Sandia National Laboratories

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Completion of IER 305: Molybdenum Sleeve Experiments
Preparations for Performing IER 441: Epithermal Tantalum Experiments

David Ames

Contributors: Gary Harms (SNL), Nicolas Leclaire (IRSN), Jeremy Bez (IRSN), Beth Hanson (SNL), Jason Soares (SNL), Patrick Ward (SNL), Augie Chapa (SNL), Mathieu Dupont (ORNL)

NCSP Technical Program Review

February 21, 2024

Hosted by Brookhaven National Laboratory

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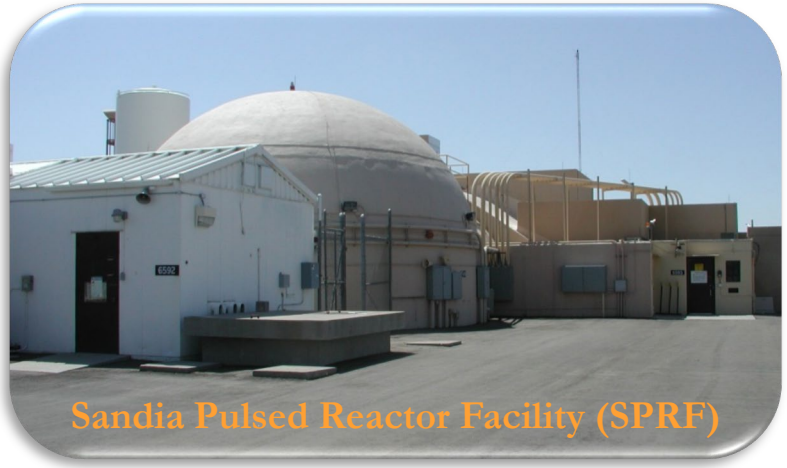
OVERVIEW

- Sandia Critical Experiments
  - 7uPCX
  - BUCCX
  - Assembly Design
- Completion of IER 305
  - CED-3b
  - CED-4a
  - CED-4b
- Preparing to Perform IER 441
  - New Hardware
  - Critical Configurations
  - Next Steps
- Acknowledgements

Sandia Critical Experiments (SCX)


Sandia Pulsed Reactor Facility (SPRF)

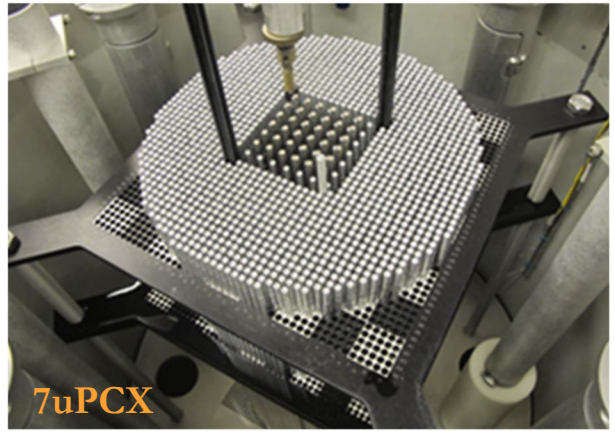
CX Assembly Tank and Dump Tank

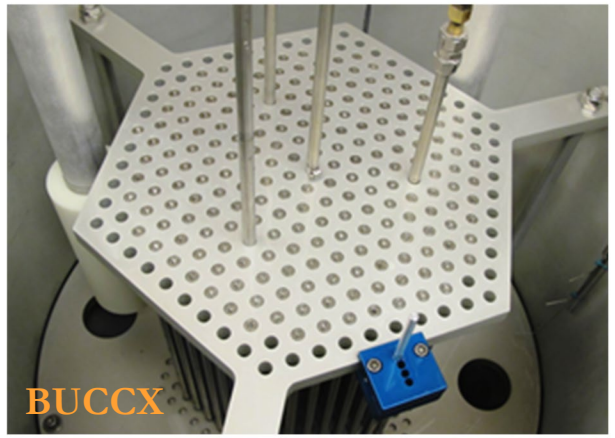
The Seven Percent Critical Experiment (7uPCX)

- UO_2 fuel (6.9% ^{235}U)
- Four sets of grid plates
  - 45x45 Square pitch array (0.8 cm)
  - 45x45 Square pitch array (0.855 cm)
  - Triangular pitch array (1.55 cm) – IER 305
  - Triangular pitch array (1.02 cm) with central test region – IER 441
- Fuel rod diameter 0.635 cm
- Fuel length 48.9 cm
- Seven Experimental Series in the ICSBEP Handbook
  - LCT-078, 080, 096, 097, 101, 102, 111, ???

The Burnup Credit Critical Experiment (BUCCX)

- UO_2 fuel (4.3 % ^{235}U)
- Two sets of grid plates
  - Triangular pitch array (2.0 cm)
  - Triangular pitch array (2.8 cm)
- Fuel locations 397 and 271
- Fuel rod diameter 1.38 cm
- Fuel length 49.2 inch
- Two Experimental Series in the ICSBEP Handbook
  - LCT-079, 099


7uPCX


BUCCX

Sandia Critical Experiments: IER 305 and IER 441

The Seven Percent Critical Experiment (7uPCX)

- UO_2 fuel (6.9% ^{235}U)
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  - **Triangular pitch array (1.55 cm) – IER 305**
  - **Triangular pitch array (1.02 cm) – IER 441**
    - **Central test region**
- Fuel rod diameter 0.635 cm
- Fuel length 48.9 cm
- Seven Experimental Series in the ICSBEP Handbook
  - LCT-078, 080, 096, 097, 101, 102, **111**, **???**

Critical Assembly Design

Notable Design Features

- Assembly tank
  - Fuel rods and grid plates
  - Elevated for gravity release of moderator to the dump tank
  - Provides full water-reflection
- Dump tank
  - Moderator resides in dump tank until operations
  - Heater maintains temperature
- Moderator Overflow Standpipe
  - Maintain water level in assembly tank
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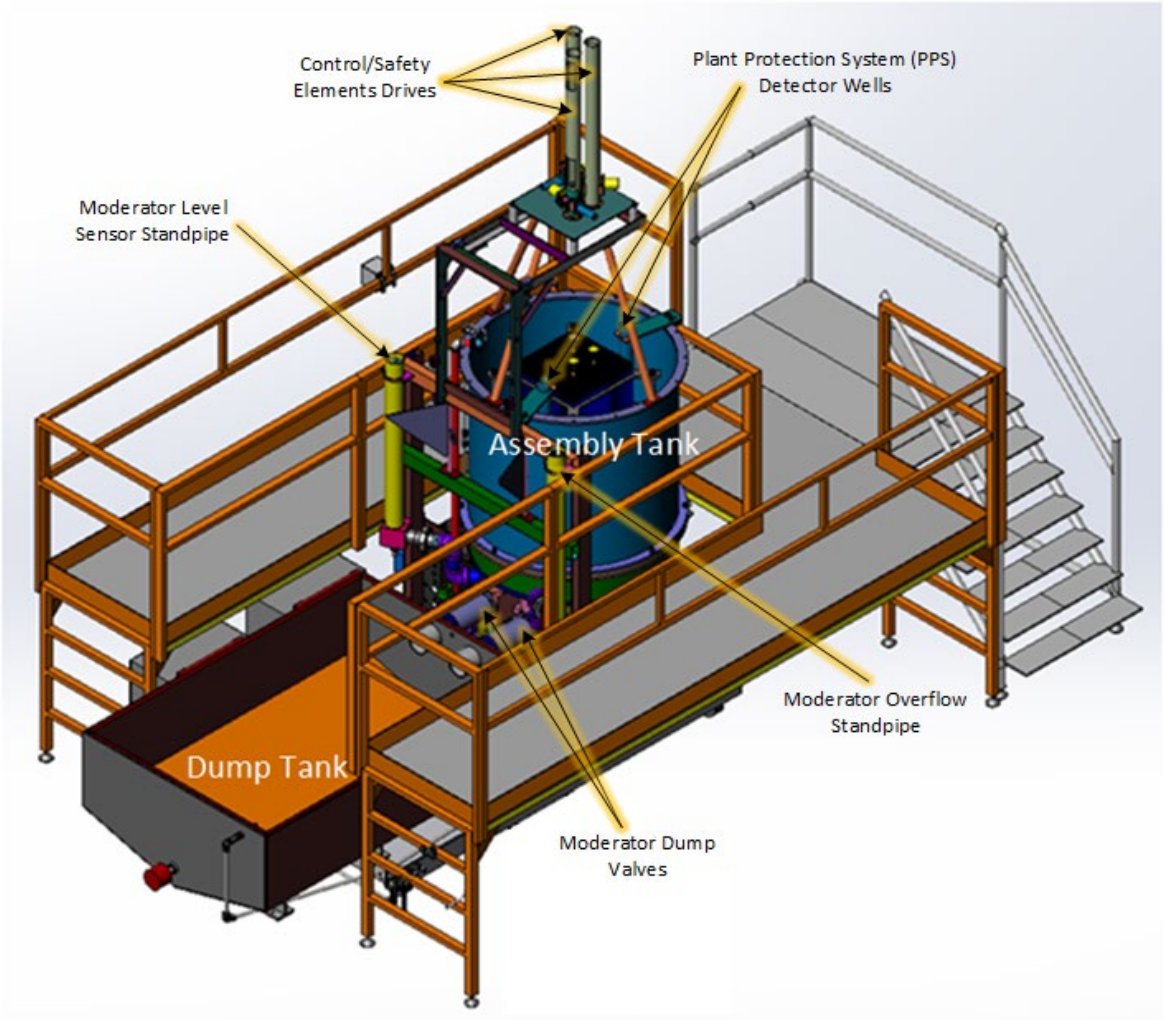
- Control and Safety Elements
  - Cluster of four rods
  - B_4C absorber section followed by 4 rod fueled section
- Plant Protection System
  - Two fission chambers



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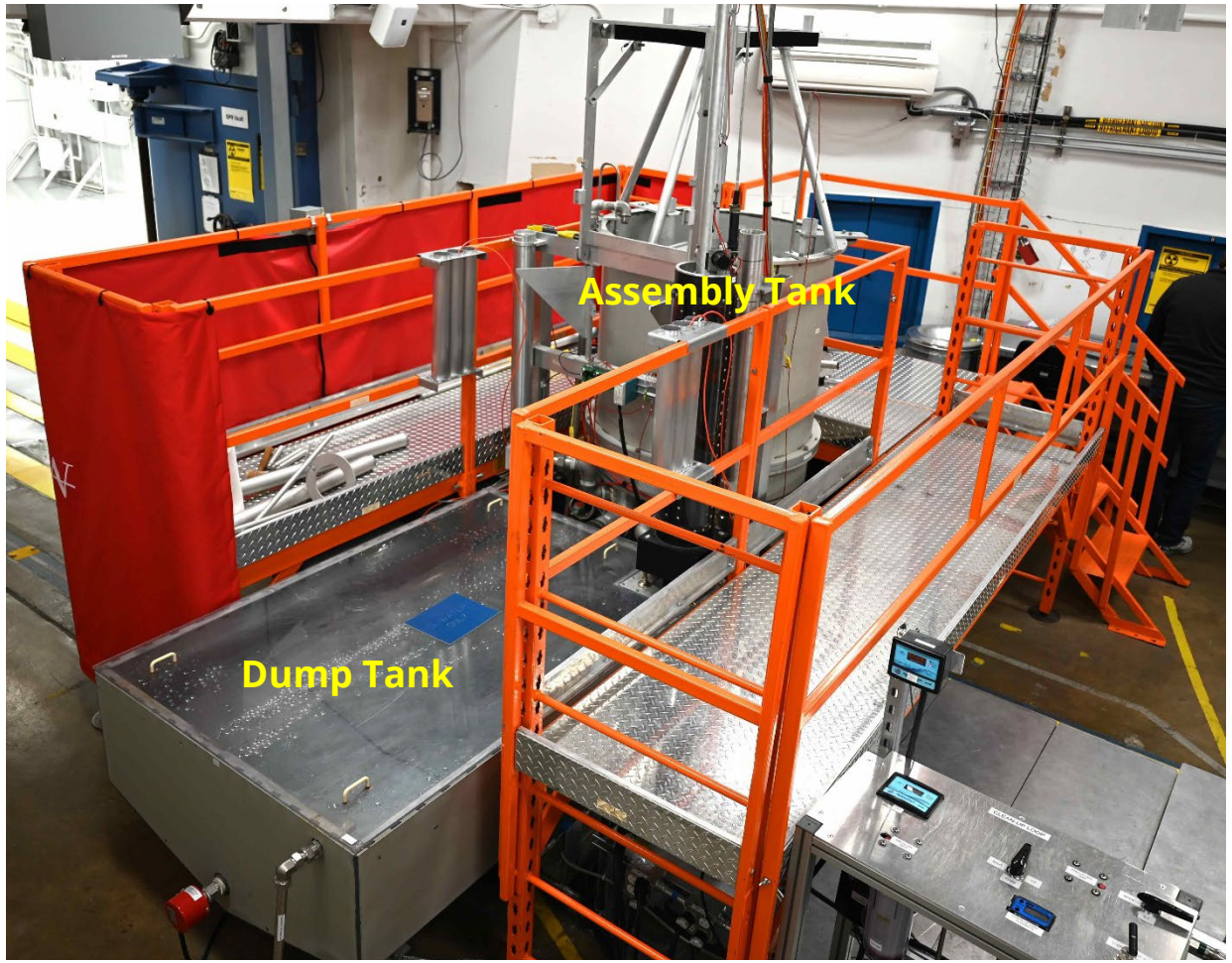
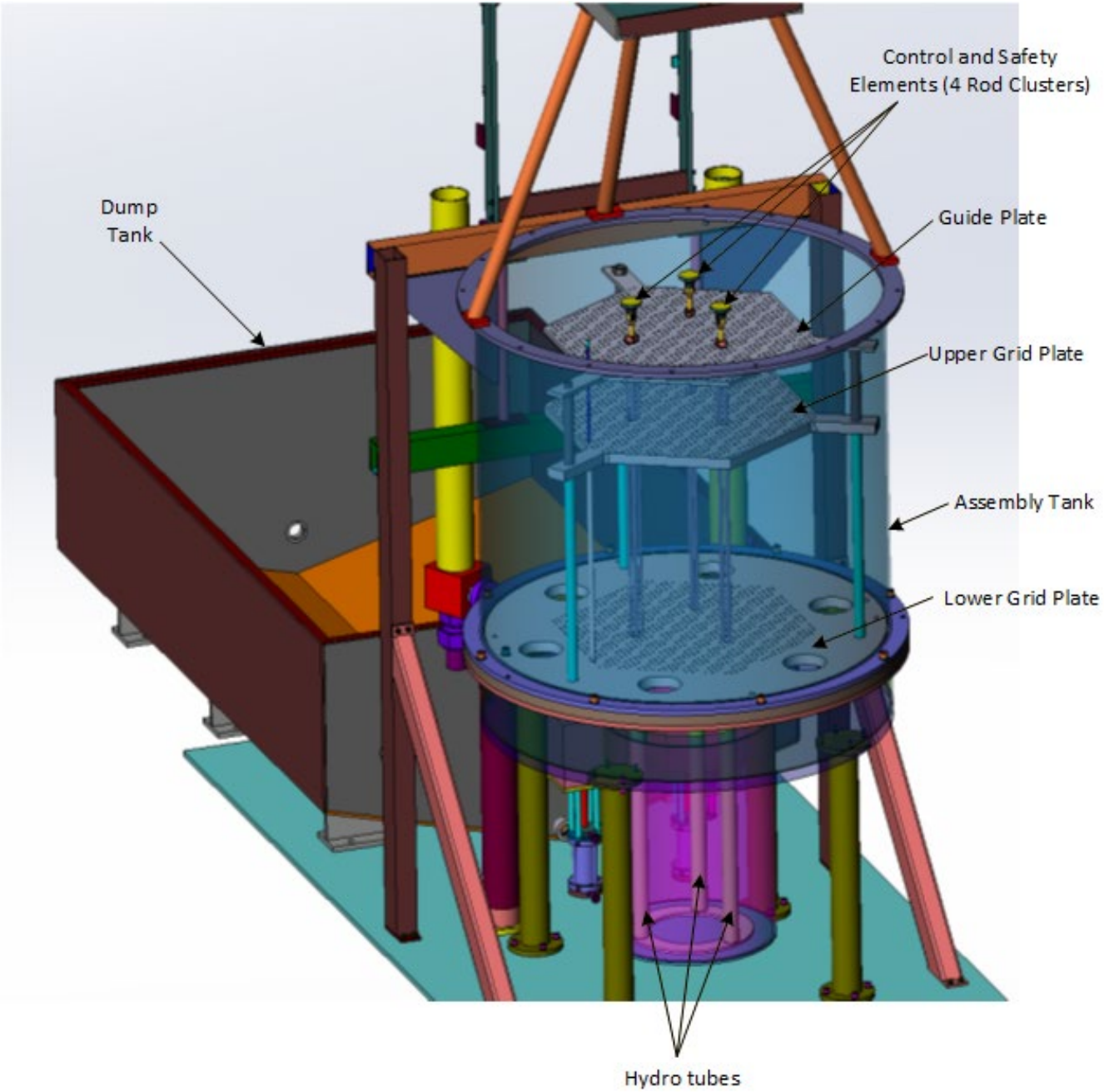


IER 305: New Equipment

Notable design features (new equipment)

- Grid Plates (Guide, Upper, and Lower)
  - Maintain spacing of fuel rods
  - Triangular pitch (1.55 cm)
- Molybdenum Sleeves
  - Placed between upper and lower grid plates
  - Centered on fuel rods
  - 400 sleeves
- Additional new equipment
  - Control and safety element bundle plates
  - Hydro tubes and springs



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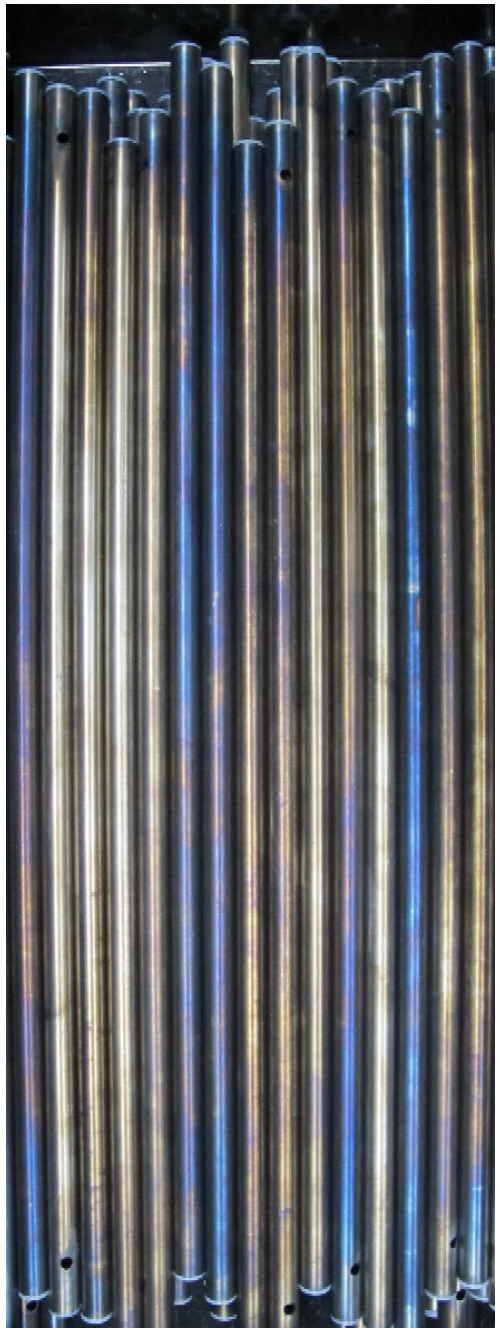
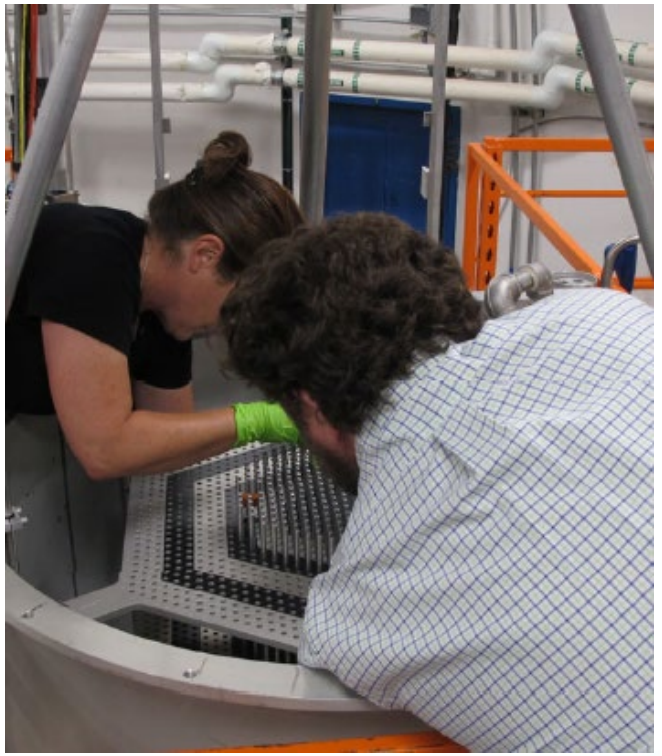
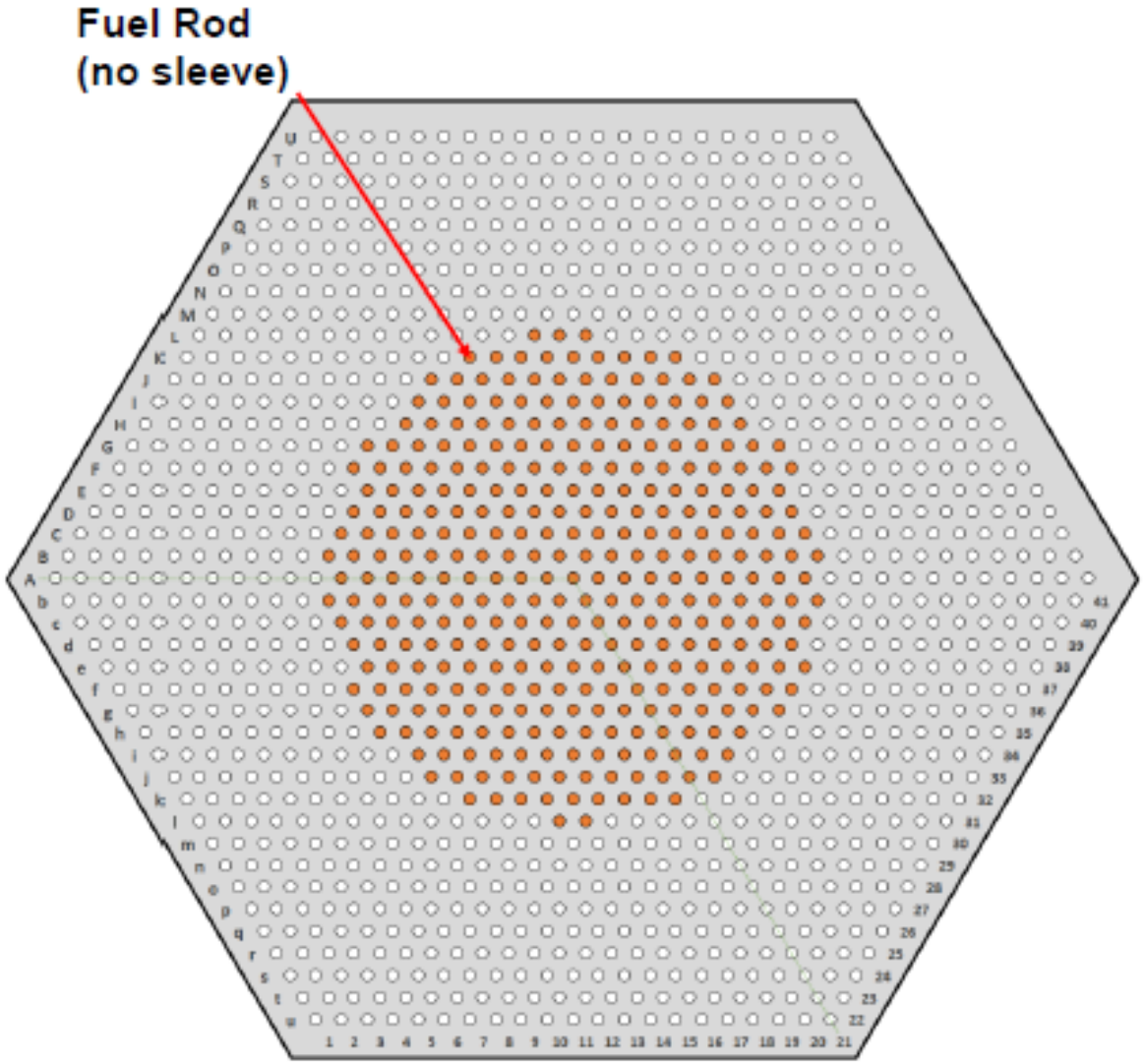


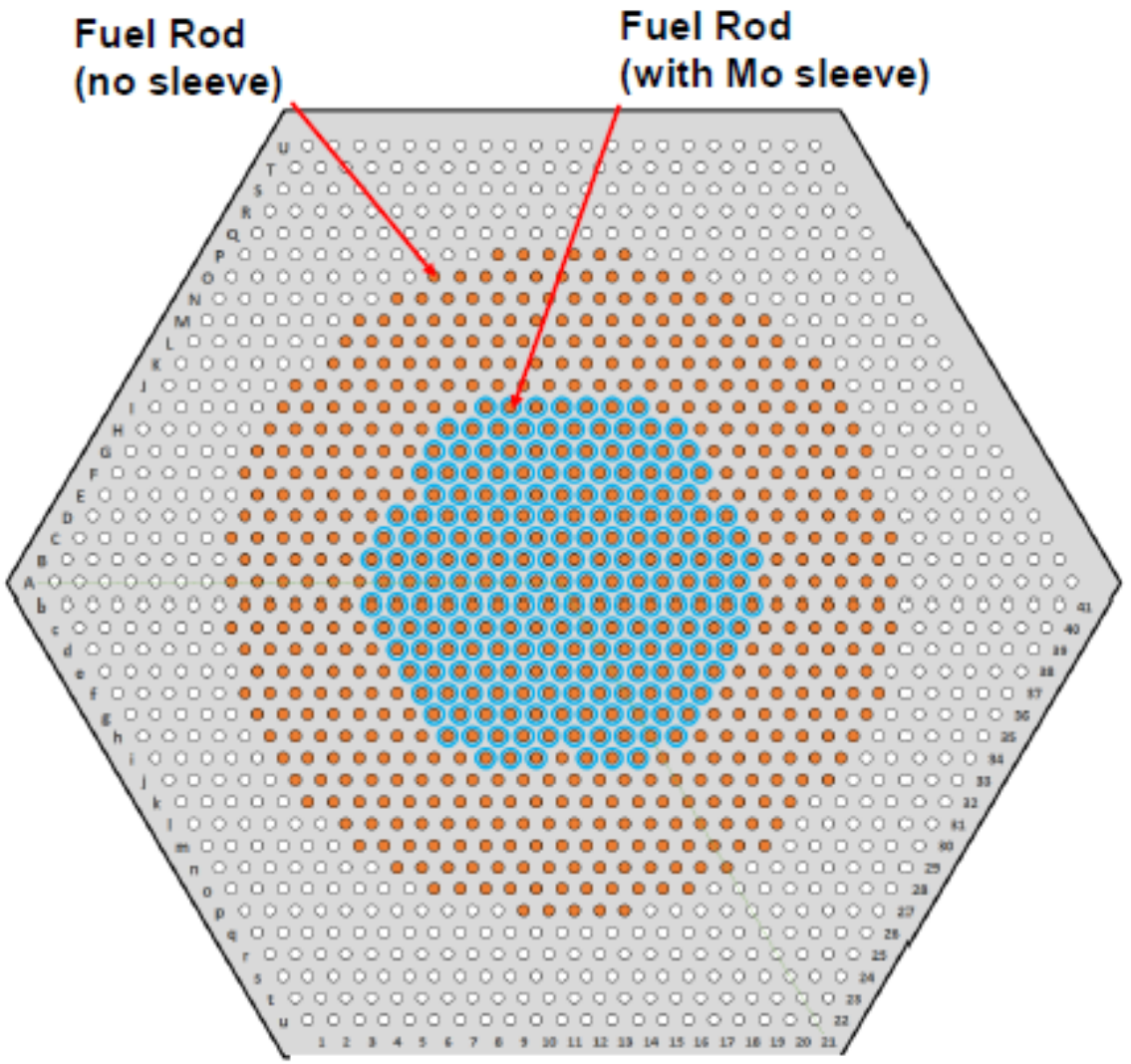


IER 305: Critical Configurations (Case 1: LCT-111)



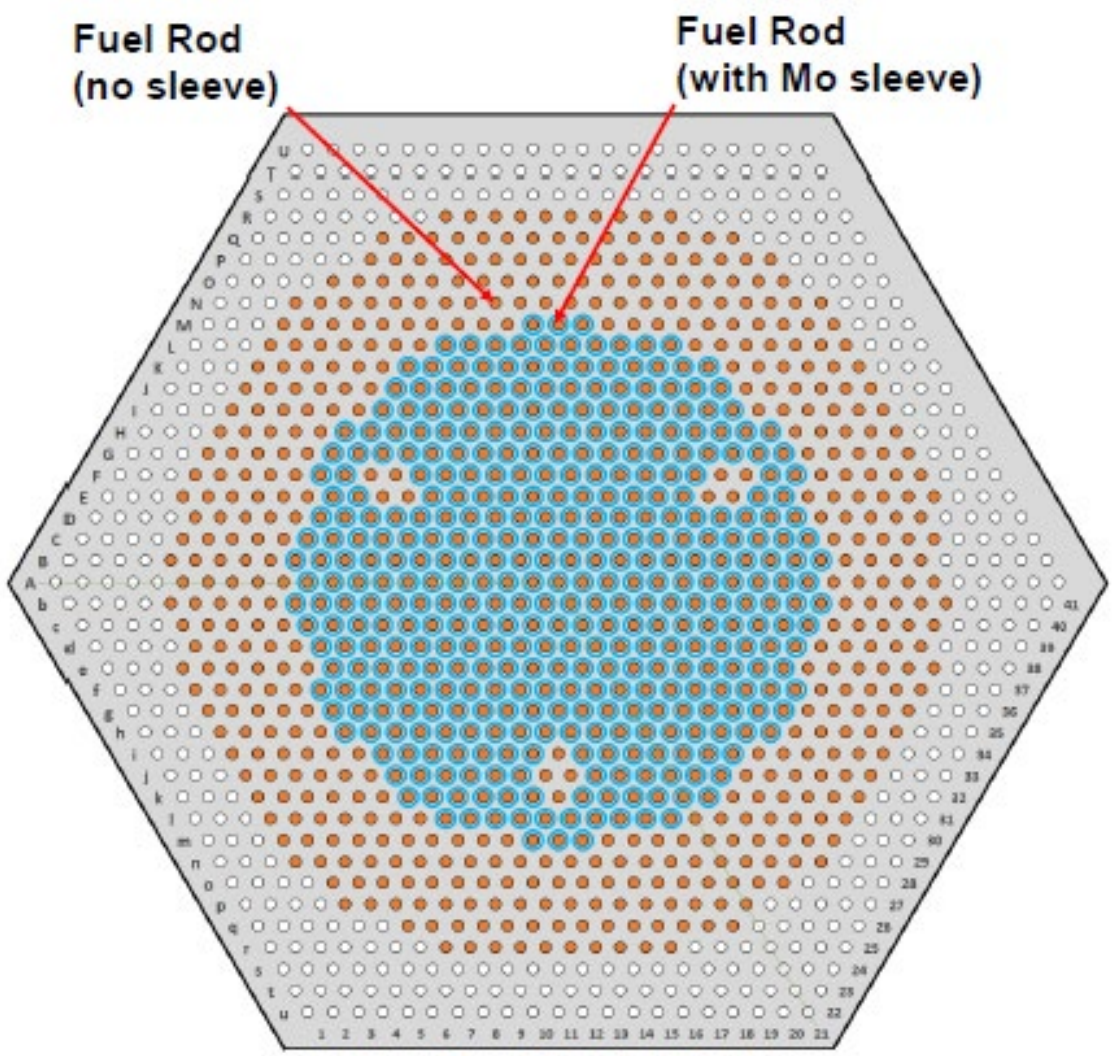
Case 1 – 340 Fuel Rods

IER 305: Critical Configurations (Case 2: LCT-111)



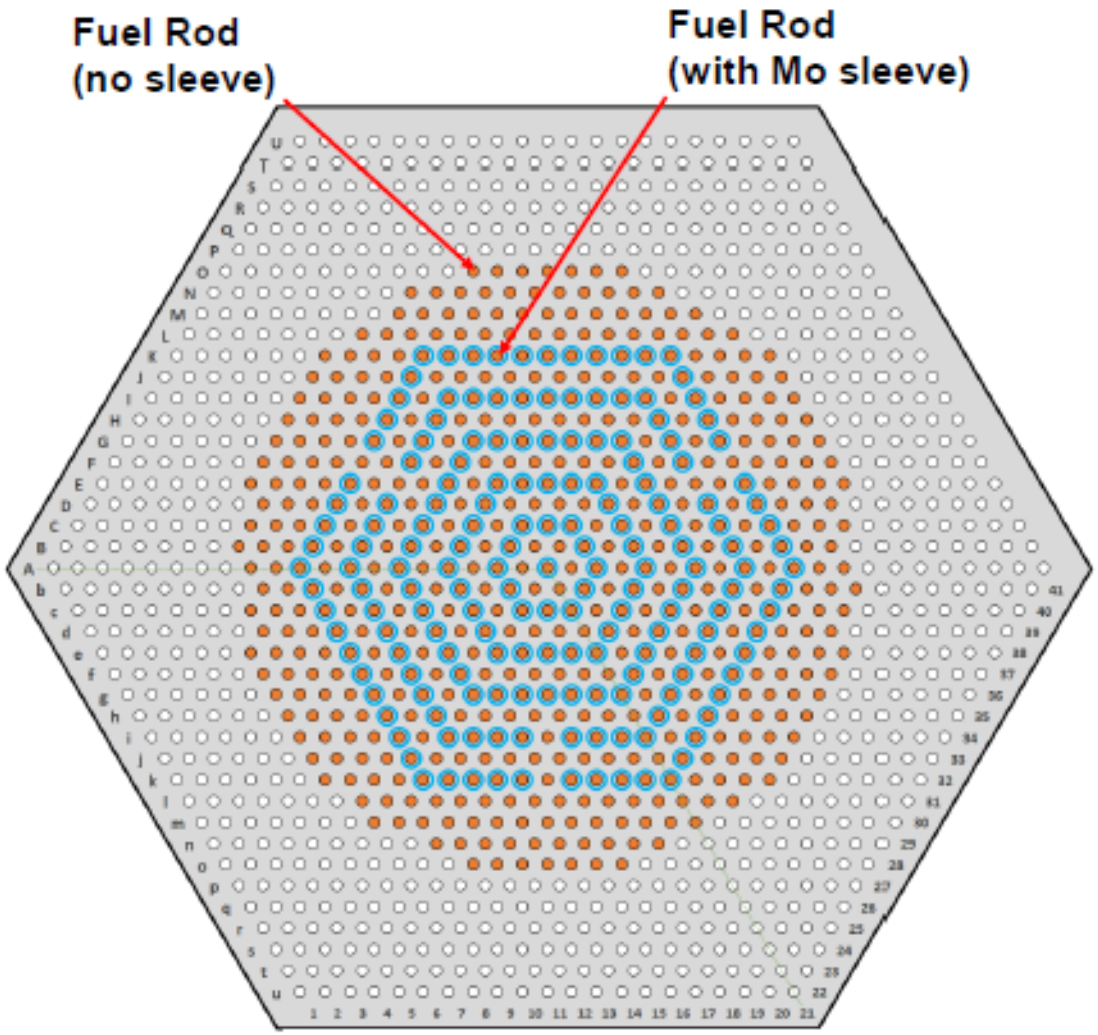
Case 2 – 645 Fuel Rods,
208 Mo Sleeves

IER 305: Critical Configurations (Case 3: LCT-111)



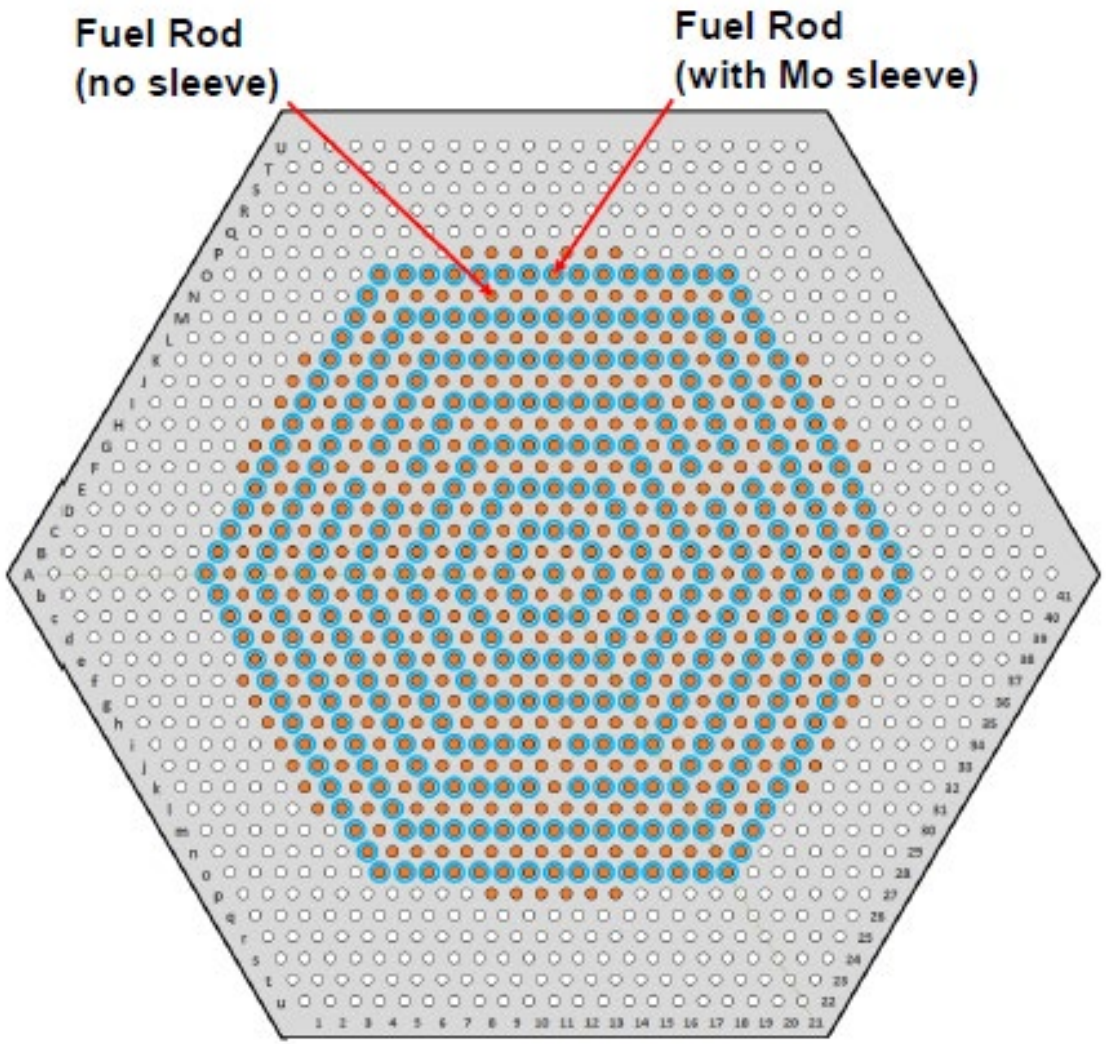
Case 3 – 867 Fuel Rods,
397 Mo Sleeves

IER 305: Critical Configurations (Case 4: LCT-111)



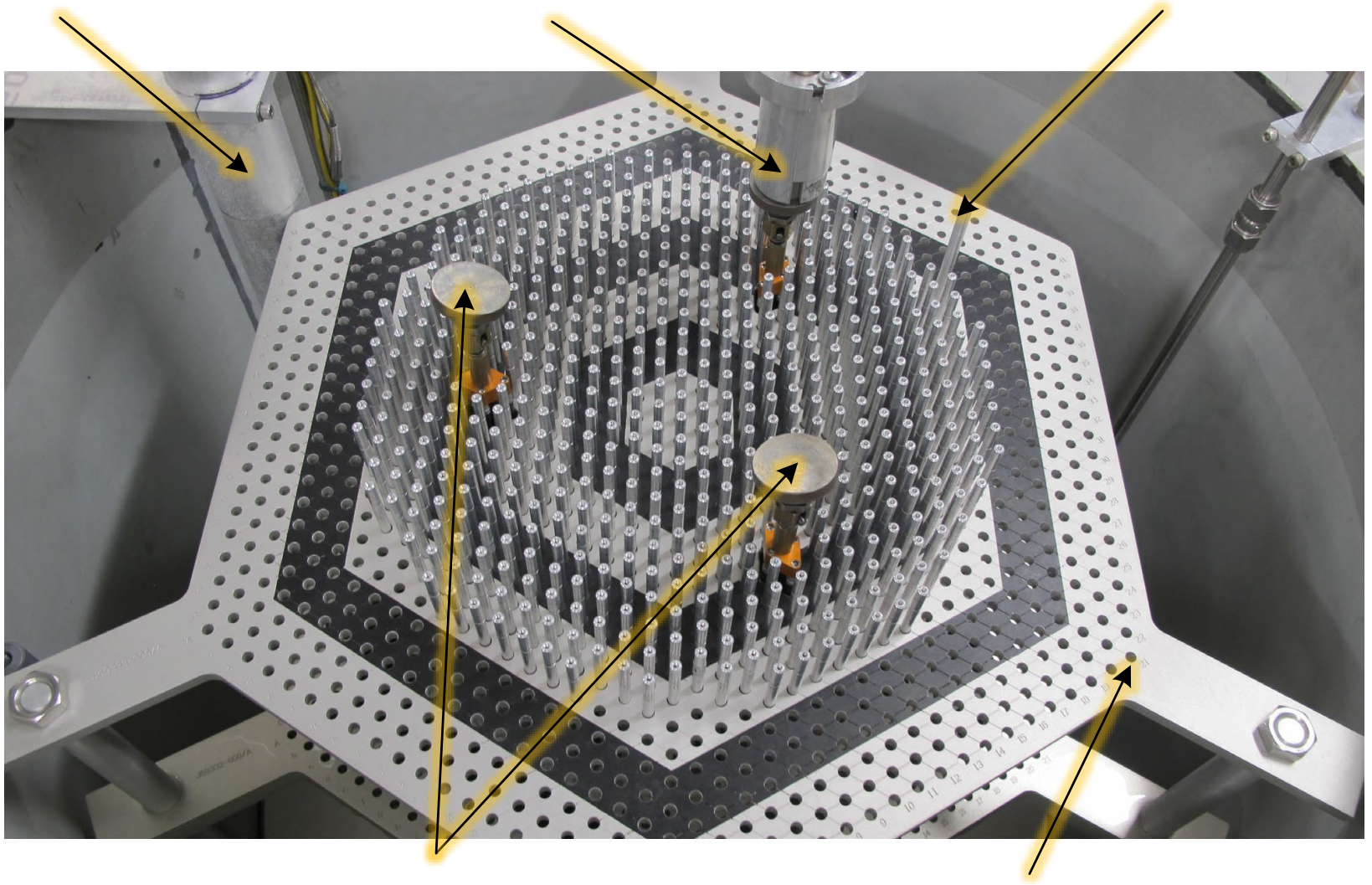
Case 4 – 575 Fuel Rods,
175 Mo Sleeves

IER 305: Critical Configurations (Case 5: LCT-111)

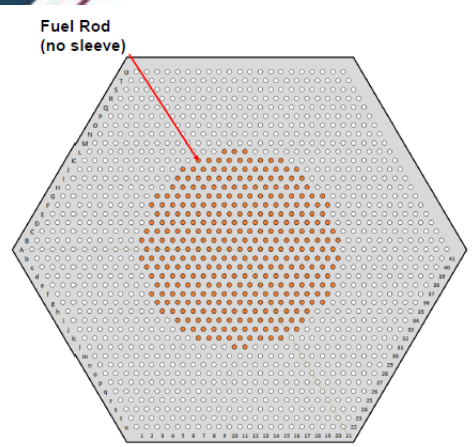


Case 5 – 670 Fuel Rods,
331 Mo Sleeves

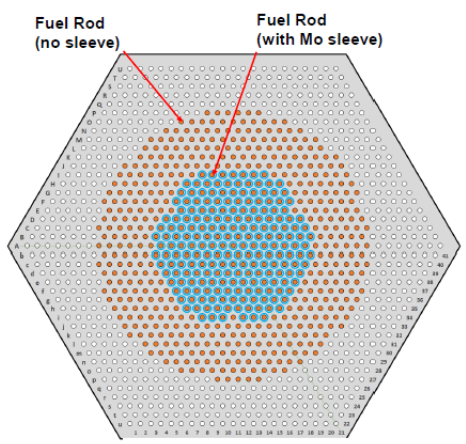
IER 305: Case 3 (LCT-111)



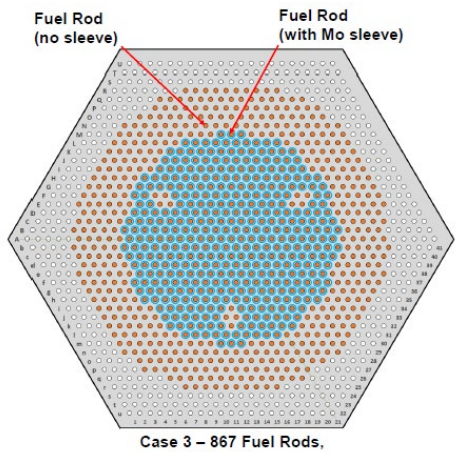
IER 305: Experiment Results (LCT-111)



Case 1 – 340 Fuel Rods



Case 2 – 645 Fuel Rods,
208 Mo Sleeves



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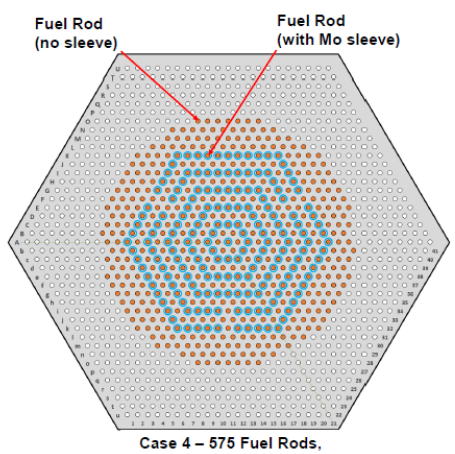

Case 4 – 575 Fuel Rods,
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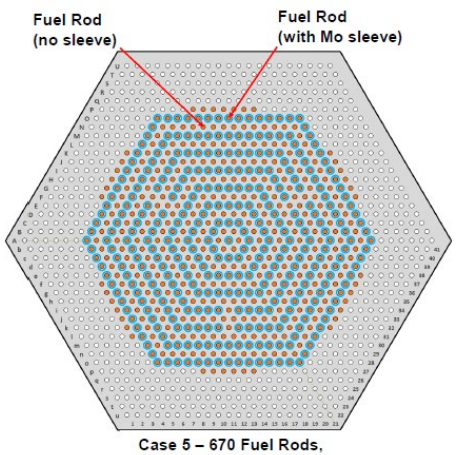
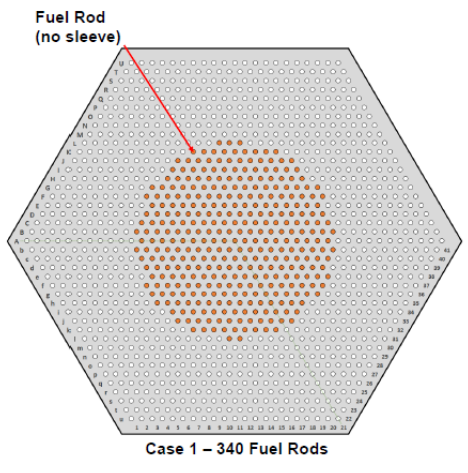


Case 5 – 670 Fuel Rods,
331 Mo Sleeves

Case	Largest Array			Previous Array Size (rods)	Extrapolated Critical Array Size (rods)	Mo-Sleeves	Temp. (°C)
	Array Size (rods)	UO_2 Mass (g)	Fuel Column Length (cm)				
1	340	37010.14	16582.8	339	340.176 ± 0.001	0	24.5
2	645	70197.84	31457.7	644	646.200 ± 0.002	208	24.2
3	867	94336.40	42293.8	866	868.147 ± 0.001	397	24.3
4	575	62568.56	27989.8	574	576.696 ± 0.005	175	24.0
5	670	72927.52	32681.9	669	671.498 ± 0.006	331	24.6

IER 305: Derived k_{eff} Results (LCT-111)



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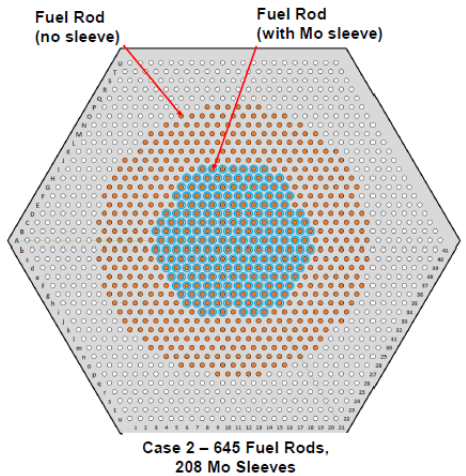
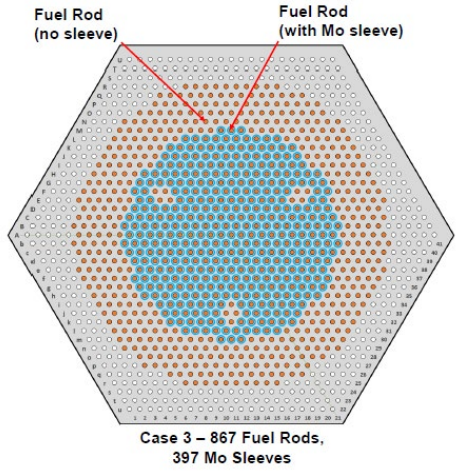


Case 2 – 645 Fuel Rods,
208 Mo Sleeves



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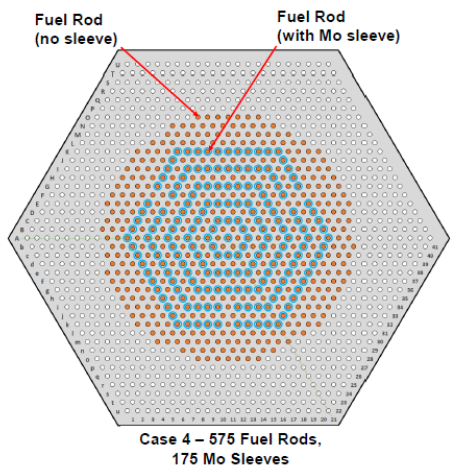

Case 4 – 575 Fuel Rods,
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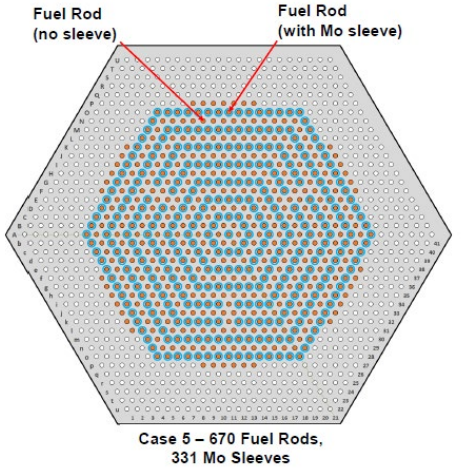
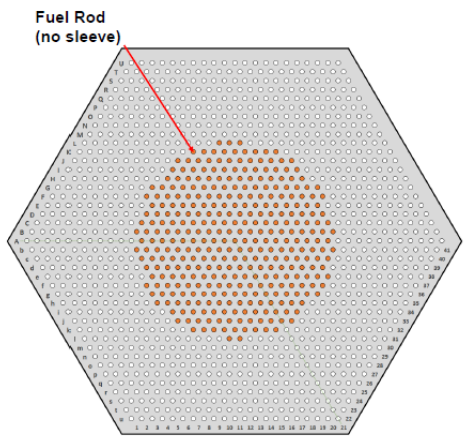


Case 5 – 670 Fuel Rods,
331 Mo Sleeves

Case	Largest Measured Array			Smaller Measured Array		
	Fuel Rods	k_{eff}	Uncertainty	Fuel Rods	k_{eff}	Uncertainty
1	340	0.999887	0.000006	339	0.999245	0.000042
2	645	0.999554	0.000043	644	0.999183	0.000078
3	867	0.999690	0.000041	866	0.999419	0.000076
4	575	0.999200	0.000060	574	0.998730	0.000095
27	670	0.999490	0.000053	669	0.999150	0.000088

IER 305: Benchmark-Model k_{eff} and Uncertainty Results (LCT-111)



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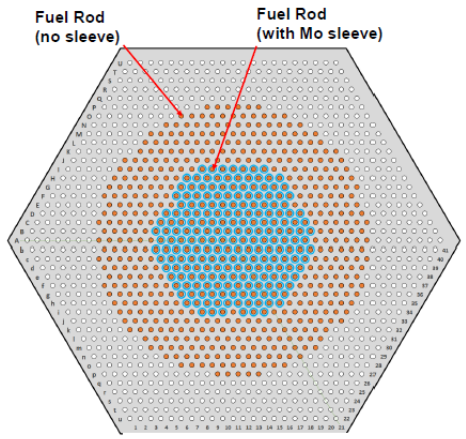

Case 2 – 645 Fuel Rods,
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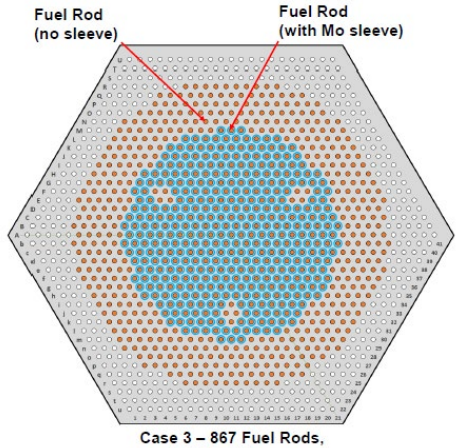

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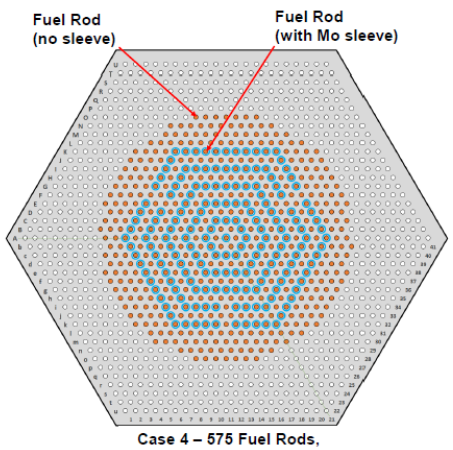

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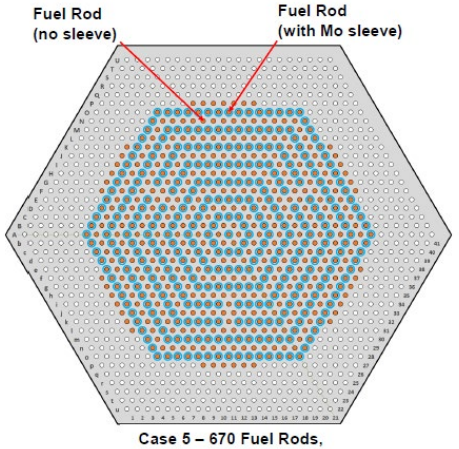

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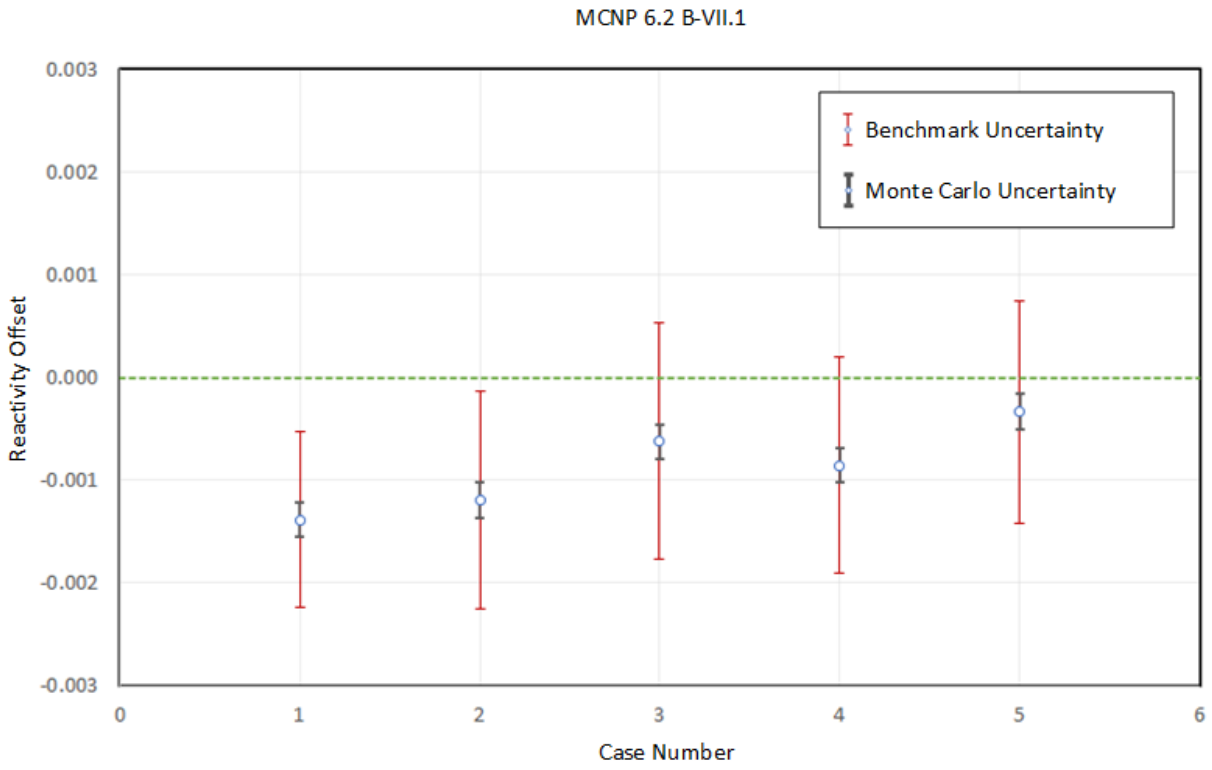
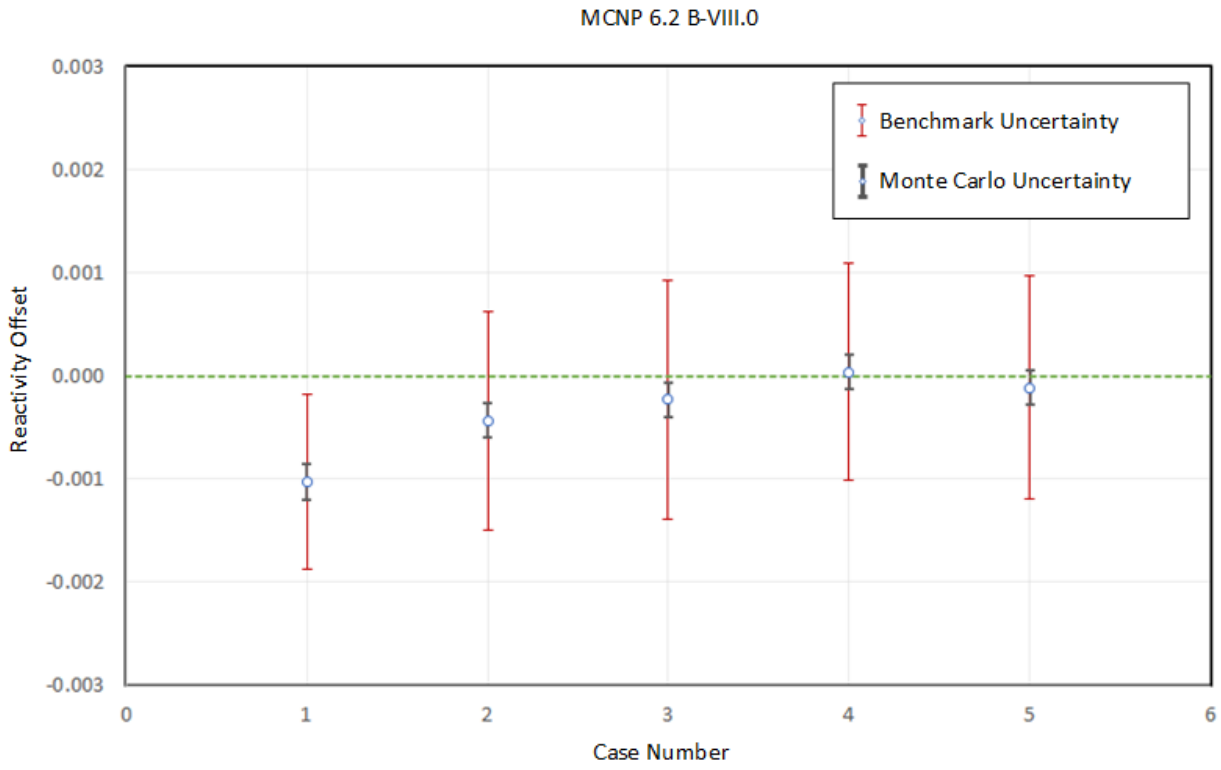
Case	Experiment		Simplification Bias		Temperature Correction		Experiment Uncertainty	Benchmark Model	
	k_{eff}	Unc.	Δk_{eff}	Unc.	Δk_{eff}	Unc.		k_{eff}	Unc.
1	0.999887	0.000006	-0.00011	0.00002	-0.00001	0.00000	0.00085	0.99977	0.00085
2	0.999554	0.000043	-0.00008	0.00002	0.00001	0.00000	0.00106	0.99949	0.00106
3	0.999690	0.000041	-0.00013	0.00002	0.00002	0.00000	0.00115	0.99958	0.00115
4	0.999200	0.000060	-0.00014	0.00002	0.00001	0.00000	0.00104	0.99907	0.00105
5	0.999490	0.000053	-0.00012	0.00002	0.00000	0.00000	0.00108	0.99937	0.00108

IER 305: Results – Reactivity Offset (LCT-111)

Calculated k_{eff} for the benchmark model and evaluated benchmark model k_{eff} for same configuration





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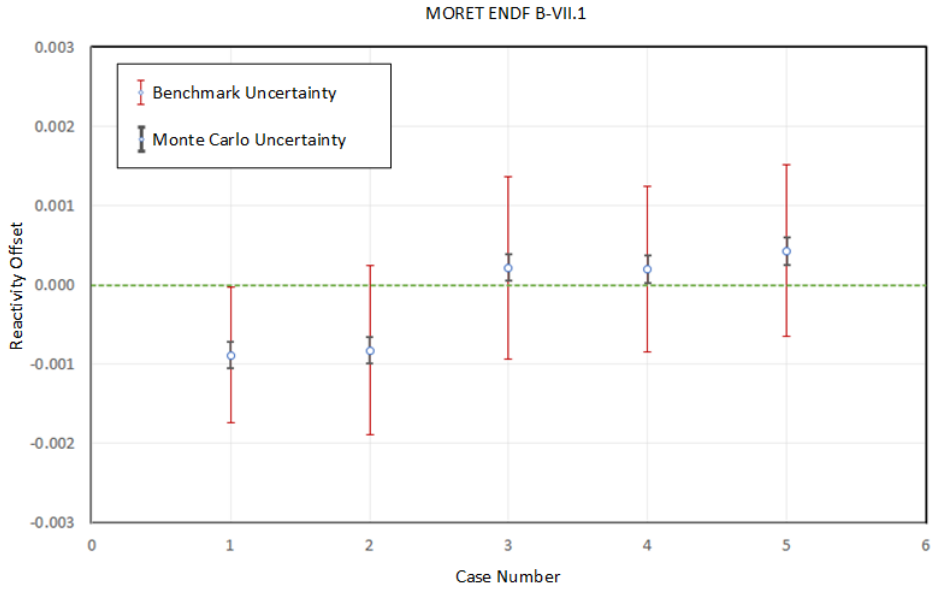

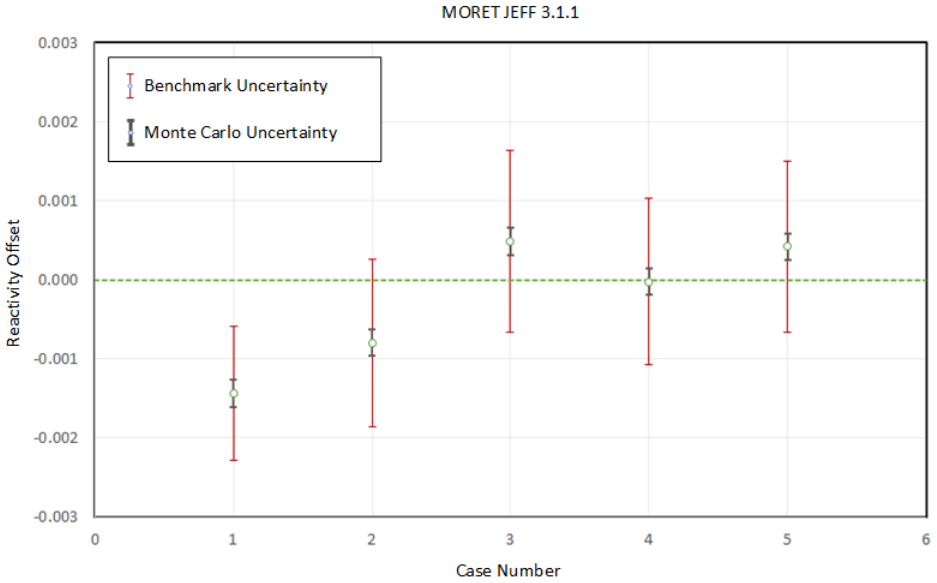

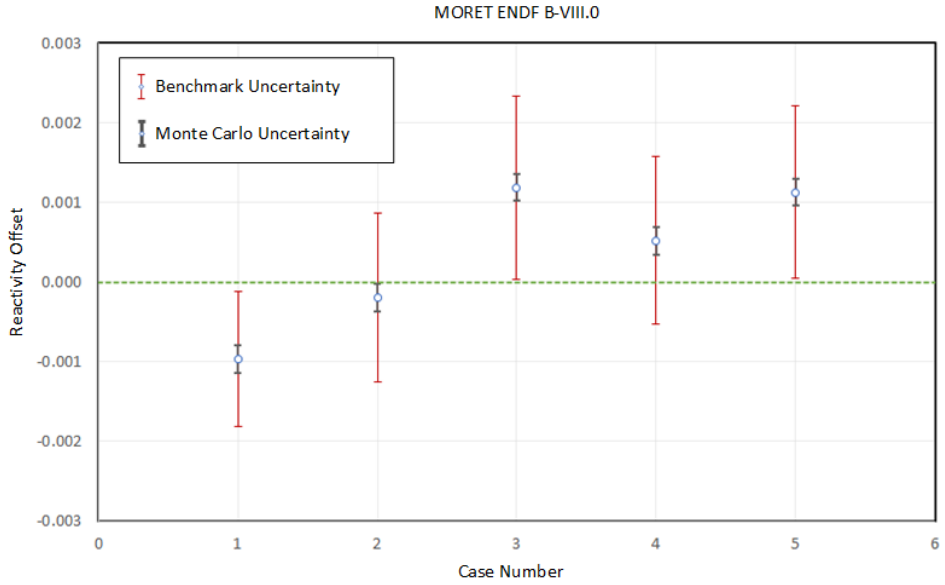

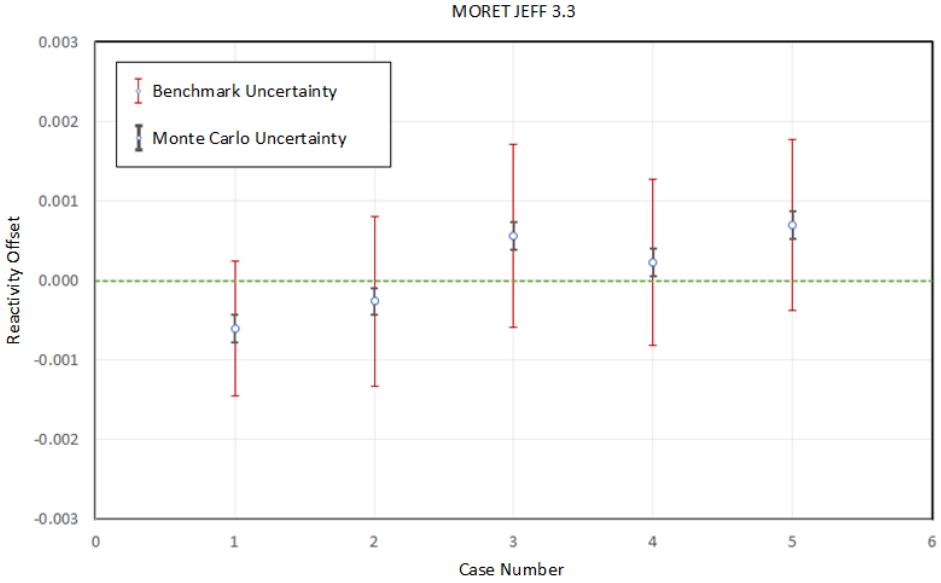

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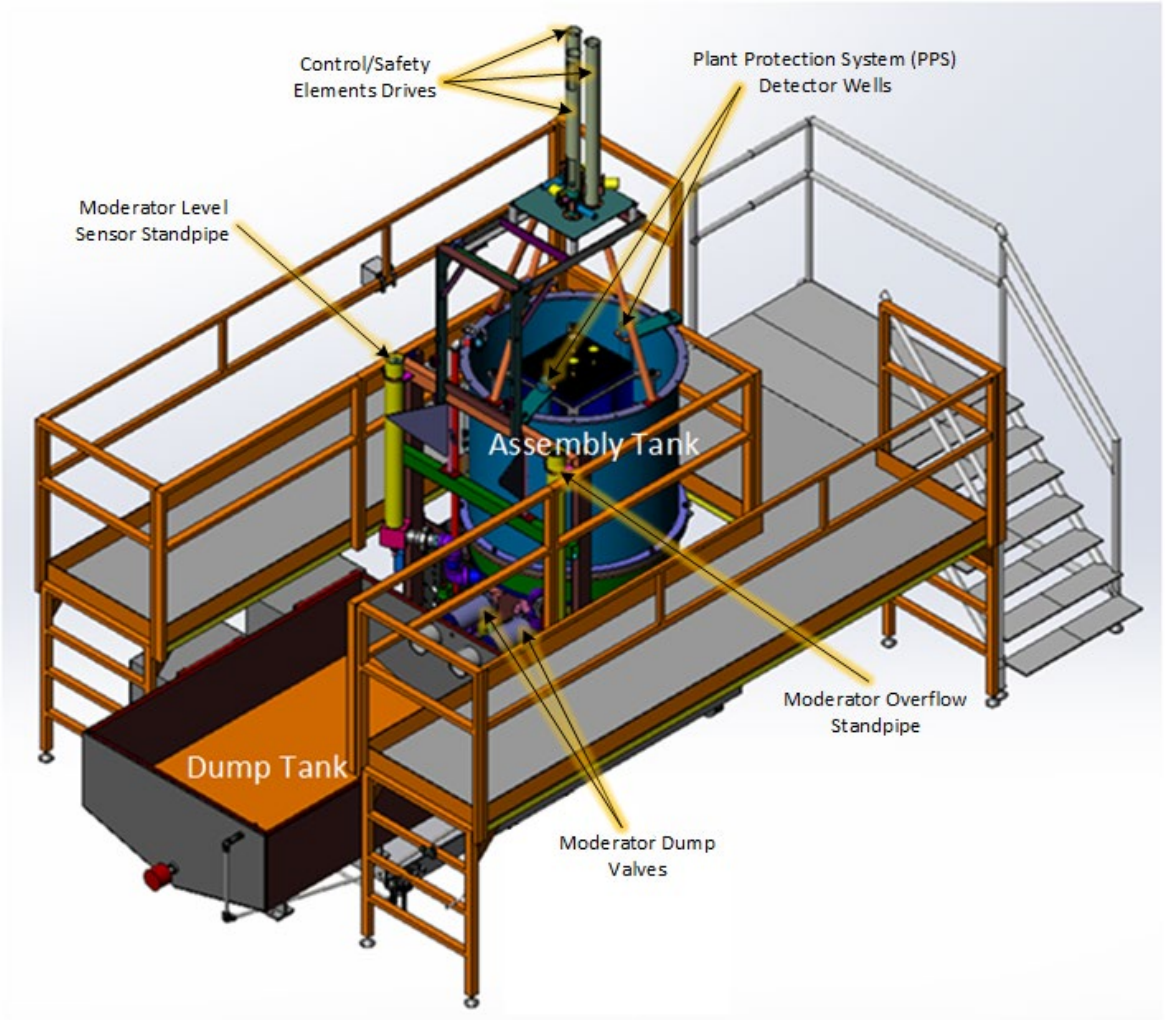

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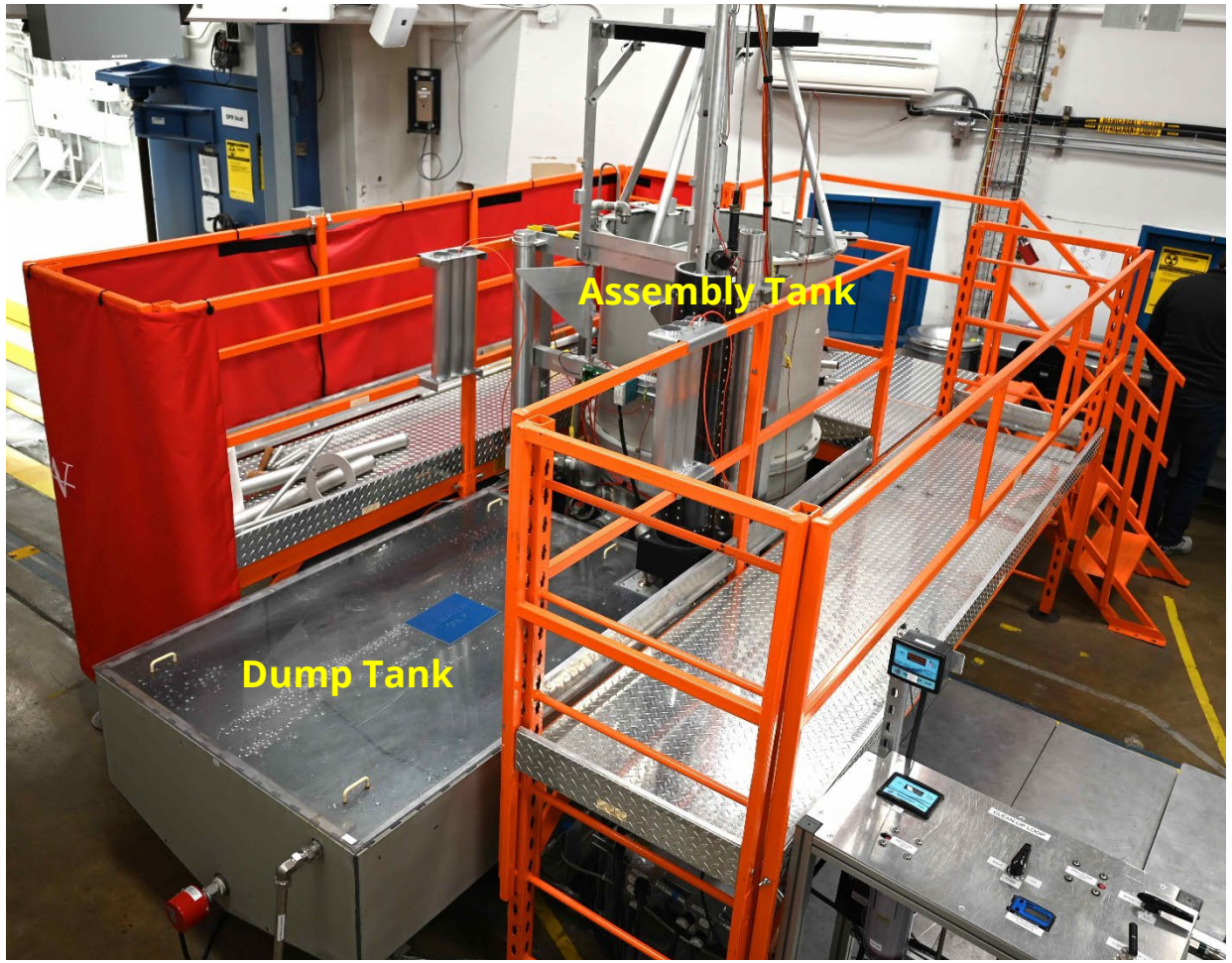
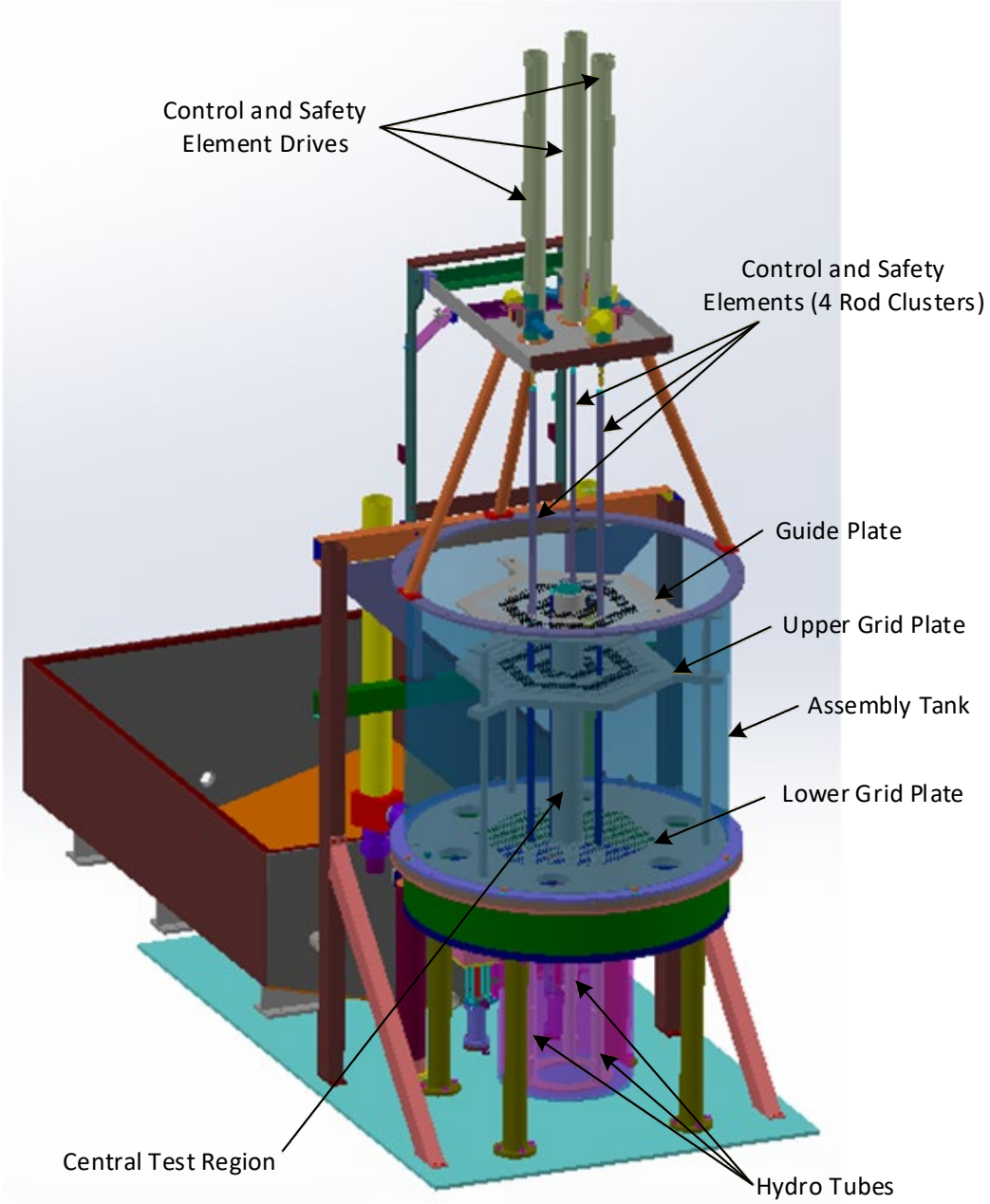


IER 441: New Hardware

- Control and Safety Element bundle plates
  - Maintain spacing of the 4 rod clusters
- Grid Plates (Guide, Upper, and Lower)
  - Maintain spacing of fuel rods
  - Triangular pitch (1.02 cm)
- Hydro Tubes and Springs
  - Gravity drop of control and safety elements
- Central test region
  - Outer Diameter 9.5 cm
  - Length 78 cm
  - Dry cavity
  - Lined with cadmium
  - Maintain spacing of test rods
  - 85 test rod locations
  - Triangular pitch (0.81 cm)
- Tantalum rods
  - Pure tantalum (> 99.95%)
  - Dimensions match fuel rods (about 1 cm longer)



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- **Control and Safety Element bundle plates**
  - **Maintain spacing of the 4 rod clusters**
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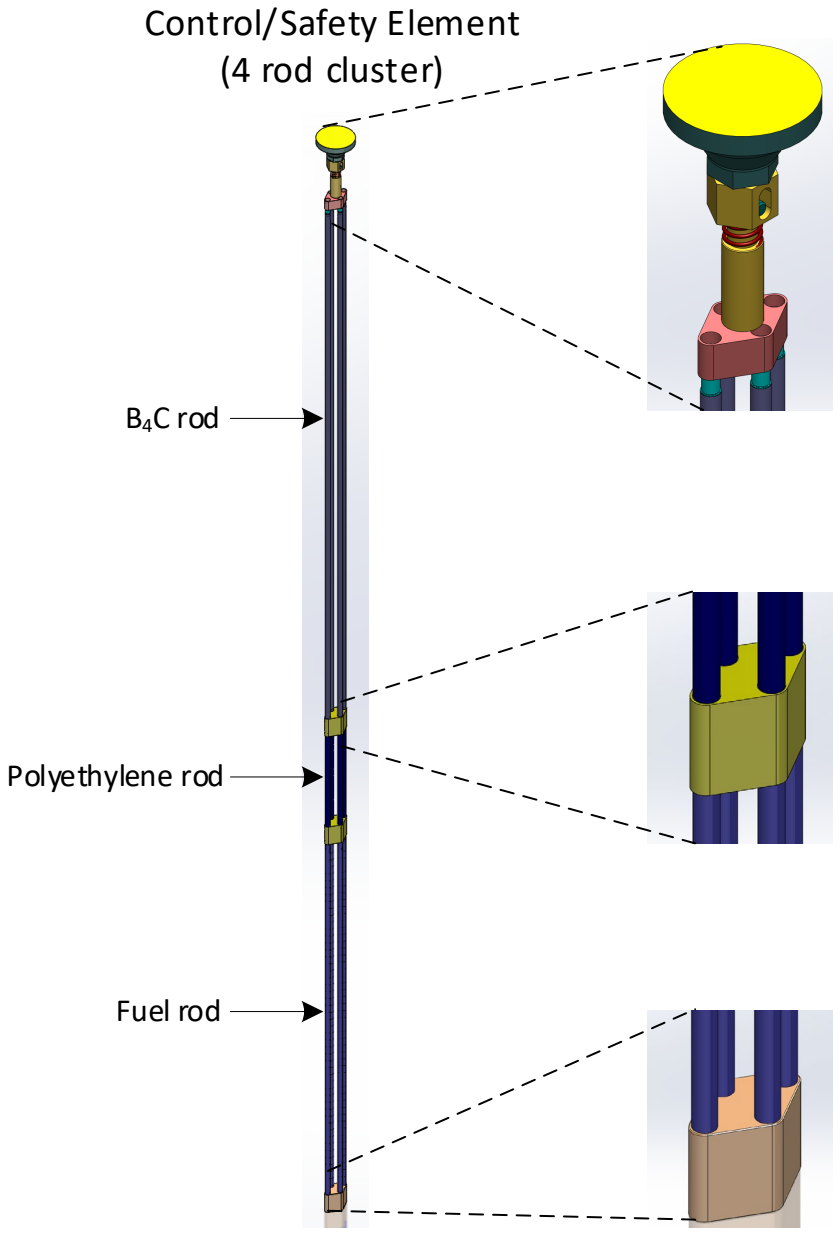
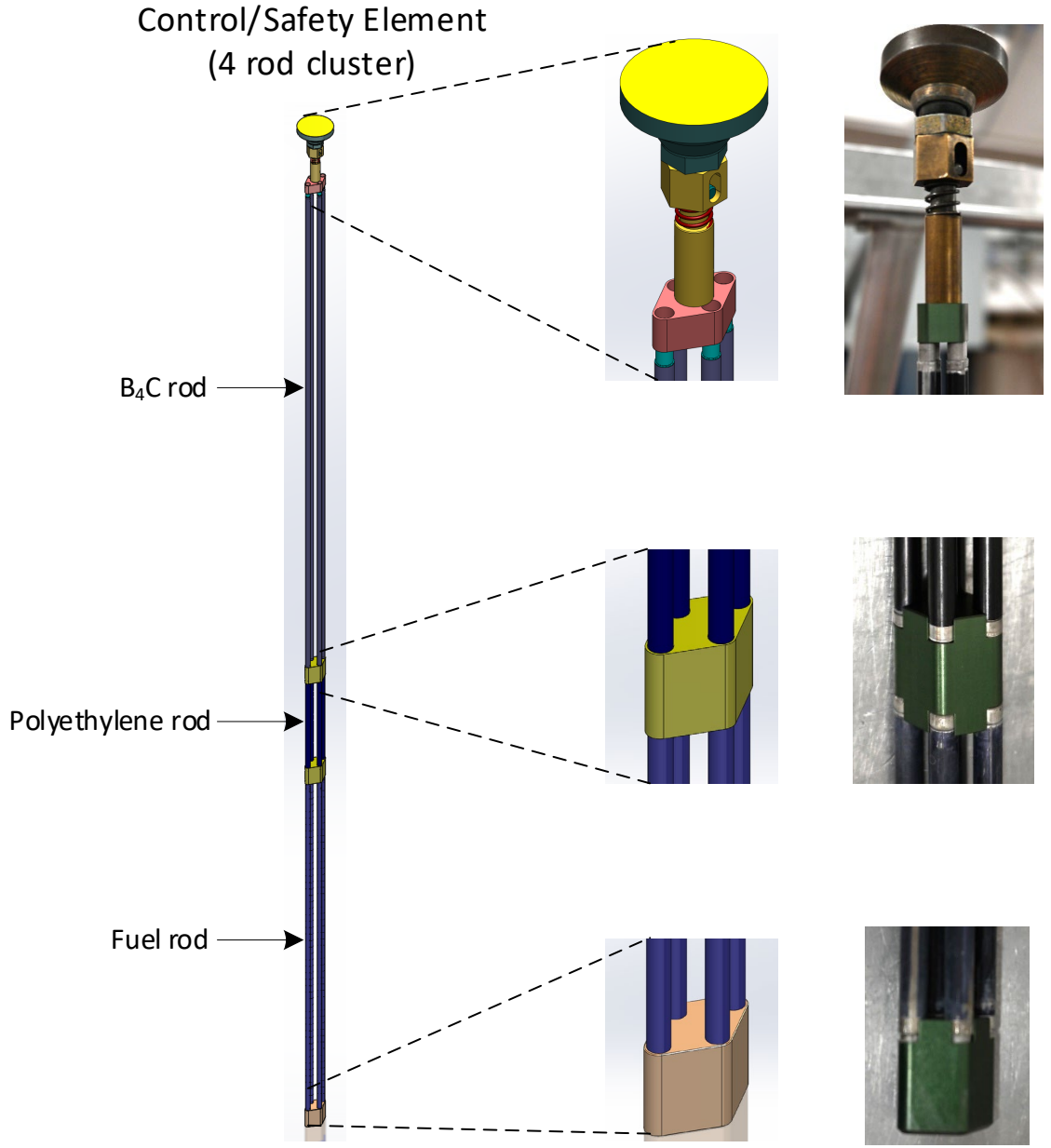
- Tantalum rods
  - Pure tantalum (> 99.95%)
  - Dimensions match fuel rods (about 1 cm longer)



IER 441: New hardware

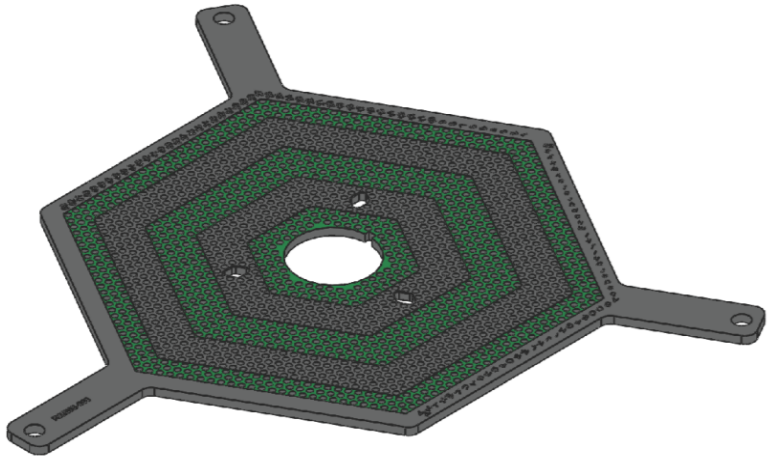
- Control and Safety Element bundle plates
  - Maintain spacing of the 4 rod clusters
- Grid Plates (Guide, Upper, and Lower)

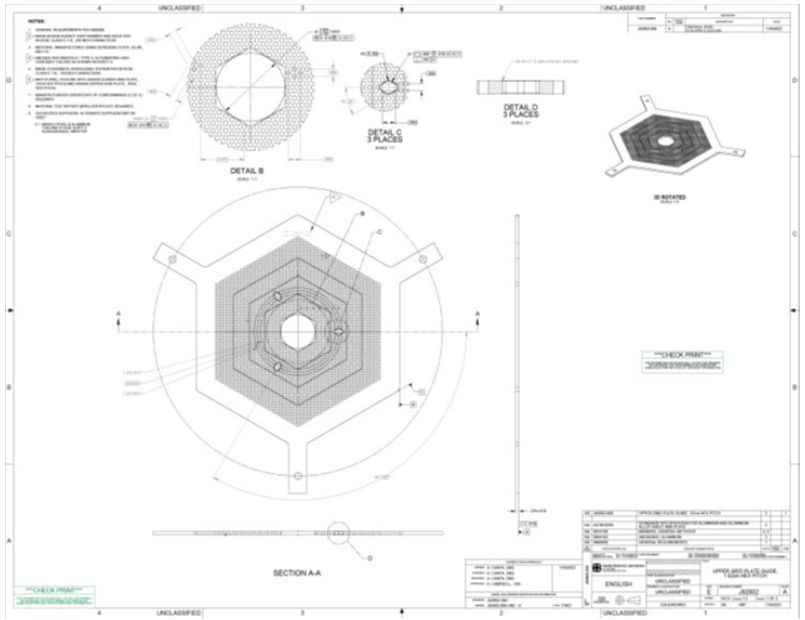
  - Dimensions match fuel rods (about 1 cm longer)



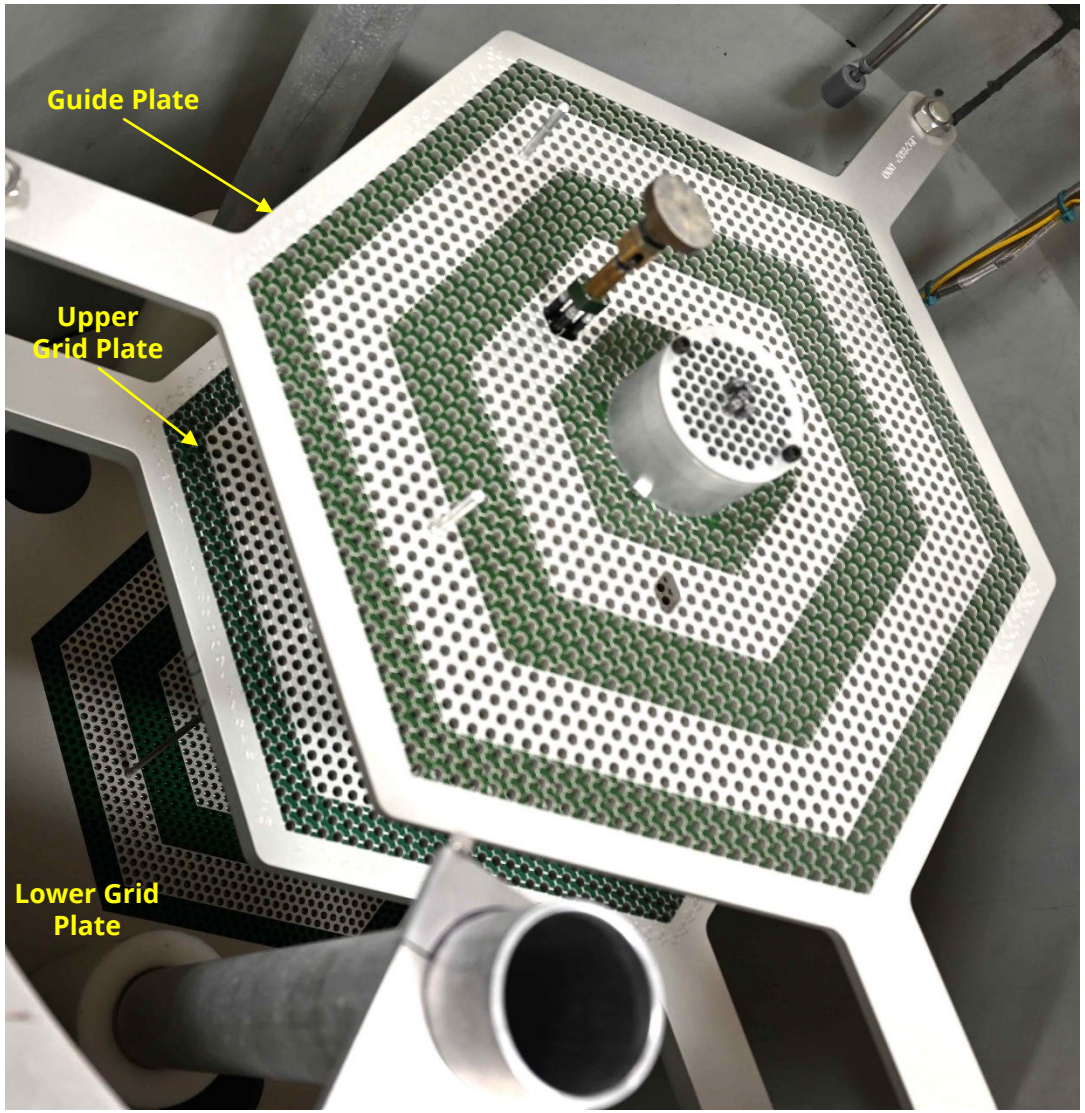
IER 441: New Hardware

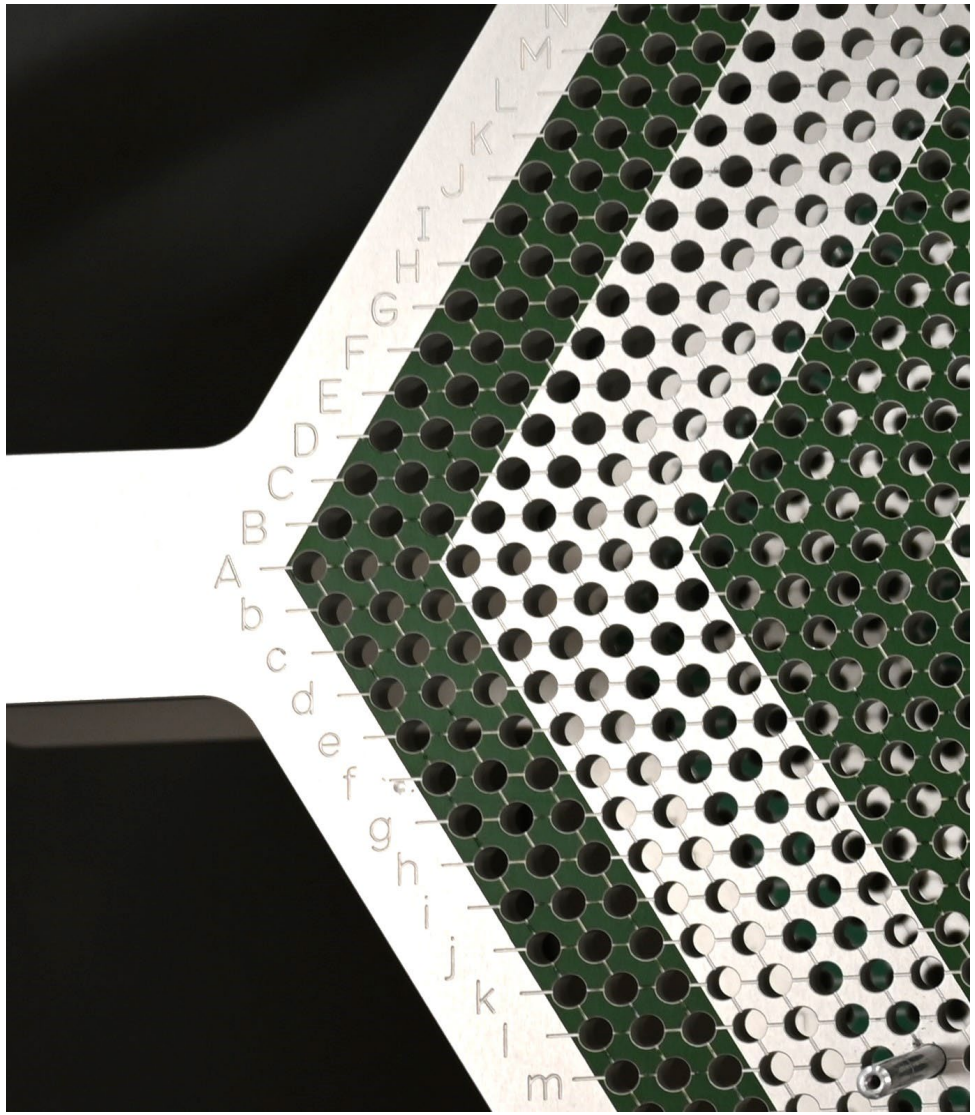
- Control and Safety Element bundle plates
  - Maintain spacing of the 4 rod clusters
- **Grid Plates (Guide, Upper, and Lower)**
  - **Maintain spacing of fuel rods**
  - **Triangular pitch (1.02 cm)**
- Hydro Tubes and Springs
  - Gravity drop of control and safety elements
- Central test region
  - Outer Diameter 9.5 cm
  - Length 78 cm
  - Dry cavity
  - Lined with cadmium
  - Maintain spacing of test rods
  - 85 test rod locations
  - Triangular pitch (0.81 cm)
- Tantalum rods
  - Pure tantalum (> 99.95%)
  - Dimensions match fuel rods (about 1 cm longer)





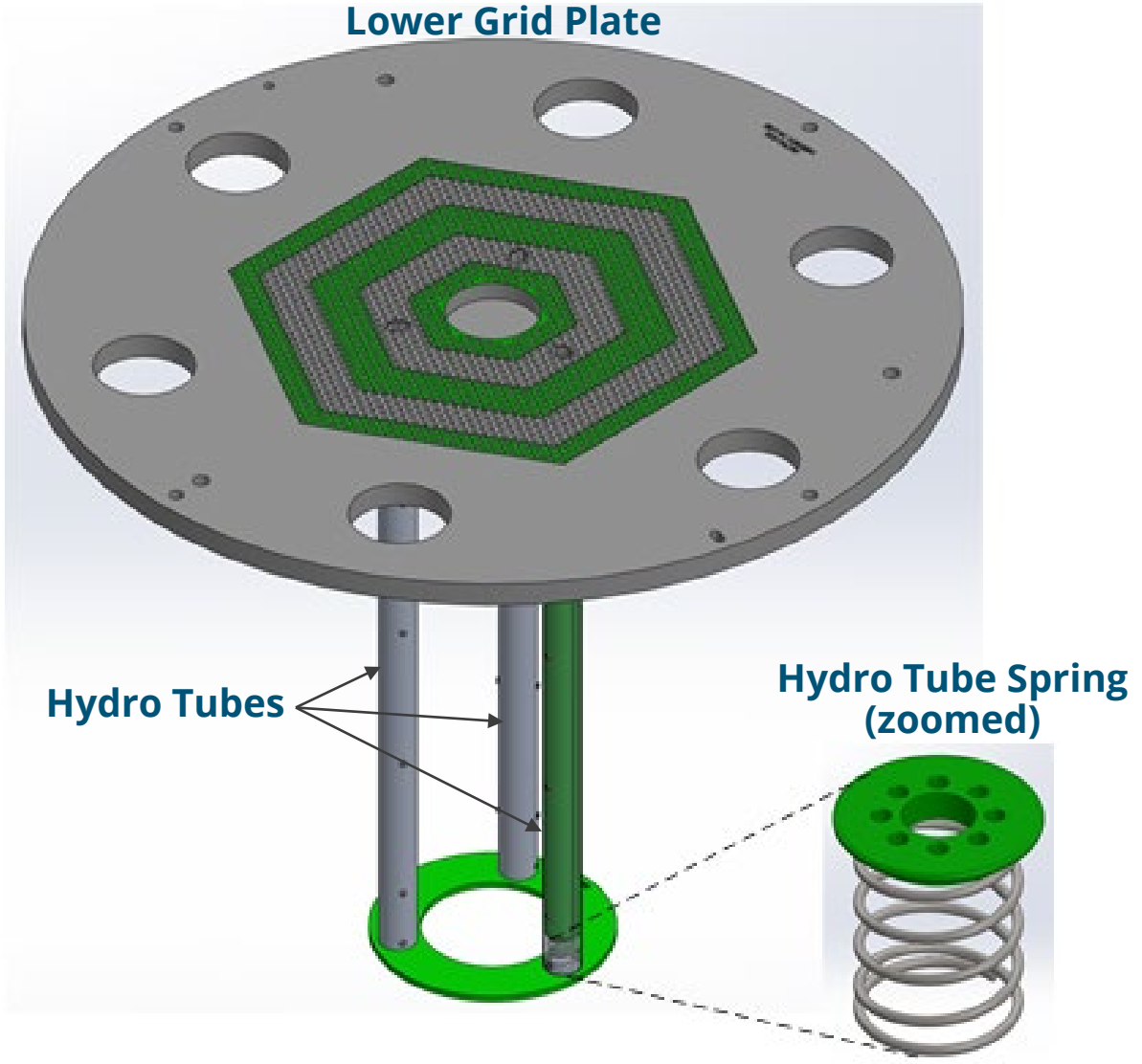
IER 441: New Hardware – Guide and Grid Plates





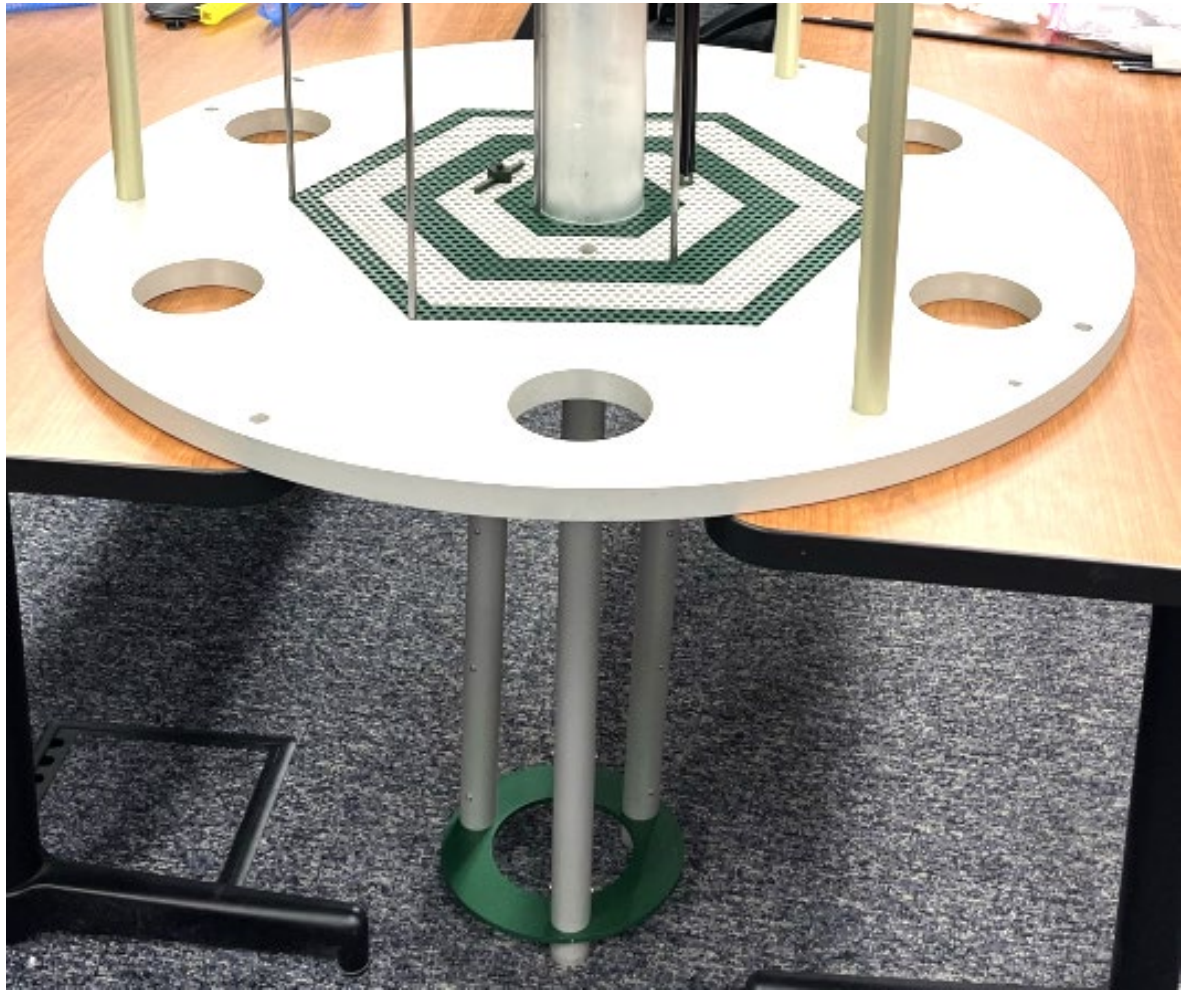
IER 441: New Hardware

- Grid Plates (Guide, Upper, and Lower)
  - Maintain spacing of fuel rods
  - Triangular pitch (1.02 cm)
- Control and Safety Element bundle plates
  - Maintain spacing of the 4 rod clusters
- Hydro Tubes and Springs
  - Gravity drop of control and safety elements
- Central test region
  - Outer Diameter 9.5 cm
  - Length 78 cm
  - Dry cavity
  - Lined with cadmium
  - Maintain spacing of test rods
  - 85 test rod locations
  - Triangular pitch (0.81 cm)
- Tantalum rods
  - Pure tantalum (> 99.95%)
  - Dimensions match fuel rods (about 1 cm longer)



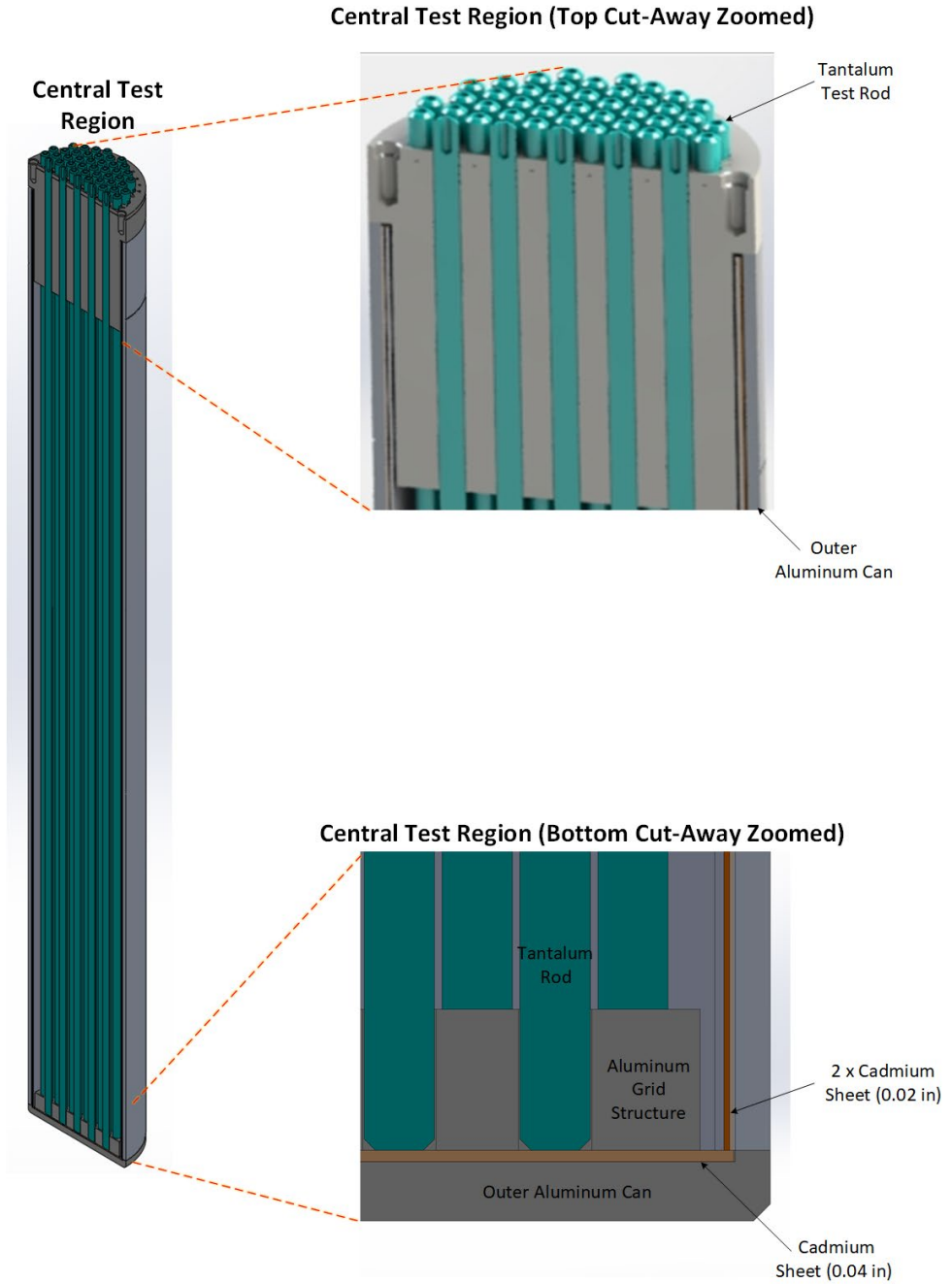
IER 441: New Hardware

- Grid Plates (Guide, Upper, and Lower)
  - Maintain spacing of fuel rods
  - Triangular pitch (1.02 cm)
- Control and Safety Element bundle plates
  - Maintain spacing of the 4 rod clusters
- Hydro Tubes and Springs
  - Gravity drop of control and safety elements
- Central test region
  - Outer Diameter 9.5 cm
  - Length 78 cm
  - Dry cavity
  - Lined with cadmium
  - Maintain spacing of test rods
  - 85 test rod locations
  - Triangular pitch (0.81 cm)
- Tantalum rods
  - Pure tantalum (> 99.95%)
  - Dimensions match fuel rods (about 1 cm longer)

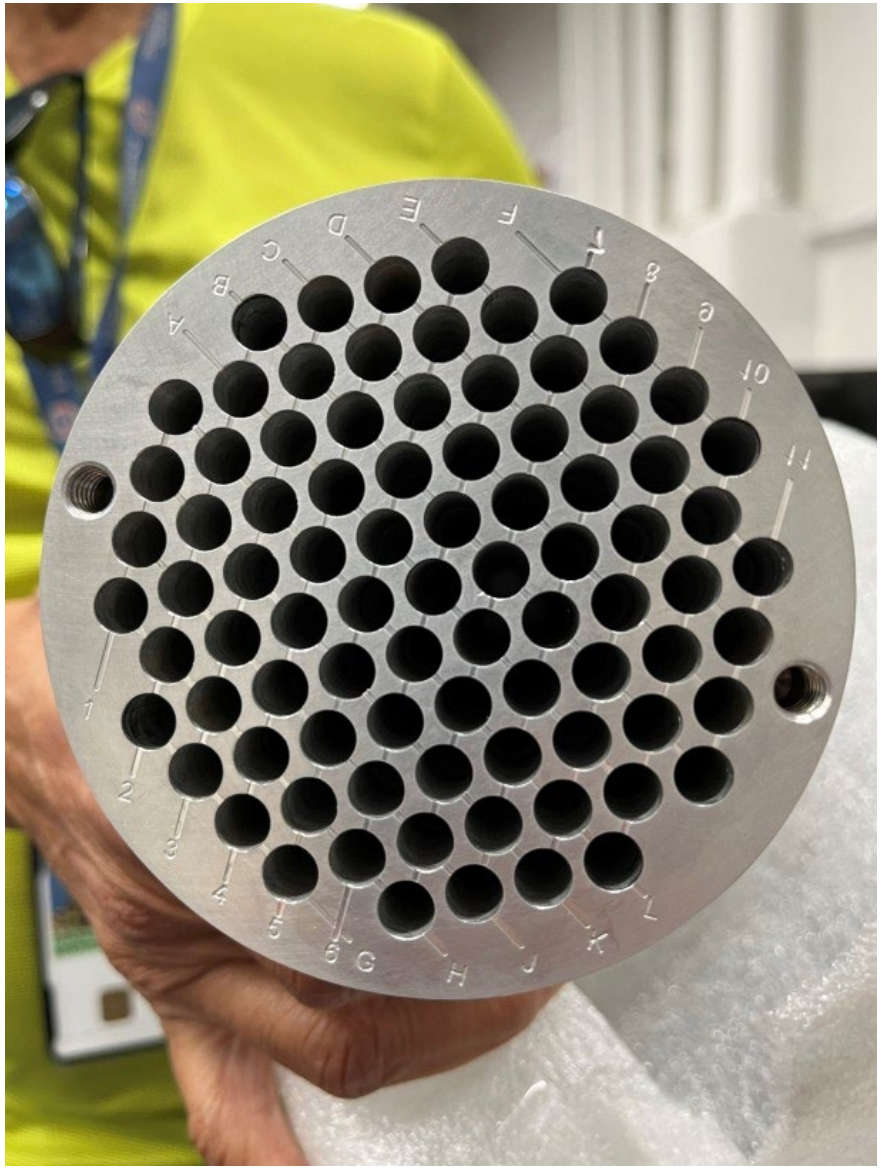


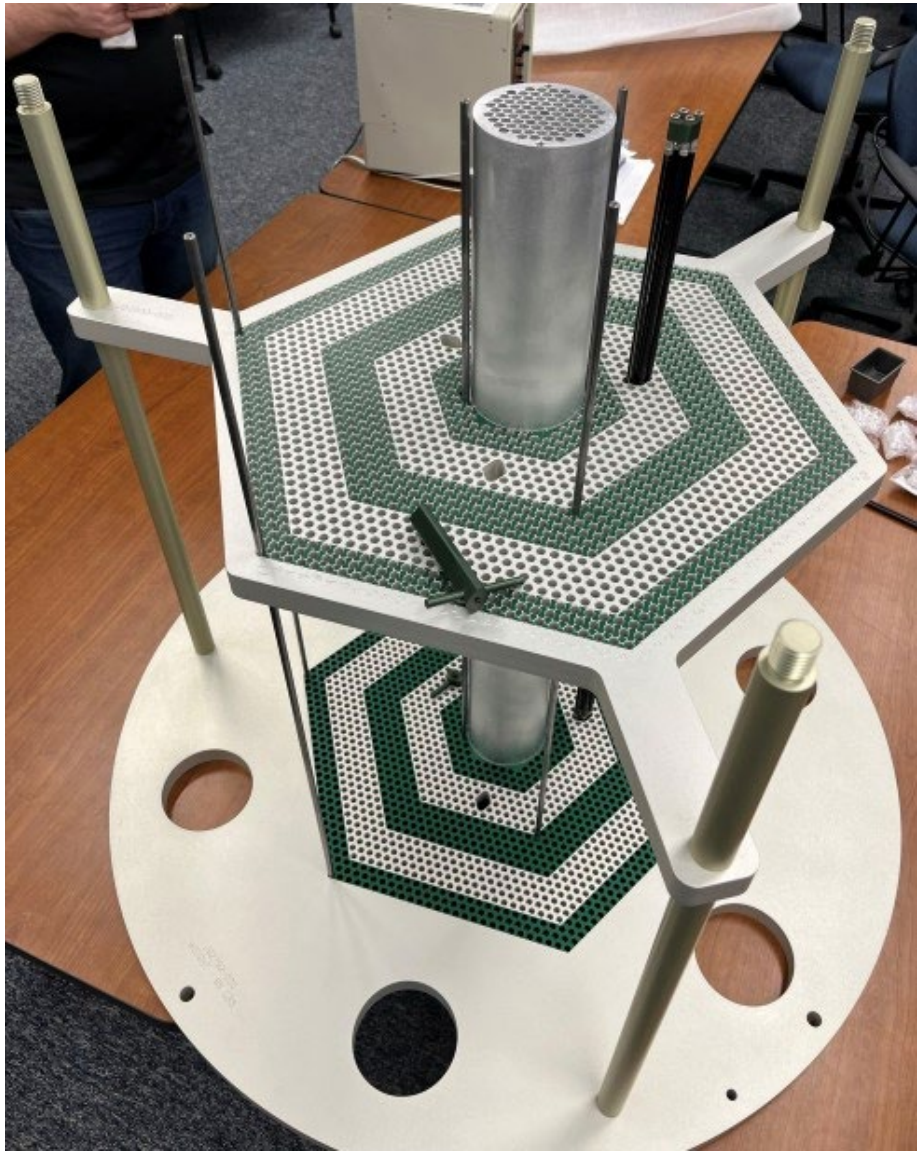
IER 441: New Hardware

- Grid Plates (Guide, Upper, and Lower)
  - Maintain spacing of fuel rods
  - Triangular pitch (1.02 cm)
- Control and Safety Element bundle plates
  - Maintain spacing of the 4 rod clusters
- Hydro Tubes and Springs
  - Gravity drop of control and safety elements
- **Central test region**
  - **Outer Diameter 9.5 cm**
  - **Length 78 cm**
  - **Dry cavity**
  - **Lined with cadmium**
  - **Maintain spacing of test rods**
  - **85 test rod locations**
  - **Triangular pitch (0.81 cm)**
- Tantalum rods
  - Pure tantalum (> 99.95%)
  - Dimensions match fuel rods (about 1 cm longer)

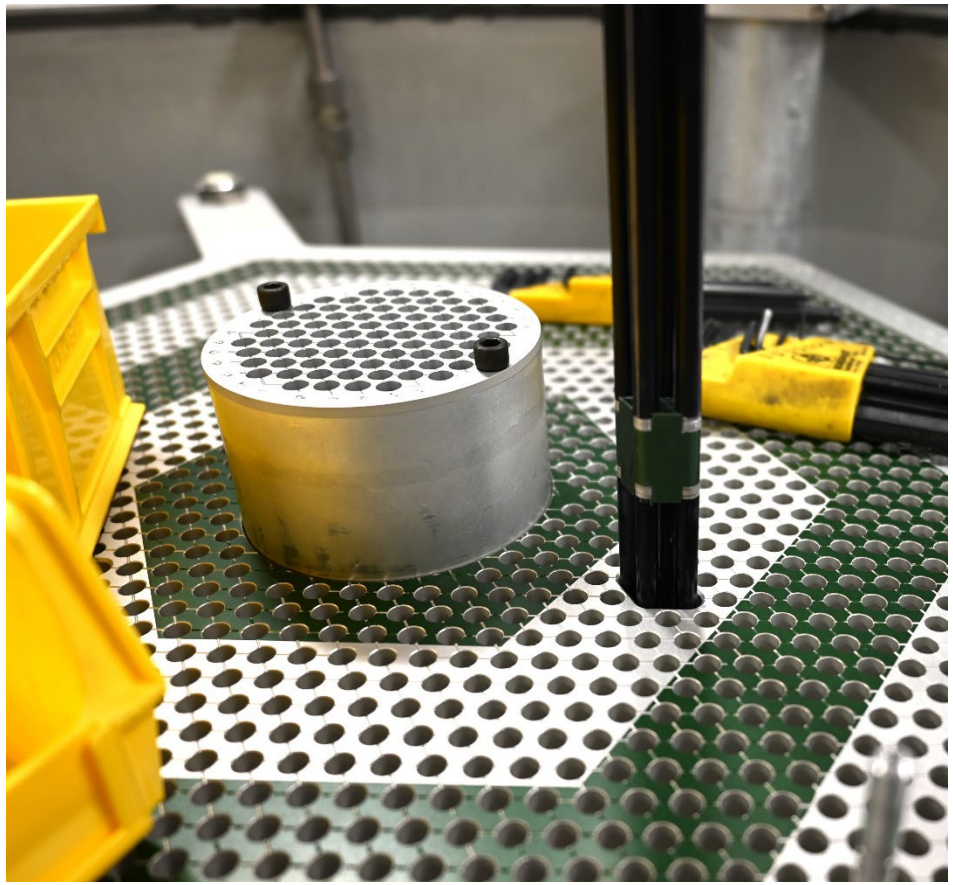


IER 441: New Hardware – Central Test Region

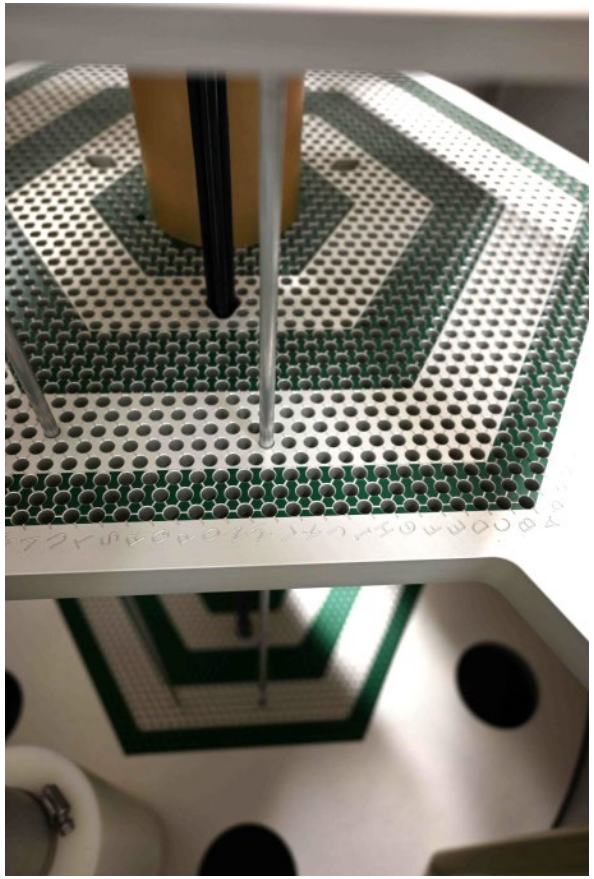




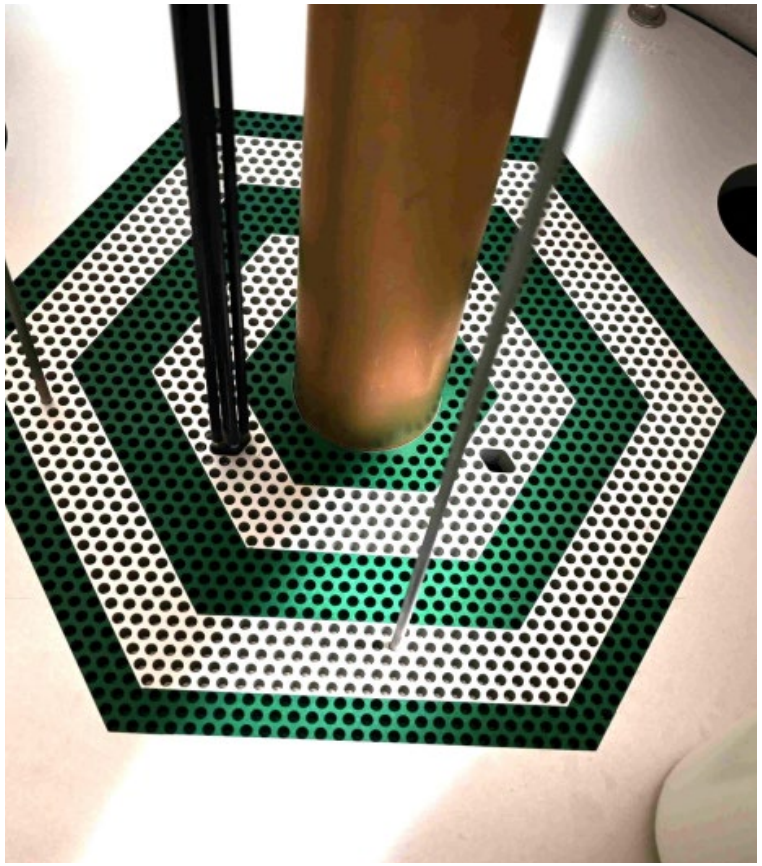
IER 441: New Hardware – Central Test Region



View from above Guide Plate



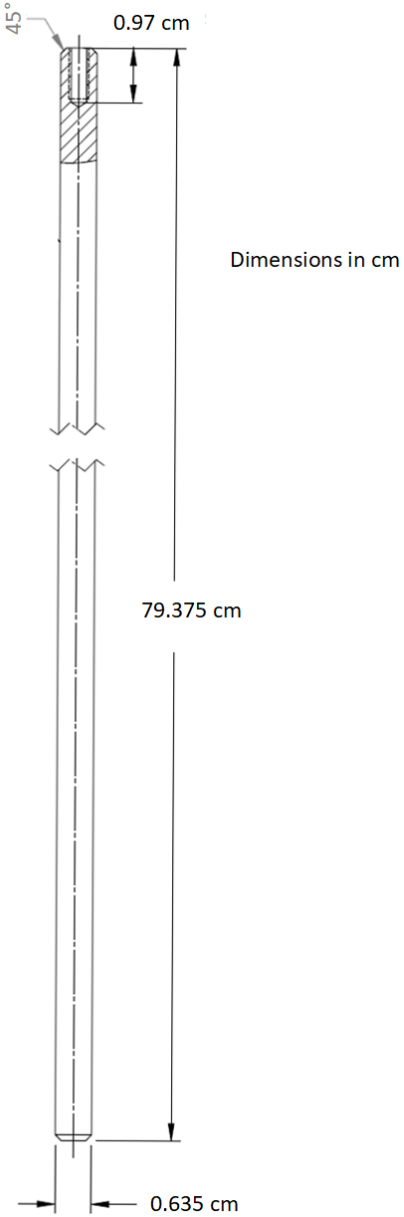
Between Guide Plate and Upper Grid Plate



Above Lower Grid Plate

IER 441: New Hardware

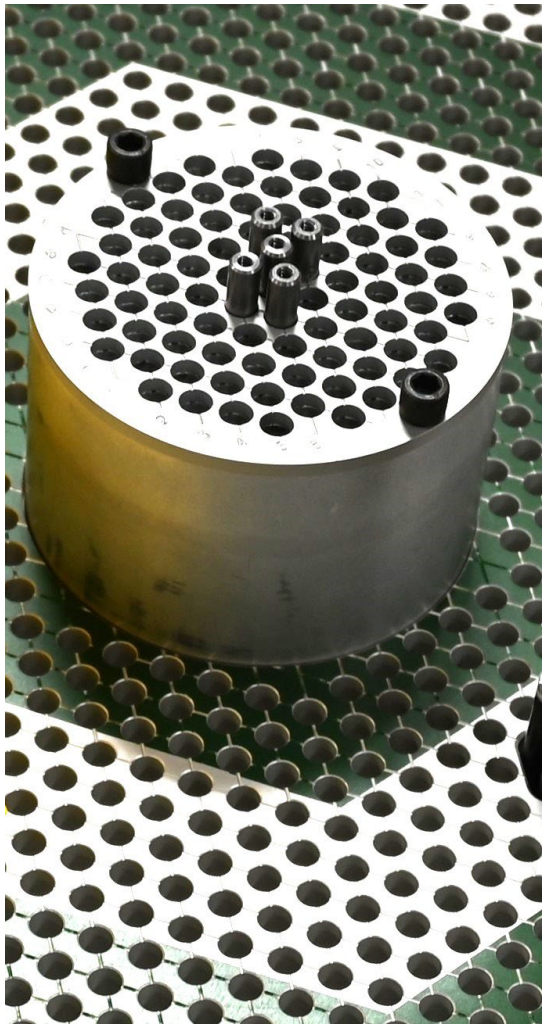
- Grid Plates (Guide, Upper, and Lower)
  - Maintain spacing of fuel rods
  - Triangular pitch (1.02 cm)
- Control and Safety Element bundle plates
  - Maintain spacing of the 4 rod clusters
- Hydro Tubes and Springs
  - Gravity drop of control and safety elements
- Central test region
  - Outer Diameter 9.5 cm
  - Length 78 cm
  - Dry cavity
  - Lined with cadmium
  - Maintain spacing of test rods
  - 85 test rod locations
  - Triangular pitch (0.81 cm)
- **Tantalum rods**
  - **Pure tantalum (> 99.95%)**
  - **Dimensions match fuel rods (about 1 cm longer)**



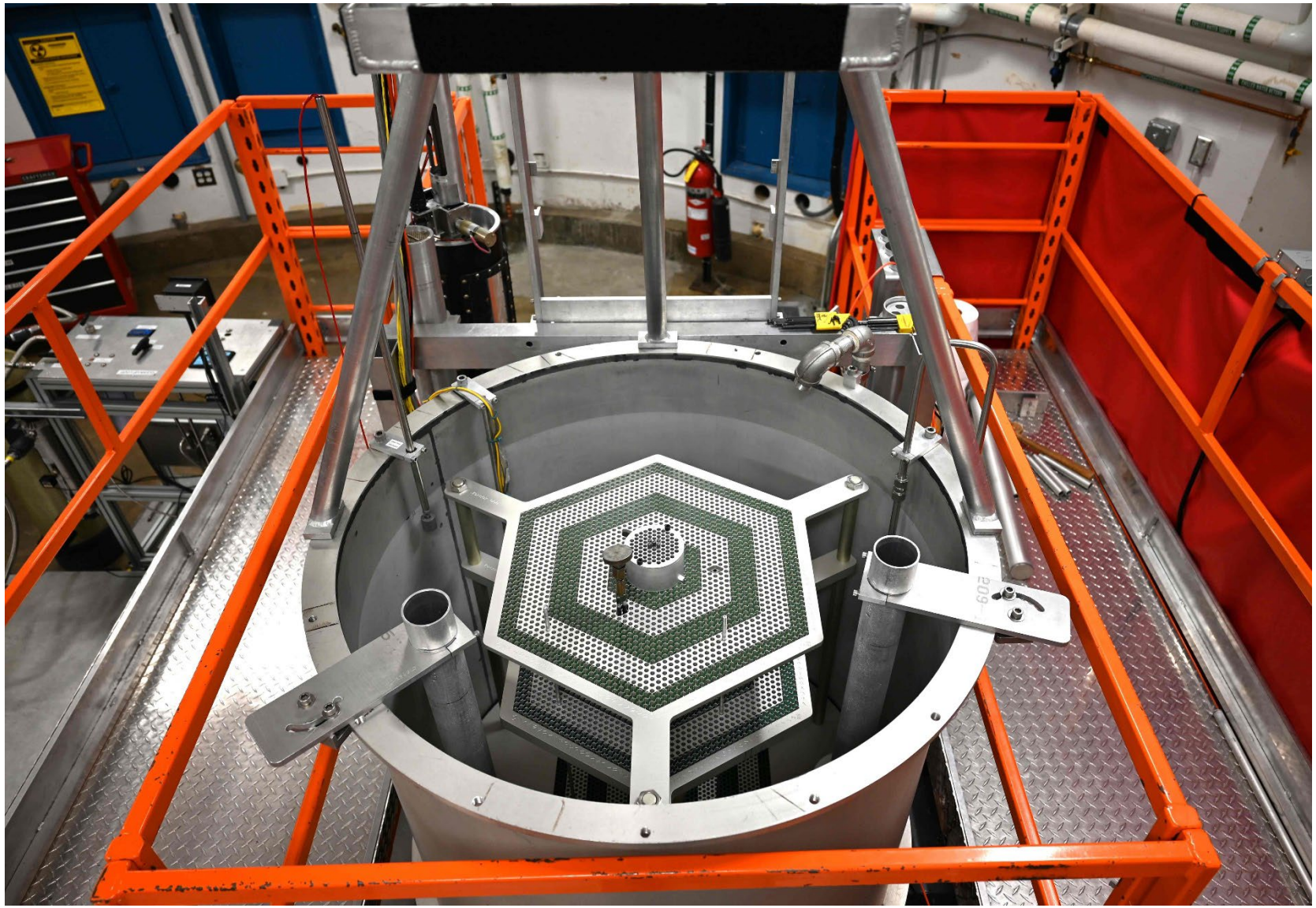
Tantalum rods

- Commercially pure
  - 99.95%
  - ASTM B365-12
- Fabricated from same heat load
- Elemental compositions including impurities
- Etched with serial numbers

IER 441: New Hardware – Tantalum Rods



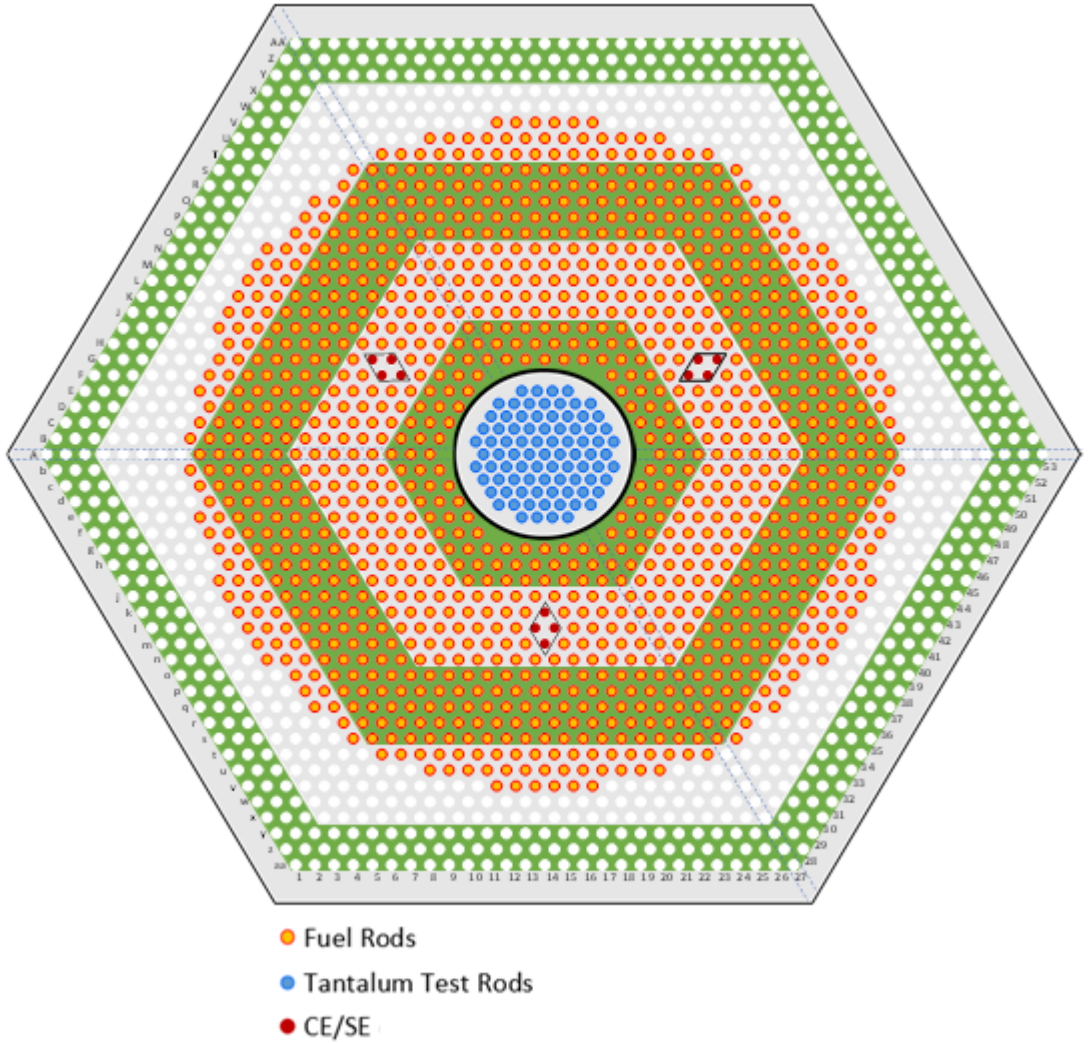
IER 441: New Hardware



IER 441: Experiment Method

Approach-to-Critical Experiments

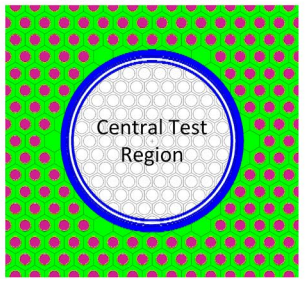
- Number of fuel rods is the free parameter
  - Loaded from center towards outside of the array
  - Maintain a roughly cylindrical cross section of the array
  - Loading order identical for each experiment
  - Each fuel rod in the same array location in every configuration
- Control and Safety Elements fully withdrawn
- Initial configuration
  - Calculated k_{eff} ~ 0.90 (786 fuel rods)
  - Calculated k_{eff} ~ 0.95 (954 fuel rods)
- Inverse count rate at successive fuel configurations
  - Extrapolated to zero to obtain estimate of critical array size



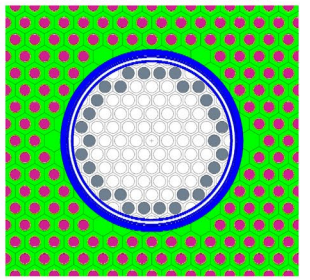
IER 441: Critical Configurations

Case	Ta-rods	Fuel Rods	Ta Worth ($\Delta k/k \pm \sigma$)	Three group energy-dependent Ta absorption rates		
				<0.625 eV	0.625 eV–100 keV	>100 keV
1	0	1044	-	-	-	-
2	7	1068	0.460 ± 0.006 %	1.40 %	93.89 %	4.72 %
3	18	1086	1.078 ± 0.006 %	1.30 %	93.75 %	4.95 %
4	19	1084	0.944 ± 0.006 %	1.52 %	92.52 %	5.97 %
5	30	1110	1.656 ± 0.006 %	1.11 %	93.55 %	5.34 %
6	37	1108	1.499 ± 0.006 %	1.47 %	91.46 %	7.07 %
7	61	1136	2.081 ± 0.006 %	1.38 %	90.43 %	8.19 %
8	85	1158	2.546 ± 0.004 %	1.27 %	89.59 %	9.15 %
No Cd	85	1134	5.725 ± 0.004 %	30.96 %	62.87 %	6.17 %

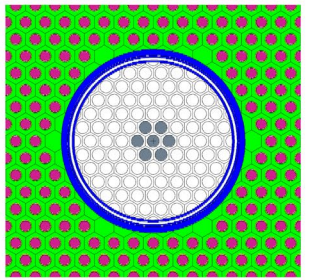
Case 1: No Tantalum



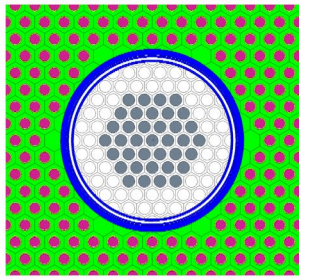
Case 5: 30 Tantalum Rods



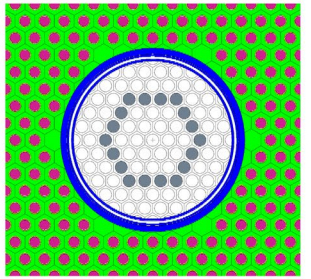
Case 2: 7 Tantalum Rods



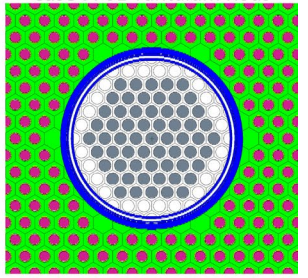
Case 6: 37 Tantalum Rods



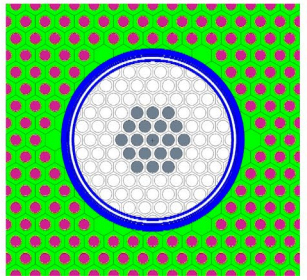
Case 3: 18 Tantalum Rods



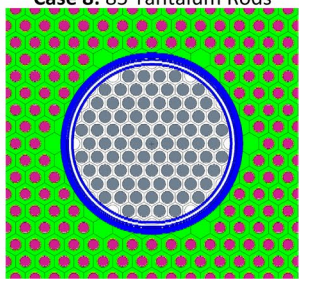
Case 7: 61 Tantalum Rods



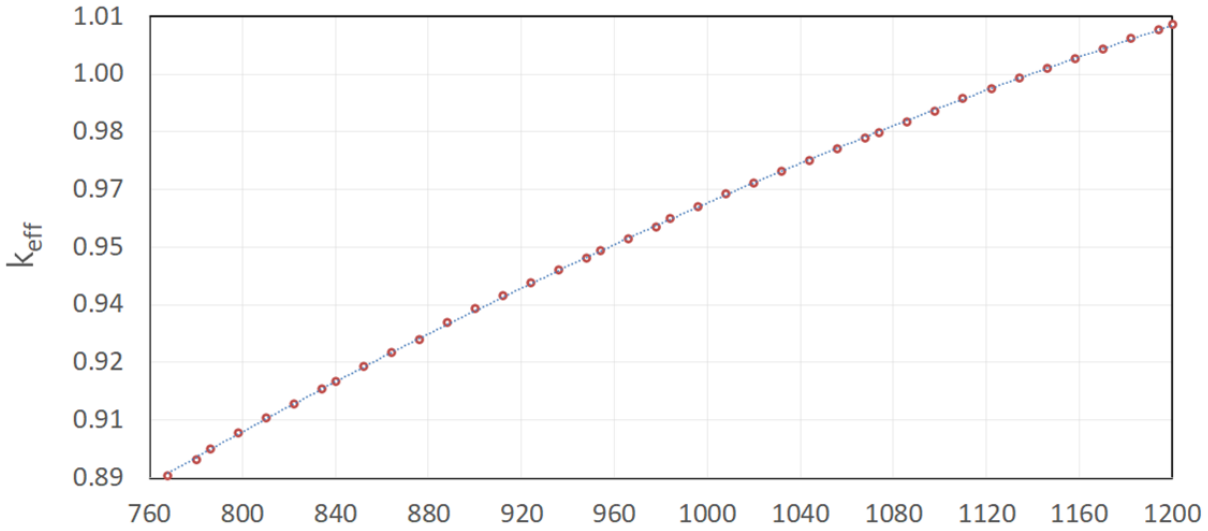
Case 4: 19 Tantalum Rods

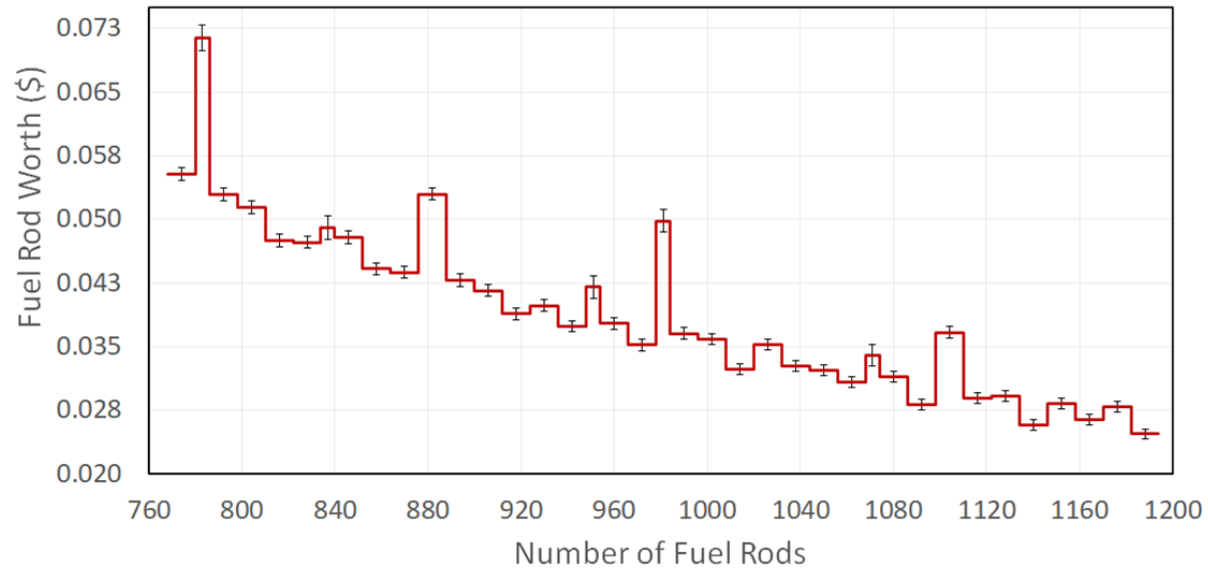


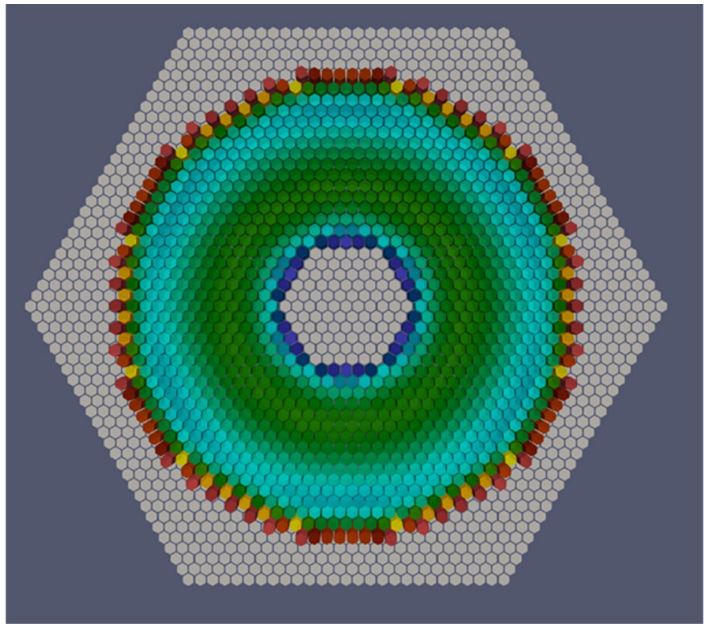
Case 8: 85 Tantalum Rods

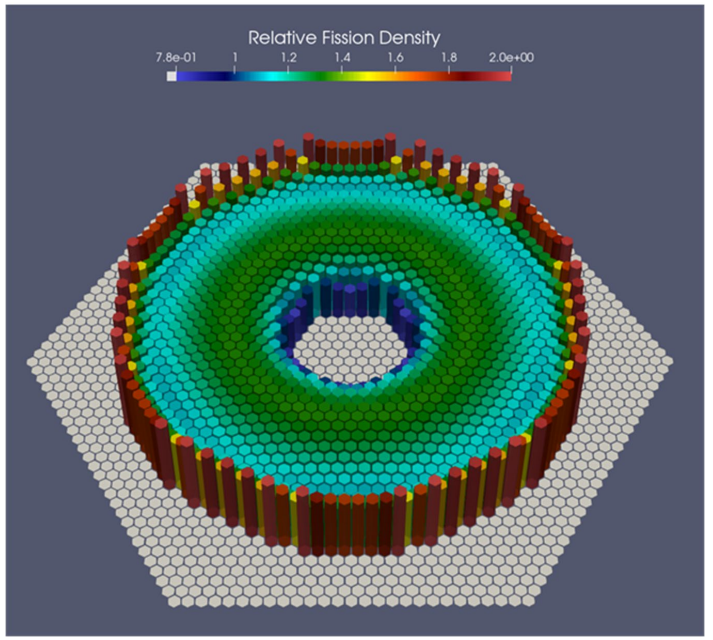


IER 441: Critical Configuration Case 8 (85 Ta rods)









IER 441: Next Steps

- Complete CED-3a by FY24Q2
  - Final fit and form test
  - Finalize experiment schedule
- Complete CED-3b by FY24Q4
  - Begin experiments in March
  - ORNL visit for experiments
    - Mathieu Dupont
    - BJ Marshall
- Evaluation and Publication (ICSBEP)
  - ICSBEP TRG Spring 2025
  - CED-4a by FY25Q2
  - CED-4b by FY25Q4

Acknowledgements

Thank you

- Sandia: Gary Harms, Augie Chapa, Beth Hanson, Jason Soares, Patrick Ward, Elijah Lutz, Cassandra Wilson
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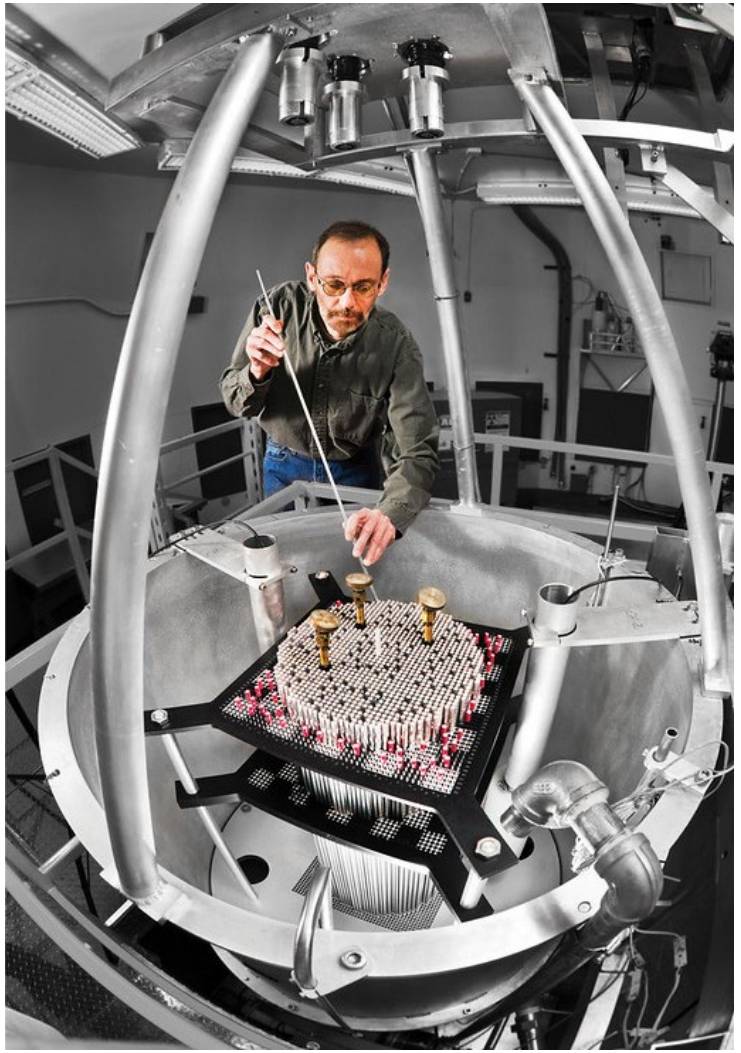
- DOE NCSP: The critical experiments at Sandia are supported by the DOE Nuclear Criticality Safety Program (NCSP), funded and managed by the National Nuclear Security Administration for the Department of Energy.



Questions?