SAND2016-11346C

Titanium and Aluminum Rod-Replacement Experiments in Fully-Reflected 6.90% Enriched UO_2 Fuel Rod Lattices

American Nuclear Society

Winter Meeting and Technology Expo

Las Vegas, NV

November 9, 2016

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Sandia National Laboratories

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Critical Experiments with Titanium

- This experiment was done to answer a request from SRNL for integral critical experiments with titanium in a thermal system
- This experiment series was done as a set of progressive fuel-rod-replacement experiments in the 7uPCX critical assembly
- We used titanium and aluminum replacement rods
- A benchmark evaluation (LEU-COMP-THERM-097) is being prepared for publication in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*
- We are working on a set of experiments with titanium sleeves on another set of fuel rods (BUCCX)

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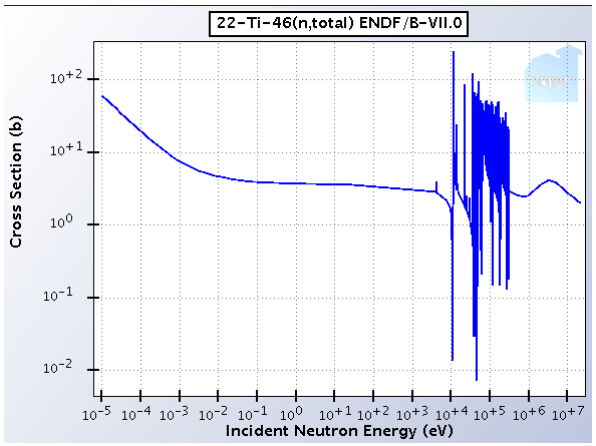
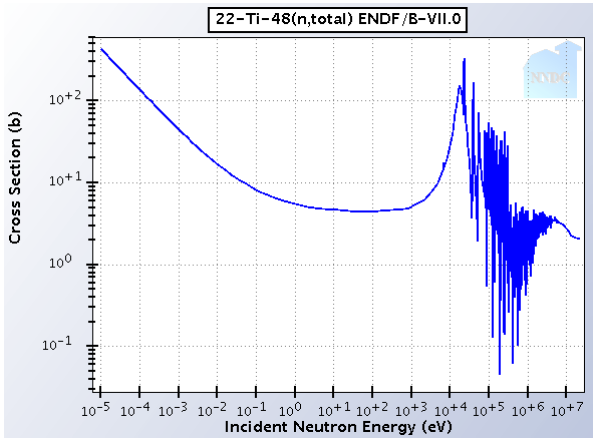
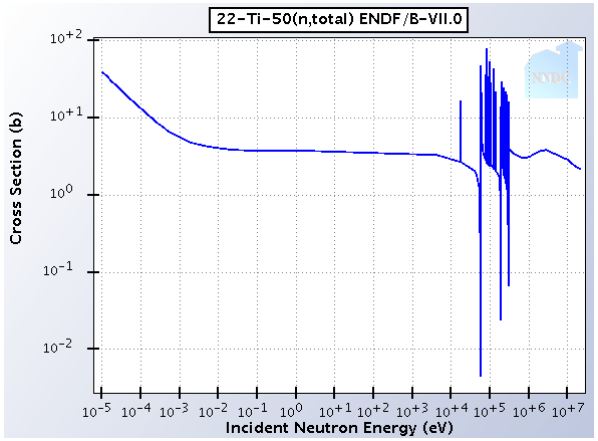
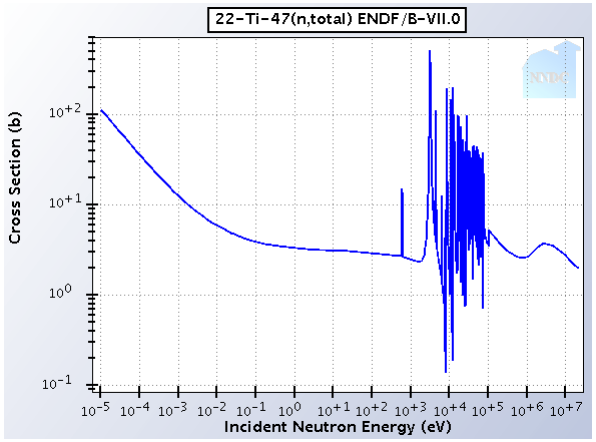
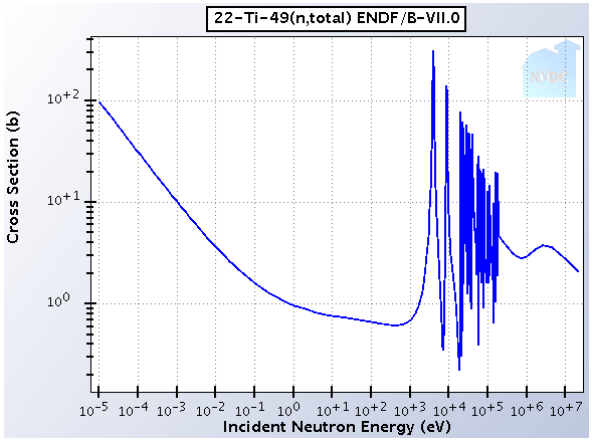
Titanium cross sections











Thermal absorption cross sections:

^{46}Ti (8.25%): 0.6 b

^{47}Ti (7.44%): 1.7 b

^{48}Ti (73.72%): 7.9 b

^{49}Ti (5.41%): 2.2 b

^{50}Ti (5.18%): 0.18 b

Ti (natural): 6.1b

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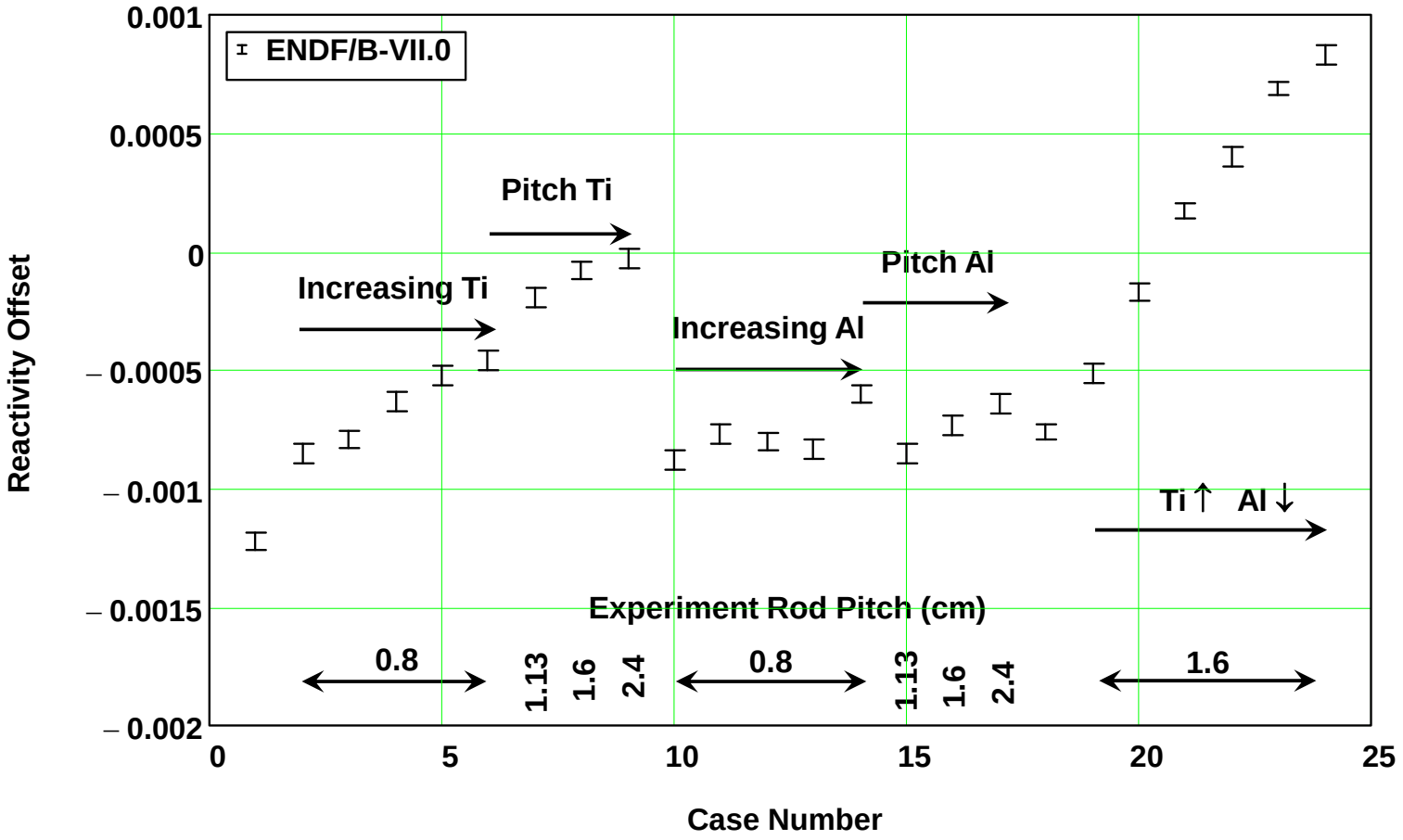
MCNP6.1.1 + ENDF/B-VII.0
Calculation of Benchmark Models



Expt.	Ti	0	4	9	16	25	36	36	36	36	0	0	0	0	0	0	0	0	0	0	4	9	16	25	36	Ti	Expt.
Rods	Al	0	0	0	0	0	0	0	0	0	4	9	16	25	36	36	36	36	0	36	32	27	20	11	0	Al	Rods
	Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Case	

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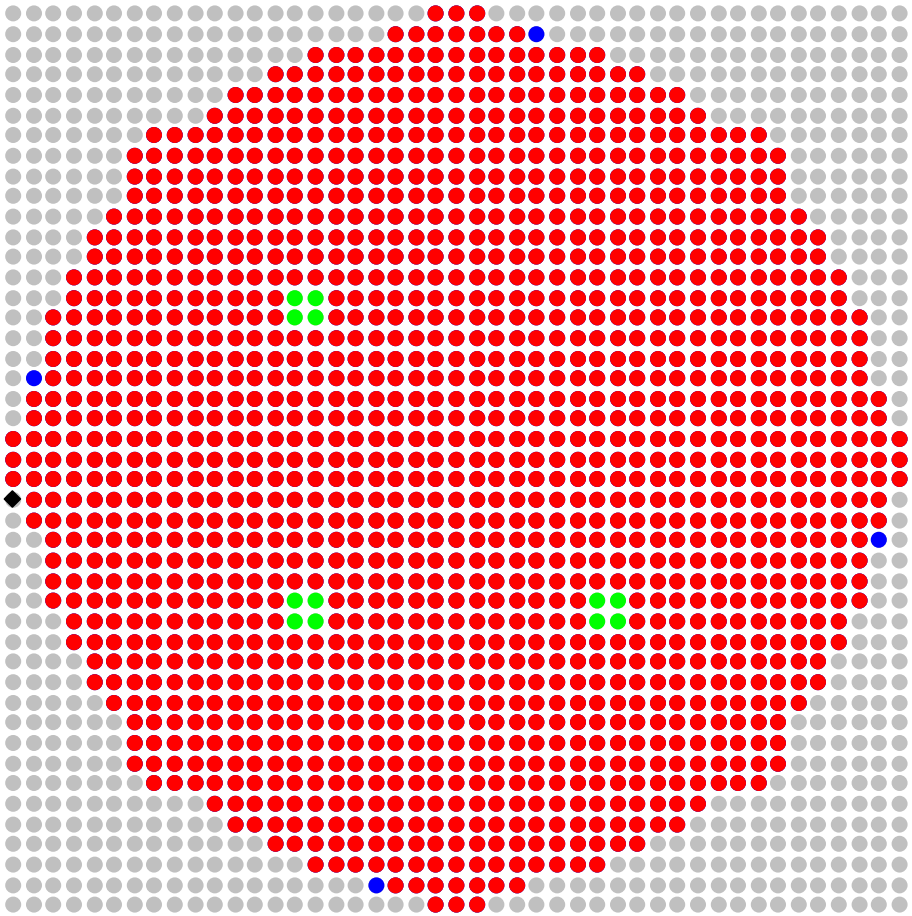
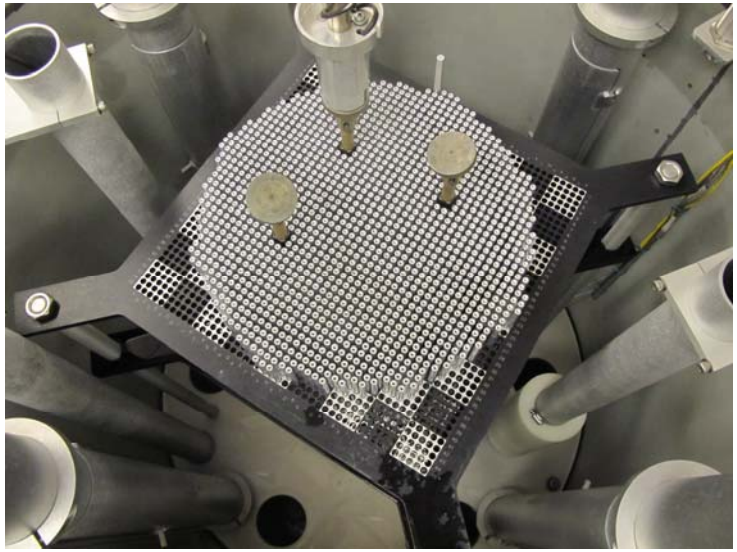
Case 1



- Fuel Rod
- Incremental Fuel Rod
- Control/Safety Rod
- Empty Grid Location
- Source Location



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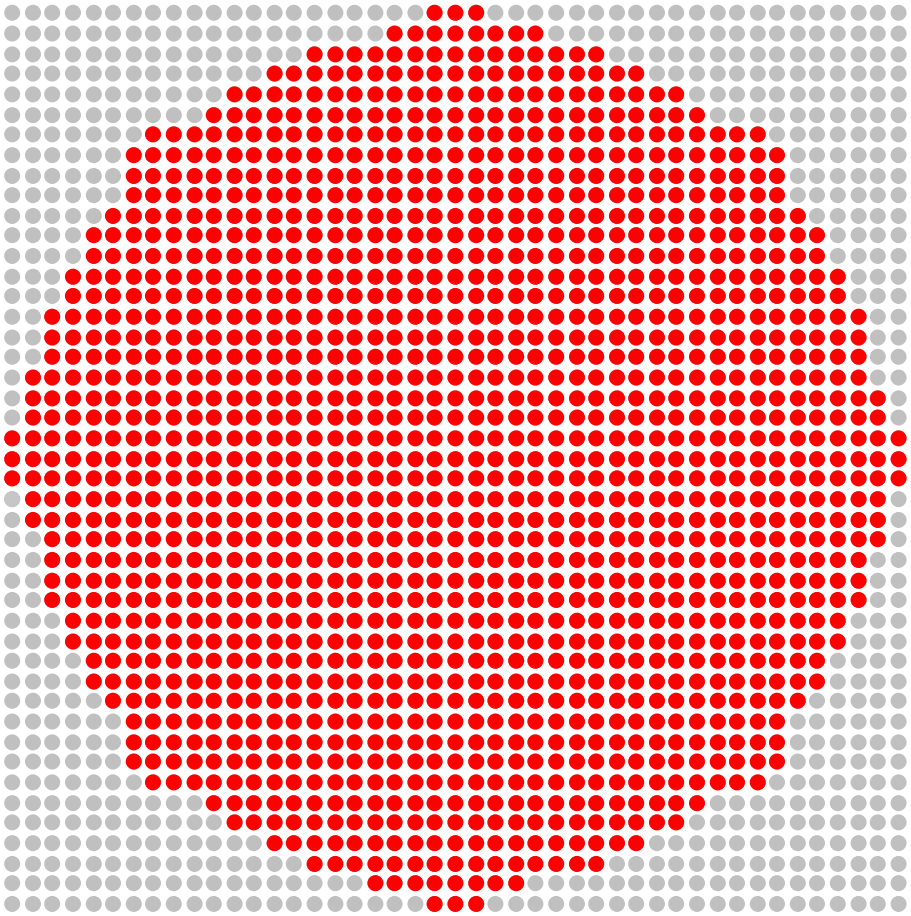
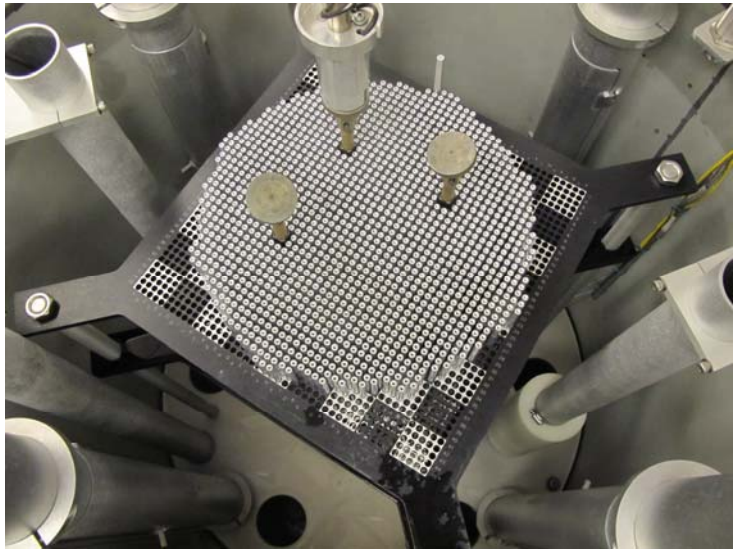
Case 1



- Fuel Rod
- Empty Grid Location



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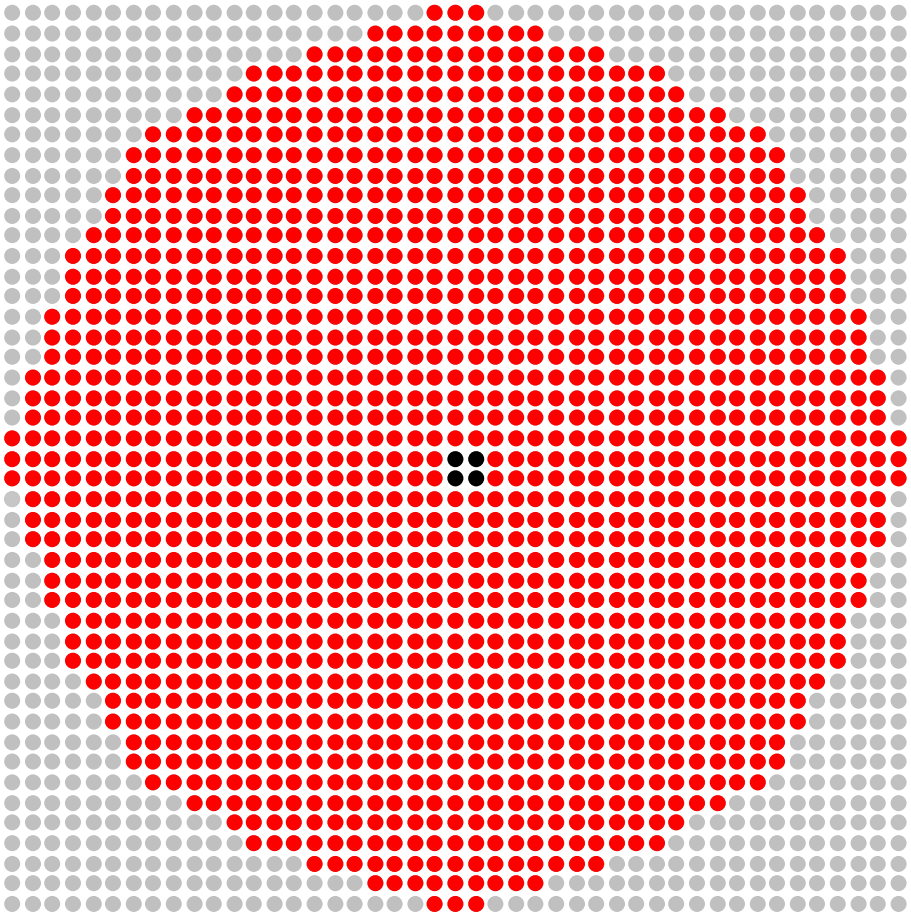
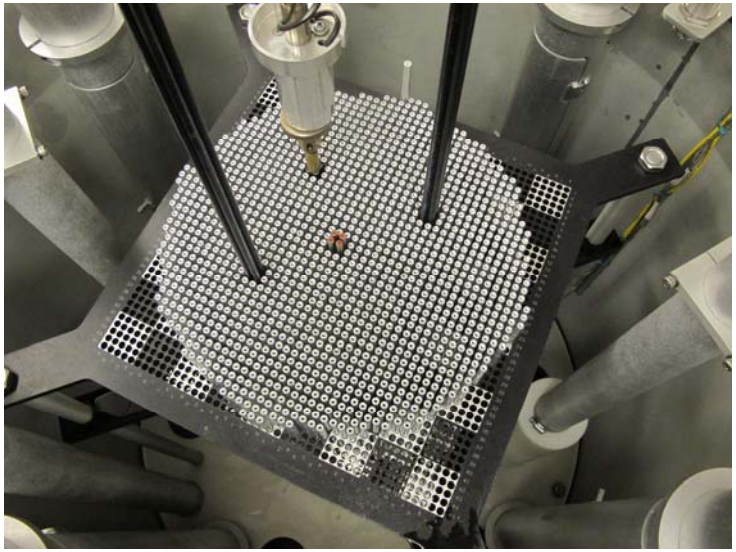


- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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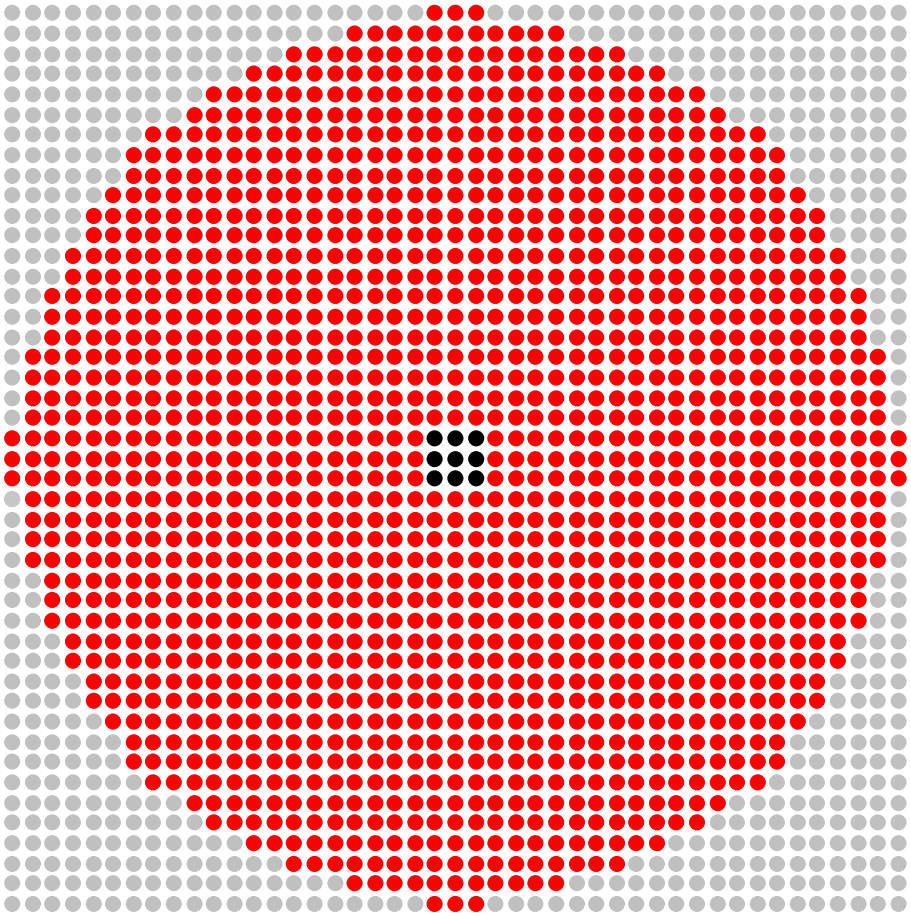
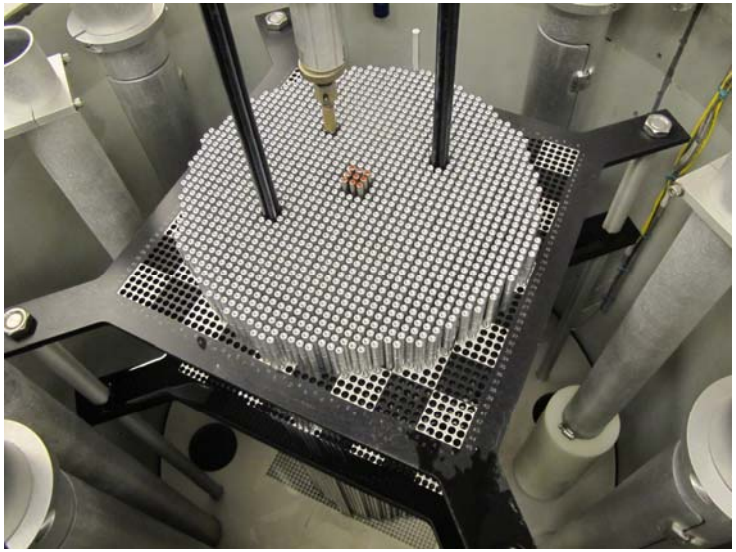
Case 3



- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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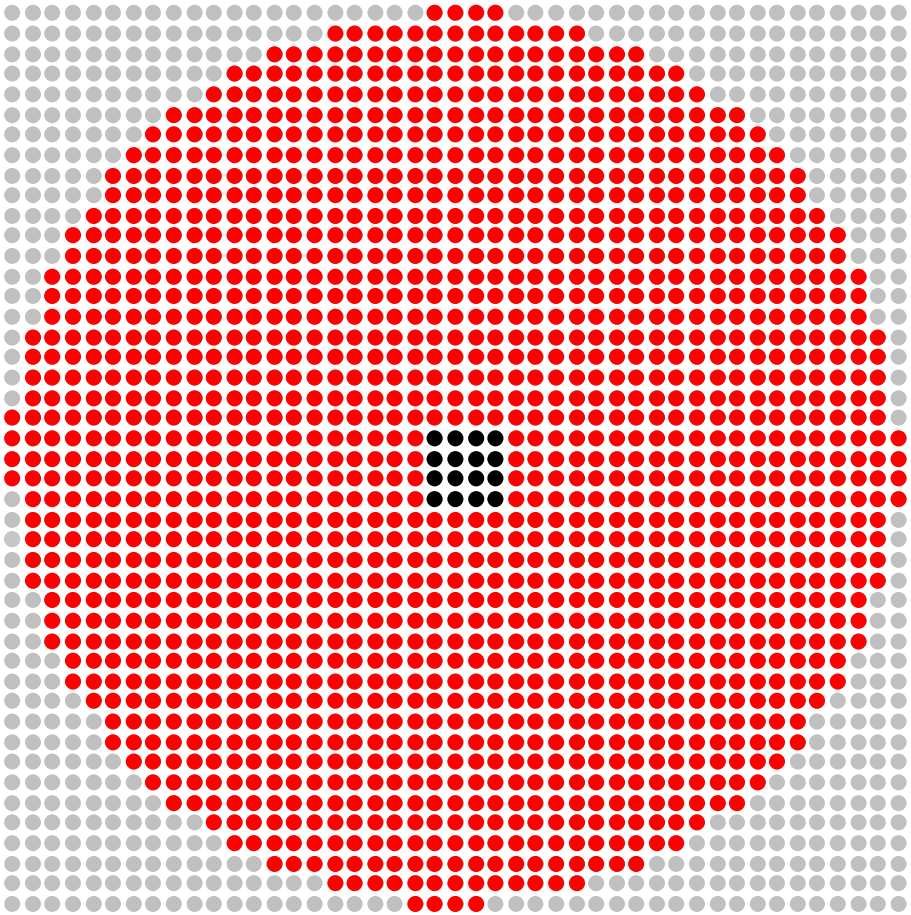
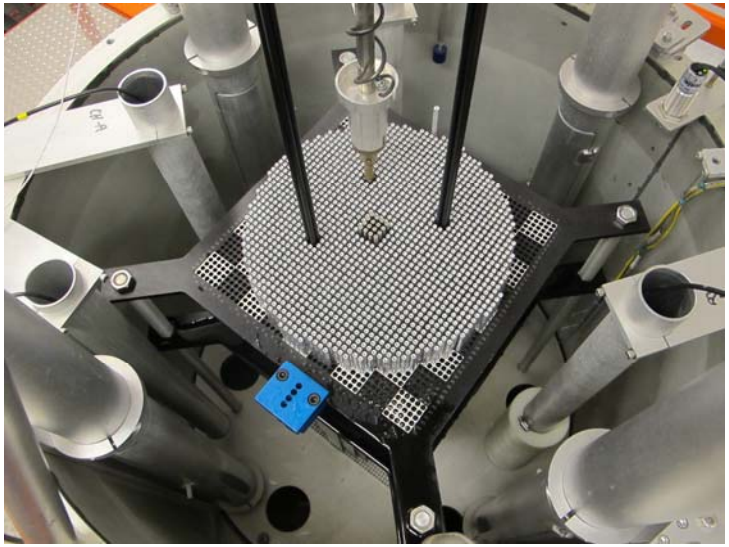


- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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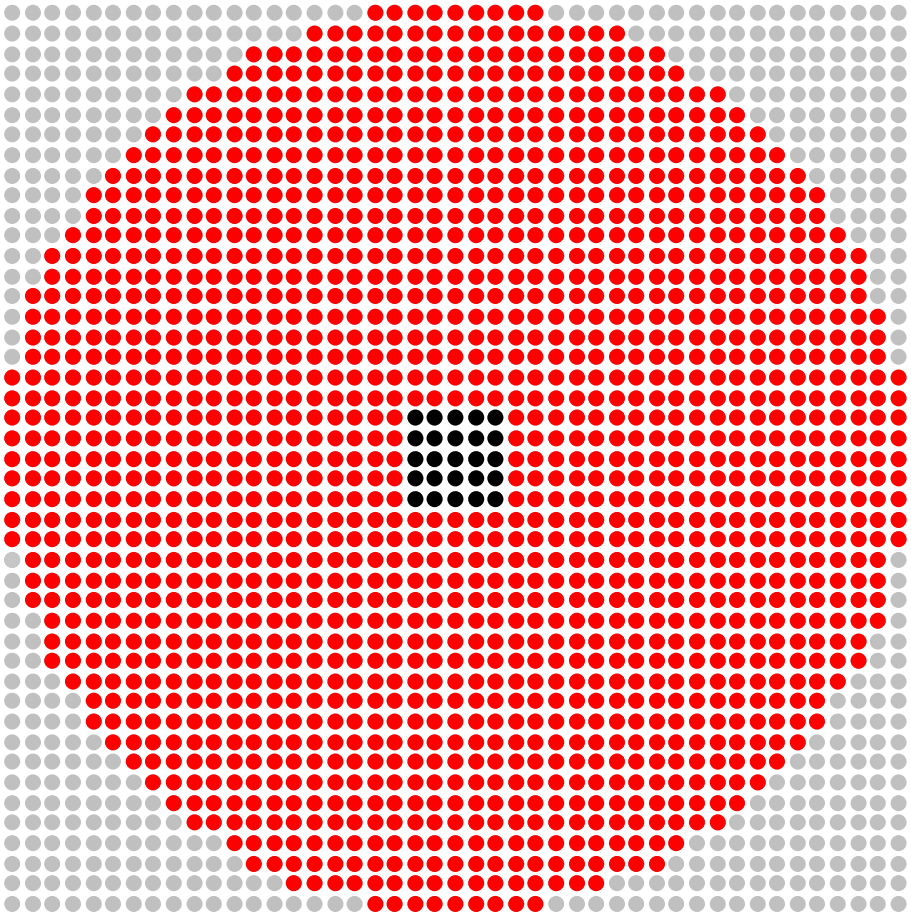
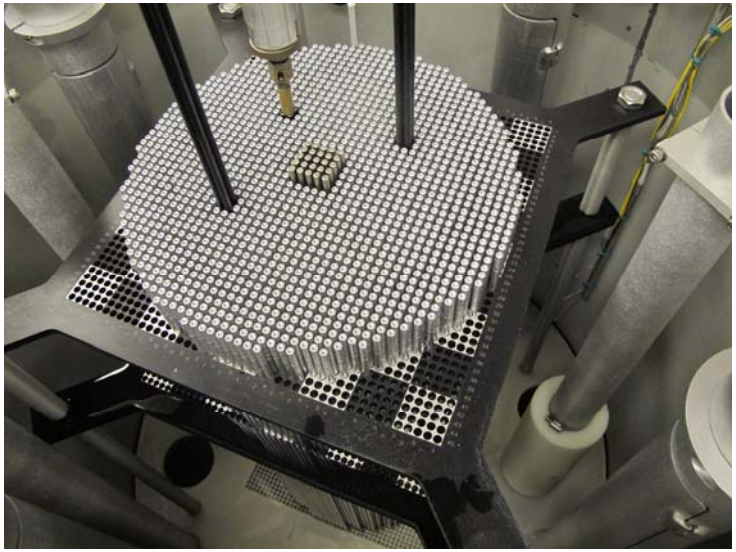


- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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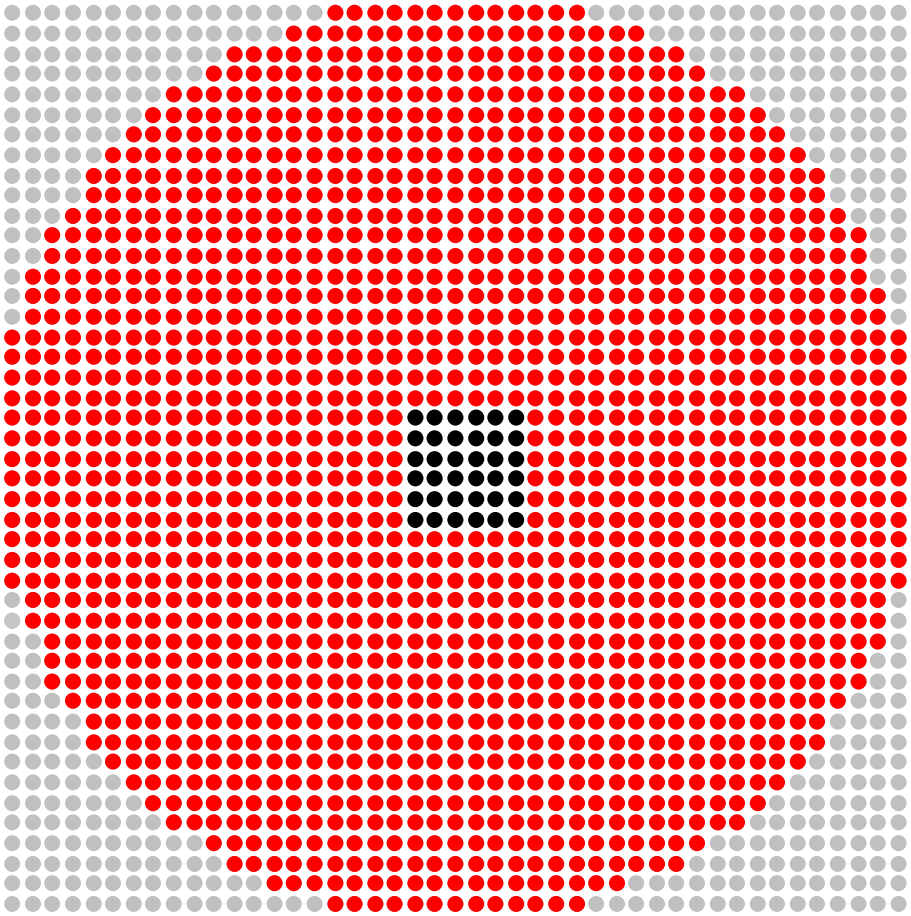
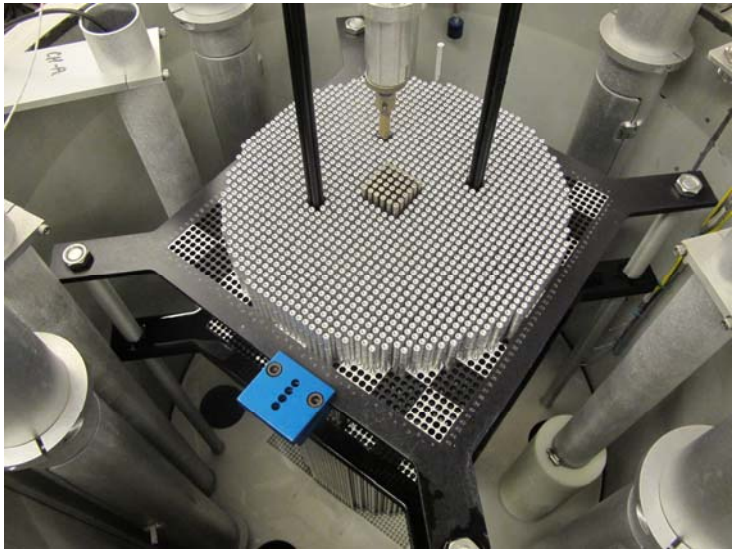


- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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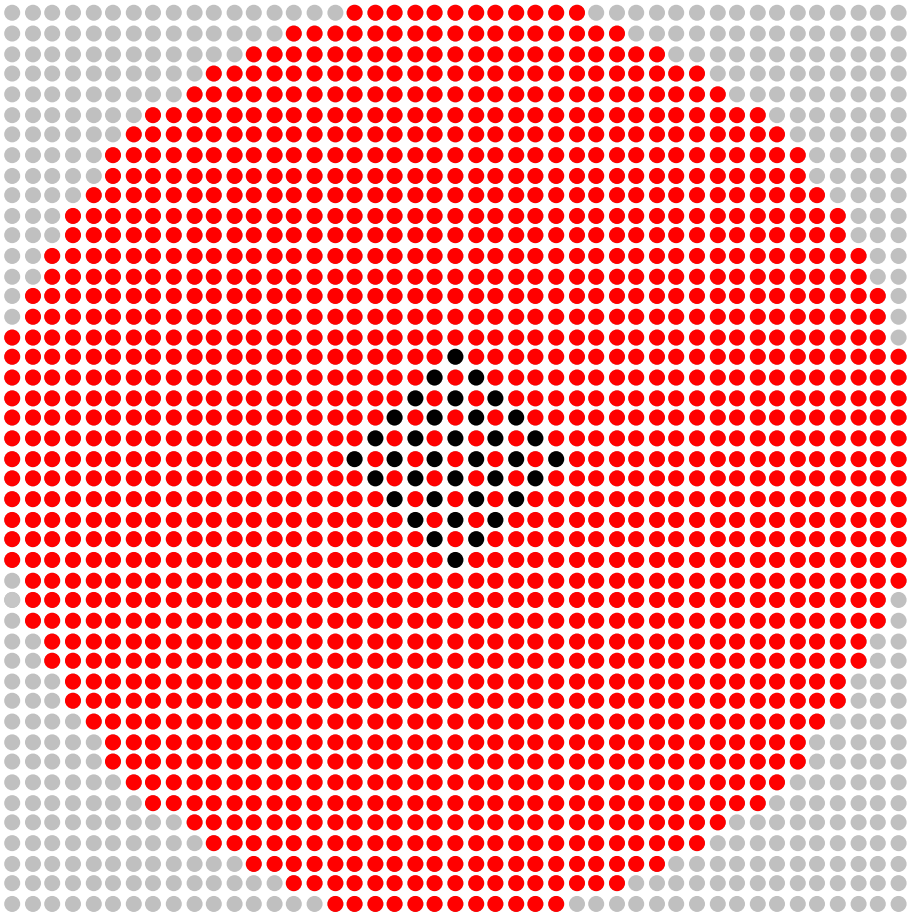
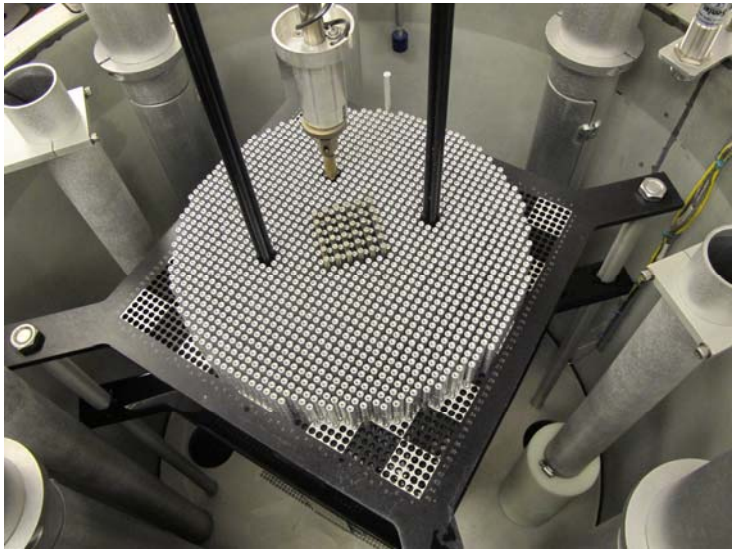


- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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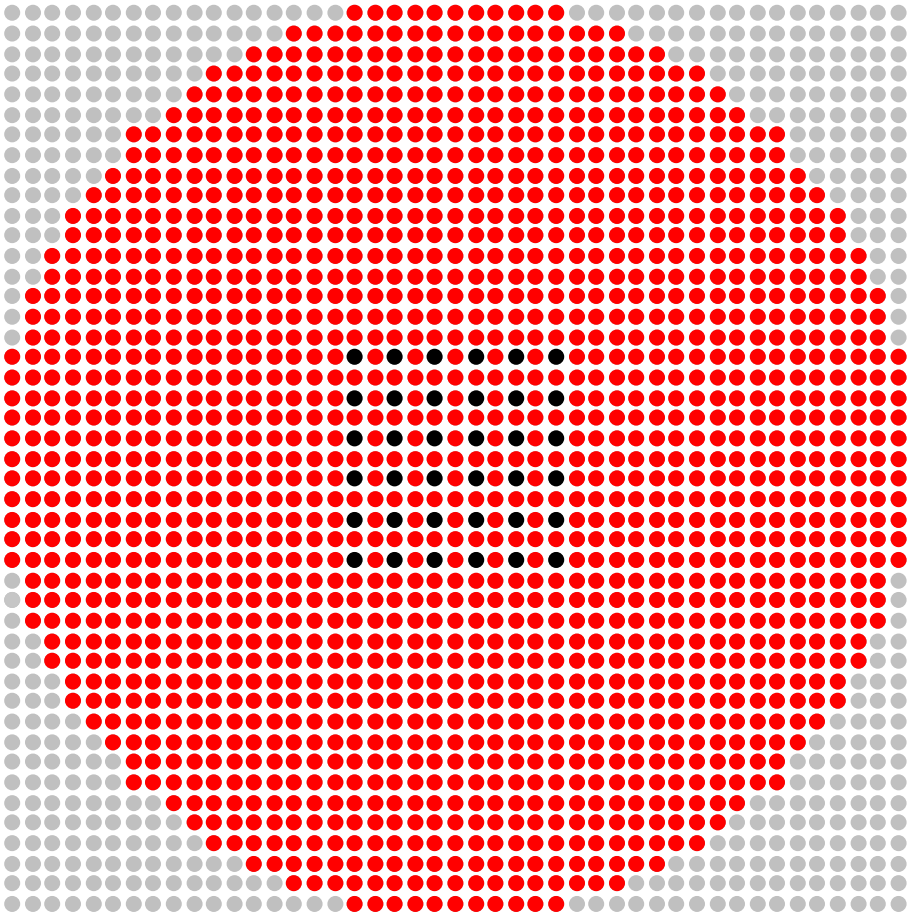
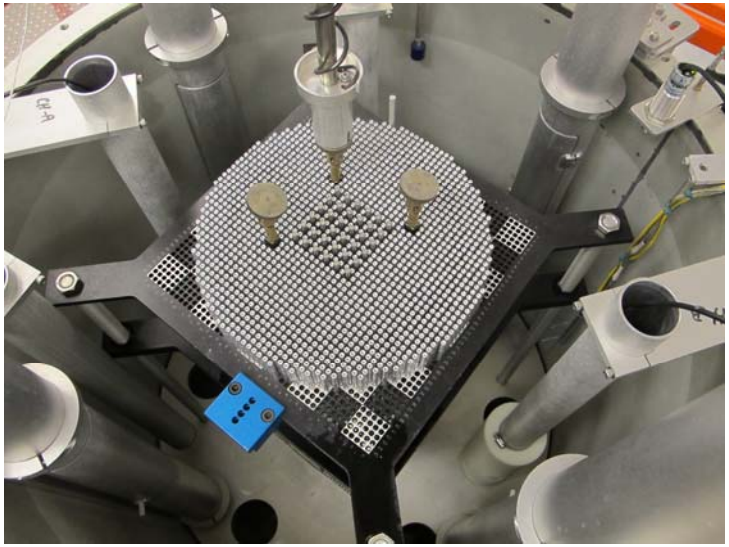


- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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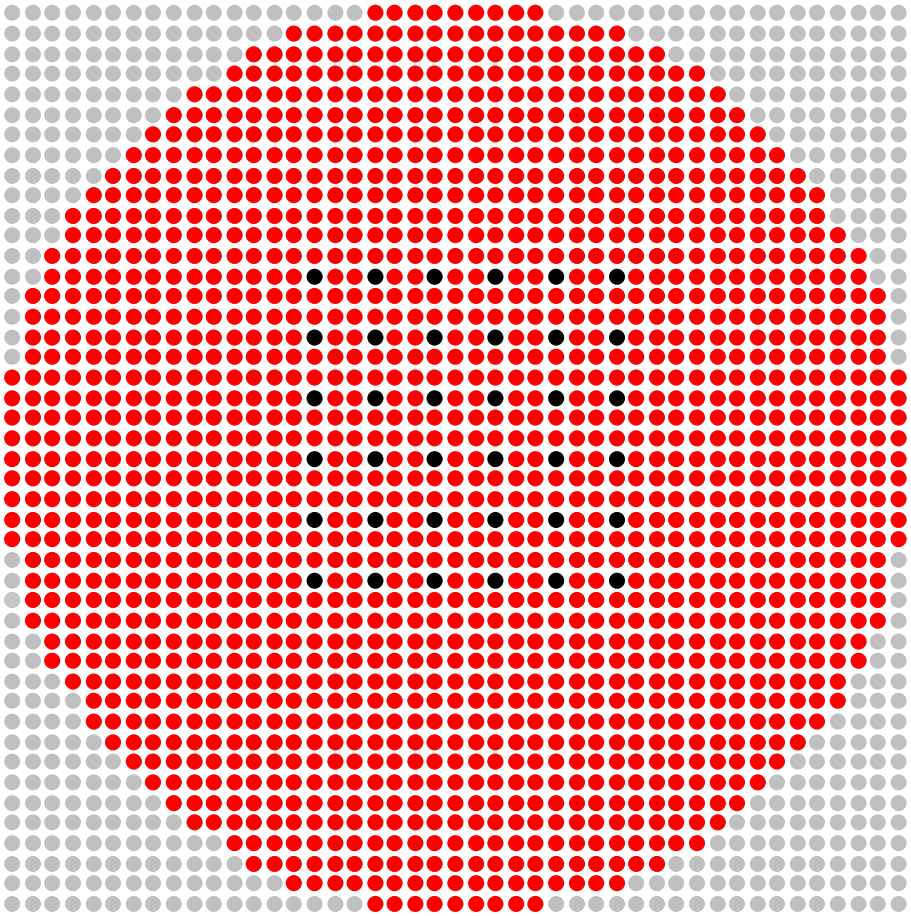
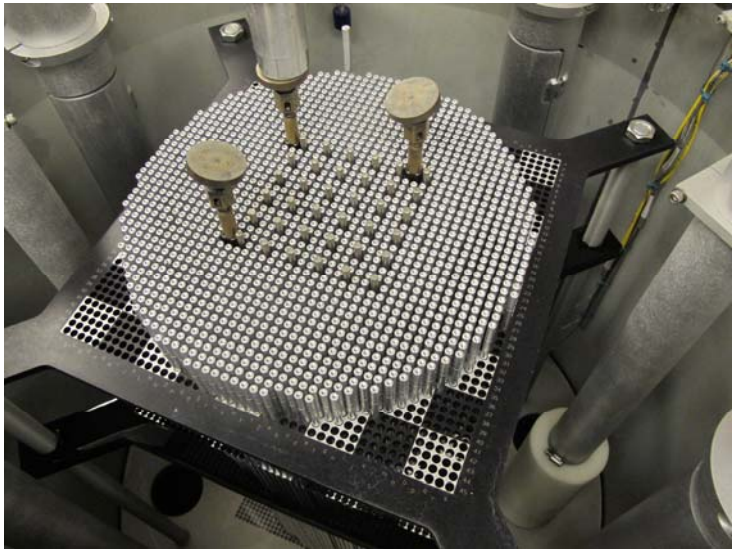


- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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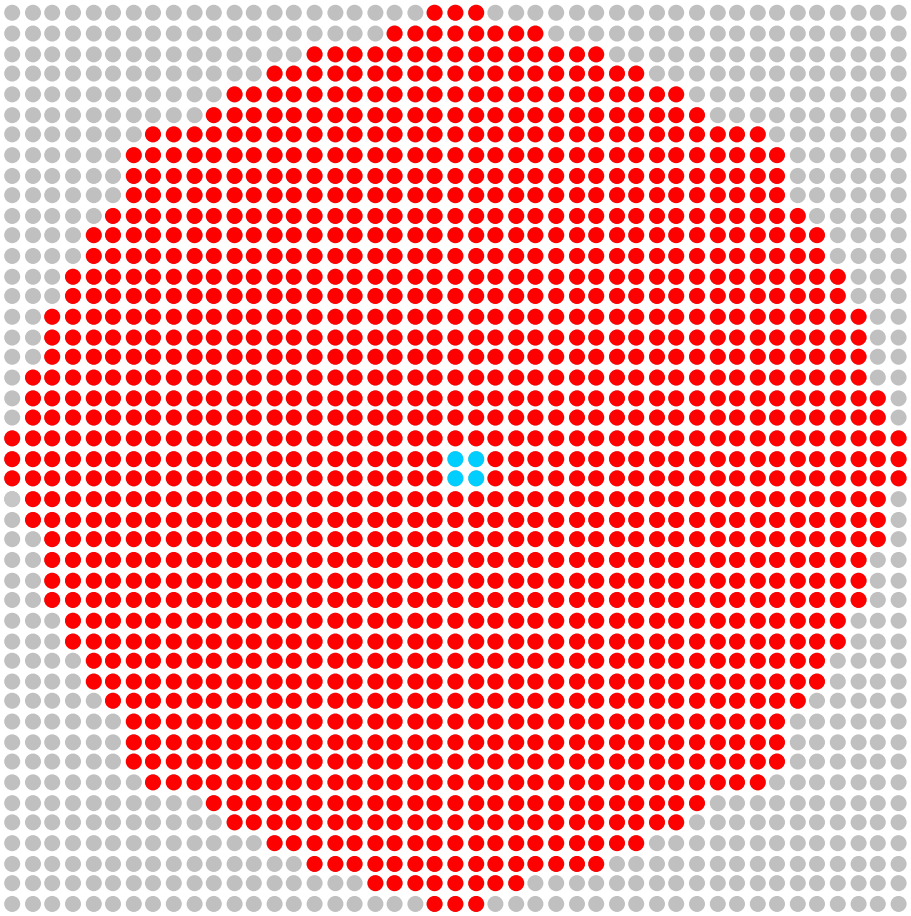
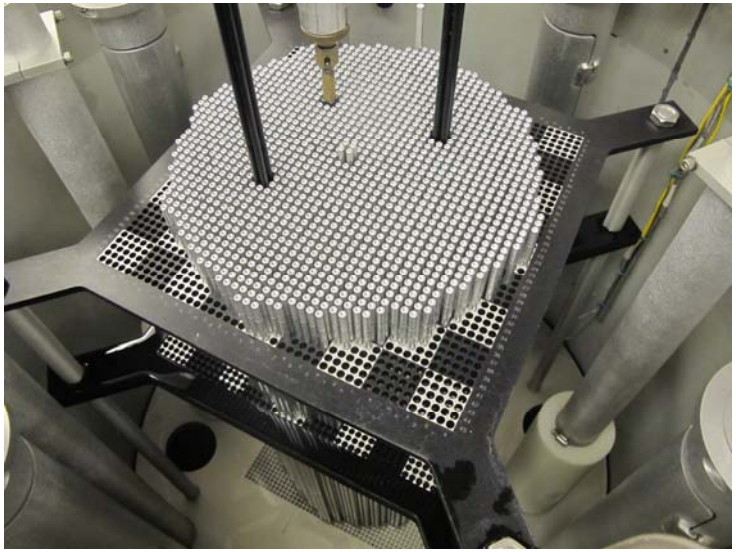


- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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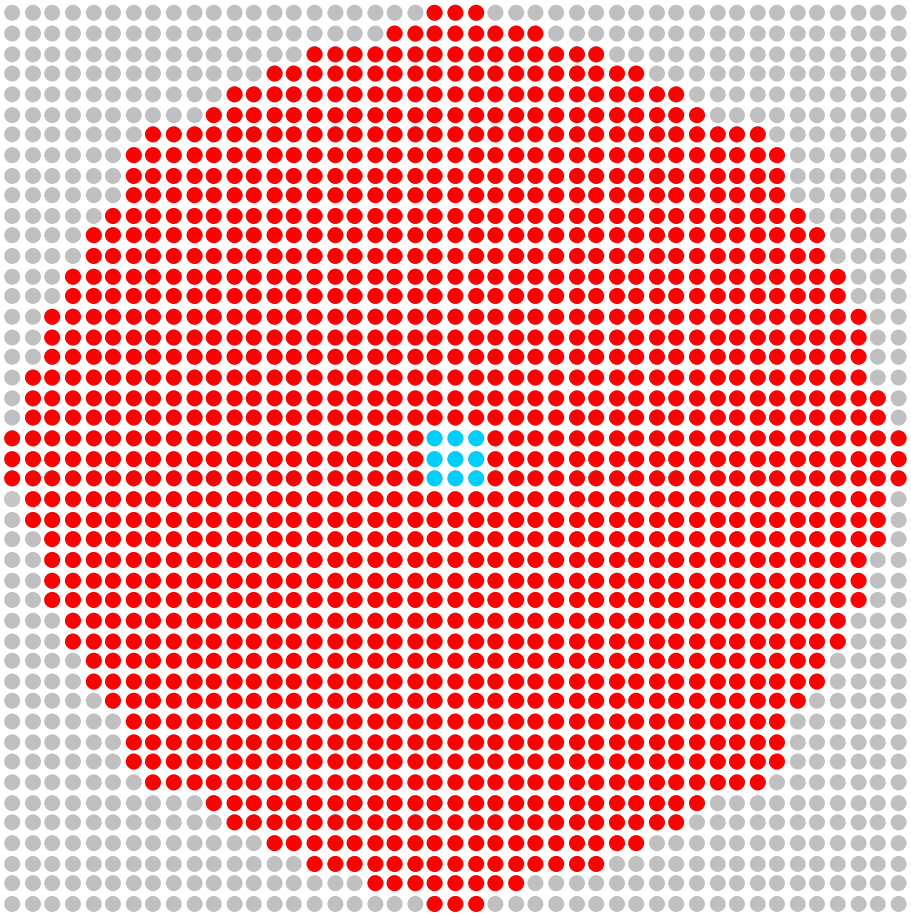
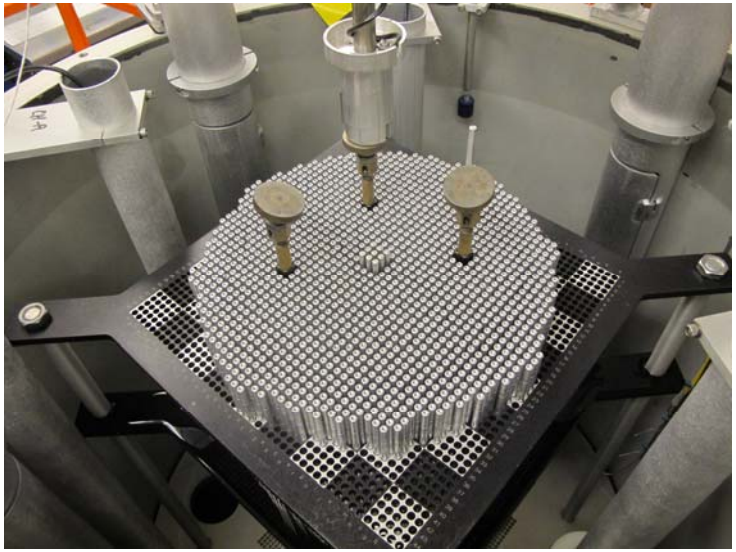


- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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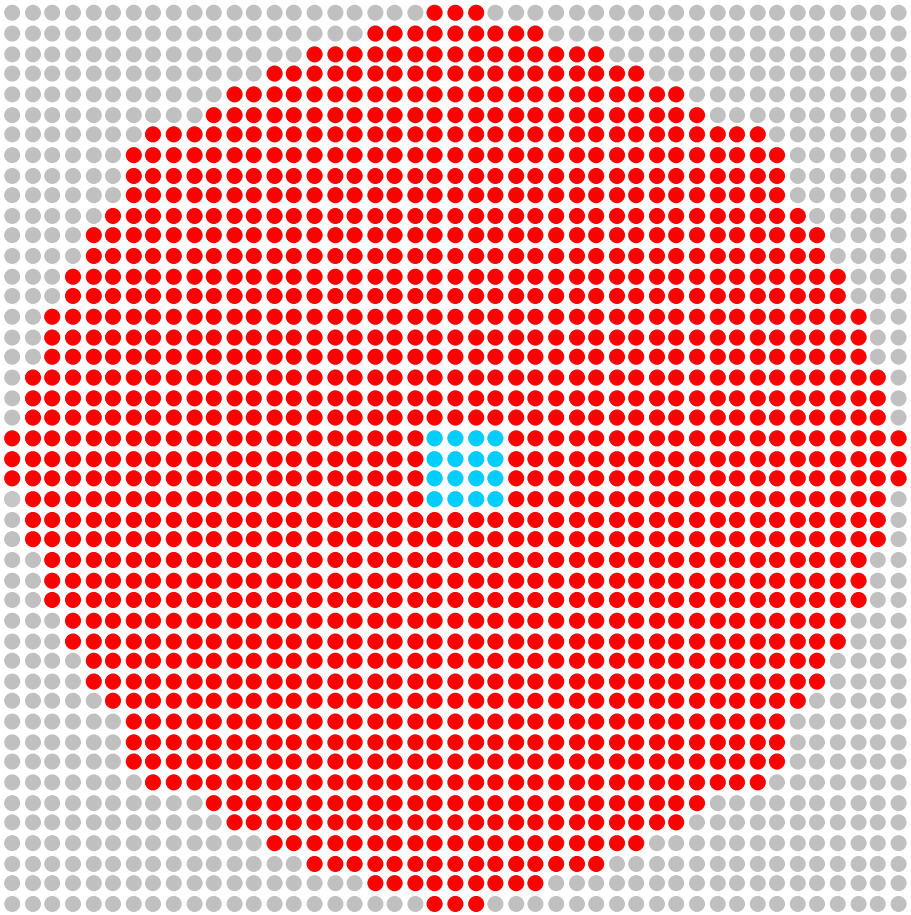
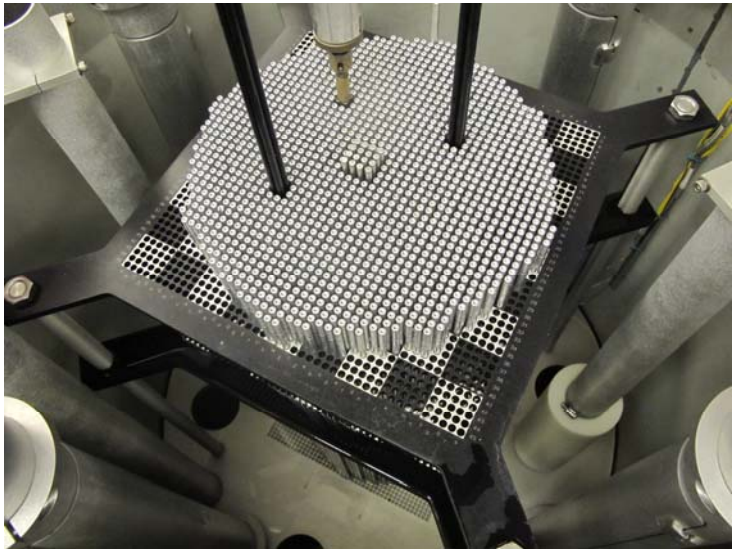
Case 12



- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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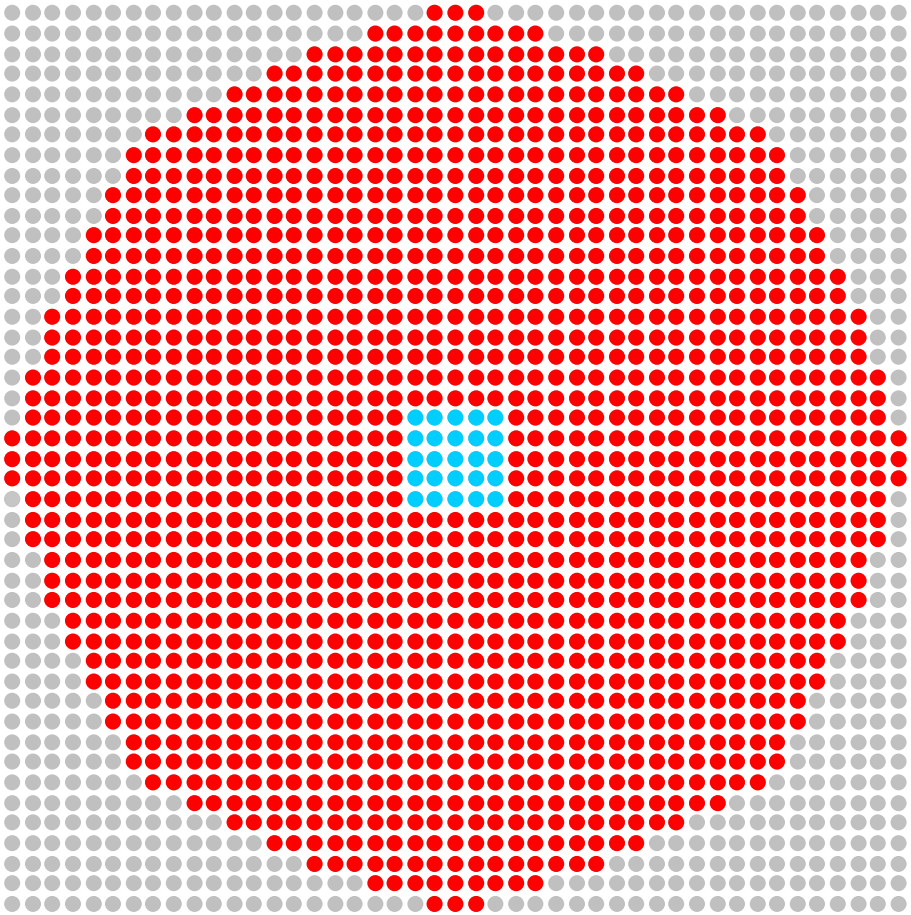
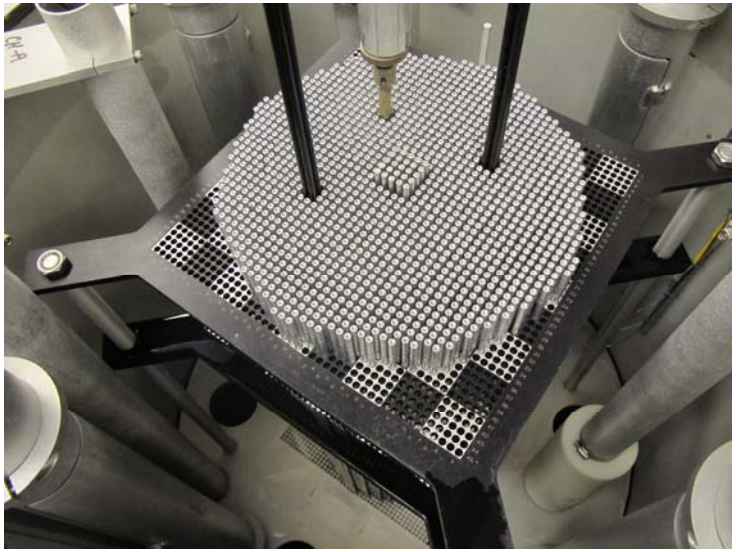
Case 13



- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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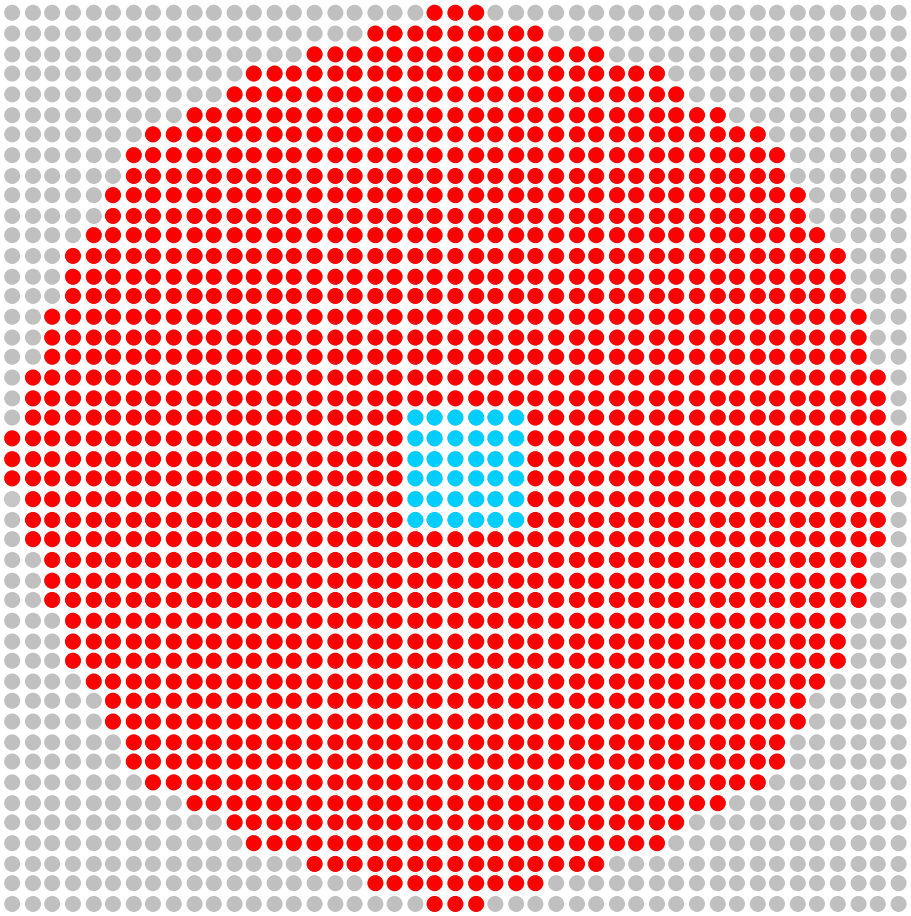
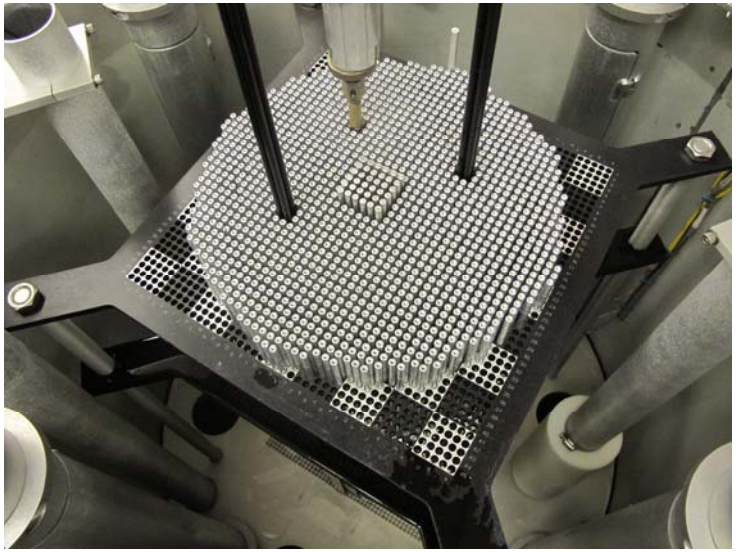


- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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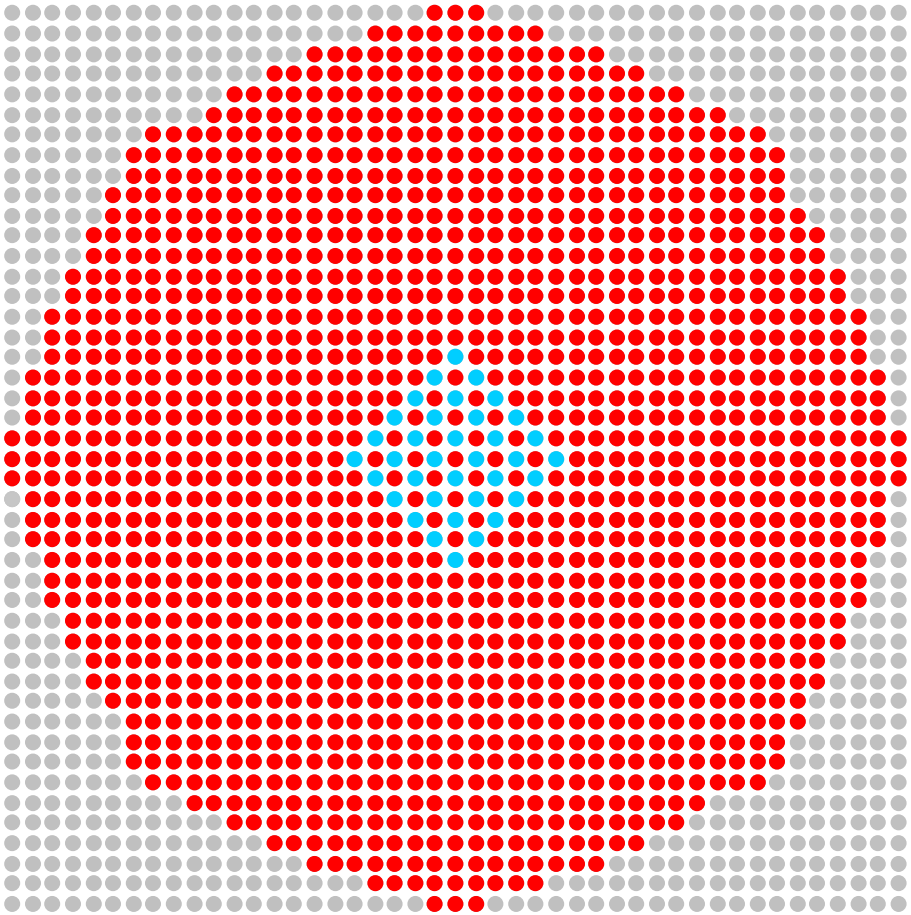
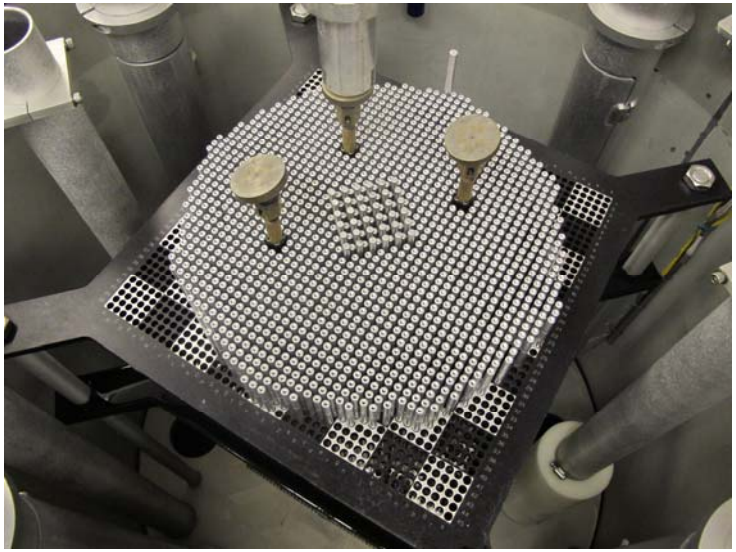


- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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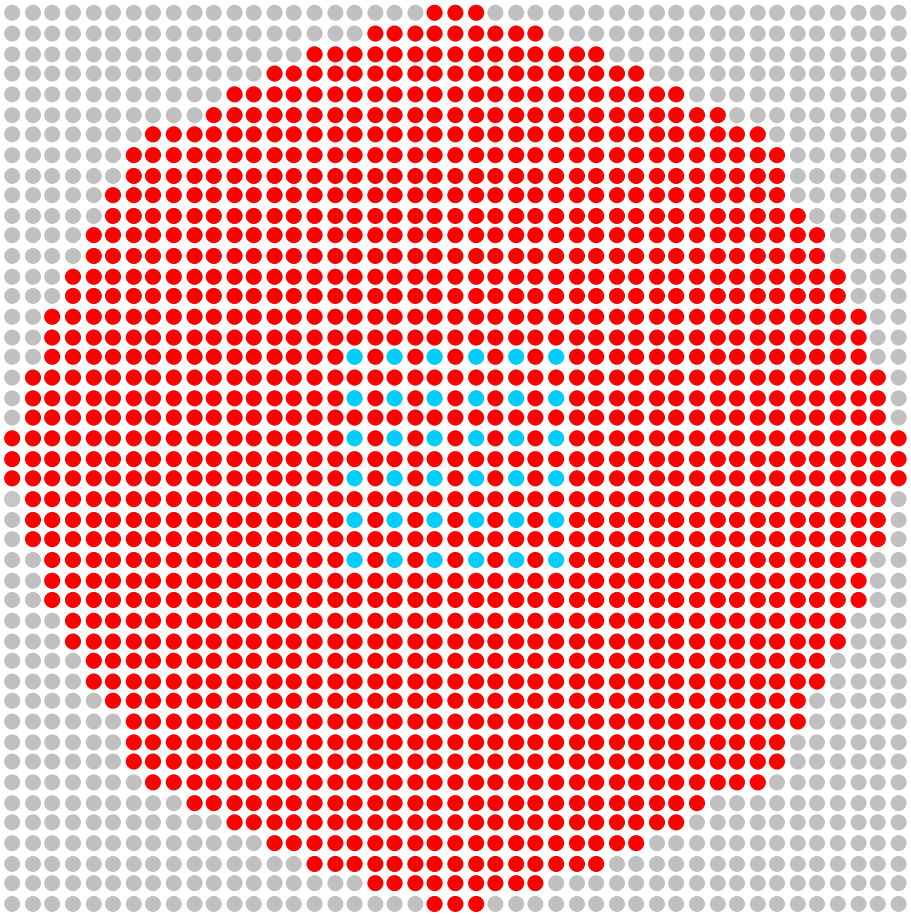
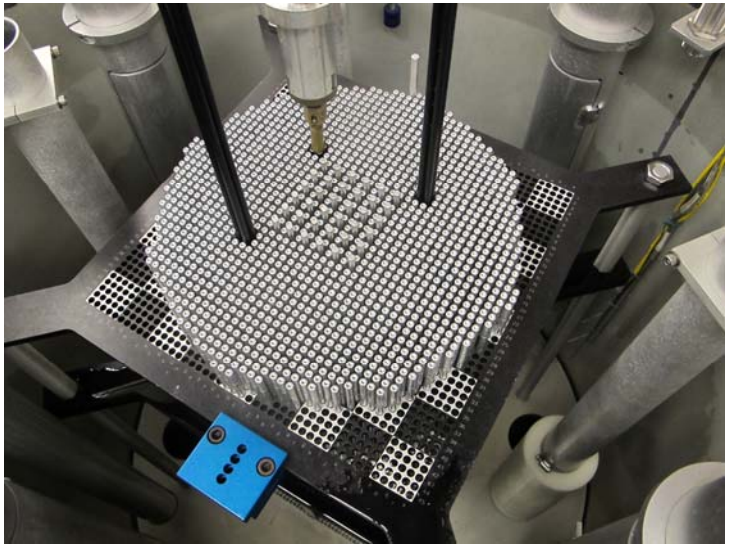


- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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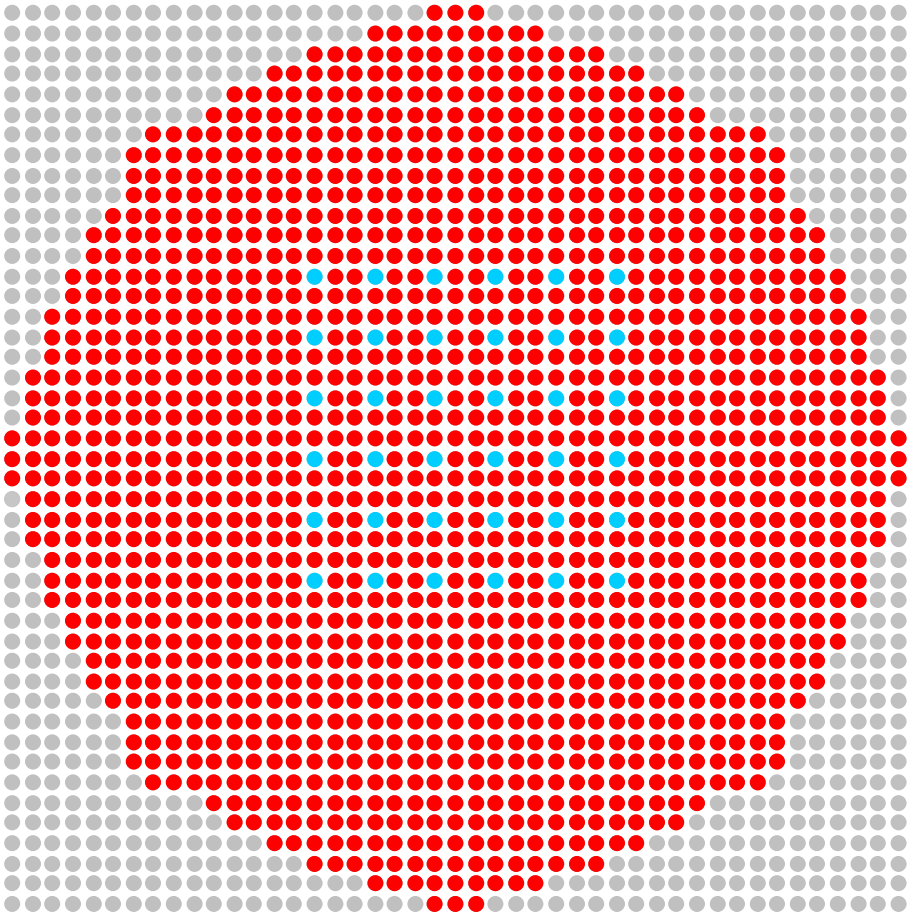
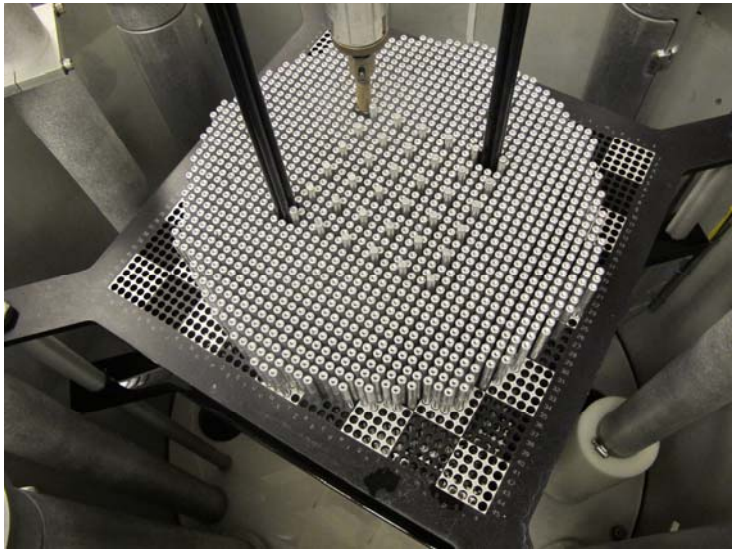


- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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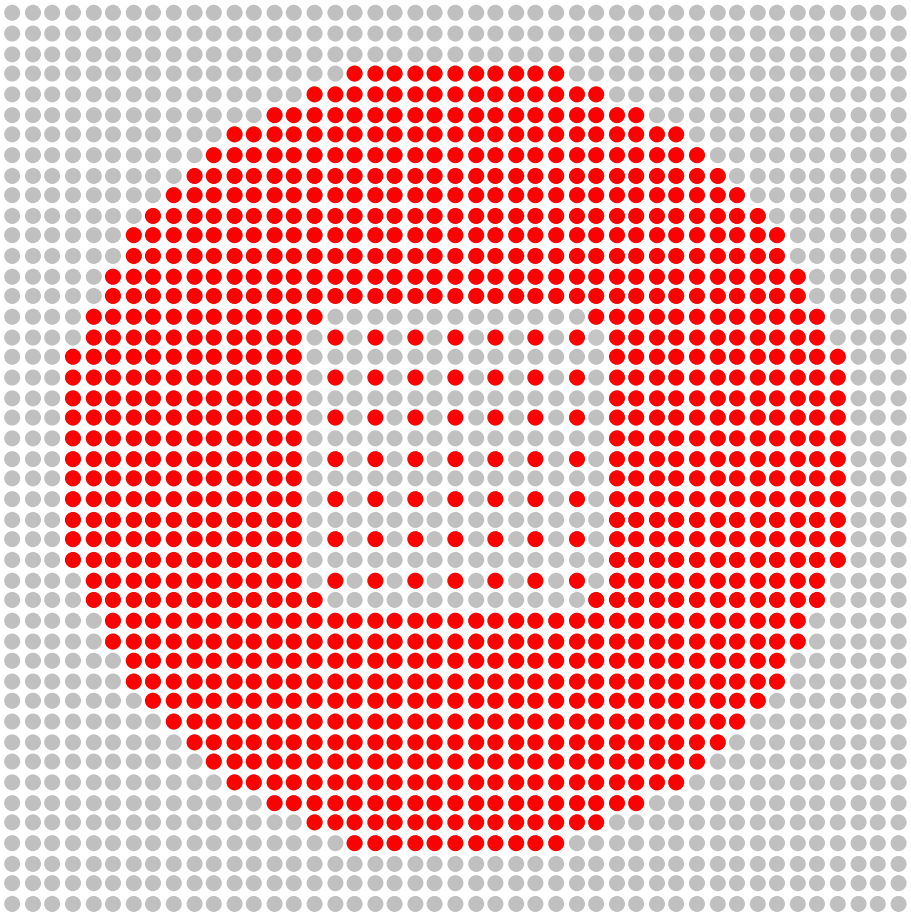
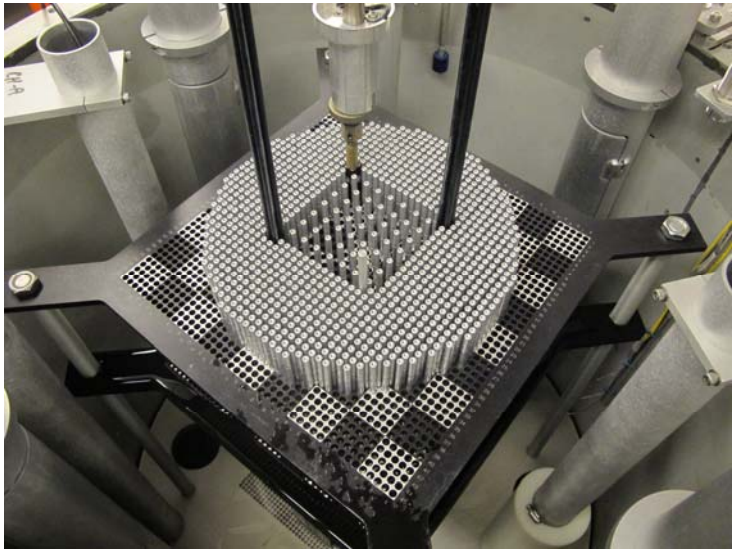


- Fuel Rod
- Empty Grid Location



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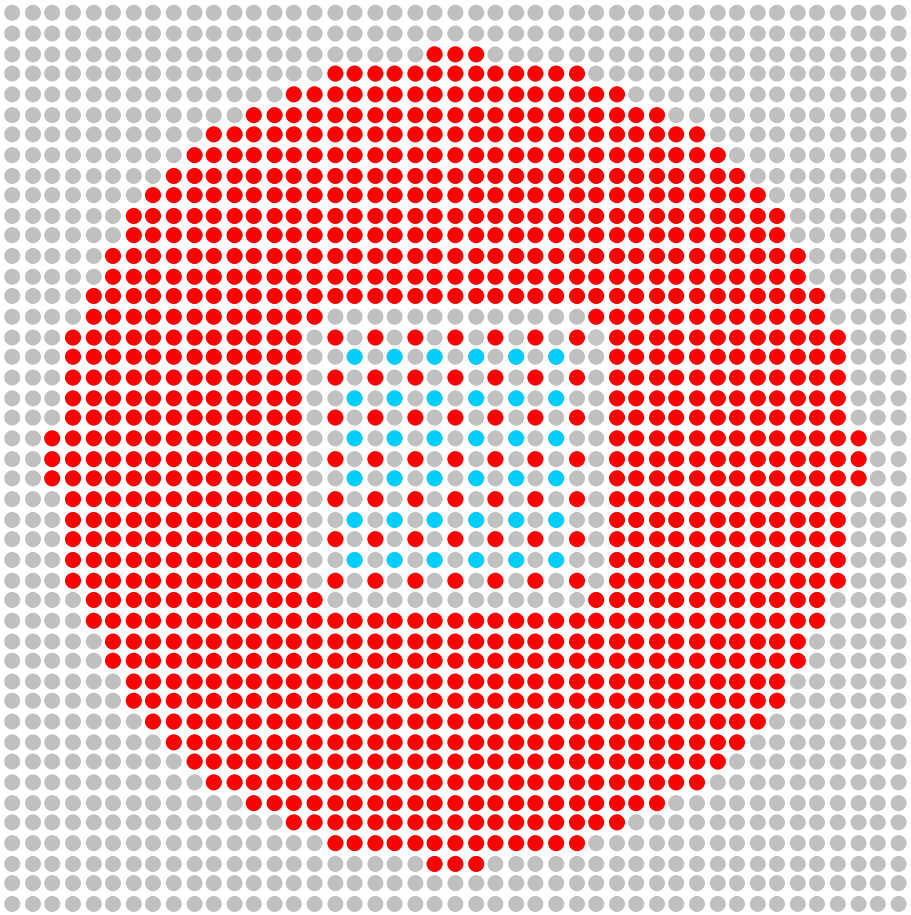
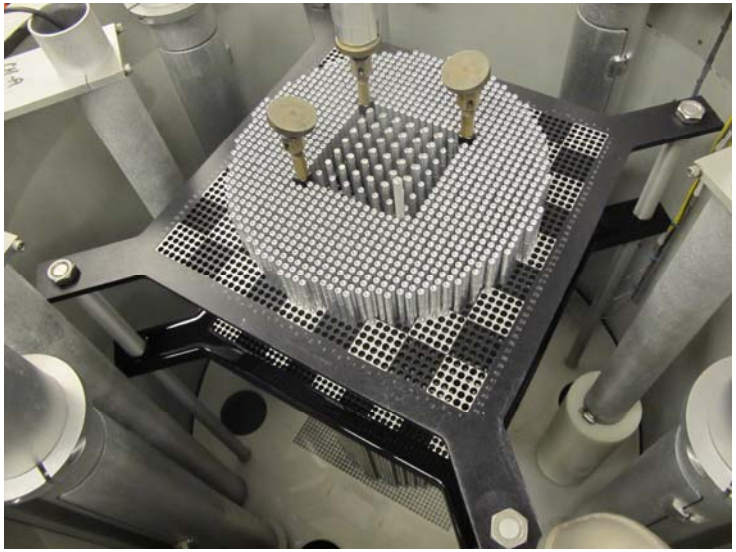
Case 19



- Fuel Rod
- Empty Grid Location
- Aluminum Experiment Rod



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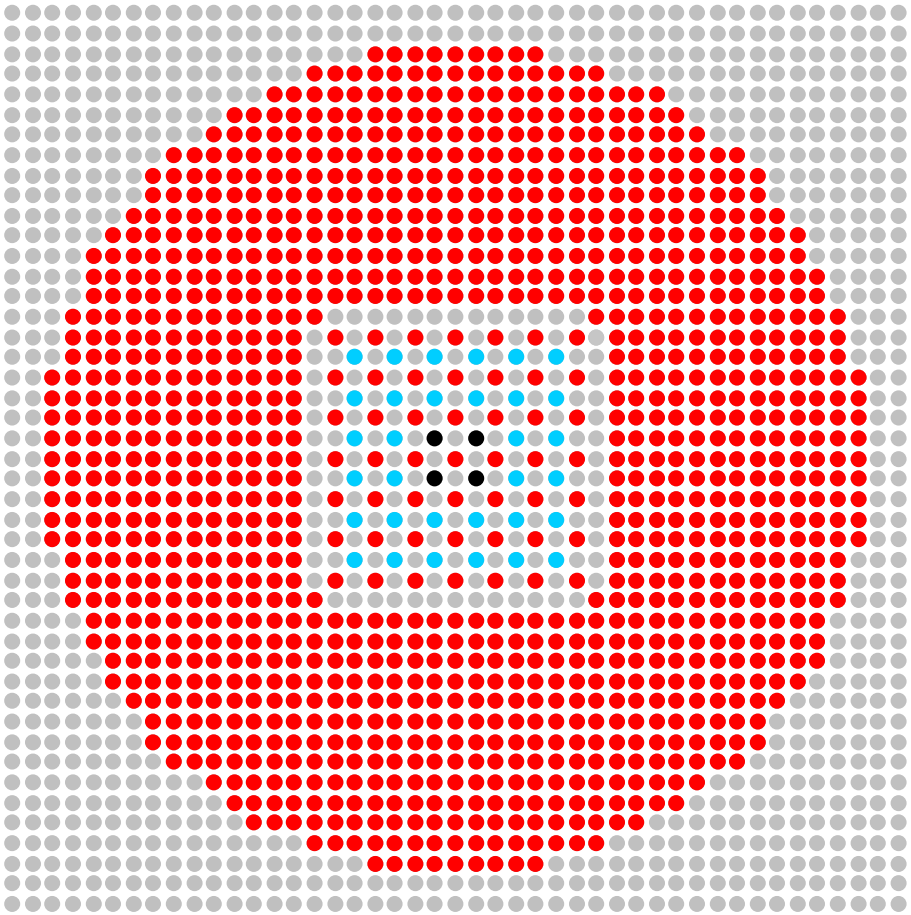
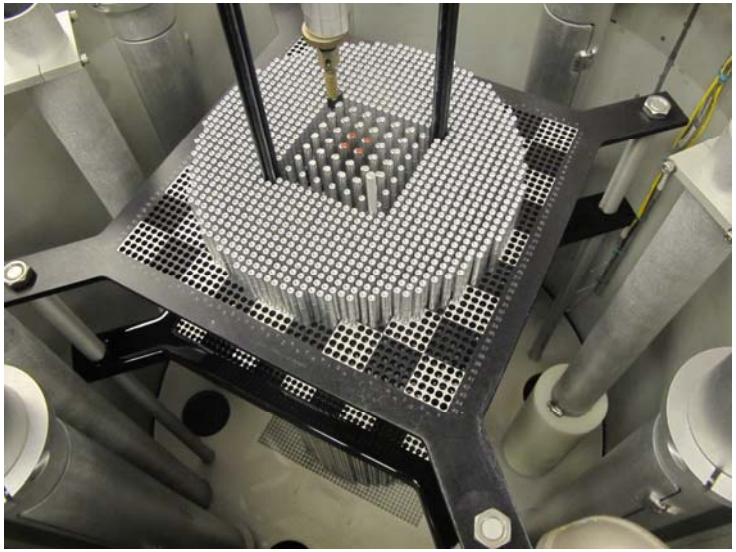
Case 20



- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod
- Aluminum Experiment Rod



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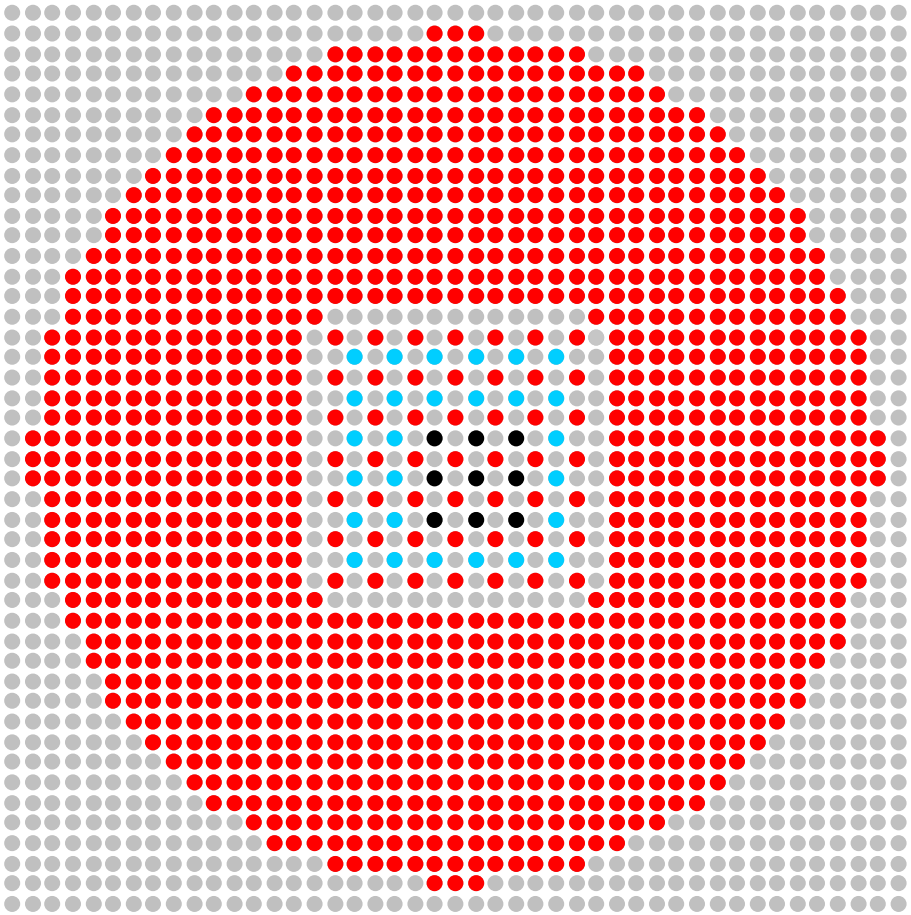
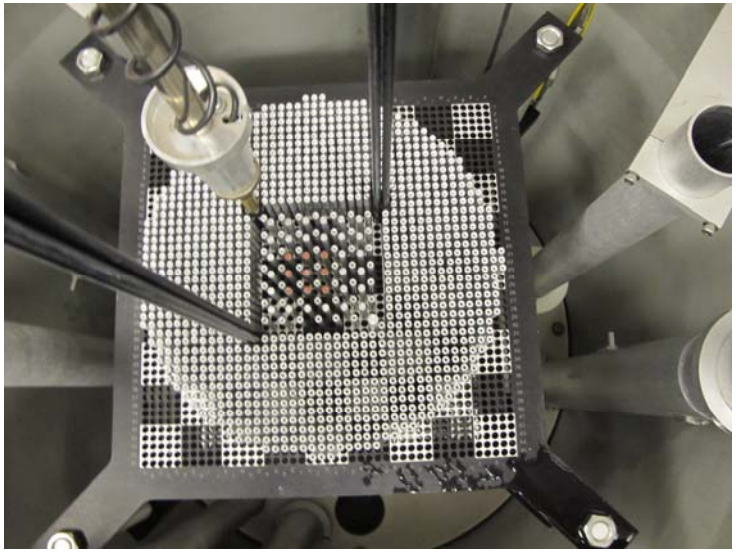
Case 21



- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod
- Aluminum Experiment Rod



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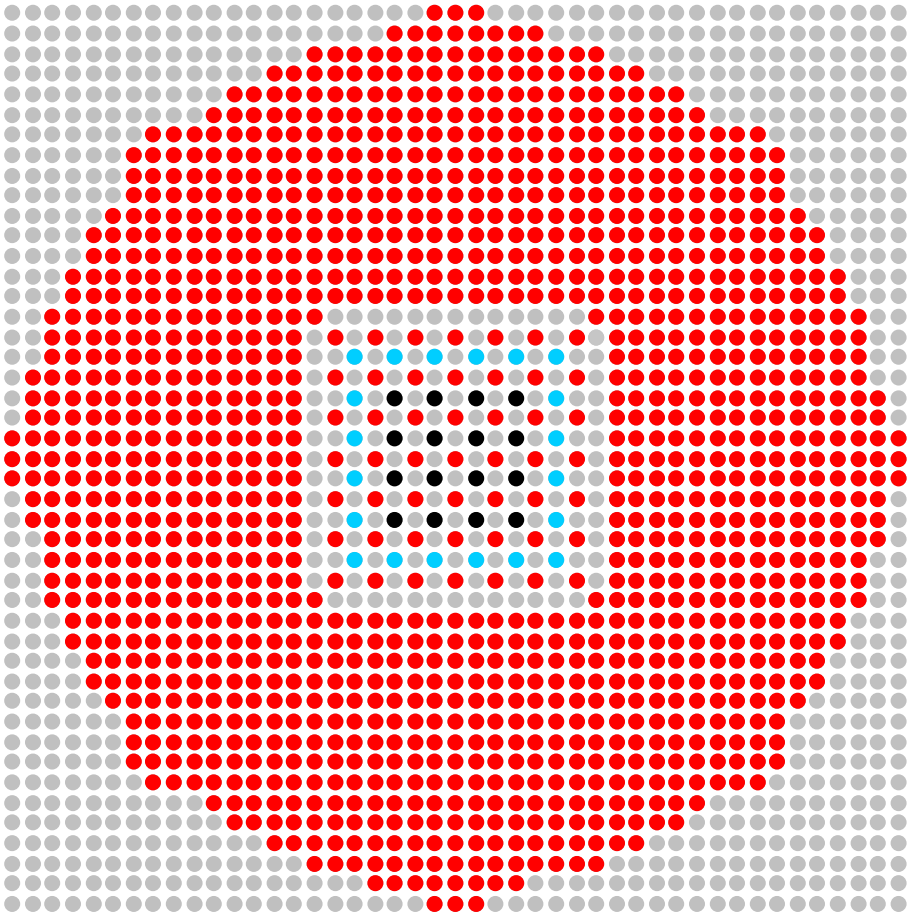
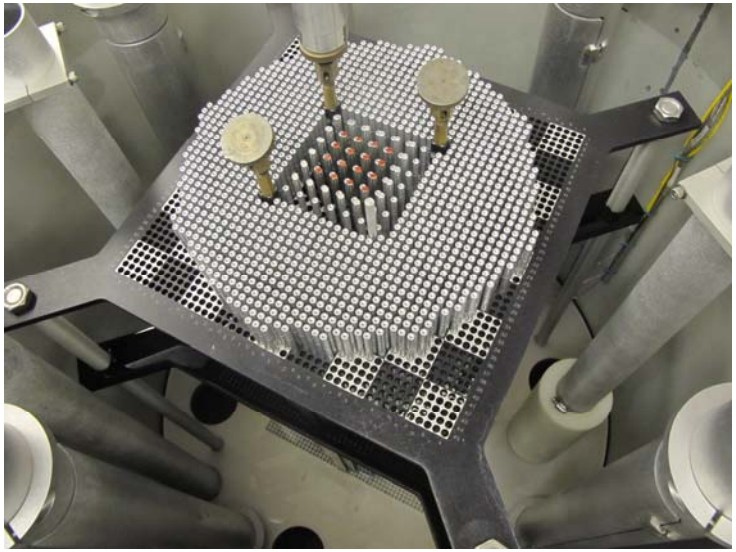
Case 22



- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod
- Aluminum Experiment Rod



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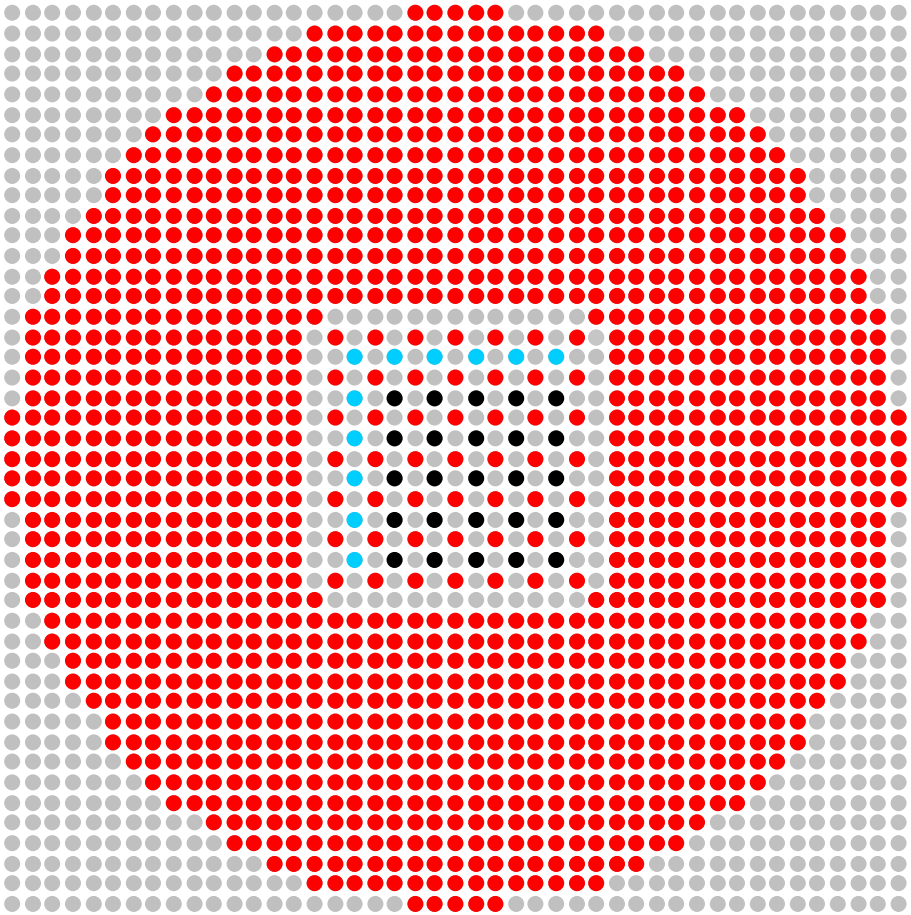
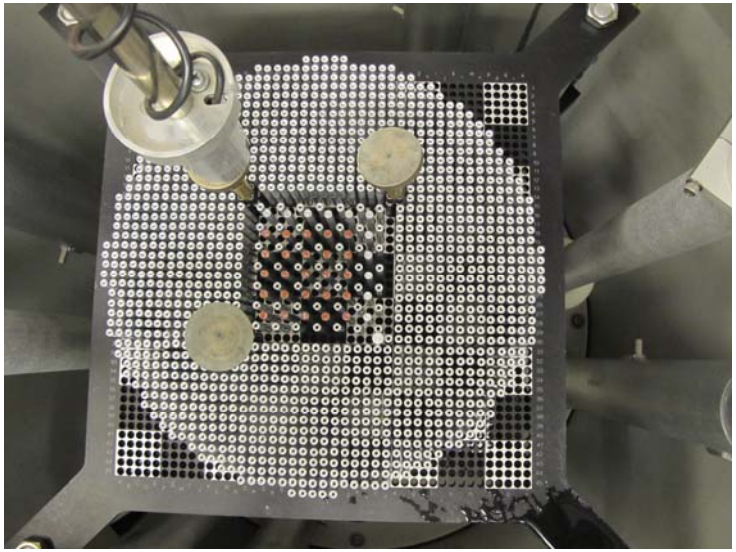
Case 23



- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod
- Aluminum Experiment Rod



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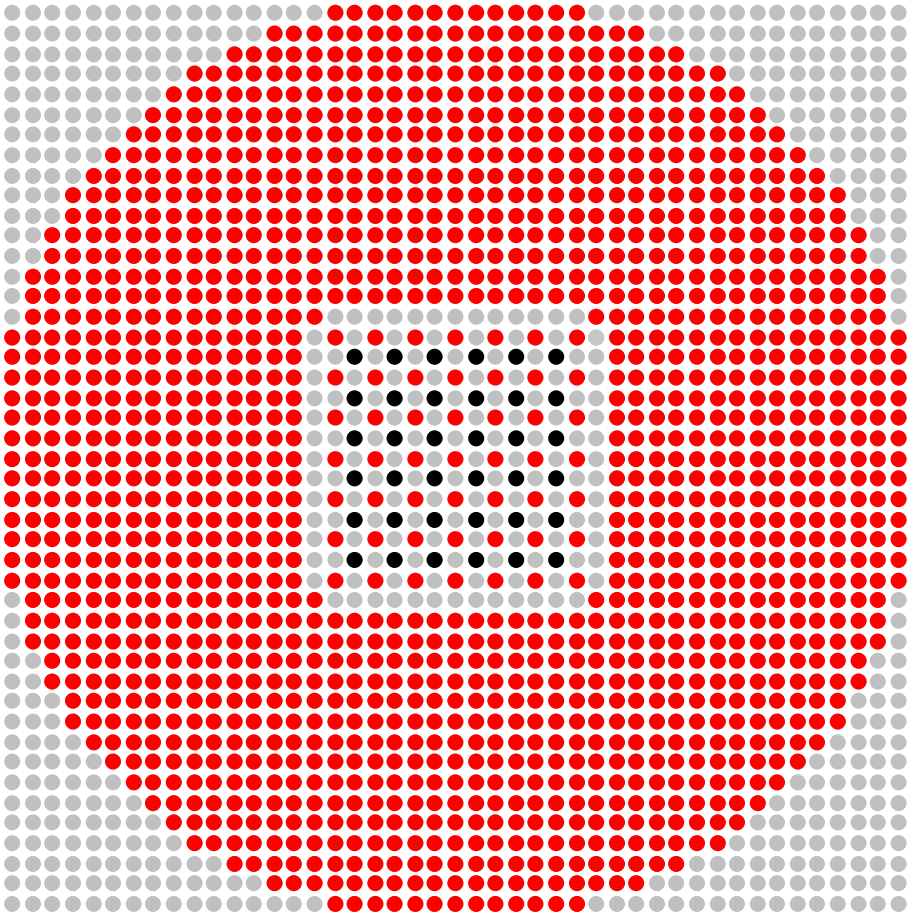
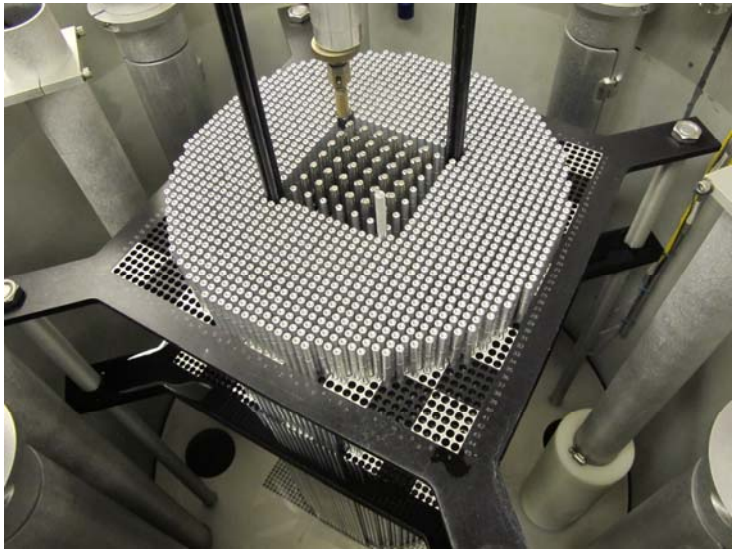
Case 24



- Fuel Rod
- Empty Grid Location
- Titanium Experiment Rod



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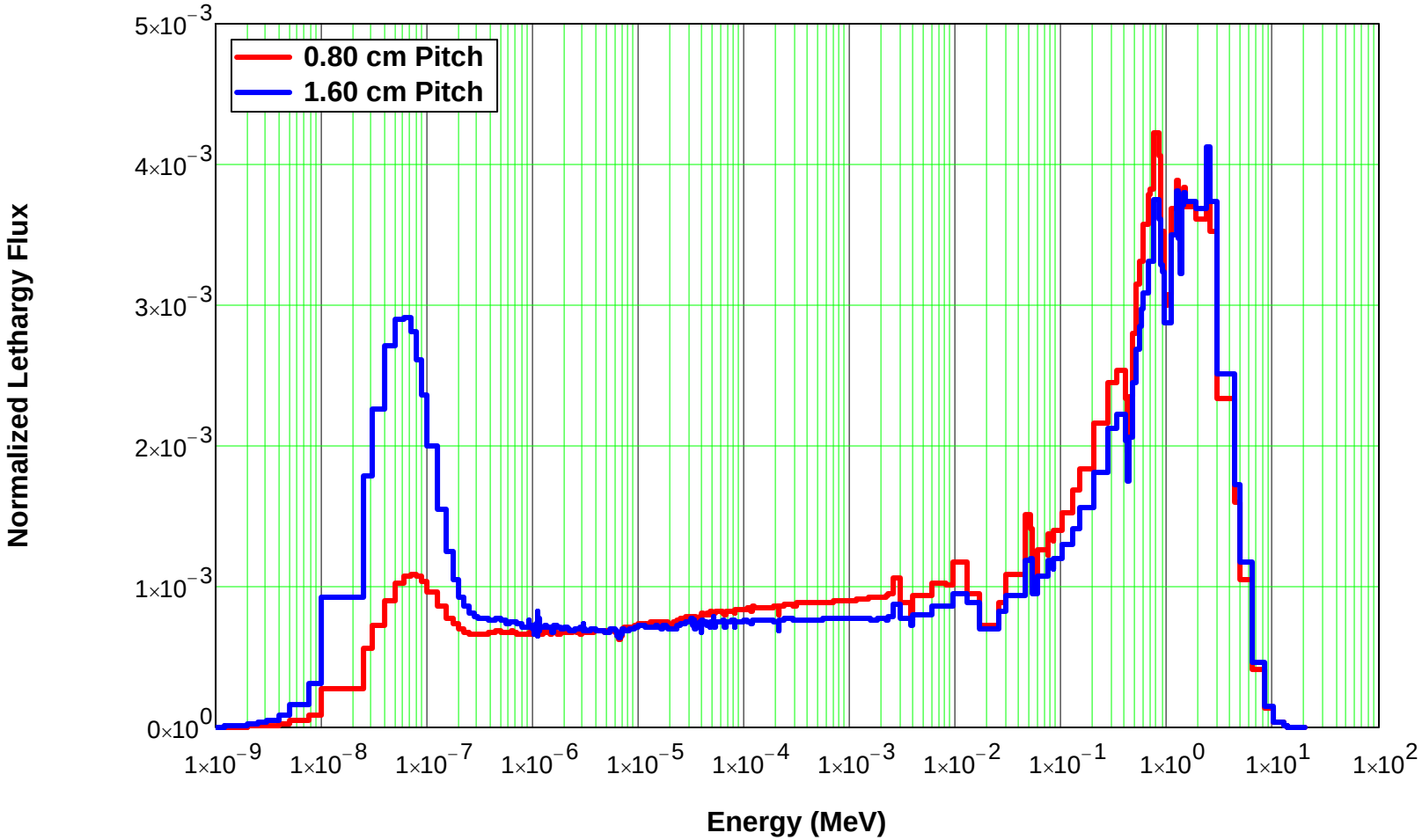
A comparison of the neutron spectra in the titanium rods



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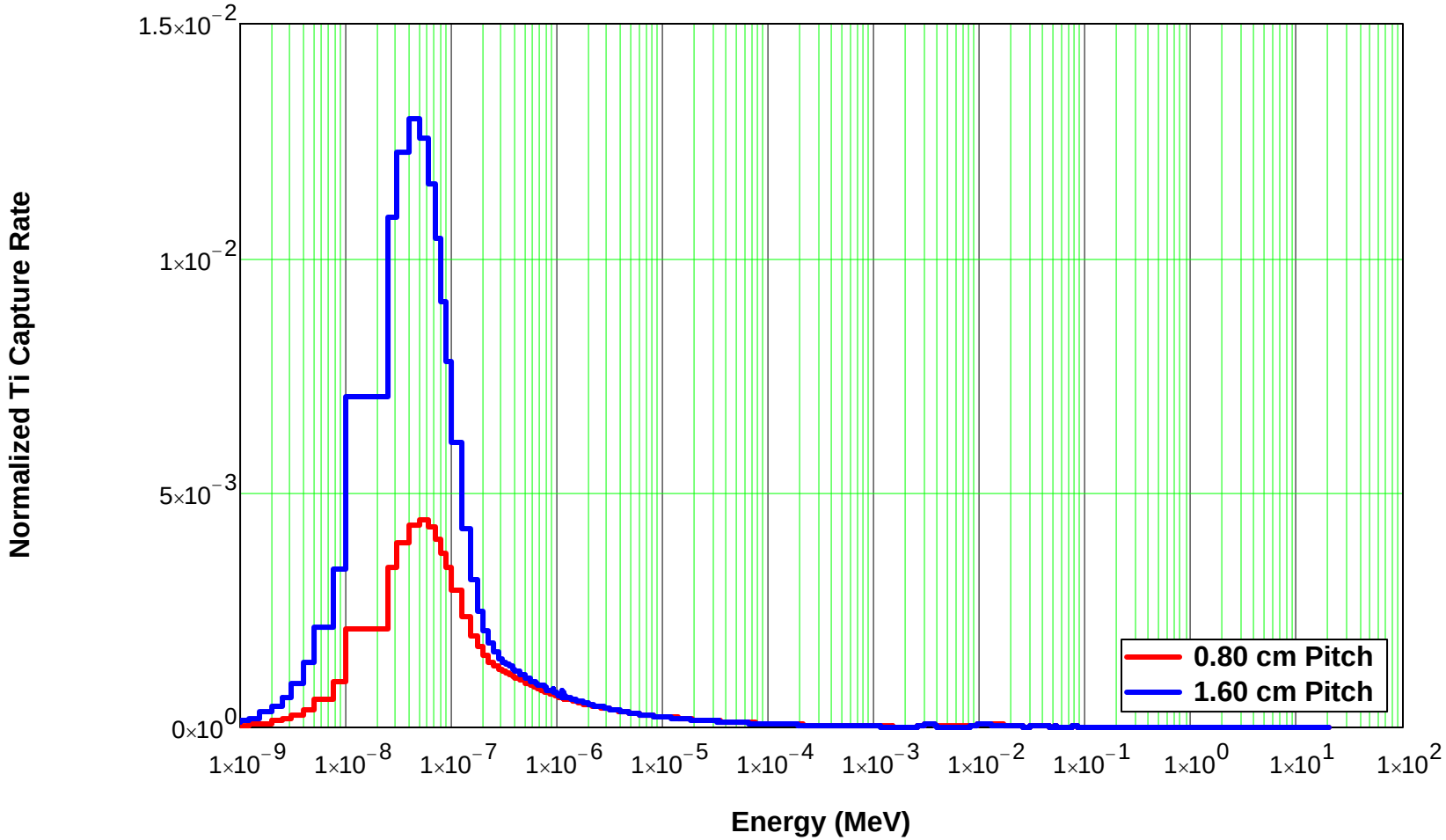
A comparison of the capture rate in the titanium rods



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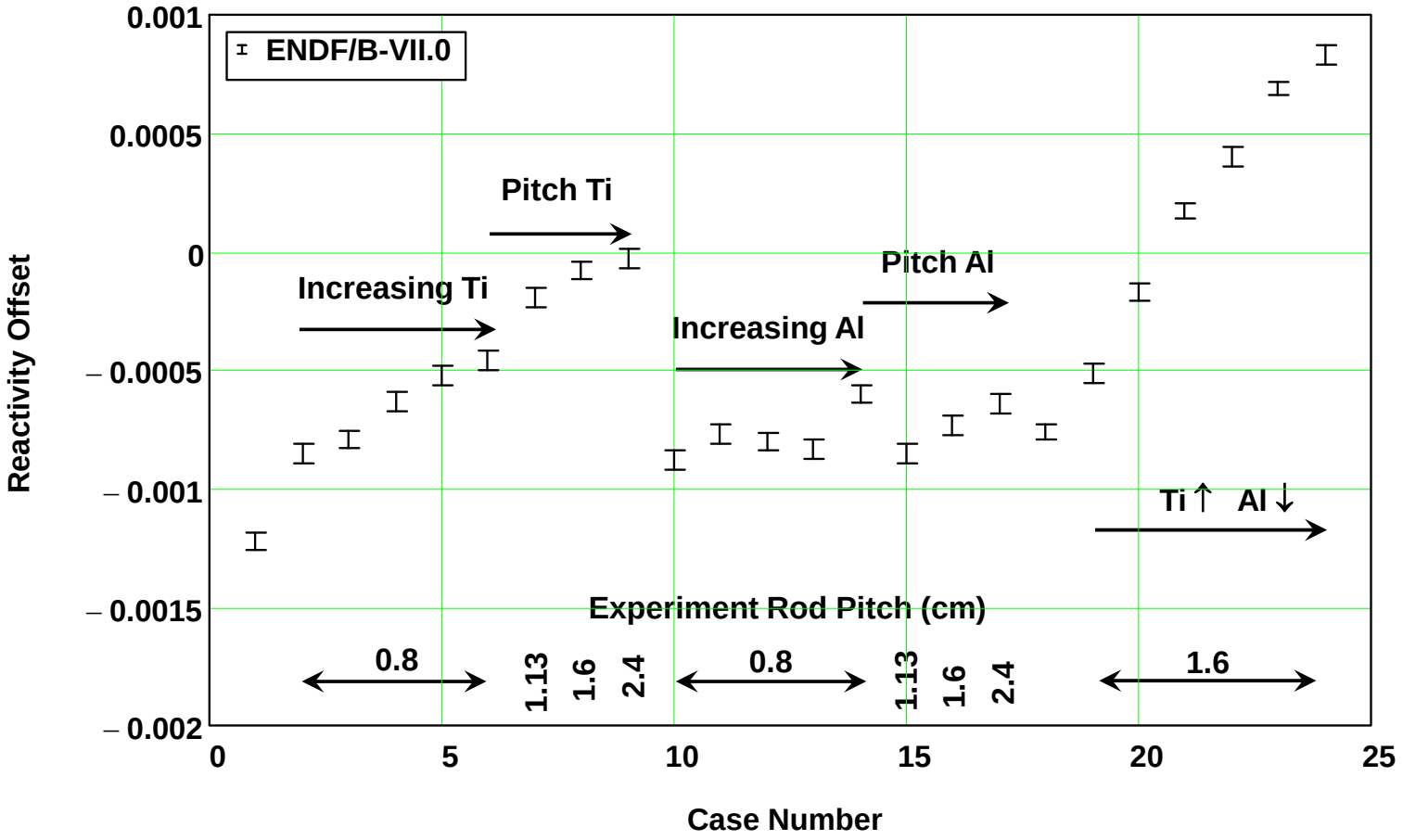
MCNP6.1.1 + ENDF/B-VII.0
Calculation of Benchmark Models



Expt.	Ti	0	4	9	16	25	36	36	36	36	0	0	0	0	0	0	0	0	0	0	4	9	16	25	36	Ti	Expt.
Rods	Al	0	0	0	0	0	0	0	0	0	4	9	16	25	36	36	36	36	0	36	32	27	20	11	0	Al	Rods
	Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Case	

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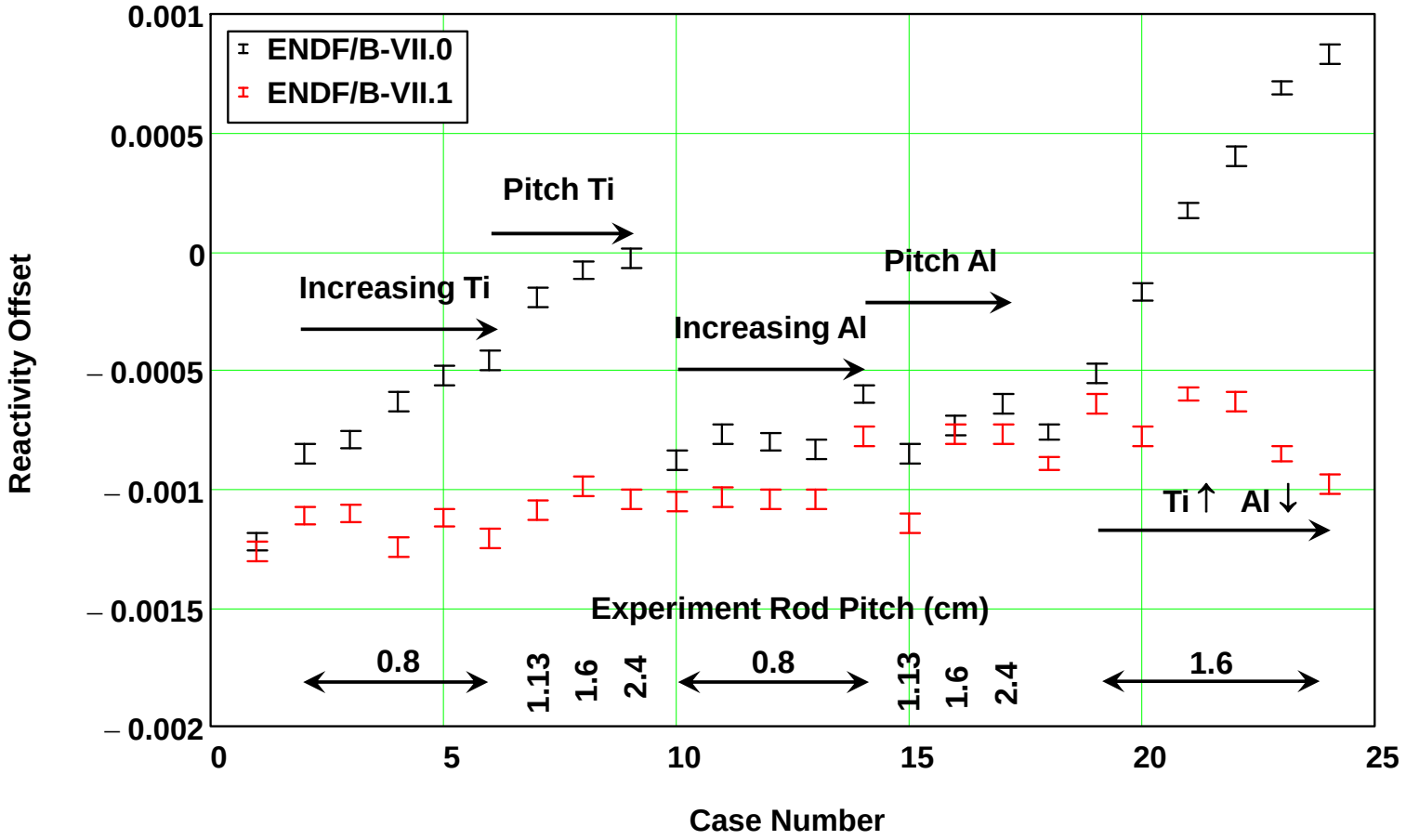
Add ENDF/B-VII.1 cross sections



Expt.	Ti	0	4	9	16	25	36	36	36	36	0	0	0	0	0	0	0	0	0	0	4	9	16	25	36	Ti	Expt.
Rods	Al	0	0	0	0	0	0	0	0	0	4	9	16	25	36	36	36	36	0	36	32	27	20	11	0	Al	Rods
	Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Case	

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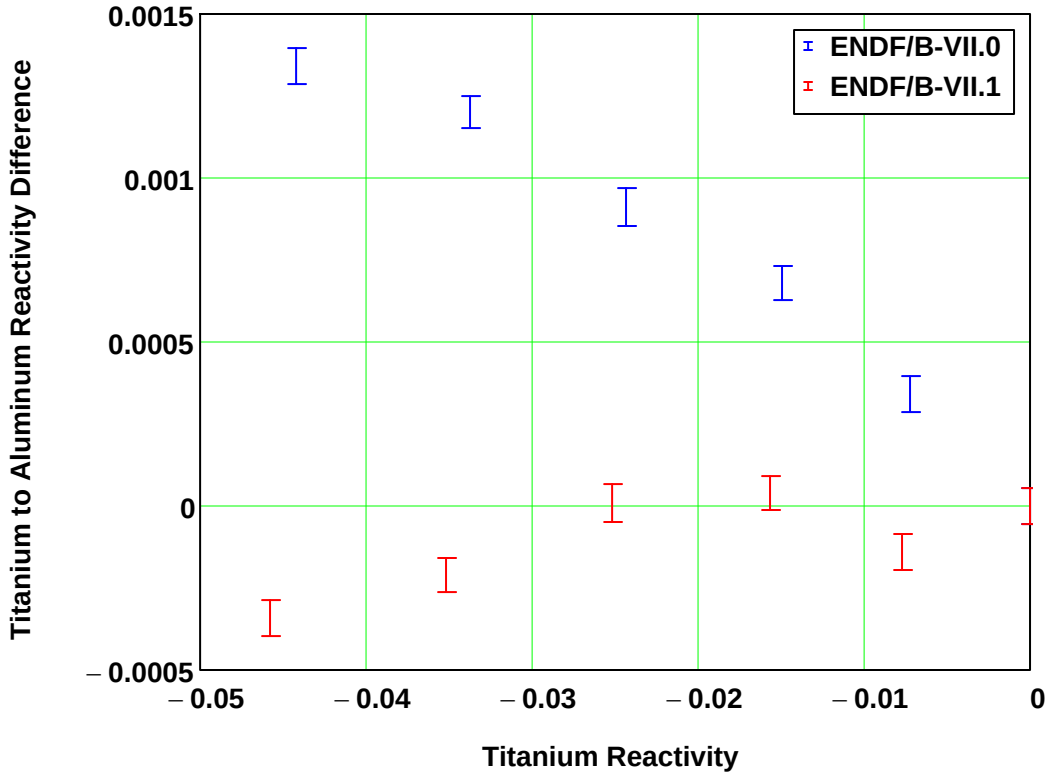
The experiments test changes to the Ti cross sections

The ^{48}Ti capture cross section was increased about 6% between ENDF/B-VII.0 and ENDF/B-VII.1



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The bottom line in the LCT097 evaluation

Case	Experiment		Simplification Bias		Temperature Correction		Experiment Uncertainty	Benchmark Model	
	k_{eff}	Unc.	Δk_{eff}	Unc.	Δk_{eff}	Unc.		k_{eff}	Unc.
1	0.99940	0.00010	0.00000	0.00004	0.00000	0.00000	0.00108	0.99940	0.00109
2	0.99942	0.00012	0.00000	0.00004	0.00000	0.00000	0.00098	0.99942	0.00099
3	0.99933	0.00011	0.00000	0.00004	0.00001	0.00000	0.00098	0.99934	0.00098
4	0.99947	0.00011	0.00007	0.00004	0.00001	0.00000	0.00098	0.99955	0.00098
5	0.99941	0.00011	0.00006	0.00004	0.00000	0.00000	0.00098	0.99947	0.00098
6	0.99964	0.00010	0.00005	0.00004	0.00000	0.00000	0.00098	0.99969	0.00098
7	0.99946	0.00011	0.00006	0.00004	0.00001	0.00000	0.00098	0.99953	0.00098
8	0.99956	0.00014	0.00005	0.00004	0.00000	0.00000	0.00098	0.99961	0.00099
9	0.99948	0.00011	-0.00002	0.00004	0.00000	0.00000	0.00098	0.99946	0.00098
10	0.99913	0.00010	0.00000	0.00004	0.00000	0.00000	0.00106	0.99913	0.00107
11	0.99911	0.00010	-0.00002	0.00004	0.00000	0.00000	0.00106	0.99909	0.00107
12	0.99925	0.00010	0.00005	0.00004	0.00000	0.00000	0.00106	0.99930	0.00107
13	0.99941	0.00009	0.00014	0.00004	0.00000	0.00000	0.00106	0.99955	0.00107
14	0.99936	0.00013	0.00007	0.00004	0.00000	0.00000	0.00106	0.99943	0.00107
15	0.99959	0.00009	0.00012	0.00004	0.00001	0.0000	0.00106	0.99972	0.00107
16	0.99981	0.00009	-0.00004	0.00004	0.00001	0.00000	0.00106	0.99978	0.00107
17	0.99944	0.00010	0.00001	0.00004	0.00001	0.00000	0.00106	0.99946	0.00107
18	0.99967	0.00012	-0.00002	0.00004	0.00000	0.00000	0.00077	0.99965	0.00078
19	0.99938	0.00012	0.00013	0.00004	-0.00001	0.00000	0.00077	0.99950	0.00078
20	0.99957	0.00013	0.00009	0.00004	-0.00001	0.00000	0.00077	0.99965	0.00078
21	0.99982	0.00012	-0.00005	0.00004	-0.00001	0.00000	0.00077	0.99976	0.00078
22	0.99946	0.00010	0.00000	0.00004	-0.00001	0.00000	0.00067	0.99945	0.00068
23	0.99958	0.00011	-0.00005	0.00004	-0.00001	0.00000	0.00067	0.99952	0.00068
24	0.99961	0.00010	0.00006	0.00004	-0.00001	0.00000	0.00067	0.99966	0.00068

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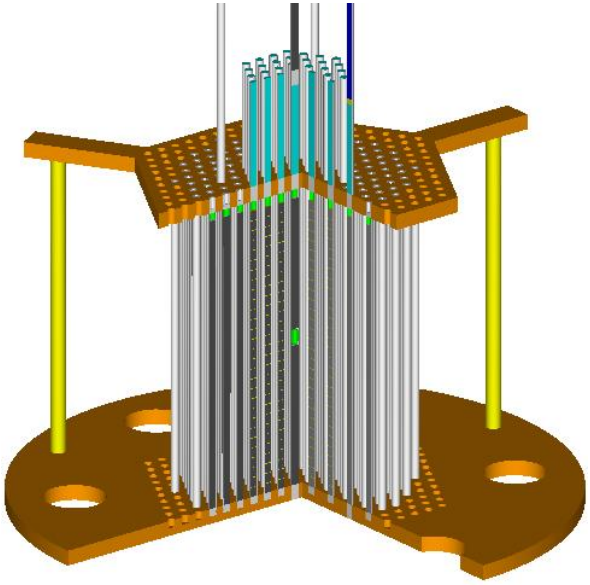
What's next at SCX? BUCCX/Ti



- In 2002, we performed some critical experiments with rhodium
- The Burnup Credit Critical Experiment (BUCCX) uses the same assembly tank but a completely different core
- We built a critical assembly in which we could insert fission product materials to measure reactivity effects
- We completed a set of experiments with rhodium foils between the fuel pellets
- The experiment is documented as LEU-COMP-THERM-079 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments

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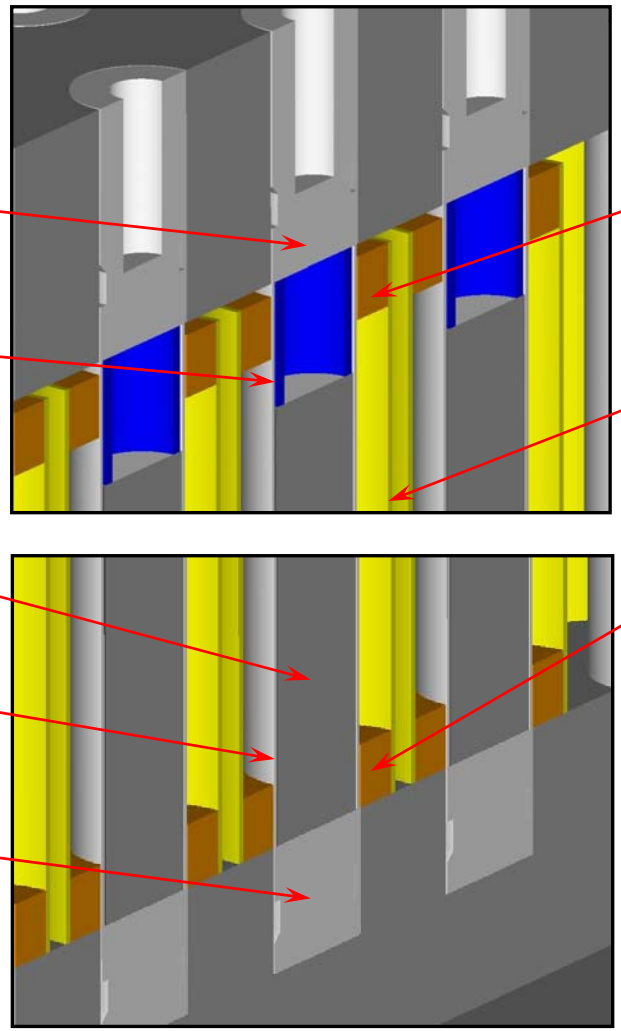
The next titanium experiment uses the BUCCX assembly



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Sandia Critical Experiments