Sandia National Laboratories

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IER 441: Experiments to Measure the Effect of Tantalum on Critical Systems (SNL/ORNL)

Presented by David Ames (SNL)

Contributors: Mathieu Dupont (ORNL), Gary Harms (SNL), Augie Chapa (SNL), Elijah Lutz (SNL)

NCSP Technical Program Review

February 21-23, 2023

Hosted by Sandia National Laboratories

Albuquerque, NM

SAND2023 – 12567PE

Overview

Sandia Critical Experiments Program
- 7uPCX
- BUCCX

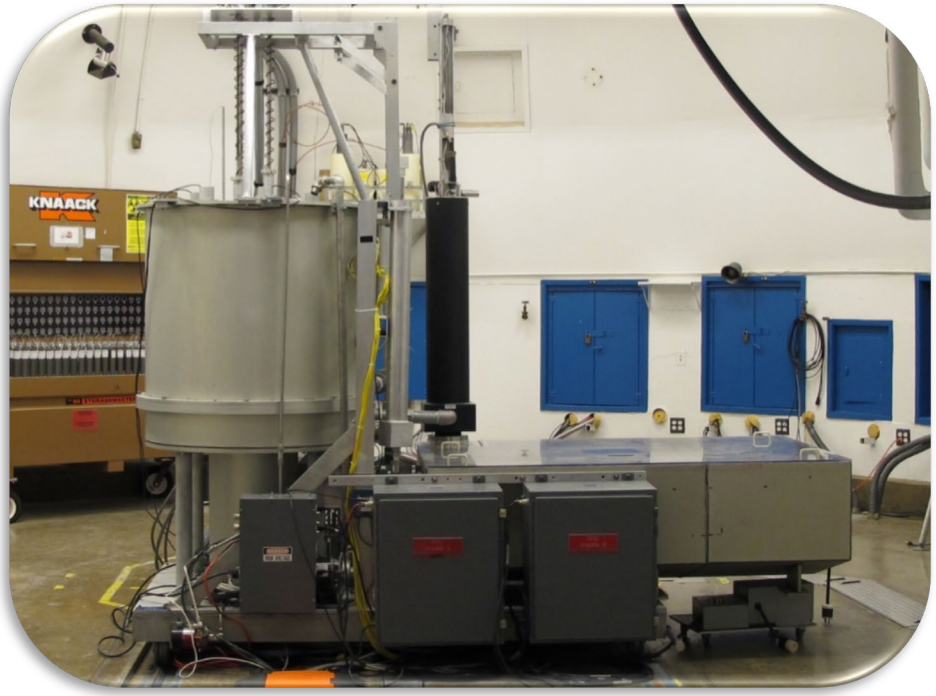
Motivation for Experiments

Experiment Design (ORNL Lead – CED 1 & 2)

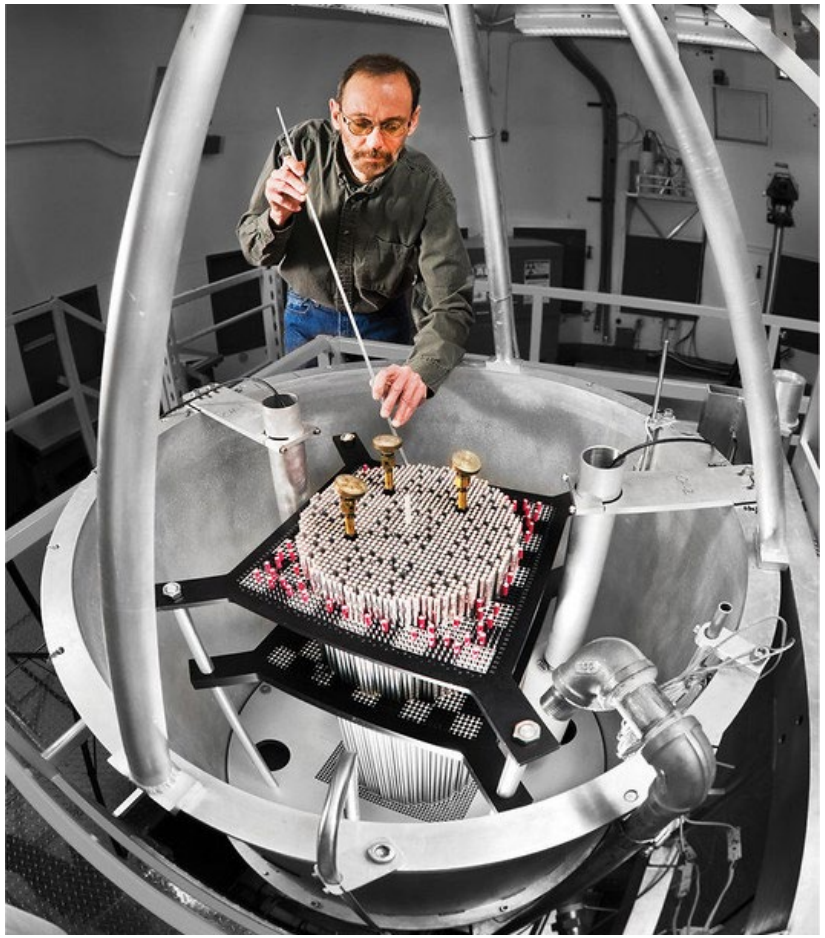
Perform Experiments (**SNL Lead – CED 3a** & 3b)
- Design modifications
- Hardware procurement
- Conduct experiments – June to October 2023

Experiment Evaluation and Publication (ICSBEP)
- Technical Review Group Meeting – April 2024

Acknowledgements



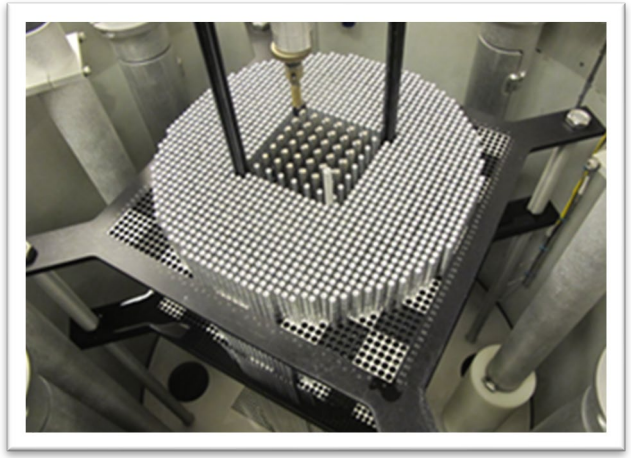
Sandia Critical Experiments Program



7uPCX

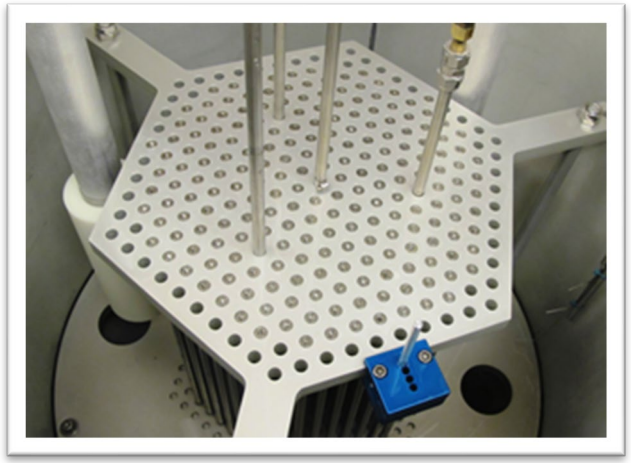
The Seven Percent Critical Experiment (7uPCX)

- UO_2 fuel (6.9%)
- 45x45 Square pitch array (0.315 and 0.337 inch)
- Triangular pitch array (0.61 inch)
- Fuel rod diameter 0.25 inch
- Fuel length 19.25 inch
- LCT-078, 080, 096, 097, 101, 102, 10?(IER 305)



The Burnup Credit Critical Experiment (BUCCX)

- UO_2 fuel (4.3%)
- Triangular pitch (0.787 and 1.1 inch)
- Fuel locations 397 and 271
- Fuel rod diameter 0.544 inch
- Fuel length 19.37 inch
- LCT-079, 099



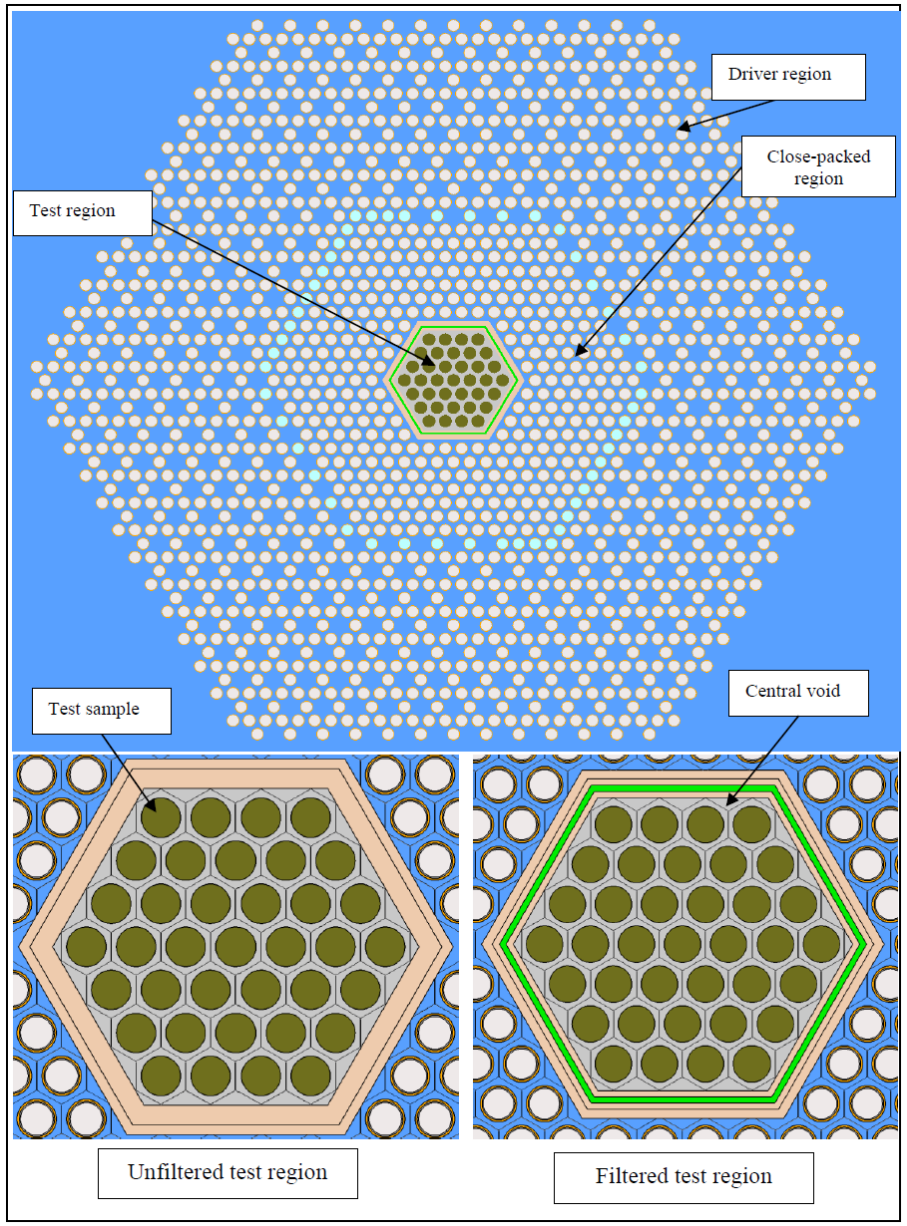
IER 441

Experiment motivation

- Develop ability to test epithermal/intermediate energy cross sections for materials using 7uPCX
- Applicable to Savanah River Site and Hanford Tank Farms (DOE-EM)

Notable design features from CED-2 (ORNL Lead)

- Triangular pitched grid plates
  - 0.800 cm
- Two fuel regions
  - Close-packed region (under-moderated)
  - Driver region (every other fuel rod removed)
- Central test region
  - Dry cavity
  - Lined with cadmium
- Tantalum test material
  - Nineteen materials considered
  - Multiple configurations with up to 37 tantalum rods
- Approach-to-Critical
  - Fuel rods removed from Close-packed region



IER-441 CED-2 report

IER 441

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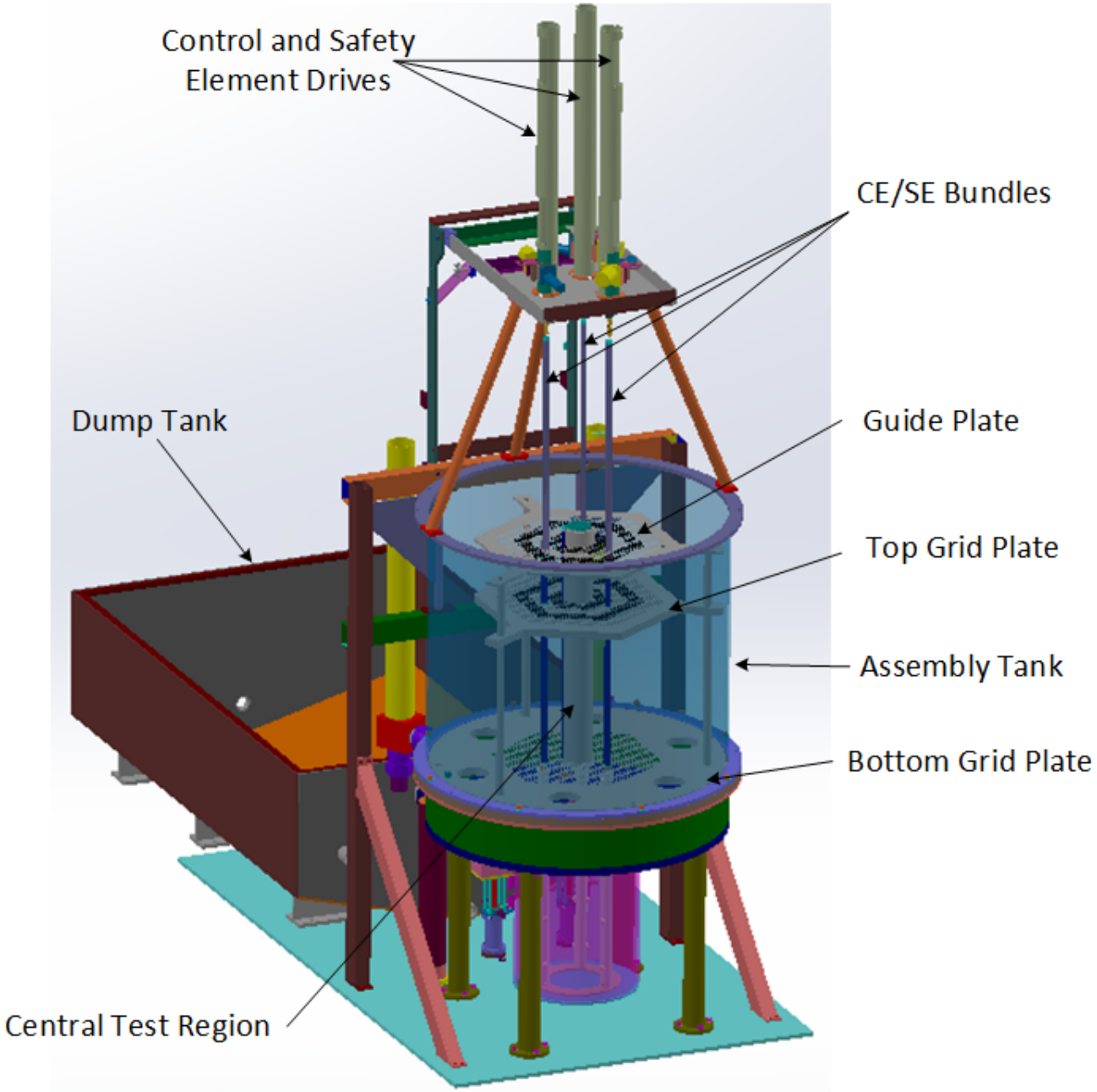
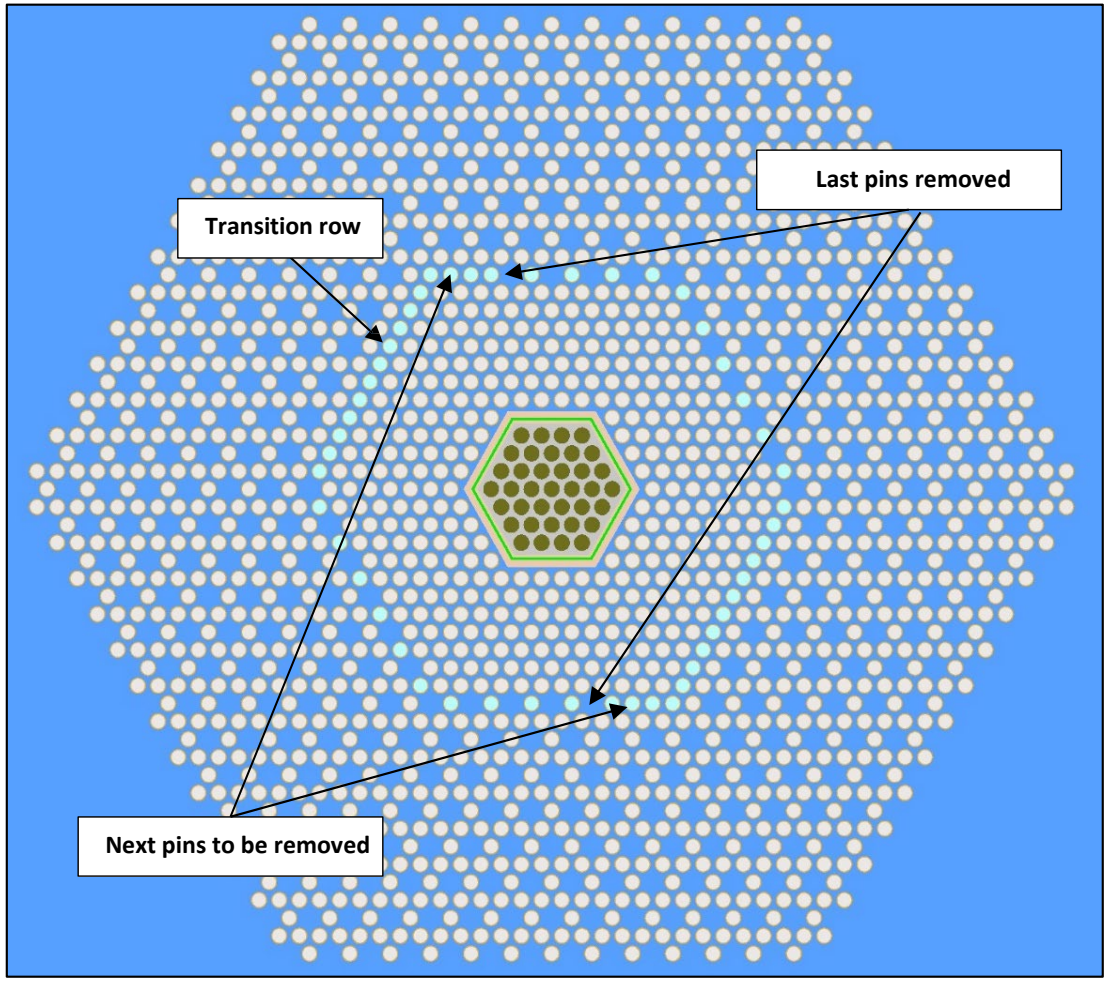


Design Modifications

1. Approach-to-critical process
   - Add fuel rods from the center towards the outside while maintaining a roughly cylindrical cross section of the array.
   - Consistent with past experiments at SNL and provides ability to start approach at k_{eff} ~ 0.90 and 0.95
2. Grid plate hole pitch
   - 0.80 cm (criticality cannot be reached in normal fuel loading)
     - Evaluated a range from 0.80 cm to 1.5 cm
3. Driver region
   - Simplified fuel loading pattern
4. Amount and placement of tantalum rods
   - Increased reactivity worth
5. Geometric shape of central test region
   - Hexagonal vs cylindrical
     - Manufacturing restrictions



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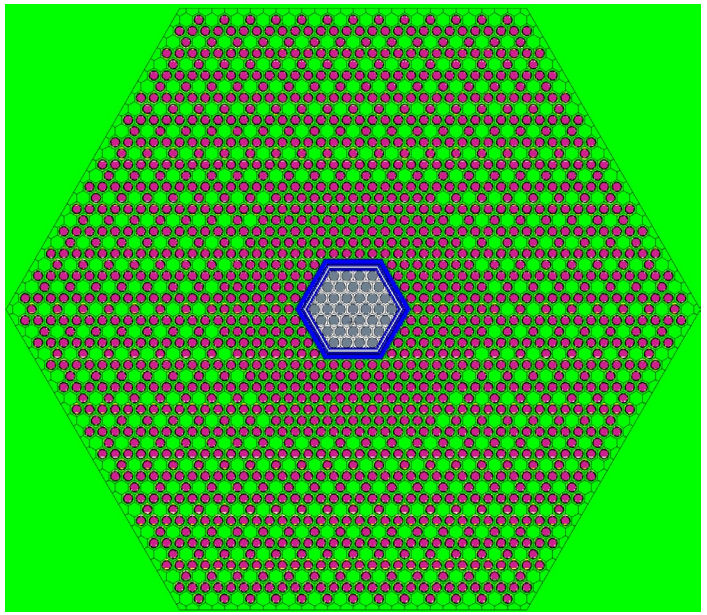
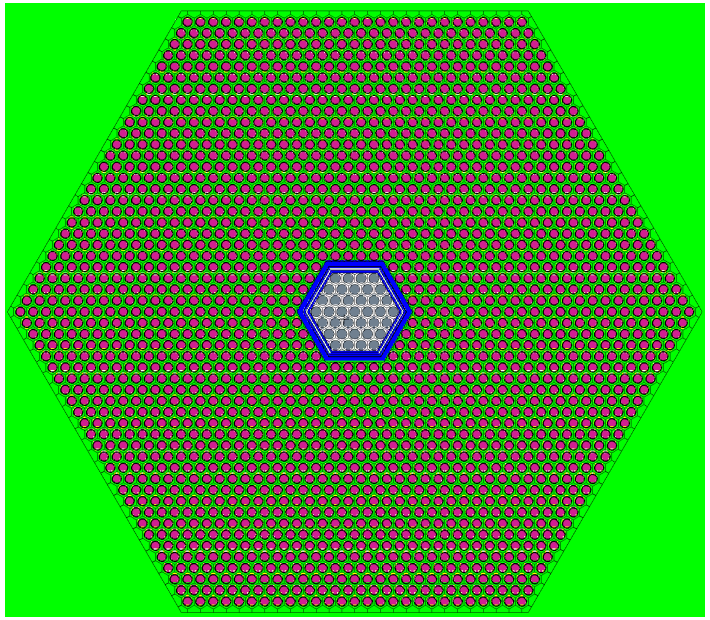


CED-2 critical configuration (pitch = 0.80 cm)



k_{eff} ~ 0.93

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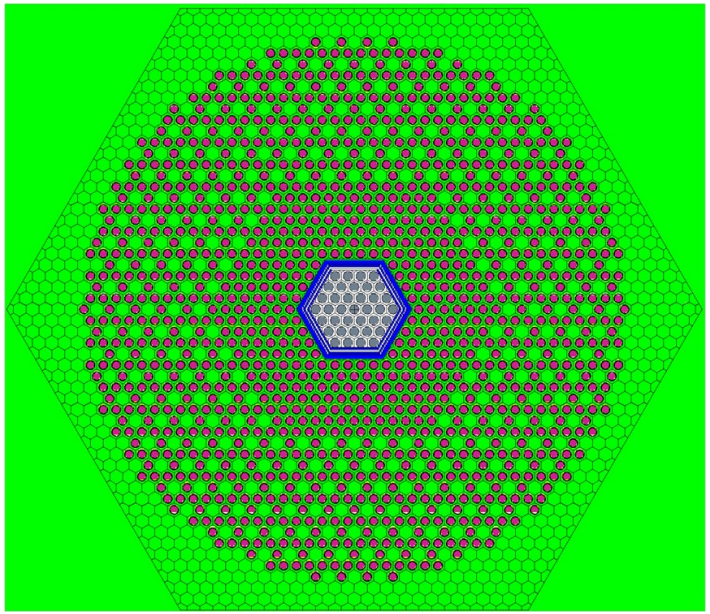
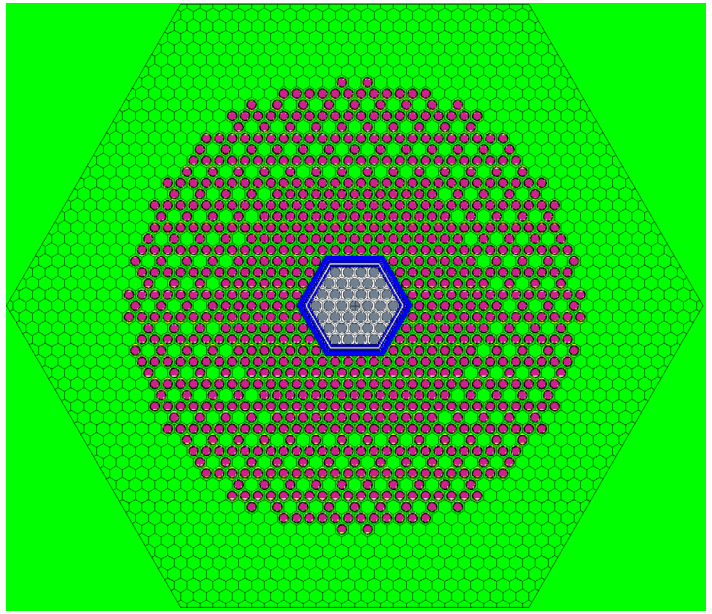


Critical configuration (pitch = 0.86 cm)



k_{eff} ~ 0.90

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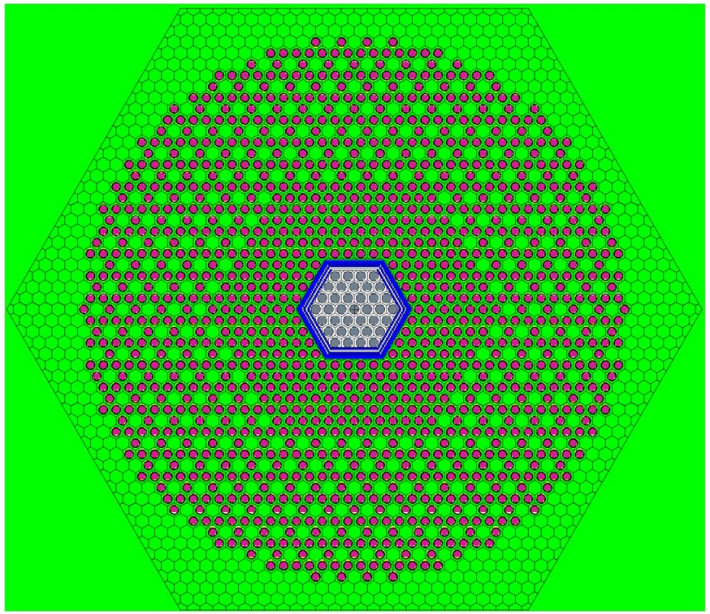

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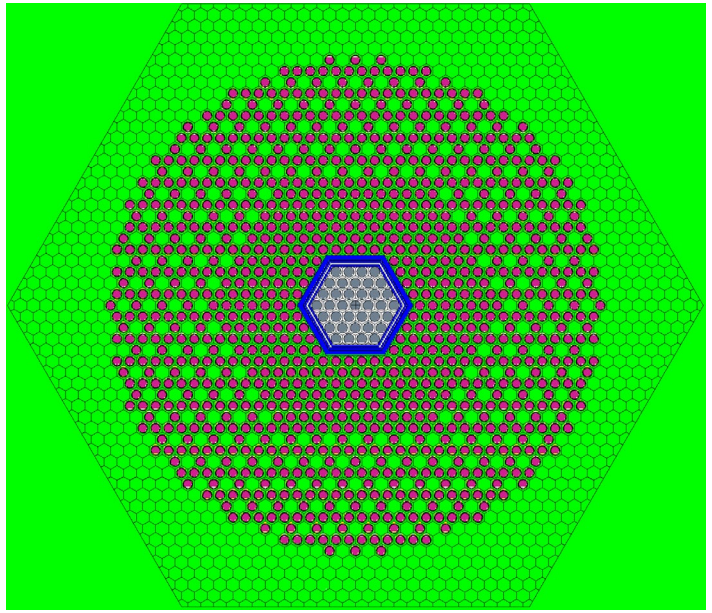

k_{eff} ~ 0.95

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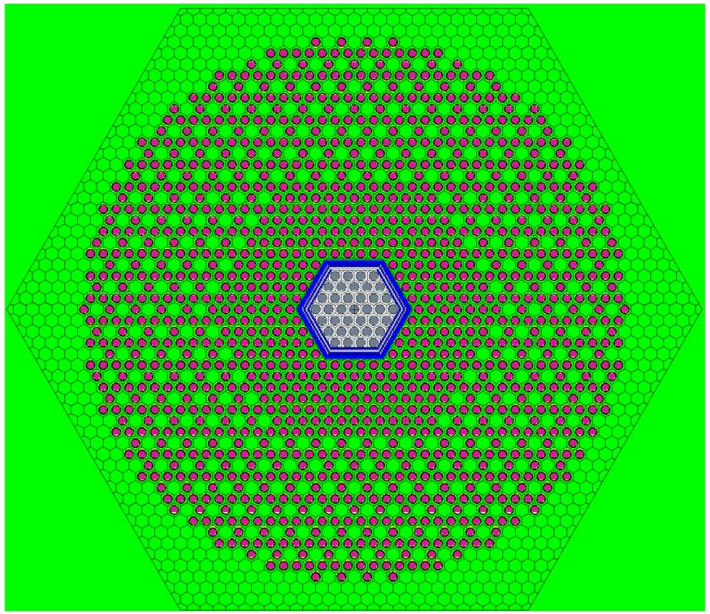
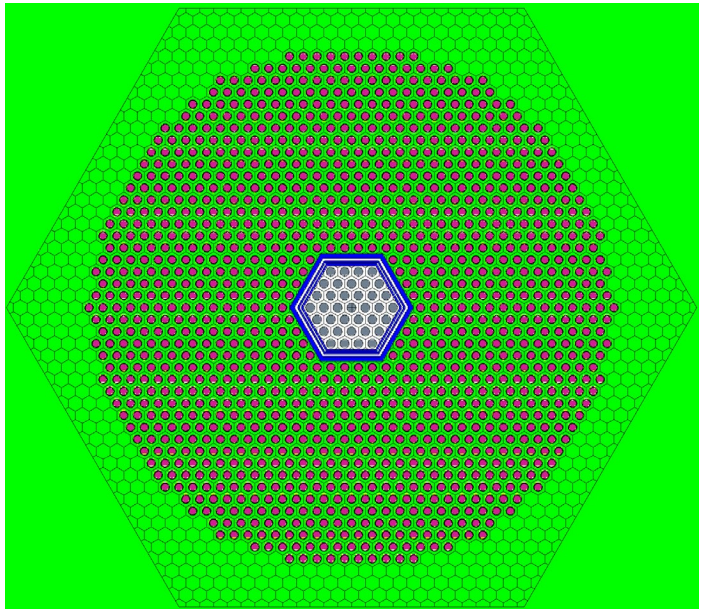


Driver Region (pitch = 0.86 cm)



No Driver Region (pitch = 0.97 cm)

Design Modifications

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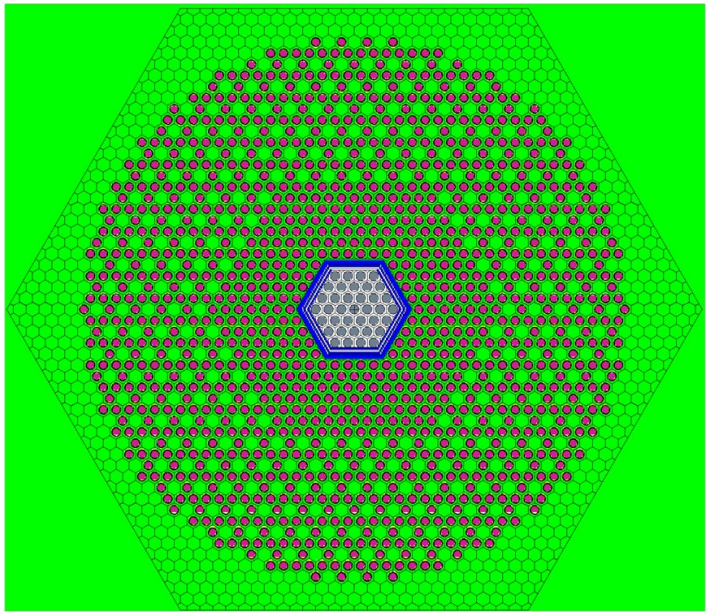
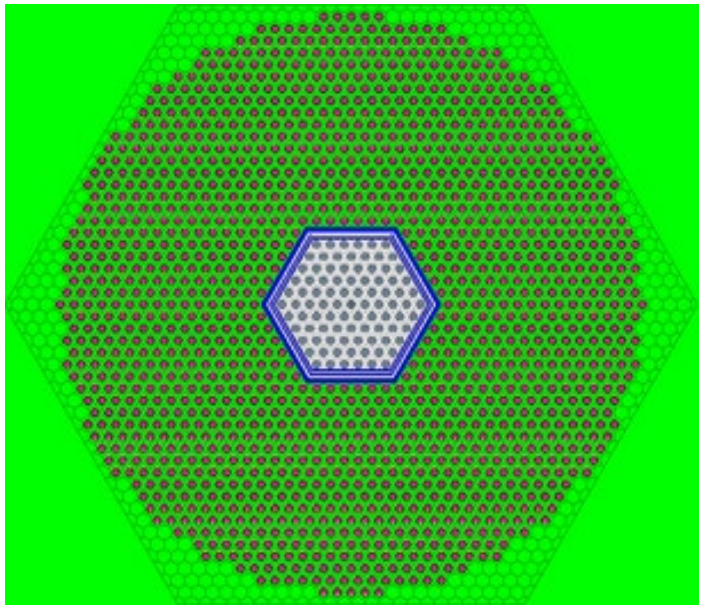


Driver Region (pitch = 0.86 cm)



91 Tantalum rods (pitch = 0.97 cm)

Design Modifications

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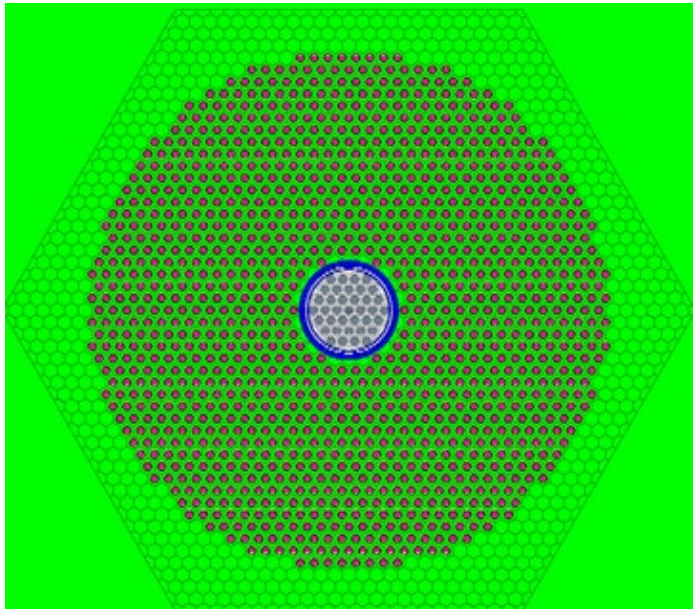
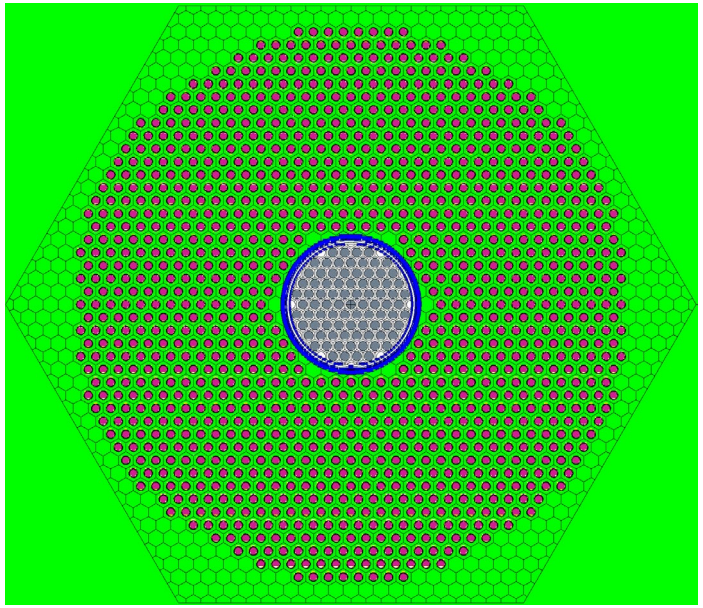


Cylindrical Test Region (37 Ta-rods)



Cylindrical Test Region (85 Ta-rods)

Optimized Configuration

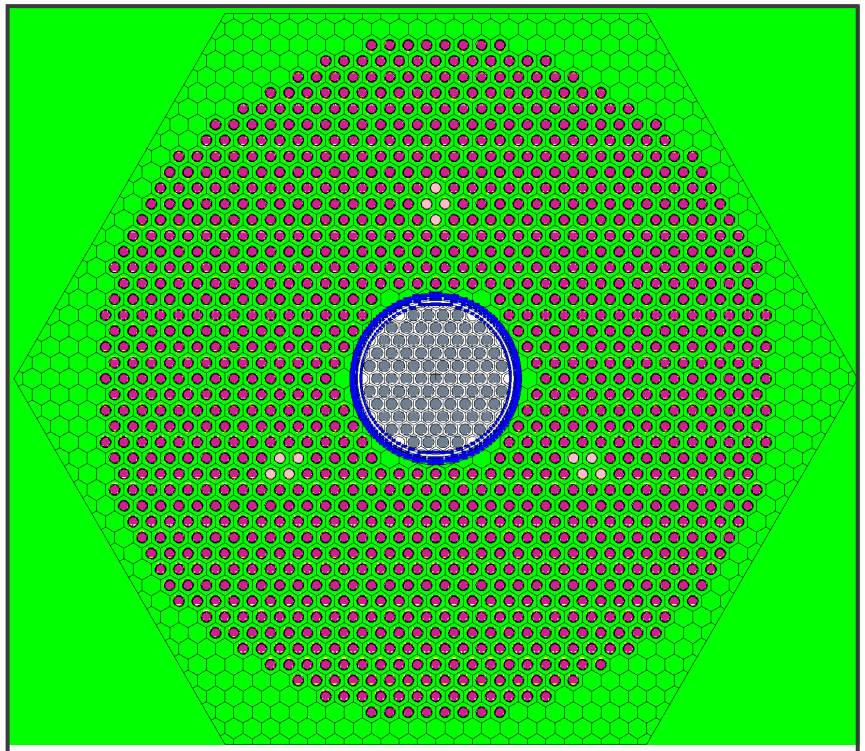
- Maximize tantalum reactivity worth
- Maximize tantalum absorption within the intermediate energy range
  - Pitch of the fuel rods (0.80 – 1.5 cm)
  - Pitch of the tantalum rods in the central test region (0.80 – 1.5 cm)
  - Number of tantalum rods (1 – 91 rods)
  - Thickness of cadmium (0.25 – 3.00 mm)
  - Outer diameter and thickness of the test region can (targeting standard sizes)

CED-2:

Ta Worth (Δk/k ± σ)	Three group energy-dependent Ta absorption rates		
	<0.625 eV	0.625 eV – 100 keV	>100 keV
1.654 ± 0.011 %	1.26 %	90.10 %	8.65 %

Baseline Configuration:

Ta Worth (Δk/k ± σ)	Three group energy-dependent Ta absorption rates		
	<0.625 eV	0.625 eV – 100 keV	>100 keV
2.546 ± 0.004 %	1.27 %	89.59 %	9.15 %

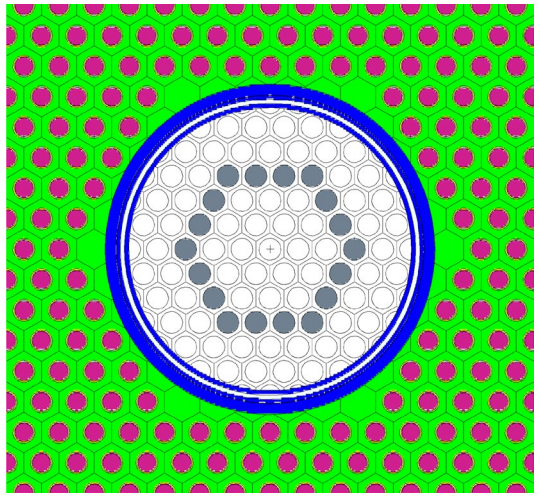


1158 fuel rods (keff = 0.99936 ± 0.00003)
Fuel element worth near critical = 0.029 $
Fuel rod pitch = 1.016 cm
Tantalum rods = 85
Tantalum rod pitch = 0.8128 cm
Aluminum test region can OD = 9.525 cm
Aluminum test region can WT = 0.3175 cm
Cadmium filter thickness = 0.102 cm

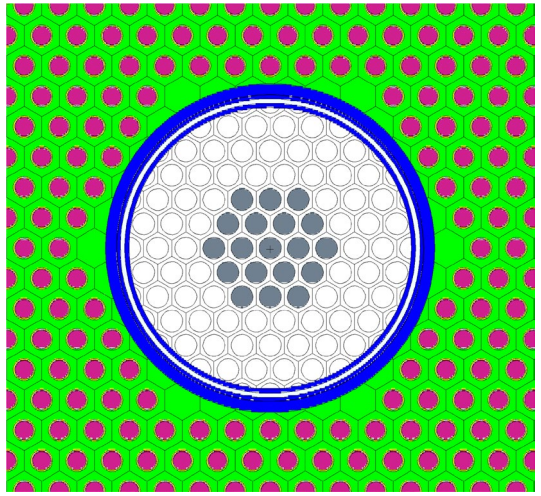
Experiment Cases

Ta-rods	Cd-filter	Fuel rods	Ta Worth (Δk/k ± σ)	Three group energy-dependent Ta absorption rates		
				<0.625 eV	0.625 eV–100 keV	>100 keV
85	Yes	1158	2.546 ± 0.004 %	1.27 %	89.59 %	9.15 %
	No	1134	5.725 ± 0.004 %	30.96 %	62.87 %	6.17 %
61	Yes	1136	2.081 ± 0.006 %	1.38 %	90.43 %	8.19 %
	No	1106	4.971 ± 0.005 %	34.17 %	60.52 %	5.31 %
37	Yes	1108	1.499 ± 0.006 %	1.47 %	91.46 %	7.07 %
	No	1074	3.927 ± 0.005 %	38.58 %	57.10 %	4.32 %
30	Yes	1110	1.656 ± 0.006 %	1.11 %	93.55 %	5.34 %
	No	1078	4.253 ± 0.005 %	38.76 %	58.03 %	3.20 %
19	Yes	1084	0.944 ± 0.006 %	1.52 %	92.52 %	5.97 %
	No	996	2.832 ± 0.005 %	43.31 %	53.29 %	3.39 %
18	Yes	1086	1.078 ± 0.006 %	1.30 %	93.75 %	4.95 %
	No	1000	3.167 ± 0.005 %	42.96 %	54.22 %	2.82 %
7	Yes	1068	0.460 ± 0.006 %	1.40 %	93.89 %	4.72 %
	No	936	1.552 ± 0.005 %	47.57 %	49.93 %	2.50 %
1	Yes	1044	0.093 ± 0.006 %	1.20 %	95.43 %	3.37 %
	No	900	0.342 ± 0.006 %	50.16 %	48.11 %	1.73 %

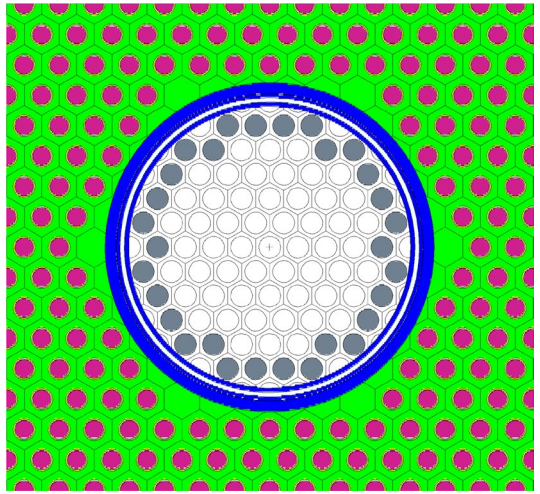
18 Ta-rods



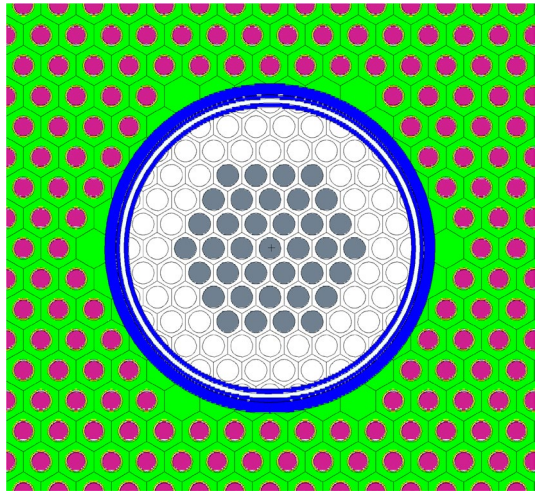
19 Ta-rods



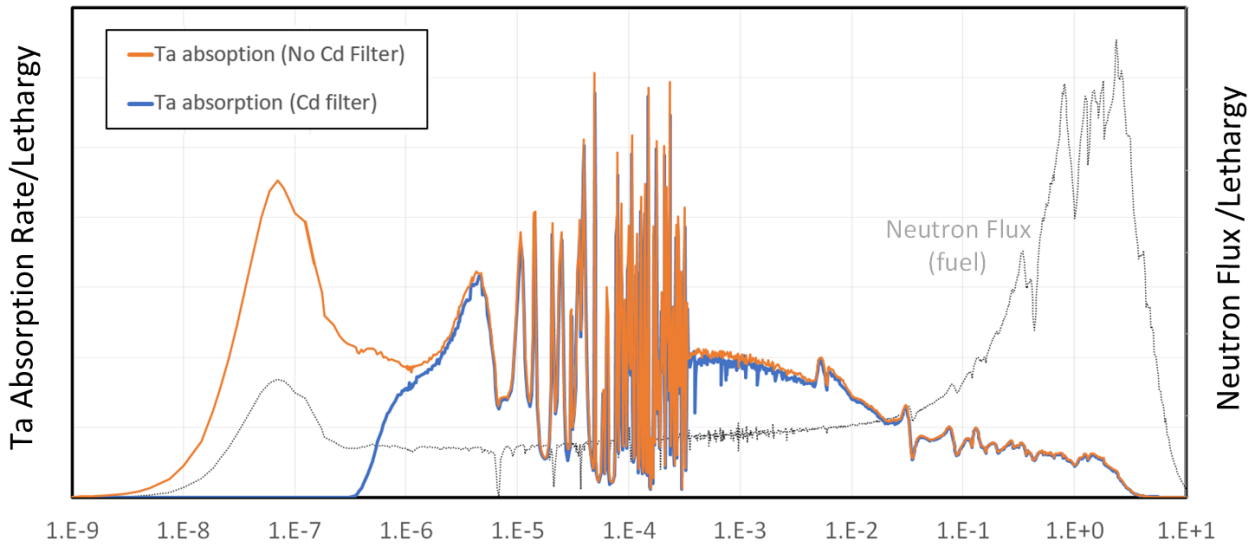
30 Ta-rods

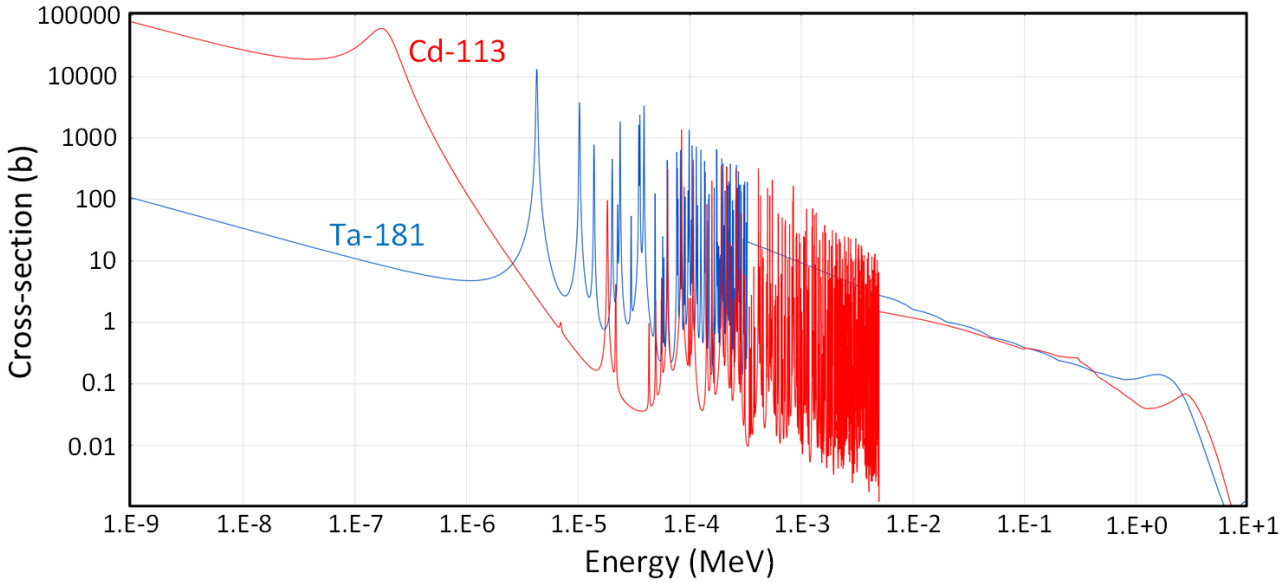


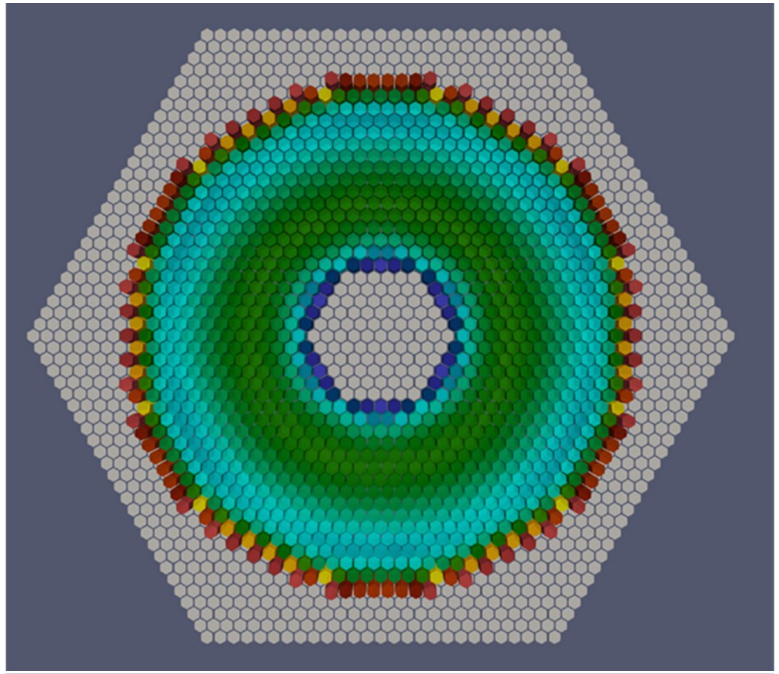
37 Ta-rods

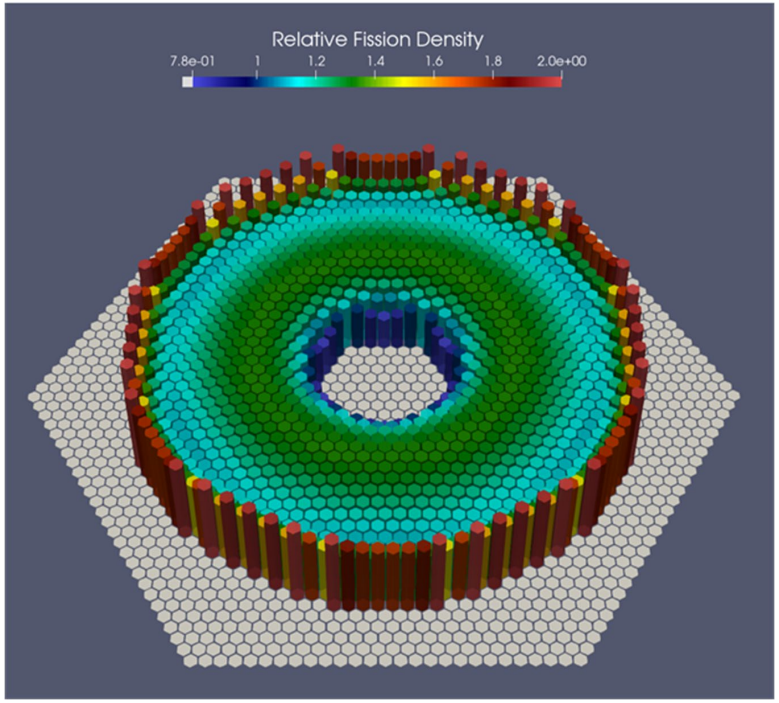


85 Ta-Rods Configuration

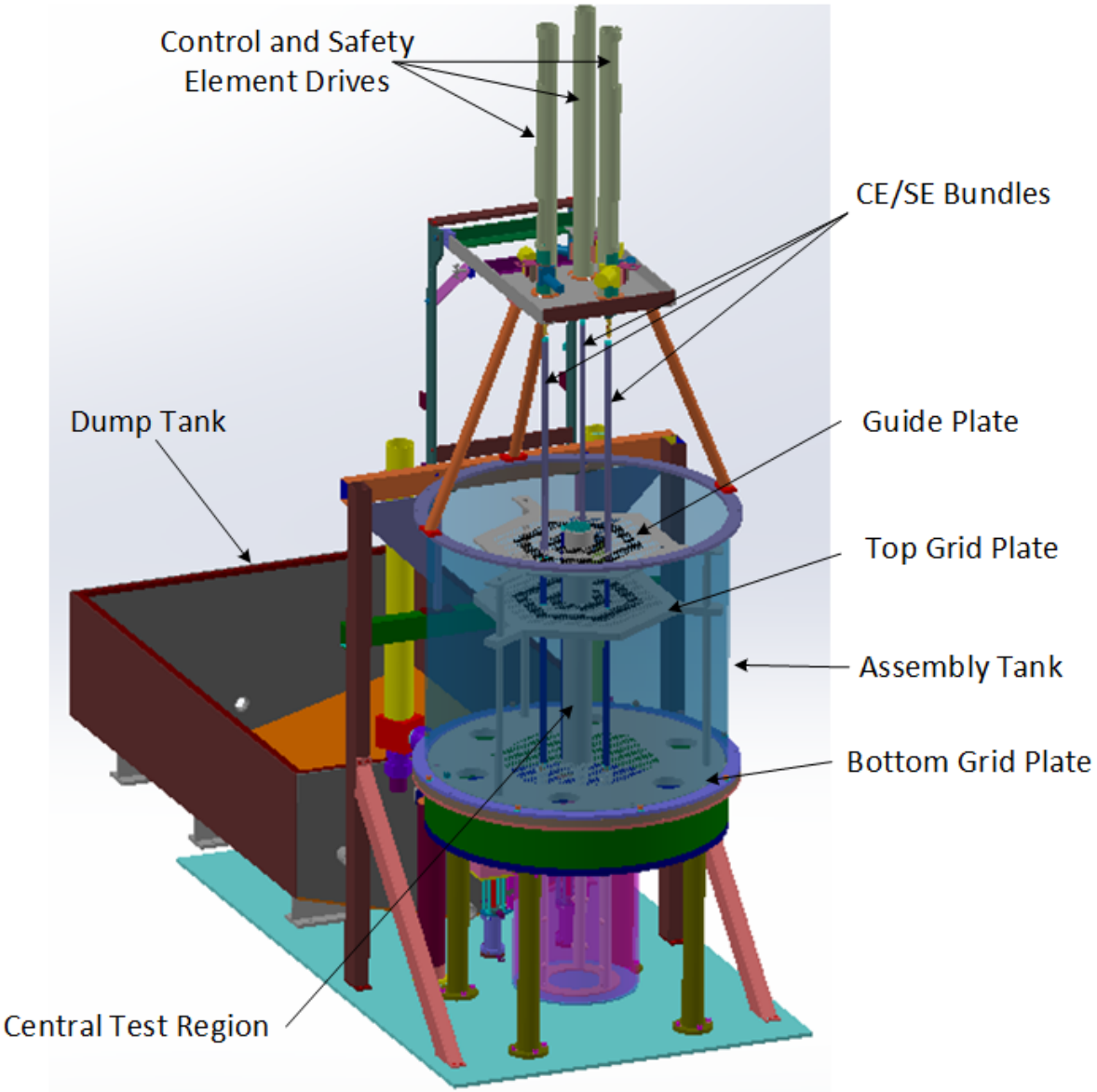


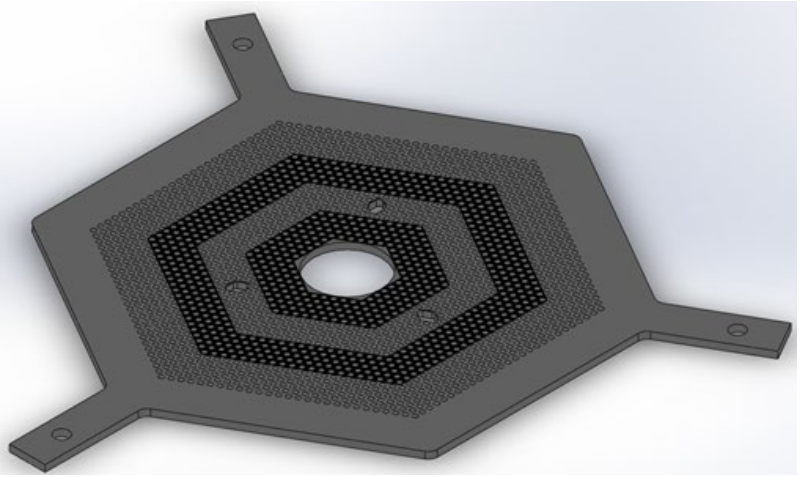


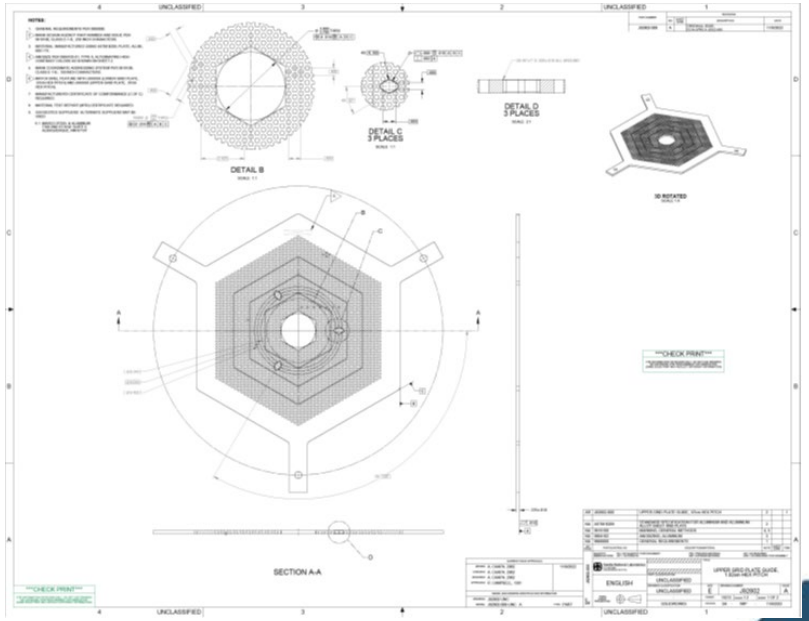




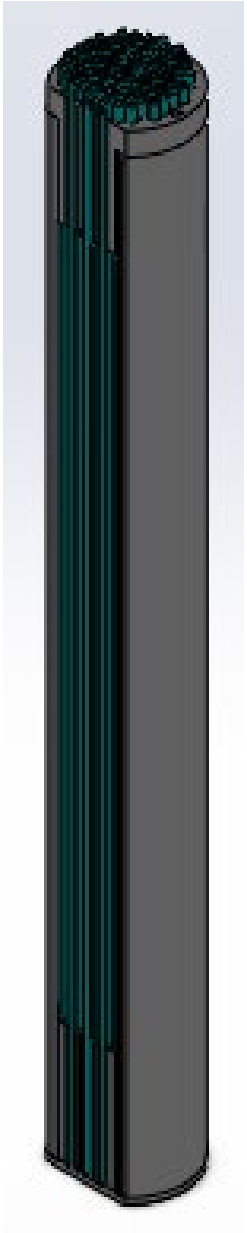
New Hardware

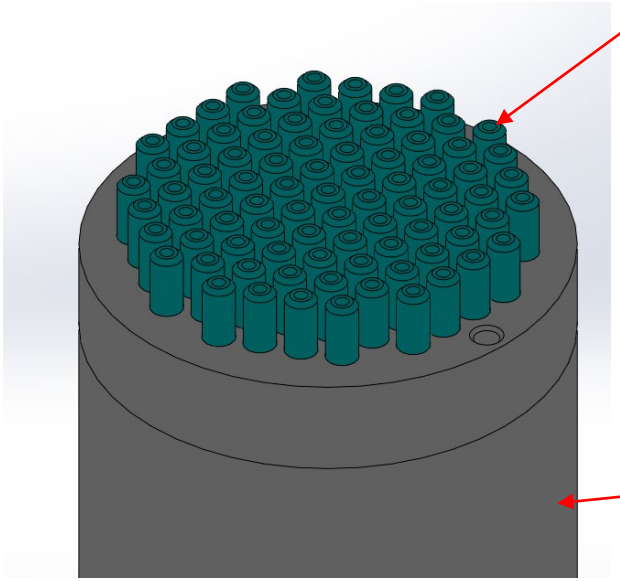


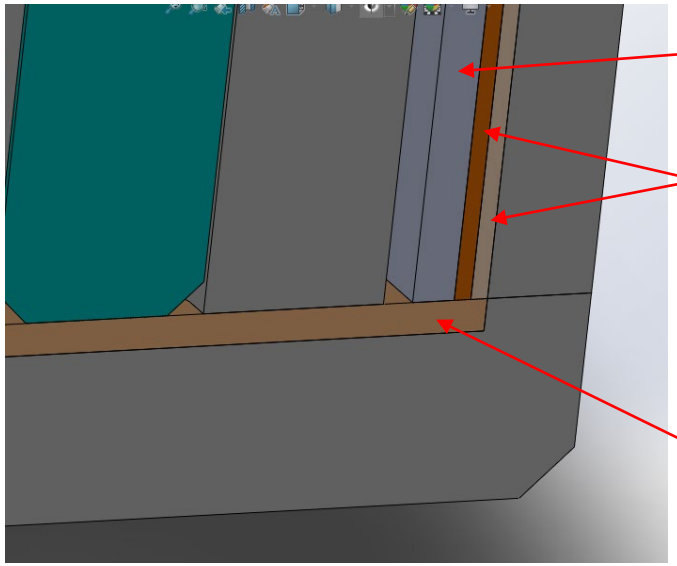




Central Test Region







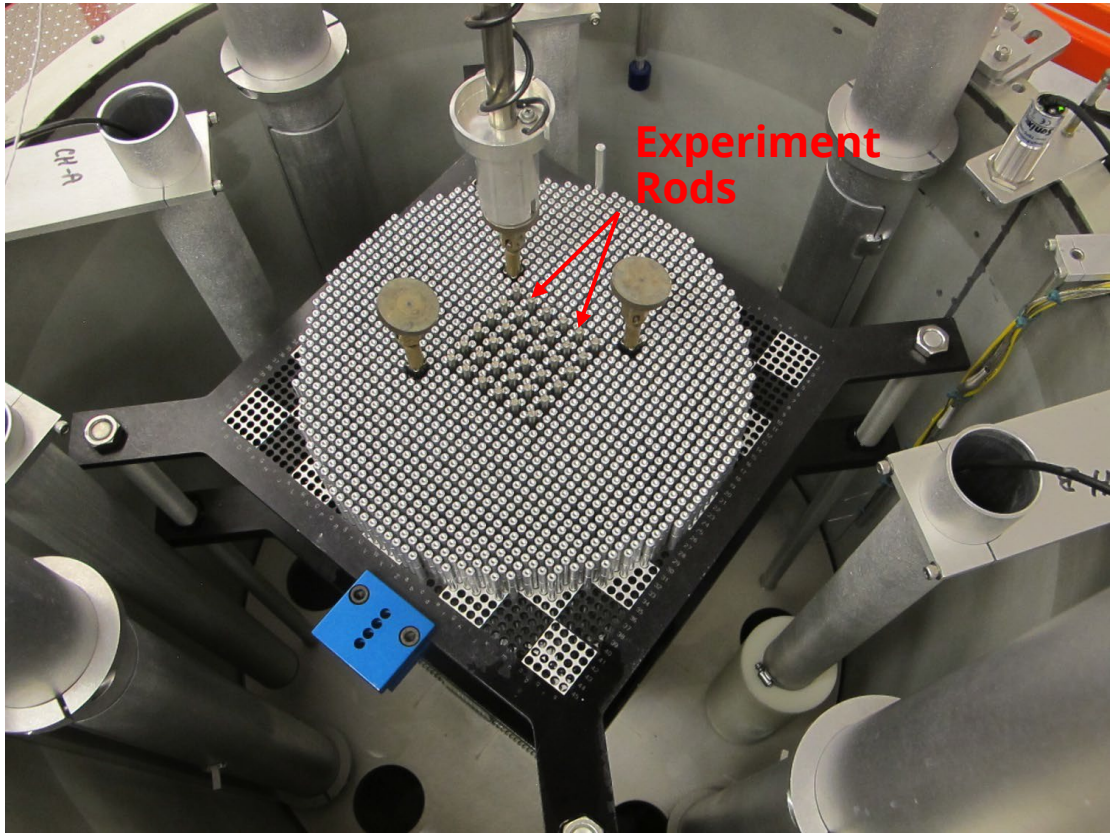
SWX-240 Cadmium Sheets

Cadmium sheets are commonly used for attenuation of thermal neutrons because of its high cross-section. This high cross-section makes it effective even in the form of sheets. Reactor grade cadmium sheets are available in thicknesses from 0.01" to 0.06".

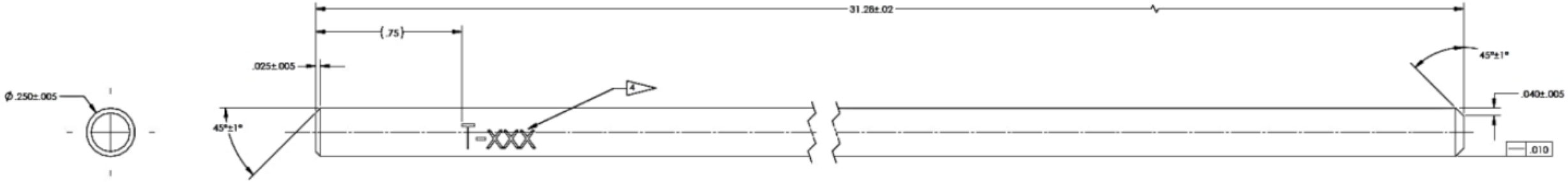
Size Code	Thickness		Width		Length	
X	0.010"	0.25mm	17"	432mm	36"	914mm
A	0.020"	0.51mm				
A2	0.025"	0.64mm				
B	0.032"	0.81mm				
C	0.040"	1.02mm				
D	0.060"	1.52mm				

Tantalum Rods

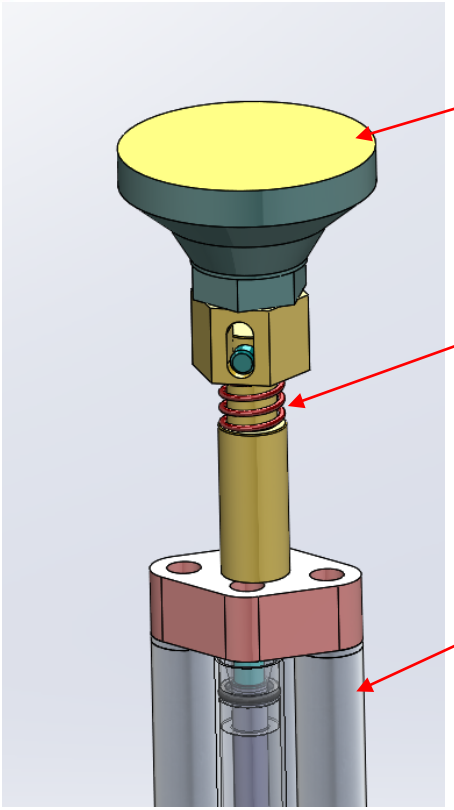
- Commercially pure
  - 99.95%
  - Meet requirements of ASTM B365-12
- Fabricated from same heat load
- Elemental compositions including impurities
- Etched with serial numbers



LCT-097 with titanium experiment rods



Safety and Control Element Bundle

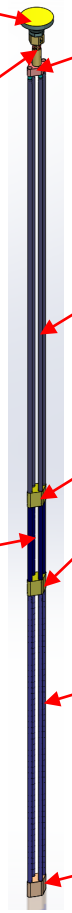


LEVELING PAD (L-1)

UPPER PLUG SPRING

ALUM SLEEVE

POLYTHLENE ROD



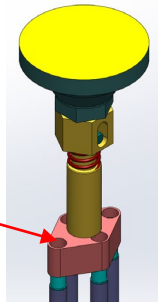
BUNDLE PLATE, UPPER

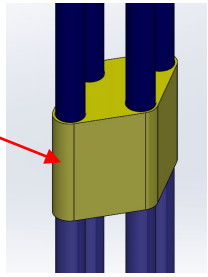
B4C ROD ASSEMBLY

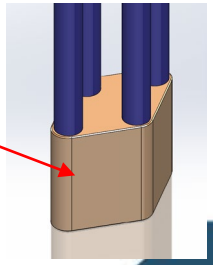
BUNDLE PLATE, MIDDLE

FUEL ROD

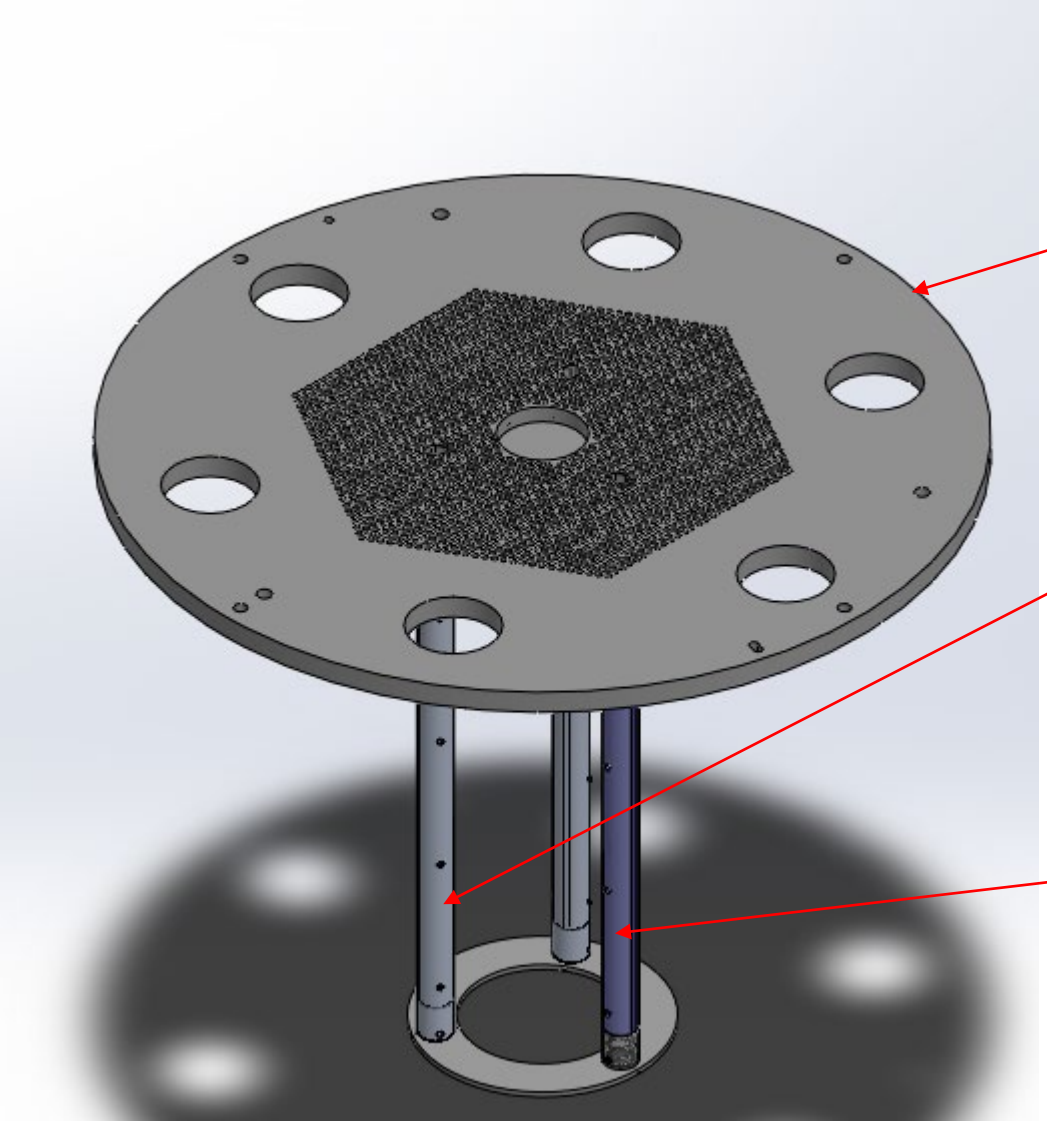
BUNDLE PLATE, LOWER



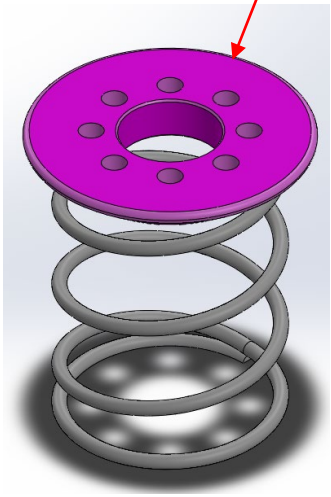




Lower Grid Plate and Hydro Tube



HYDRO TUBE, SPRING



Design Control Requirements

Design Team

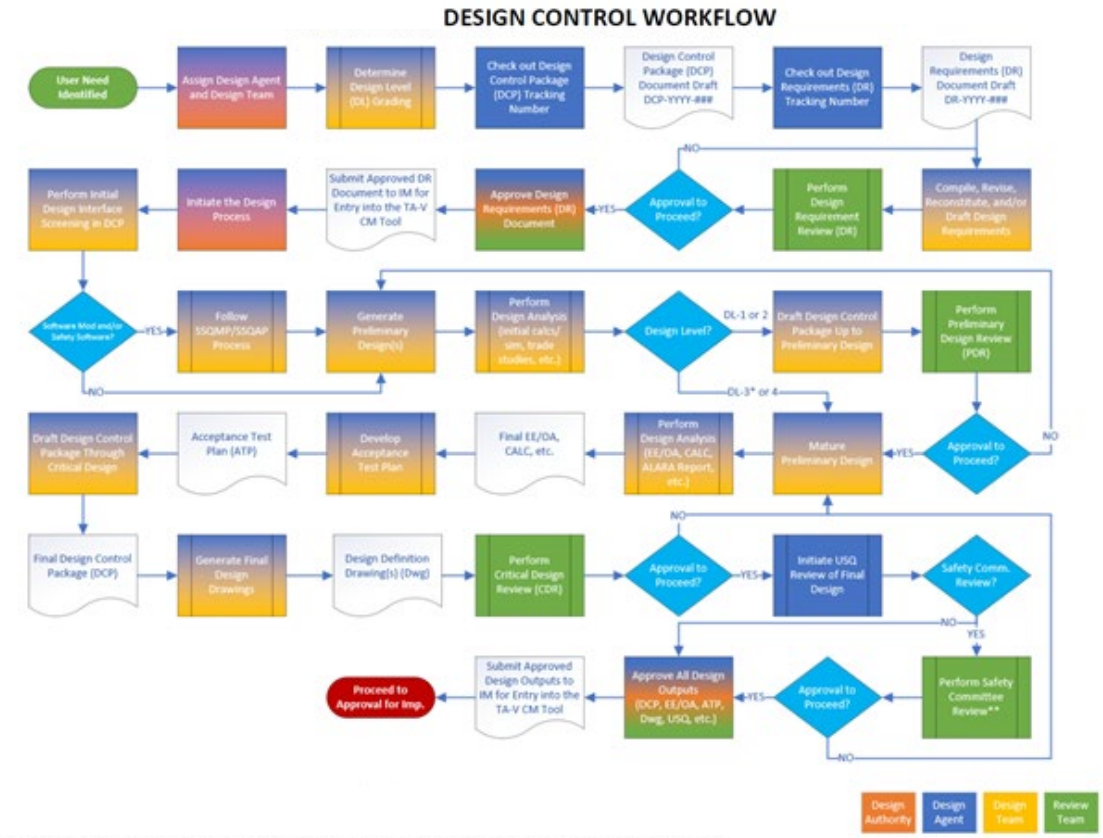
- Experimenters: David Ames, Gary Harms, Elijah Lutz
- Facility & Operations: Beth Hanson, Jason Soars, Patrick Ward
- Product Design: Augie Chapa, Alex Mace
- System Engineering & QA: Cassandra Wilson, Michael Black

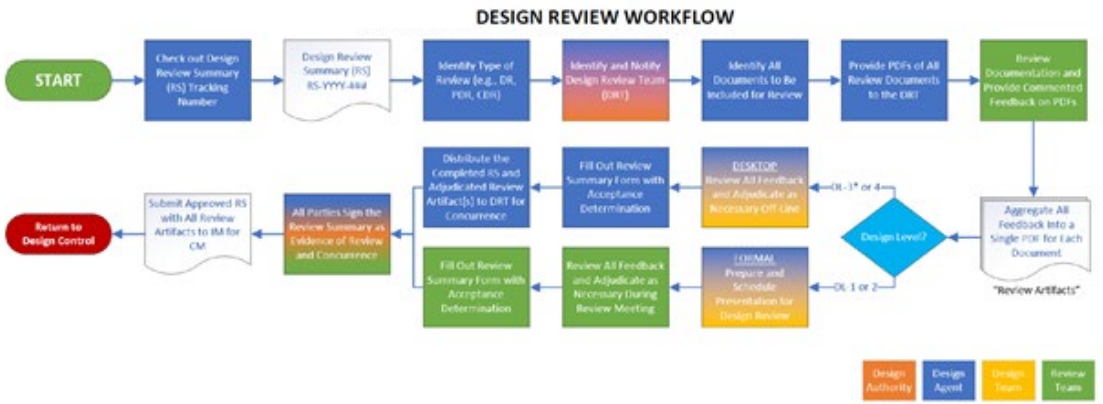
Notable items required for newly implemented NQA-1 process

- Total documents (39)
- Total pages (over 250)
- Required signatures (105)
- Approval to proceed steps (4)
- Design Drawings (over 30)
- Additional Requirements (design analysis, acceptance test plan, committee reviews, bidding process, etc.)

Lessons learned

- IER 305
- IER 304 and 452





Next Steps

Procurement Process

- Complete Design Control Requirements (nearly complete – out to manufacturing liaison Feb. 28)
- Manufacture equipment and receive parts by May 30, 2023
- Parts inspection, fit check, and field changes (if needed) – completed in June 2023

Safety Committee Review and Approval to Perform Experiments June 2023

- Core Analysis Report and Experiment Plan

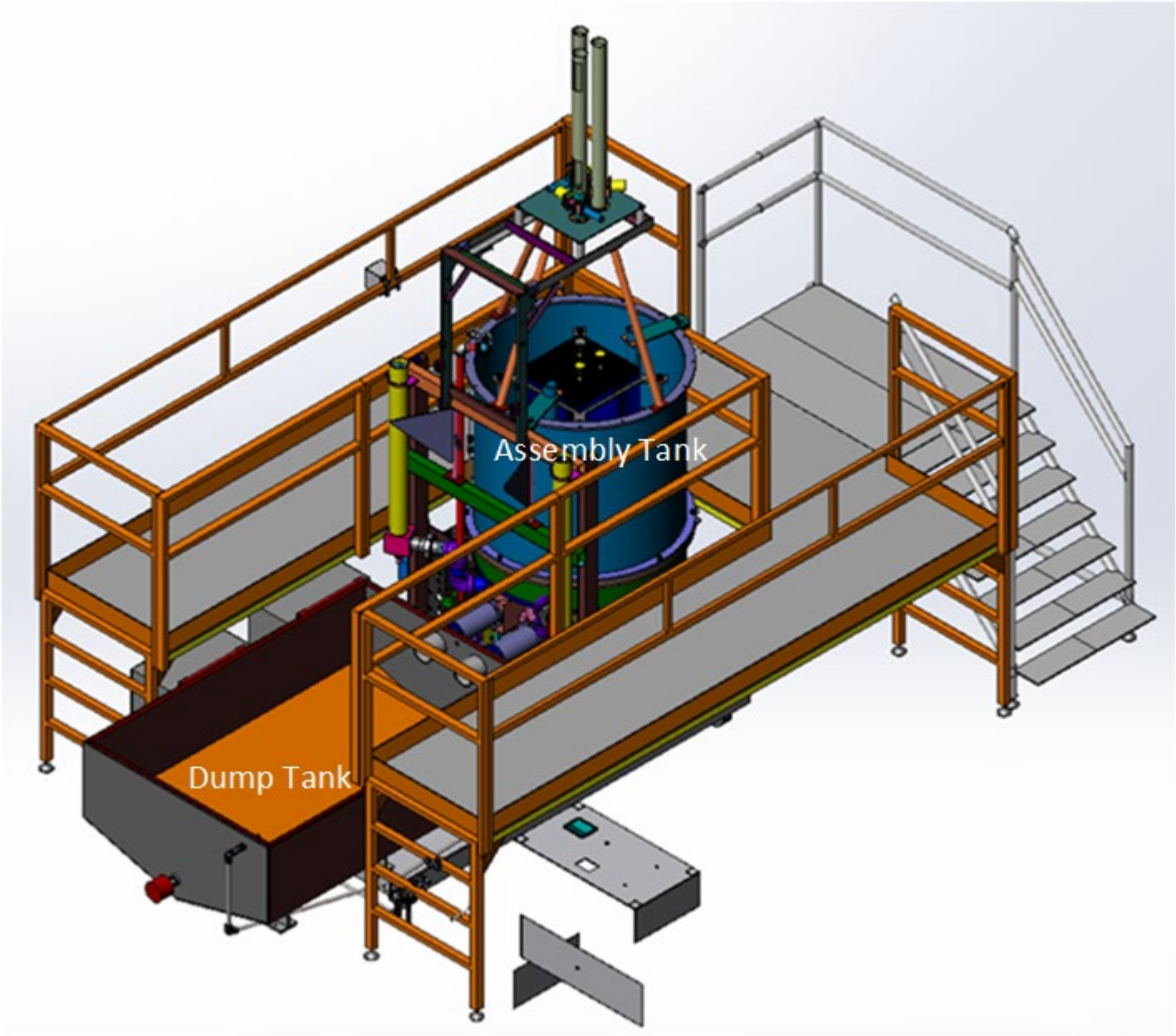
Perform Experiments – starting in July and completed by end of Oct. 2023

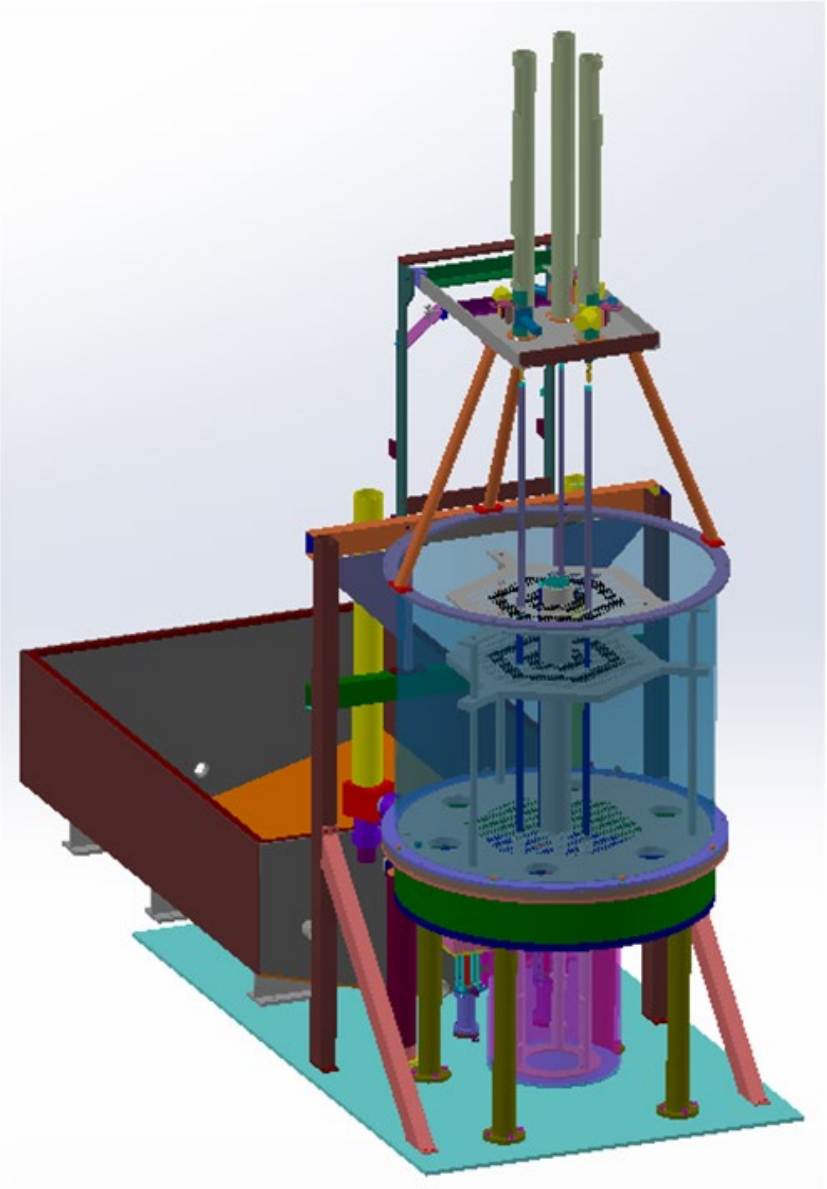
Evaluation and Publication (ICSBEP TRG Meeting April 2024)

Acknowledgements

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.

7uPCX

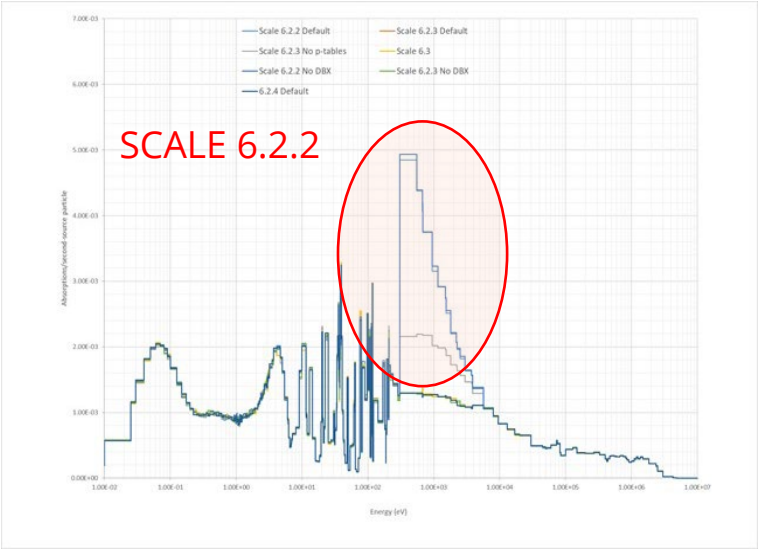




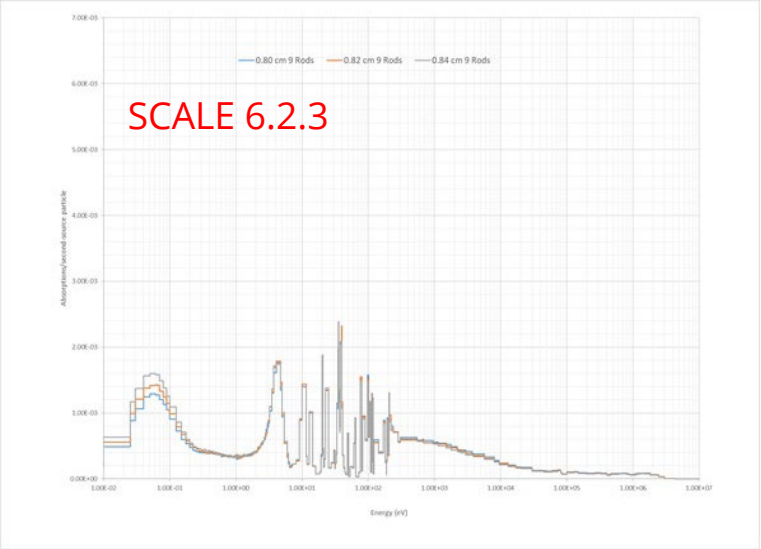
Extra slides

Error in SCALE 6.2.2 calculations

- Peak in Ta absorption starting near 300 eV not present in SCALE 6.2.3.
- Issue with how the reaction rates were tallied in SCALE 6.2.2 (no issue with k_{eff})



Neutron absorption reaction rate spectrums for Ta test samples in filtered configurations



Configuration 10 results (SCALE 6.2.2 – Keno-VI):

Ta Worth % (Δk_{eff}) ± σ	Five group energy-dependent Ta absorption rates				
	<1 eV	1eV – 100 eV	100eV – 1 keV	1 keV – 1 MeV	>1 MeV
1.666 ± 0.011	3.7%	26.8%	33.7%	34.3%	1.5%

Configuration 10 results (MCNP6.2):

Ta Worth % (Δk_{eff}) ± σ	Five group energy-dependent Ta absorption rates				
	<1 eV	1eV – 100 eV	100eV – 1 keV	1 keV – 1 MeV	>1 MeV
1.654 ± 0.011	3.6%	37.0%	21.1%	36.1%	2.1%