U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Nuclear Science User Facilities

Overview of FY16 PIE Activities

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NSUF Nuclear Science User Facilities

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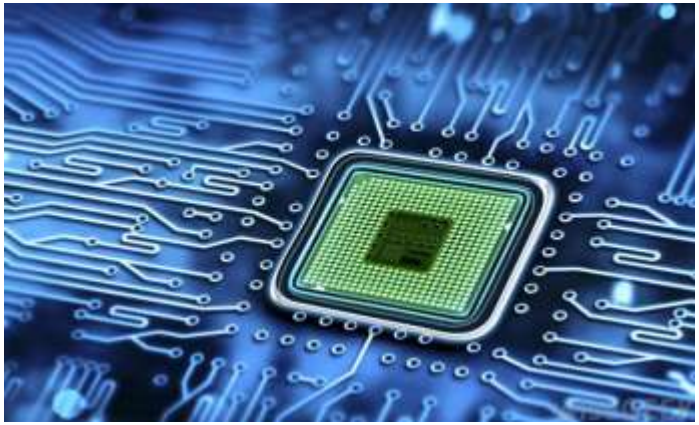
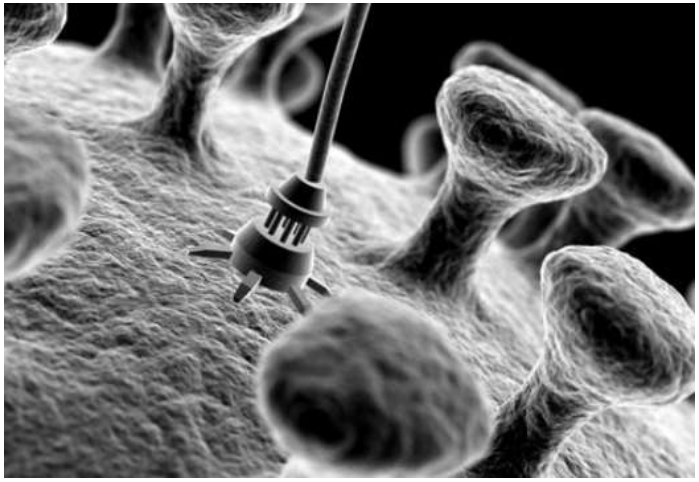
Why Post-Irradiation Examination (PIE)?

NSUF Nuclear Science User Facilities

- Understanding how materials change and their fundamental characteristics (strength, chemical, thermal properties, etc.) during and after irradiation is critical to:
  - lengthening the life spans of existing reactors
  - developing accident tolerant fuels
  - reducing costs for new reactors
  - the safe, long-term disposal of waste
- While some PIE is based on macro-scale analysis (visual inspection, tensile/mechanical testing, etc.), analysis at the micro- and nano-scale will hold the key to advancing nuclear energy
- **Approach:** Apply the analysis tools so successfully used in advancing nano-technology, computer and aerospace industries to nuclear fuels and materials





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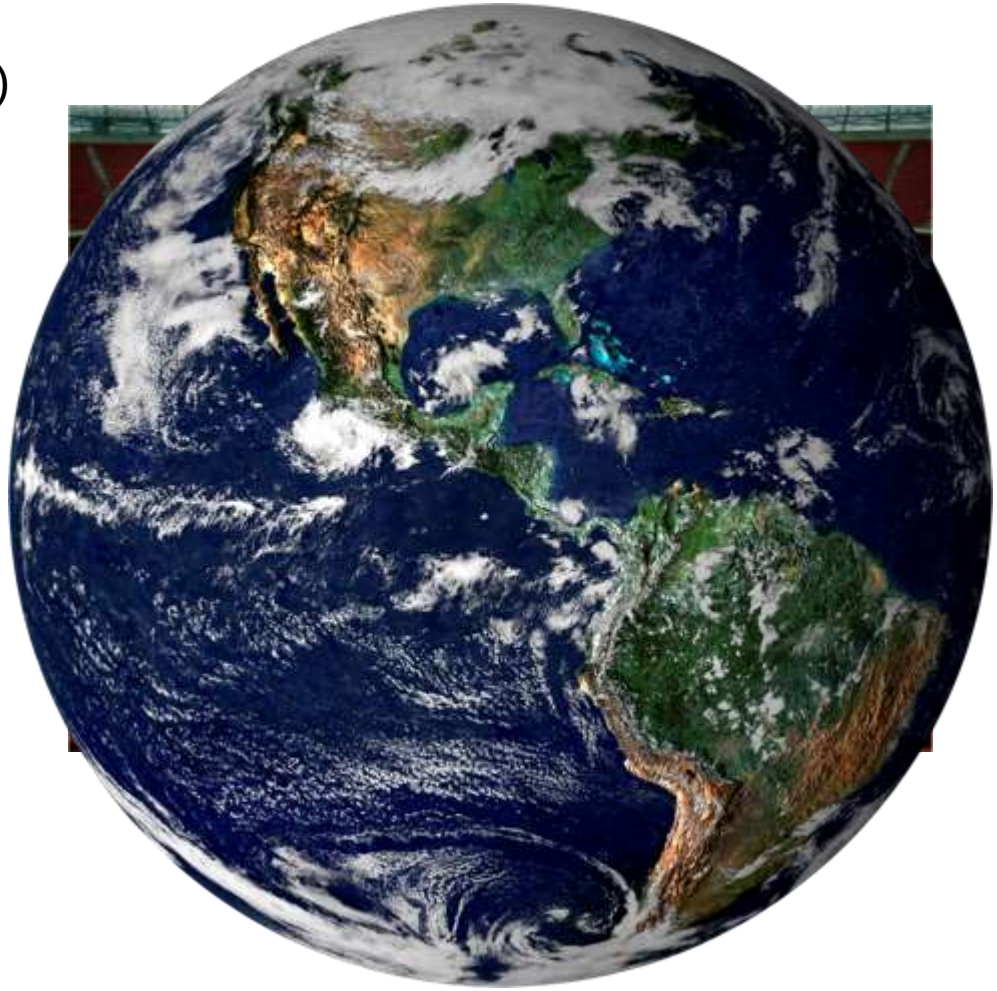
Scale of Characterization Techniques

NSUF Nuclear Science User Facilities

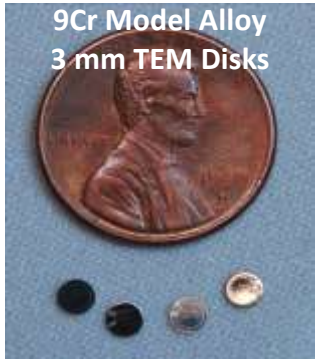
- The Earth – 12,742,000 m (diameter)
  → (full scale)
- Vermont – 127,420 m (width)
  → (10^{-2} scale)
- Football field – 127.4 m (with end zone)
  → (10^{-5} scale)
- Ruler – 12.7 cm (~length)
  → (10^{-8} scale)
- Nickel – 1.27 mm (thickness)
  → (10^{-10} scale)

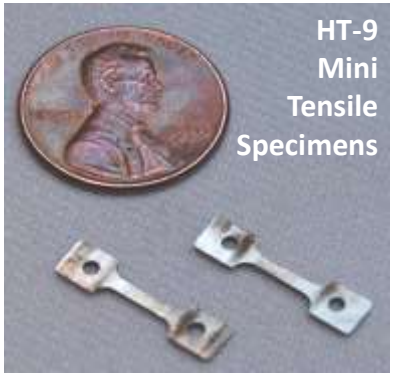


PIE Samples

- **Common Test Materials:** metals, ceramics, SiC, graphites, fuel specimens, etc.

- **Common Specimen Sizes:** TEM disks, tensile specimens, resistivity rods, hardness blocks, compact test specimens, etc.





Sample Origins for PIE Analysis

Irradiated in ATR:

- Simple Static Capsules
- Instrumented Lead Experiments
- Pressurized Water Loops
- Hydraulic Shuttle Irradiation System

Irradiated in NSUF Partner Facility Reactors:

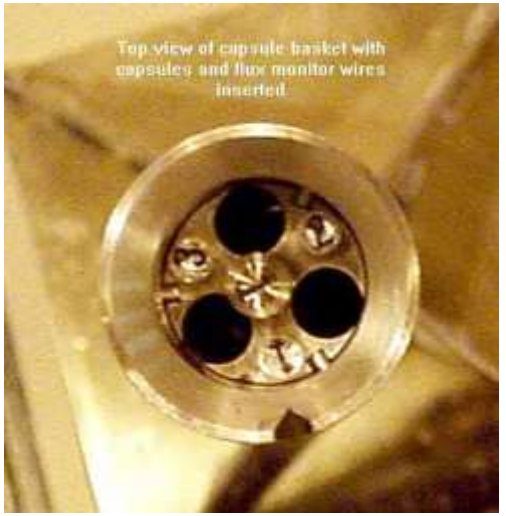
- HFIR
- MIT

Legacy Materials:

- EBR-II
- FFTF

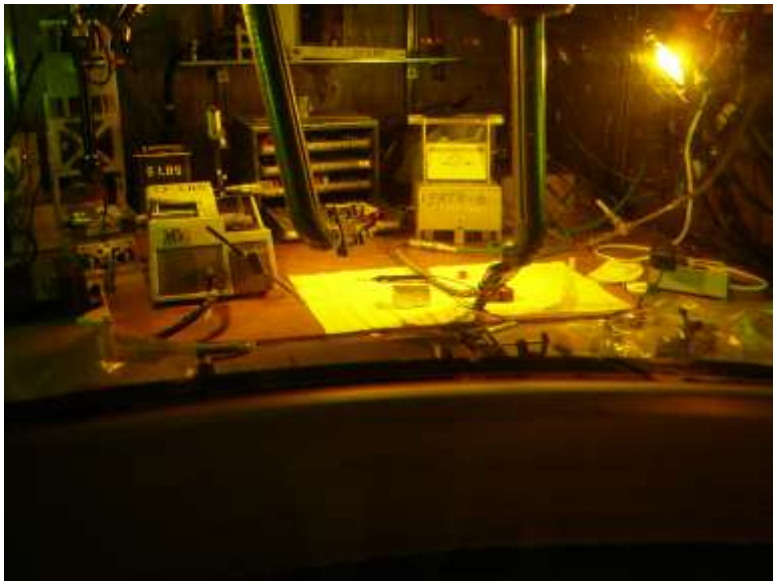
Donated:

- EPRI
- Atomic Energy of Canada (AEC)
- Naval Reactors



PIE Activities

- **Types of PIE activities performed:**
  - Transmission Electron Microscopy (TEM)
  - Scanning Electron Microscopy (SEM)
  - Atom probe
  - Thermal properties (laser flash, differential scanning calorimetry, dilatometry, etc.)
  - Micro- and nano-hardness testing
  - Tensile testing
  - X-ray diffractometry
  - Resistivity
  - Mass spectrometry
- **Sample preparation:**
  - Cutting/mounting/grinding/polishing
  - Cleaning and decontamination
  - Focus Ion Beam (FIB)



PIE Activities

- **PIE Analysis Experiments Completed:**
  - Atomic Energy of Canada (Canada National Laboratory)
  - University of California-Santa Barbara (UCSB) (-1 and -2)
  - UC Berkeley at PNNL
  - University of Florida (UF)
  - University of Wisconsin (UW)
  - North Carolina State University (NCSU)
  - University of Illinois (UI)
  - Michigan PIE Only
  - Drexel PIE Only
  - Drexel University
  - Drexel MAX
  - Idaho State MANTRA (-1, -2 and -3)
  - Utah State University (USU)
  - EPRI-ZG-A and EPRI-ZG-B
  - UC Berkley (MITR)
  - Penn State (MITR)

FY16 PIE Activities

- **FY16 PIE Activities:**
  - University of California-Berkeley (Accident Tolerant LWR Fuel)
    - Completed analysis at PNNL
  - University of Central Florida (UCF) UCF-1 and Boise-8418 (Metallic Fuels)
    - Completed beam line testing at IIT MRCAT in April
  - UCSB-2 (High Fluence Embrittlement Library for LWR Vessel Life Extension)
    - Experiment disassembled and samples cataloged
    - Sample analysis through other DOE programs on-going
    - Remaining samples entered in NSUF library
  - Utah State University (USU) (Thermal neutron filter)
    - Completed Laser flash, dilatometry, and tensile testing analysis
  - University of Illinois (UI) UI-355 and UI-8305 (Reactor Material Studies for LWR Life Extension)
    - 47 tensile specimens have been shipped to APS, ~75 samples more prepared for shipment
    - Beam time is expected in late calendar year 2015
  - UI-8312 (Reactor Material Studies for LWR Life Extension)
    - Four sample conditions analyzed for TEM, atom probe, and nano-indentation
    - Eight more prepared for analysis

FY16 PIE Activities

- **FY16 PIE Activities (cont):**
  - EPRI (Reactor Structural and Cladding Materials)
    - EPRI-2
      - load frame (stress corrosion cracking), tensile testing, and TEM analysis
    - Zirconium growth
      - TEM analysis
  - SAM-1 (Fiber Optic Temperature Sensors and Graphite Materials)
    - Experiment received at HFEF and capsules prepared for shipment to I3 (18 capsules)
    - Disassembly at I3 will eliminate unwanted of alpha cross-contamination
  - Rapid Turn-around Experiments (RTE) using sample library materials:
    - RTE-530 – Samples from AECL GS1-6, GS4-6 and GS4-12 (D2M09). Samples prepared at EML and shipped to the University of California-Berkeley (UCB) for additional analysis
    - RTE-567 – Samples from UCSB-1 (LA, LD, and CM6). Samples prepared at EML, analyzed at CAES, and shipped to the University of Manchester for further analysis
    - RTE-590 and RTE-593 – Samples from UCSB-1, packets 5-2 and 7-1, consisting of the FeCr series (Fe-3Cr through Fe-18Cr). Samples prepared at EML and sent to CAES for analysis

FY17 Work

- **New/Continuing of work in FY17:**
  - SAM-1 (disassembly at I3 and analysis at INL and Texas A&M)
  - UCF-1 and MO-8418 (beam time at IIT MRCAT)
  - UI-8305 (beam time at IIT MRCAT)
  - UI-8312 (sample analysis at CAES)
  - EPRI
    - samples from EPRI-2 and EPRI-3 in load frame and tensile testing
    - TEM analysis
  - DG-10639 (Thermal Neutron Filter Materials) (welding and sample preparation at Westinghouse's MCOE)
  - BSU-10181 (Welding Behavior of High Fluence Stainless Steel Reactor Materials)
  - RTEs

FY18 and Beyond Work

- **Future (FY18 – beyond):**
  - Boise State University (BSU) (Accident Tolerant Fuels)
  - Boise-8242 (Irradiation Effects on Powder Metallurgy-Hot Isostatic Press Alloys)
  - CSM-10584 (Irraddiation Effects on Stainless Steel and Inconel Specimens Produced Additive Manufacturing)
  - Idaho State-10537 (Performance of Ultrafine-Grained and Nanocrystalline Reactor Structural and Cladding Steels Produced by Equal-Channel Angular Pressing (ECAP) and High-Pressure Torsion (HPT))
  - GE-Hitachi-10393 (Radiation Effects on Materials Produced by Direct Metal Laser Melting (DMLM) Fabrication)
  - UCF-3 (Metallic Fuels)

Summary

- **Significant number of experiments completed through PIE**
- **Pipeline of new experiments from planning through PIE continuing:**
  - Several new experiments in irradiation planning and fabrication phase
  - On-going analysis with samples being analyzed at MFC, CAES, IIT MRCAT, I3, and Westinghouse's MCOE
  - Expanding ties with NSUF partners
- **Significant challenges:**
  - Competing programs at MFC
  - Reactor operations
  - Significant rise in number of proposals
- **Many accomplishments:**
  - Relevant science being conducted
  - INL/University collaboration (recruiting opportunities)
  - CAES/Partner Facility utilization
  - New capabilities