Thermal Analysis of Irradiated U-Mo Alloy Fuel Samples

HOTLAB-2013

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Pacific Northwest
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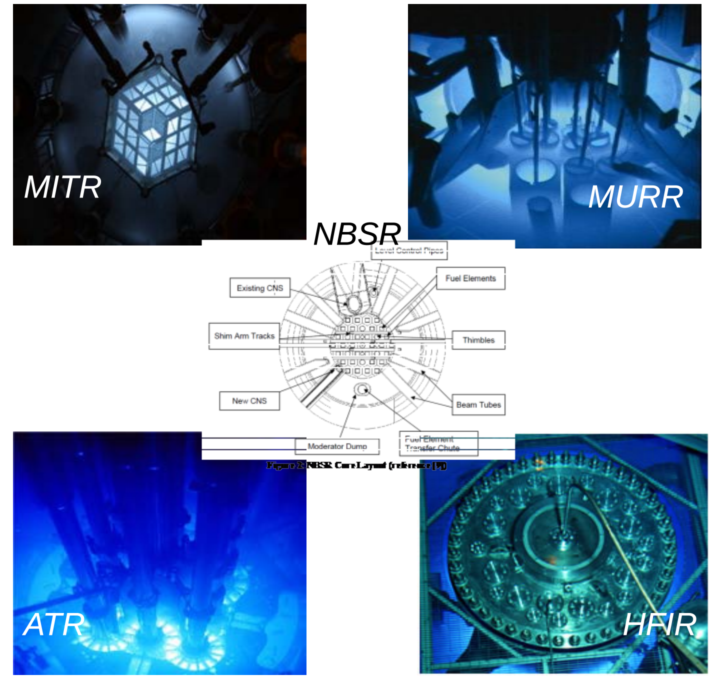
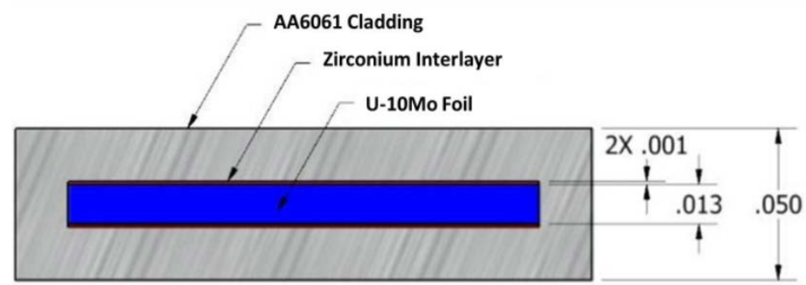
Development of high density LEU fuel

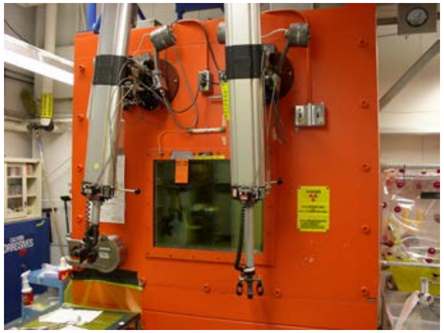
- The Global Threat Reduction Initiative (GTRI) is supporting development of a high density LEU fuel
- The new fuel would support the conversion of as many as five US High Performance Research Reactors
- The fuel is based on a U-Mo alloy and consists of a monolithic foil design
- PNNL leads the fuel fabrication efforts for the GTRI and supports other aspects of the program, including physical property characterization of unirradiated and irradiated fuel samples





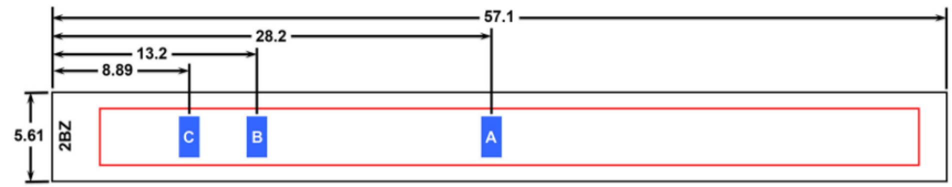
RPL Hotcell Capabilities

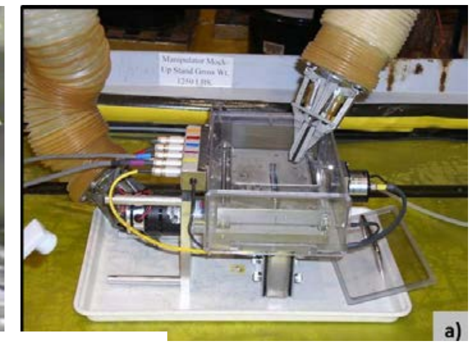
- Radiochemical Process Laboratory (RPL) is a Cat 2 facility with capabilities for:
  - Handling, characterizing, and cutting of irradiated fuel and structural materials
- A total of seven hotcells currently dedicated to thermal-physical property measurements of irradiated fuel
  - PDC1 – TG/DTA-MS utilized for small scale testing of fission product release as a function of time and temperature
  - PDC2 – LFA utilized to obtain thermal diffusivity as a function of temperature
  - ISC1 – Optical microscope utilized to obtain layer thicknesses and microstructural information
  - SAL3 – Pycnometer utilized to obtain density
  - SAL4 – Analytical chemistry digestion
  - SAL5 – Metallography preparation equipment (pot, grind, polish)
  - SAL6 – Sample sectioning equipment and DSC utilized to obtain heat capacity as a function of temperature

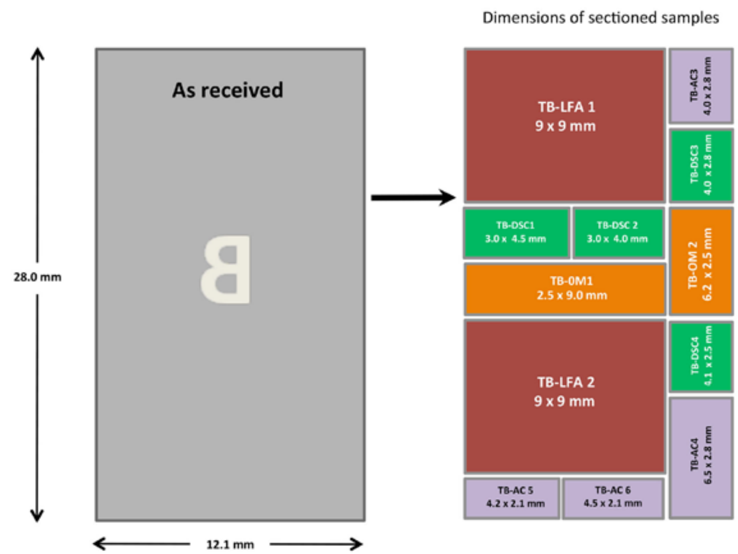


Thermal Physical Property Measurements of Irradiated Fuel

- PNNL received four fuel segments ~25 mm long × ~13 mm wide segments from INL
- Segments are from the AFIP-2BZ fuel plate and consist of five distinct layers and range in average burnup from ~45-70% ^{235}U
- Segments were sectioned into multiple samples at PNNL for measurement and analysis to obtain:
  - Thermal Diffusivity
  - Density
  - Specific Heat Capacity
  - Chemistry and Isotopics
  - Layer thickness and Microstructural information
  - Fission product release







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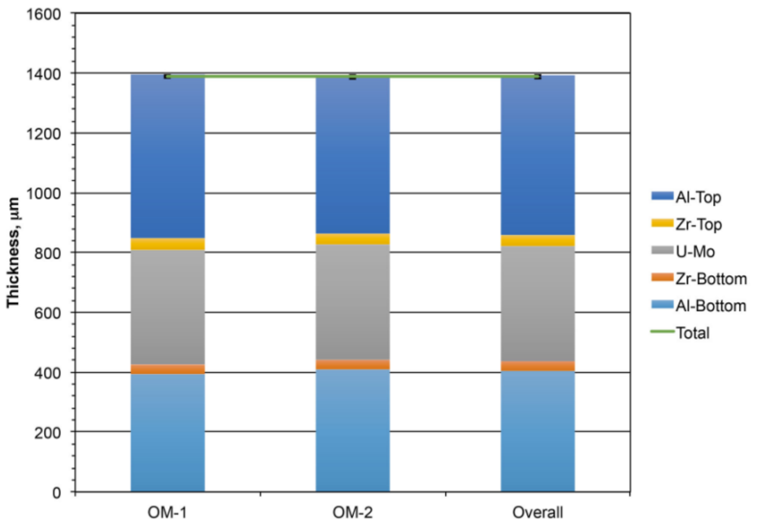
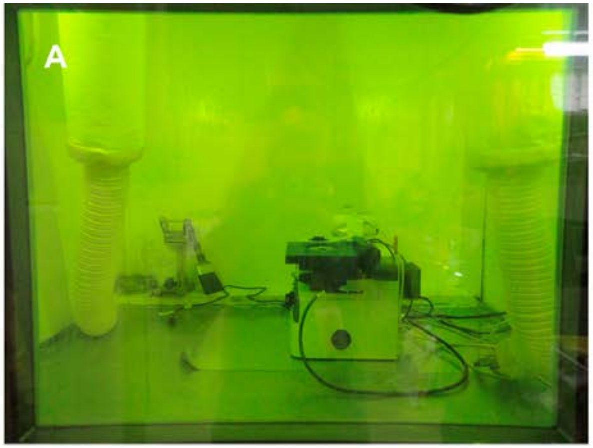
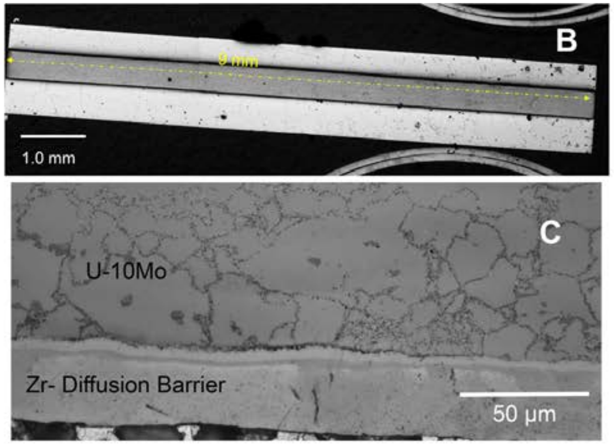
Optical Microscopy Measurements

- Pre-measurement and post-measurement standard run to calibrate the instrument
- Multiple measurements taken at roughly equidistant points across the length of the sample
  - Al Clad – Top and Bottom
  - Zr layer – Top and Bottom
  - Fuel meat
  - Entire sample thickness







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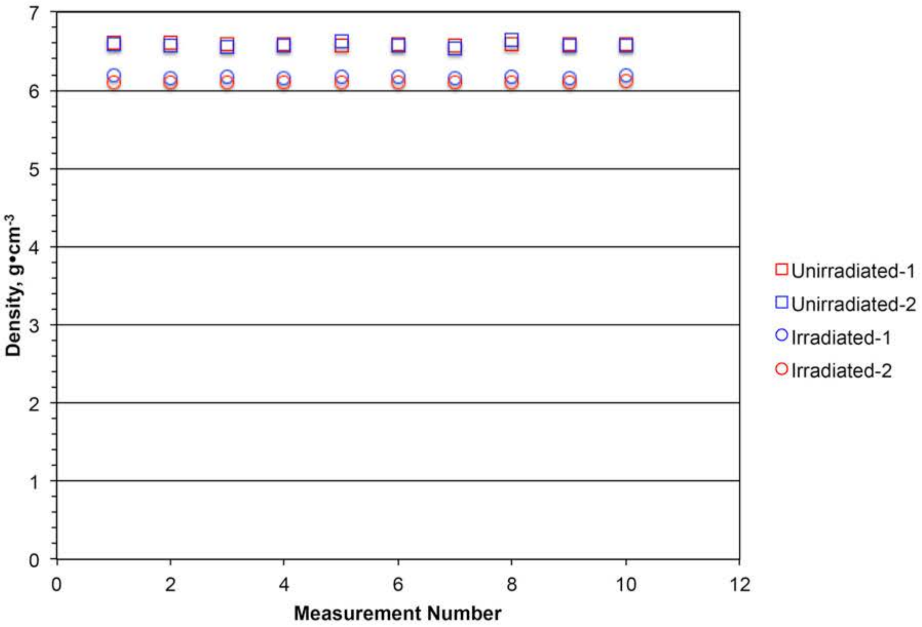
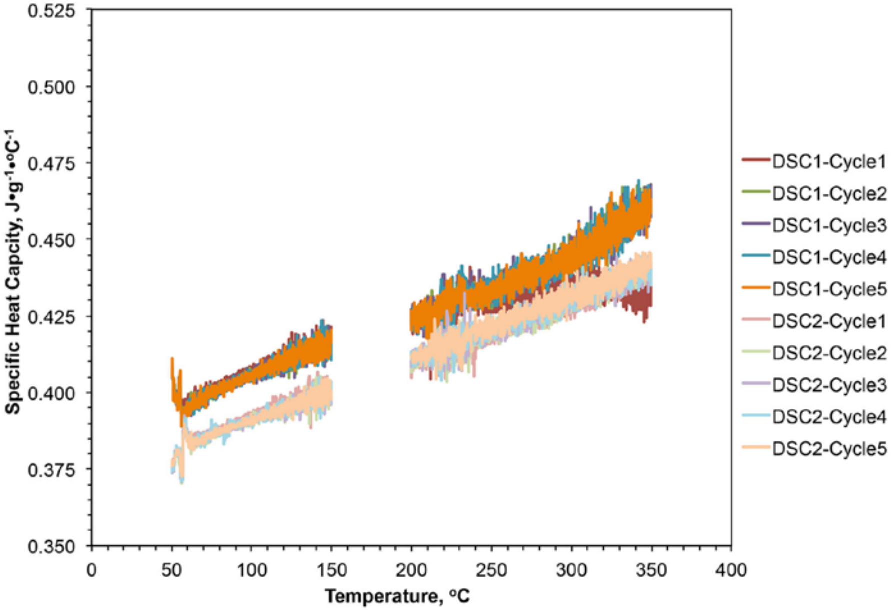
Density Measurements

- Pre-measurement and post-measurement standard run to validate equipment functionality
- Ten measurements taken at room temperature utilizing a gas pycnometer



Specific Heat Capacity Measurements

- Pre-measurement and post-measurement melt checks (In, Pb, Zn) run to validate temperature and enthalpy
- Samples subjected to two different heating profiles
  - Low temperature cycle – 40°C to 150°C
  - High temperature cycle – 200°C to 350°C
- Five sets of measurements over each cycle acquiring data upon both heating and cooling
- Specific heat capacity calculated using a modified Ratio method



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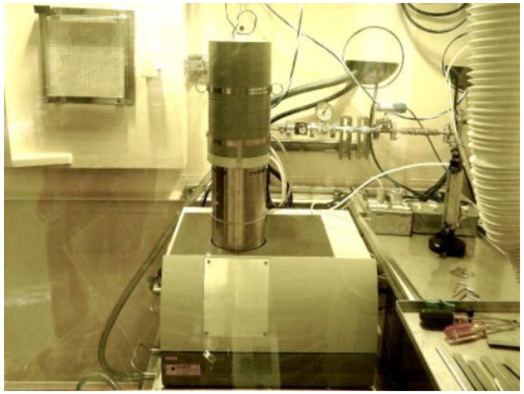
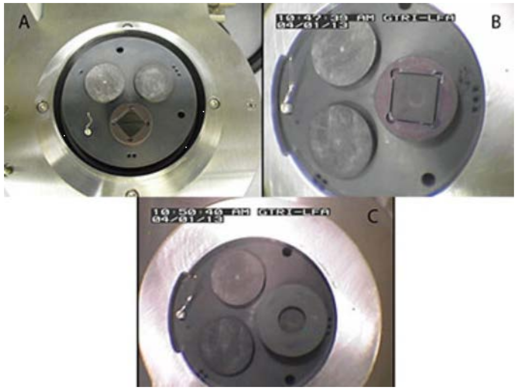
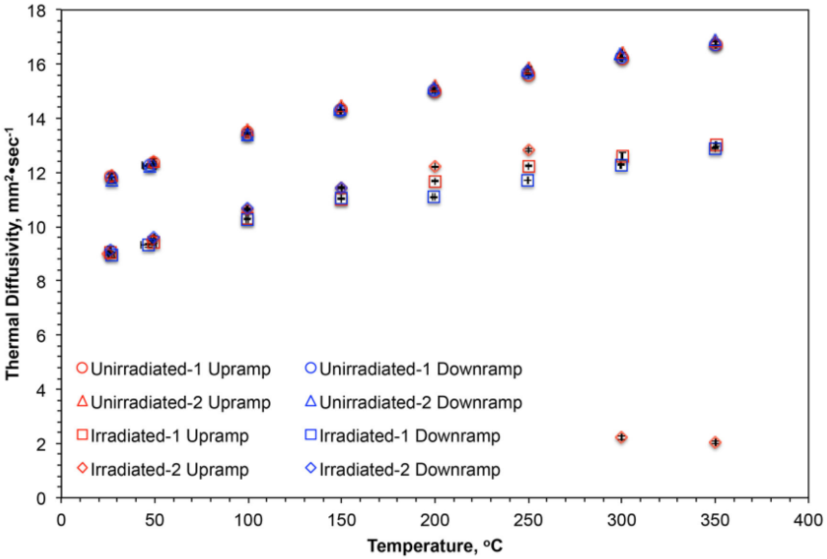
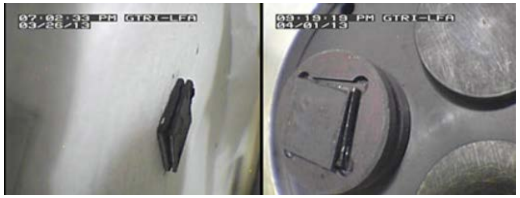
Laser Flash Analysis

- Pre-measurement and post-measurement iron standard run to validate equipment functionality
- Samples are coated with graphite and subjected to two different heating cycles
  - Low temperature cycle – 25°C to 150°C
  - High temperature cycle – 200°C to 350°C
- Five measurements taken at each temperature on both upramp and downramp
- Thermal diffusivity calculated using the Cape-Lehman + pulse correction model



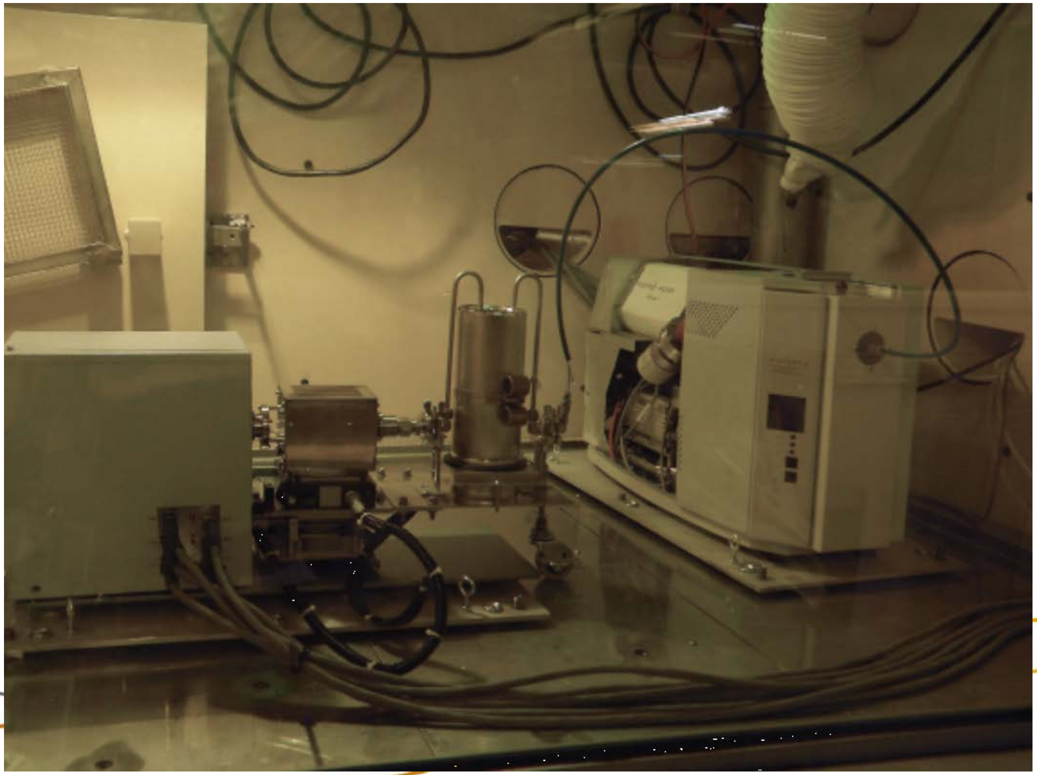






TG-DTA/MS

- Utilize thermogravimetric and differential thermal analysis coupled with mass spectroscopy to obtain both temperature and mass change information as indicators of gaseous fission product release and/or material phase changes
- “Cold” liner to plate out other fission product species, particularly cesium and iodine
- Perform multiple dynamic measurements over different temperature ranges and hold times
  - One fuel segment produces 21 “ideal” samples plus 11 “non-ideal” samples



Summary

- A variety of thermal property measurement equipment has been installed into hot cells at the Pacific Northwest National Laboratory
- The equipment is very capable of performing the desired measurements and the processes / procedures that have been put in place are adequate for obtaining the required data to calculate thermal conductivity of irradiated fuel on small samples
- Preliminary measurements on unirradiated and irradiated fuel samples have been presented to validate the equipment functionality
- The thermal properties (density, specific heat capacity, thermal diffusivity) of the U-Mo alloy are indeed affected by irradiation
- Additional measurements are currently underway that will allow determination of thermal conductivity as a function of temperature and burnup
- Small scale tests to evaluate fission product release as a function of temperature will begin soon