



Results from the Seven Percent Critical Experiment

Nuclear Criticality Safety Program Technical Seminar

**Oak Ridge National Laboratory
March 1, 2011**

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Sandia National Laboratories**



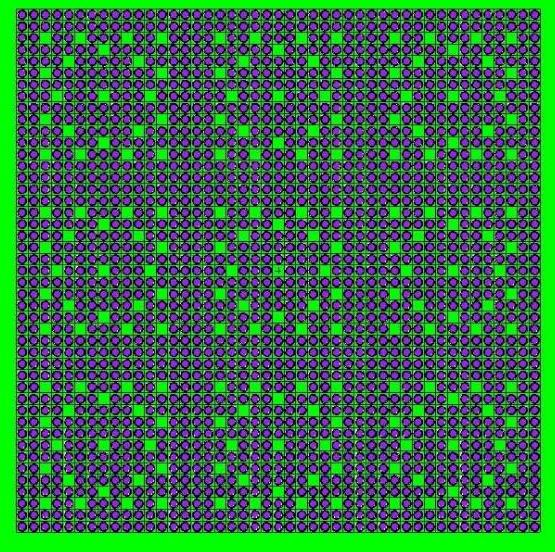
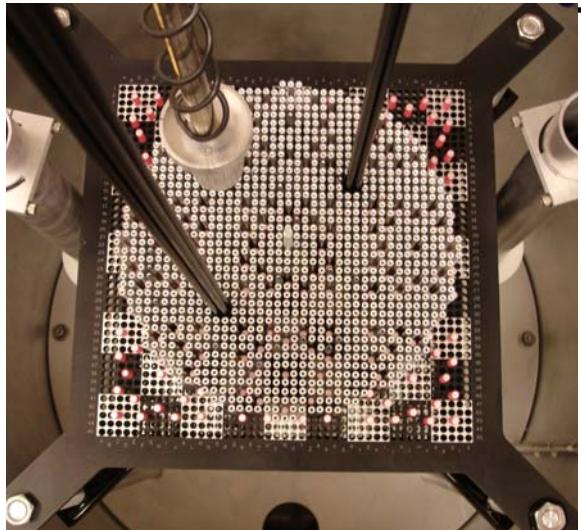
The 7uPCX started as a NERI project

Reactor Physics and Criticality Benchmark Evaluations for Advanced Nuclear Fuel

- The project was originally funded by the Nuclear Energy Research Initiative (NERI)
- The NERI project team:
 - AREVA Federal Services, LLC (Lynchburg, VA) – Conceptual Design, Analysis, Project Management
 - Sandia National Laboratories – Hardware Design, Transportation, Procurement, Experiments
 - Oak Ridge National Laboratory - Analysis
 - University of Florida - Analysis
- The NNSA NCSP is now funding the critical experiments

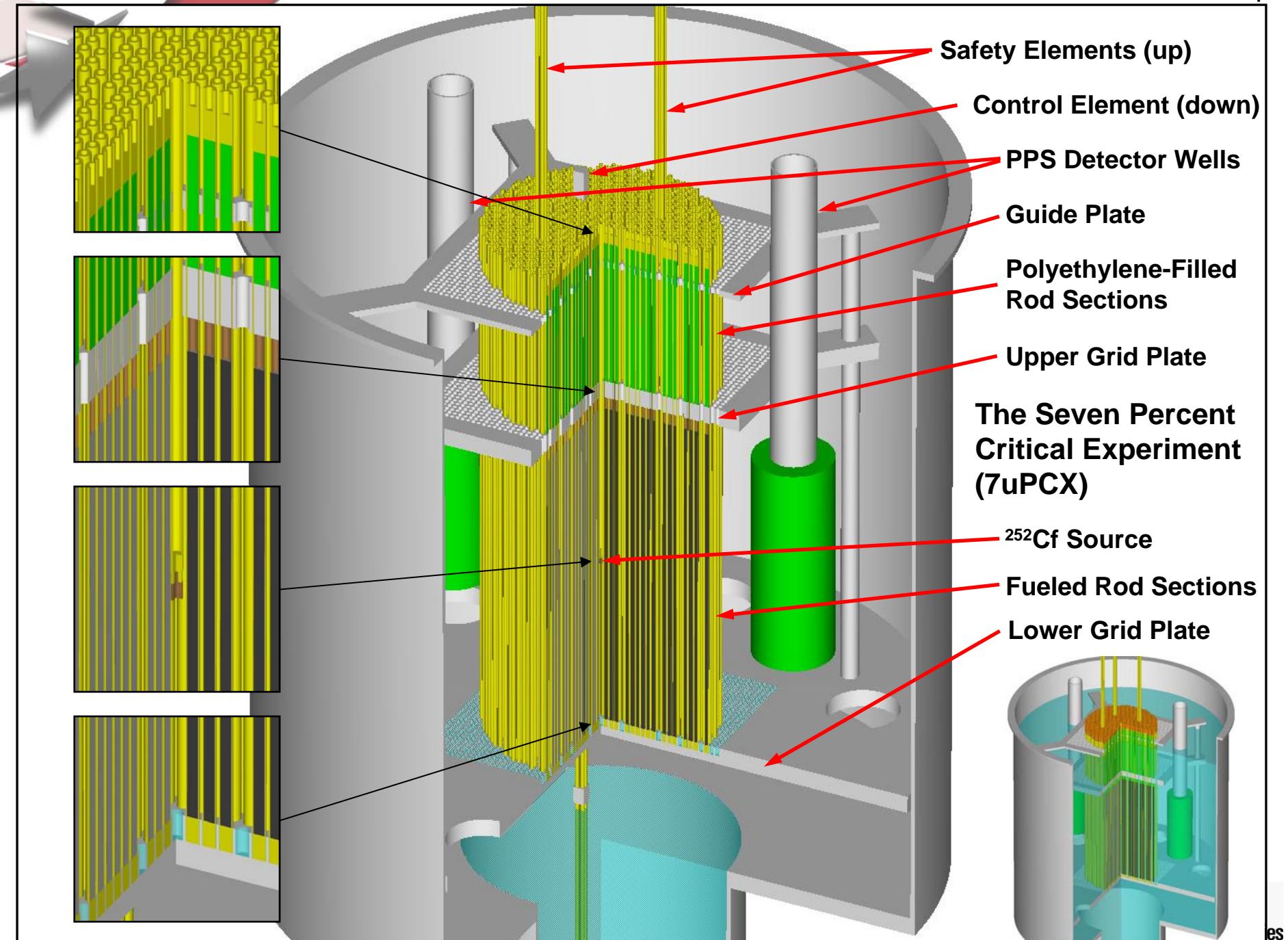


The Seven Percent Critical Experiment (7uPCX) is a reactor physics experiment



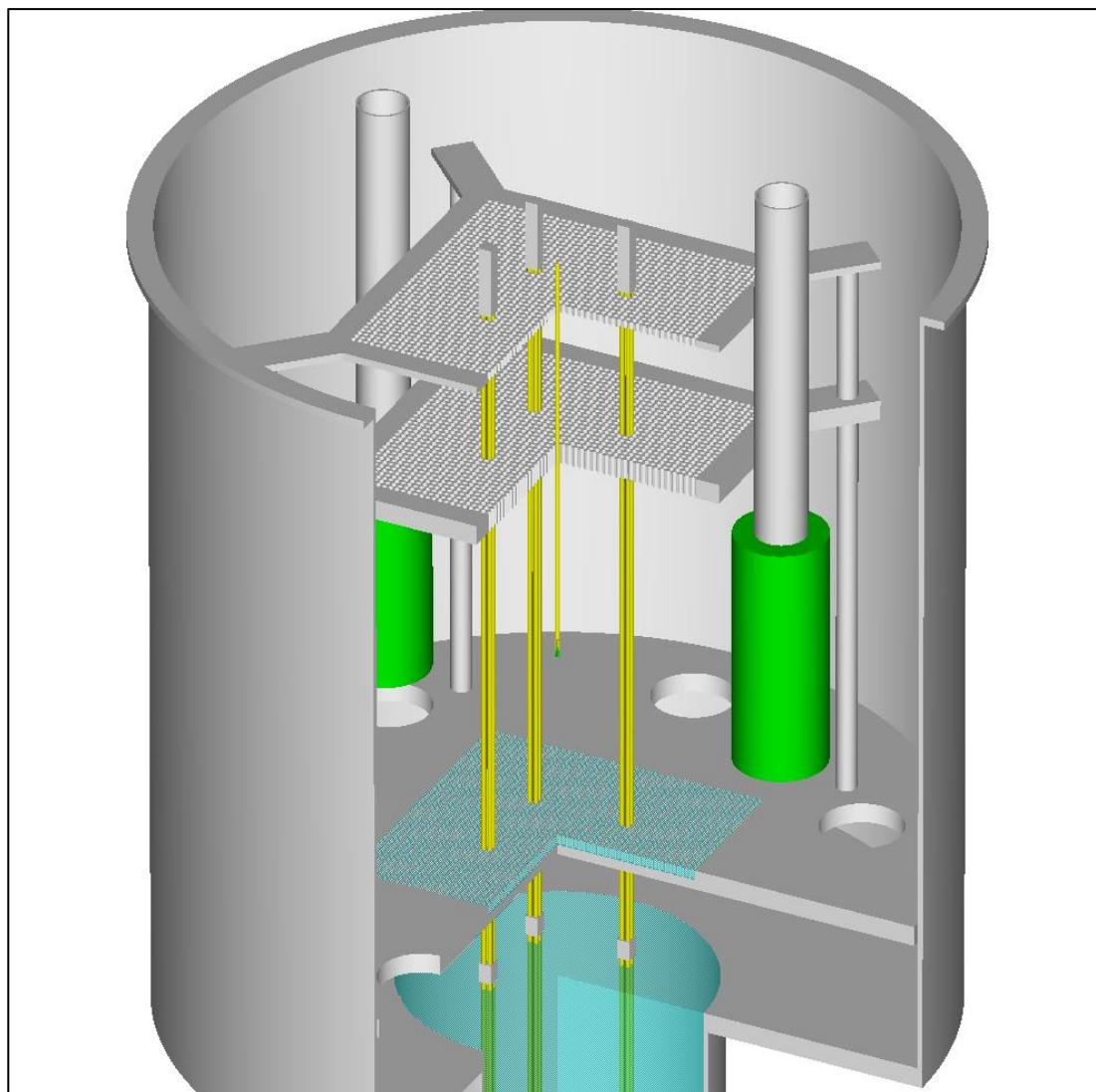
Project Objective: *Design, perform, and analyze critical benchmark experiments for validating reactor physics methods and models for fuel enrichments greater than 5-wt% ^{235}U*

- We built new 6.9% enriched experiment fuel
- We built critical assembly hardware to accommodate the new core
- The core is a 45x45 array of rods to simulate 9 commercial fuel elements in a 3x3 array
- The experiment is a reactor physics experiment as well as a critical experiment
- Additional measurements will be made
 - Fission density profiles
 - Soluble poison worth
 - Water hole worth





The shut-down configuration of the assembly



Fuel: 12 - CE/SE only

Safety Elements: Down

Control Element: Down

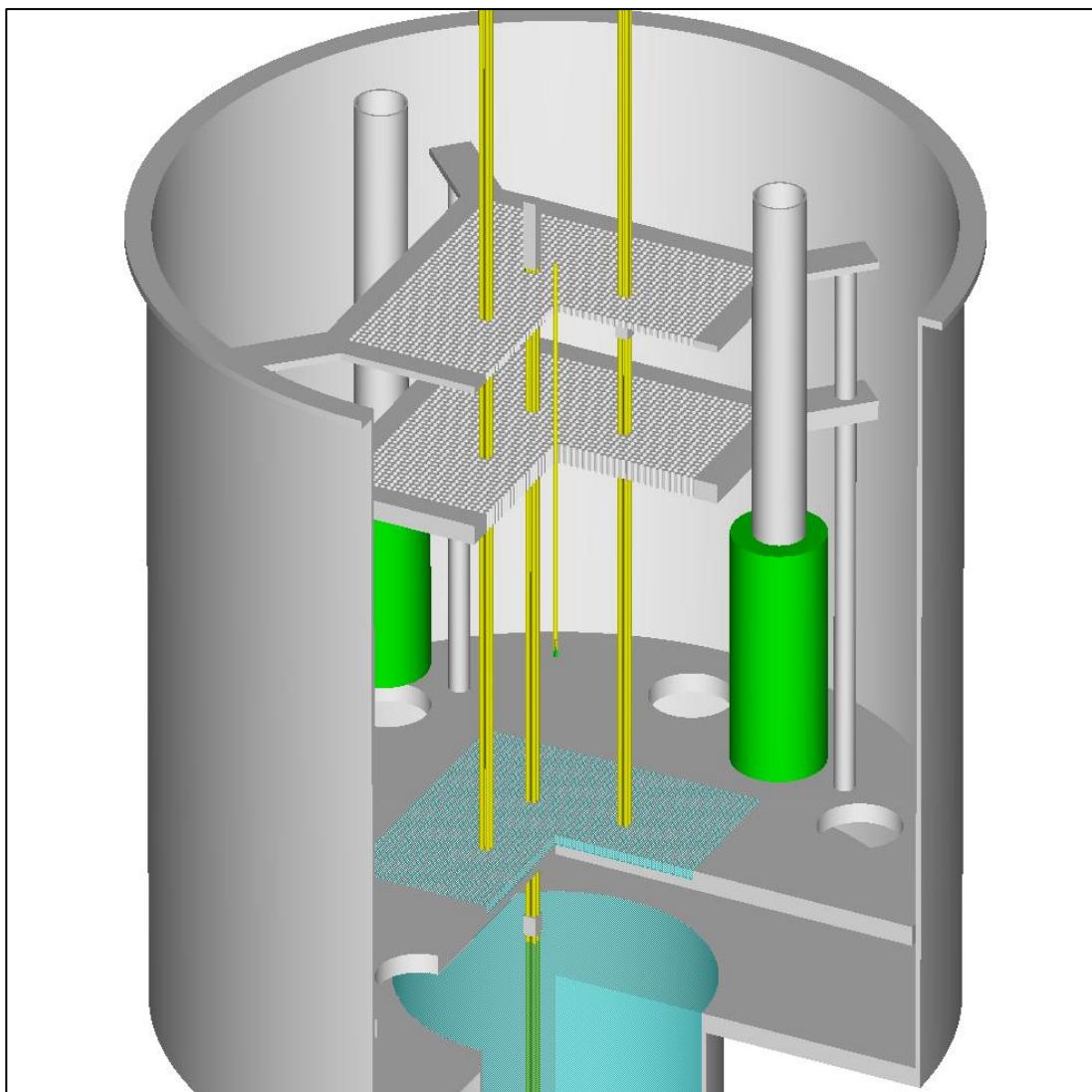
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “shut down.” Entry into the reactor room is allowed. The control system need not be manned. Fuel may be removed or added but a “new” configuration may not be built.



Raise the safety elements



Fuel: 12 - CE/SE only

Safety Elements: Up

Control Element: Down

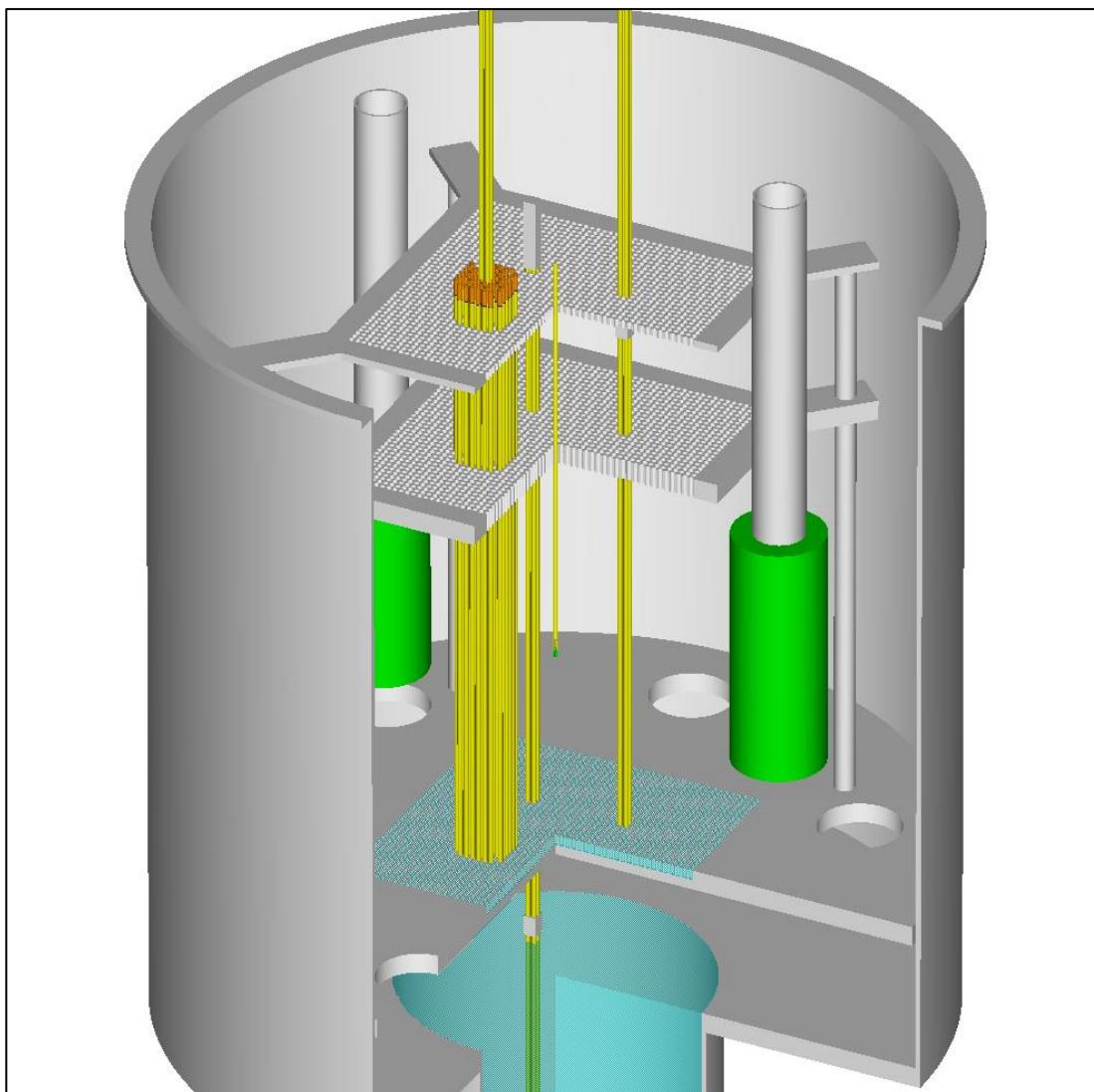
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 64

Safety Elements: Up

Control Element: Down

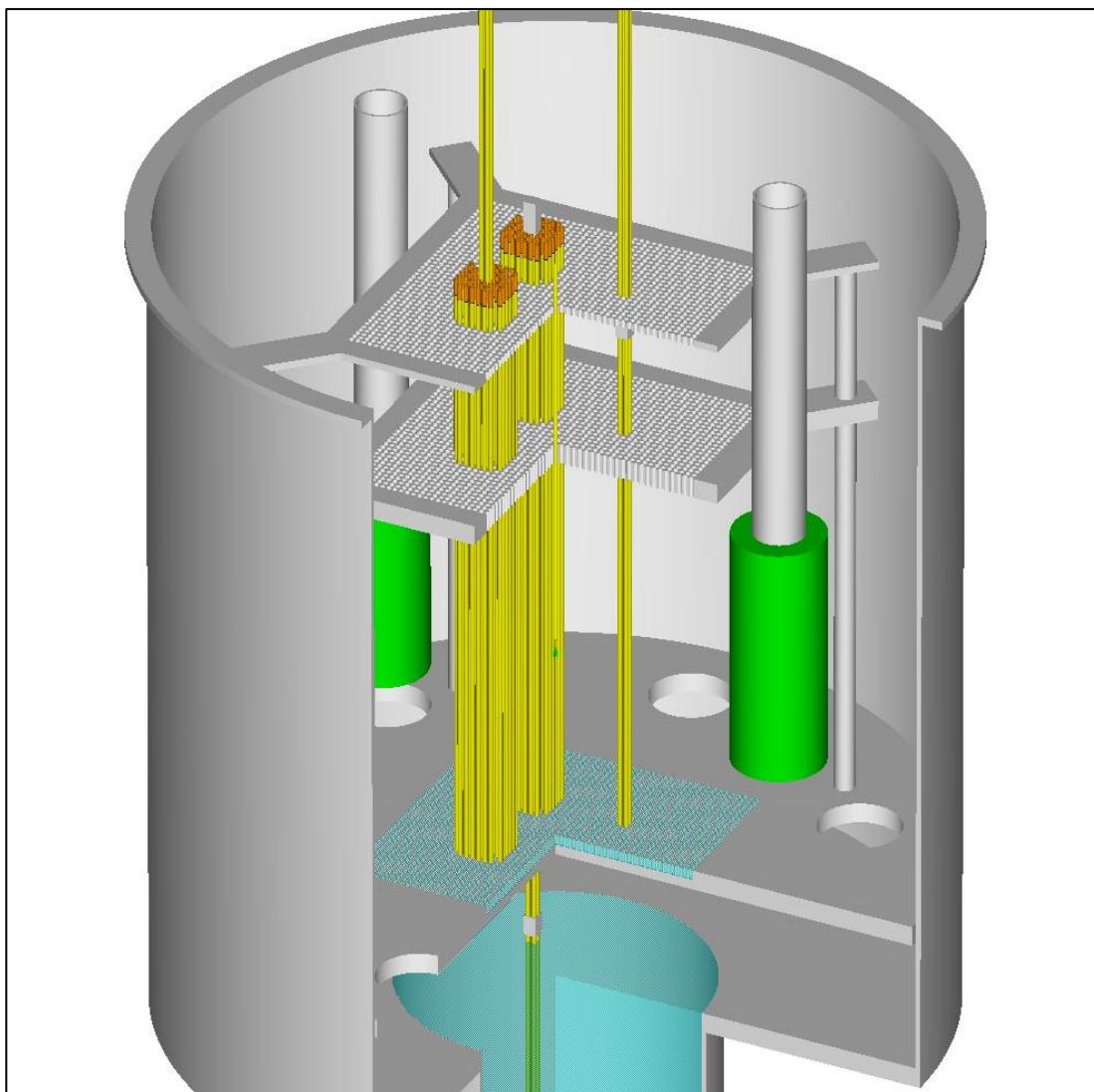
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 116

Safety Elements: Up

Control Element: Down

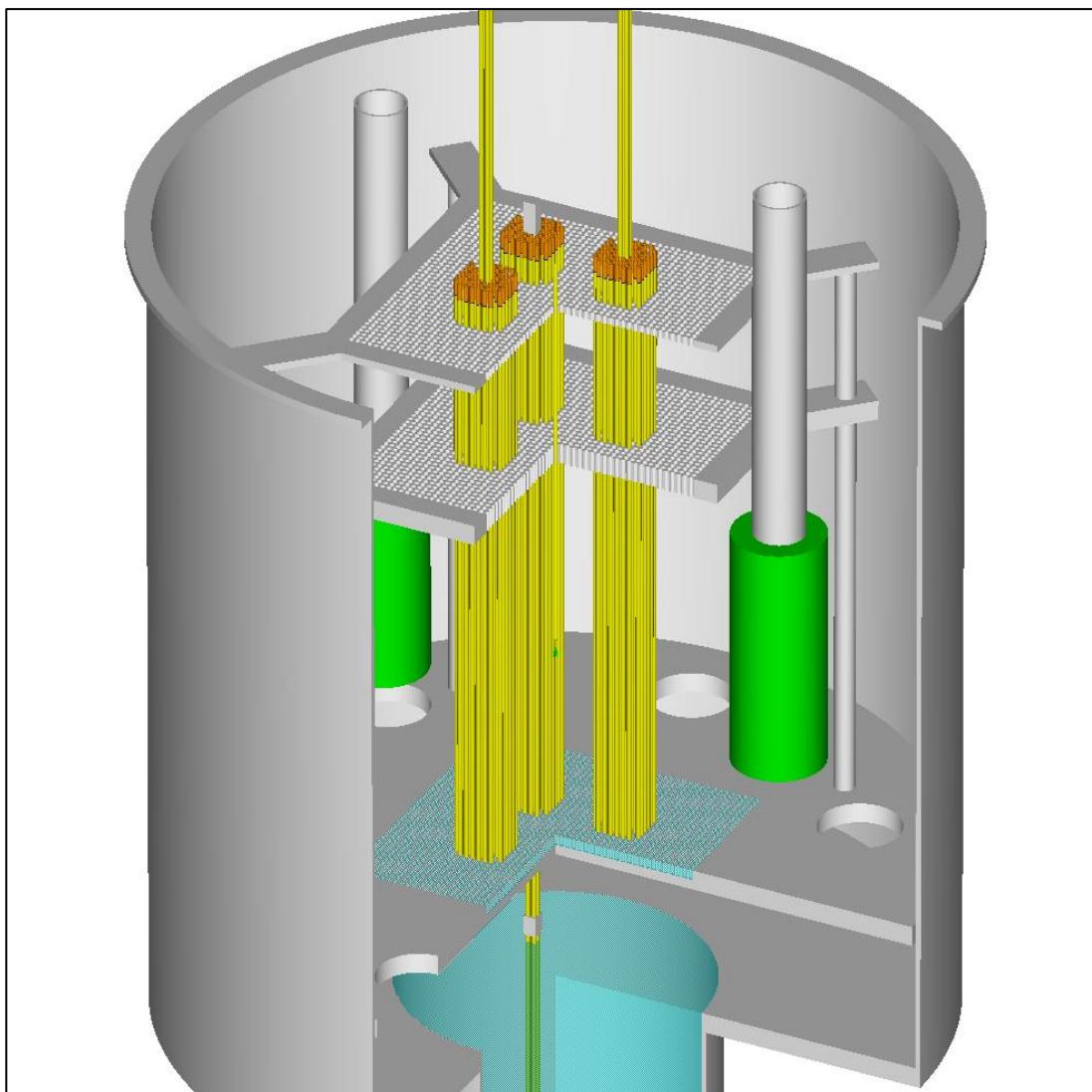
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 168

Safety Elements: Up

Control Element: Down

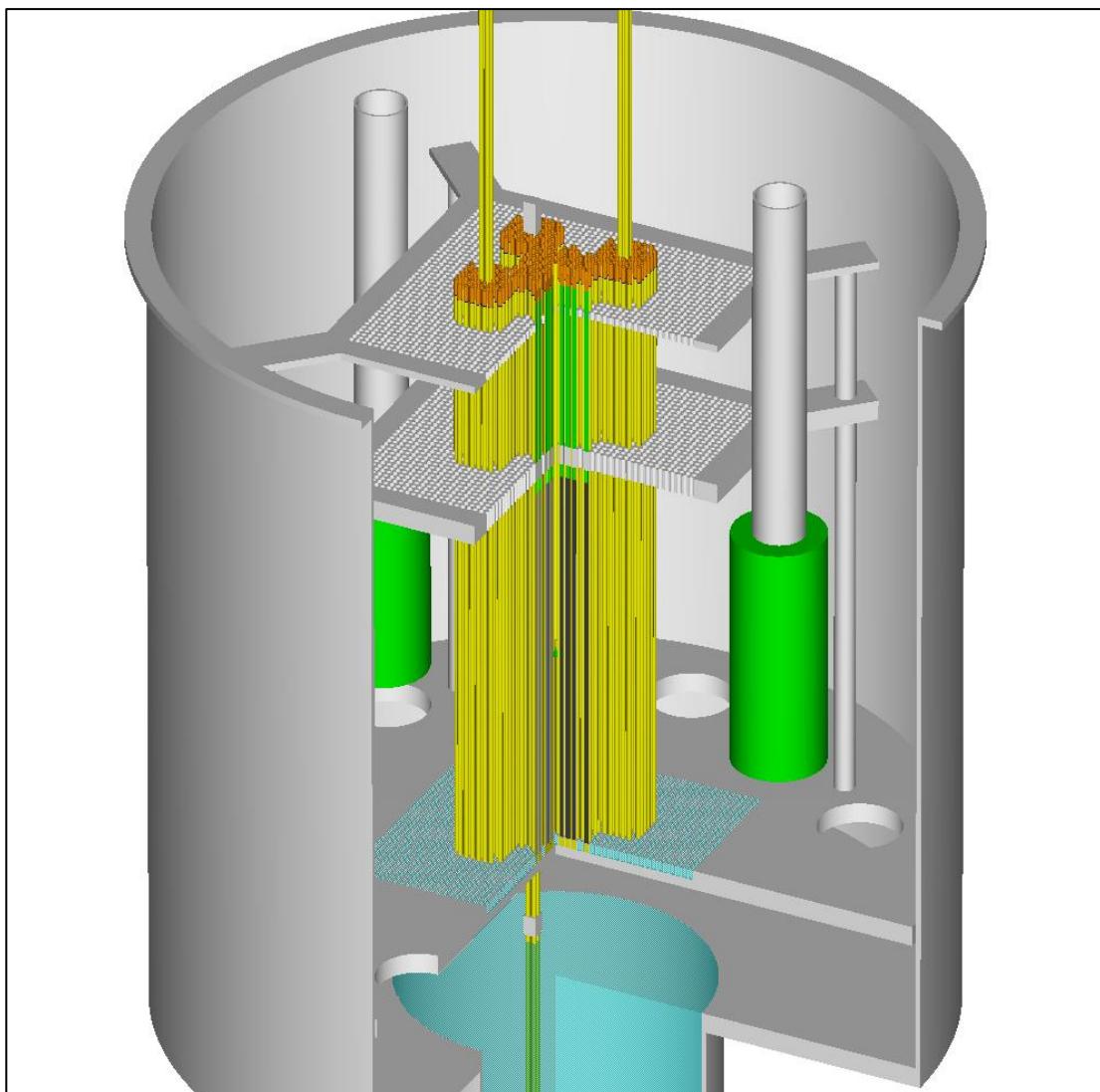
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 318

Safety Elements: Up

Control Element: Down

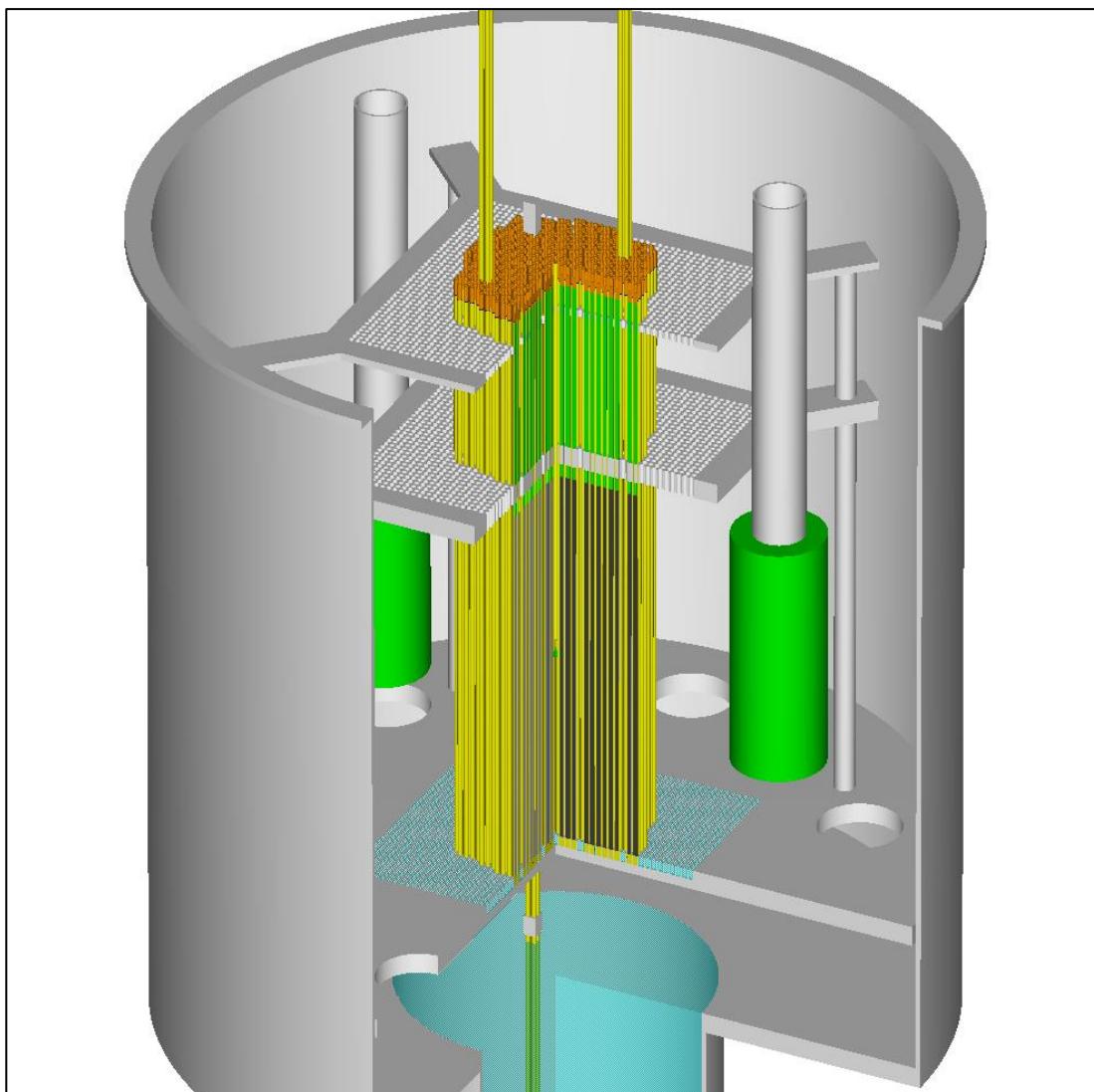
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 548

Safety Elements: Up

Control Element: Down

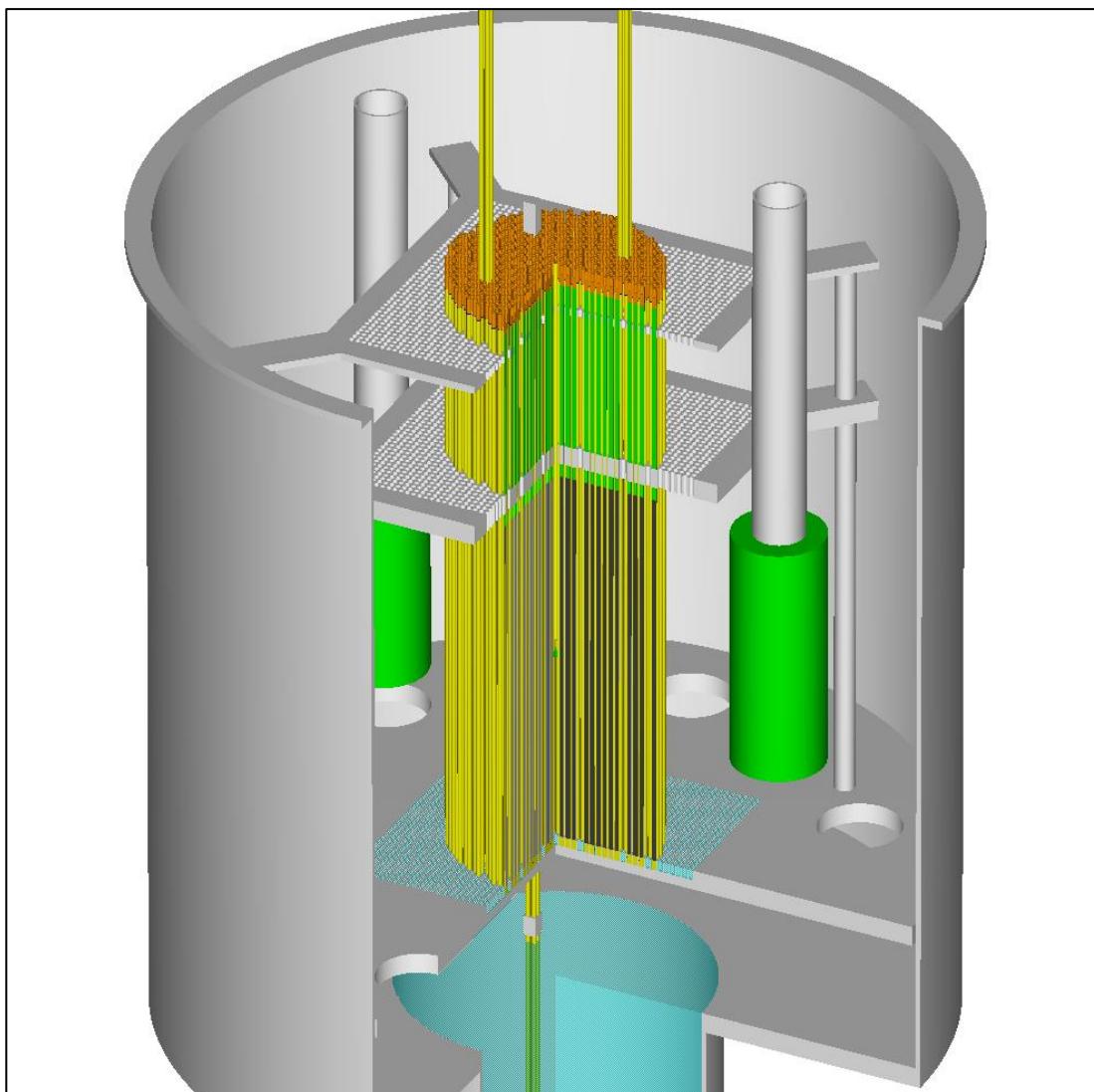
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 740

Safety Elements: Up

Control Element: Down

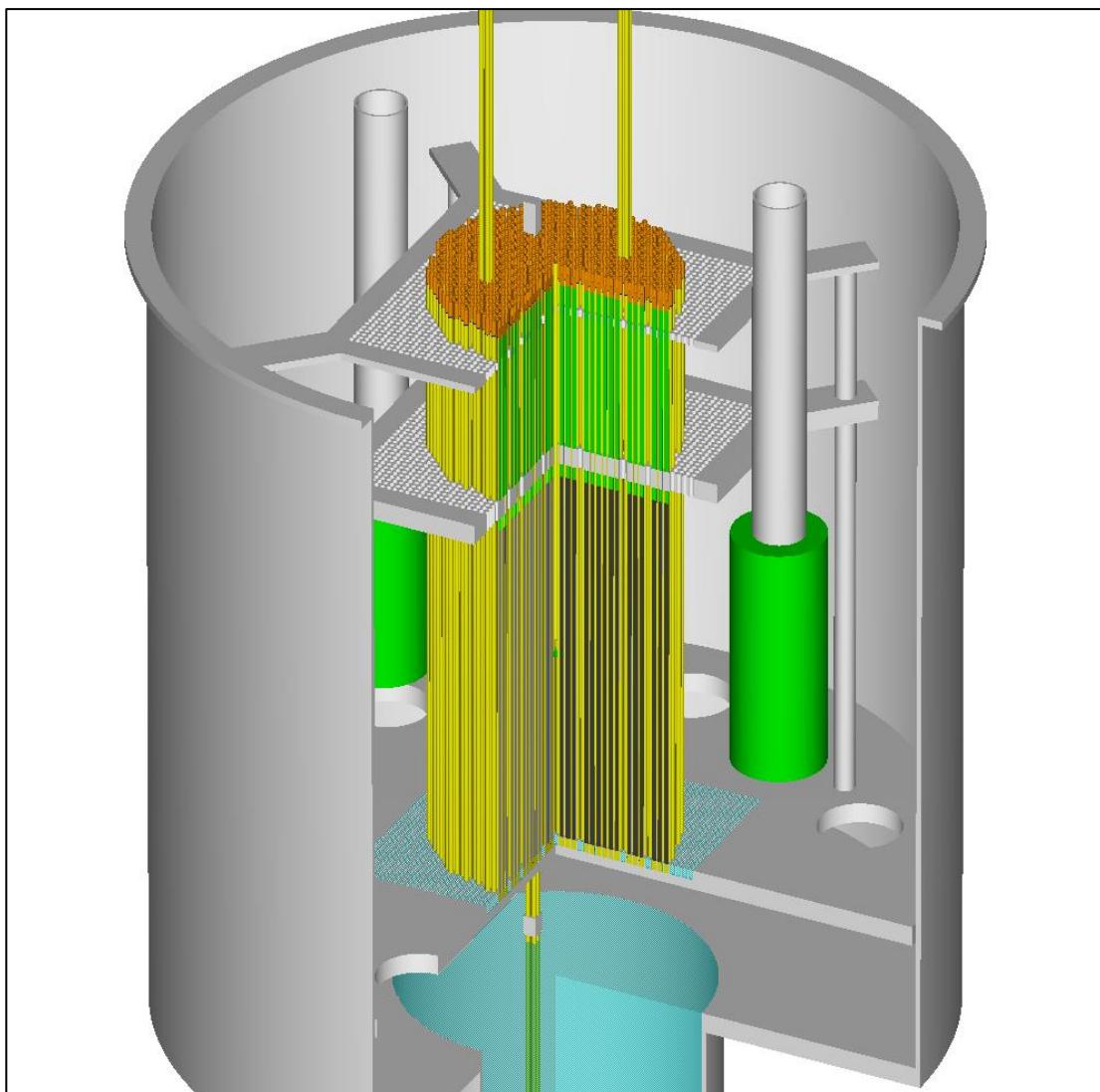
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 956

Safety Elements: Up

Control Element: Down

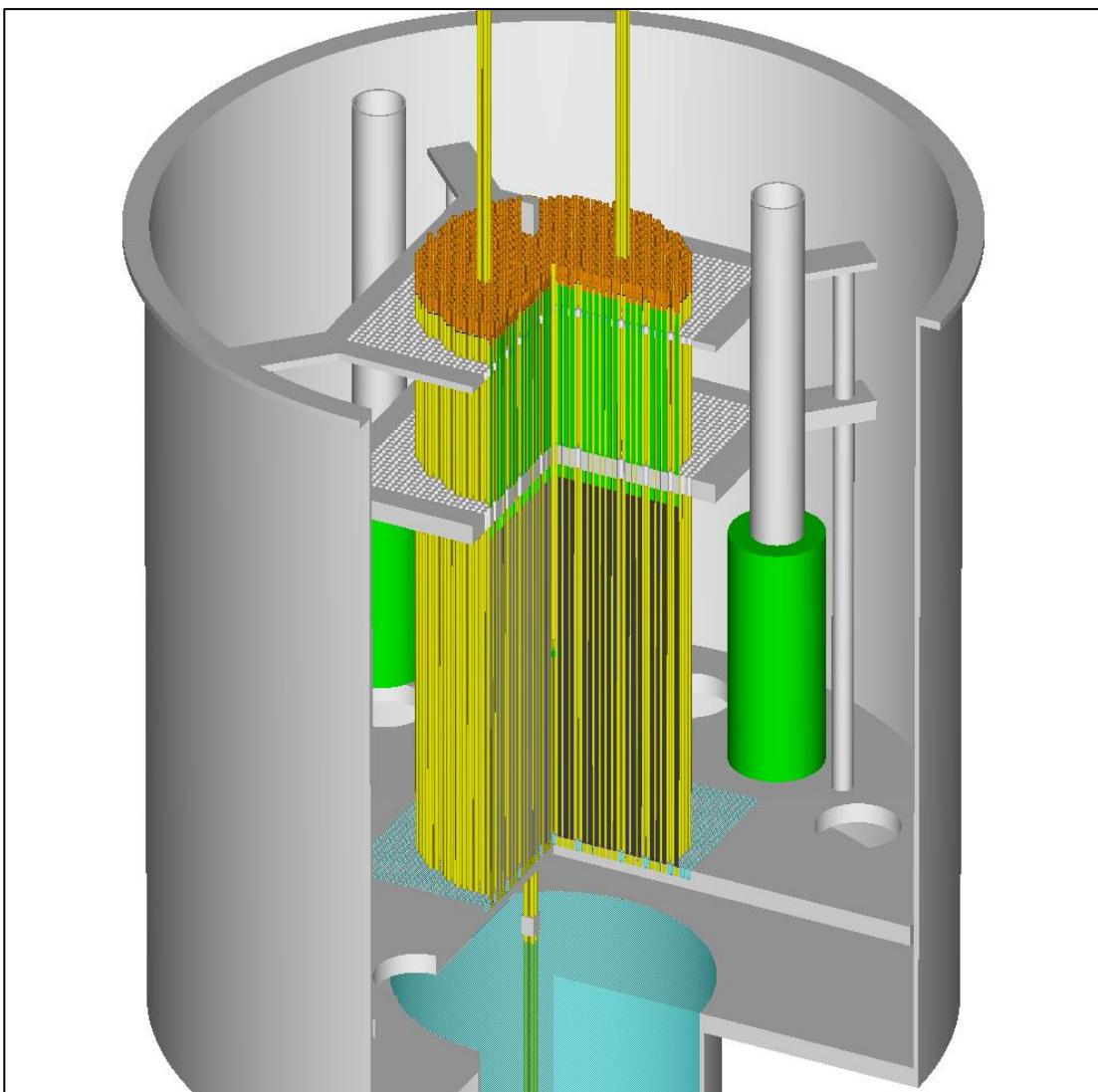
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Add fuel



Fuel: 1136

Safety Elements: Up

Control Element: Down

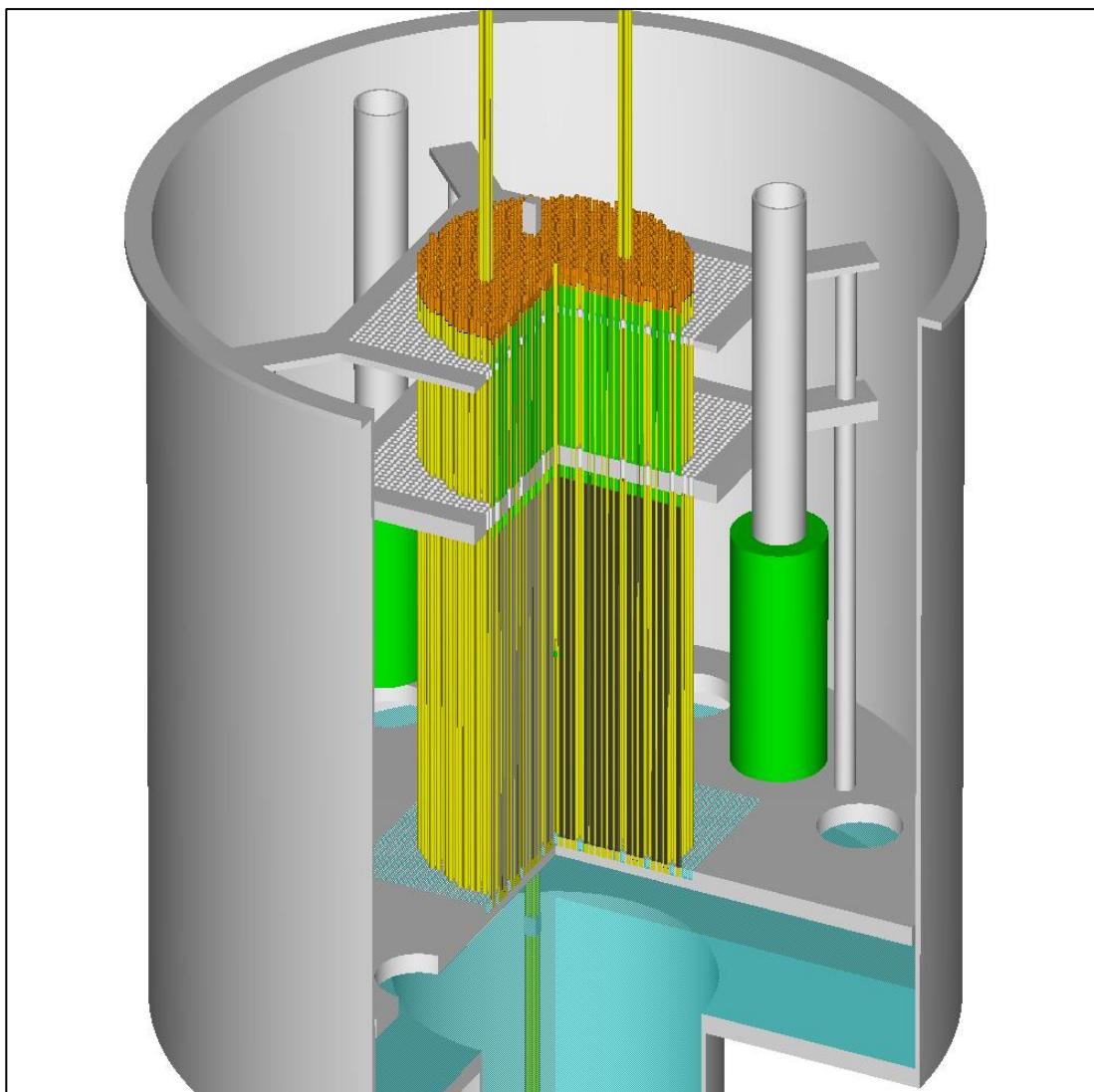
Core Tank: Empty

Personnel: Allowed

In this condition, the assembly is “operating” and a qualified operator must be at the controls at all times. Entry into the reactor room is allowed. Fuel may be added to or removed from the array.



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

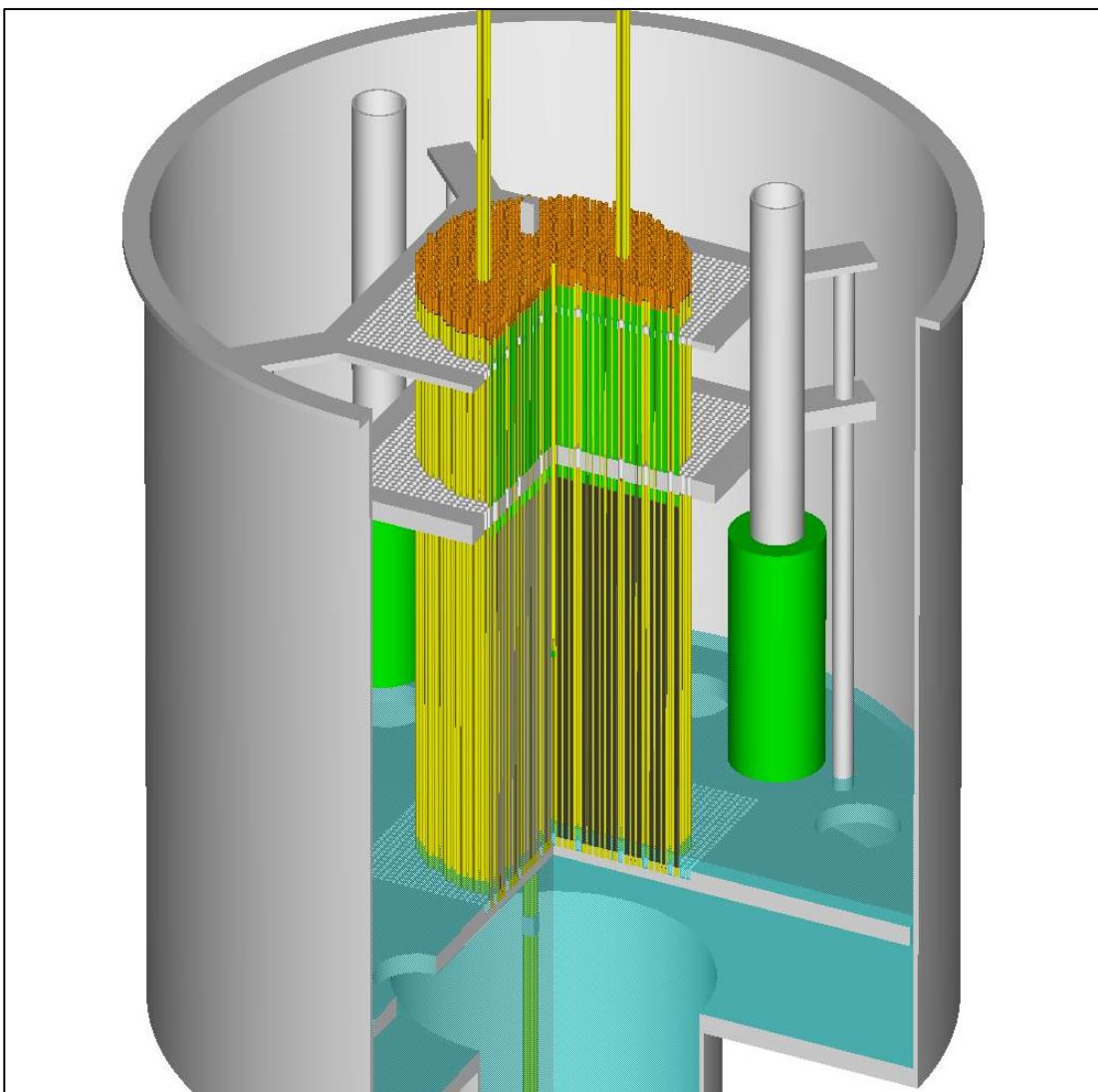
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

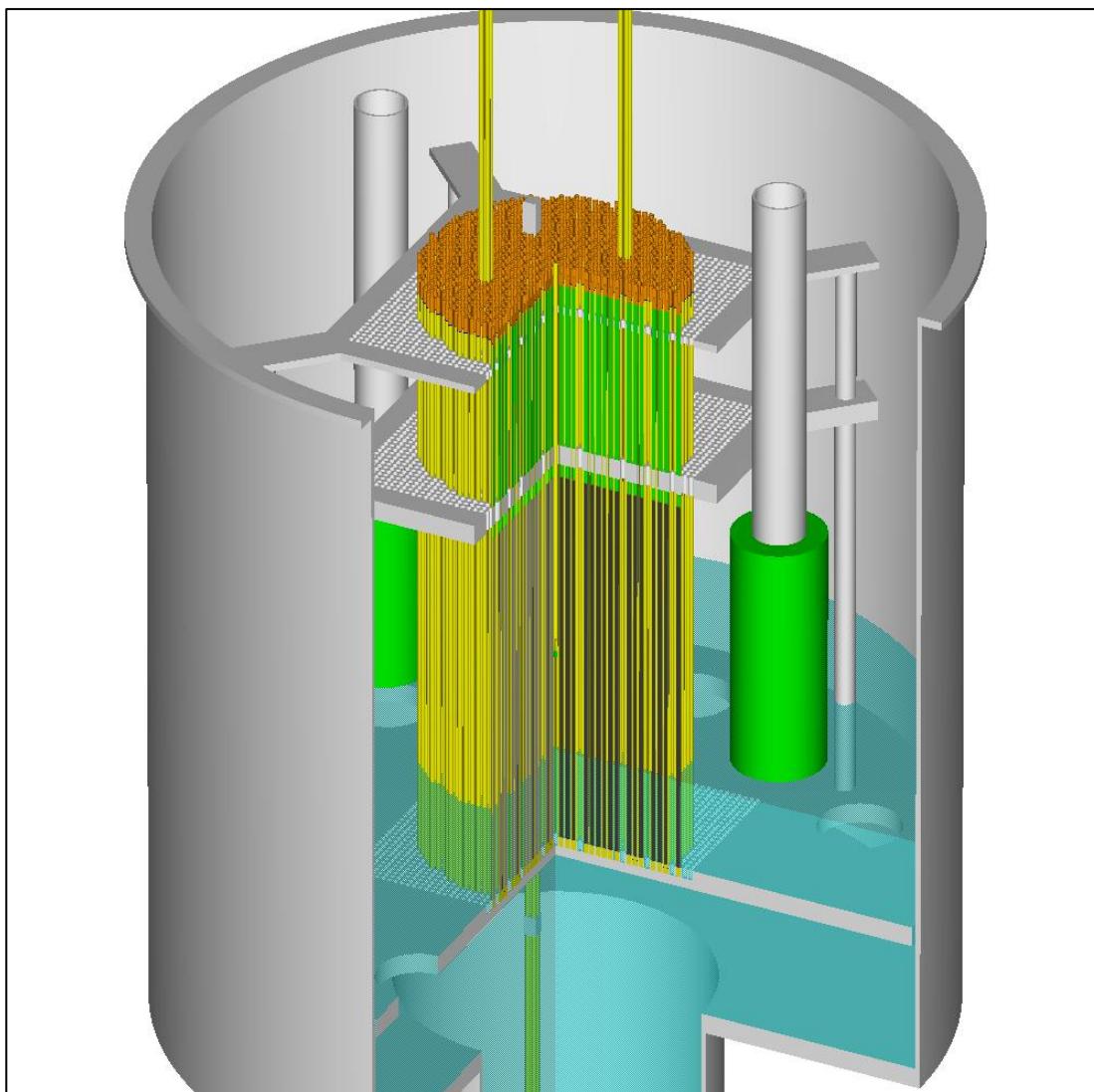
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

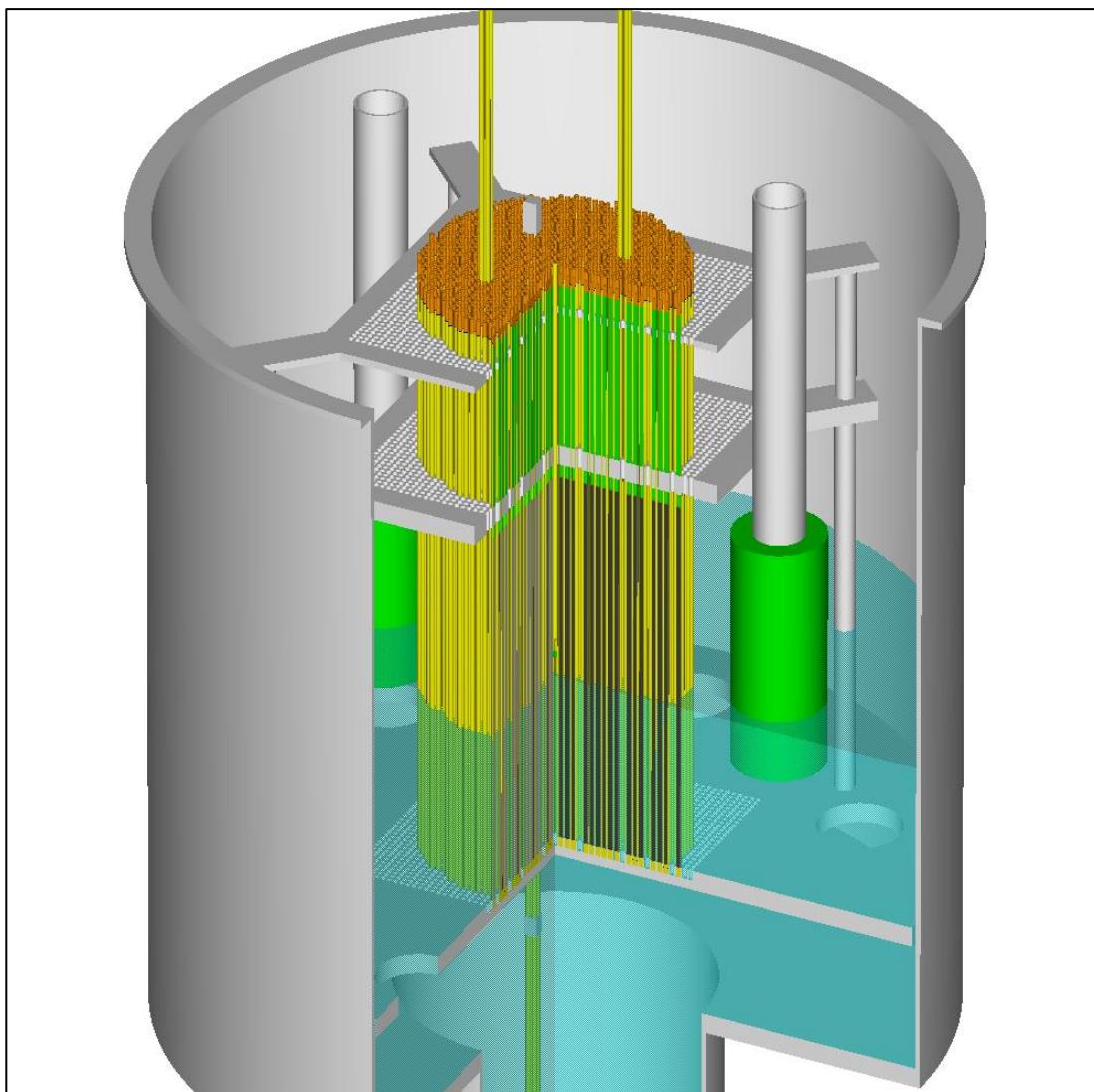
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

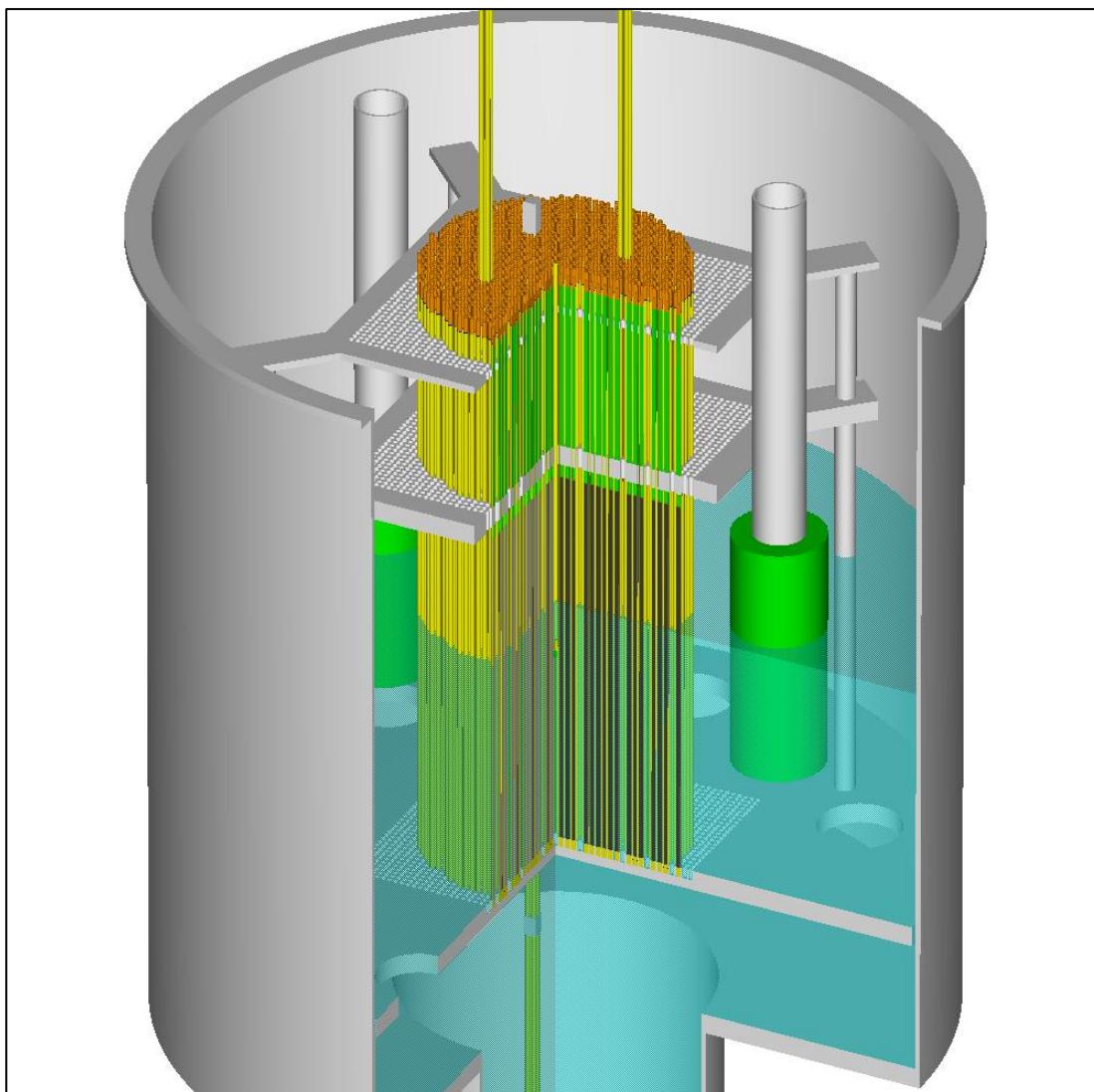
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

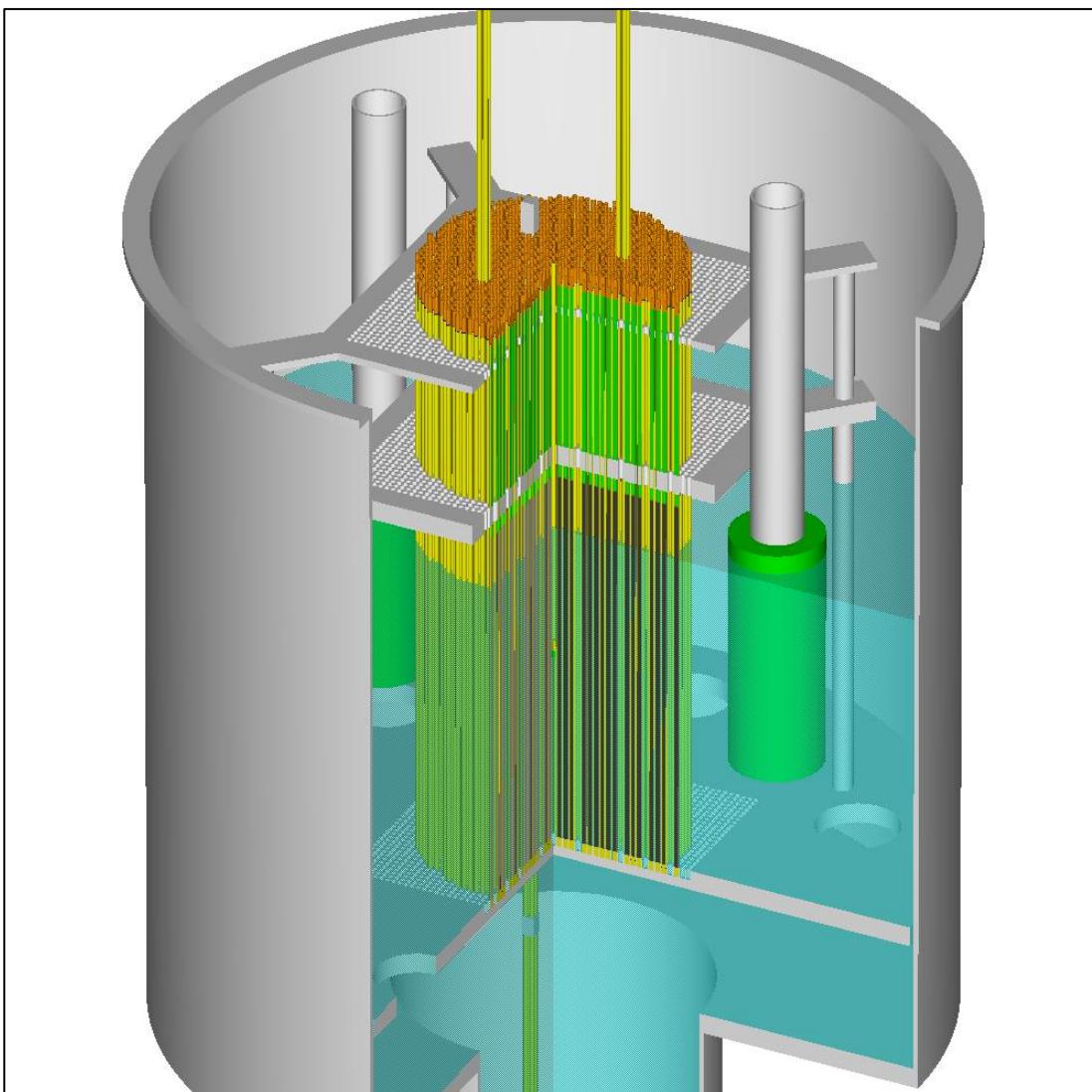
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

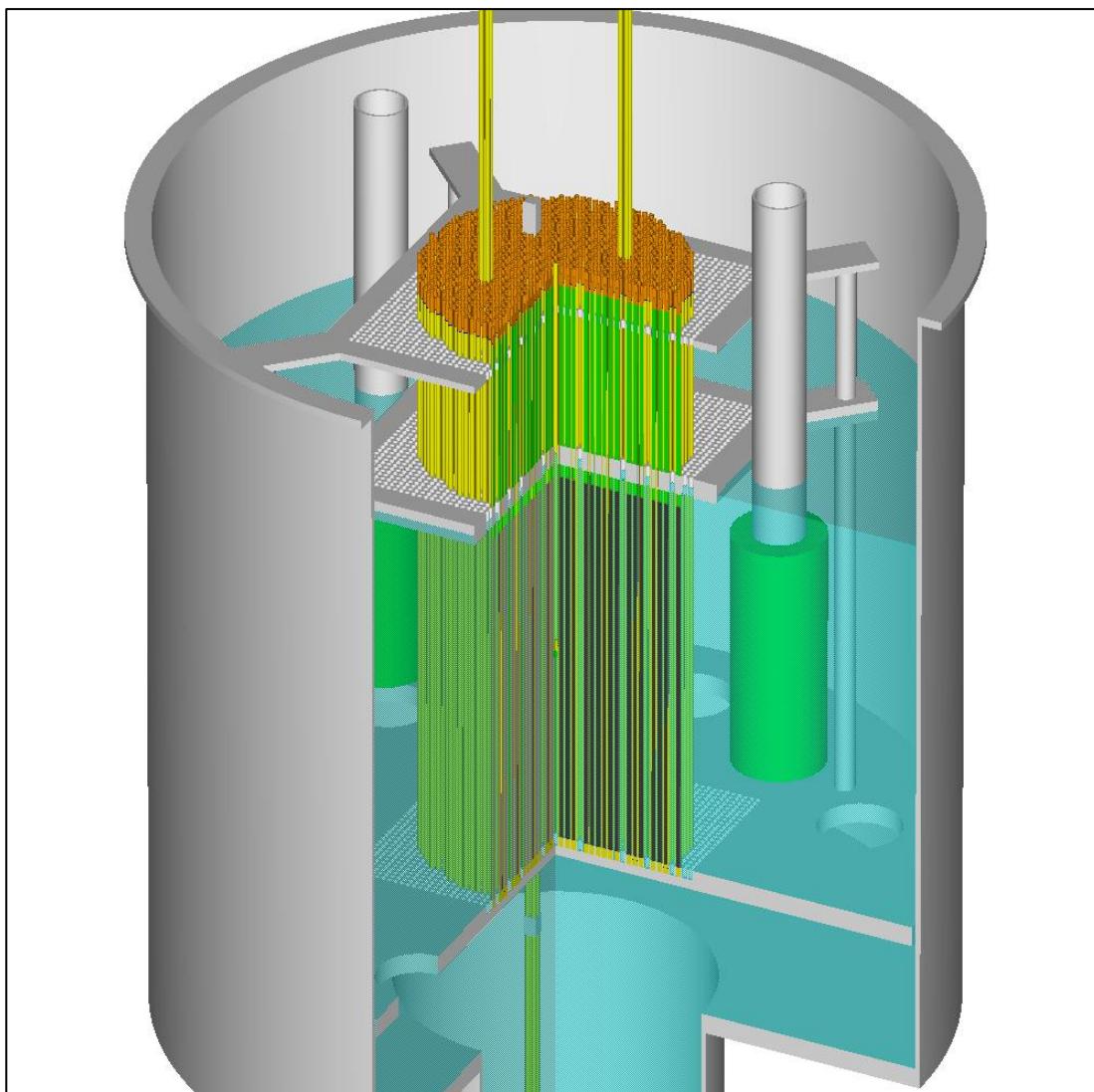
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

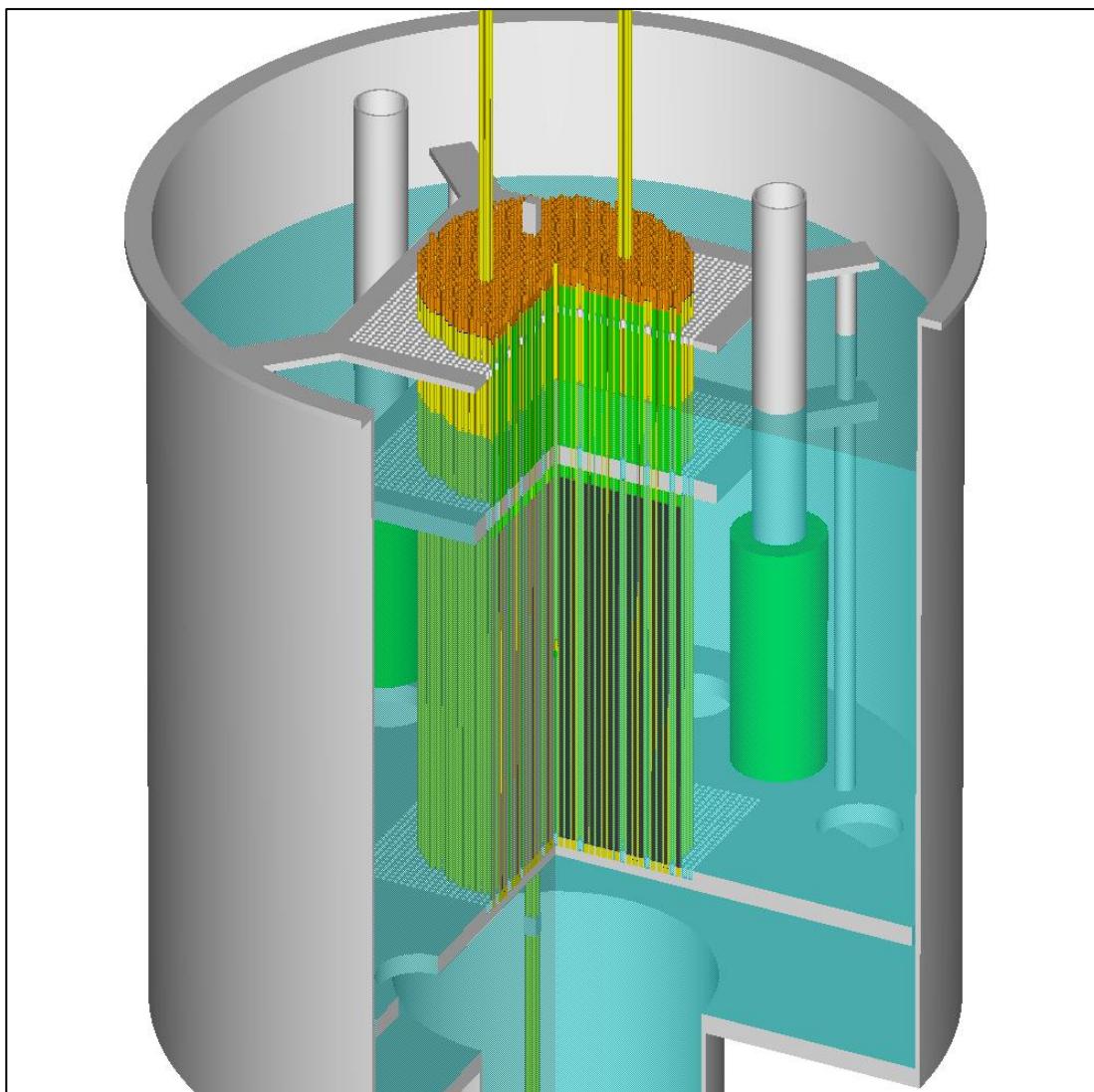
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



Fill the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

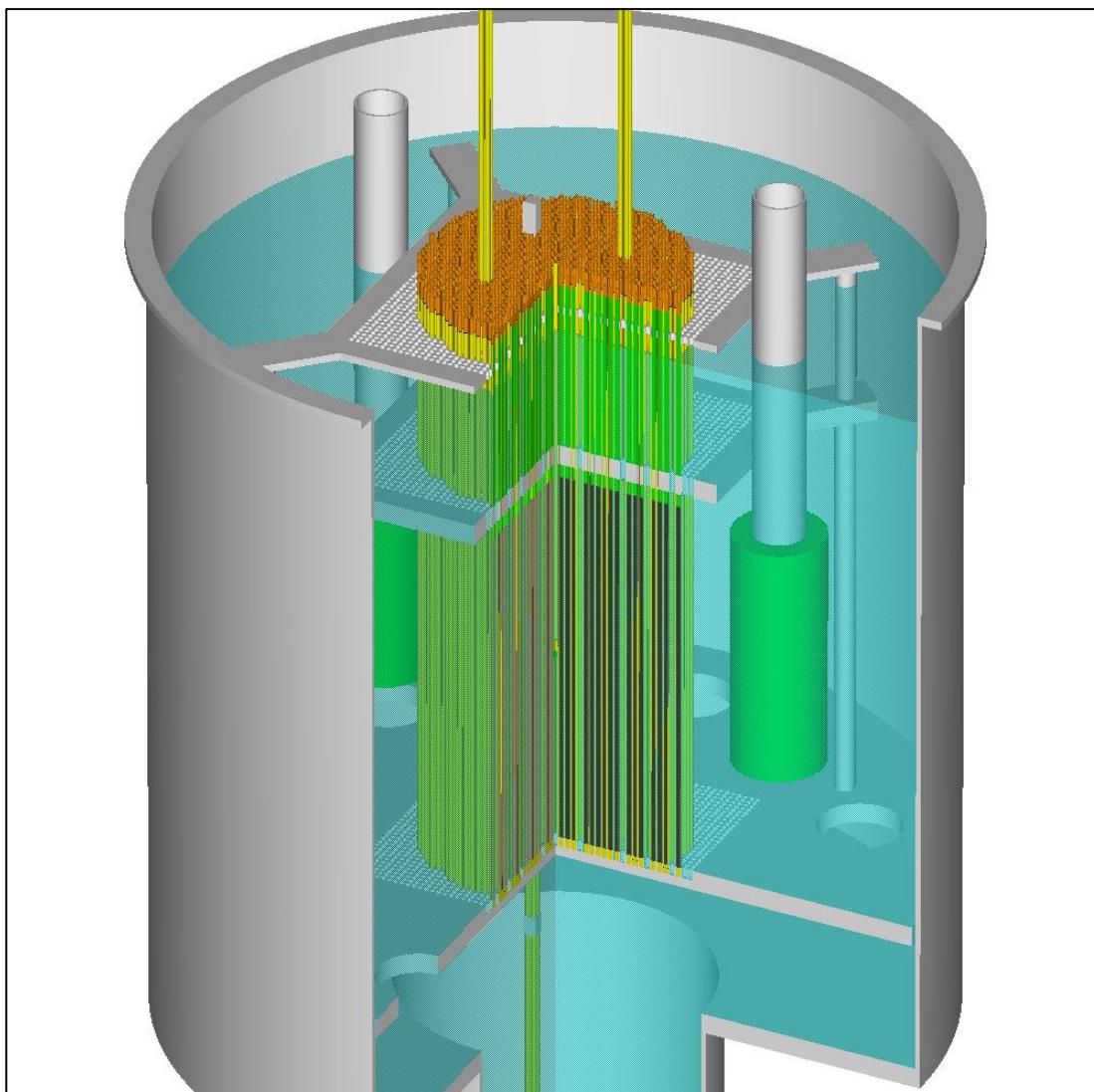
Core Tank: Filling

Personnel: Excluded

**Filling the core tank requires
about 15 minutes.**



The core tank is full



Fuel: 1136

Safety Elements: Up

Control Element: Down

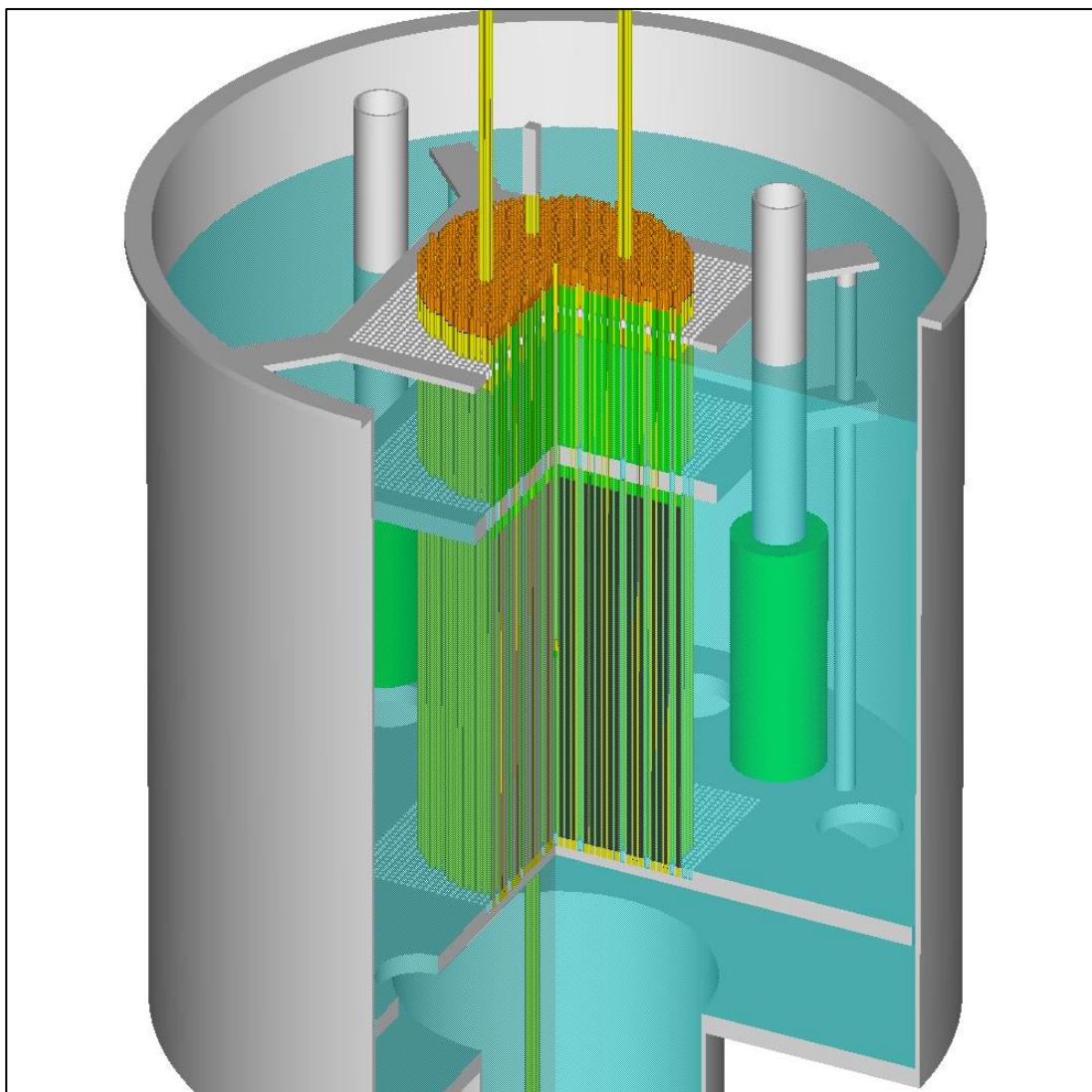
Core Tank: Full

Personnel: Excluded

At this point, the “fast” fill pump is disabled by an interlock and the recirculation pump is turned on. Moderator enters under the water’s surface and drains to the dump tank through a stand pipe.



Raise the control element



Fuel: 1136

Safety Elements: Up

Control Element: Raising

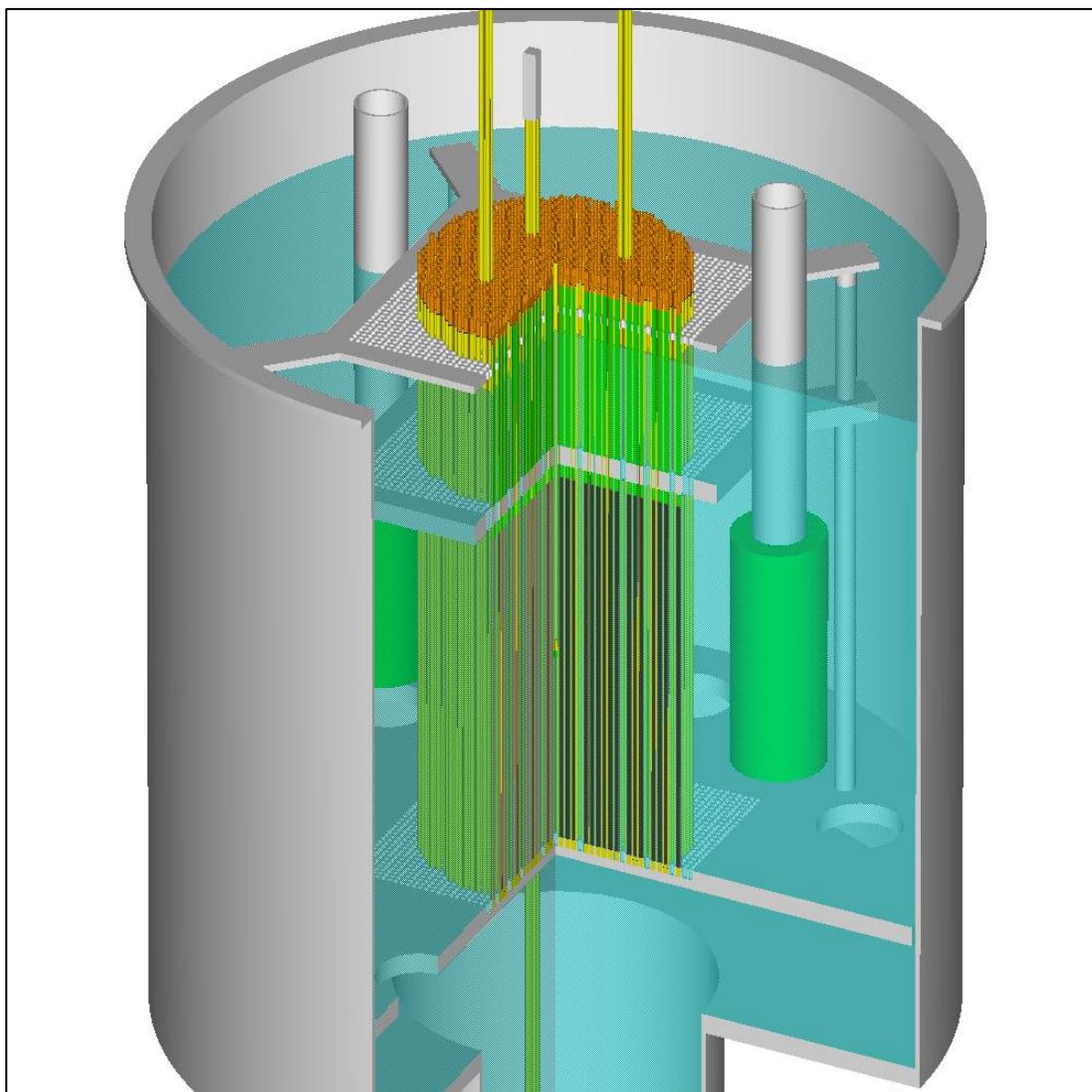
Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.



Raise the control element



Fuel: 1136

Safety Elements: Up

Control Element: Raising

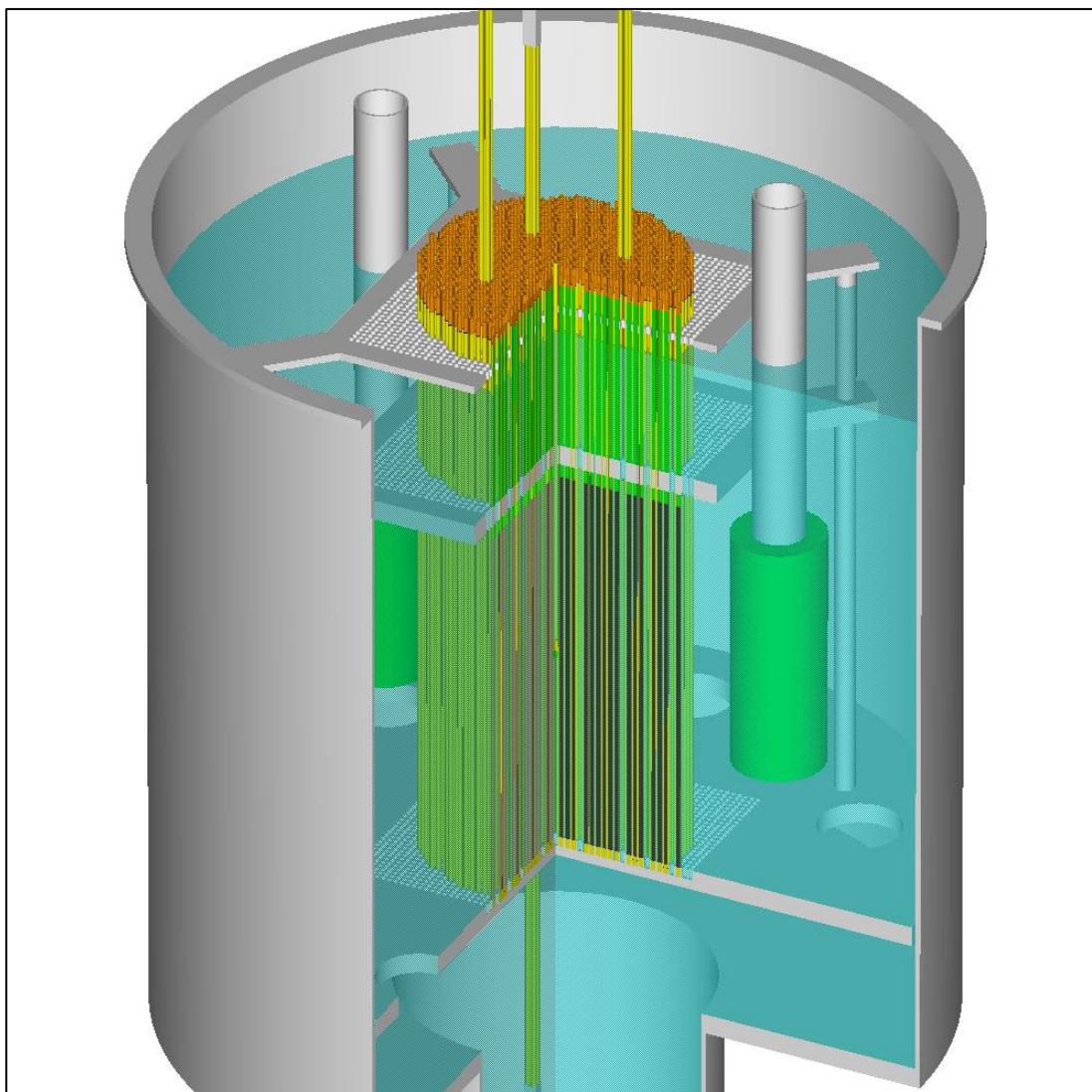
Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.



Raise the control element



Fuel: 1136

Safety Elements: Up

Control Element: Raising

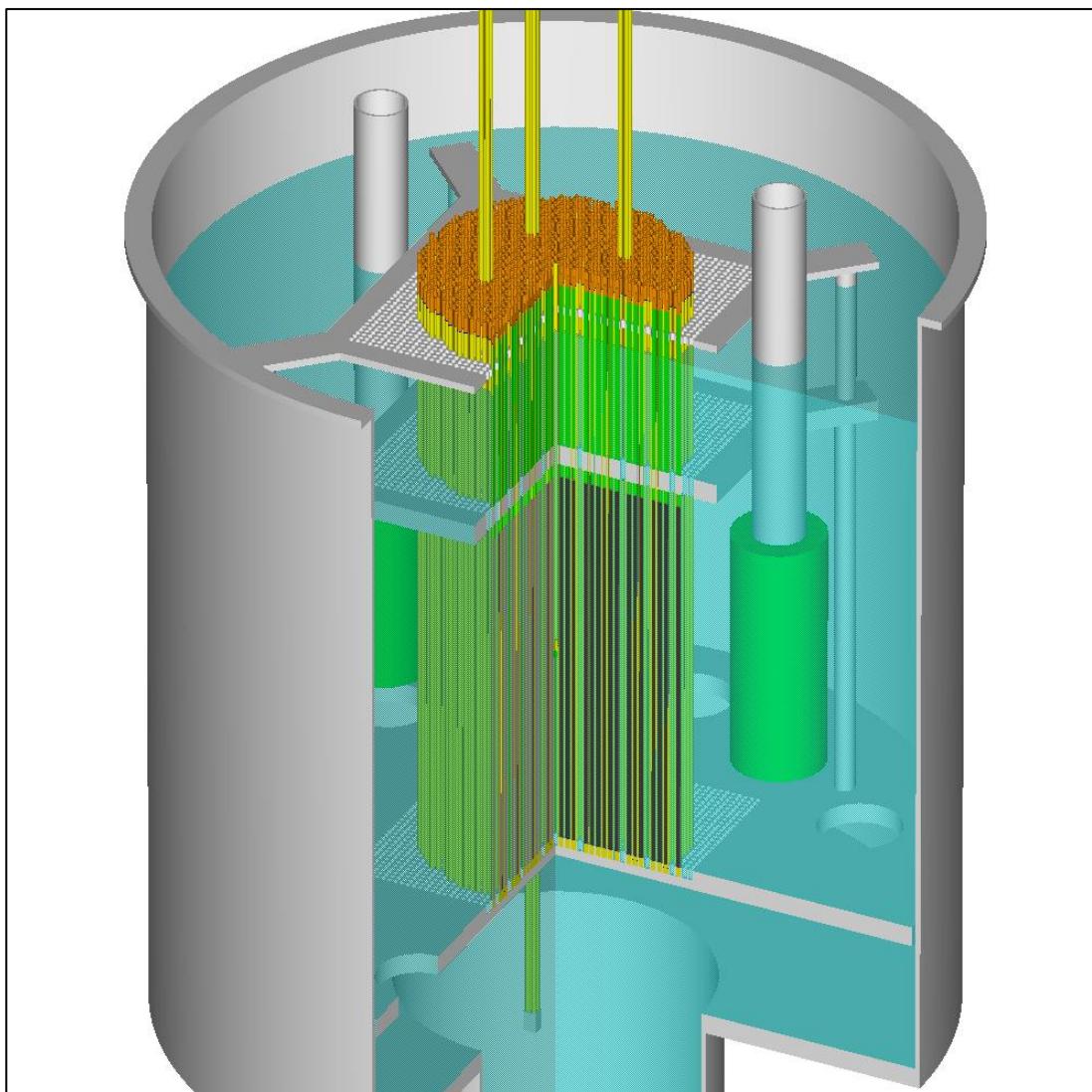
Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.



Raise the control element



Fuel: 1136

Safety Elements: Up

Control Element: Raising

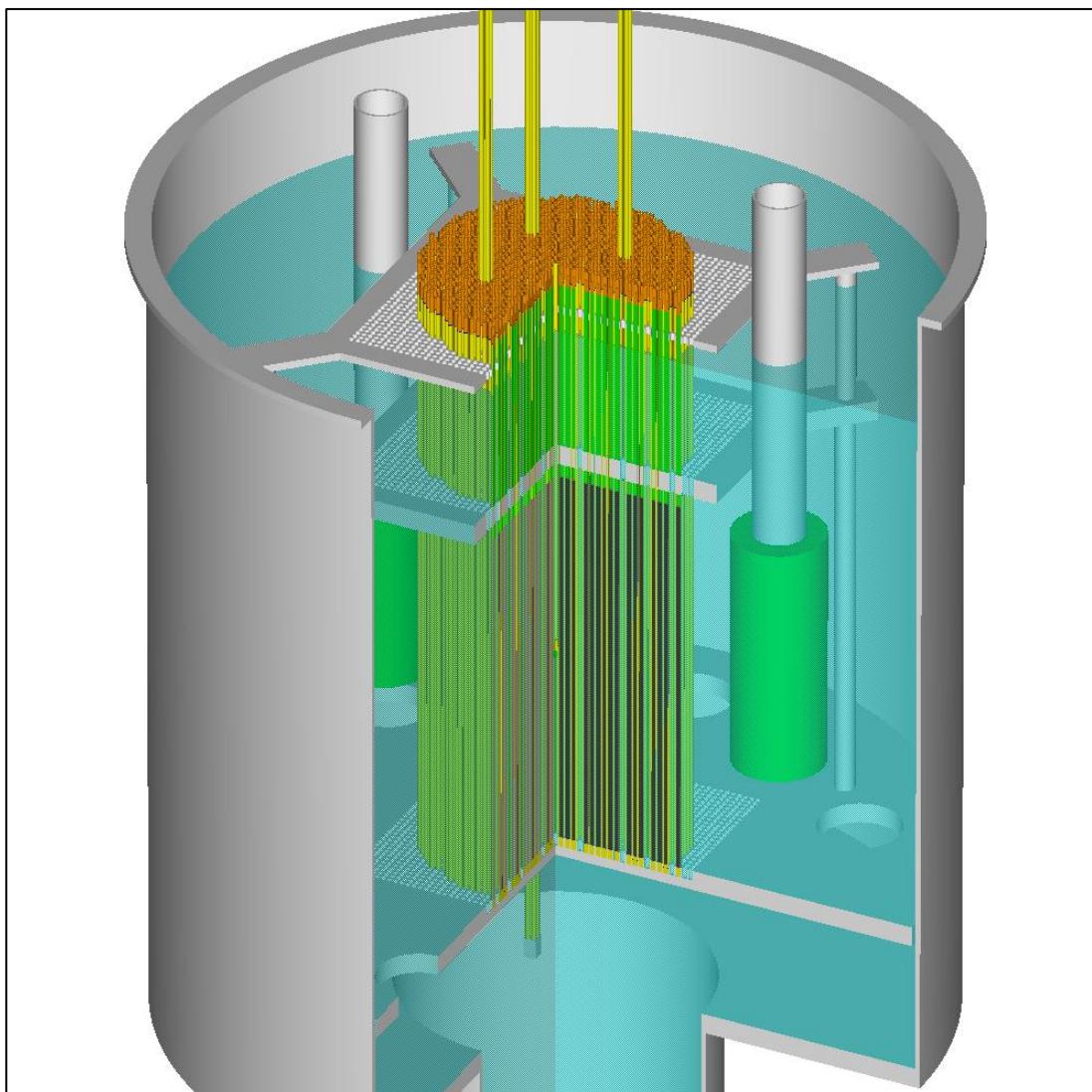
Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.



Raise the control element



Fuel: 1136

Safety Elements: Up

Control Element: Raising

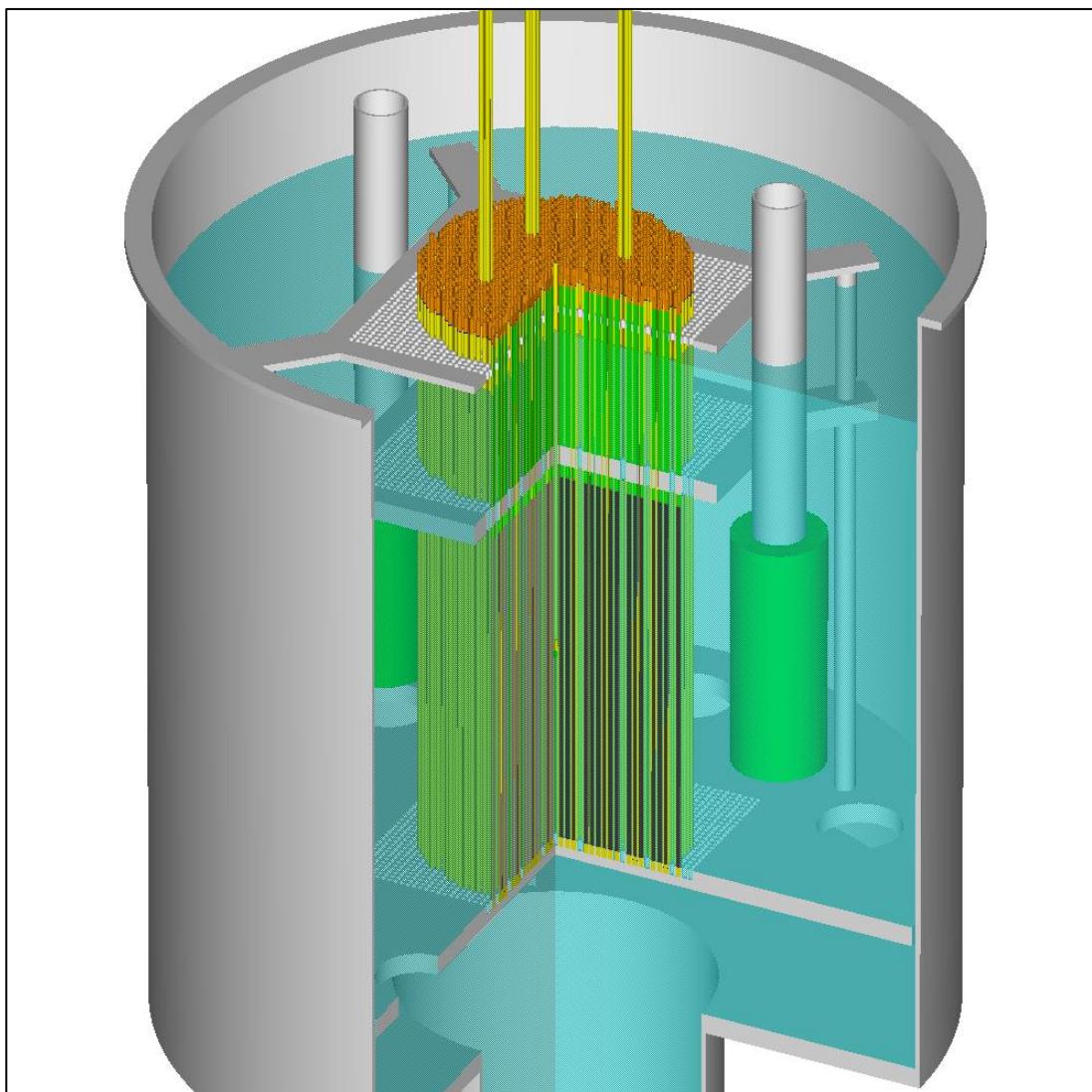
Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.



Raise the control element



Fuel: 1136

Safety Elements: Up

Control Element: Raising

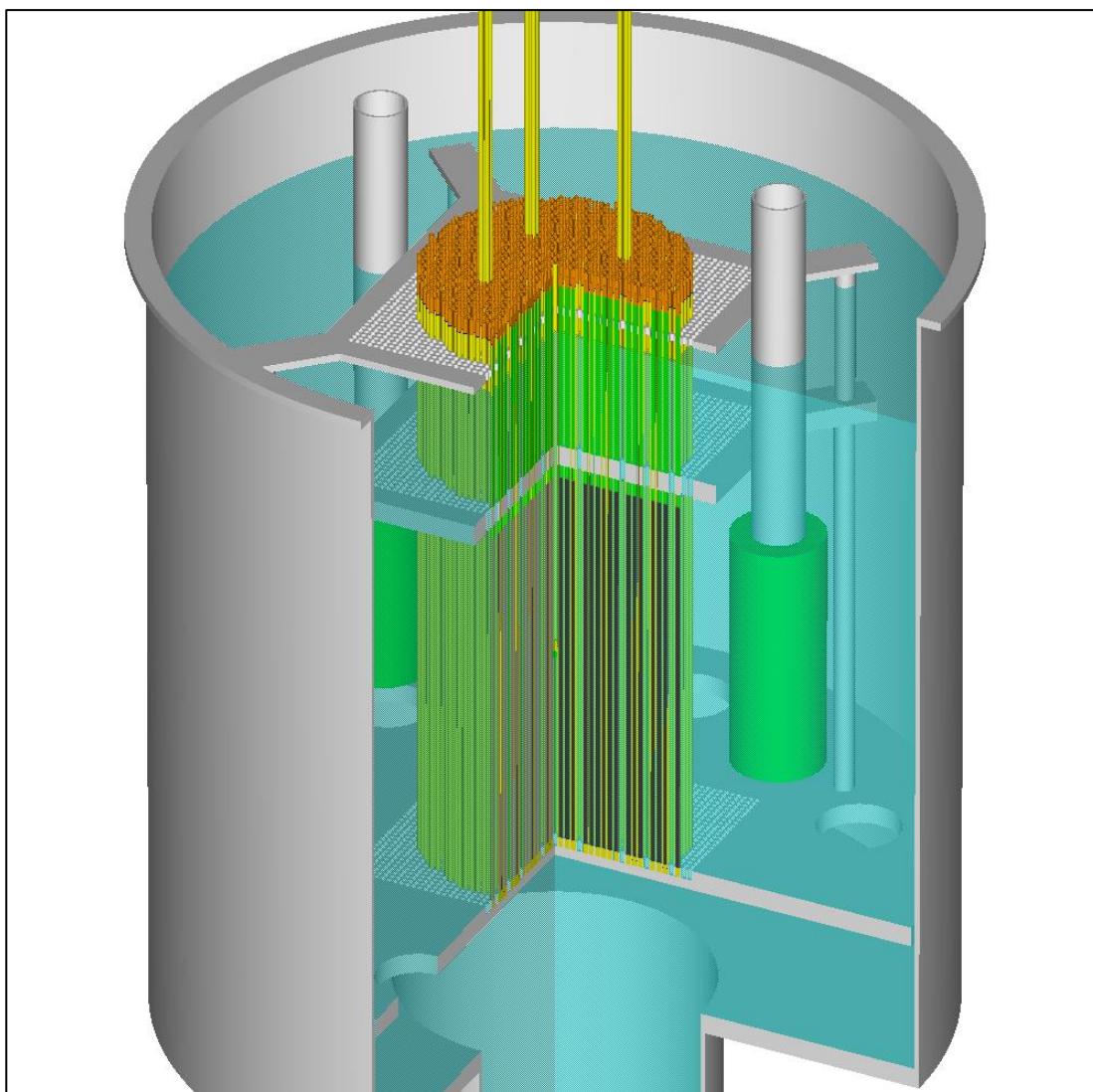
Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.



The assembly reaches its most reactive state



Fuel: 1136

Safety Elements: Up

Control Element: Up

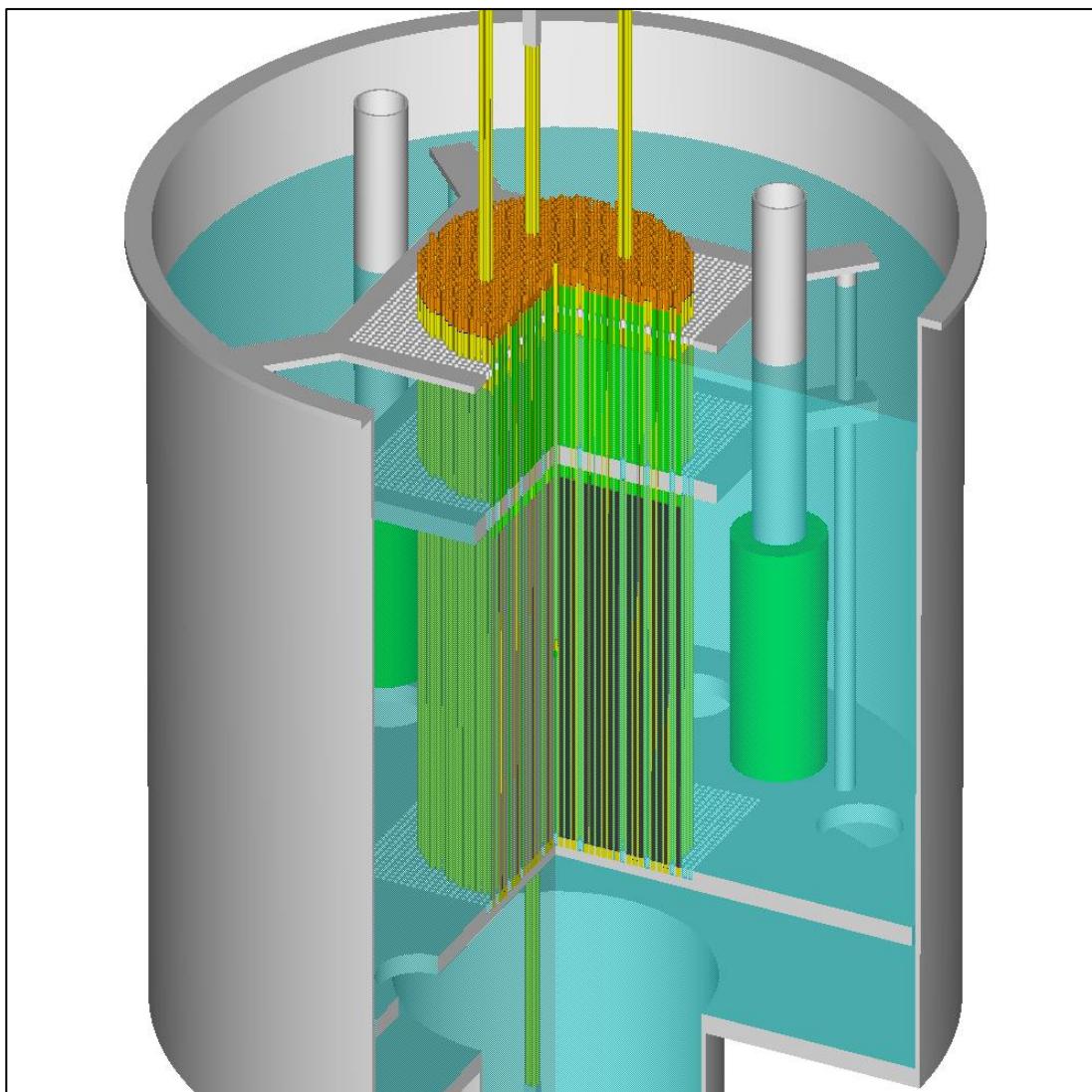
Core Tank: Full

Personnel: Excluded

With all control and safety elements up and full reflection (>6 in. of water on all sides), this is the highest reactivity state of the assembly. Multiplication measurements are made in this configuration.



Lower the control element



Fuel: 1136

Safety Elements: Up

Control Element: Lowering

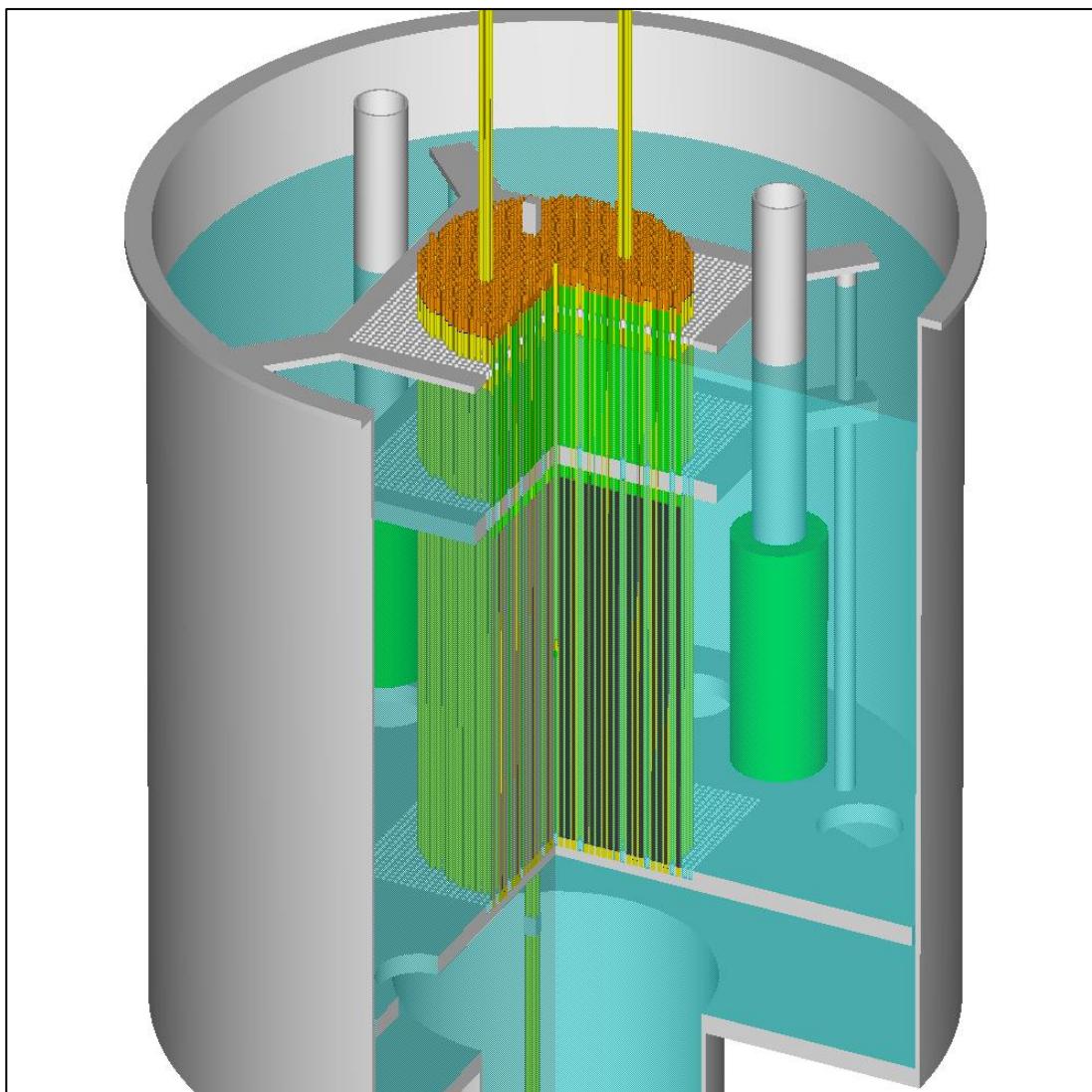
Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to lower the control element.



Lower the control element



Fuel: 1136

Safety Elements: Up

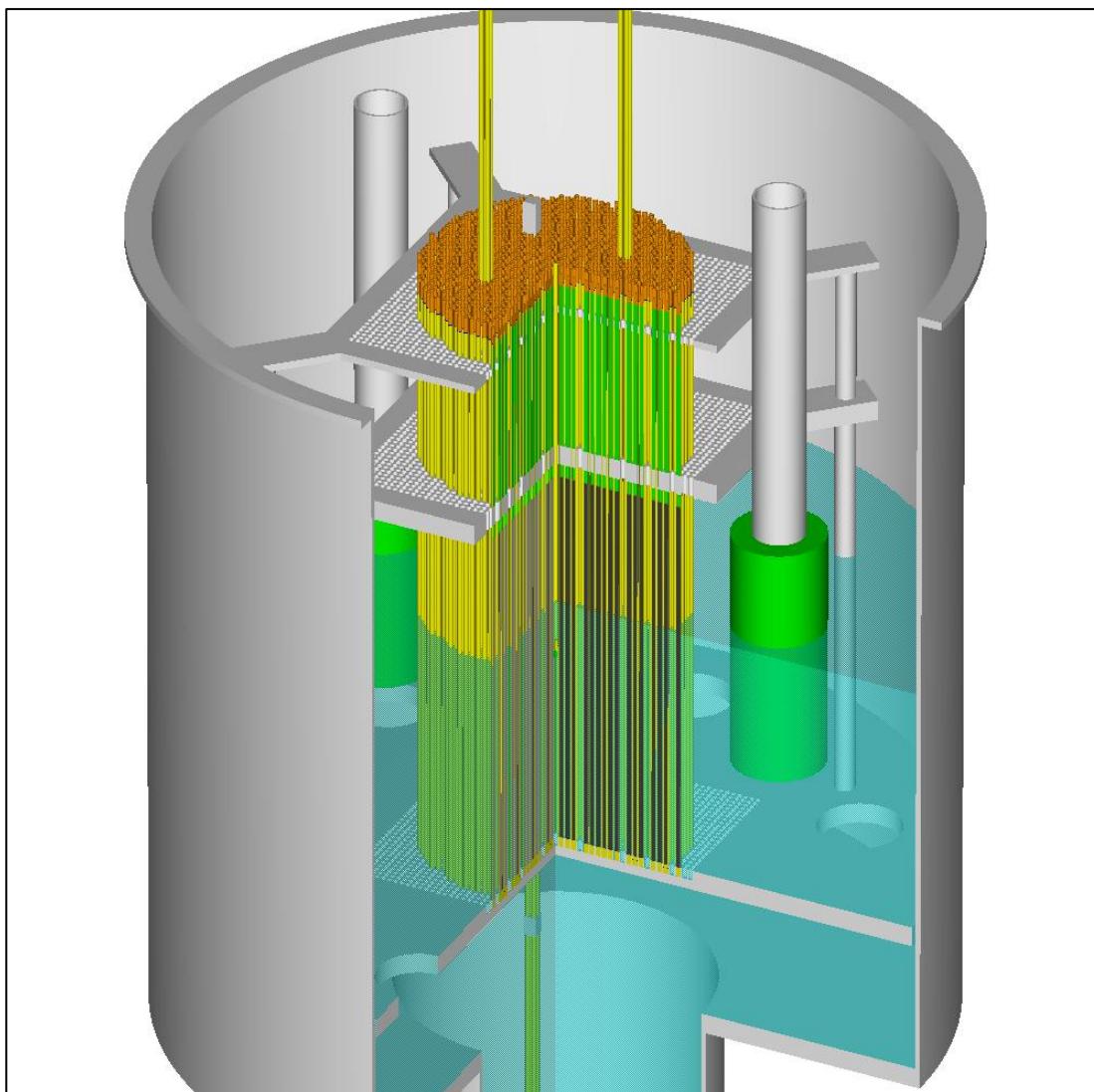
Control Element: Down

Core Tank: Full

Personnel: Excluded



Drain the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

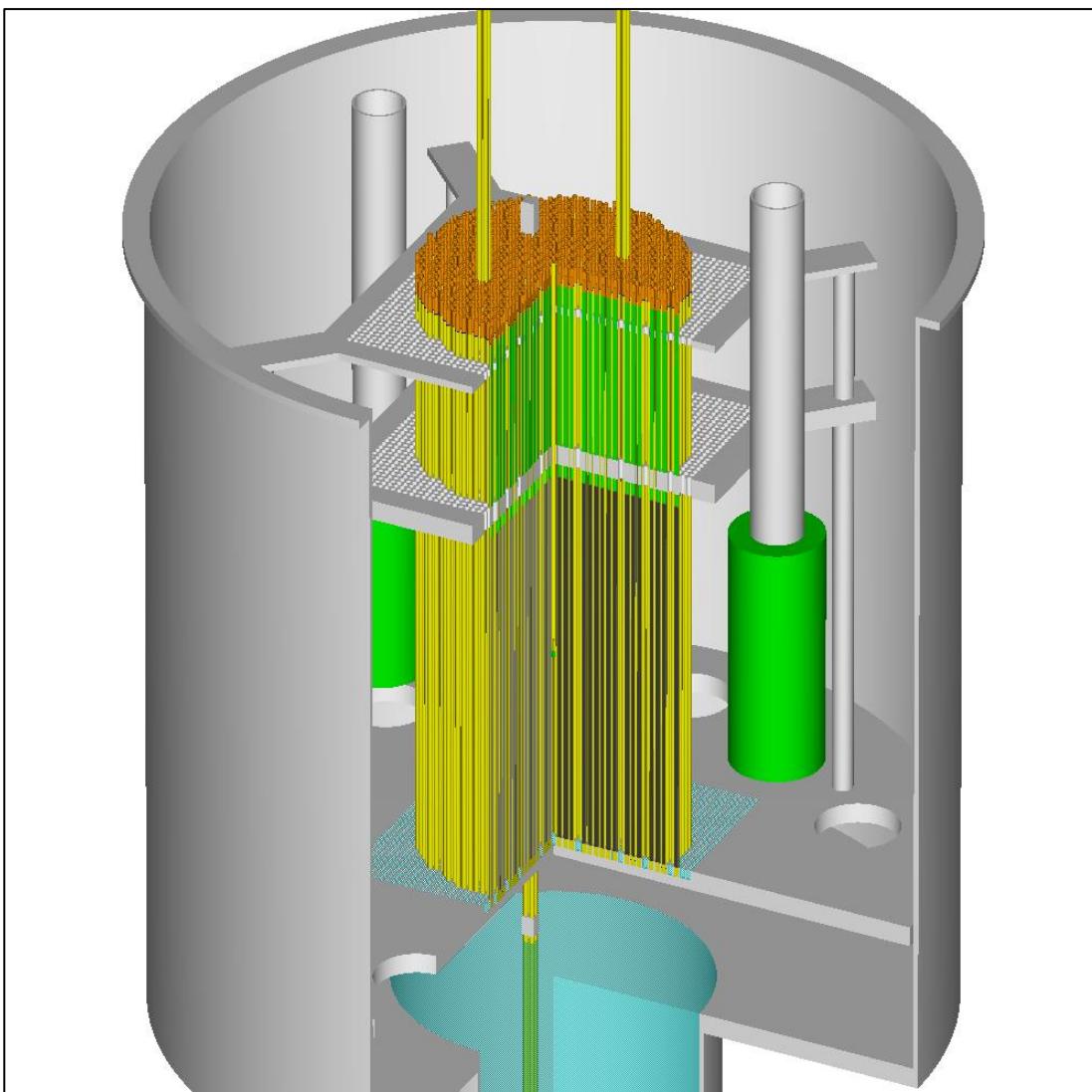
Core Tank: Draining

Personnel: Excluded

**Draining the core tank requires
only a few seconds.**



Drain the core tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

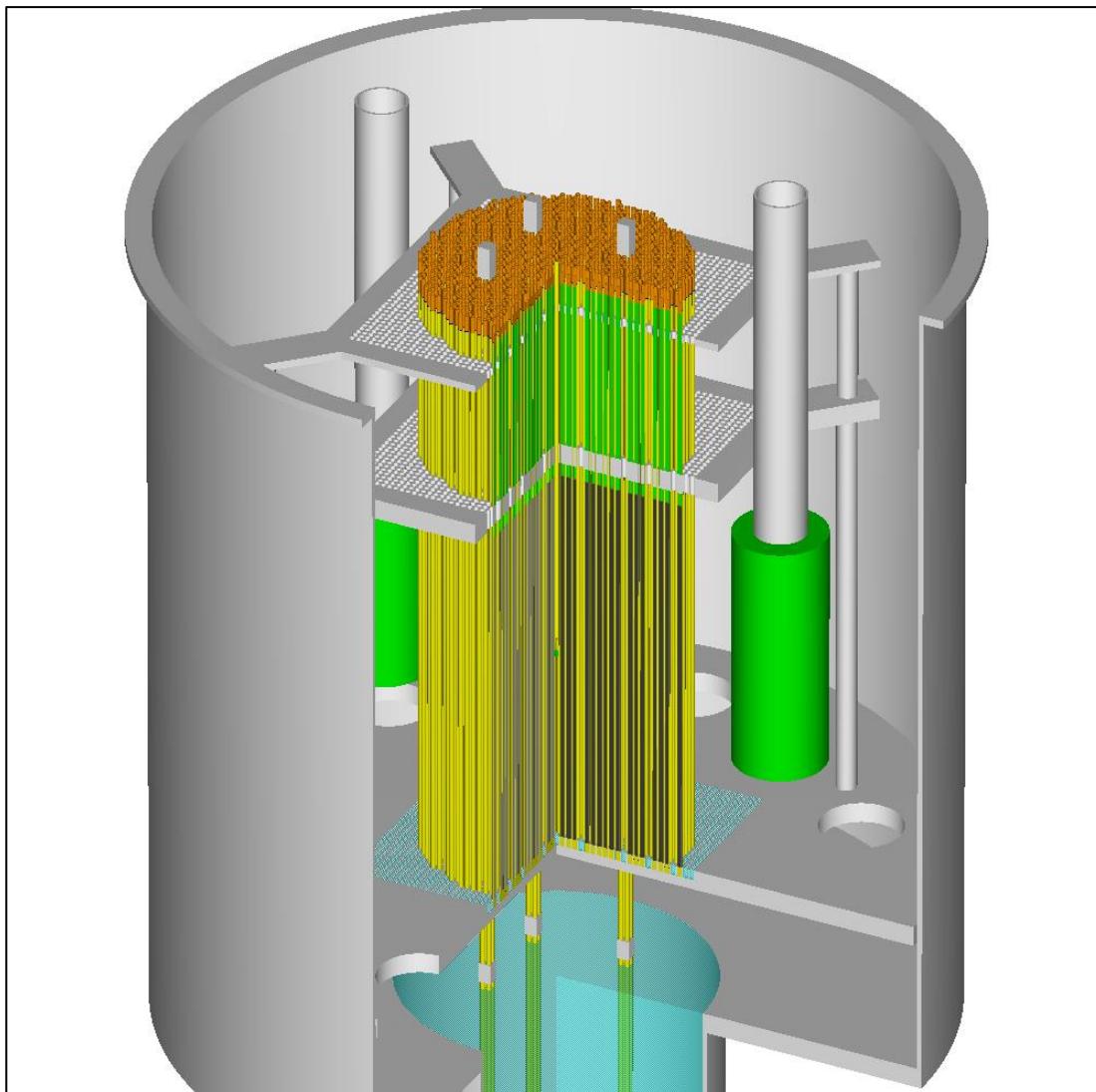
Core Tank: Empty

Personnel: Allowed

**Now we are back to a condition
where fuel may be added to or
removed from the array.**



The shut-down configuration of the assembly



Fuel: 1136

Safety Elements: Down

Control Element: Down

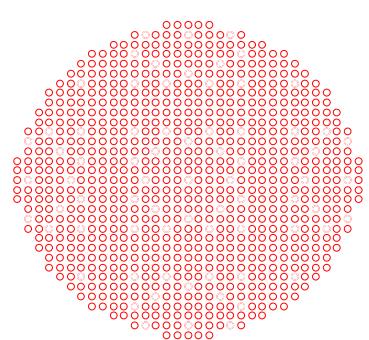
Core Tank: Empty

Personnel: Allowed

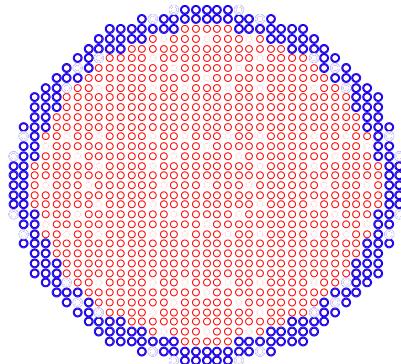
In this condition, the assembly is “shut down.” Entry into the reactor room is allowed. The control system need not be manned. Fuel may be removed or added but a “new” configuration may not be built.



Core configurations during the first approach-to-critical experiment (1)



740



956

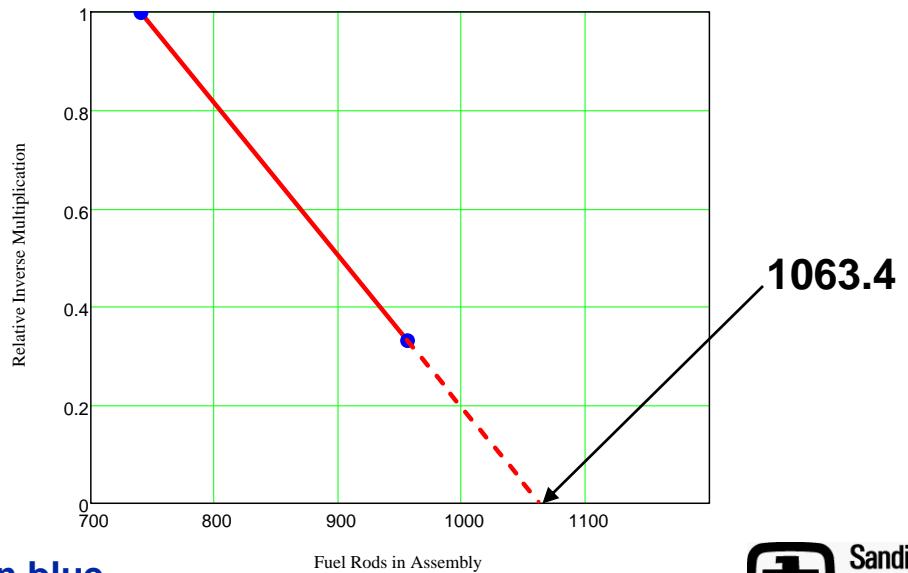
The first two arrays have $k_{\text{eff}} \sim 0.9$ and $k_{\text{eff}} \sim 0.95$ (calculated)

$$\text{Multiplication: } M = \frac{1}{1 - k_{\text{eff}}}$$

$$\frac{1}{M} = 1 - k_{\text{eff}}$$

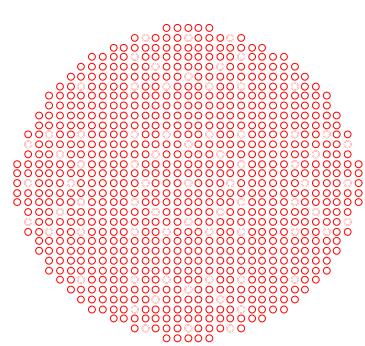
Project the two inverse multiplication measurements to zero and add half the increment to get the next array – in this case 1009 elements

The incremental fuel elements are shown in blue

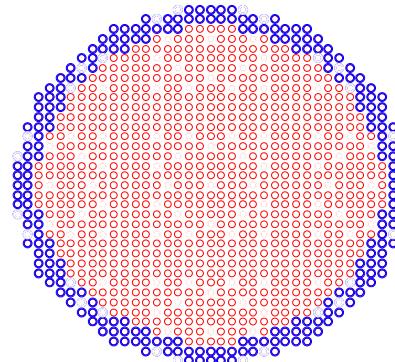




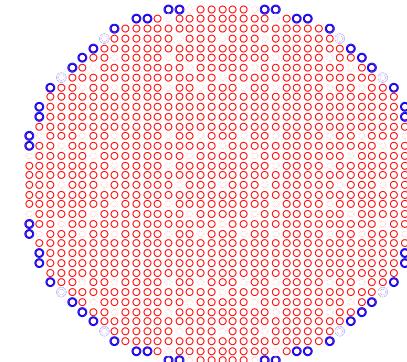
Core configurations during the first approach-to-critical experiment (2)



740

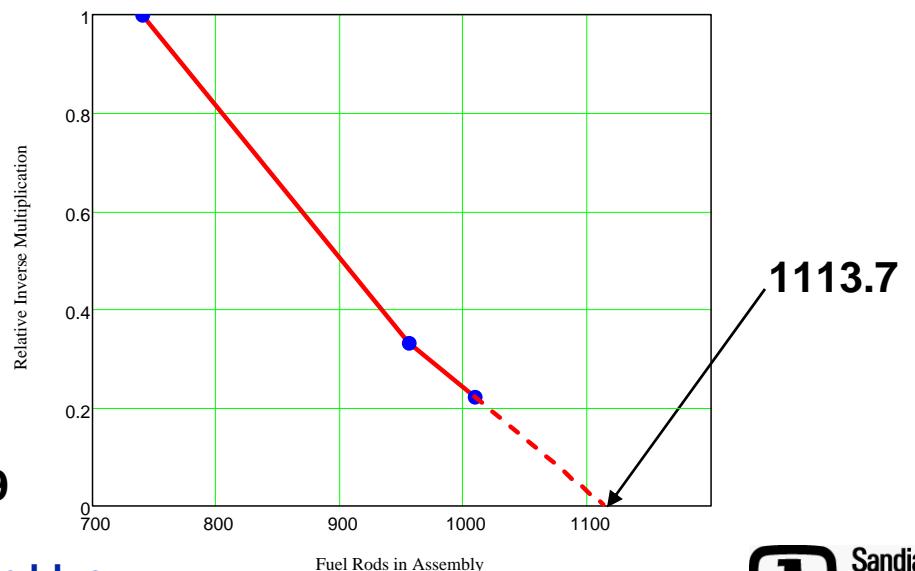


956



1009

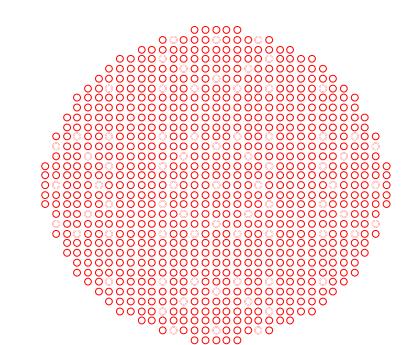
The next array: 1059



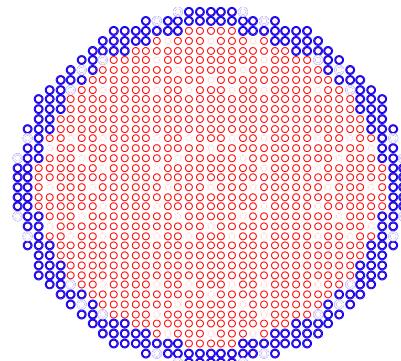
The incremental fuel elements are shown in blue



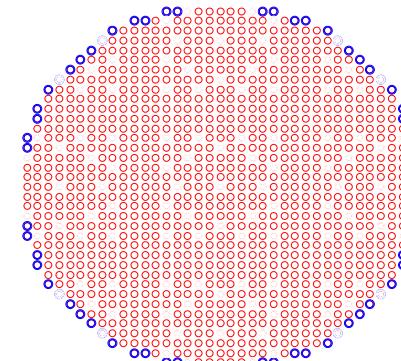
Core configurations during the first approach-to-critical experiment (3)



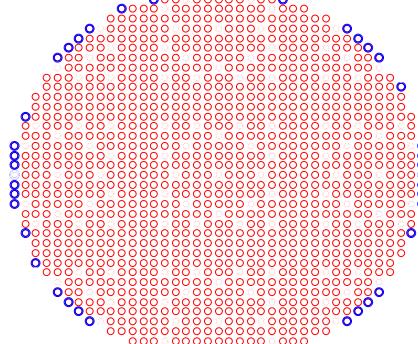
740



956

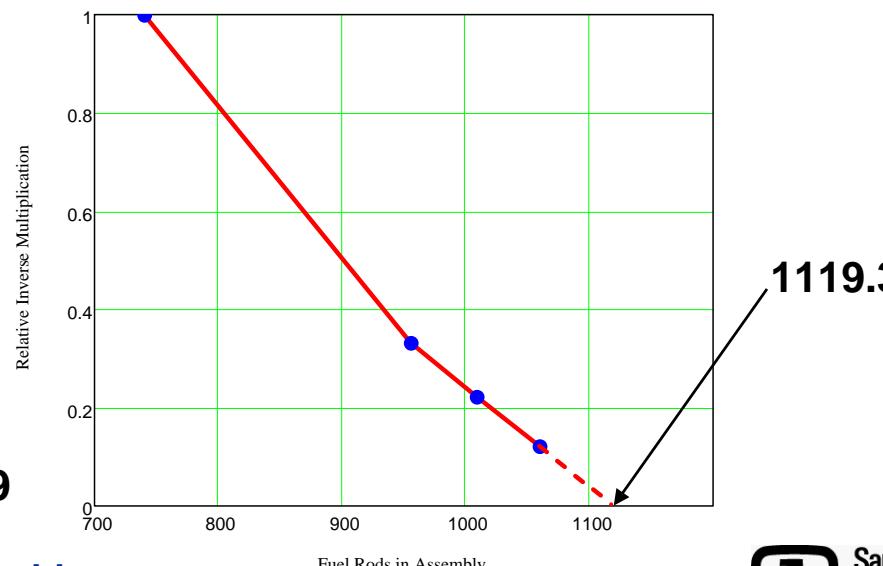


1009



1059

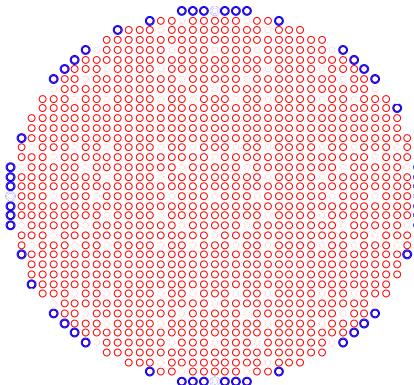
The next array: 1089



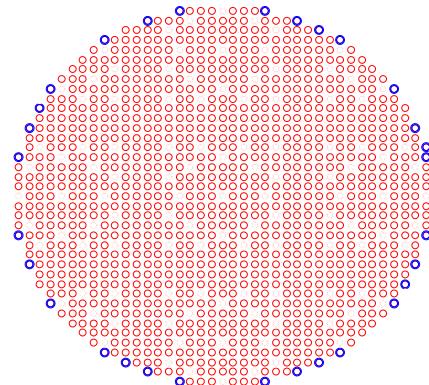
The incremental fuel elements are shown in blue



Core configurations during the first approach-to-critical experiment (4)



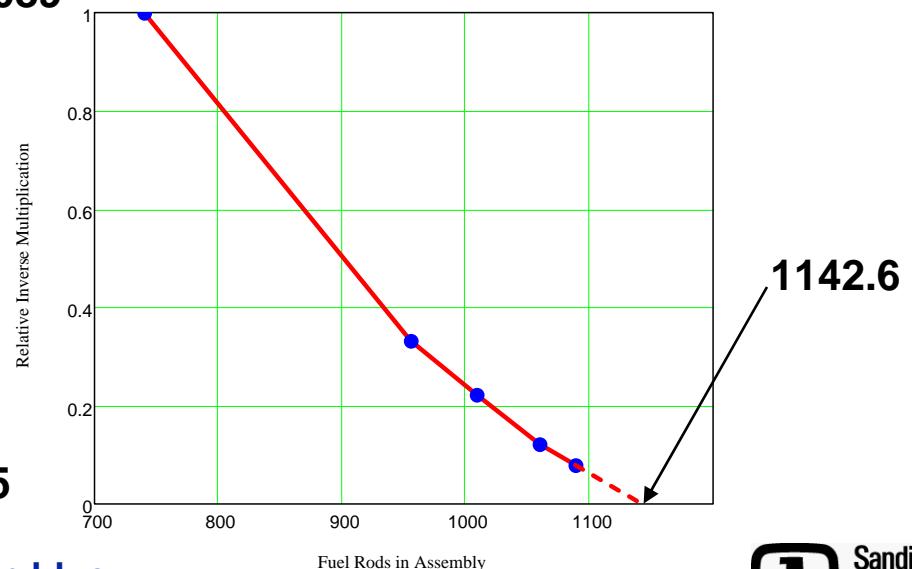
1059



1089

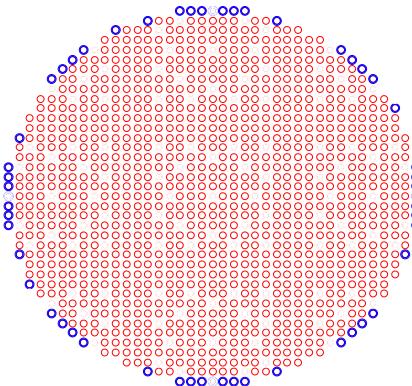
The next array: 1115

The incremental fuel elements are shown in blue

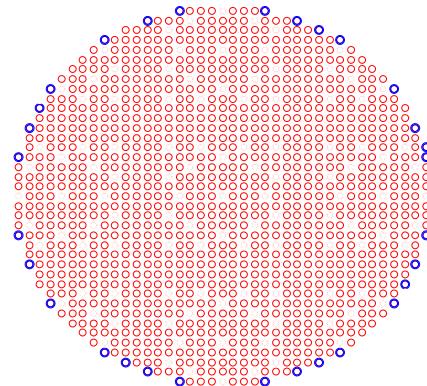




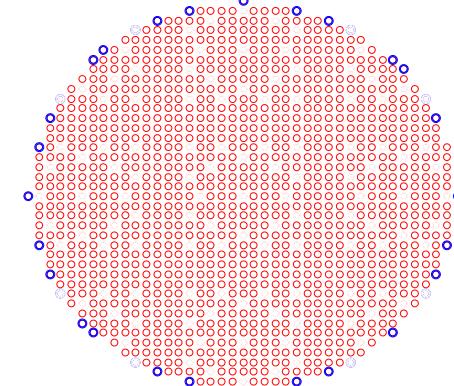
Core configurations during the first approach-to-critical experiment (4)



1059



1089

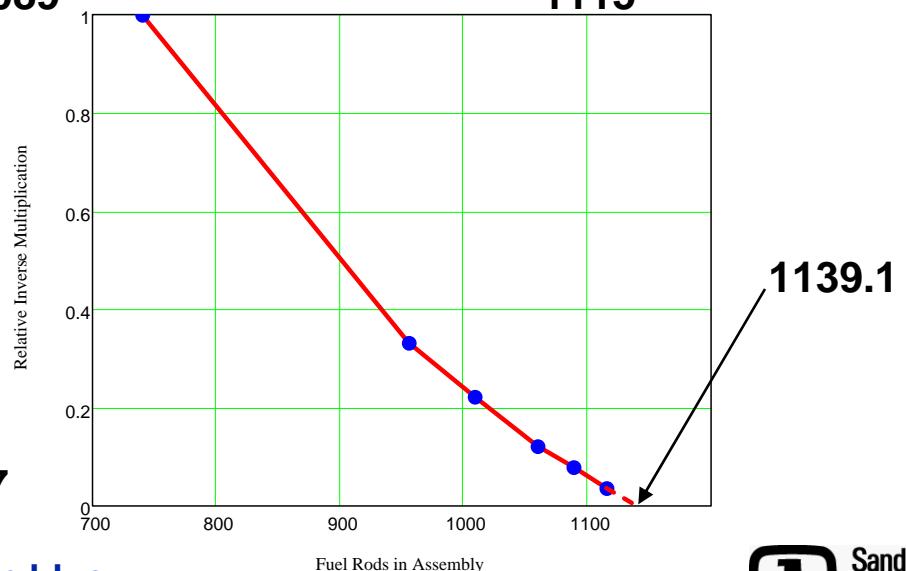


1115

We also made measurements with 1127, 1136, 1140, and 1144 elements (all subcritical). A core with 1148 elements was supercritical.

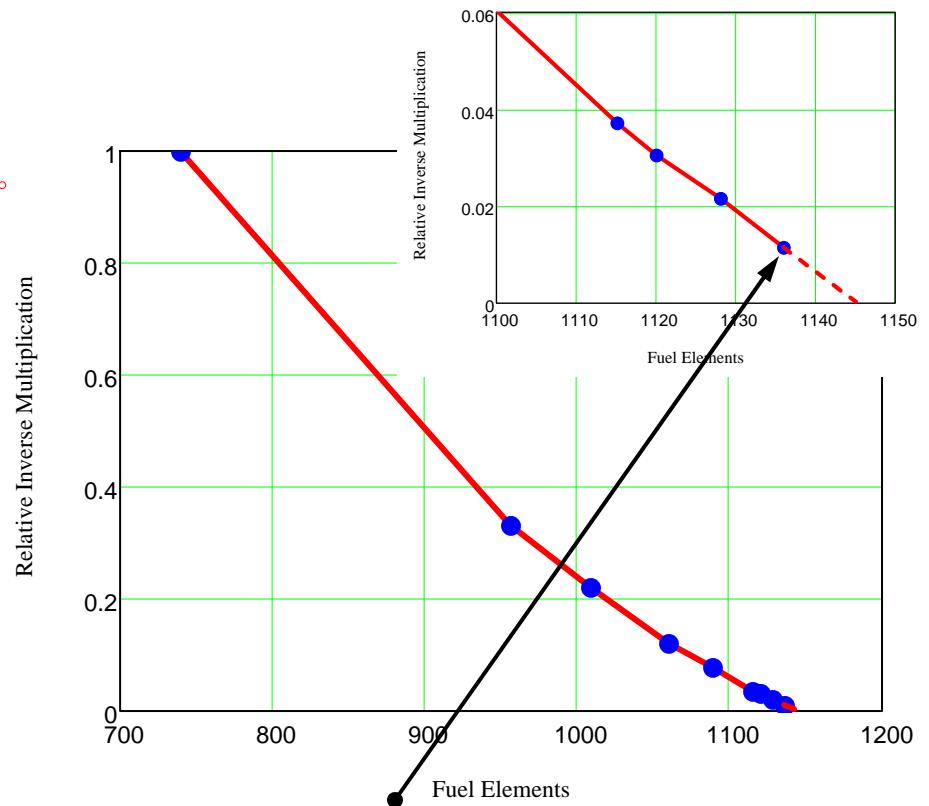
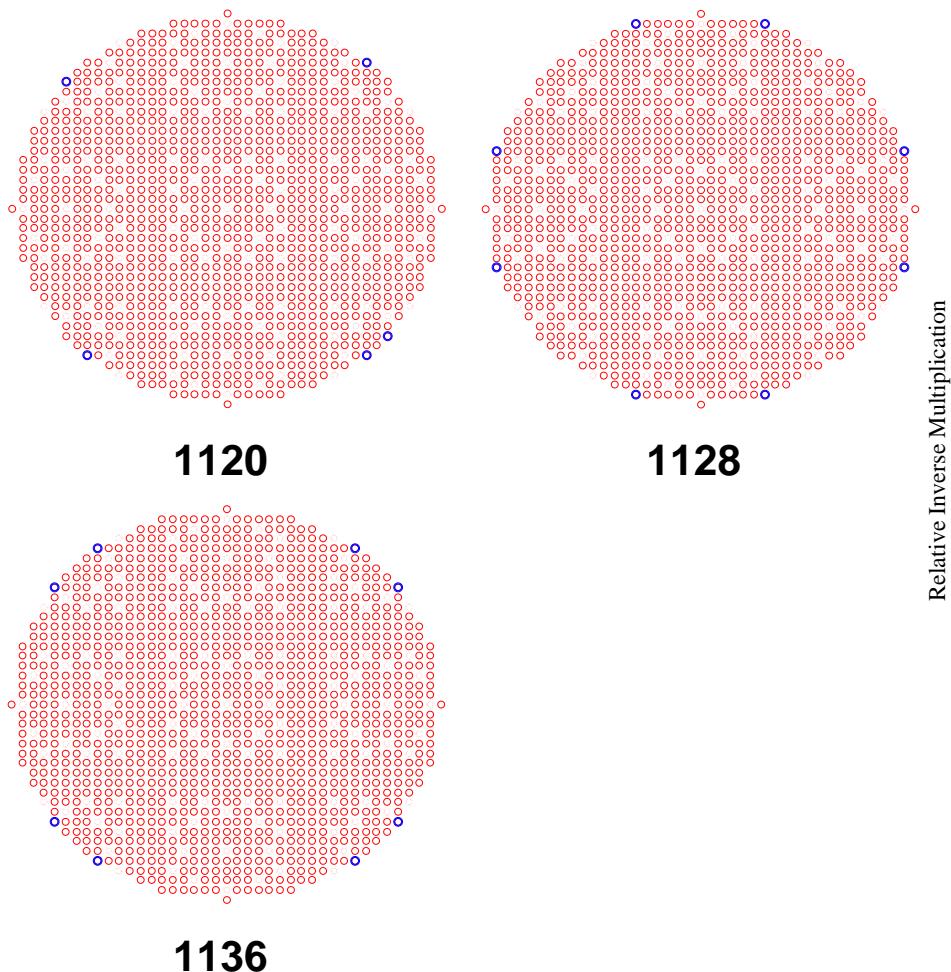
The next array: 1127

The incremental fuel elements are shown in blue





Core configurations during the first approach-to-critical experiment (5)



At 1136 fuel elements:

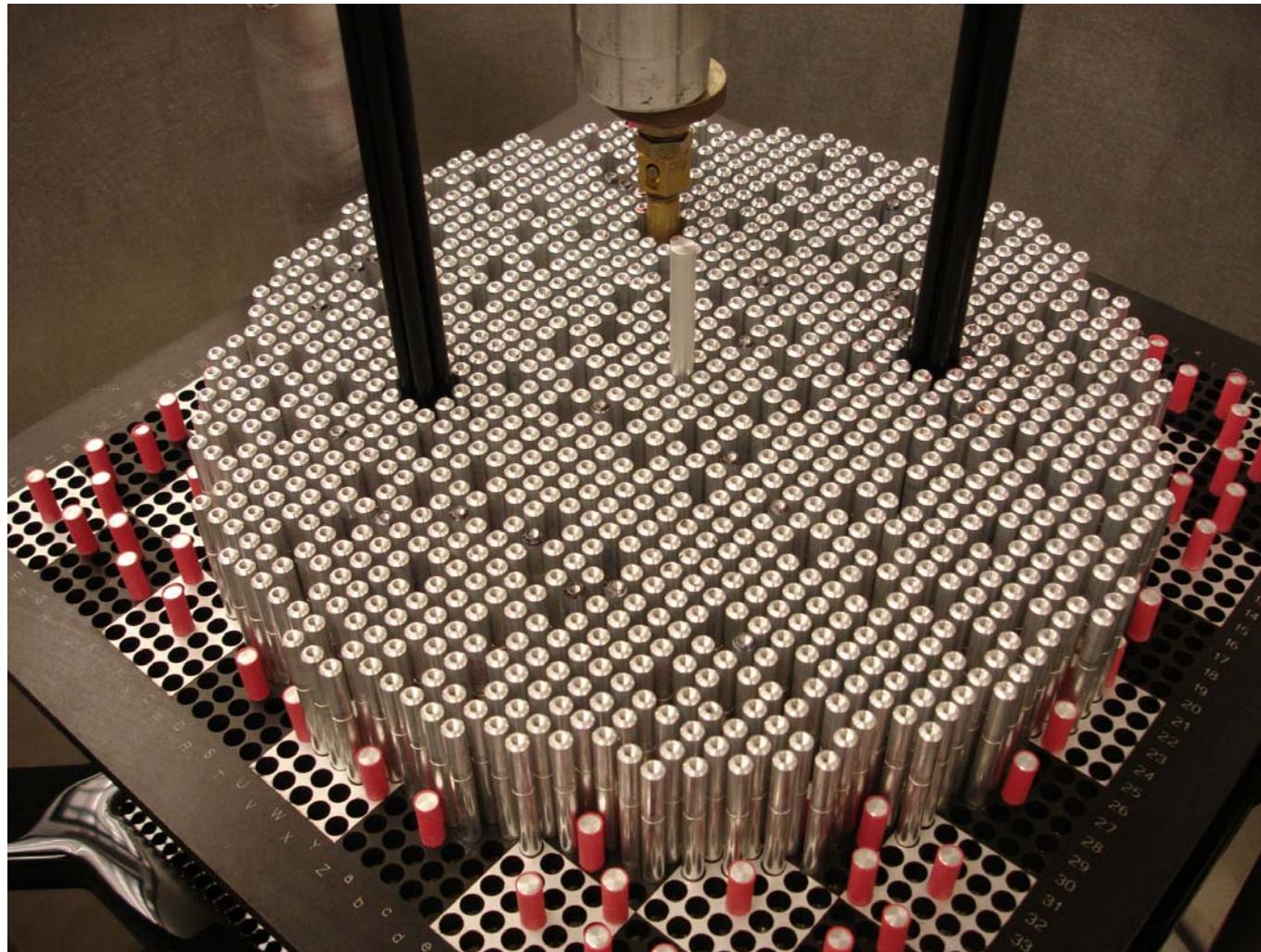
$$N_{\text{crit}} = 1145.3$$

$$k_{\text{eff}} = 0.9984$$

$$M \sim 610$$



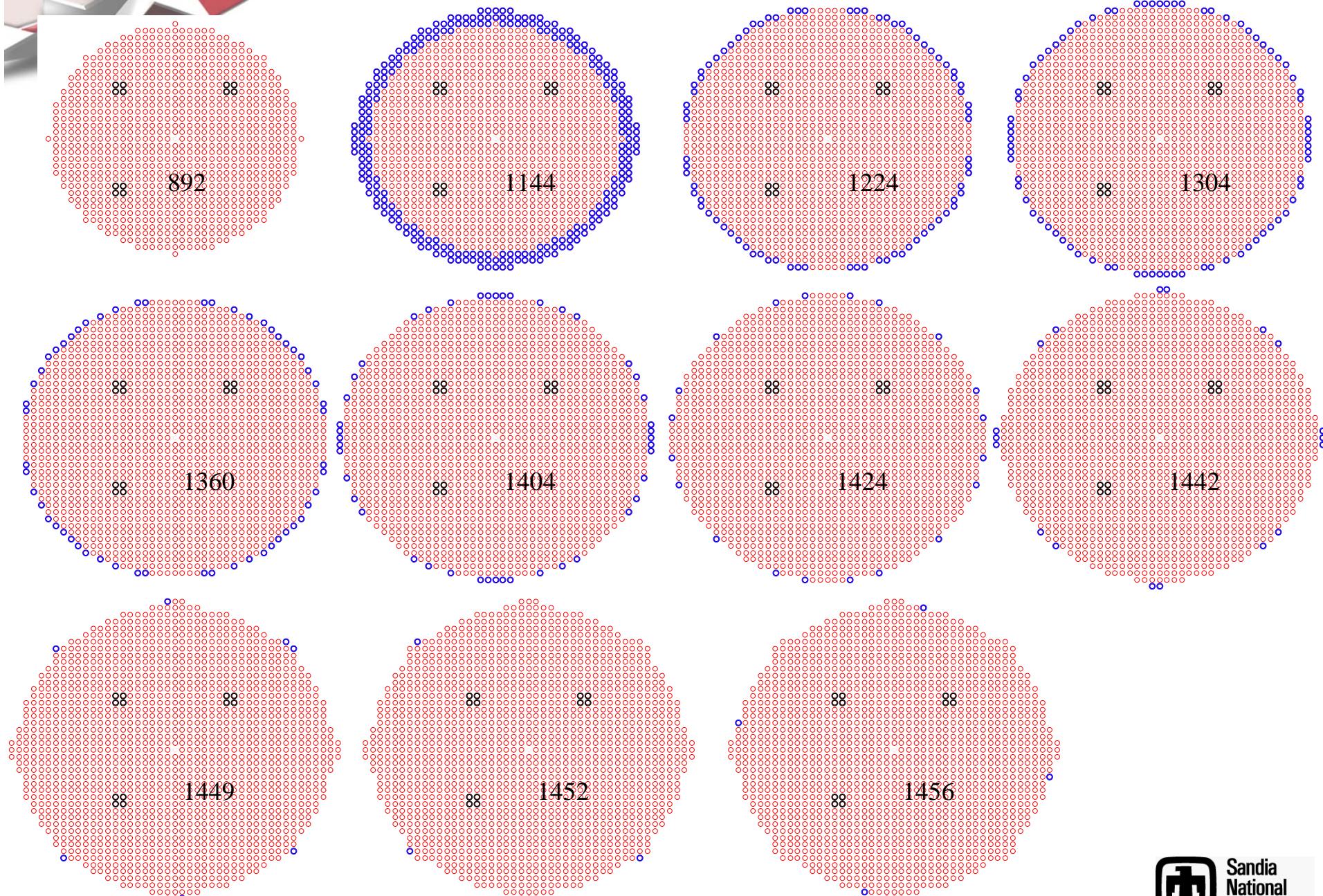
The first 7uPCX core at the end of the approach





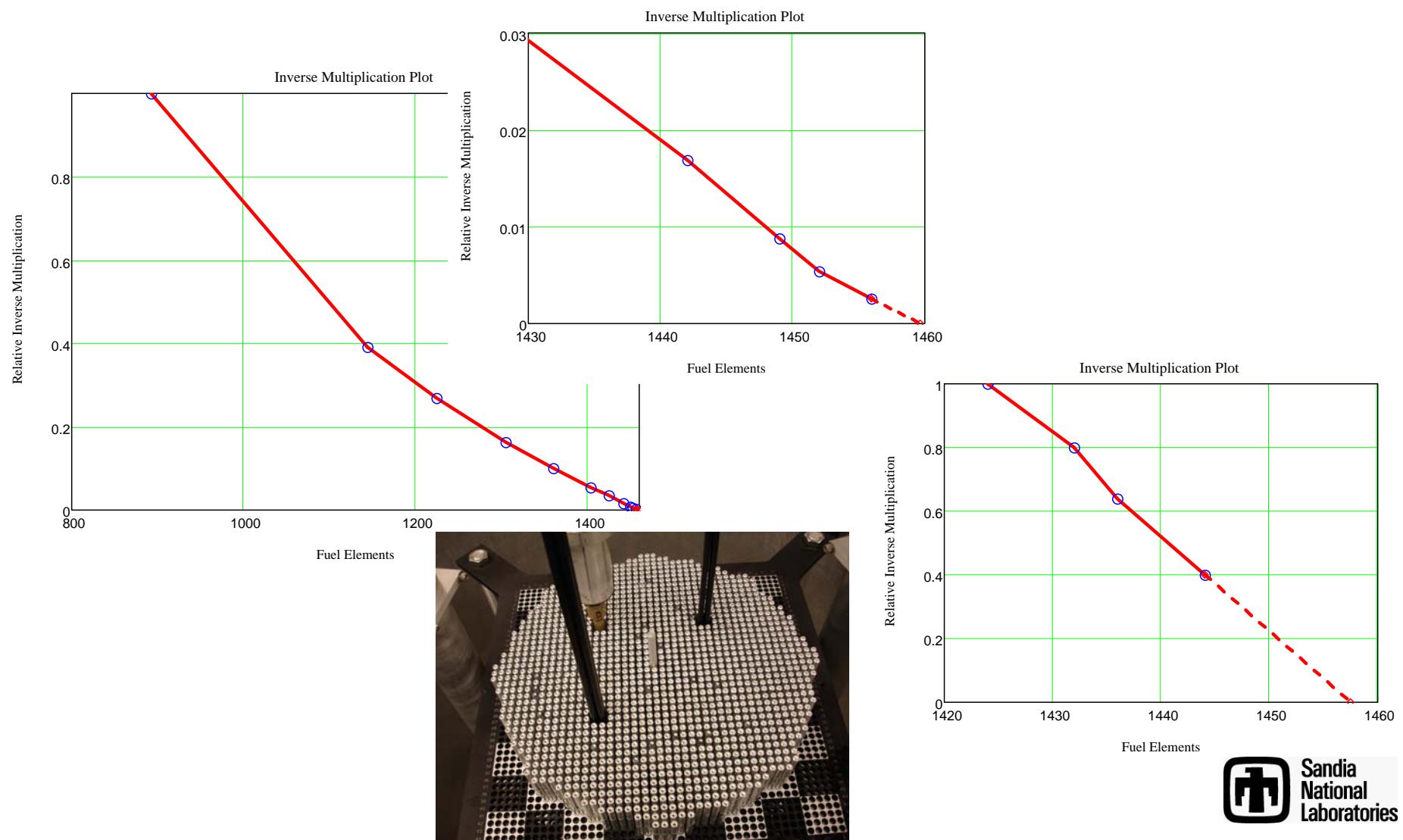
Core "A" Configurations Starting 2/9/10

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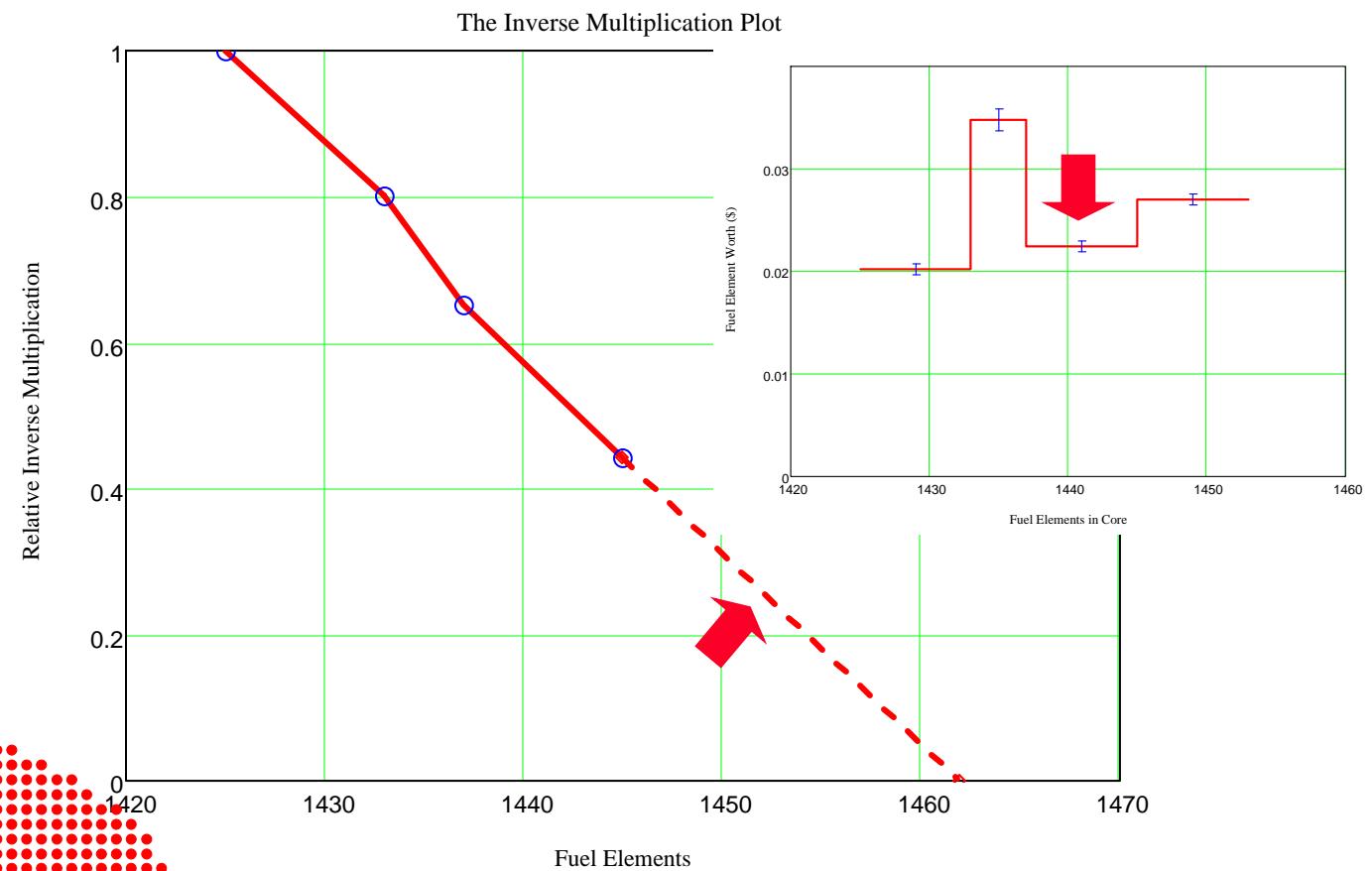
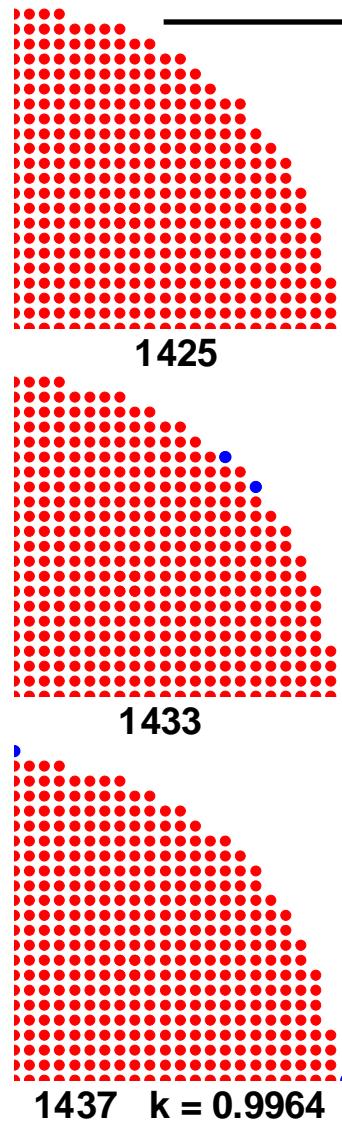


The “A” core



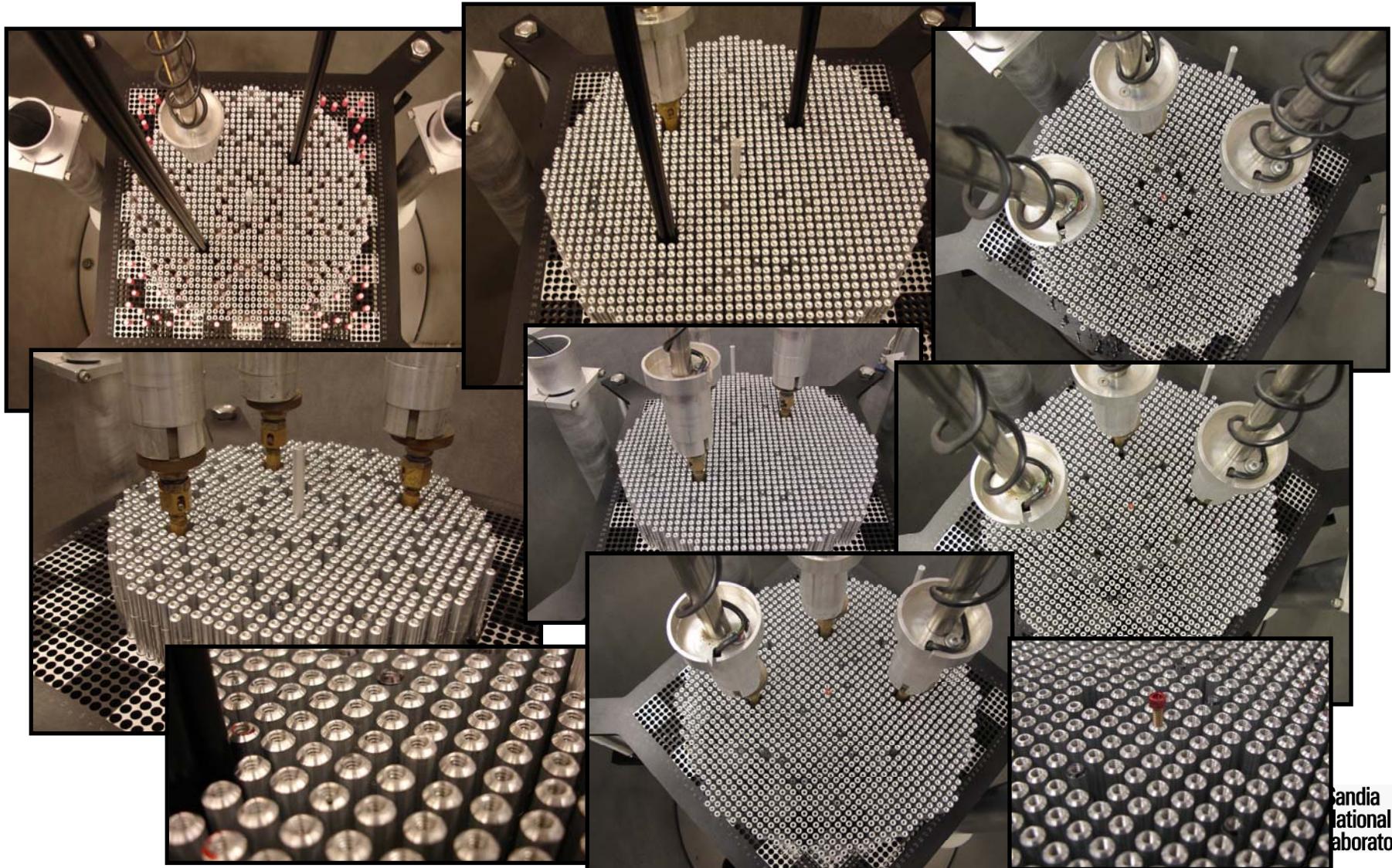


k_{eff} from Approach Data





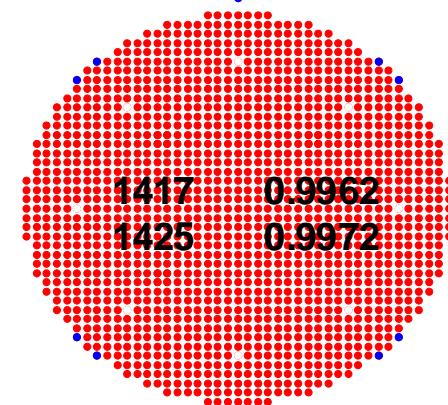
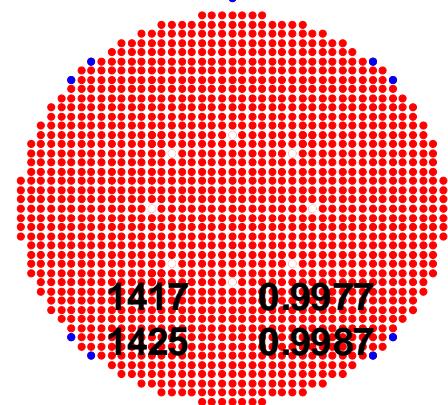
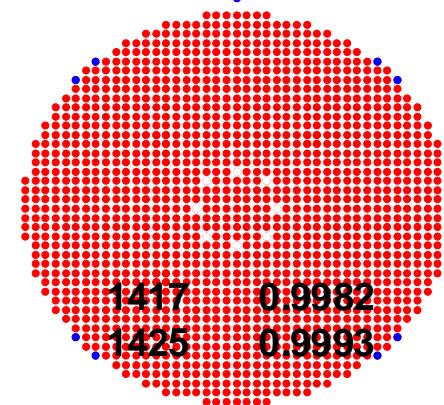
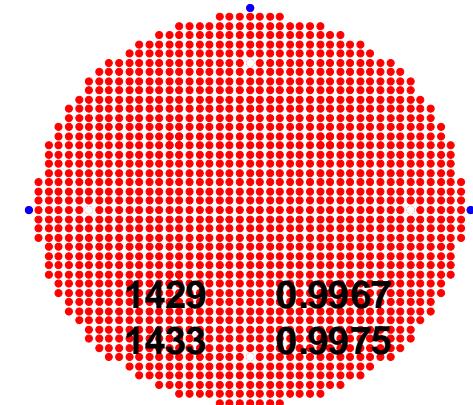
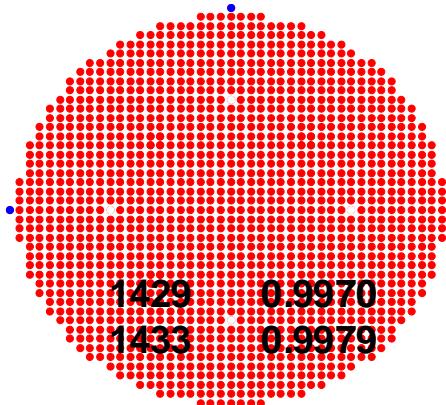
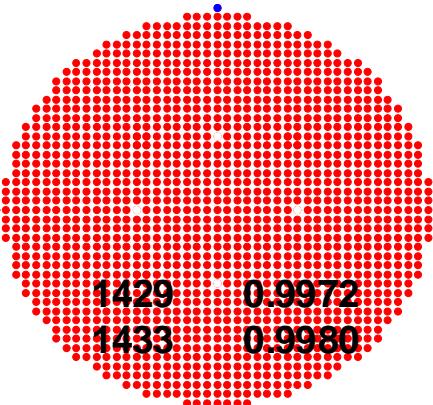
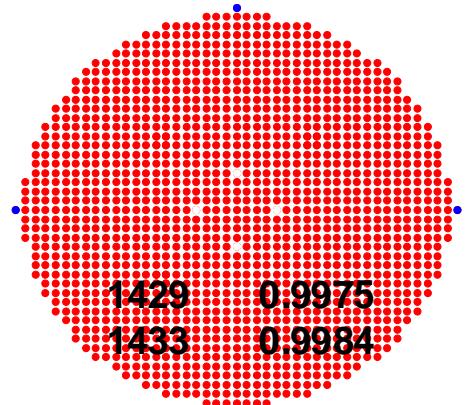
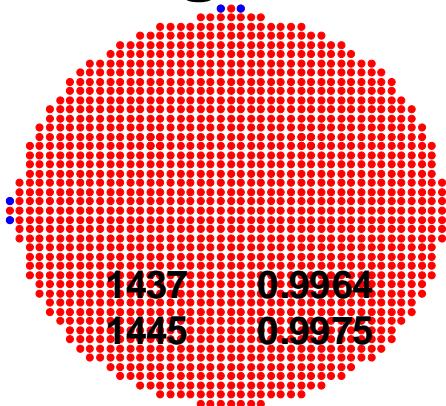
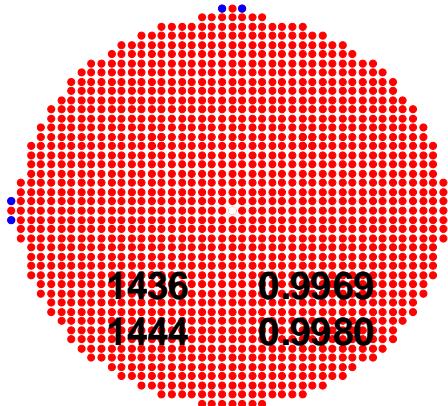
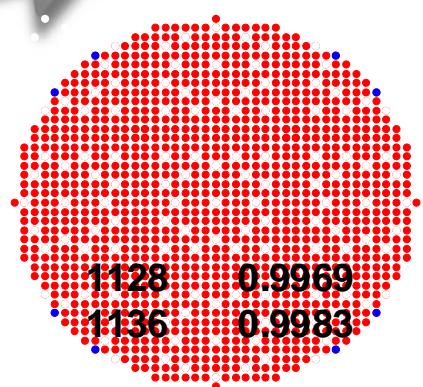
We have performed critical experiments on several 7uPCX configurations



Sandia
National
Laboratories



7uPCX Critical Configurations





The 7uPCX experiment matrix

- **We have two grid plate sets**
 - The sets were chosen to bound the fuel-to-water ratio of commercial PWRs
 - A full set of experiments will be done at each pitch
- **We will find the array that is critical with pure water moderator**
- **We will search for the boric acid concentration in the moderator that gives a critical array with all fuel element positions filled**
- **Fission density measurements will be made on the fully-loaded core**

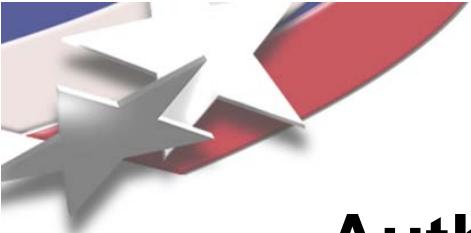


The Future for the Sandia Criticals

- We will maintain the critical experiment capability for the foreseeable future
 - The NCSP plans to support the operation of the critical experiments
- We are developing a critical experiments training course module as part of the DOE NCSP Nuclear Criticality Safety Engineer training program
- We will continue to work through the 7uPCX experiment matrix
 - Complete measurements on the cores with pure water moderator
 - Perform experimentation with dissolved boron in the moderator
- Other experiments are under development

Critical Experiments at Sandia





The Phase Space our Authorization Basis Allows is Large

- Our design space:
 - UO_2 fuel
 - Metal Cladding
 - Light Water Moderator
 - <20% Enrichment
 - <500 kg of UO_2 in the reactor room
 - >50 kg of UO_2 in a critical configuration