# *Post-Irradiation Annealing Studies of Small-Scale U-Mo Monolithic Fuel Samples*

## HOTLAB-2014

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Pacific Northwest
NATIONAL LABORATORY

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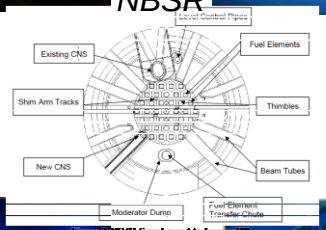
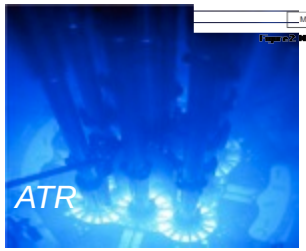
# Development of high density LEU fuel

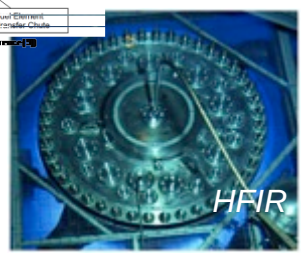
- The Global Threat Reduction Initiative (GTRI) is supporting development of a high density LEU fuel
- The new fuel would support the conversion of as many as five US High Performance Research Reactors
- The fuel is based on a U-Mo alloy and consists of a monolithic foil design
- PNNL leads the fuel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

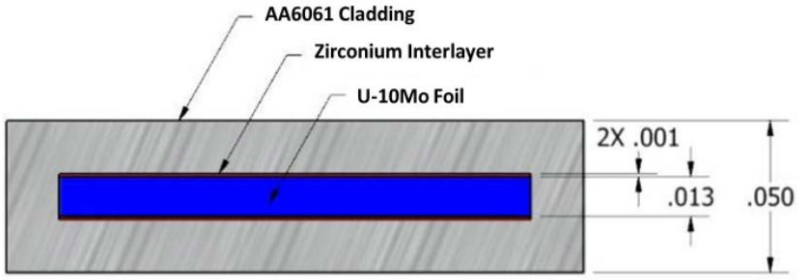


NBSR



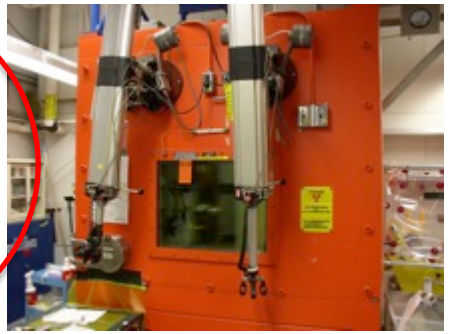



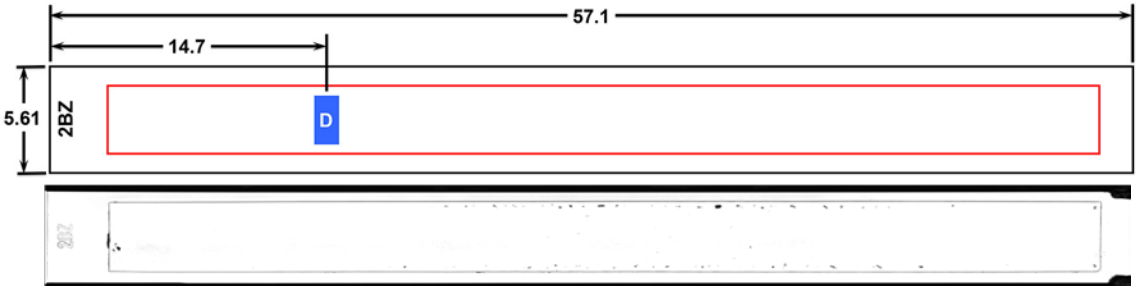
# RPL Hotcell Capabilities

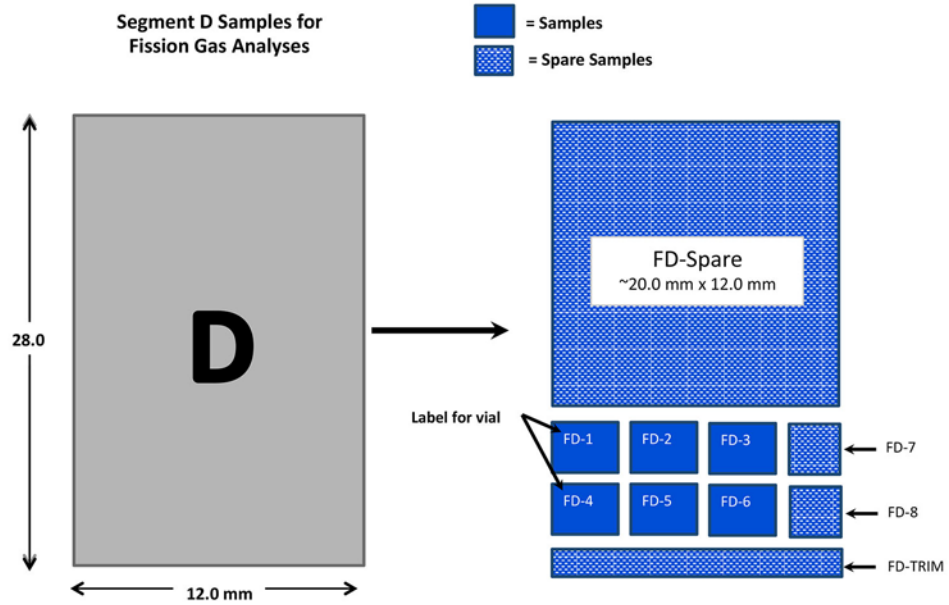
- Radiochemical Process Laboratory (RPL) is a Cat 2 facility with capabilities for:
  - Handling, characterizing, and cutting of irradiated fuel and structural materials
- A total of eight hotcells currently dedicated to thermal-physical property measurements of irradiated fuel
  - PDC1 – TG/DTA-MS utilized 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
  - SAL2 – Pycnometer utilized to obtain density
  - SAL2,3,4 – 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

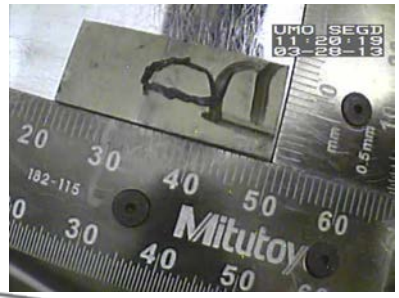


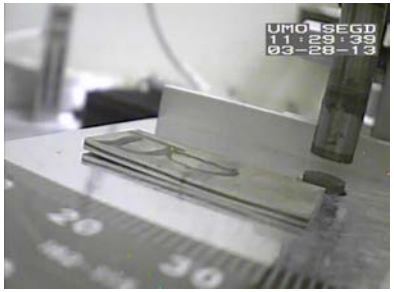
# Experimental Materials

- Segment D was from AFIP-2BZ fuel plate
  - 132.4 EFPD in ATR CFT
  - Surface heat flux of ~237 W•cm$^{-2}$
- PNNL received a fuel segment ~25 mm long × ~13 mm wide from INL
- Segment had an average burnup of ~49%
- Segment was sectioned into smaller samples at PNNL for fission product release measurements

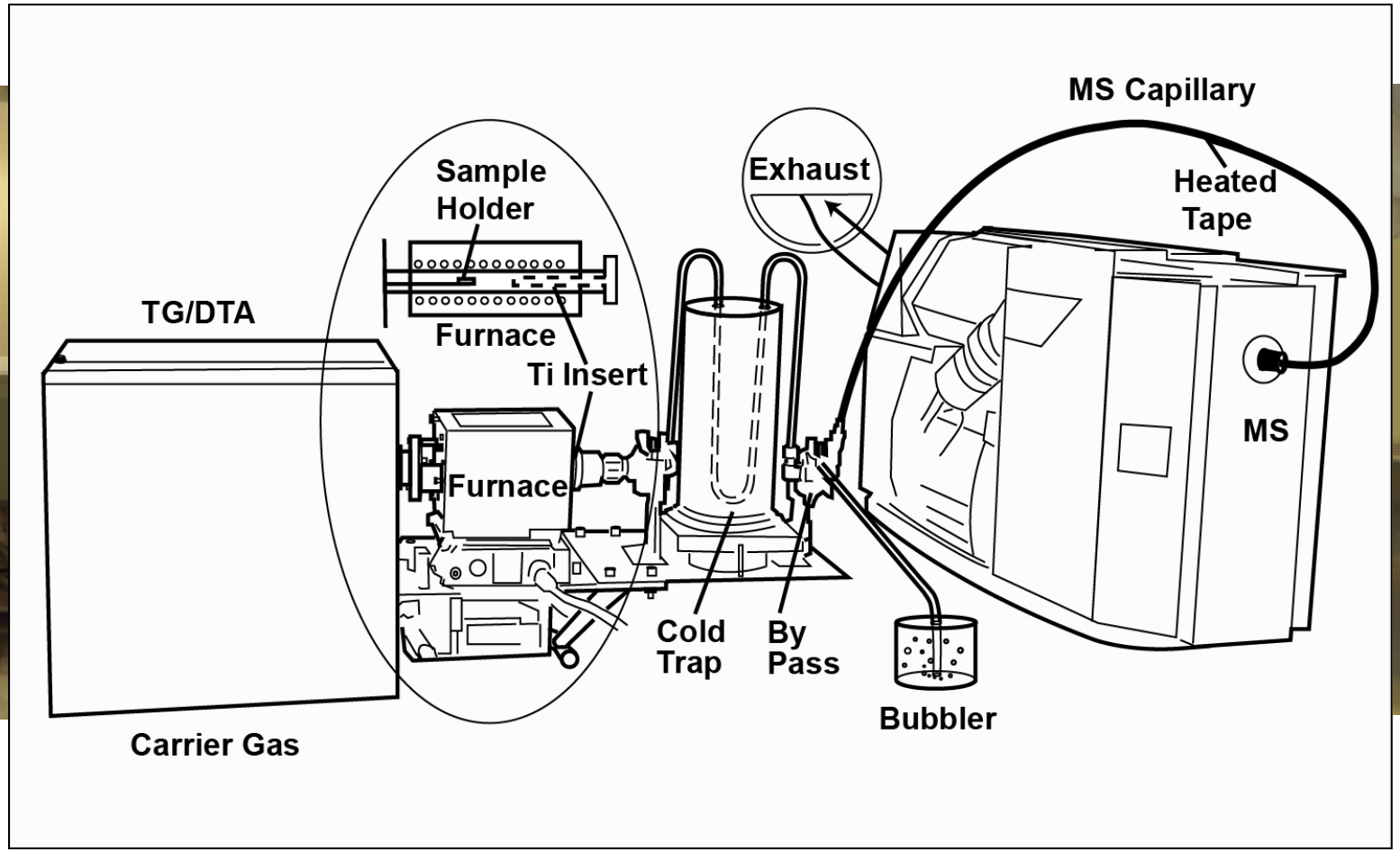


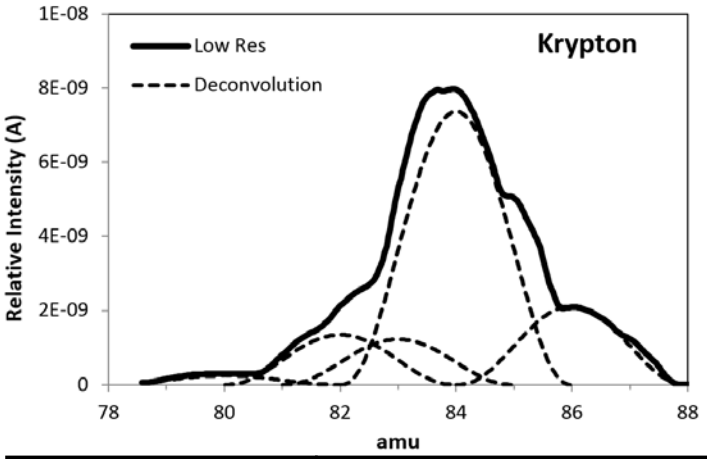



# Equipment Set-up

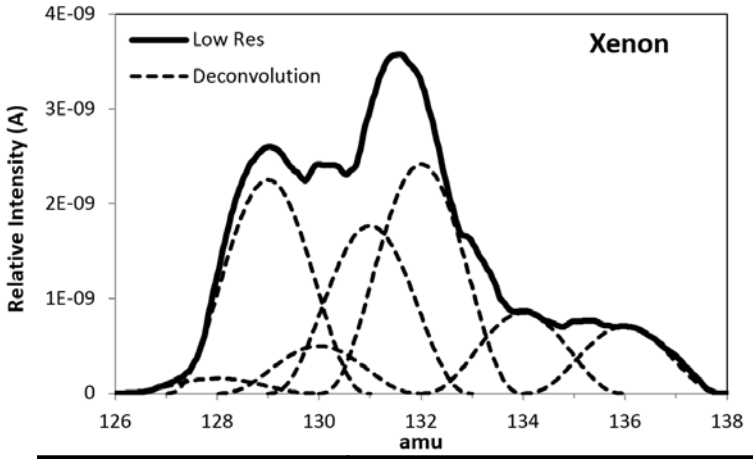



# Peak Analysis

- Calibration gases analyzed for isotopic distribution to correlate concentration with a specific amu being measured
- Low resolution settings used due to small sample size and low heating rate
  - Increased the amount of data acquired per unit of elapsed time
  - Required deconvolution as a result of peak broadening and overlap
- Measured peaks within 3% of natural abundance isotopic values



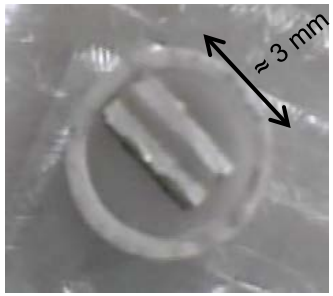

| Stable Kr Isotopes amu | Natural Abundance % | Measured % |
|---|---|---|
| 80 | 2.3 | 2.0 |
| 82 | 11.6 | 11.0 |
| 83 | 11.5 | 10.0 |
| 84 | 57.0 | 59.8 |
| 86 | 17.3 | 17.2 |

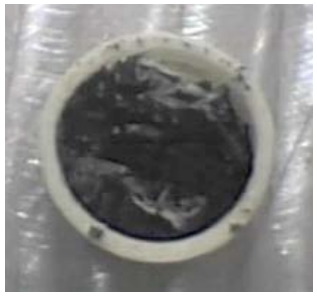


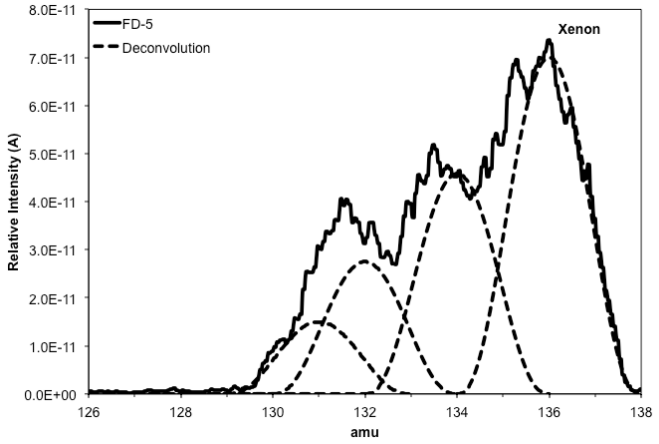

| Stable Xe Isotopes amu | Natural Abundance % | Measured % |
|---|---|---|
| 128 | 1.9 | 1.8 |
| 129 | 26.4 | 26.0 |
| 130 | 4.1 | 5.8 |
| 131 | 21.2 | 20.4 |
| 132 | 26.9 | 27.9 |
| 134 | 10.4 | 9.8 |
| 136 | 8.9 | 8.2 |

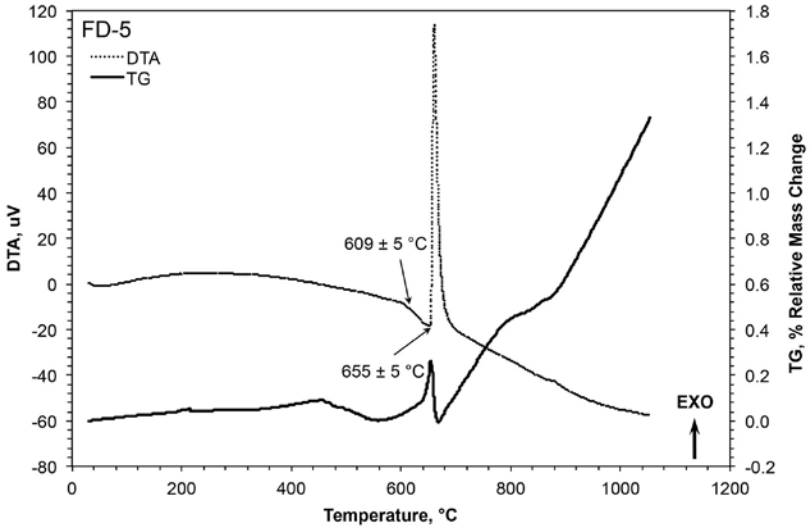
# Irradiated Sample FD-5

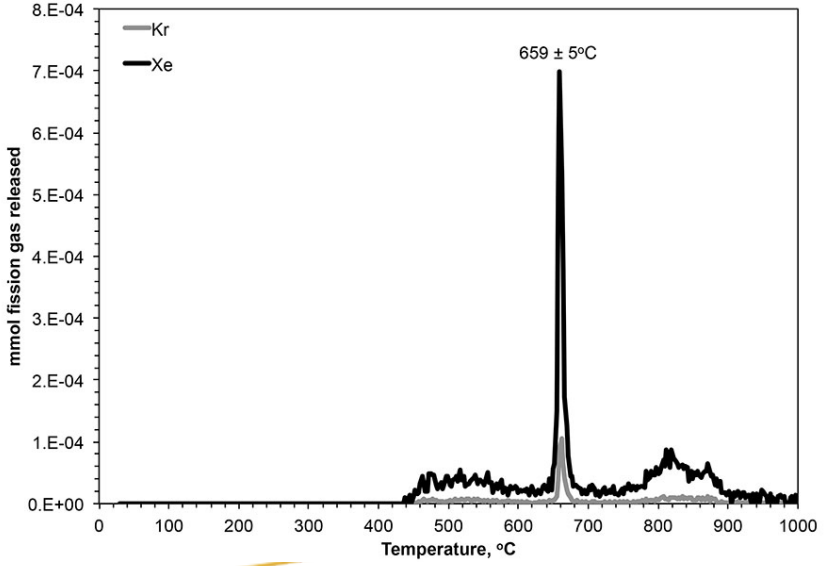
- Due to small sample size the system was optimized by decreasing the resolution and scan rate
  - More data points over the thermal cycle (lower °C/scan)
  - Enhanced sensitivity through increase in ion current signal by a factor of:
    - ≈ 20 for Kr
    - ≈ 30 for Xe



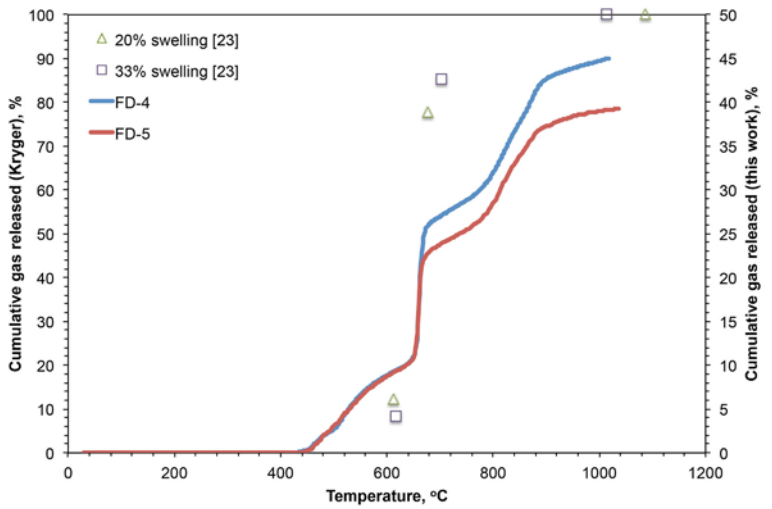


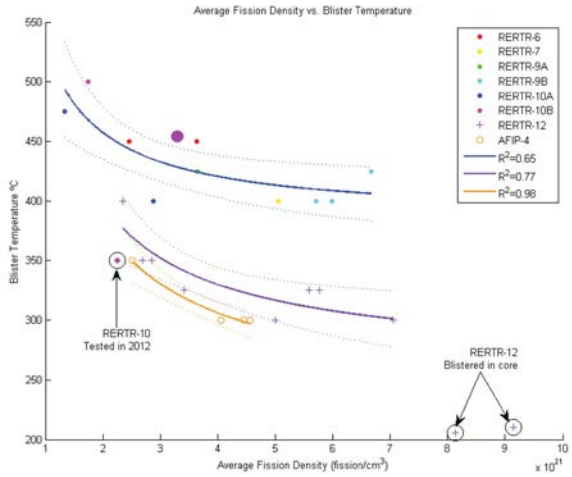



# Fission Gas Release Mechanisms

- First release at 455 ºC
  - Precipitation of gaseous fission products from solid solution
  - Coalescence into large pores that escape through exposed edges of sample
- Second release at ~640 ºC
  - Onset of cladding melt at 654 ºC
  - Exothermic reaction between liquid Al and solid Zr at 654 ºC
  - Massive swelling of fuel and loss of cladding constraint
- Third release between 770 and 885 ºC
  - Melt temperature of U-10Mo is ~1140 ºC
  - Homologous temperature is typically 2/3 of melt temperature
  - Lattice diffusion makes significant contribution to solid-state diffusion at this temperature
- Additional studies to deduce whether all of FG was released, or whether residual remains in sample is underway




Meyer et al., INL/EXT-12-26500, June 2012, p. 3

# Summary

- A variety of thermal property measurement equipment has been installed into hot cells at the Pacific Northwest National Laboratory
- Small scale tests to evaluate fission product release as a function of temperature have been performed and optimized
- The equipment is very capable of performing the desired measurements and the processes / procedures that have been put in place are adequate for obtaining FG release data on small samples
- Initial measurements reveal three distinct FG releases for clad monolithic U-Mo samples
- Data correlates well with historical measurement, but full release was not observed
- Additional measurements are currently underway to evaluate correlations used to calculate FG release and residual FG in the sample