Advances in Research and Test Reactor Plate Stability for LEU Conversion

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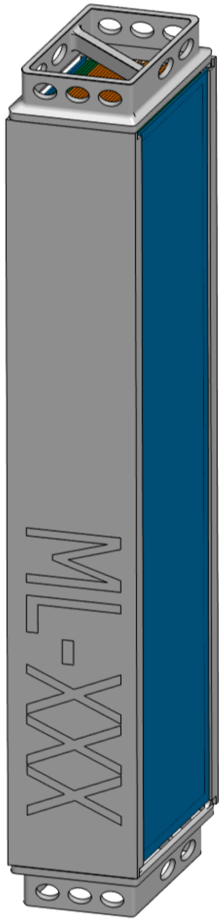
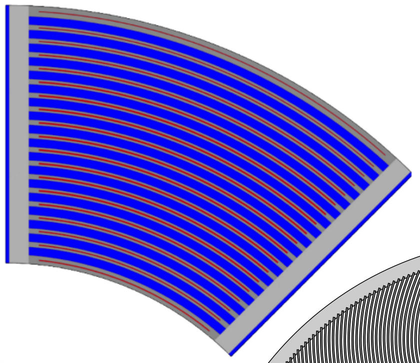
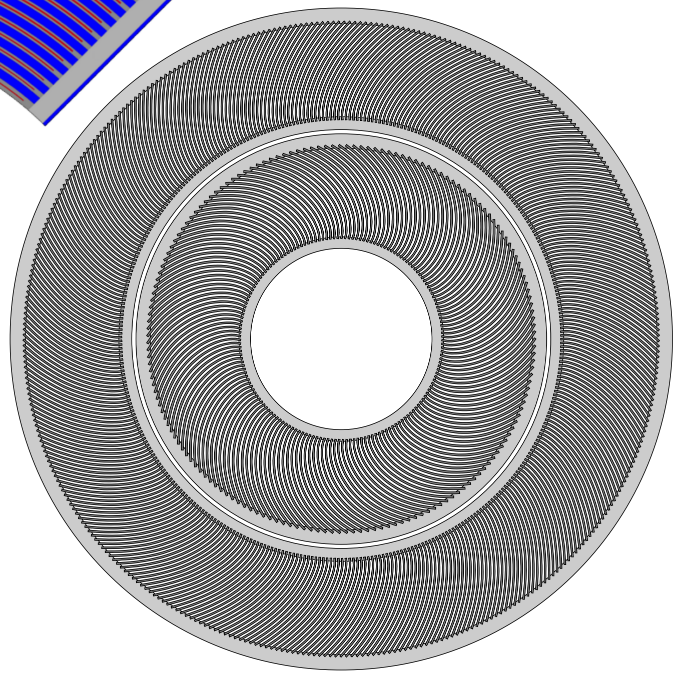
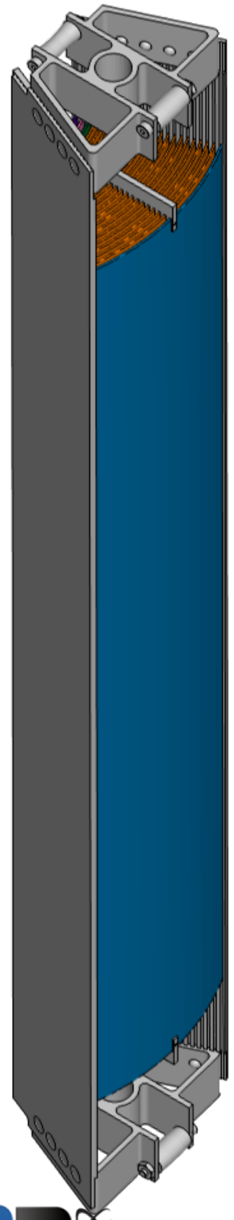
U.S. High Performance Research Reactor Designs

- U.S. Reactor Conversion Program converting U.S. High Performance Research Reactors (USHPRR) to high assay low-enriched (19.75%) fuel
  - Massachusetts Institute of Technology Reactor (MITR)
  - Univ. of Missouri Research Reactor (MURR)
  - National Institute of Standards & Technology Reactor (NBSR)
  - Idaho National Laboratory - Advanced Test Reactor (ATR)
  - Oak Ridge National Laboratory - High Flux Test Reactor (HFIR)
- Preliminary Designs completed for LEU U-10Mo monolithic fuel elements
- HFIR pursuing U_3Si_2 dispersion fuel 4.8-5.3 gU/cc









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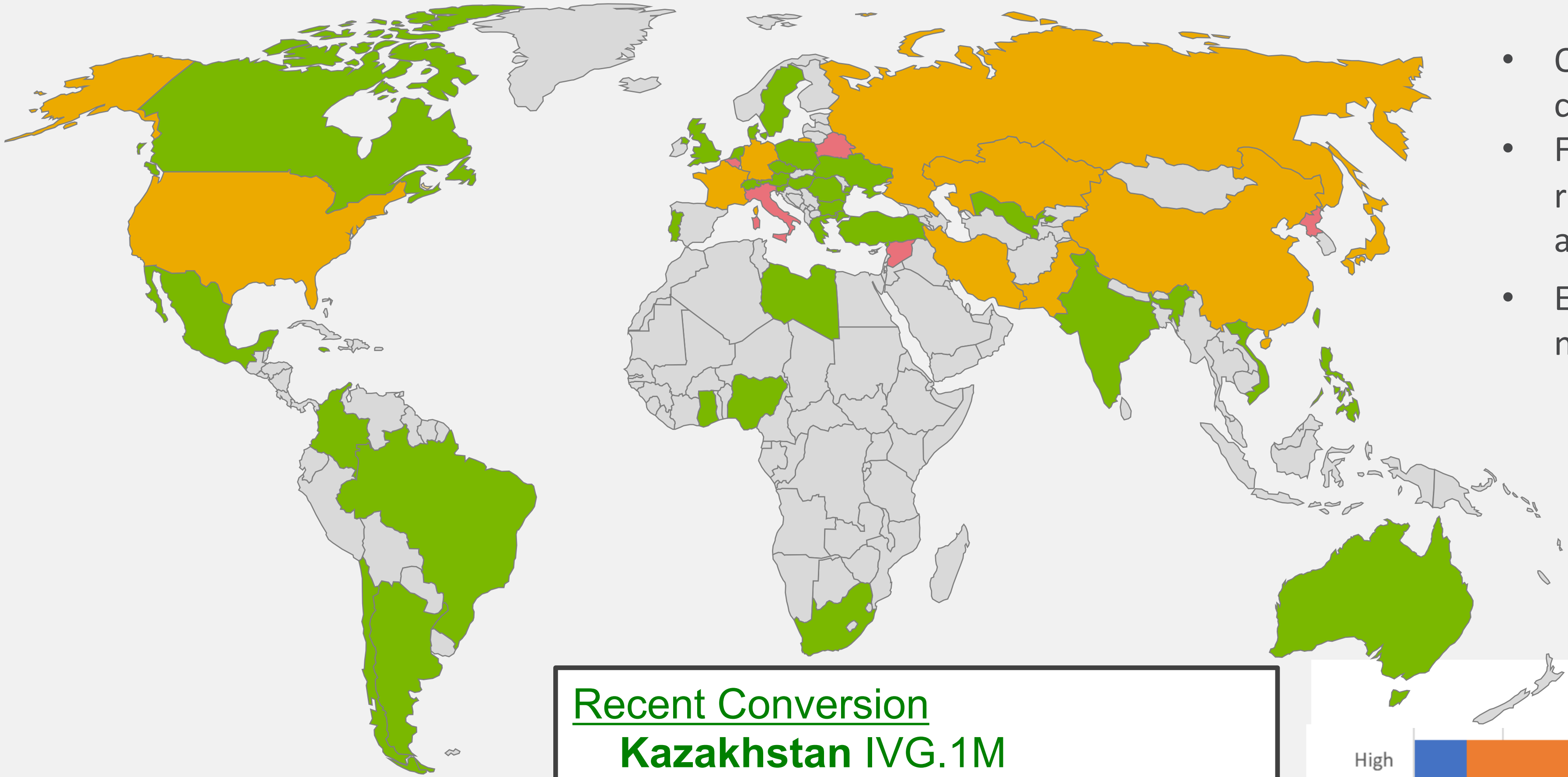
Reactor Conversions from Highly Enriched Uranium Worldwide Status



- Reactor Conversions complete
- Reactor Conversions occurred but scope remains
- Reactor Conversions have not yet occurred

- Over 70 reactor conversions to LEU completed
- For remaining reactors, one-third of reactors to be converted are high flux and high utilization
- Each conversion contributes to nonproliferation
  - High-performance reactors refuel multiple times annually
  - EU and USHPRR and other HPRR provide major reductions to civilian use of HEU

Recent Conversion

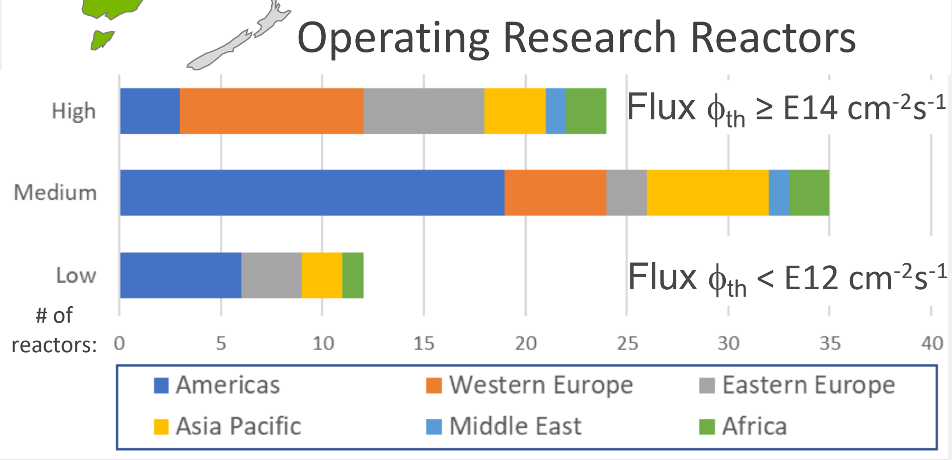
Kazakhstan IVG.1M

LEU 1st critical 2022 @ power 2023

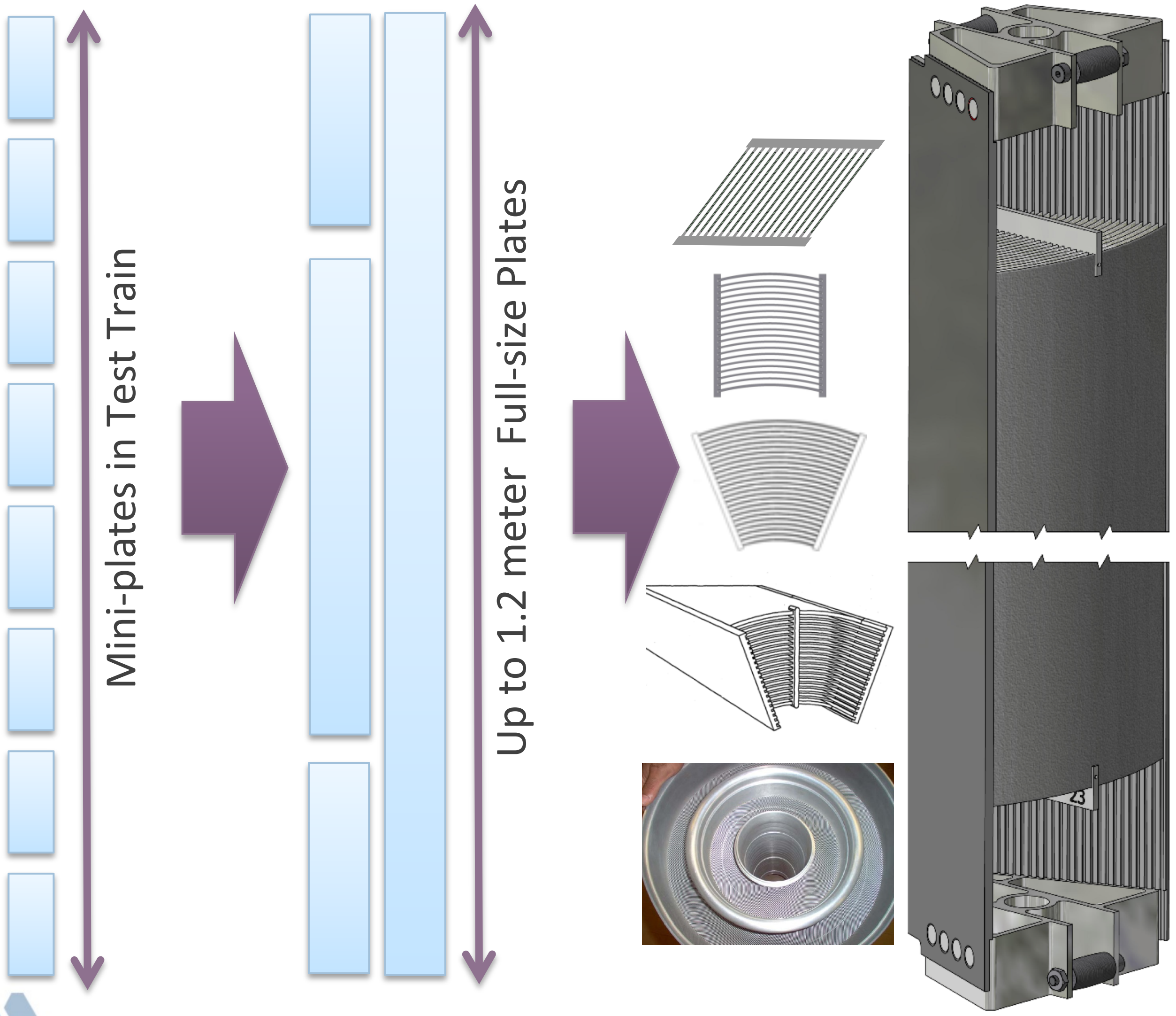
Next ~2 years (manufacturing in-progress)

Japan (KUCA wet & dry cores)

Belgium (BR2)



USHPRR Conversion Project Progression



- Phased LEU Conversion Strategy
  - Assembly/core design
  - Fabrication development & demonstration
  - Progressive irradiations & assembly hydraulic testing
    - **Scale:** mini-plate, full-size plate, test element
    - **Volume:** single plates to multiple qualification assemblies
    - **Maturity:** progress to full product demonstration
  - Regulatory review in stages
    - **Preliminary UMo report** ✓
    - **Preliminary Design & Safety Analysis** ✓
    - **Final Fuel Qualification Report**
    - **Conversion Analysis with final fabrication & irradiation data**

    → Conversion SAR

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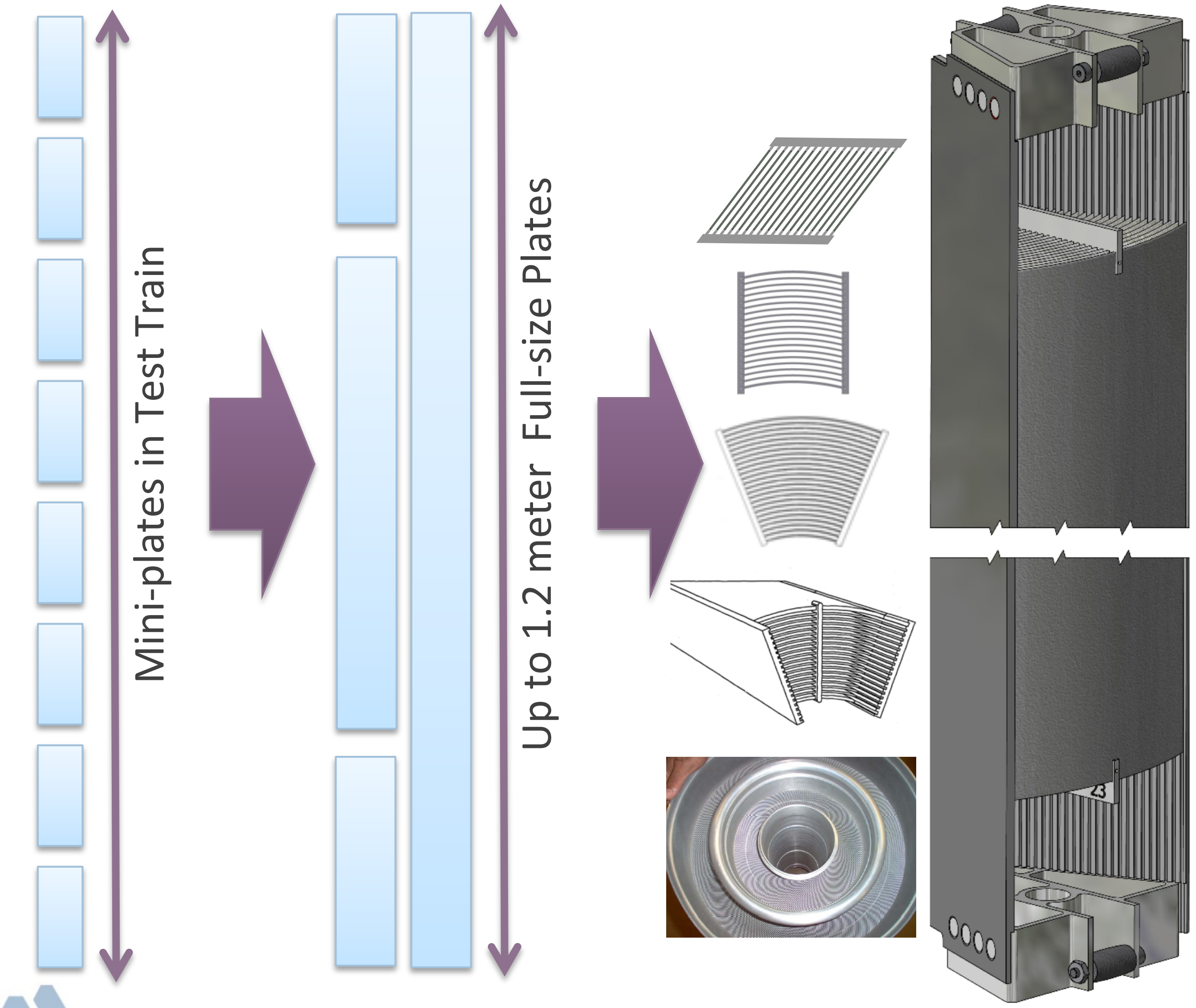
USHPRR Conversion Project Progression



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Procurement Specifications ✓

Reactor Fuel Element Drawings ✓(5)

1st Commercial RFP ✓

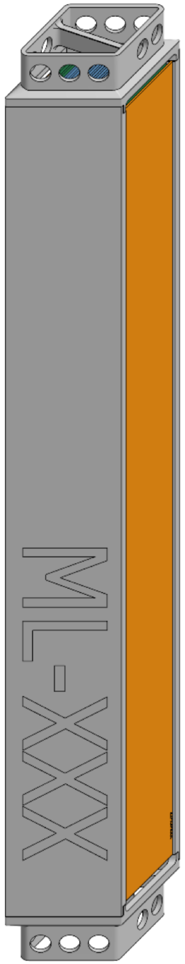
U.S. High Performance Research Reactor Detailed Design

- LEU Preliminary design completed
  - LEU fuel element designs included some thinner plates
    - Half of the USHPRR plates are thinner

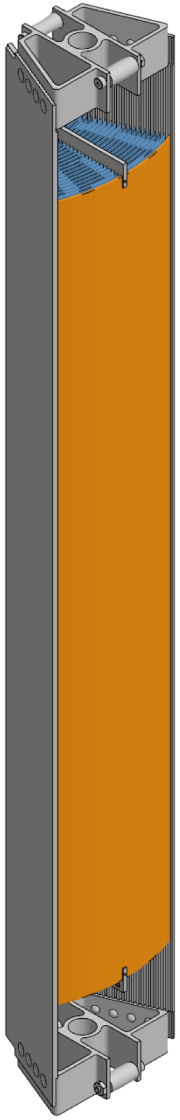
Plate Thickness	LEU	HEU	Plate Type
MURR (1-22)	1.1 mm	1.3 mm	Curved
MITR (1-19)	1.2 mm no fins	1.5 mm, 2 mm w/fins	Flat

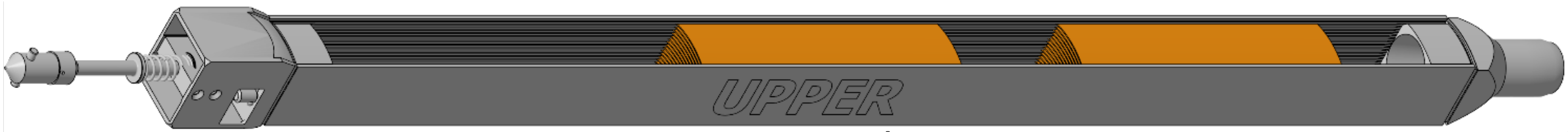
  - Extended burnups for high-density fuel
  - Maintains performance, some power uprates
- Progress on detailed design
  - Single specification for U-10Mo fabrication
  - Fuel element drawings maturation
  - Working on feedback from full element fabrication

MITR LEU element



MURR LEU element



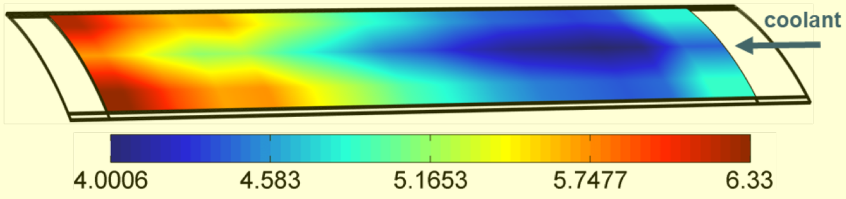


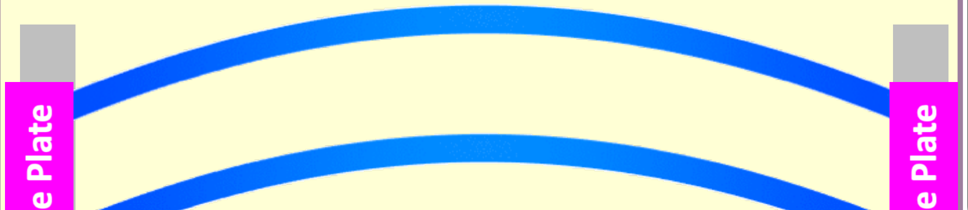
NBSR LEU element

Structural Analysis in Detailed Design

Irradiation Thermo-Mechanical

Fission Density Distribution at EOL, 10^{21}fis.cm^{-3}



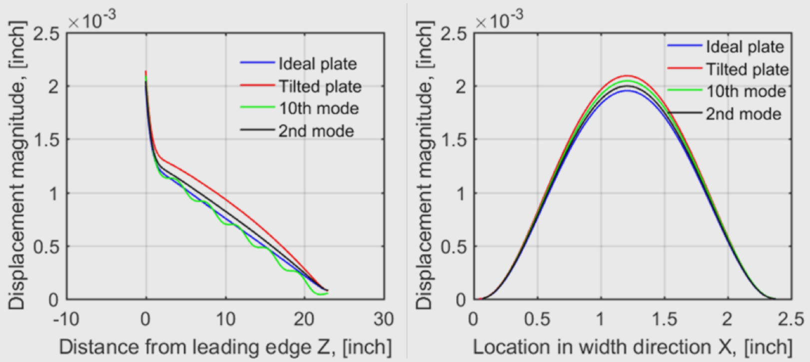


Two Plates & Coolant Channel (scale enhanced)

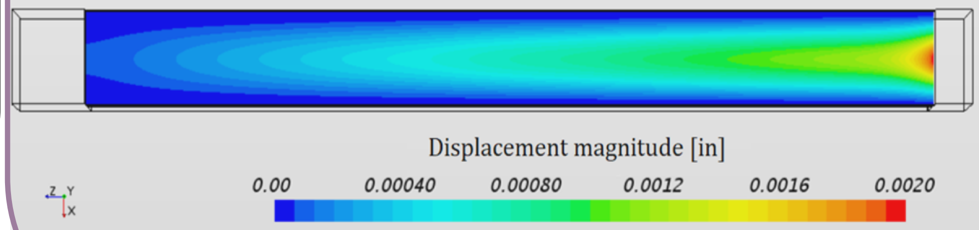
- **Includes structural evaluations of the components modified for LEU conversion**
- **Plate-level and assembly-level with coolant channels**
- **Comprehensive prediction of effects before testing**
  - **Irradiation tests**
  - **Flow testing**
- **Supports LEU designs, including thinner plates**

Fluid-structure Interaction (FSI)

Predicted fuel plate displacement profile at
(a) plate center line (b) plate leading edge



Fuel plate displacement contour

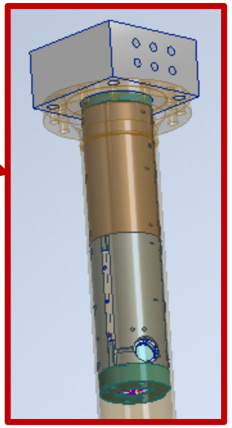


LEU U-10Mo Fuel Element Design Testing

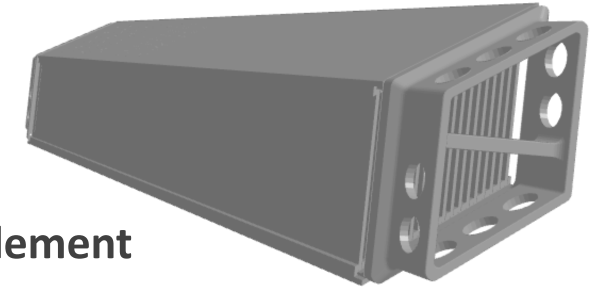
Irradiation Testing @ATR & BR2

- Irradiate Design Demonstration Elements (DDE) assemblies
- Fuel plates identical to the designs
- Adjusted only to fit into test reactor
- Commercially-fabricated fuel assemblies

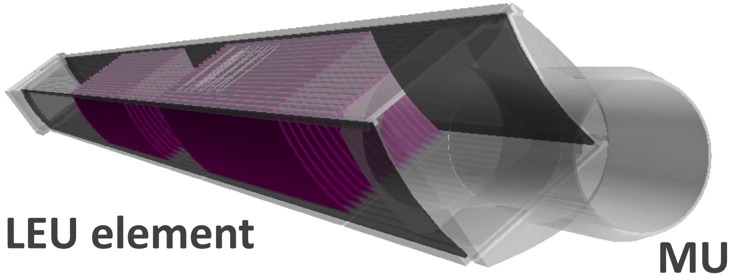
Hydraulic Testing @OSU HMFTF



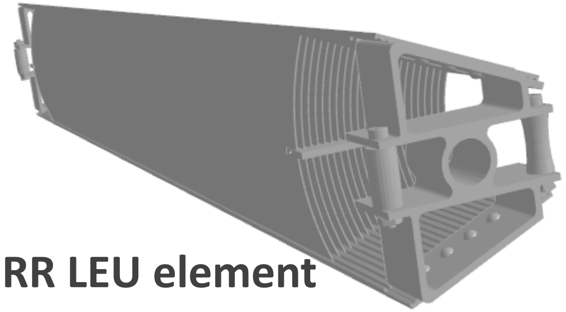
Flow Test Vehicle



MITR LEU element



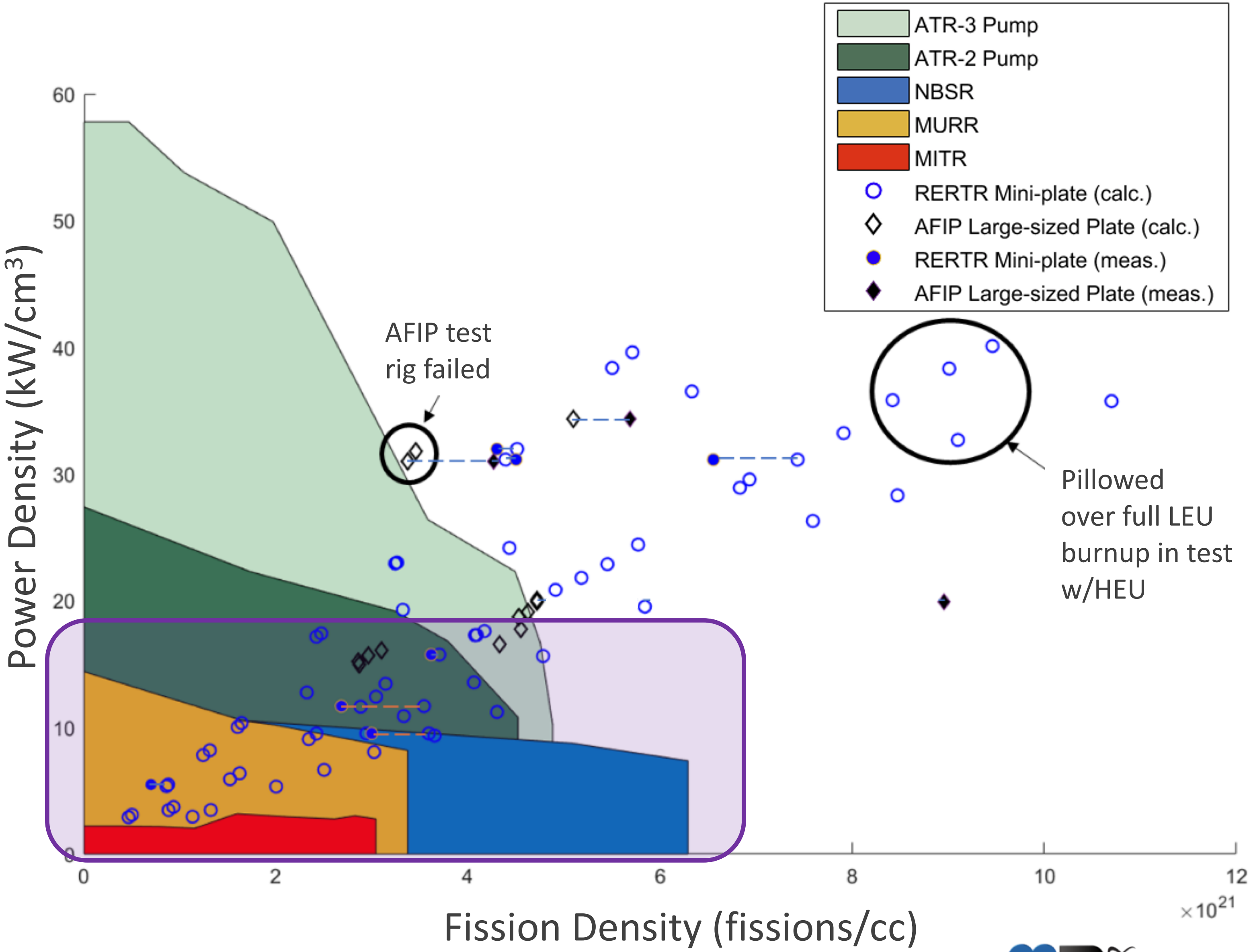
NBSR LEU element



MURR LEU element

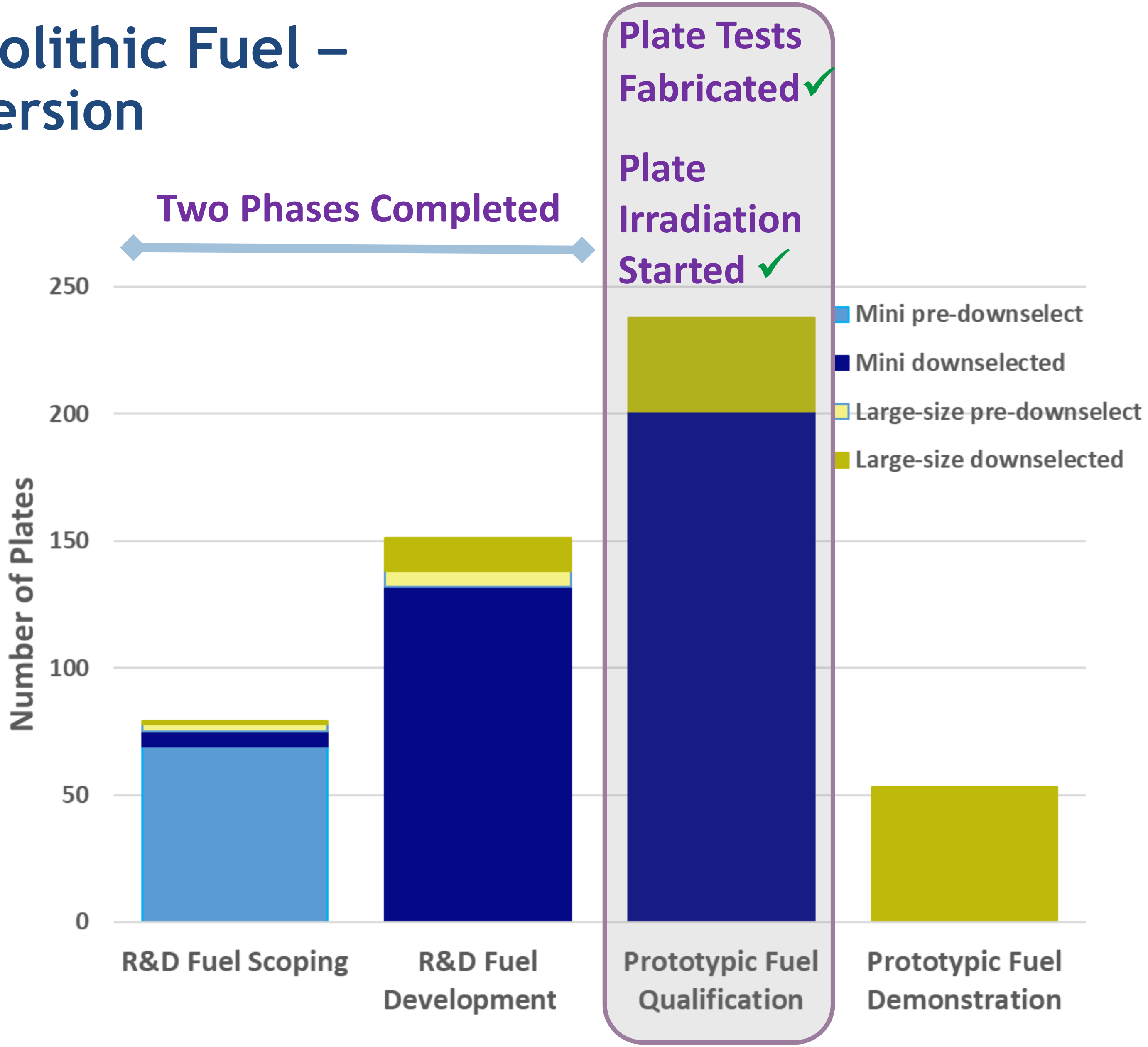
USHPRR Reactor Design Parameters & U-10Mo Irradiation Testing

- LEU design space well-covered for first planned conversions (pre-commercial fabrication)
  - No failures in fuel testing until plates exceed full LEU burnup
  - Future testing with each reactor-specific fuel plate & element designs → **prototypic commercially fabricated LEU tests**
- ATR conversion requires testing at higher power density



Irradiation Testing of U-10Mo Monolithic Fuel – Data at Time of First USHPRR Conversion

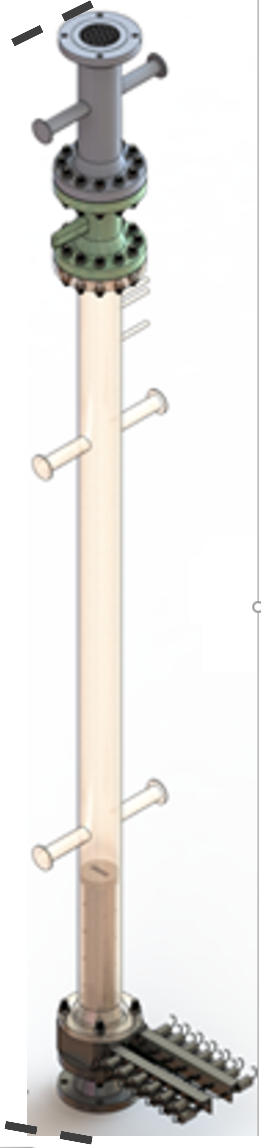
- USHPRR has completed several stages and has substantial progress towards fuel qualification
- Presently all commercially fabricated plates – showing no performance issues to date
- Completed fabricating mini-plate and full-sized plate tests
  - All commercially fabricated
  - Finishing inspections on full-size plates
  - Qualification irradiations have begun
- Next step is full fuel assemblies



LEU Fuel Element Hydraulic Testing

Oregon State University (OSU)
Hydro-Mechanical Fuel Test Facility

- Conversion Fuel Element hydraulic performance tests to demonstrate that no failure modes are observed in the redesigned USHPRR LEU elements
  - **Redesigned USHPRR LEU elements**
  - **Account for variables in reactor flow conditions**
- Combined with Hydraulic Performance evaluation modeling
  - Validated modeling based on plate experiments
- Flow testing of the **prototypic commercially-fabricated LEU conversion elements** will observe for significant deformations in the plates and coolant channel changes



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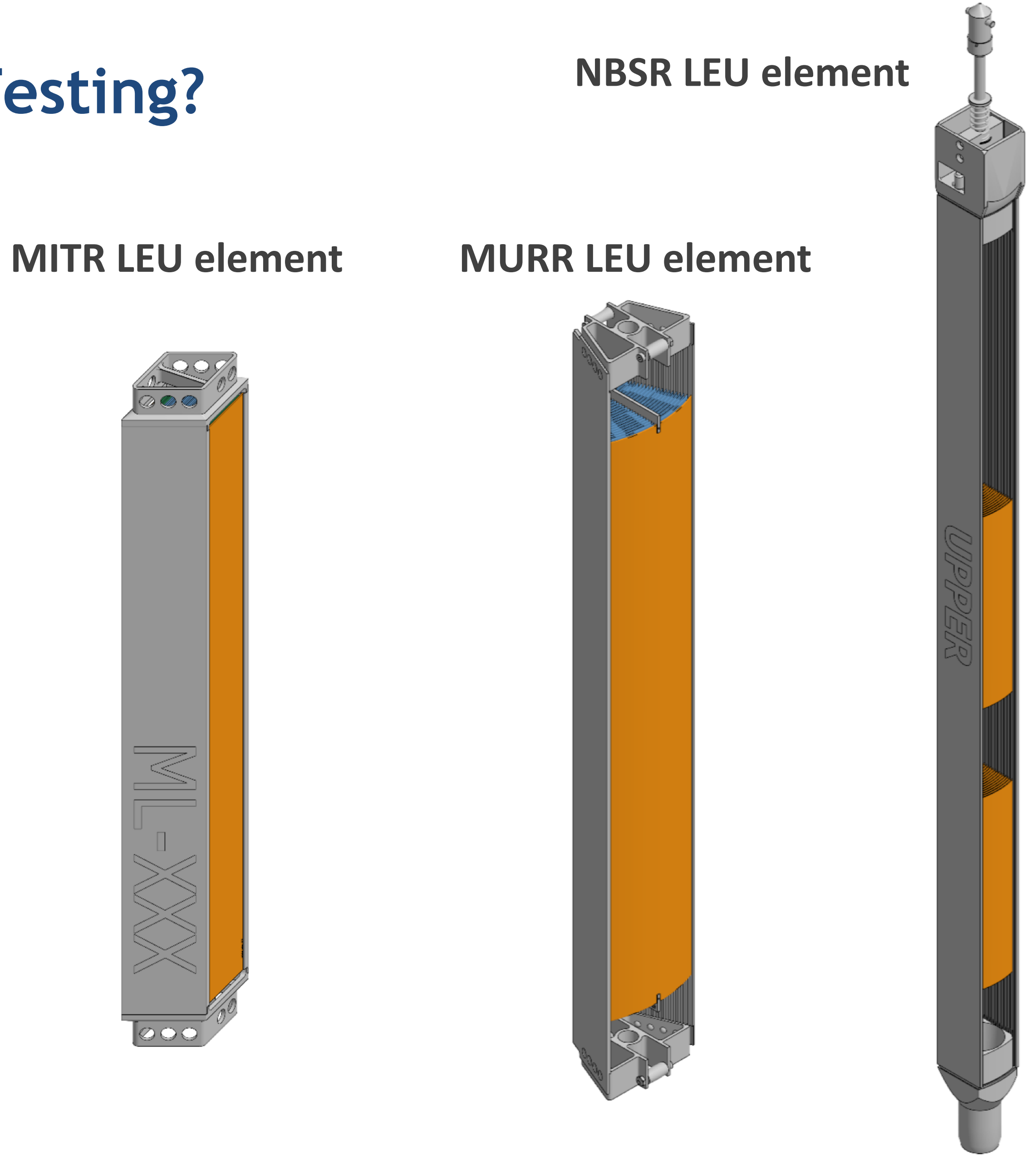
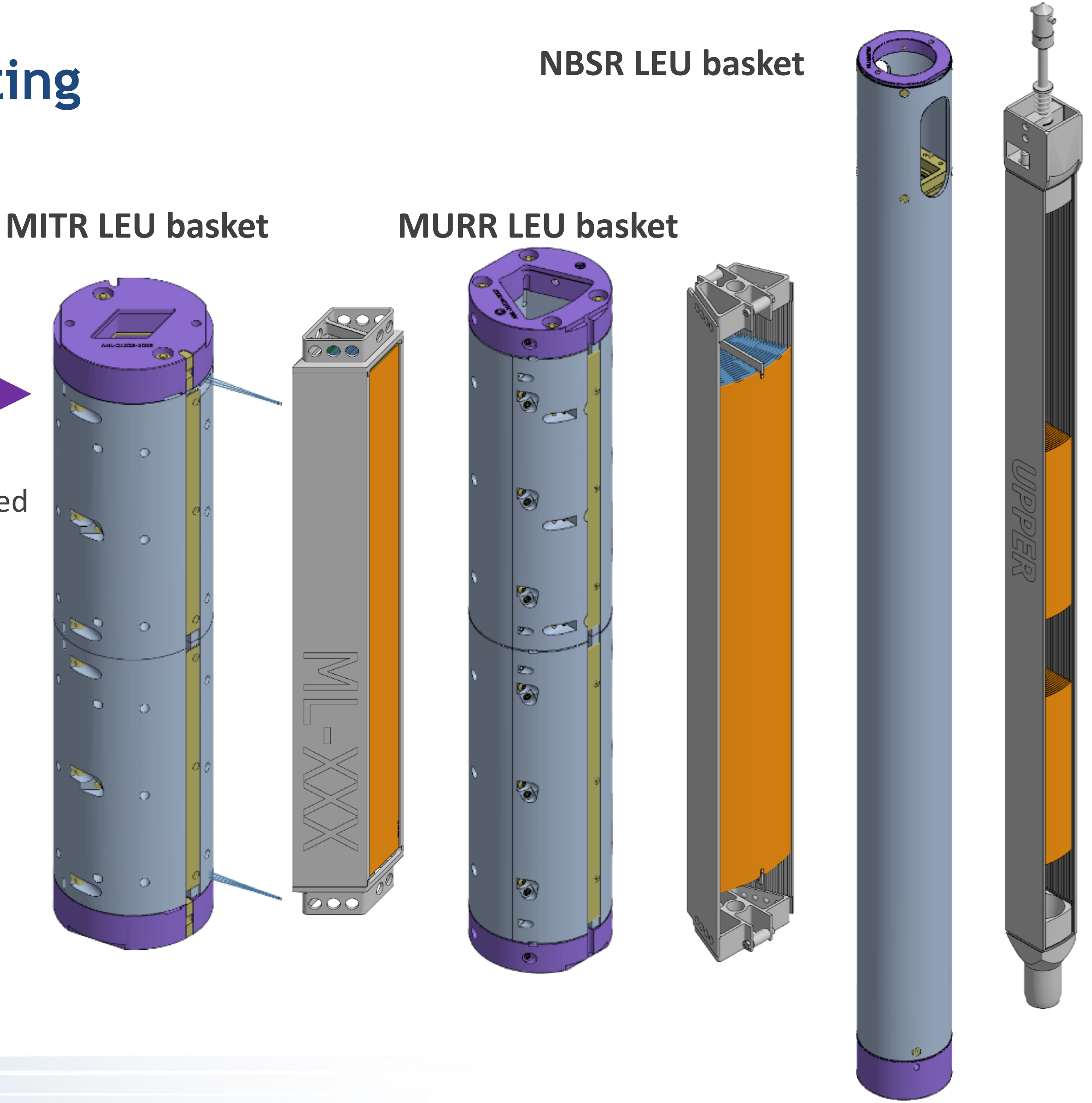
Why LEU Fuel Element Hydraulic Testing?

- The hydro-mechanical stability of the fuel elements should be evaluated
- U.S. NRC guidelines
- Re-design of the LEU fuel elements vs. HEU include, as needed:
  - Change number of plates
  - Remove fins
  - Some plates thinner
  - Coolant channel gap thickness
  - Fuel density
  - Multiple fuel thicknesses per element
  - Element weight
  - Increased flow velocity



Fuel Element Hydraulic Testing

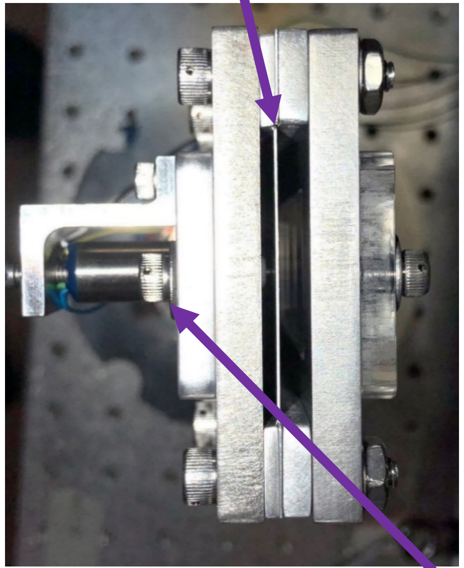
- Hydraulics testing requires several components
- Test vehicles for LEU fuel elements
  - MIT test vehicle for LEU fuel element
    - Prototype designed, manufactured & fit tested
  - MURR test vehicle
    - Basket being fabricated
  - NBSR test vehicle
    - Basket being designed
- Sensors to detect plate behavior in coolant channels during testing
- Post-test examination for deformations

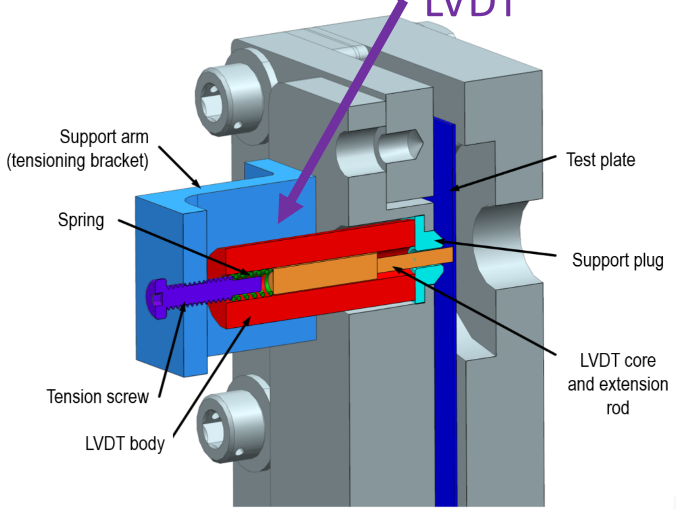


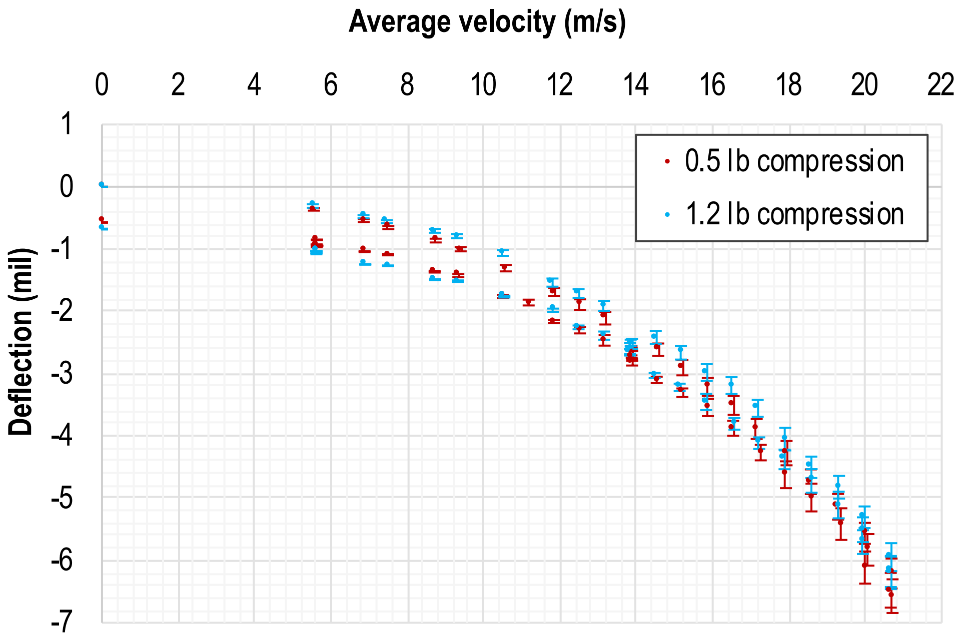
Sensor Evaluation

Endurance Flow Loop at OSU

LVDT Sensor Test with Flat Plate and Curved Plate







- LVDT detects small deflections of thin plates with desired accuracy
- Experimental and Fluid-Structure analysis shows LVDT does not disturb the characteristics of flow-induced deformation
- Other sensors tested (inductive, laser systems, borescope and machine vision) not selected

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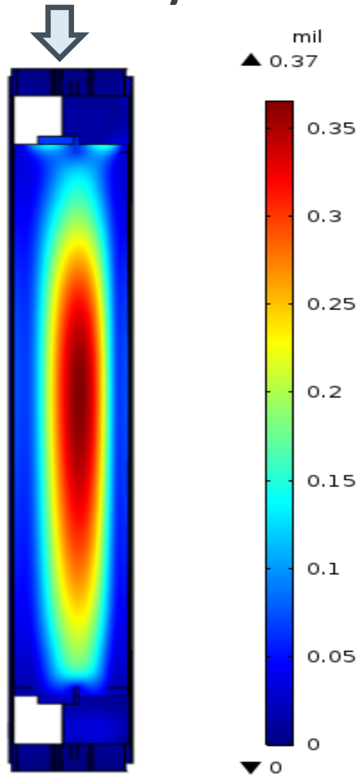
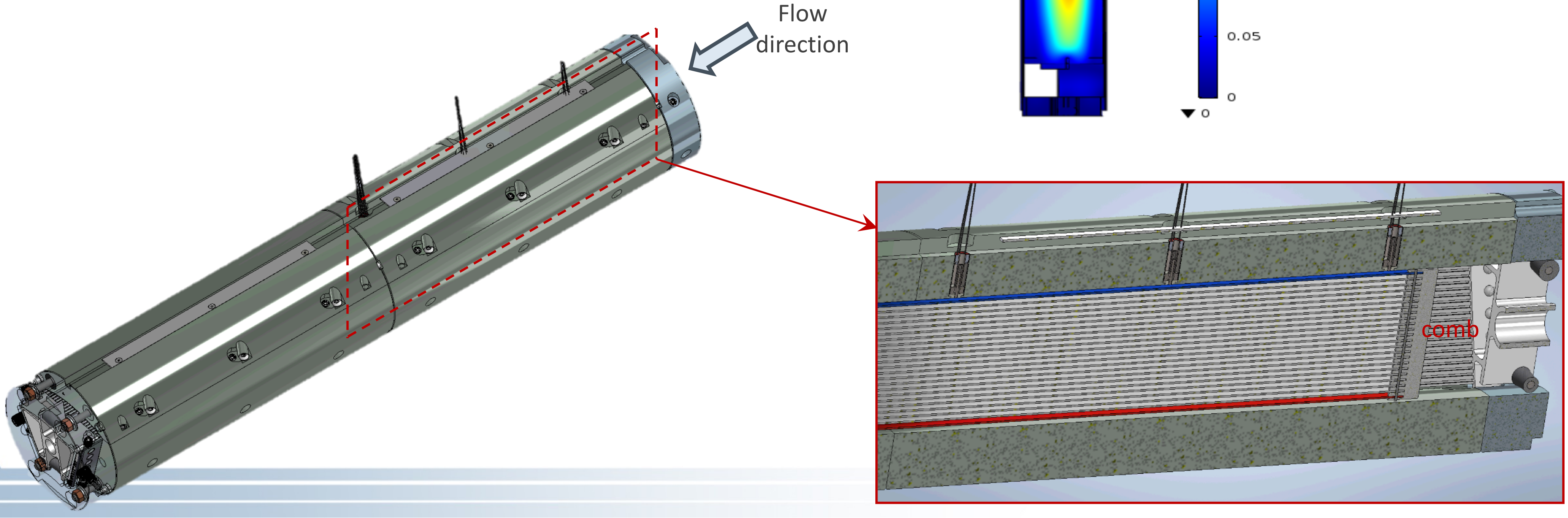
Selecting Sensor Positions - MURR

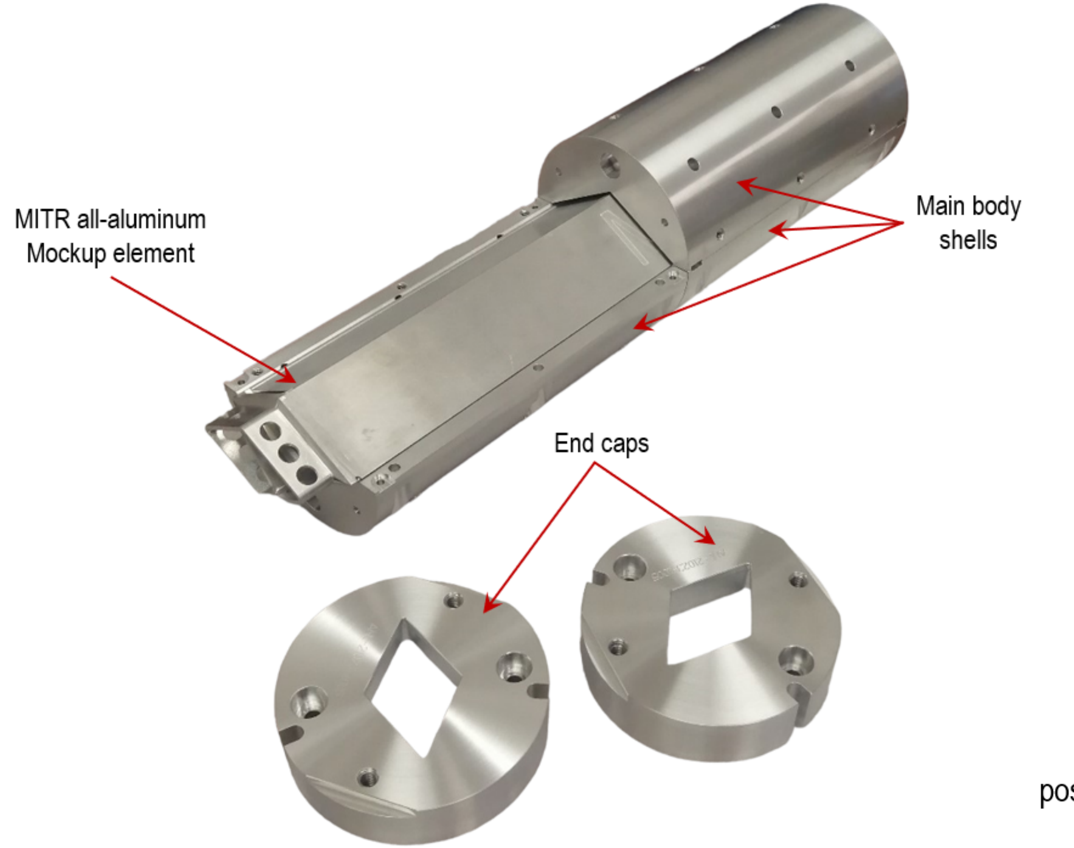
- Depending on the analyzed limiting case for the MURR LEU fuel element, the maximum displacement may occur at a different location along the plate
  - Combs
  - Outer channel gap thickness
- Three LVDT sensor locations are considered adequate

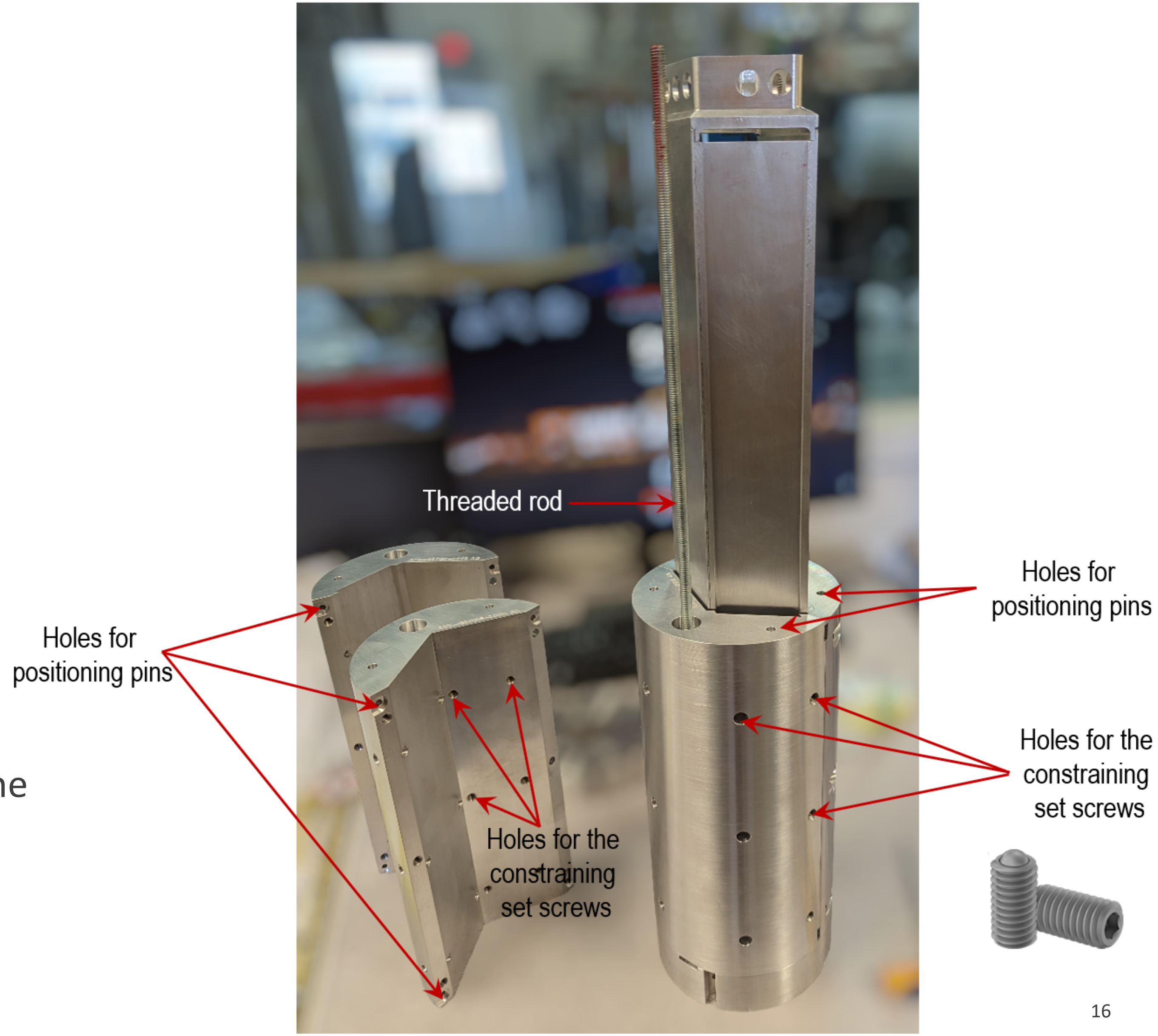
MURR LEU FSI Analysis





Prototype MITR Basket and Mock-up Fuel Element Fit Test





- The MITR basket machined at Argonne was shipped to OSU and successfully completed fit testing with the MITR dummy element machined at MIT
- Preliminary experiment execution plan was developed by Argonne, MIT, and OSU

Advances in Research and Test Reactor LEU Designs for Conversion

Engineering Design

- Single specification for U-10Mo fuel fabrication completed
- Fuel element drawings maturation
- Next is feedback from full element fabrication

Structural Analysis

- Irradiation thermo-mechanical structural analysis being performed includes irradiation effects
- Hydraulic fluid-structure modeling of plate movements being used to design hydraulic testing

Hydraulic Testing

- Hydraulic test vehicle design, prototypes and fit testing for MITR, MURR and NBSR
- Experiment execution test LEU fuel elements with thinner plates and higher flows, as-needed for conversion
- LVDT sensors selected to detect plate deflection during flow testing of elements
- Pre- and post-test examination for deformations will be performed using channel gap probe

Advances in plate stability and testing support LEU conversion efforts

Acknowledgements

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Brookhaven National Laboratory

Argonne National Laboratory

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