U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Nuclear Science User Facilities

NSUF Research Highlights 2015

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Idaho National Laboratory

NSUF
Nuclear Science
User Facilities

NSUF Research Highlights

- Irradiation experiments
- PIE
- RTE
- Nuclear data measurement and instrumentation development

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Drexel University
ATR Irradiation Experiment
Prof. Michel Barsoum, Dr. Jian Gan, INL

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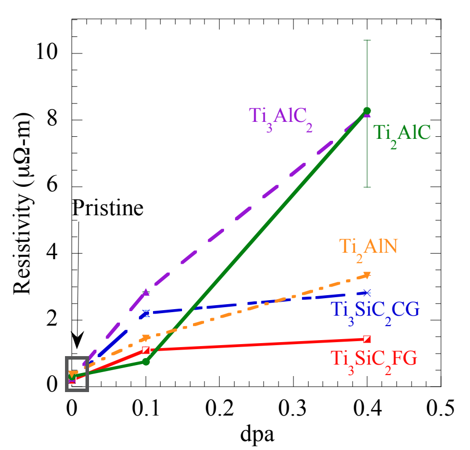
Motivation
MAX ($M_{n+1}AX$ stoichiometry) phase ceramics have properties of a mixture of traditional ceramics and metals (toughness and high temperature strength). The irradiation data for MAX phase ceramics is needed for their application in nuclear reactor systems.

Materials	Temperatures (°C)	Dose (dpa)
Ti_3SiC_2, Ti_3AlC_2, SiC	100, 600 & 1000	0.1, 1.0 & 9.0

Sample retrieval at HFEF showing problems for Capsule-G, 100°C, 1 dpa

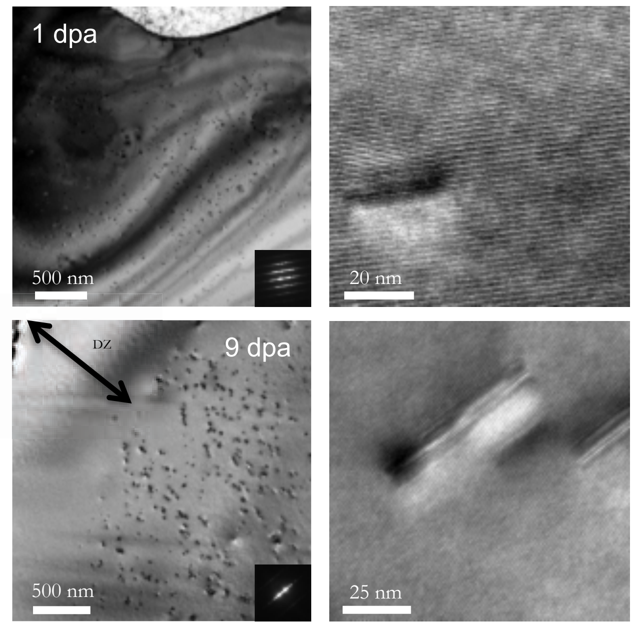
Drexel, Grad Student Darin Tallman

Resistivity as a function of dose. Indication of defect structure build-up.



"Advanced Damage-Tolerant Ceramics: Candidates for Nuclear Structural Applications"

Ti_3SiC_2
500°C



TEM Images of ATR Irradiated MAX

Scientific Impact
MAX phase show better resistance to irradiation damage compared to corresponding MX binary and significant recovery at temperatures as low as 500°C. Insight gained can further development of improved high temperature structural ceramics for reactor applications.

UCSB-1 and UCSB-2 ATR Irradiation Experiments

Prof. G. Robert Odette, Dr. Takuya Yamamoto, Dr. Jim Cole, INL, Dr. Brandon Miller, INL

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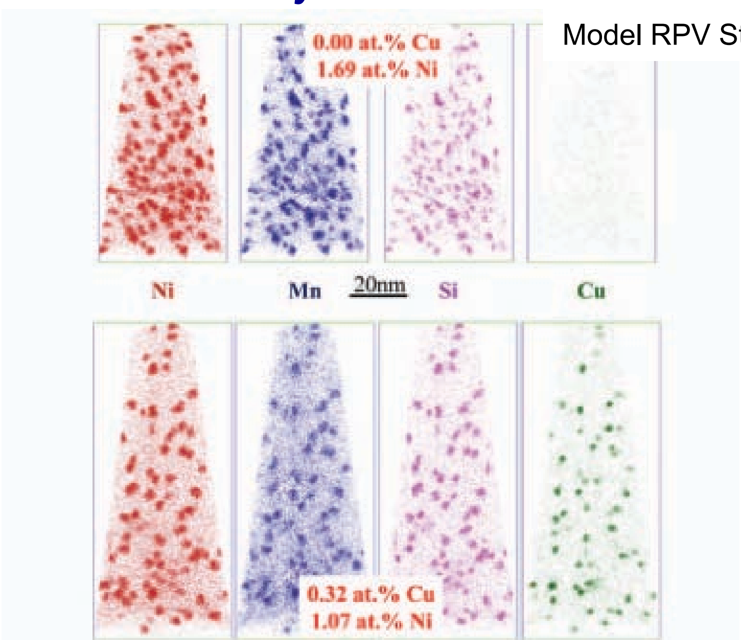
Motivation

Create large library of materials to evaluate scientific issues surrounding radiation-induced degradation in reactor structural materials and evaluate near end-of-life embrittlement behavior in reactor pressure vessel steels

"Characterization of the Microstructures and Mechanical Properties of Advanced Structural Alloys for Radiation Service"

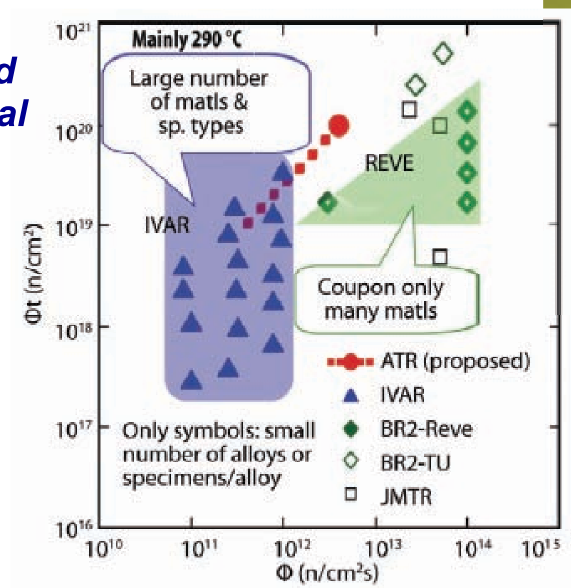


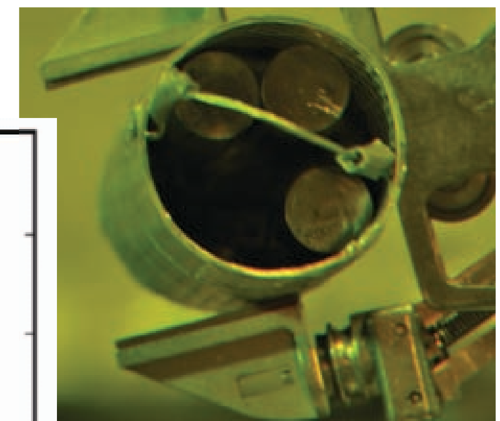
Model RPV Steels

P.B. Wells et al. / Acta Materialia 80 (2014) 205–219

"High Fluence Embrittlement Database and ATR Irradiation Facility for LWR Vessel Life Extension"

Large matrix of RPV steels irradiated in instrumented lead with active temperature control.





Materials being shipped to ORNL to support testing campaign under DOE-NE LWRS program

Scientific Impact

Better understanding of embrittlement mechanisms in this important class of materials across temperature, dose, dose-rate regimes can aid in developing predictive material aging models.

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Utah State University
ATR Irradiation Experiment

Prof. Heng Ban, Dr. Donna Post-Guillen, INL

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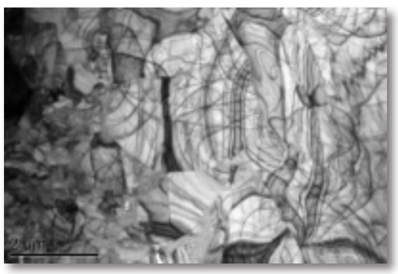
Motivation
Assess irradiation performance of new material developed to enable fast flux materials and fuels testing in ATR. Employs a conduction-cooled neutron absorber made of $HfAl_3$ intermetallic particles distributed in an aluminum matrix

Irradiated, annealed at 550°C for 20 min

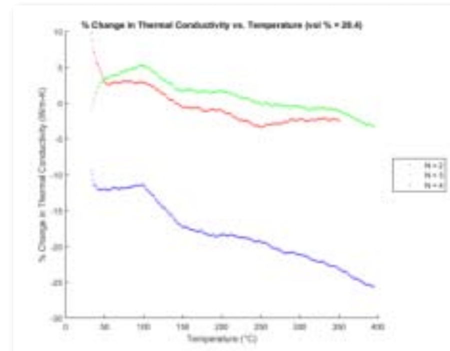


TEM image shows bend contours, indicating strain-release during annealing

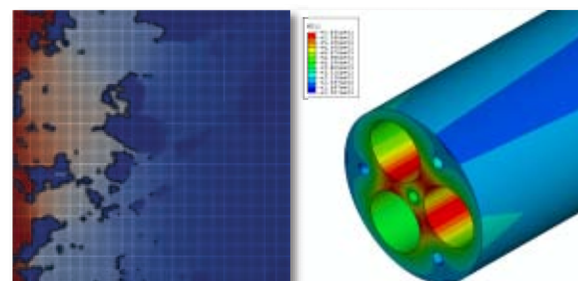
After annealing, nano-sized rectangular-shaped grains formed at the phase boundary between $HfAl_3$ and Al —the grains appear to grow from $HfAl_3$ phase into Al phase

"Irradiation Effect on Thermophysical Properties of $HfAl_3$-Al Composite: A Concept for Fast Neutron Testing at ATR"

Changes in thermal conductivity as a function of temperature



Modeling of heat conduction behavior using Moose



Performance and Stability Under Irradiation

Scientific Impact
Potential to expand options for conducting fast neutron irradiations in thermal spectrum test reactors through the use of neutron filters.

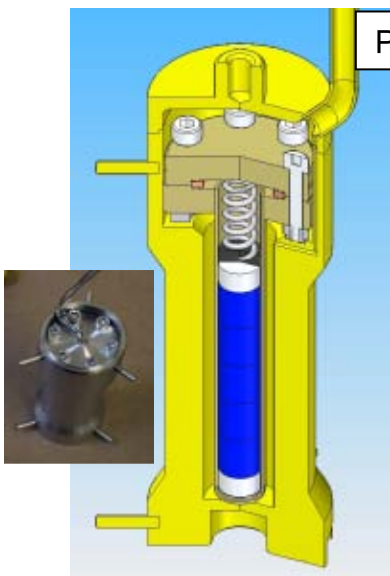
University of California, Berkeley

Prof. Don Olander, Prof. Mehdi Balooch, Dr. Dave Senor, PNNL Dr. Andy Casselas, PNNL

"Hydride LWR Fuel Rod Irradiation"

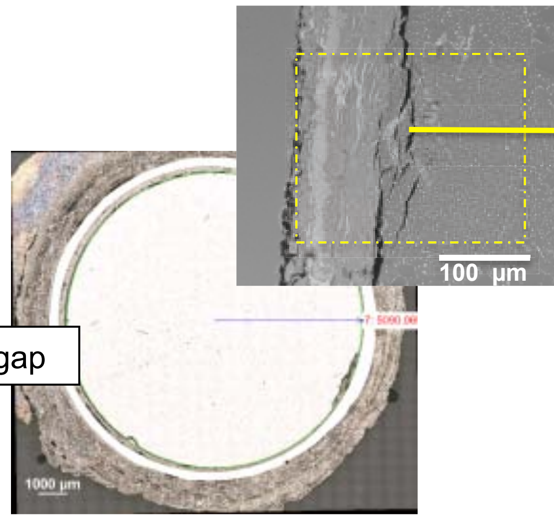
Motivation

Develop experimental U-Zr-Hydride LWR fuel with improved accident tolerance.

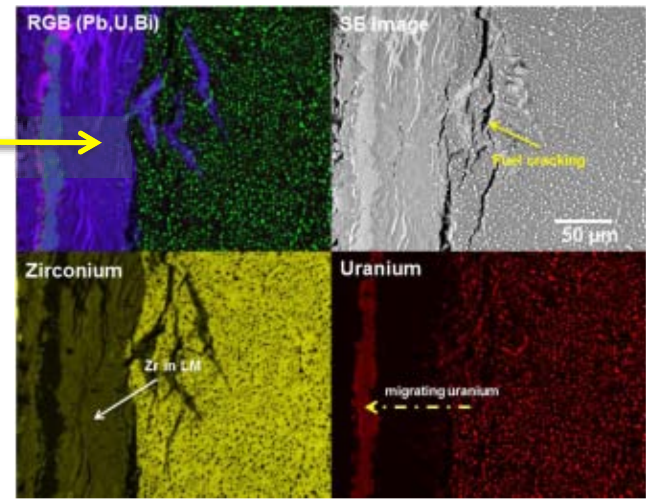


Schematic and image of experimental capsule assembly

Pb-Bi eutectic in gap



SEM cross-section images of polished fuel rodlet



EDS Map of Fuel-Clad Interface

Scientific Impact

Achieve scientific insight into the fission gas behavior of a novel LWR fuel concept and evaluate proof of concept for further development.

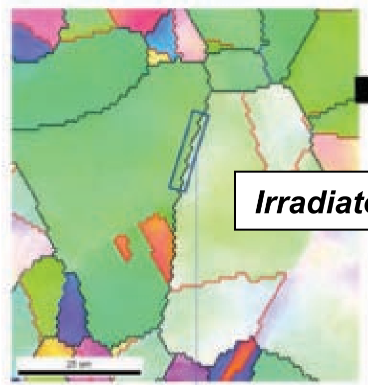
Drexel University
PIE Only and Sample Library
Professor Mitra Taheri, Dr. Jim Cole, INL

"Multi-scale Investigation of the Influence of Grain Boundary Character on RIS and Mechanical Behavior in LWR Steels"

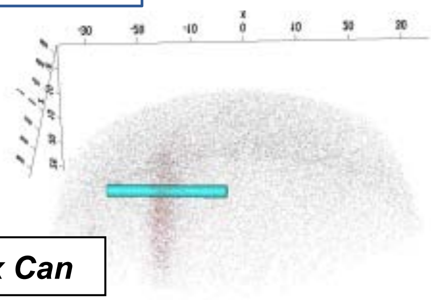
Motivation

To develop new analysis techniques using state-of-the-art tools in CAES and expand the understanding of the relationship between grain boundary orientation and radiation induced segregation in irradiated austenitic stainless steels.

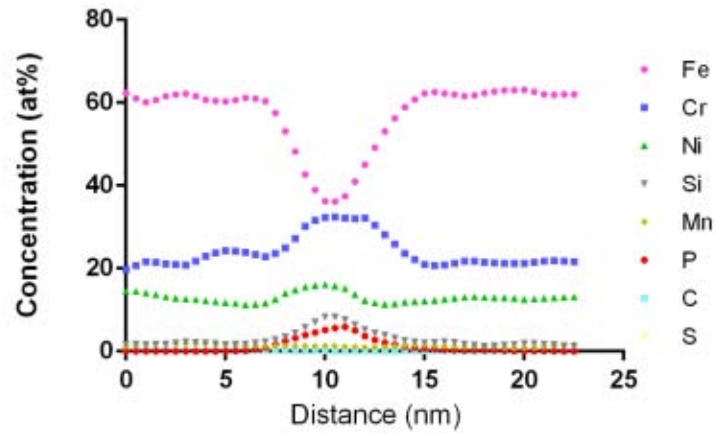
EBSD to select GB



Irradiated EBR II 316 SS Hex Can

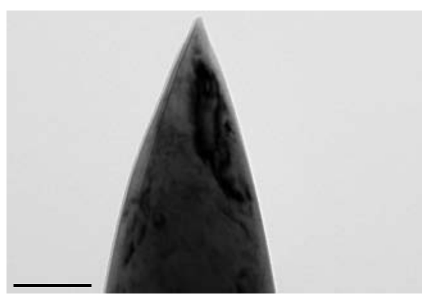


P (red) and Si (gray) ions only



Radiation Induced Segregation

TEM image of APT tip



Scientific Impact

The impact is to increase our fundamental understanding of radiation damage behavior in a widely used reactor structural material and develop a new analysis technique that can contribute to validation of computer codes created to model in-reactor materials degradation.

Grad Student Chris Barr, Drexel University

INL – MFC and CAES RTE
Dr. Assel Aitkaliyeva

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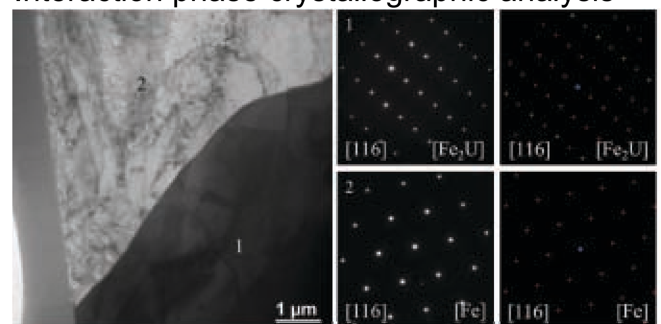
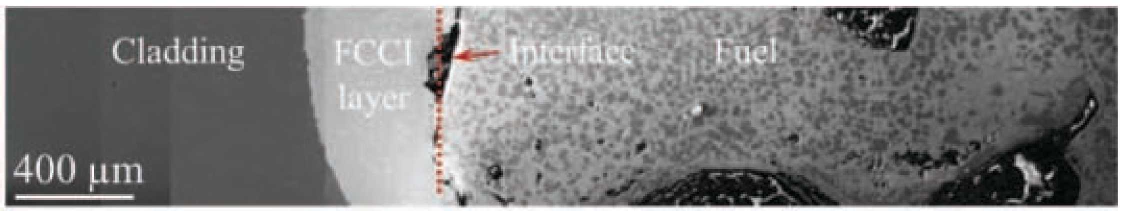
Motivation
Understanding interaction behavior between Fe-based cladding alloys and metallic nuclear fuel is critical to achieving the high burn-up levels desired for fast reactor transmutation applications being developed in the FCRD program.

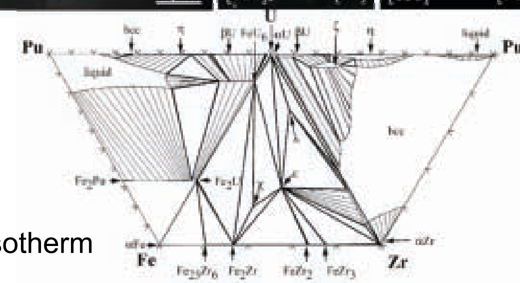
"TEM examination of phases formed between U-Pu-Zr fuels and Fe"

Interaction phase crystallographic analysis

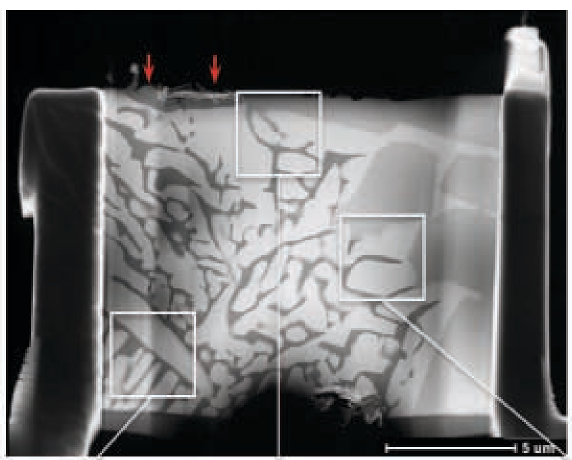




U-Pu-Zr fuel and Fe Diffusion couple



700°C Quaternary phase diagram isotherm



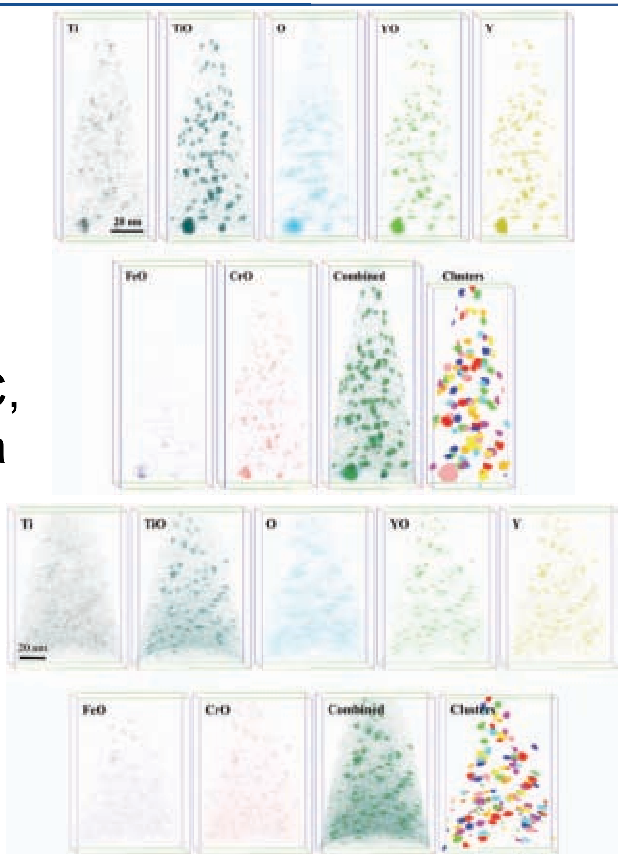
FIB liftout illustrating subsurface microstructure in U-Pu-Zr Fuel

Scientific Impact
Use of the focused ion beam-scanning electron microscope (FIB-SEM) has enabled preparation and analysis of subsurface microstructures which has never been accomplished on this type of material. Detailed phase analysis permits a better understanding of interdiffusion driven phase changes and the potential to develop undesirable lower melting point phases.

Boise State University
CAES and Sample Library RTE
Professor Janelle Wharry

Motivation
Understand how irradiation affects the hardening mechanisms of irradiated oxide dispersion strengthened (ODS) steels

"Hardening Mechanisms in Neutron- and Ion-Irradiated Fe-9Cr ODS Alloy"

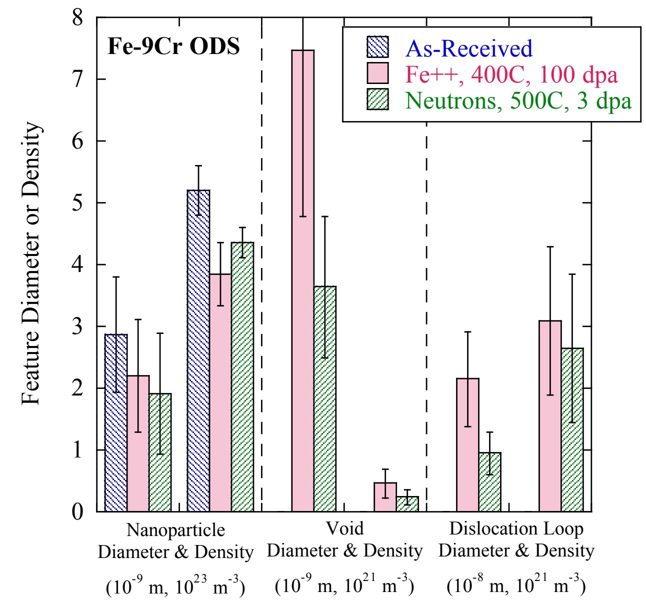


Proton

VS

Neutron

500°C,
3 dpa



Scientific Impact
Dispersion strengthened alloys are a primary candidate for advanced cladding and reactor structural materials applications. Understanding hardening and particle stability under irradiation is a key element of evaluating potential in-service performance concerns.

Grad Students Matthew J. Swenson, Corey K. Dolph

X-ray Synchrotron Studies of Nuclear Materials

Jeff Terry, IIT And MRCAT, Meimei Li, ANL

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Motivation

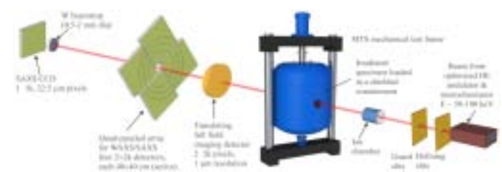
Accelerate development of new materials and predictive capabilities using advanced synchrotron characterization tools.

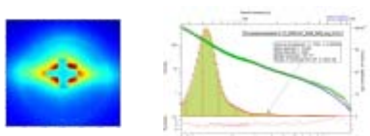
Courtesy of Dr. Meimei Li, Argonne National Laboratory

Scientific Impact

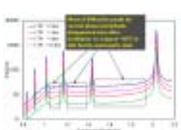
- **Bridge the gap between bulk and microscopic behavior.**
- **Expanding capability to interrogate irradiated microstructures using scientific facilities not generally available for radioactive materials.**

Combination of multiple probes (WAXS/SAXS/imaging) and intense, penetrating hard X-rays allow concurrent, multi-scale, and real time characterization of material evolution under thermal-mechanical loading.

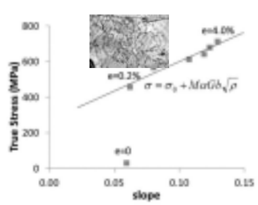




SAXS revealed nanosized particles in ODS steel

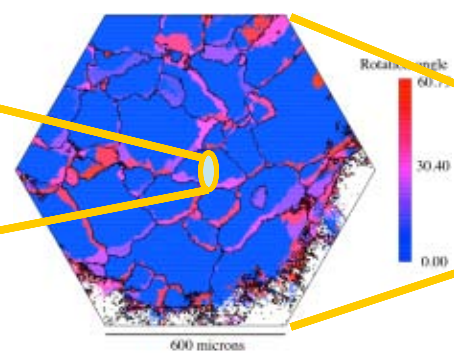


Phase stability under irradiation revealed by XRD

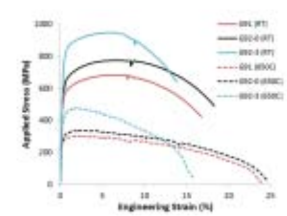


Peak profiles revealed dislocation evolution under deformation

Nanoscale structure: WAXS and SAXS



Mesoscale structure: diffraction microscopy



Macroscale stress-strain behavior

Idaho State University – ATR Irradiation, ANL ATLAS Accelerator Mass Spectrometer

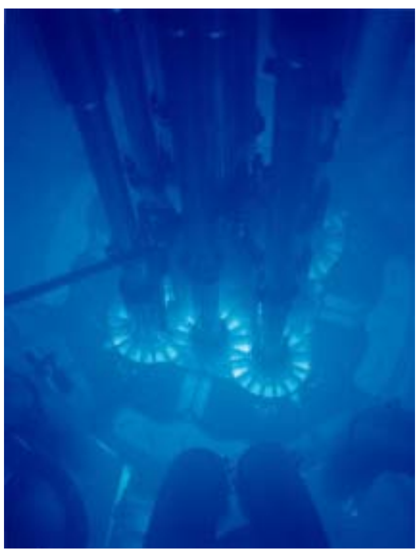
Prof. George Imel, Dr. Gilles Youinou, INL

Motivation
Infer effective neutron capture cross-sections of most actinides of interest for reactor physics in fast and epithermal neutron spectra.

"Measurement of Actinide Neutronic Transmutation Rates with Accelerator Mass Spectroscopy (MANTRA)"

ATLAS

- **First PIE measurements using Multi-Collector ICPMS at INL – Very successful campaigns: high precision/accuracy and also high throughput that would have been impossible with TIMS**
- **First-of-a-kind MC-ICPMS measurements of isotopes such as plutonium-244 and californium for which experimental data is almost non-existent**



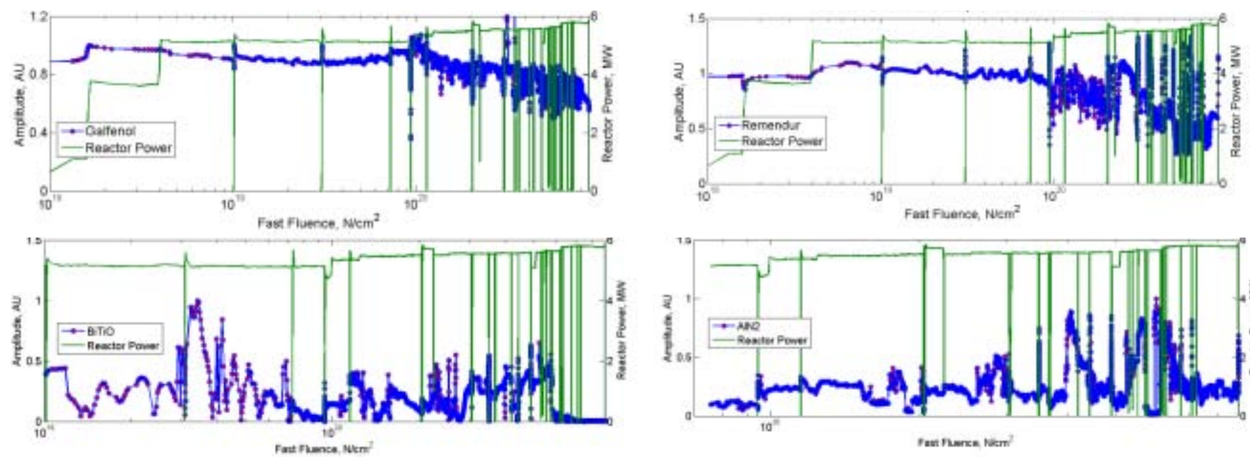
Scientific Impact
MANTRA will provide valuable information to nuclear data evaluators for the years to come. Improved nuclear data will benefit advanced modeling and simulation of future nuclear reactors and fuel cycles

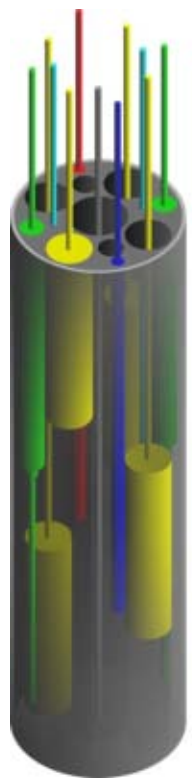
Penn State University
MIT Irradiation

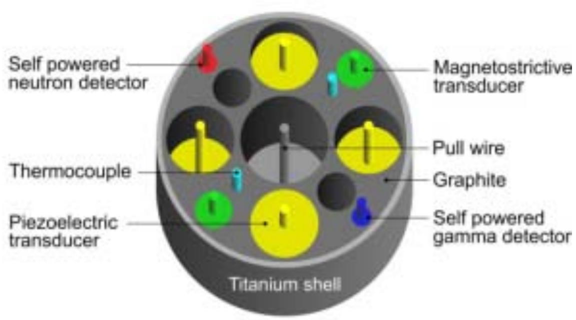
Joshua Daw, Joe Palmer (INL), Pradeep Ramuhalli, Paul Keller, Robert Montgomery (PNNL), Hual-Te Chien (ANL), Bernhard Tittmann, Brian Reinhardt (PSU), Gordon Kohse (MIT), Joy Rempe (Rempe and Associates, LLC (Formerly INL)), Jean-Francois Villard (CEA, France)

Motivation
Enable in-core use of ultrasonic sensor technologies for monitoring a wide range of parameters in material and test reactors.

"Transducers for In-pile Ultrasonic Measurements of Fuels and Materials Evolution"







Scientific Impact

- **Development of a new class of in-pile sensors and detectors that will improve the knowledgebase of in-reactor conditions and sample environment. This type of information is key to predictive fuels and materials model validation.**

Questions?