INL/CON-22-69020-Revision-0

Recent Progress in U-10Mo Mechanical and Thermophysical Property Characterization - Presentation

October 2022

Changing the World's Energy Future

Jason L Schulthess, Tsvetoslav R Pavlov, Michael P Heighes, Cynthia A Adkins, Chuting Tan, M Craig Marshall, William Alexander Hanson, Jeffrey J Giglio, James I Cole

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

October 3-5, 2022

RERTR 2022 Conference
Vienna, Austria
INL/CON-22-69020

Recent Progress in U-10Mo Mechanical and Thermophysical Property Characterization

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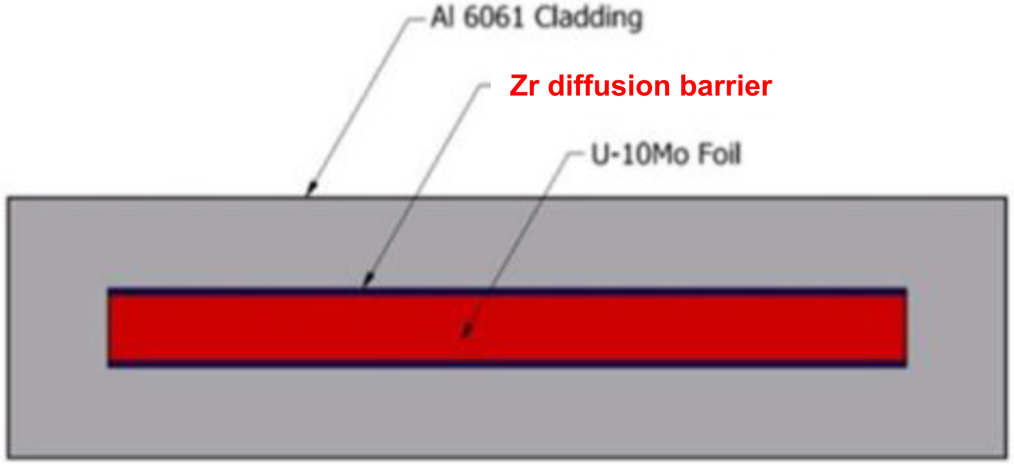
U-10Mo Fuel Qualification Supports Conversion of High Performance Research Reactors

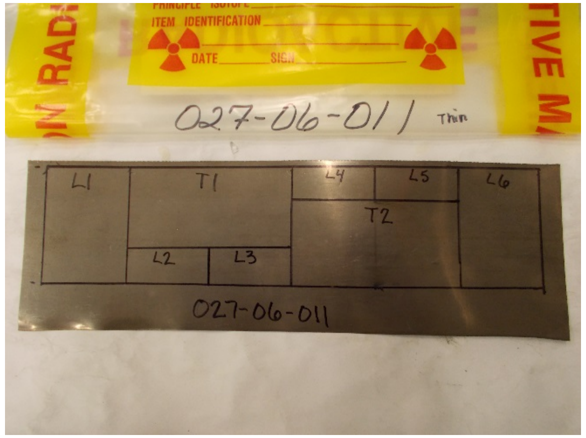
- Fuel Qualification efforts have progressed beyond laboratory scale fabricated materials, to commercially fabricated materials.
- Fuel Qualification requires that material properties be known.
  - R1.1.1a Establish, …, that thermal- and physical-property data are sufficient…[1]
  - R 1.1.2 The mechanical response of the fuel meat, …shall be established. [1]
  - In-use inspection and post-irradiation examination (PIE) of the test articles are expected to yield fuel property and fuel performance data that support a series of fuel qualification and reactor-specific fuel licensing reports submitted to a regulator. These data will also be necessary for the completion of final safety analysis for the USHPRR that will use the fuel. [2]

[1] K. Daum et al., U-10Mo Monolithic Fuel Qualification Plan, INL-EXT-30238
[2] J.A. Stillman et al., Experiment and Design Integration for U.S. High Performance Research Reactor Low-Enriched Uranium Conversion, ANL/RTR/TM-19/16.

Baseline Unirradiated Materials

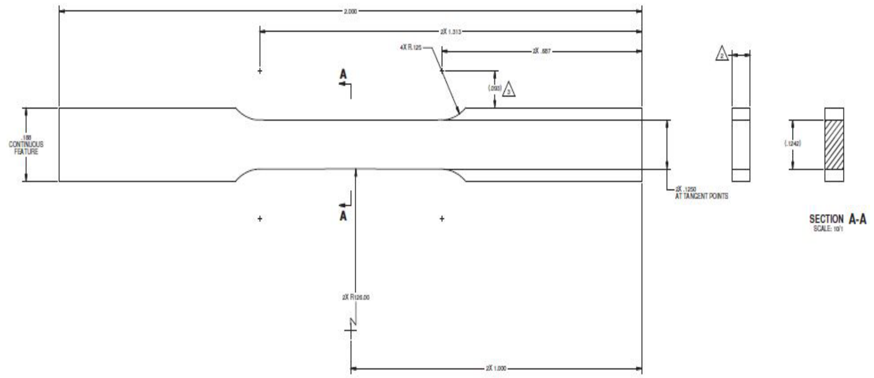
- Parent materials were prepared commercially. Although the final form of the fuel system includes a Zr diffusion barrier and Al cladding, the material tested was just the bare U-10Mo Fuel.
- Foils of two different thicknesses were used. (0.235 mm and 0.653 mm). All processing steps up to this point were common. Final thickness varied by additional cold rolling of the thinner foil. Both were heat treated (annealed) at 923 K for 1 hour after final rolling.
- For 0.235 mm foil, avg grain size (11.6-16.3 um), C content (456 ppm), Carbide Vol Frac (1.31-1.83%)
- For 0.653 mm foil, avg grain size (12.5-18.3 um), C content (262 ppm) , Carbide Vol Frac. (0.69-1.10%)





Methodology

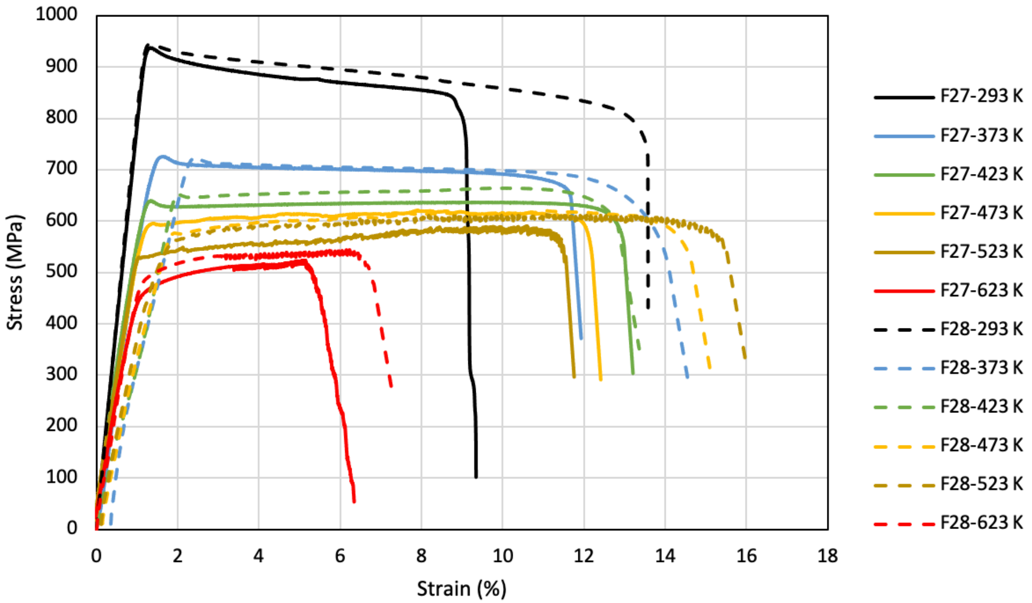
- Mechanical Properties evaluated by following ASTM E8 and ASTM E21 standard test protocols for quasi-static tensile loading with a subsize tensile specimen.
- Thermophysical properties collected with:
  - Differential Scanning Calorimeter (Netzsch DSC404), specific heat (C_p), ASTM E1269
  - Pushrod Dilatometer (Netzsch DIL402E), coefficient of thermal expansion (CTE), ASTM E228
  - Laser Flash Analyzer (Netzsch LFA427), thermal diffusivity (α), ASTM E1461



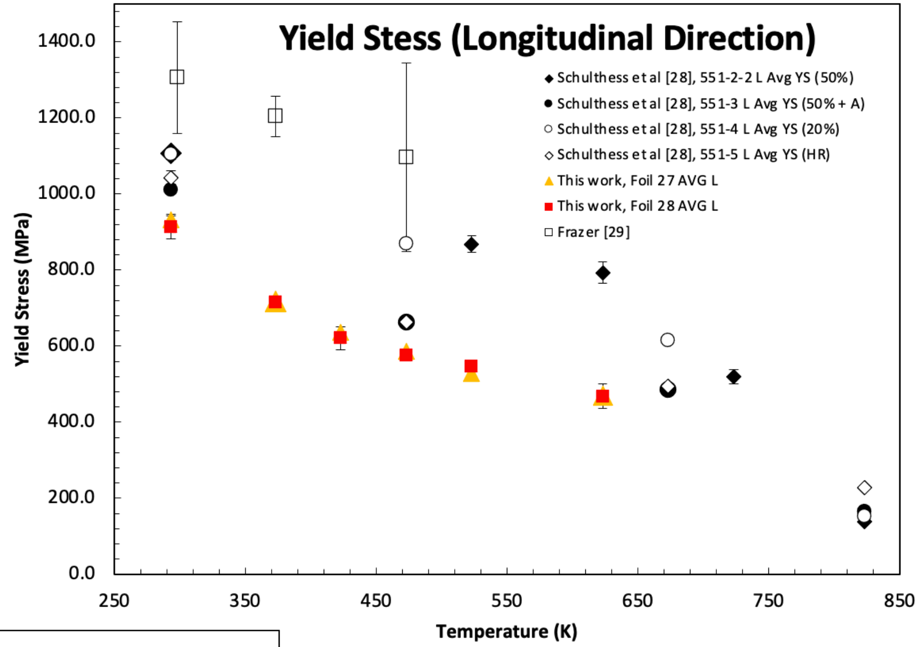
J. Schulthess, et al., Mechanical and Thermophysical properties of low enriched uranium-10wt% molybdenum rolled foils, JNM, 2022, 563, 153628.

Selected Mechanical Property Results

- F27 is the thinner foil with more C, F28 is the thicker foil with less C

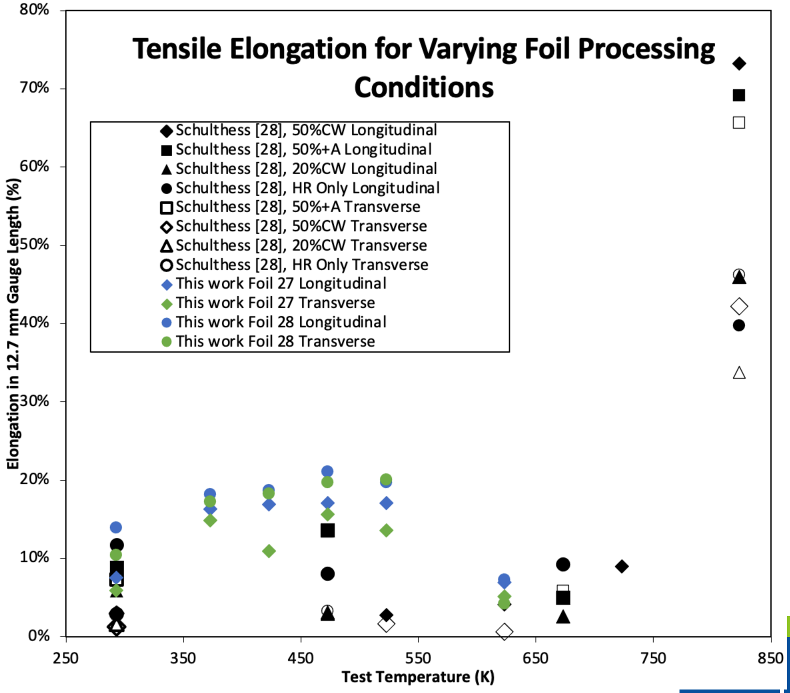


Far right, the commercial fabricated material shows much more consistent results than the lab fabricated material. Also, no difference in yield between the two foils.



Above, representative engineering stress vs. engineering strain curves.

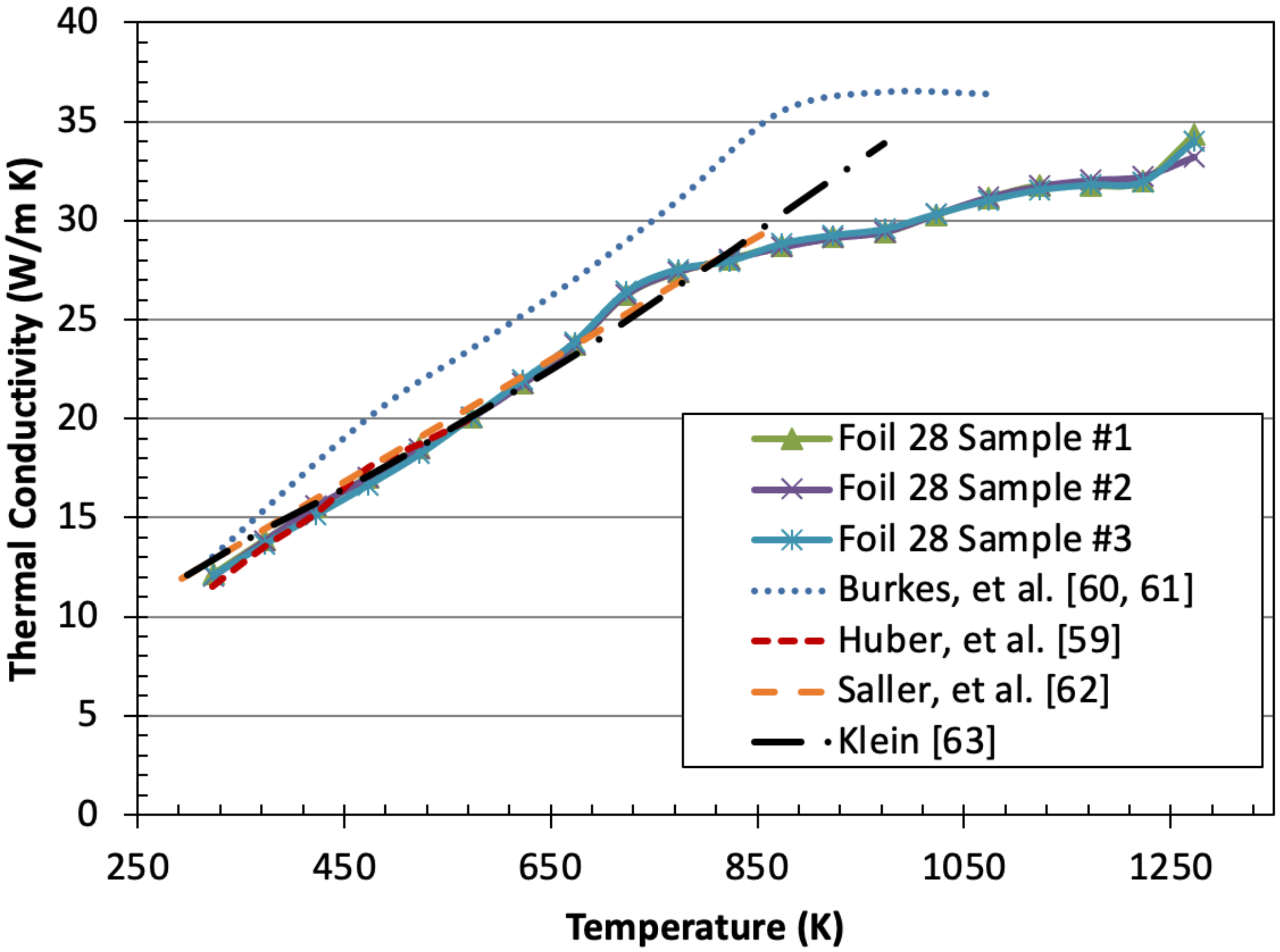
Right, total elongation, F28 consistently has additional elongation compared to F27. Note also the reduction in ductility at ~650 K.



The work by Frazer was performed by micro-cantilever beam where the average grain size was ~3 um.

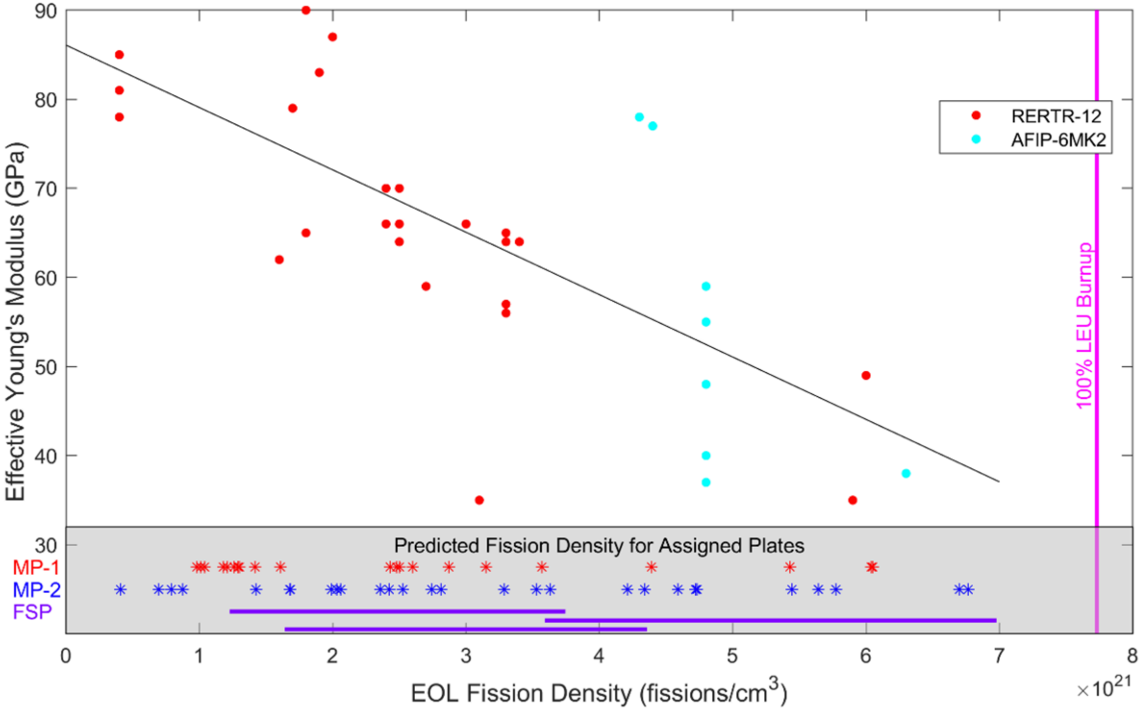
Thermal Conductivity Results

- Only results for Foil 28 (thick foil) included. Diffusivity data on the thin foil were highly variable and were considered erroneous.
- Thermal conductivity compares well to historic data up to a divergence near ~850 K.



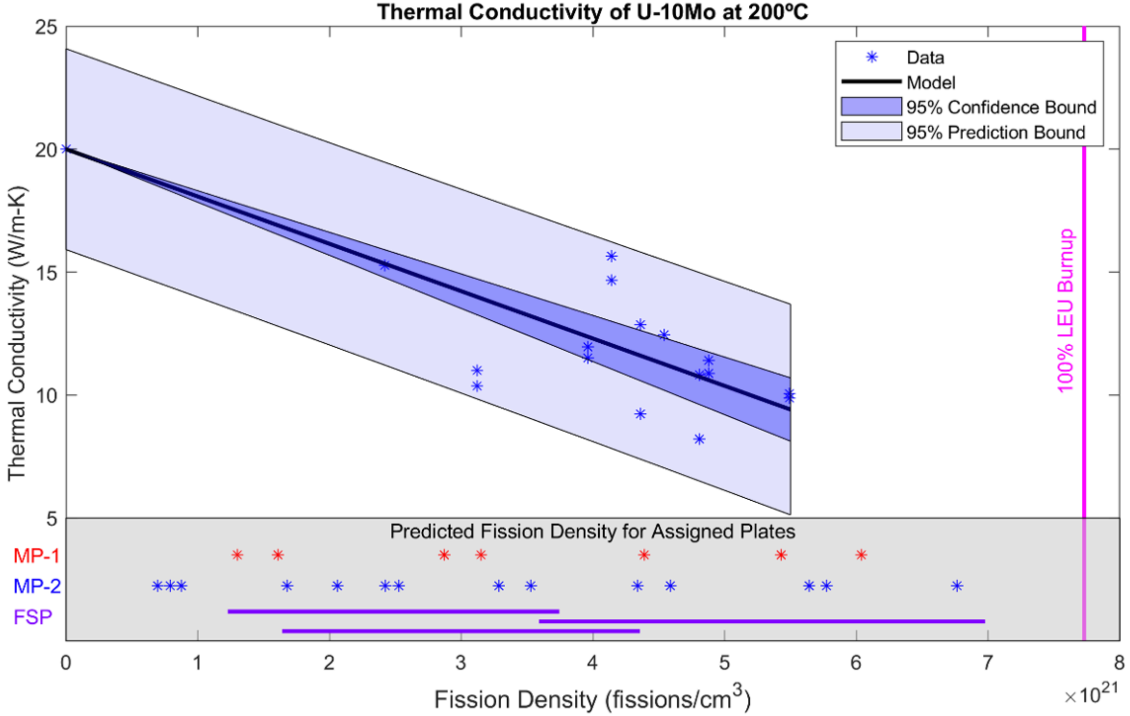
What is next?

- Paucity of data for both mechanical and thermophysical properties under relevant irradiation conditions.



J. Schulthess, et al., Mechanical properties of irradiated U-Mo alloy fuel, JNM, 2019, 515, pg. 91-106.

Will perform 4-point bending due to material constraints.



D.E. Burkes, et al., Thermal properties of U-Mo alloys irradiated under high fission power density, JNM, 2021, 547, 152823.

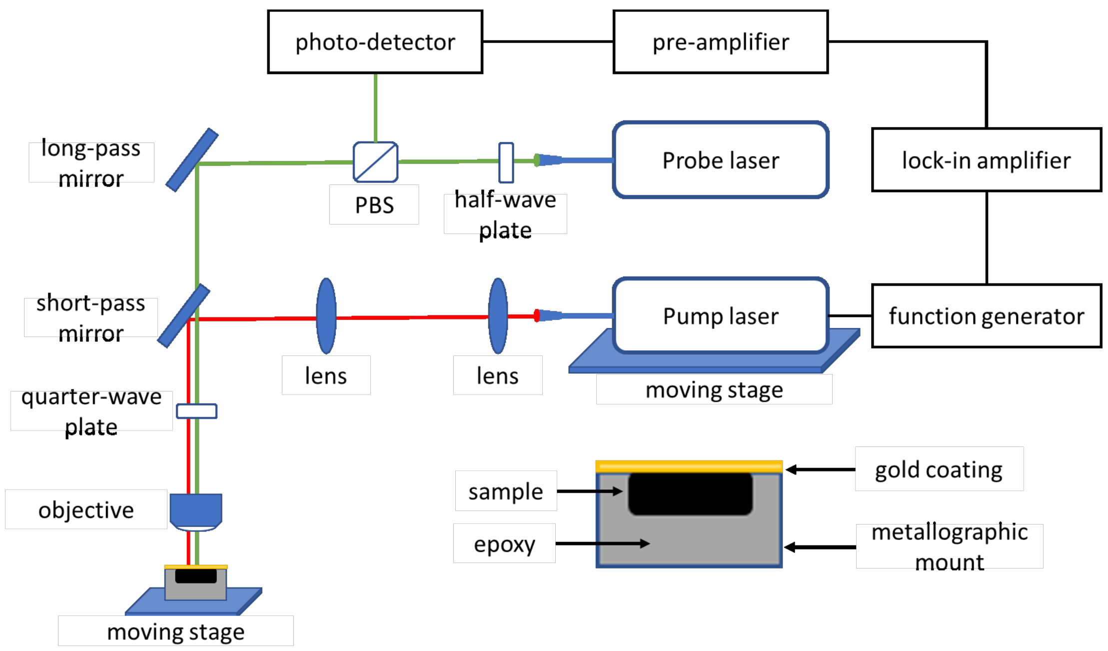
M. Marshall, et al., LEU U-10Mo Monolithic Fuel Critical Data Needs Assessment.

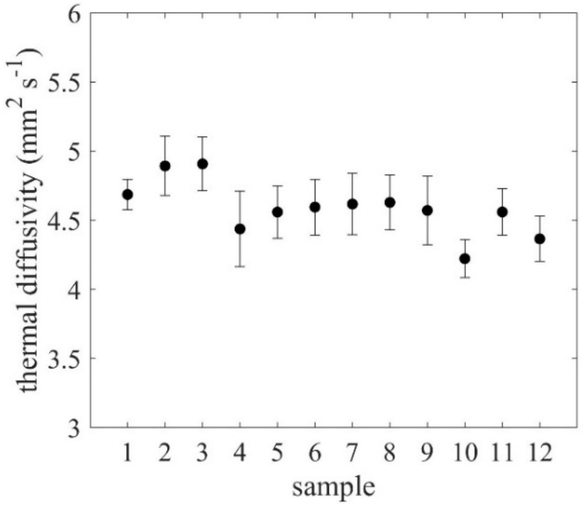
Preparations to perform thermophysical properties on irradiated material (T. Pavlov)

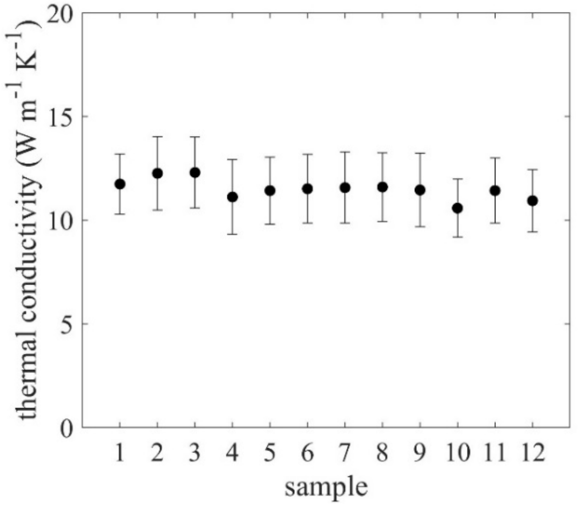
- Plate fuel geometry (layers)
- Equipment installed in a shielded enclosure
- Bulk thermal diffusivity by laser flash method
- Local thermal diffusivity by thermal reflectance (Thermal Conductivity Microscope)
- Specific heat by simultaneous thermal analyzer in differential scanning calorimetry mode
- Developed a 5-layered heat transfer model that is solved by finite element analysis

Thermal Conductivity Microscope

- At every location the thermal response measured by the detector is recorded and a phase difference between the reference (pump) and detected (probe) phases is calculated. This process is repeated at different separation distances between the pump and the probe lasers and at a range of modulation frequencies (1kHz to 100kHz).
- The phase difference is simultaneously calculated via a numerical solution to the three dimensional, two-layer transient heat transfer problem
- An optimization algorithm is employed to determine thermal diffusivity by minimizing the least squares difference between the model output and experimental data.



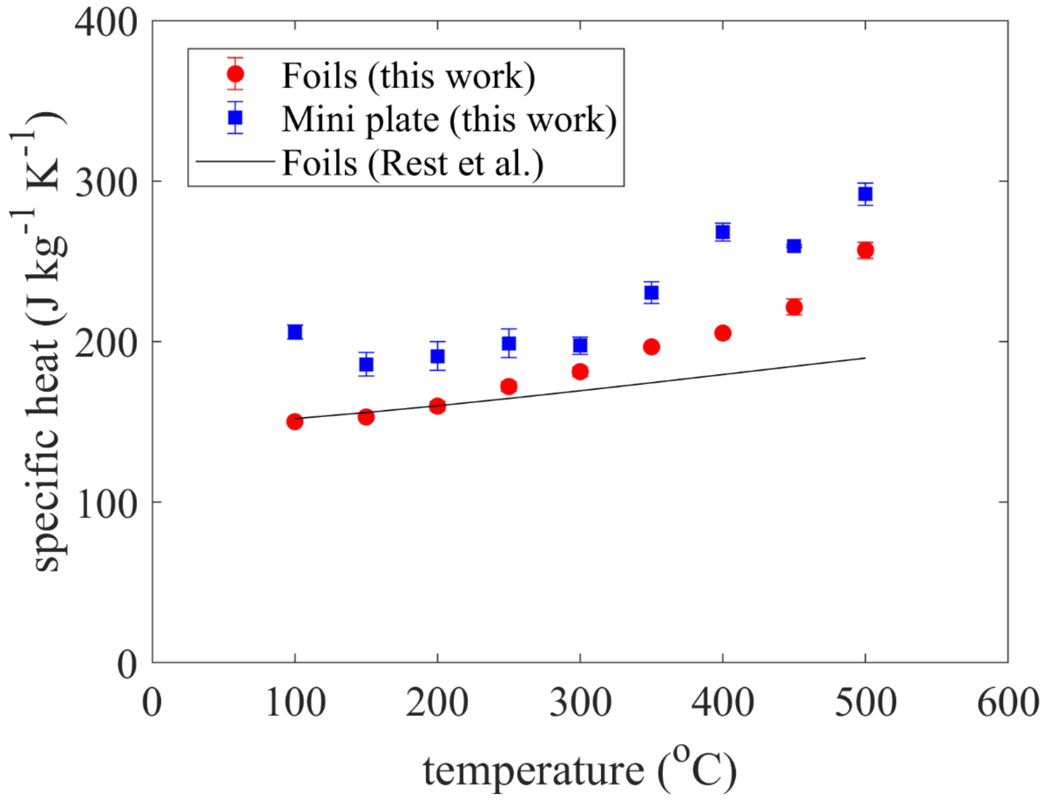




Conductivity calculated using measured diffusivity and literature values of specific heat and density using

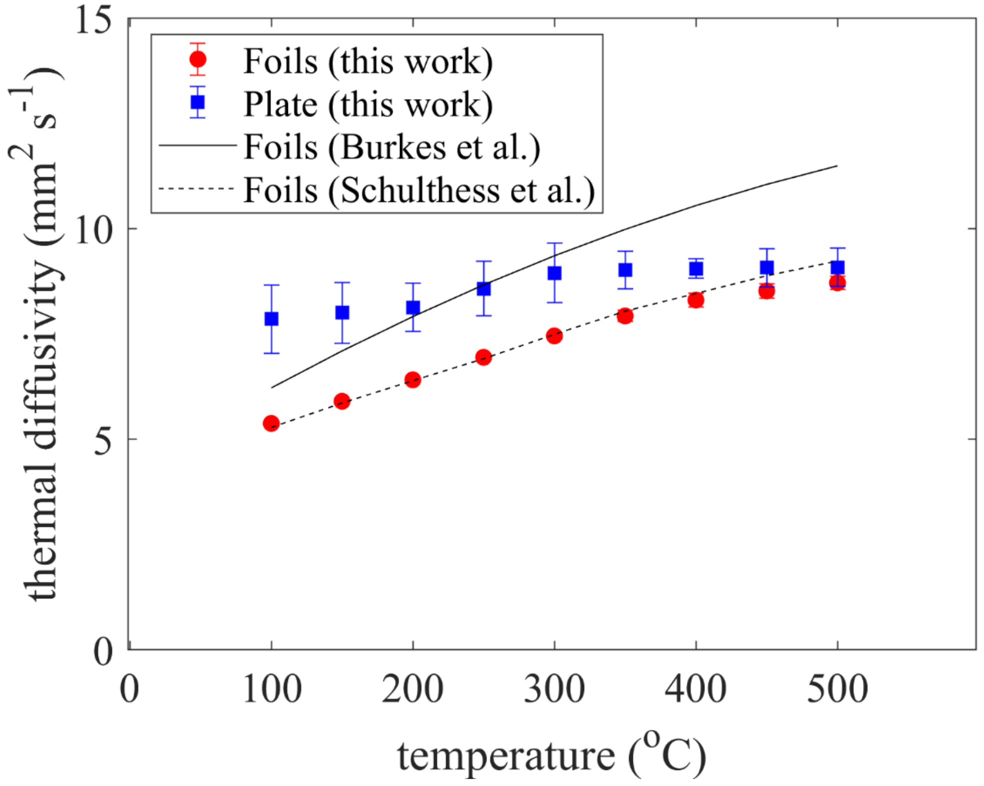
Bulk U-10Mo specific heat from DSC from both foil and layered plate (unirradiated)

- Specific heat foil data shows good agreement with previous foil data up to 300 C.
- The results obtained from fuel plates trend higher above 300 C than the data from Rest et al., and the foils from this work.
- Additional experiments are to be performed to confirm the higher specific heat values associated with the miniplates



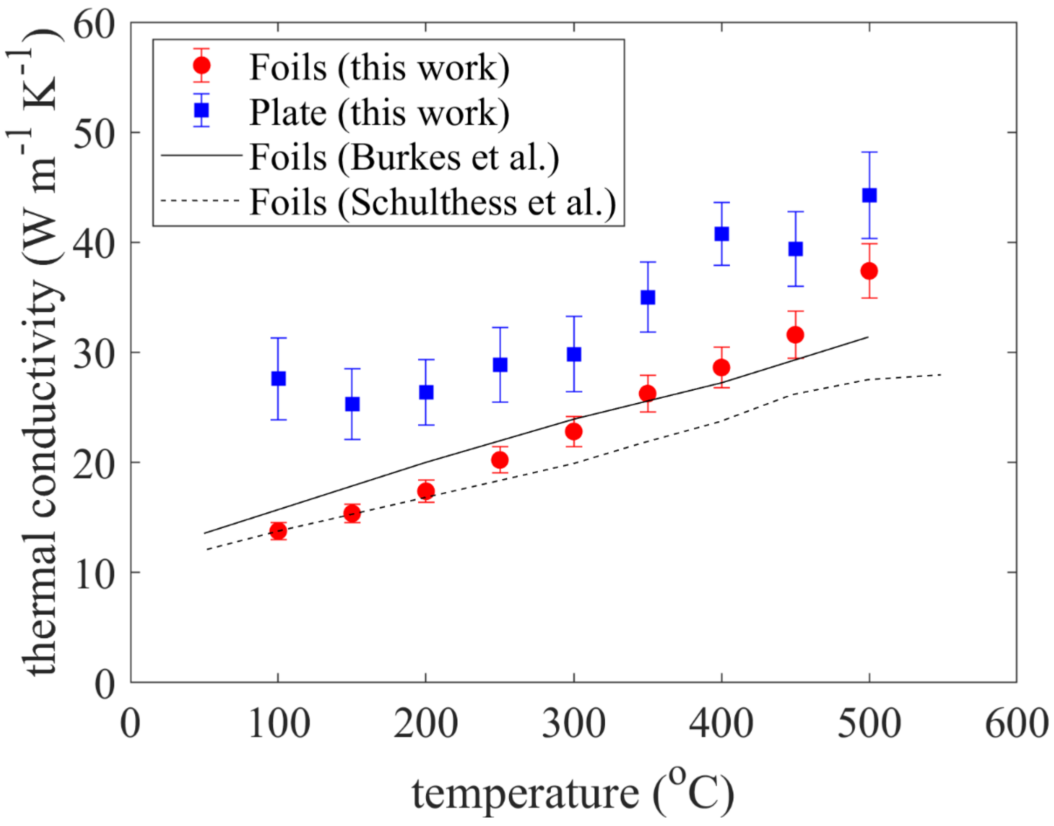
Bulk U-10Mo thermal diffusivity from LFA from both foil and layered plate (unirradiated)

- Thermal diffusivity foil data shows good agreement with previous foil data
- Higher specific heat for the plate configuration may be related to a mixed radiation-conduction heat transfer mechanism due to the pristine aluminum alloy surface being semi-transparent at the laser wavelength.
- Future work will include coating the samples with carbon paint to ensure absorptivity.



Bulk U-10Mo thermal conductivity from measured diffusivity and specific heat from both foil and layered plate (unirradiated)

- Assumed density from literature data.
- Foil data shows good agreement with previous literature.
- Fuel plate data trends higher compared to foil and is due to higher diffusivity and specific heat measurements that propagate through the calculation.
- As previously noted, additional work is planned to better understand these measurements.



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