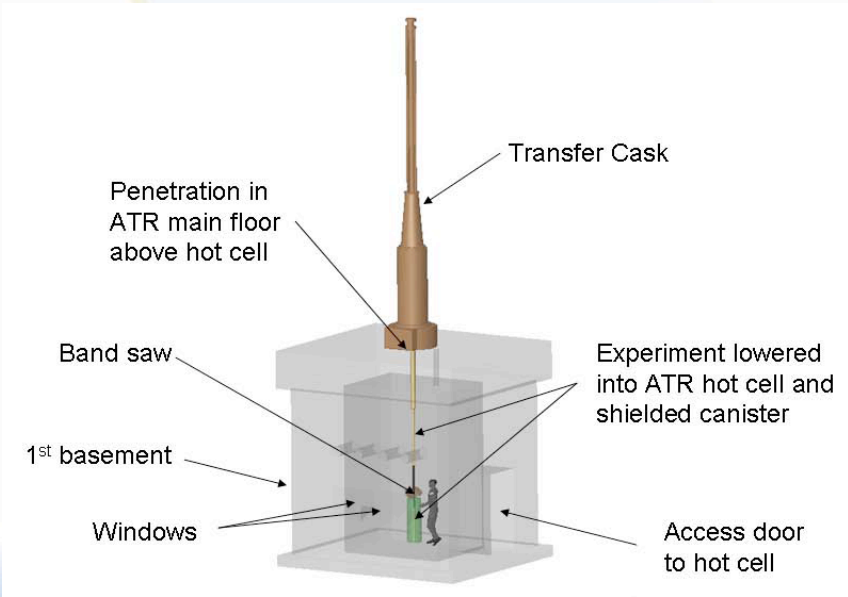
- New Facility Operational in 2009
- Initial Test Assembly in 2010 (AGR-2)
  - 2 Instrumented lead experiments planned in 2011
  - 3 Planned in 2012
- New Staff Hired in 2010, Additional Staff in 2011
- Initiated Change to Safety Basis to Increase Fissile Loading

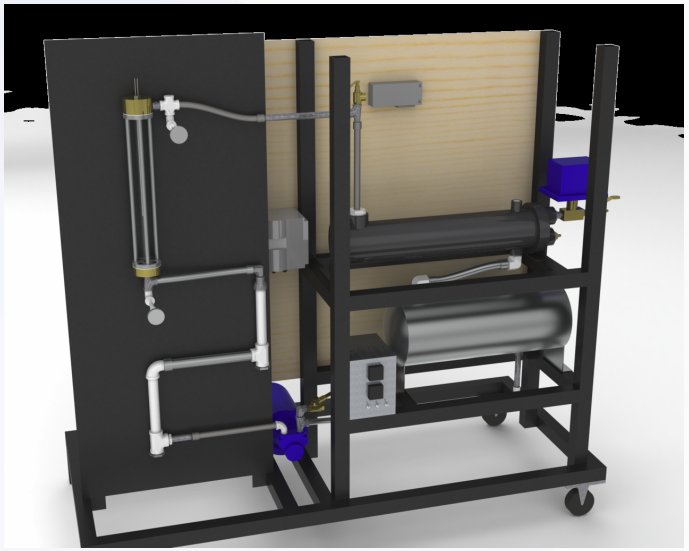
Dry Transfer Cubicle

- Instrumented Lead Experiments Require Re-Sizing Prior to Shipment
- New Capability to Dry Load – refurbished existing hot cell in ATR building
  - Completed in 2009
  - Successfully re-sized and loaded TMIST-1 and AGR-1 experiments



Boiling Water Reactor Loop

- Requested by Industry to Enable BWR Investigations, Voiding is Key
- Initial Investigation Indicates Feasibility
- Recent Design Efforts by University of Idaho (UI) Students
  - Initial test loop system design concept in 2009
  - Fabrication completed in 2010
  - Operation expected in 2010
- Next Steps
  - Scale-up to prototype, and test with fuel
  - ATR Safety Analysis for boiling in loop
  - Increased need by industry groups or partners



ATR Analysis and Modeling Upgrades

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- Seeking Increased Accuracy and Flexibility in ATR Core and Experiment Modeling
- Initiated in FY 2009 to Develop New ATR Analytical Tools
  - Develop 3D models with existing codes - Helios, Attilla, SCALE/ NEWT, MCNP
  - Validation against ATRC, ATR experiments, and ATR fuel
  - Identification of ATR in-core instrument needs
- 2010 Key Activities
  - Helios fuel depletions for 4 ATR cycles
  - ATRC tests- establish measurement instruments, test configuration
  - In-canal instruments for fuel burnup measurements, good correlation
- Future Plans – Planned completion in 2014
  - Continued Helios fuel depletions in 2011, in parallel with PDQ
  - Additional testing in ATRC – develop ATRC test criteria vs. analysis
  - Focus on integration and standardization with established industry codes

Real-time Measurements Needed to Understand Observed Irradiation Phenomena

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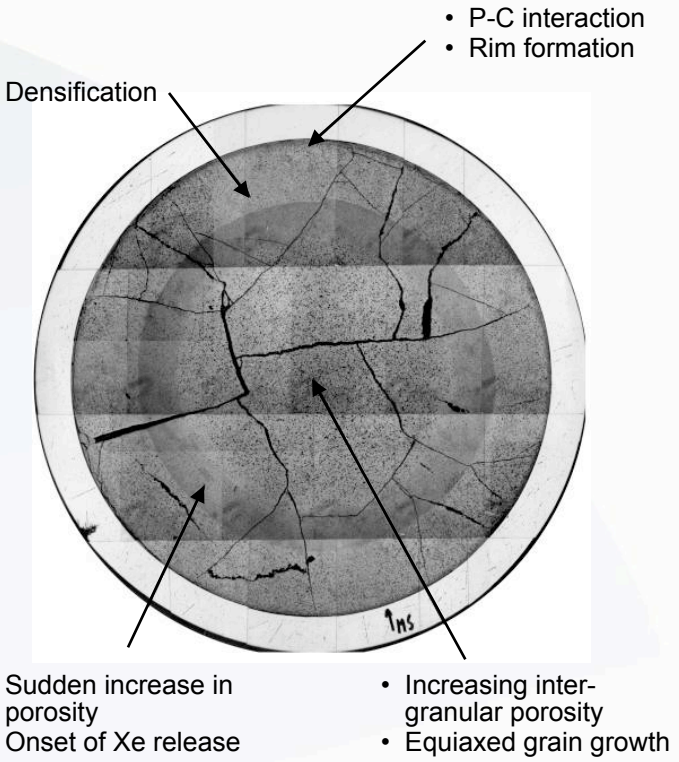
- Interrelated phenomena observed during fuel and materials irradiation
  - Cracking
  - Corrosion
  - Creep
  - Swelling
  - Densification
  - Rim formation
  - Fission gas release
  - Crud deposition
  - Pellet-Cladding Interactions
- Real-time measurements needed to understand and predict phenomena
  - Pressure
  - Temperature
  - Thermal conductivity
  - Diameter and length changes
  - Thermal and fast flux
  - Crack growth



Data needed to support FC R&D, NGNP, ATR NSUF, and LWRS programs

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Several Instrumentation Enhancements Available for Various ATR Test Locations

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Requirements for In-pile Instruments

- Reliable
- Accurate
- Miniature
- High temperature resistant
- Corrosion resistant
- Neutron / gamma 'resistant'
- Non-intrusive
- "Low" cost

Parameter	Parameter			ATR Technology	Proposed Advanced Technology	
	Static Capsule	Instr. Lead	PWR Loop		Available at Other Reactors	Developmental
Temperature	√	√	√	• Melt wires (single) • Paint spots (single) • SiC Temperature Monitors (range)		• Wireless (range) • Ultrasonic thermometers
		√	√	• Thermocouples (Type N, K, C, and HTIR-TCs)[a]		• Fiber Optics
Thermal Conductivity		√	√	• Out-of-pile examinations	• Degradation using signal changes in thermocouples	• Hot wire techniques
Fluence (neutron)	√	√	√	• Flux wires (Fe, Ni, Nb)	• Activating foil dosimeters	
		√	√		• Self-Powered Neutron Detectors (SPNDs) • Miniature fission chambers	• Moveable SPNDs
Gamma Heating		√	√		• Degradation using signal changes in thermocouples	
Dimensional	√	√	√	• Out-of-pile examinations		
		√	√		• LVDTs (stressed and unstressed) • Diameter gauge	• Ultrasonic Transducers • Fiber Optics
Fission Gas (Amount, Composition)		√	√	• Gas Chromatography • Pressure sensors • Gamma detectors • Sampling	• LVDT-based pressure gauge	• Acoustic measurements with high-frequency echography
Loop Pressure			√	• Differential pressure transmitters • Pressure gauges with impulse lines		
Loop Flowrate			√	• Flow venturis • Orifice plates		
Loop Water Chemistry			√	• Off-line sampling /analysis		
Crud Deposition			√	• Out-of-pile examinations	• Diameter gauge with neutron detectors and thermocouples	
Crack Growth Rate			√		• Direct Current Potential Drop Technique	

[a]Type C thermocouple use requires a "correction factor " to correct for decalibration during irradiation.

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ISU/CEA/INL Project Investigating Use of Real-time In-core Flux Detectors in ATRC

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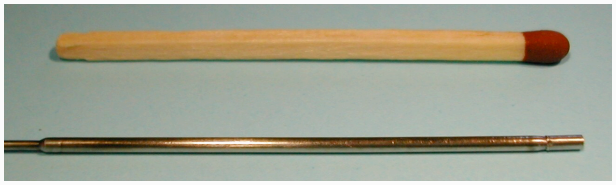
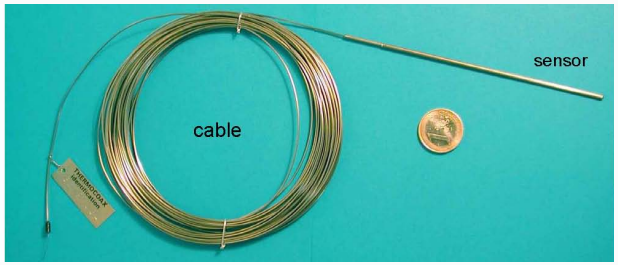


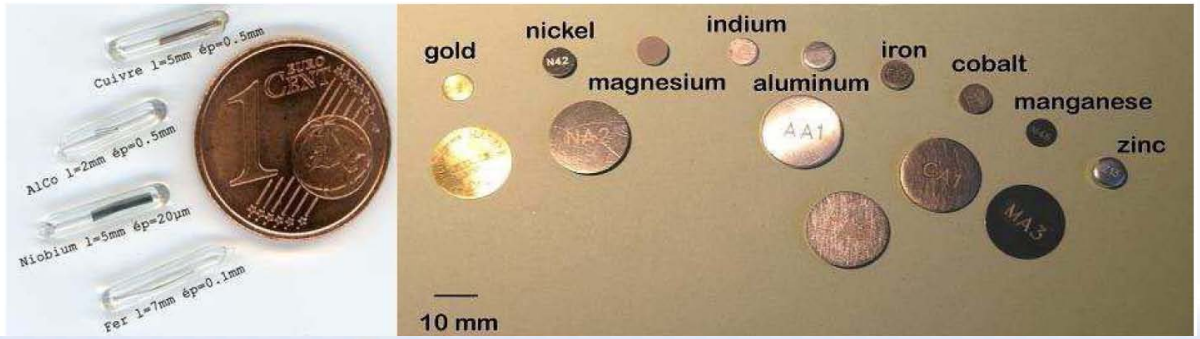
CEA fission chambers



SPNDs

BTB fission chambers

- Fast and thermal flux measurements obtained from foils, wires, SPNDs, and fission chambers
- Sensors cross-compared for response time, accuracy, and longevity.
- Data ultimately will allow development of real-time 3D ATRC core map



Flux wires and foils

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FY 2010: New PIE Capabilities

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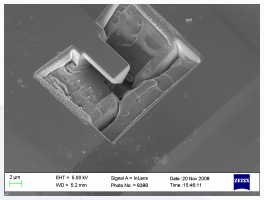
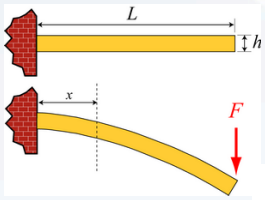
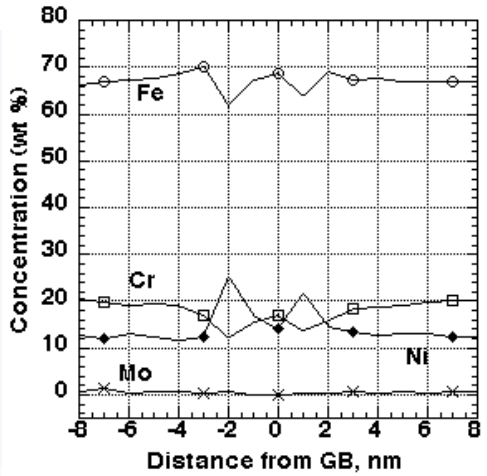
- **Mechanical properties**
  - Nanoindenter
  - Small sample mechanical testing
  - Automated micro-hardness tester
- **Analysis at micro- and nano-scale**
  - Chemical and structural analysis at the nano-scale
  - Atom Probe-identify single atoms
  - Spectroscopy-light scattering to understand atomic structure
  - SEM hot stage-real time analysis of changes in structure due to temperature
- **Sample Preparation**
  - Dual-beam FIB #2
  - Metallography Containment Upgrade
- **Fuel Examination**
  - Fuel Exam Machine optimization study

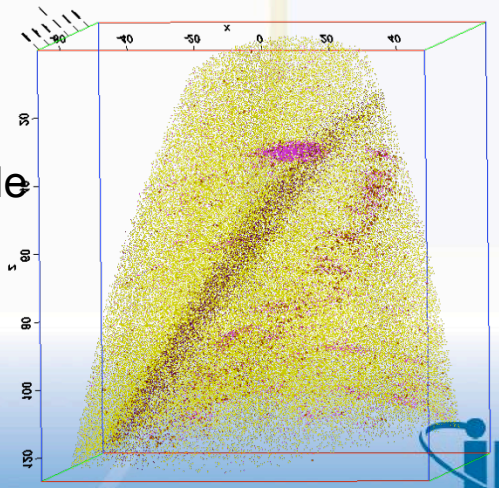




Nano-indenter, in combination with the FIB, can perform mechanical analysis on the nanometer scale

FEG-STEM can perform chemical analysis on the nanometer scale





Atom Probe maps material composition atom-by-atom in 3D

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Shielded Dual Beam Focused Ion Beam

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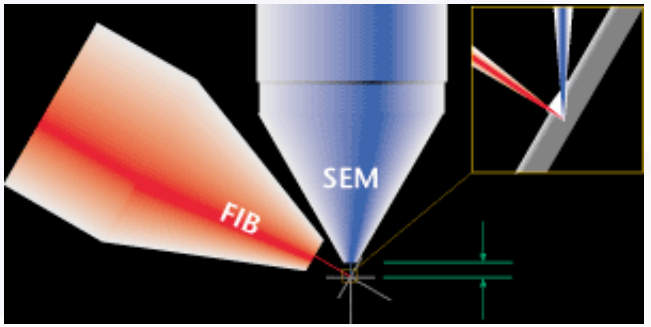
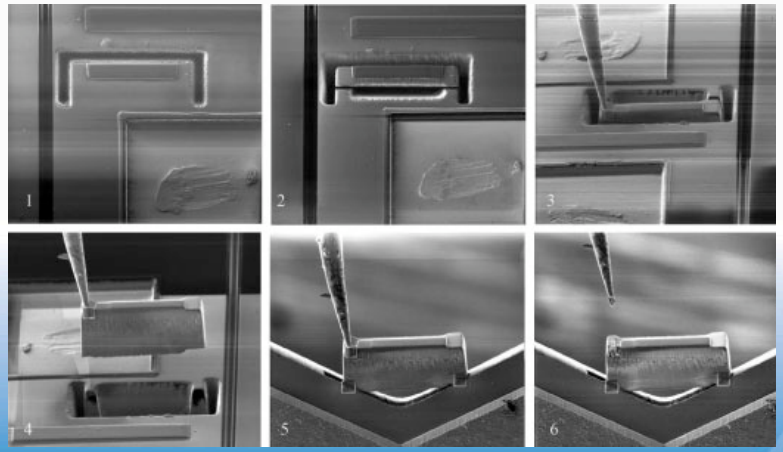
- Investigation of damage that occurs at the submicron level in irradiated fuels and materials. Prepare small volume samples of highly activated materials for subsequent examination in the Electron Microscopy Laboratory.
- Electron and ion imaging
- Site-specific microsectioning for TEM membrane preparation
- Imaging resolution: <3 nm
- 3D image and chemical reconstruction of submicron features



Two columns for simultaneous imaging and microscale milling and sectioning



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Center for Advanced Energy Studies (CAES)

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- Collaboration between INL and Idaho Universities
- Facility owned by State of Idaho
- NRC Licensed
- Imaging Laboratory will house high-end equipment for use with lower activity samples
- Atom Probe, FIB, SEM, TEM, nano-indenter
- Small sample mechanical testing
- Material quantity limits sufficient for atom probe and TEM on fuel
- Outside the INL firewall, easier remote access

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Irradiated Material Characterization Laboratory

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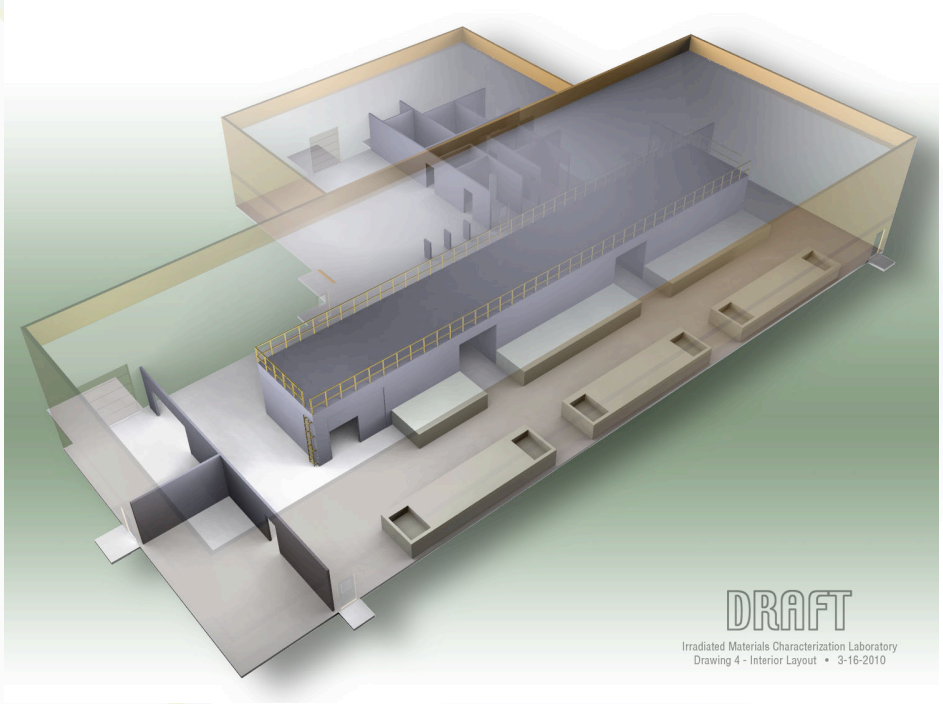
- Consolidates new post-irradiation analytical capability
  - Shielded enclosures for handling multiple irradiated fuel samples
  - Inert gloveboxes within enclosures and interfaced with instruments for contamination control
  - Enables transfer between instruments
  - Instruments can be serviced when radioactive material is removed
  - EPMA, FIB, FEG-STEM, μ-XRD, thermal analysis, mechanical testing, sample prep
- Current status
  - Currently in conceptual design
  - Ground breaking in 2011
  - Occupancy in 2012



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ATR NSUF Partnerships

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- ATR NSUF aims to meet customer needs
- ATR NSUF will include additional capability that benefits users
  - University research reactors
  - Hot cells or hot laboratories
  - Accelerator facilities
  - Analytical capability
- Process
  - Potential university or laboratory partners self-nominate
  - Expert group evaluates nominations
  - Capabilities added to next proposal solicitation

•Illinois Institute of Technology
• Massachusetts Institute of Technology
•University of Michigan
•North Carolina State University
•University of Nevada at Las Vegas
•University of Wisconsin

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University Education Programs - Goal is to Enhance Nuclear Research Workforce

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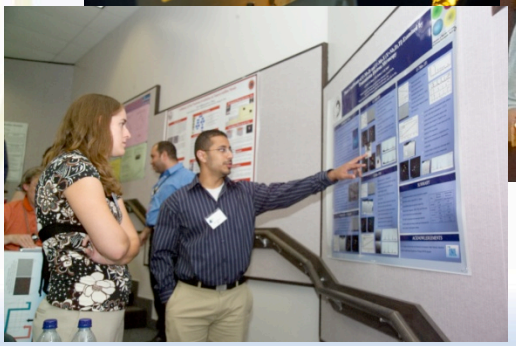
- Annual Users Week (June)
- Workshops at Conferences
  - TMS (The Minerals, Metals & Materials Society)
  - MS&T (Materials Science & Technology Meeting)
  - Environmental Degradation Conference
  - Student ANS Conference
- 23 Summer Internships in 2010
  - ATR experiment design and analysis
  - PIE activities and technique development
  - ATR Operations – for upcoming seniors leading toward full time employment following graduation
- Faculty Student Research Teams
- University Seminar Visits
- IASCC Fundamentals Workshop
- Colloquium Series
- Reactor Testing Textbook
- Post-doc Fellowships
- Sabbatical Appointments



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ATR National Scientific User Facility: Prototyping the Lab of the Future

Focal Point for Innovation — Stewards of the National Nuclear Capability

http://atrnsuf.inl.gov/

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