Non-destructive Post-Irradiation Examination and Fuel Swelling Analysis of the MP-1 Irradiation Experiment

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Abstract

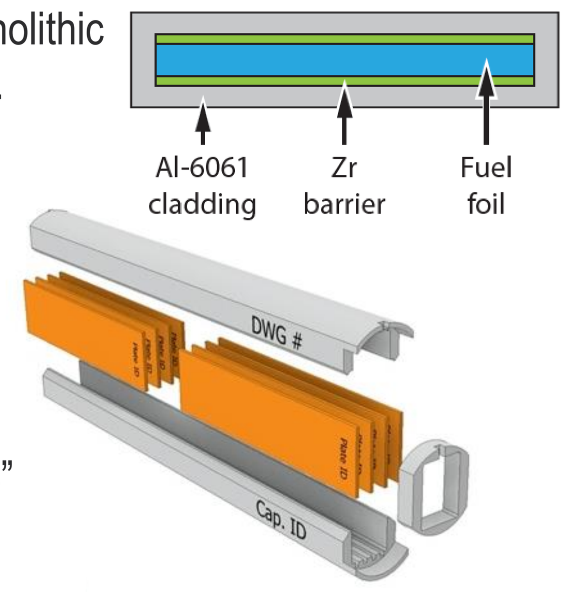
Non-destructive post-irradiation examination (NDE-PIE) and a fuel-foil swelling analysis were completed for the Mini-plate 1 (MP-1) irradiation experiment. This is the most recent test to support the generic qualification of low-enriched uranium (LEU), U-10Mo monolithic, plate-type fuel. The irradiation performance of 62 plates fabricated at a commercial scale was compared against 12 INL fabricated plates. Two fuel geometries from each source were irradiated at the INL Advanced Test Reactor, with "thick-fuel" plates irradiated at a low-power (5-10kW/cm^3) to a moderate fission density (0.76-2.82 × 10^{21} fission/cm^3) and "thin-fuel" plates irradiated at a medium-power (~20-35 kW/cm^3) to a high fission density (2.85-5.56 × 10^{21} fissions/cm^3). Highlights of the experiment NDE-PIE, including visual examination, neutron radiography, gamma spectrometry, and plate profilometry, will be presented. Additionally, the MP-1 fuel-foil swelling behavior was characterized and will be compared against the USHPRR-FQ currently recommended model of the U-10Mo swelling.

Mini-Plate 1 (MP-1) Background

- Intended to evaluate commercially fabricated U-10wt%Mo monolithic plate-type fuel with a Zr diffusion barrier and Al-cladding with…

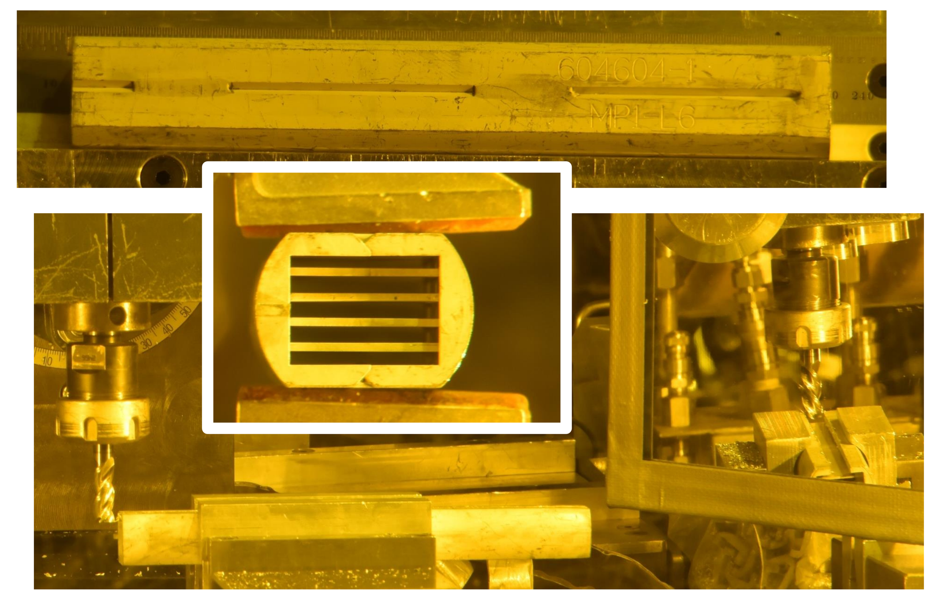
	LP Thick Fuel	MP Thin Fuel
Nominal Fuel Foil Thickness	0.6350 mm	0.2159 mm
Commercial Plates (BWXT)	34	28
Reference Plates (INL)	8	4
Total Plates	42	32
Average Power Density	5–10 kW/cm^3	20–35 kW/cm^3
Average End of Life Fission Density	0.76–2.28×10^{21} fissions/cm^3	2.85–5.56×10^{21} fissions/cm^3

- Capsules, each with 8 mini-plates, were irradiated in ATR in "B" positions and the South Flux Trap



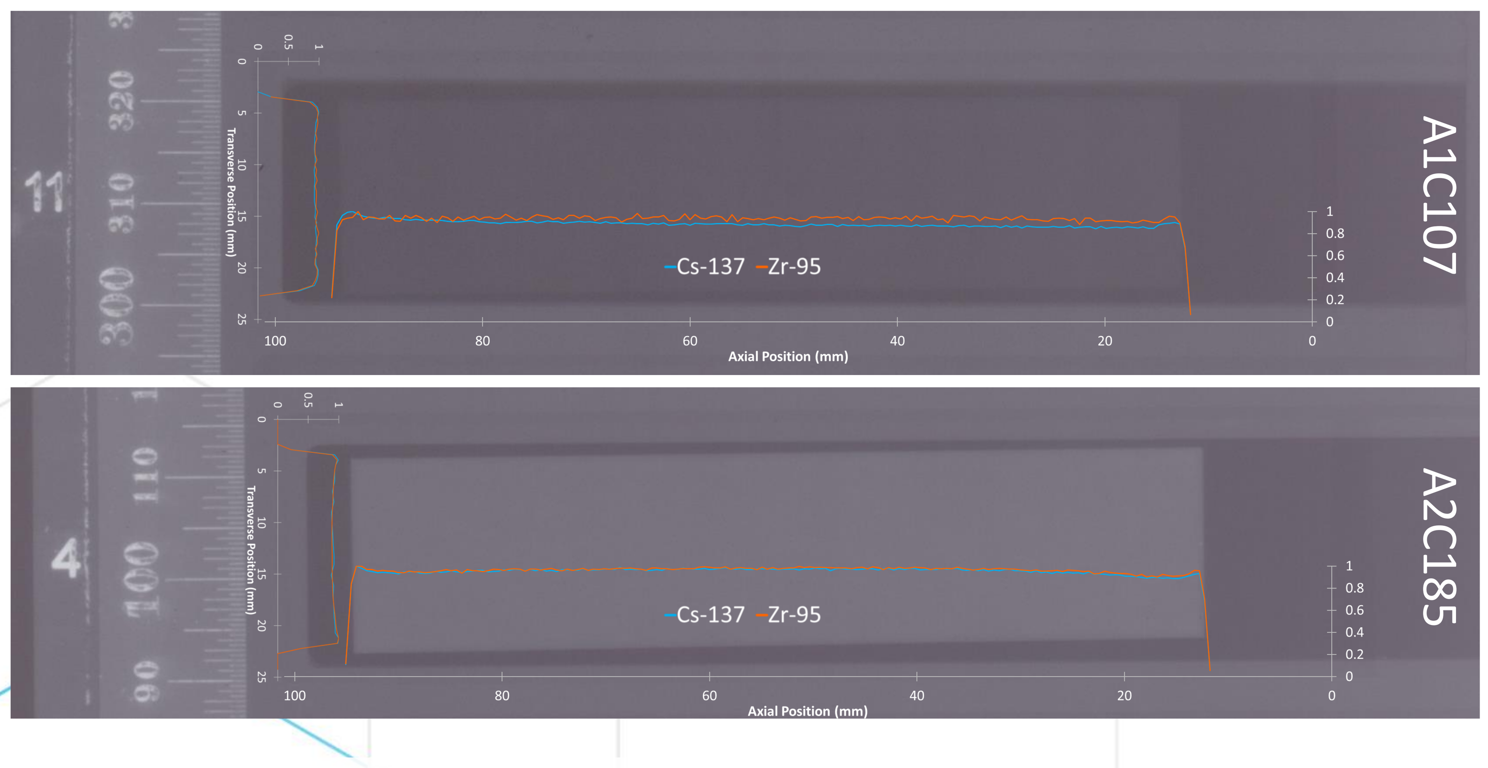
Visual Examinations

- Evaluate the condition of the capsules prior to disassembly
- Following disassembly, front and back surfaces of plates are examined and imaged



Neutron Radiography and Gamma Spectrometry

- Radiography and gamma spectrometry performed to non-destructively examine the fuel zone and fission product inventory
- No fuel cracking, relocation, or fission product migration detected



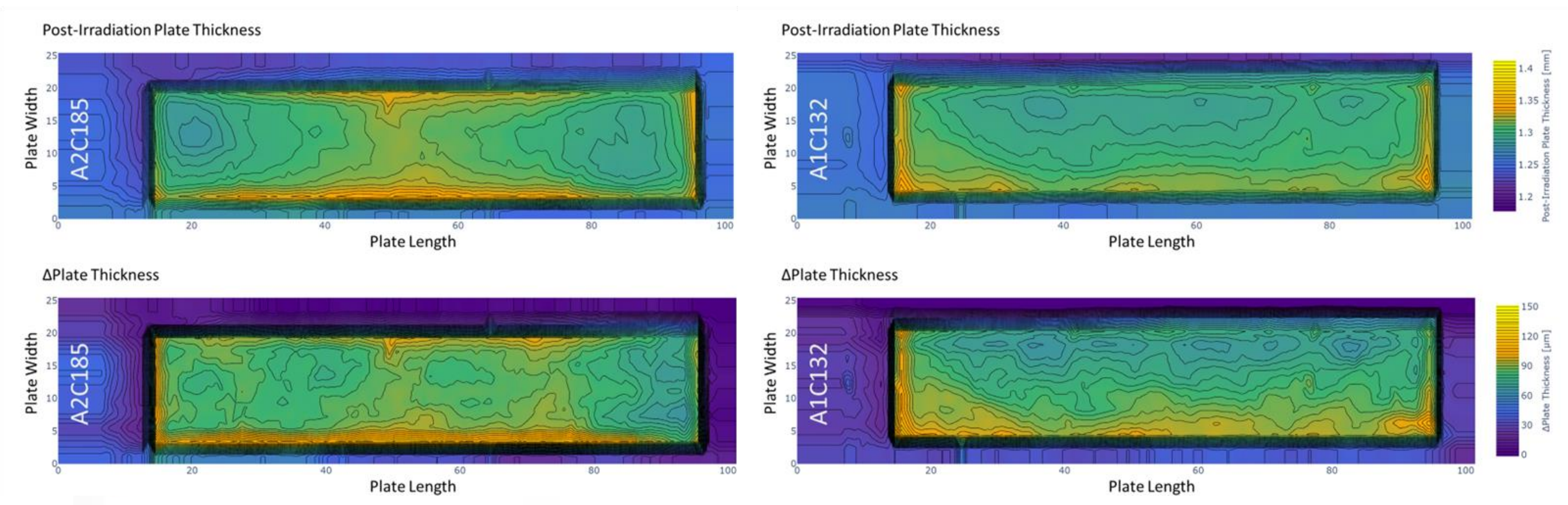
Medium Power Commercial

Low Power Commercial

Post-Irradiation Profilometry

- BONA4INL measurement bench used to characterize the surface of each mini-plate
  - 1×2 mm measurement grid utilized
  - Location resolution of ±20 µm
- Thickness measurements recorded with Sony Magnascale probes with a ±3 µm resolution
- Mini-plate profilometry appears consistent with anticipated plate swelling behavior

MP-1 Plate A2C185 MP-1 Plate A1C132



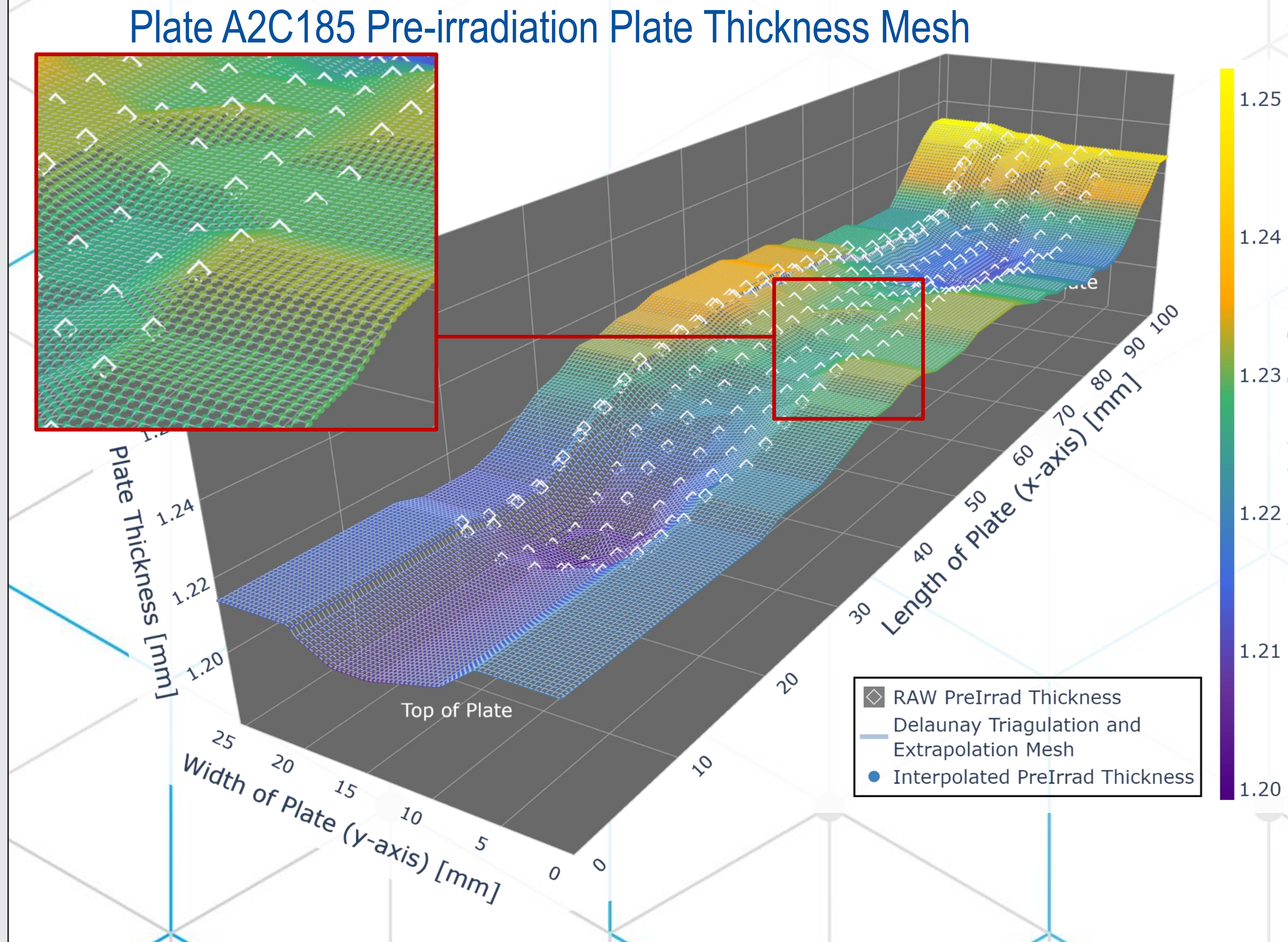
Fuel Swelling Analysis

- Associate pre- and post-irradiation profilometry measurements to ID-reference frame
- Interpolate (Delaunay triangulation) and extrapolate ("edge-hull") pre-irradiation values to PIE measurement coordinates
- Calculate Swelling
  - May neglect oxide term as correction factor is within the resolution limits of the BONA4INL measurement bench

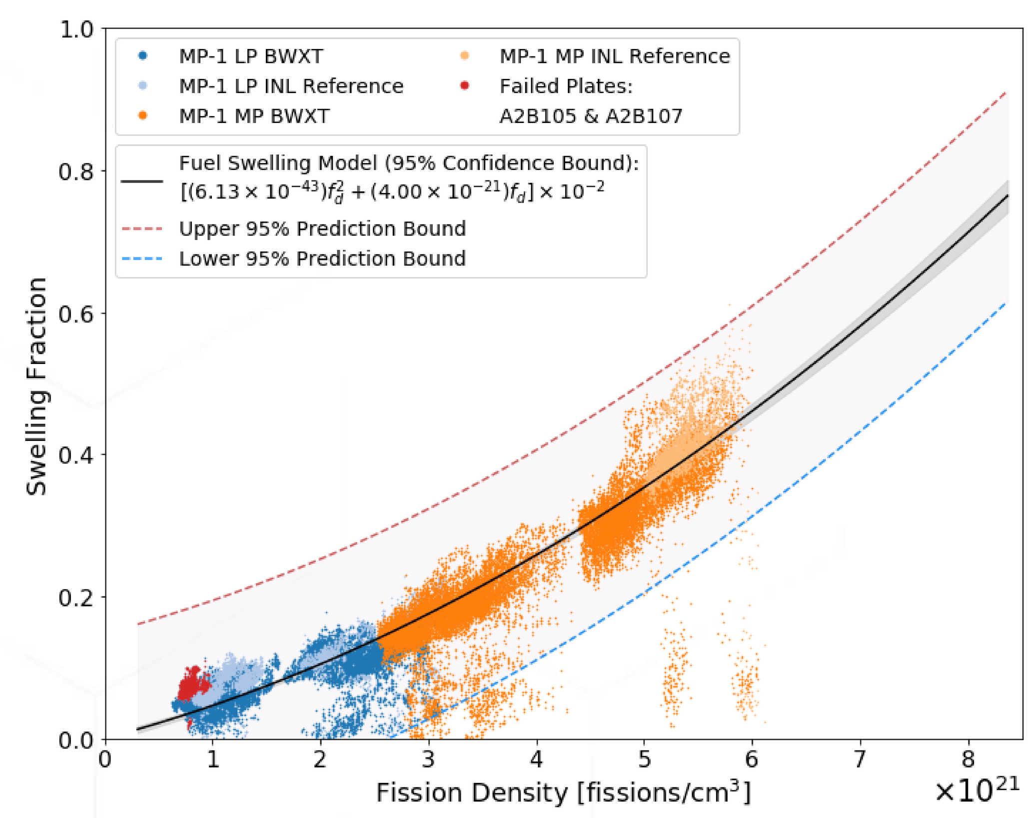
$$Fuel\ Swelling\ Fraction = \frac{T_{plate,PIE} - T_{plate,pre} - \left(1 - \frac{1}{1.975}\right)T_{ox}}{T_{foil,pre}} = \frac{T_{plate,PIE} - T_{plate,pre}}{T_{foil,pre}}$$

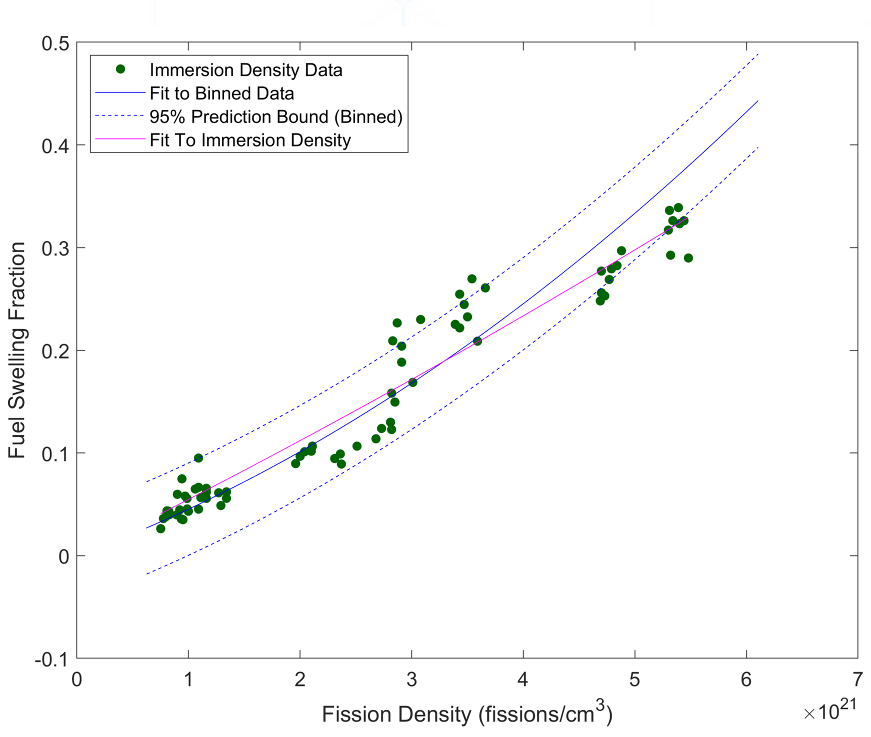
BONA4INL Resolution Limit

Plate A2C185 Pre-irradiation Plate Thickness Mesh



- Validate local fuel swelling values with…
- …currently recommended U-10Mo Swelling Model
  - Fuel swelling appears consistent with historic U-10Mo behavior
- …purely volumetric plate average swelling (immersion density)
  - Majority plate average values within prediction bands





- Comparison was made between the swelling behavior of the commercial and INL fabricated plates
- While a statistical difference is detected, each data-set appears stable and within the prediction bands of the other