



# **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**



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National Nuclear Security Administration under contract DE-AC04-94AL85000.





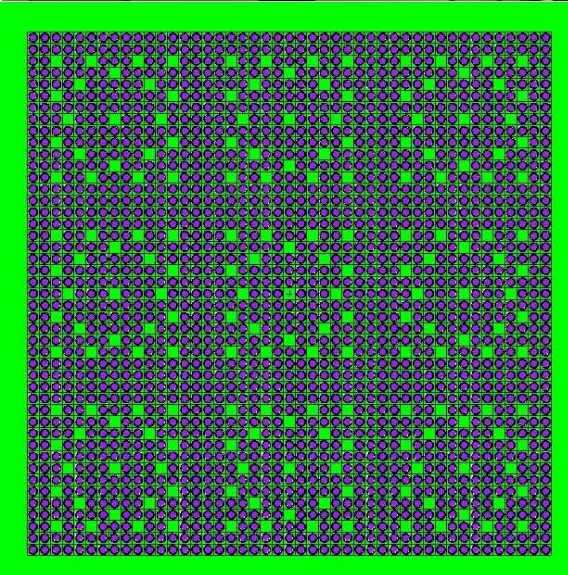
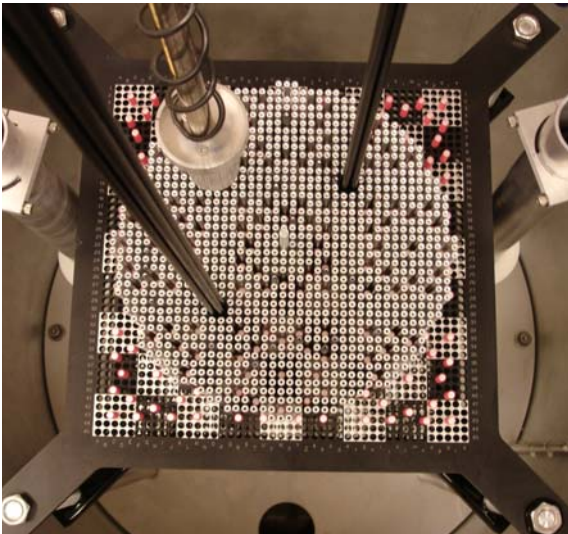
## The 7uPCX started as a NERI project

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### *Reactor Physics and Criticality Benchmark Evaluations for Advanced Nuclear Fuel*

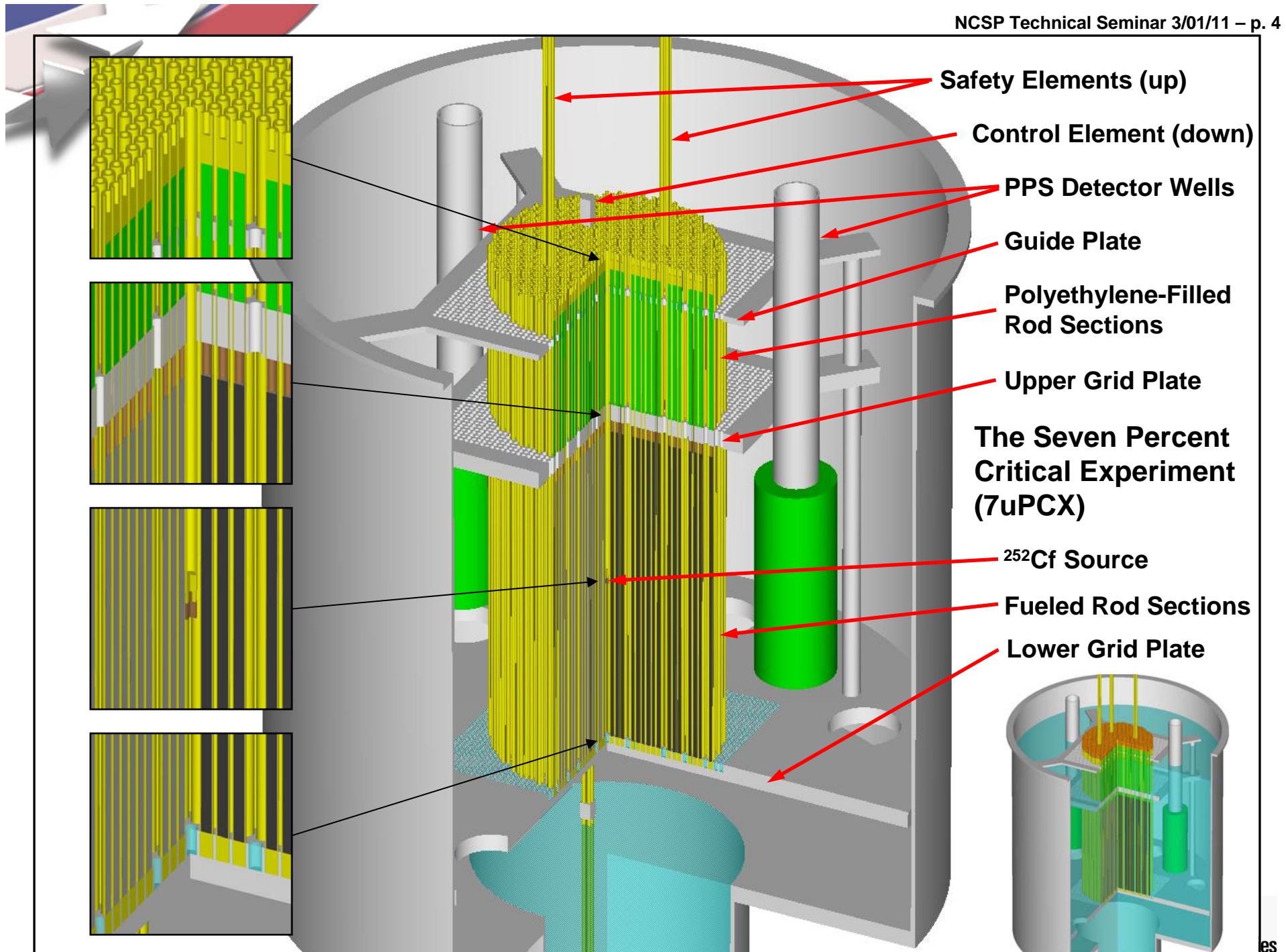
- The project was originally funded by the Nuclear Energy Research Initiative (NERI)
- The NERI project team:
  - AREVA Federal Services, LLC (Lynchburg, VA) – Conceptual Design, Analysis, Project Management
  - Sandia National Laboratories – Hardware Design, Transportation, Procurement, Experiments
  - 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

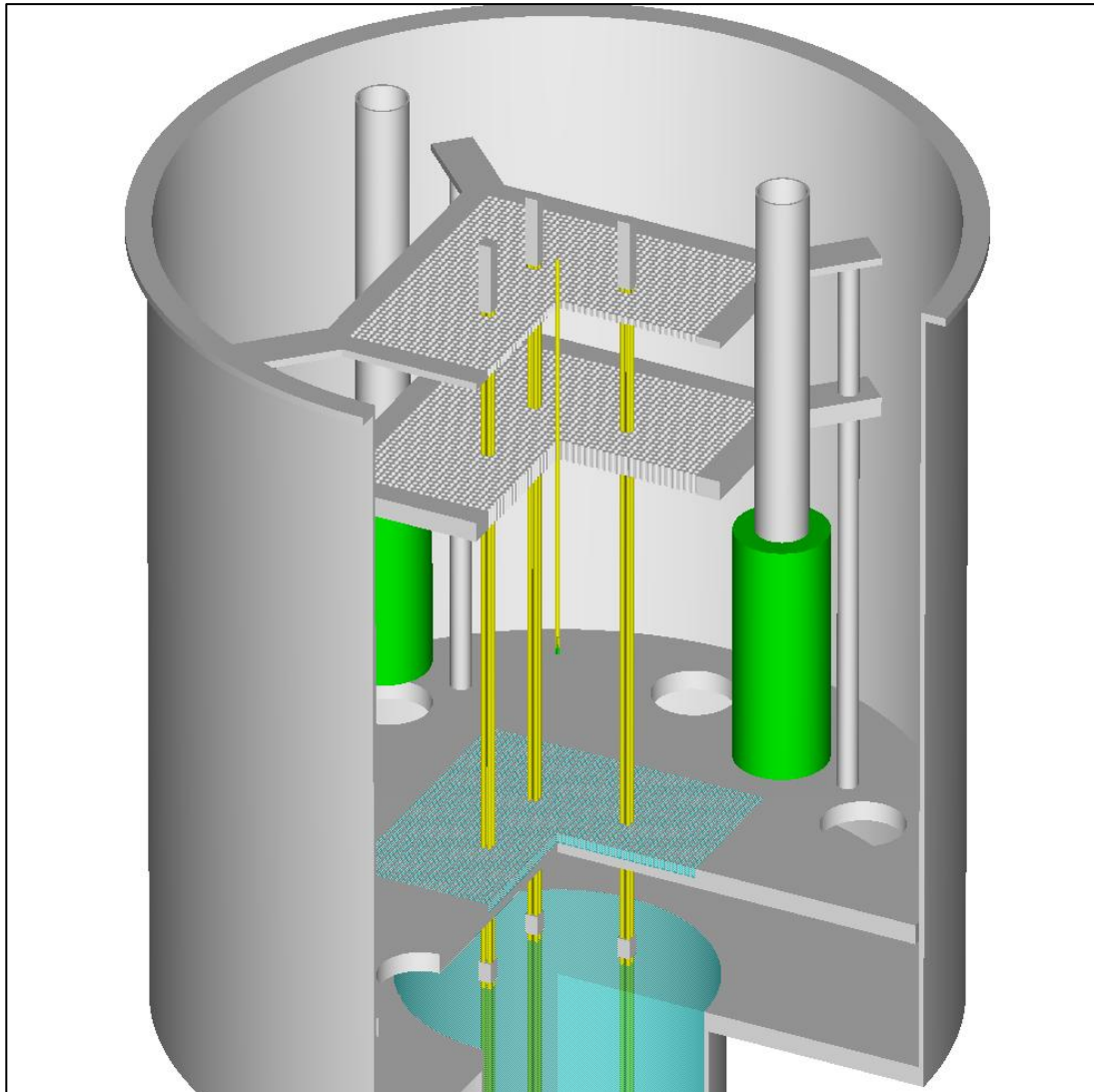


**Project Objective:** *Design, perform, and analyze critical benchmark experiments for validating reactor physics methods and models for fuel enrichments greater than 5-wt%  $^{235}\text{U}$*

- 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**

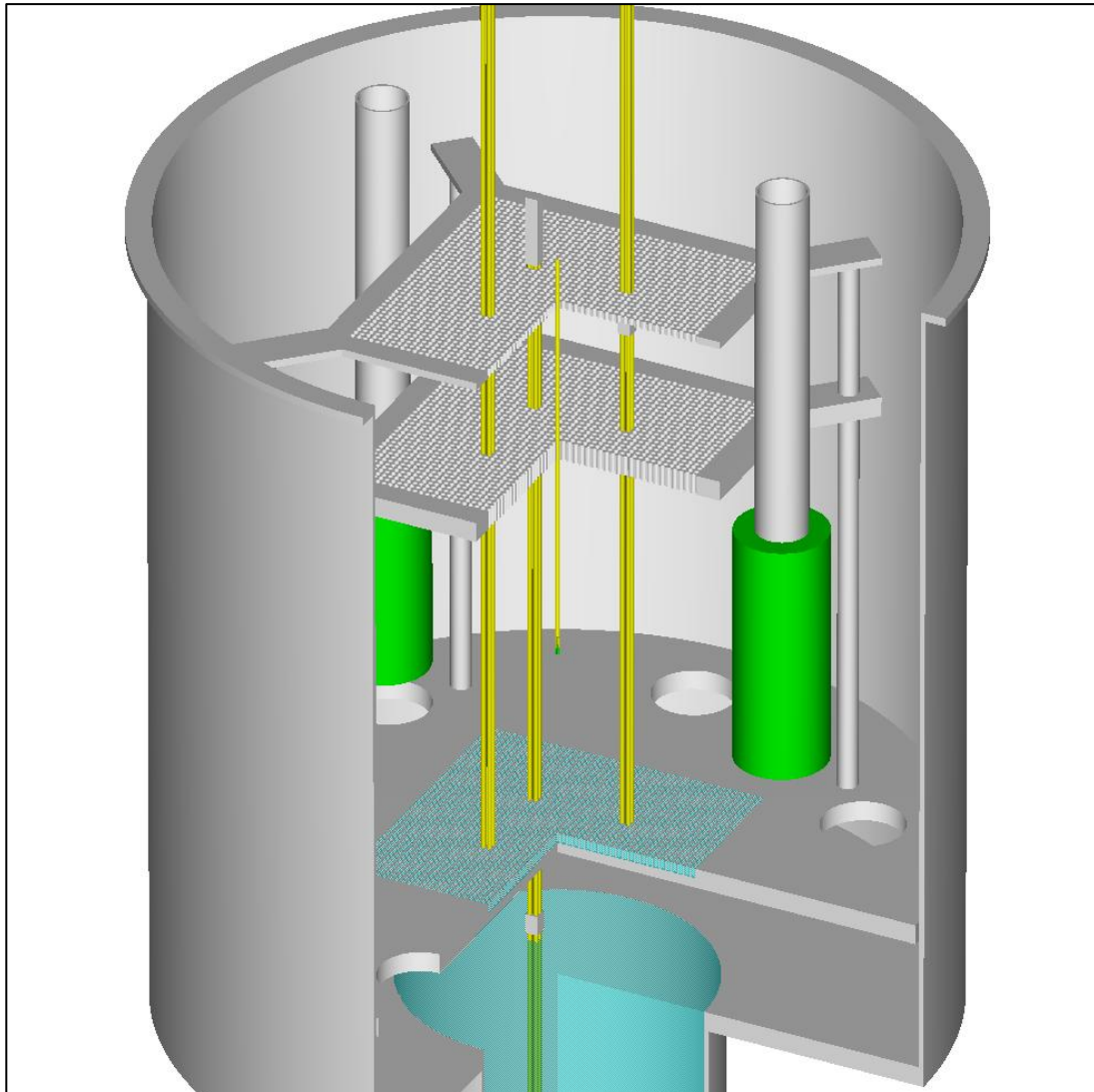
**Control Element: Down**

**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**

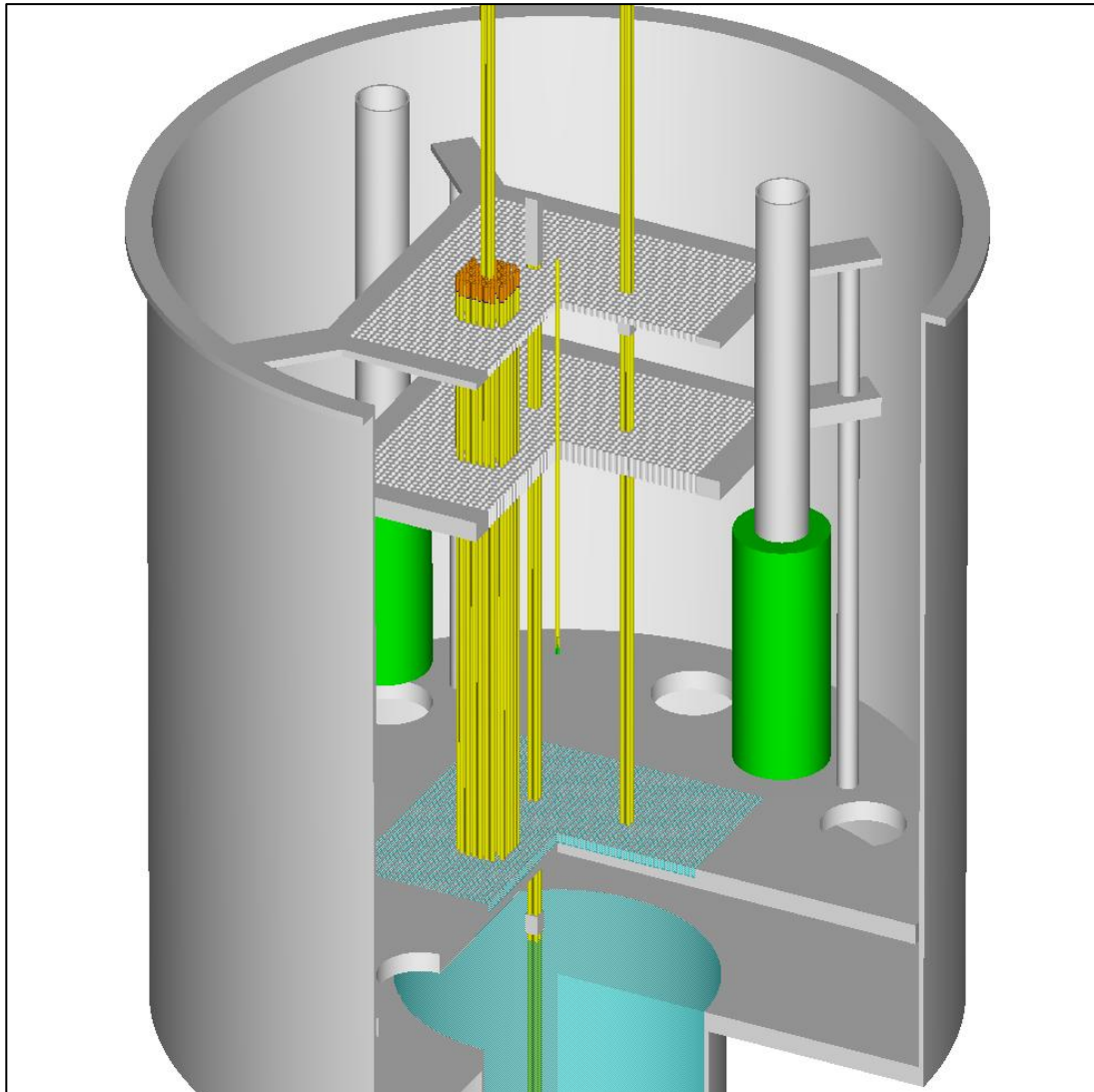
**Control Element: Down**

**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**

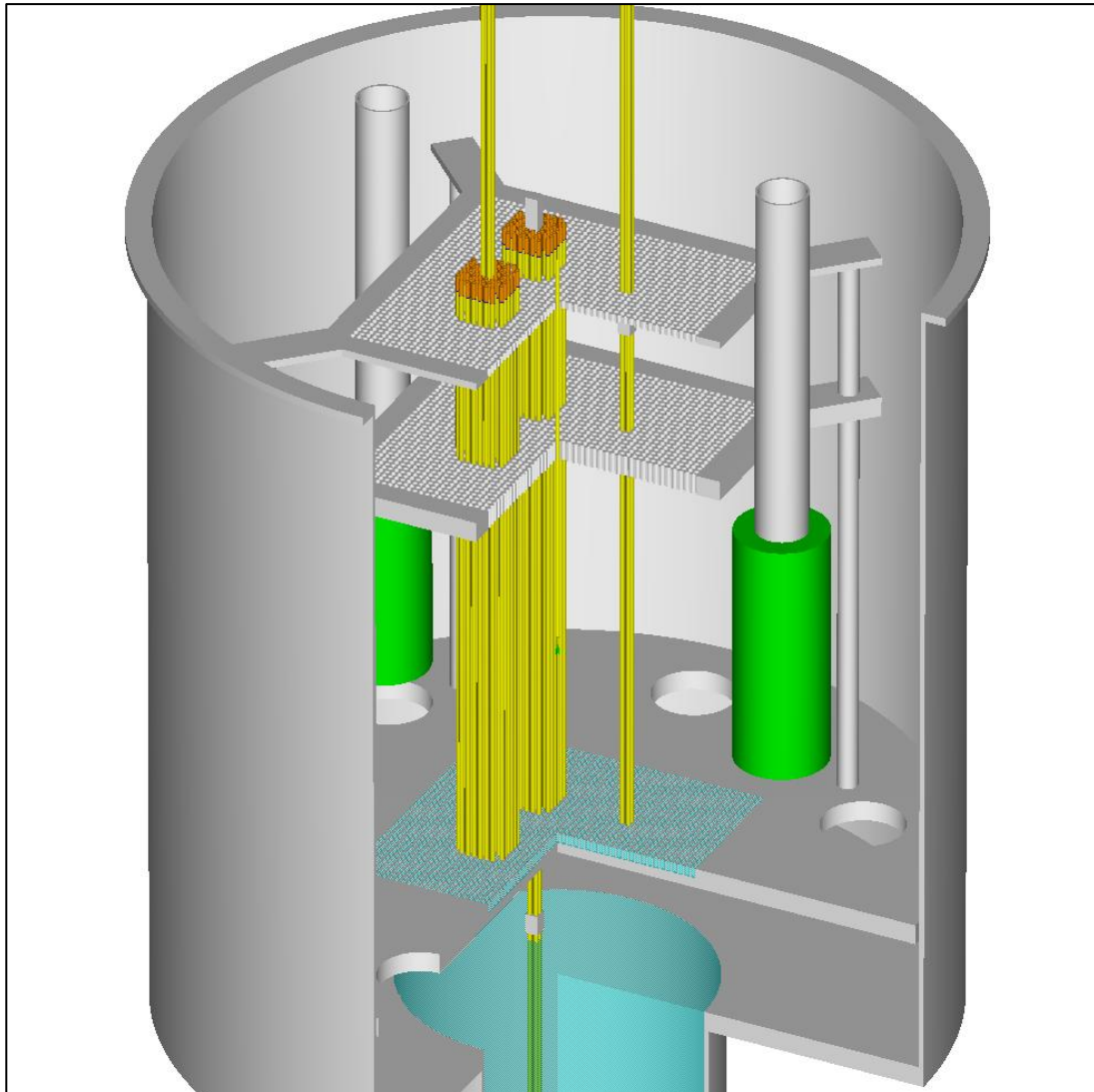
**Control Element: Down**

**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**

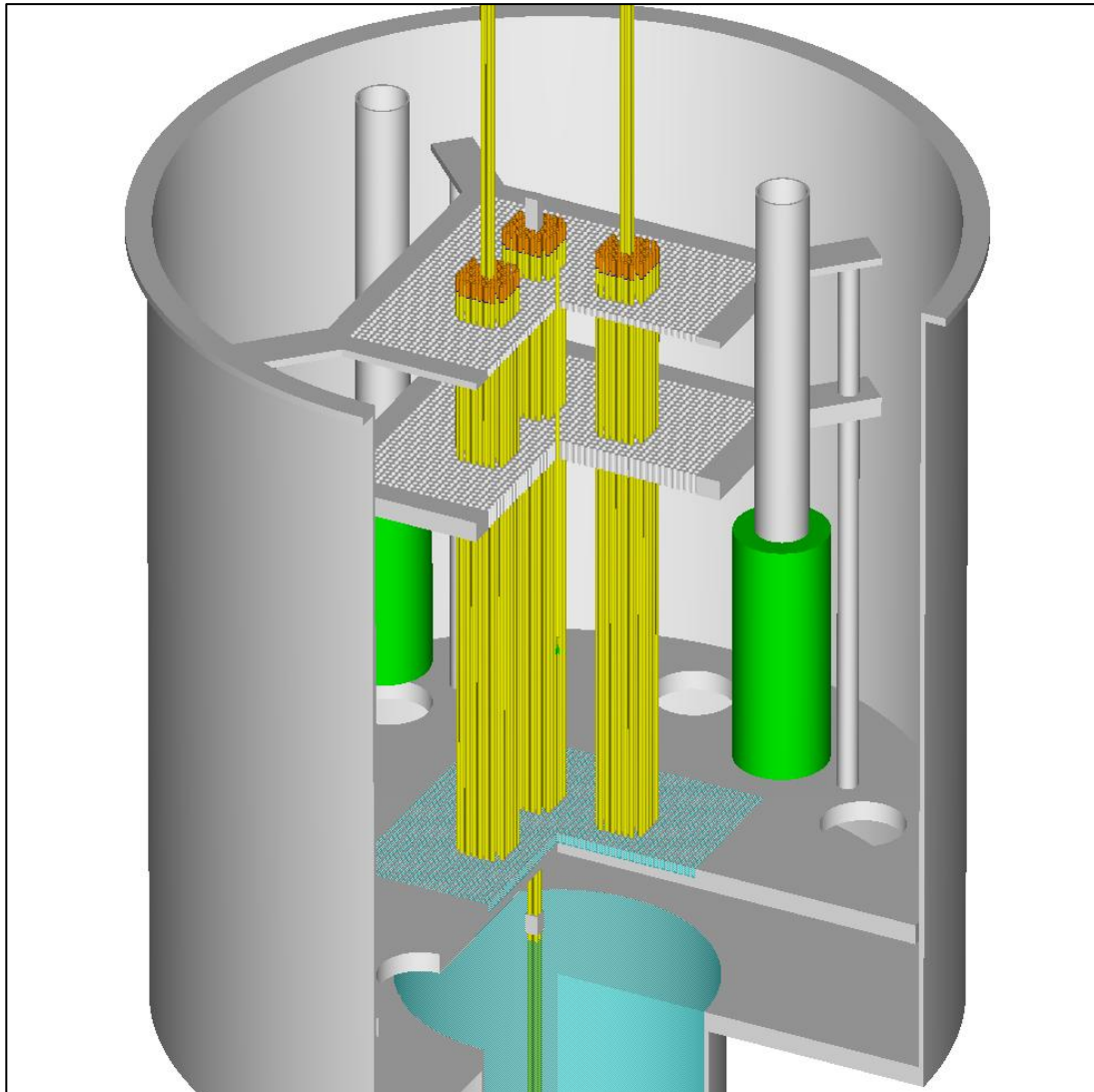
**Control Element: Down**

**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**

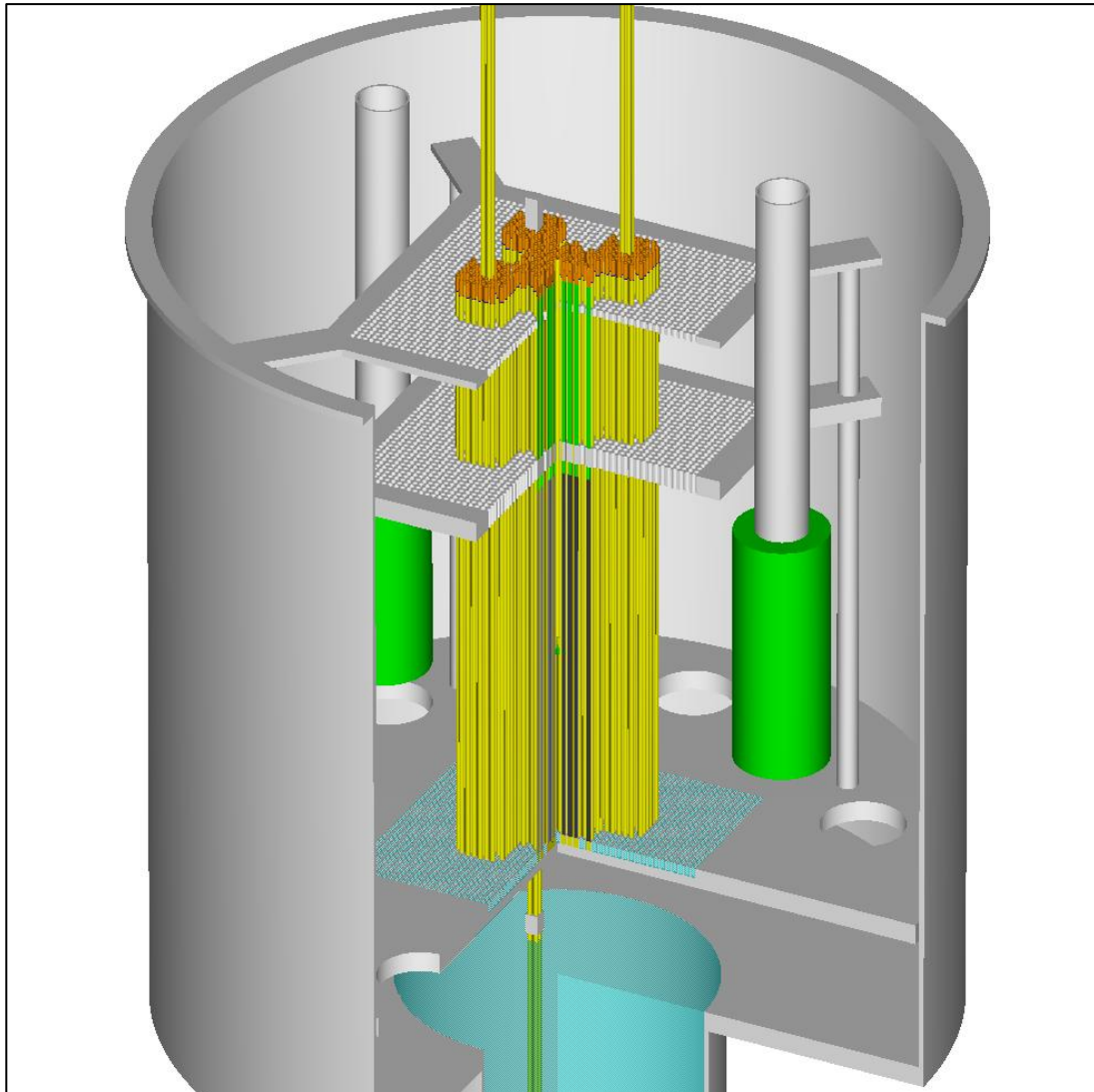
**Core Tank: Empty**

**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**

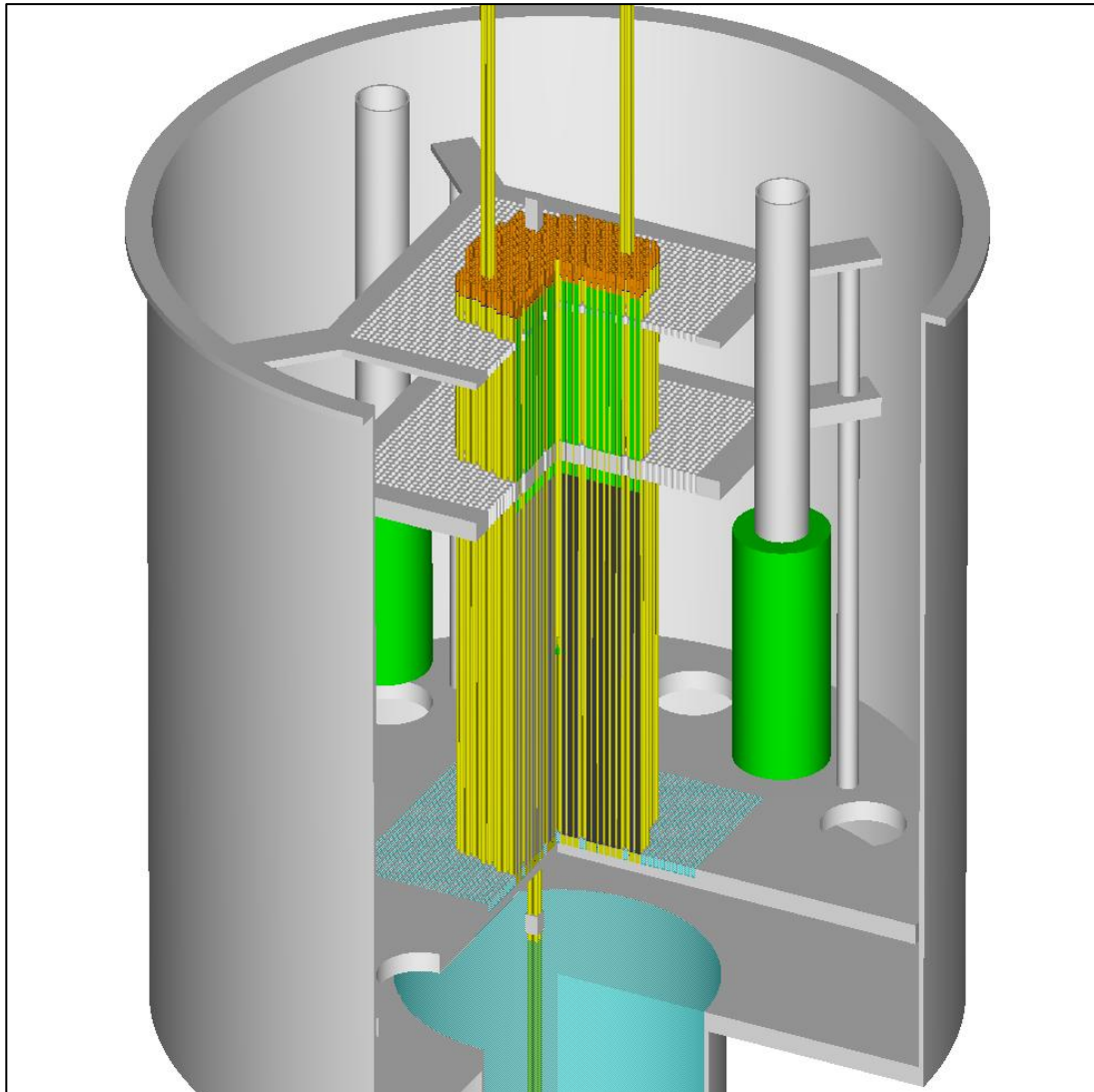
**Core Tank: Empty**

**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**

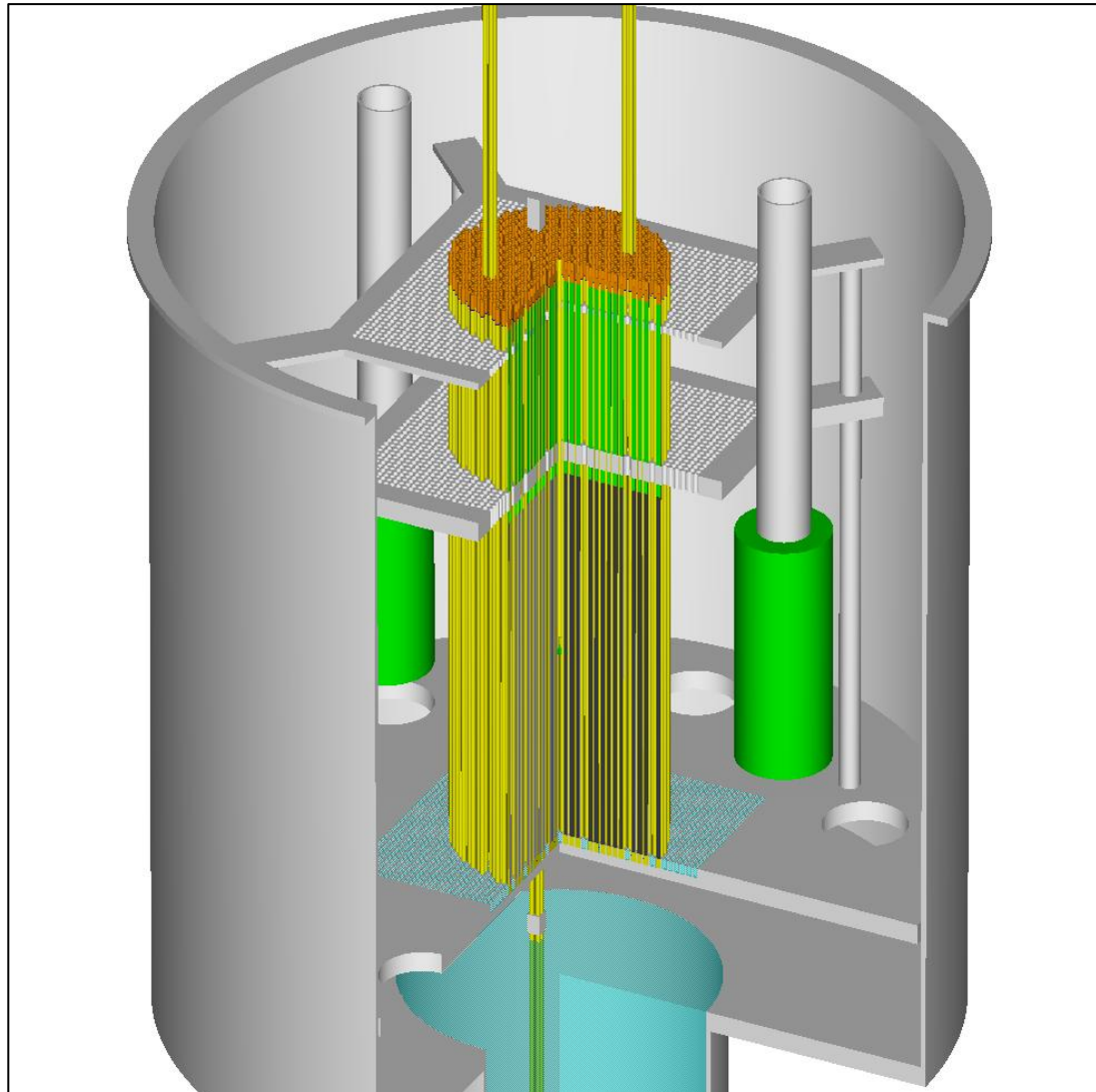
**Core Tank: Empty**

**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**

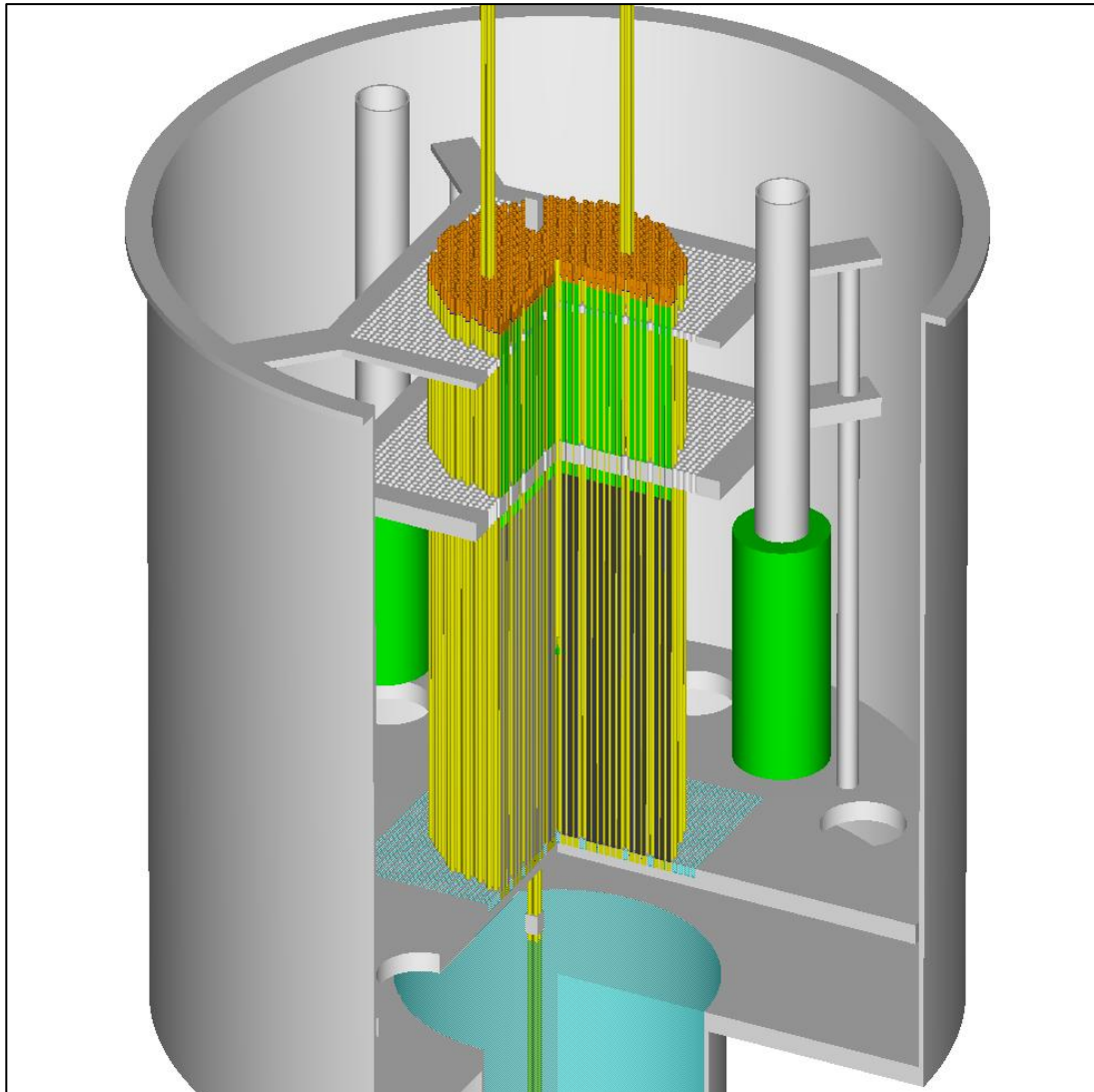
**Core Tank: Empty**

**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**

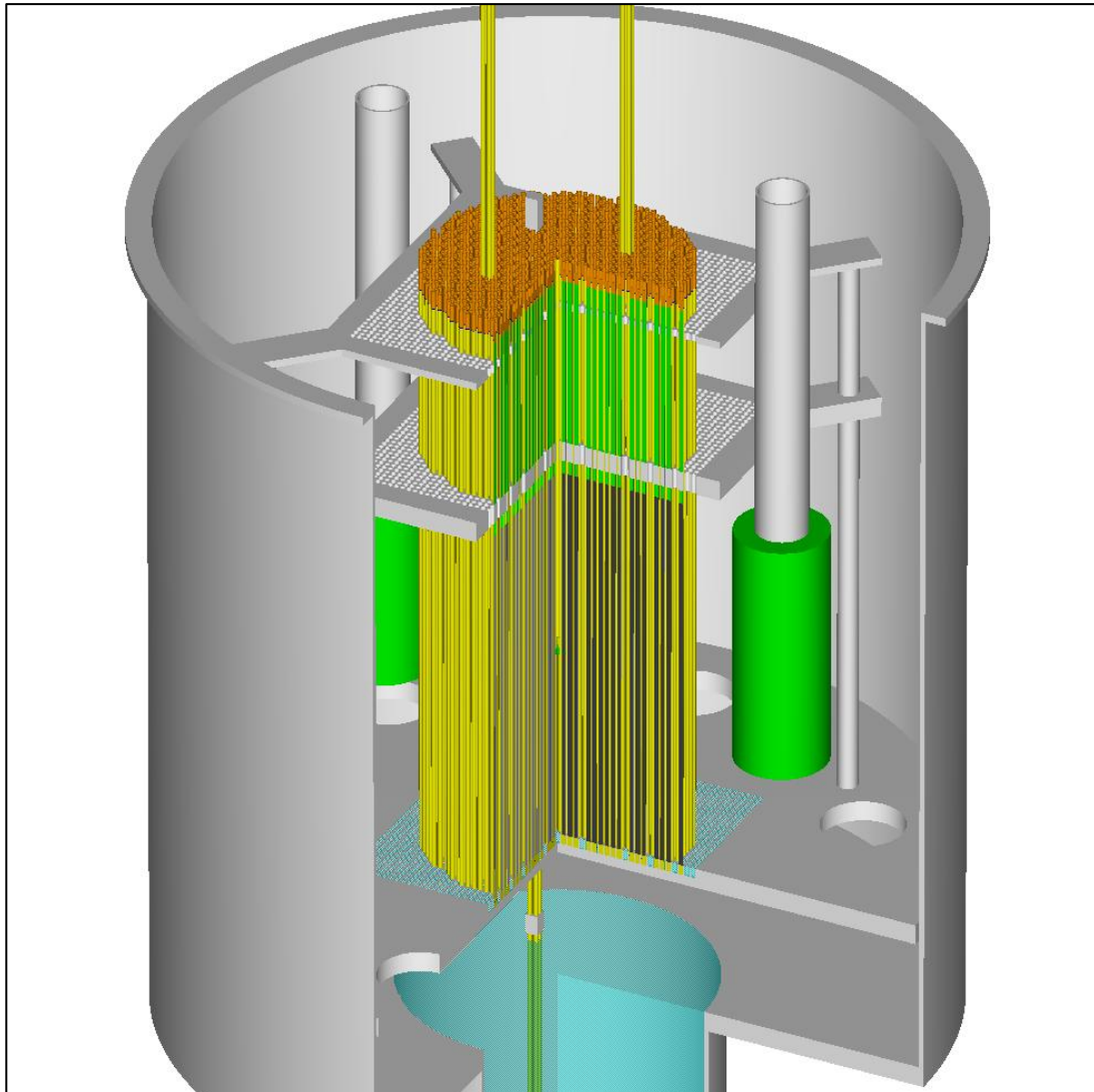
**Core Tank: Empty**

**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**

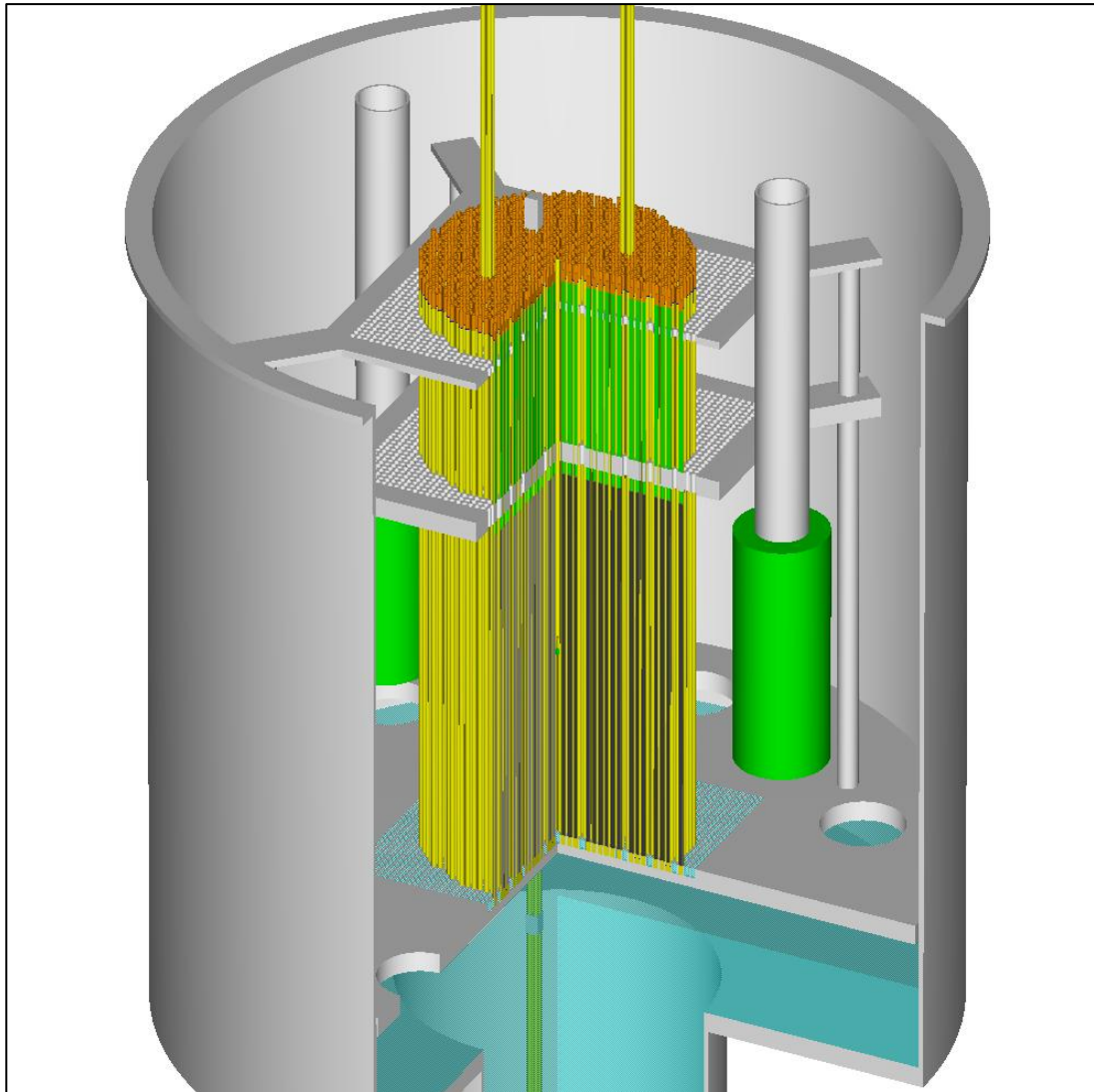
**Core Tank: Empty**

**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**

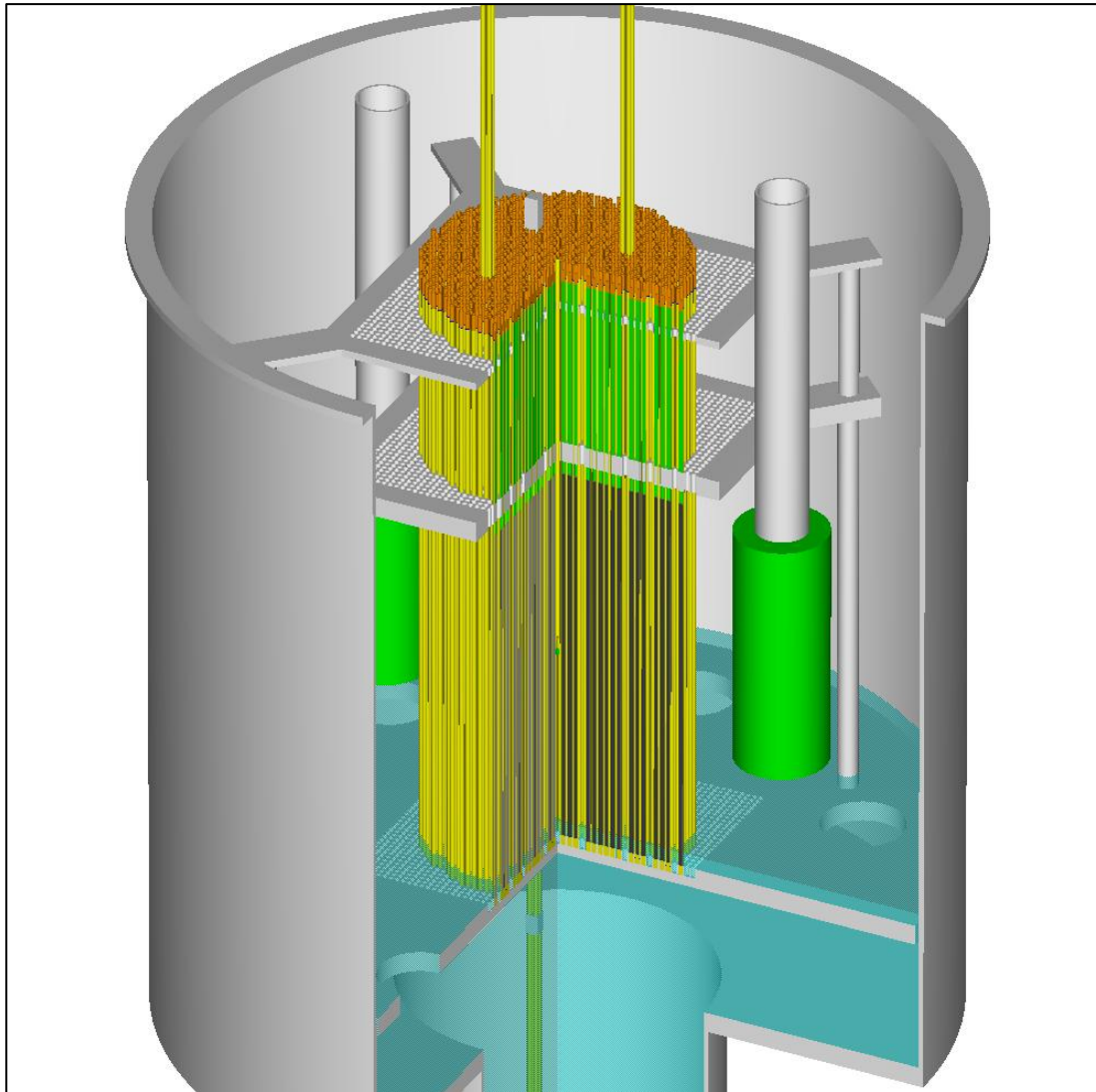
**Core Tank: Filling**

**Personnel: Excluded**

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



## Fill the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

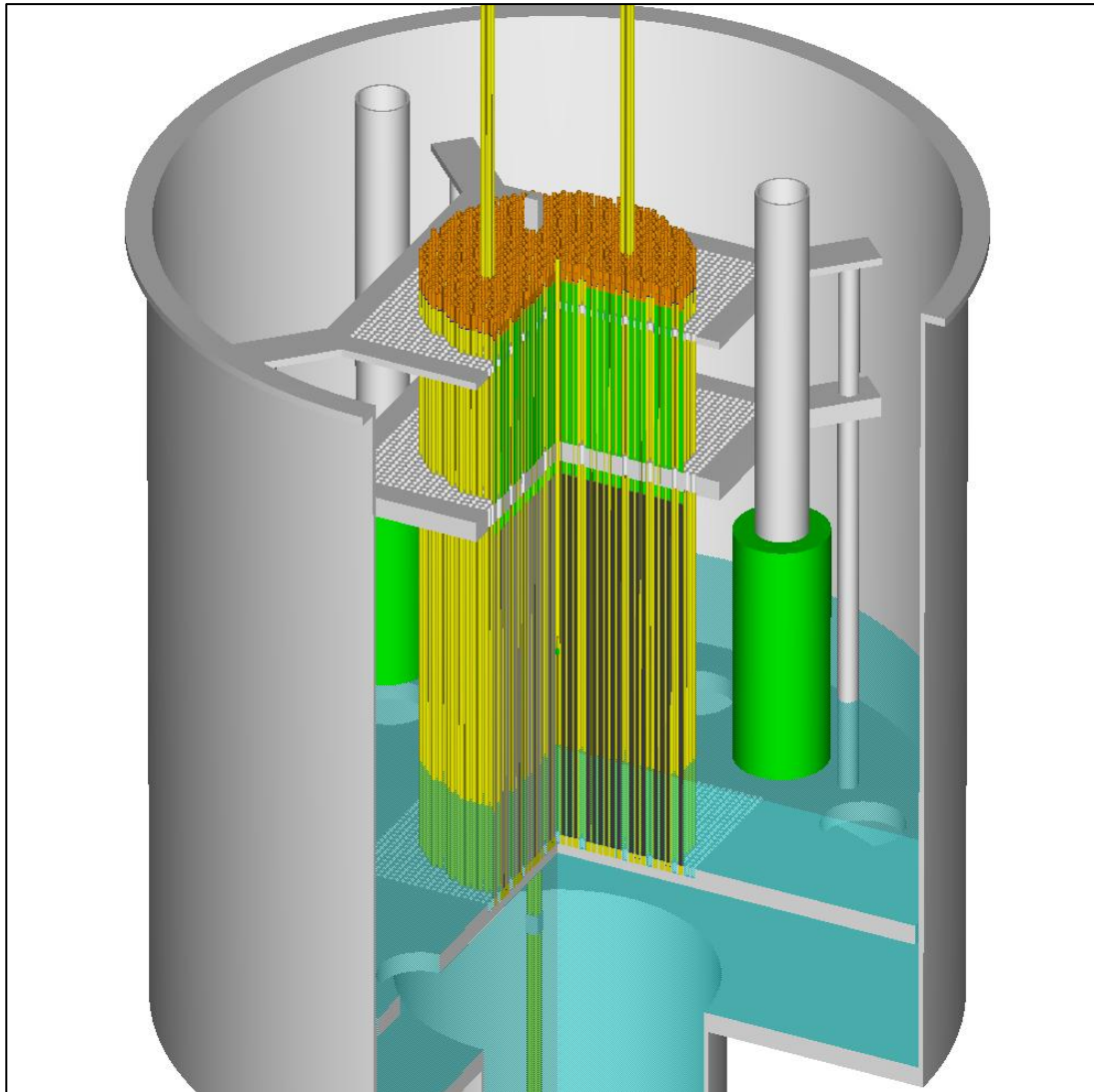
**Core Tank: Filling**

**Personnel: Excluded**

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



## Fill the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

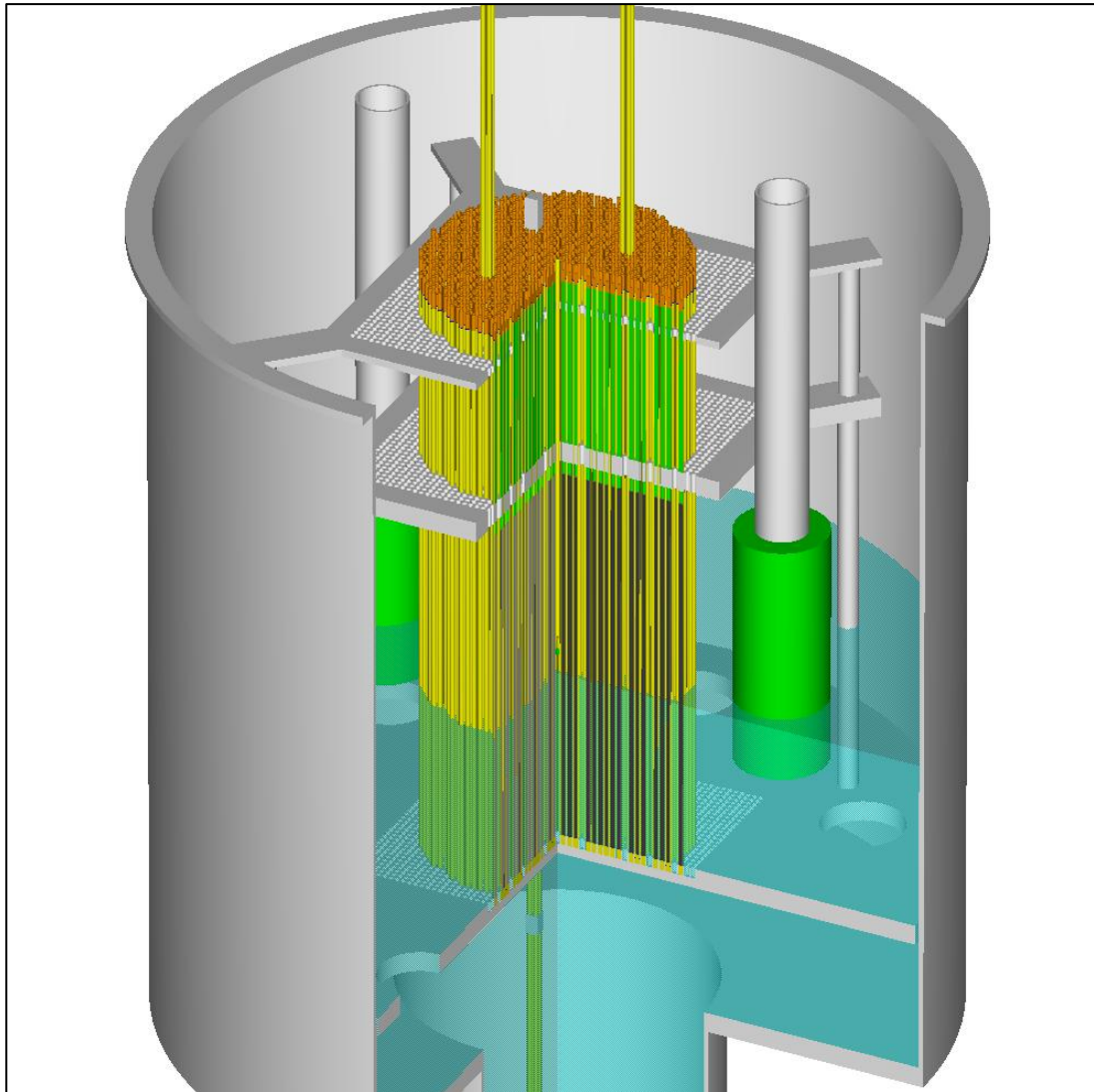
**Core Tank: Filling**

**Personnel: Excluded**

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



## Fill the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

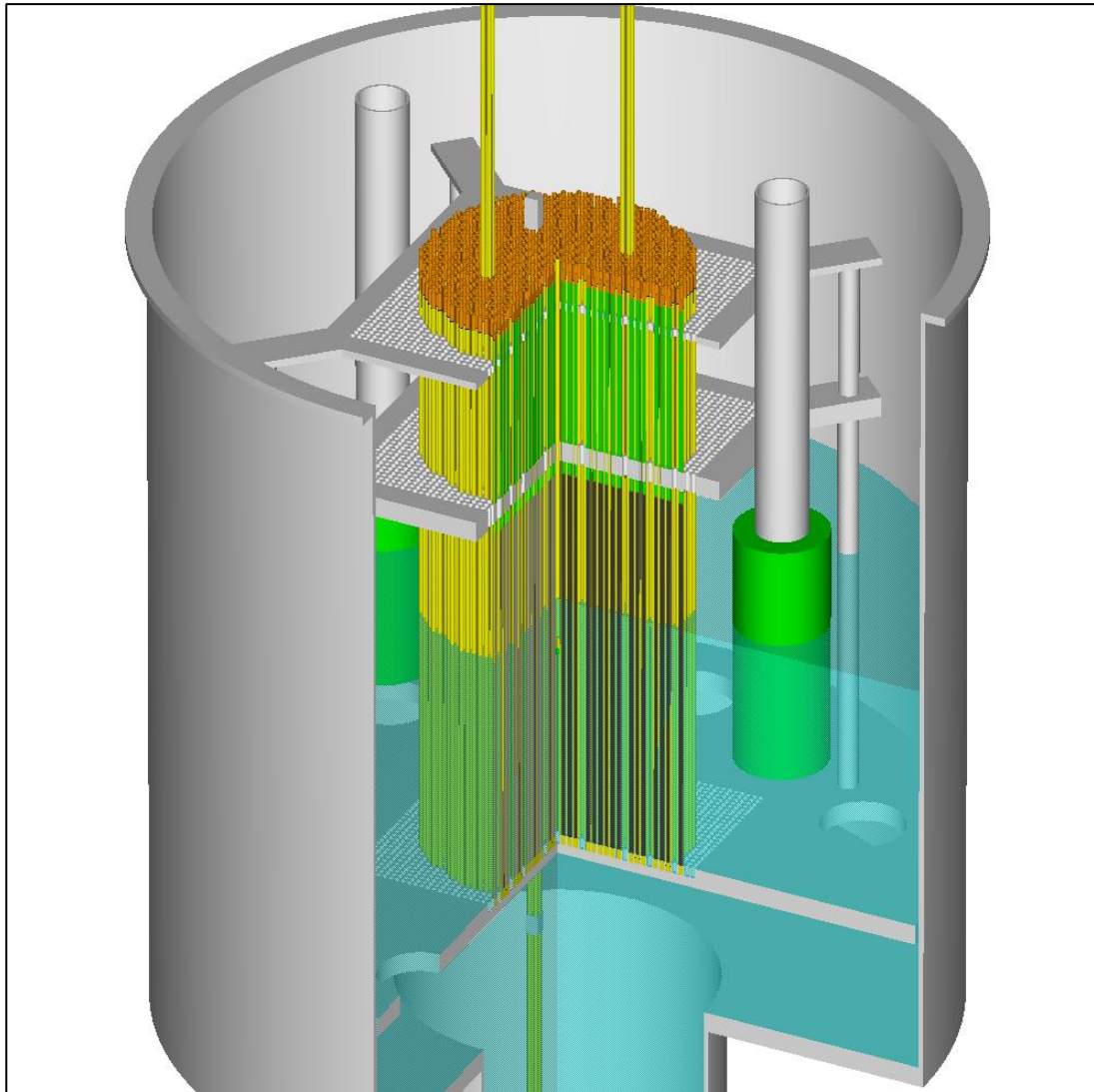
**Core Tank: Filling**

**Personnel: Excluded**

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



## Fill the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

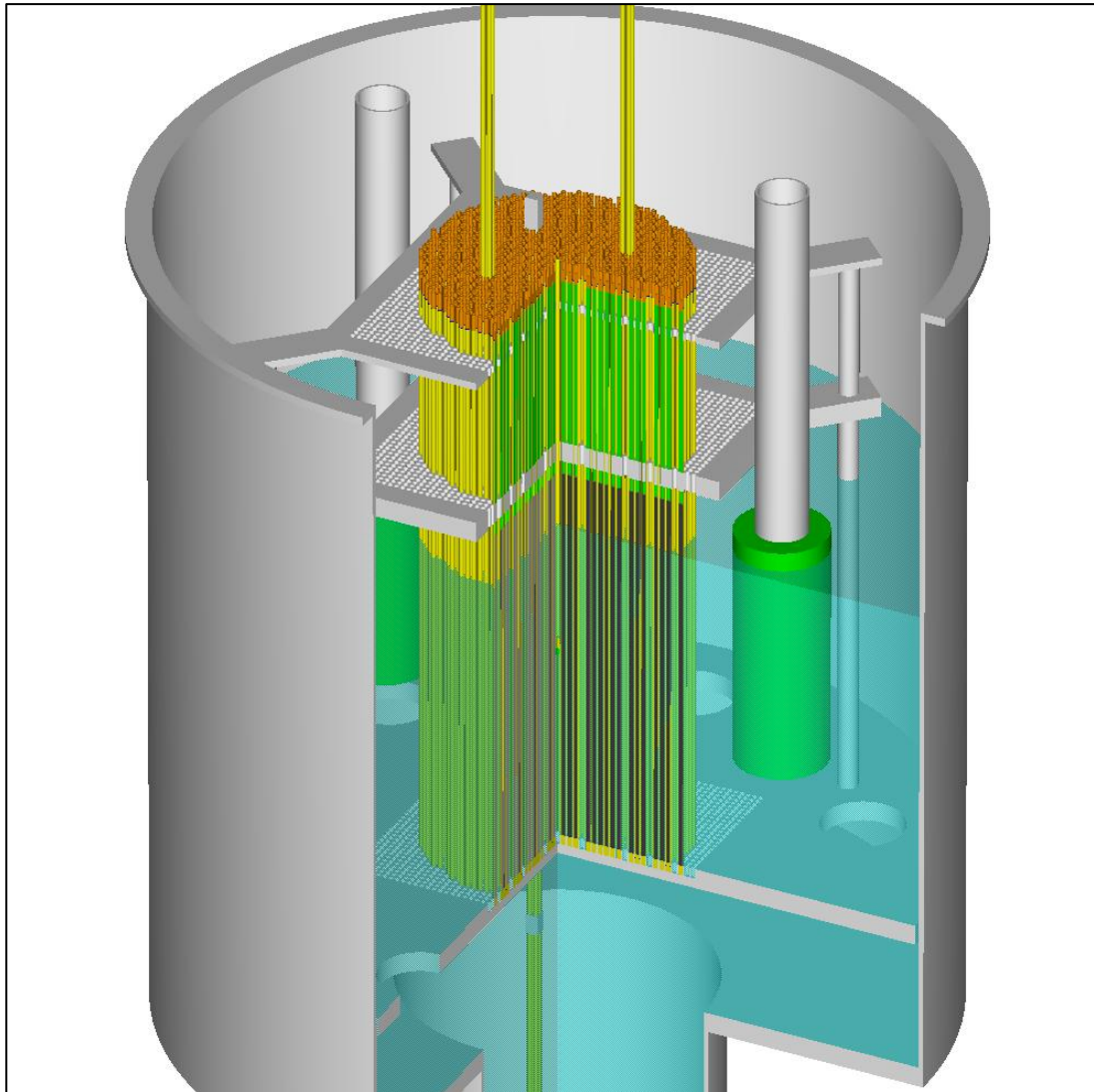
**Core Tank: Filling**

**Personnel: Excluded**

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



## Fill the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

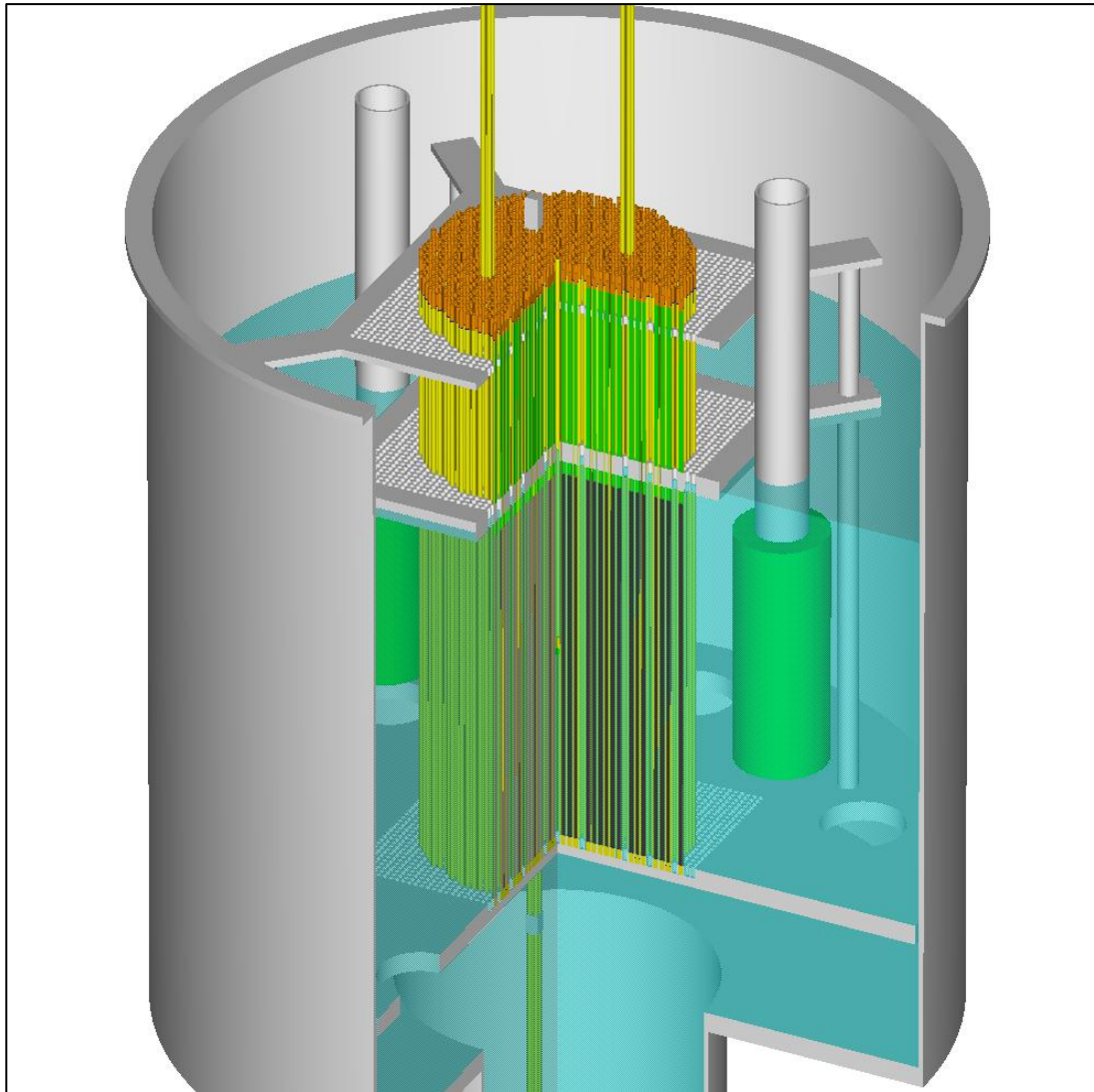
**Core Tank: Filling**

**Personnel: Excluded**

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



## Fill the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

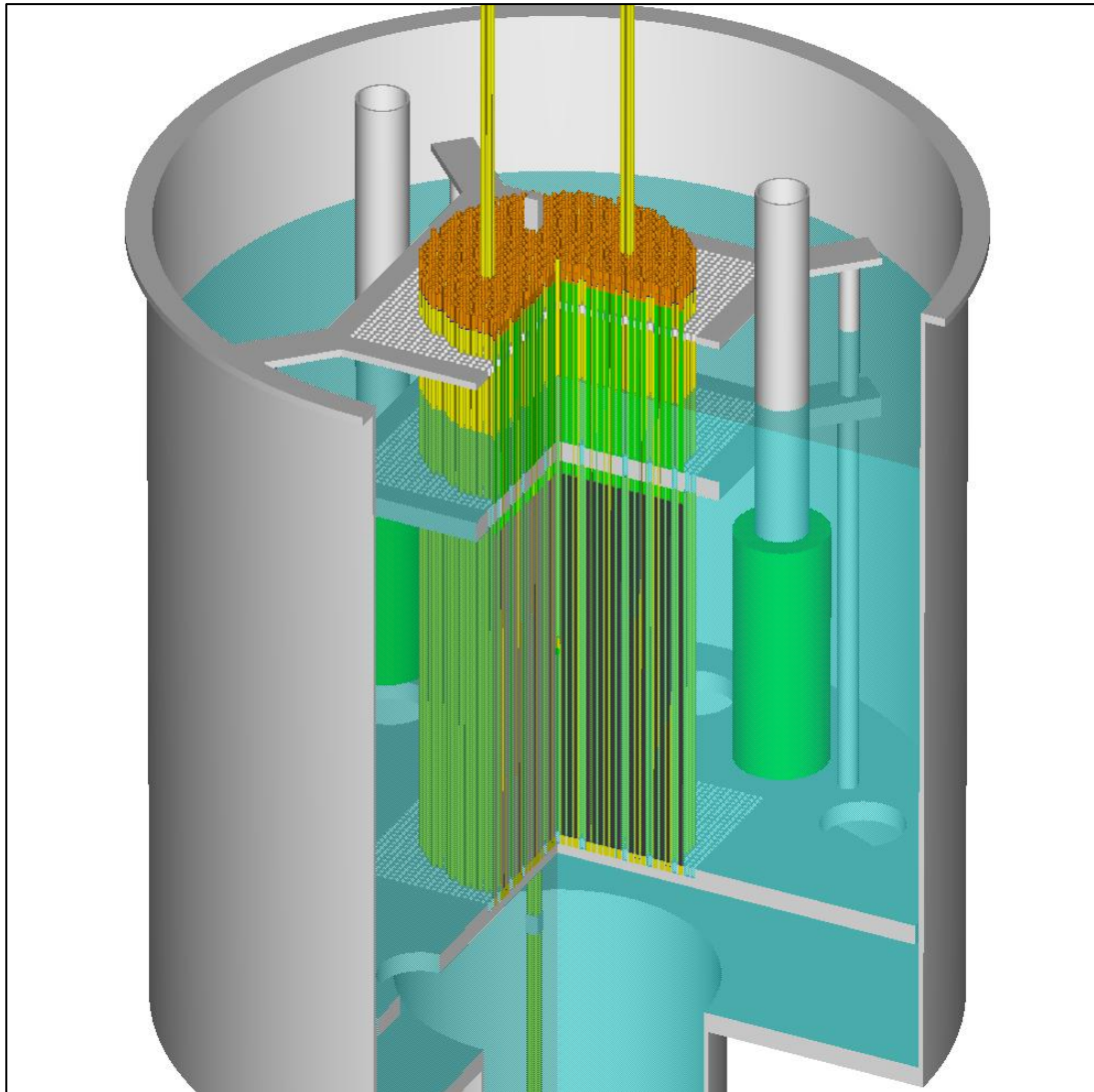
**Core Tank: Filling**

**Personnel: Excluded**

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



## Fill the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

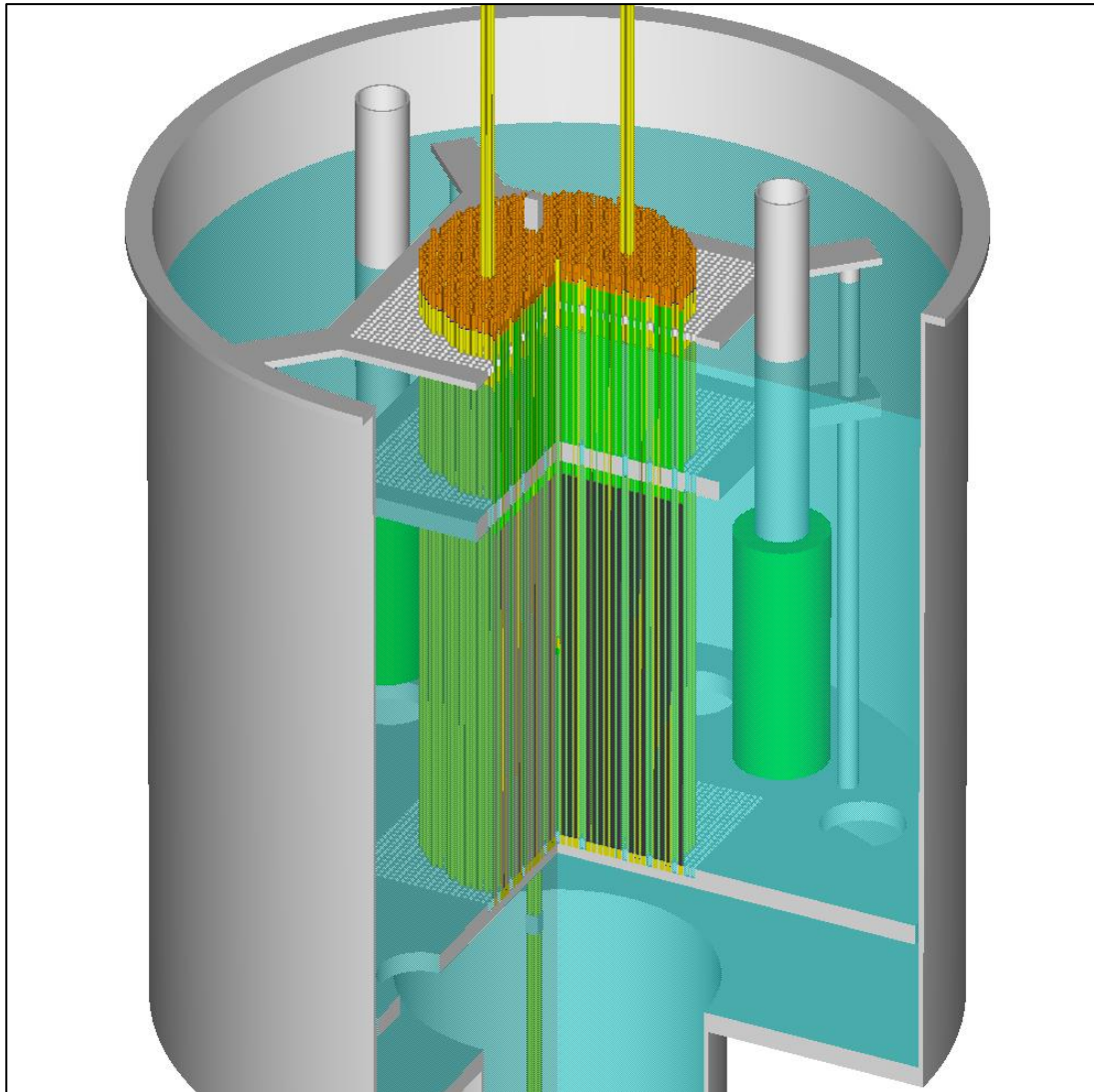
**Core Tank: Filling**

**Personnel: Excluded**

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



## The core tank is full



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

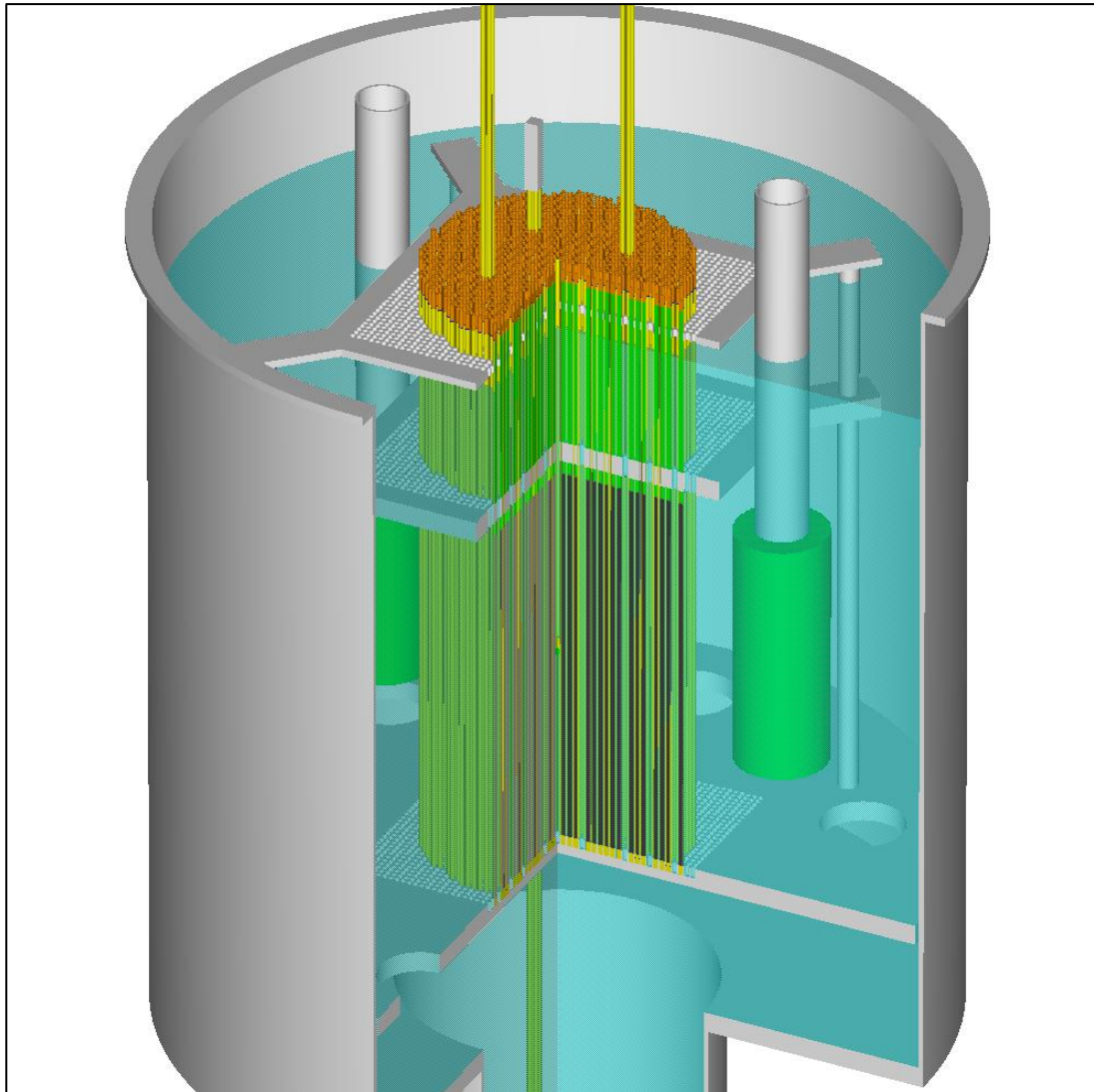
**Core Tank: Full**

**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**

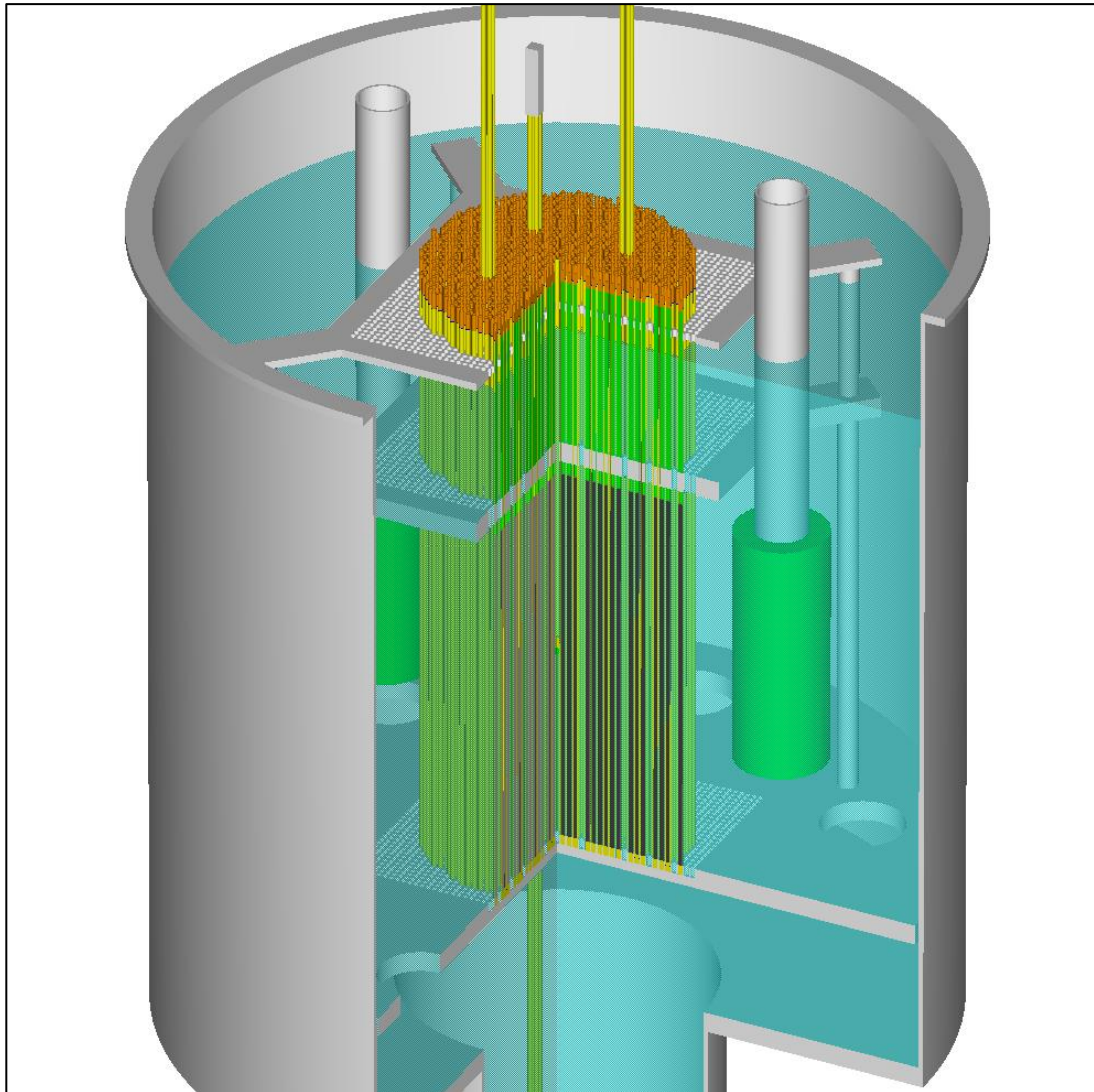
**Core Tank: Full**

**Personnel: Excluded**

**It takes about 90 seconds to raise the control element.**



## Raise the control element



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Raising**

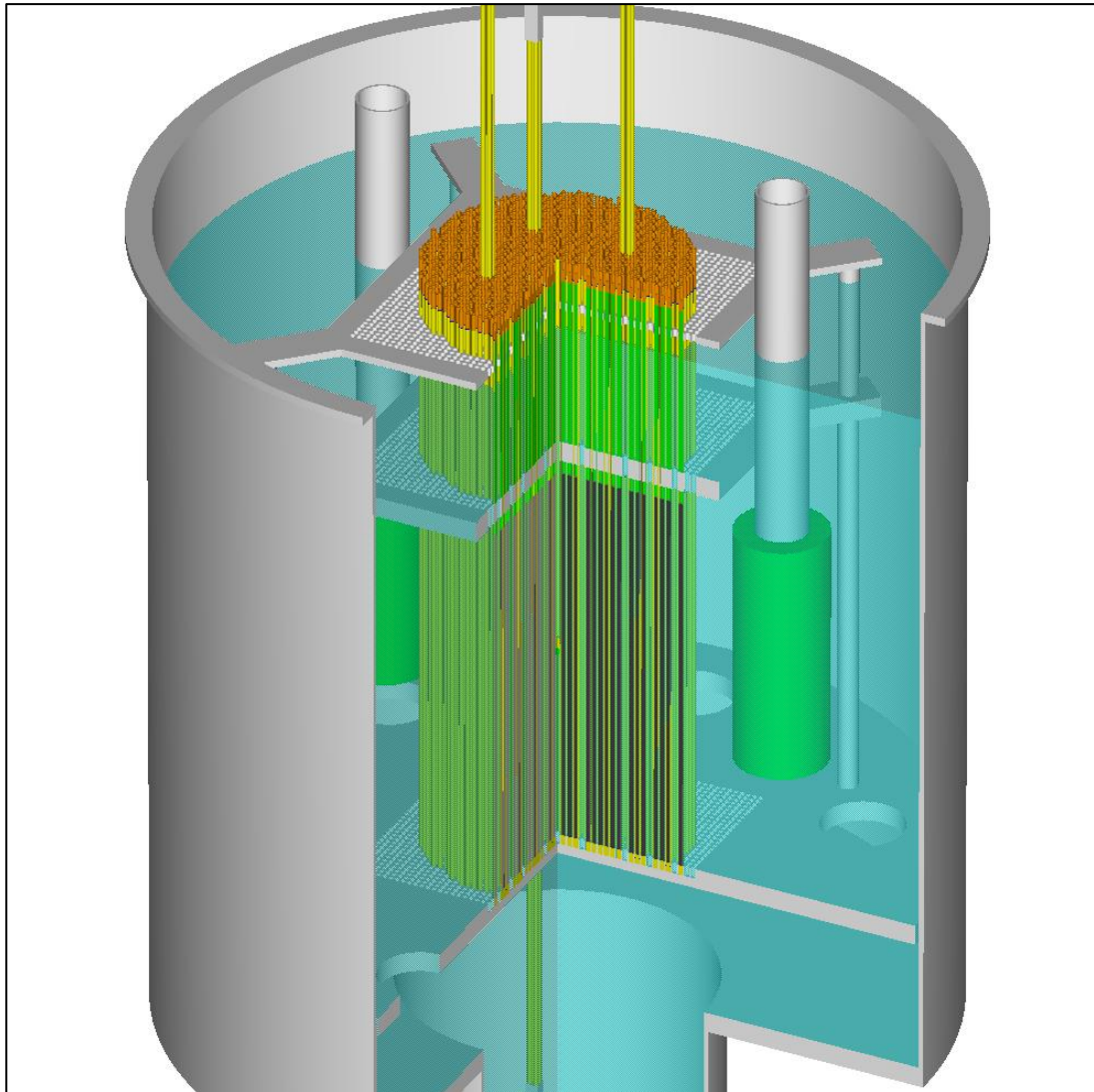
**Core Tank: Full**

**Personnel: Excluded**

**It takes about 90 seconds to raise the control element.**



## Raise the control element



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Raising**

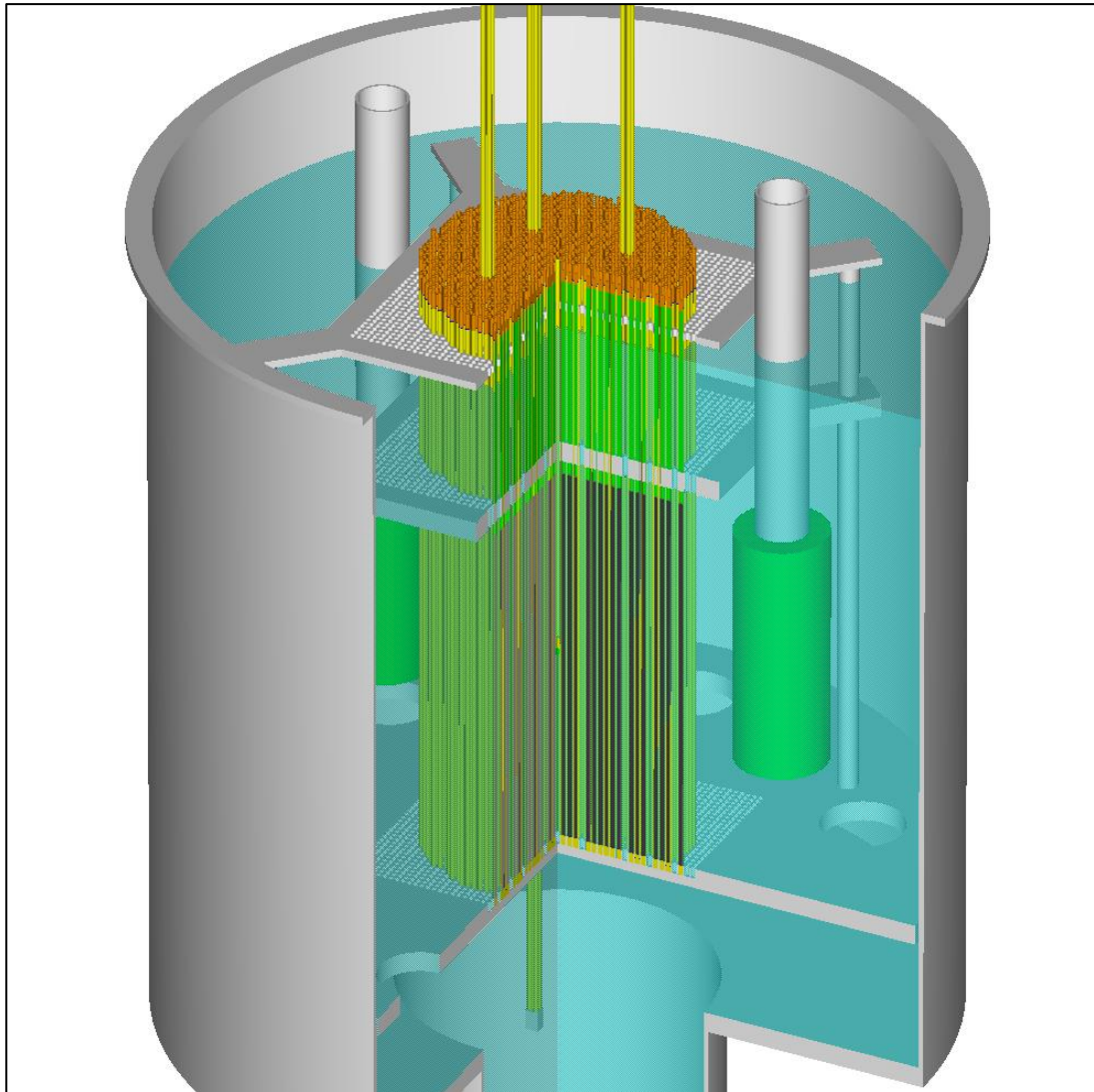
**Core Tank: Full**

**Personnel: Excluded**

**It takes about 90 seconds to raise the control element.**



## Raise the control element



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Raising**

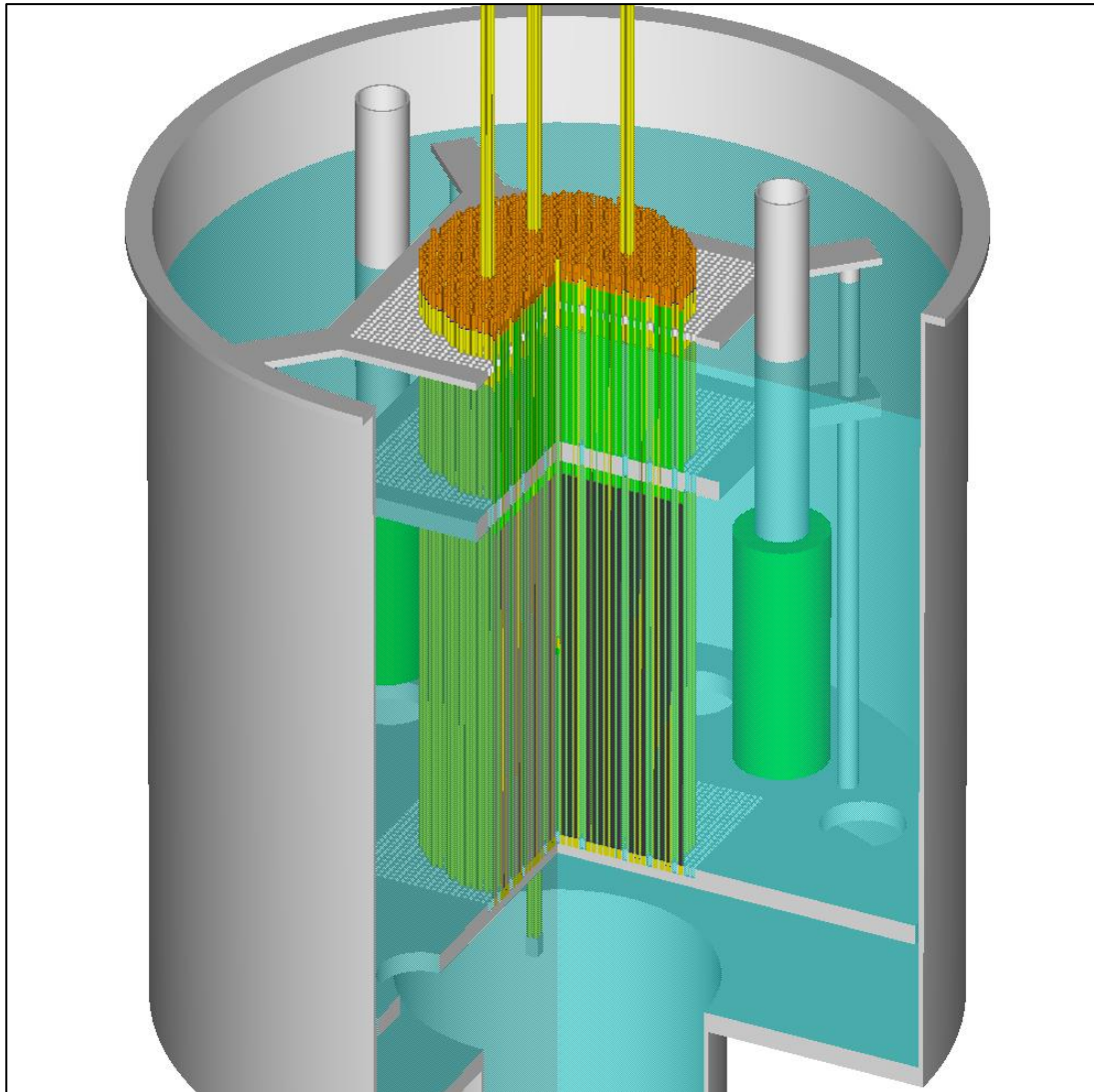
**Core Tank: Full**

**Personnel: Excluded**

**It takes about 90 seconds to raise the control element.**



## Raise the control element



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Raising**

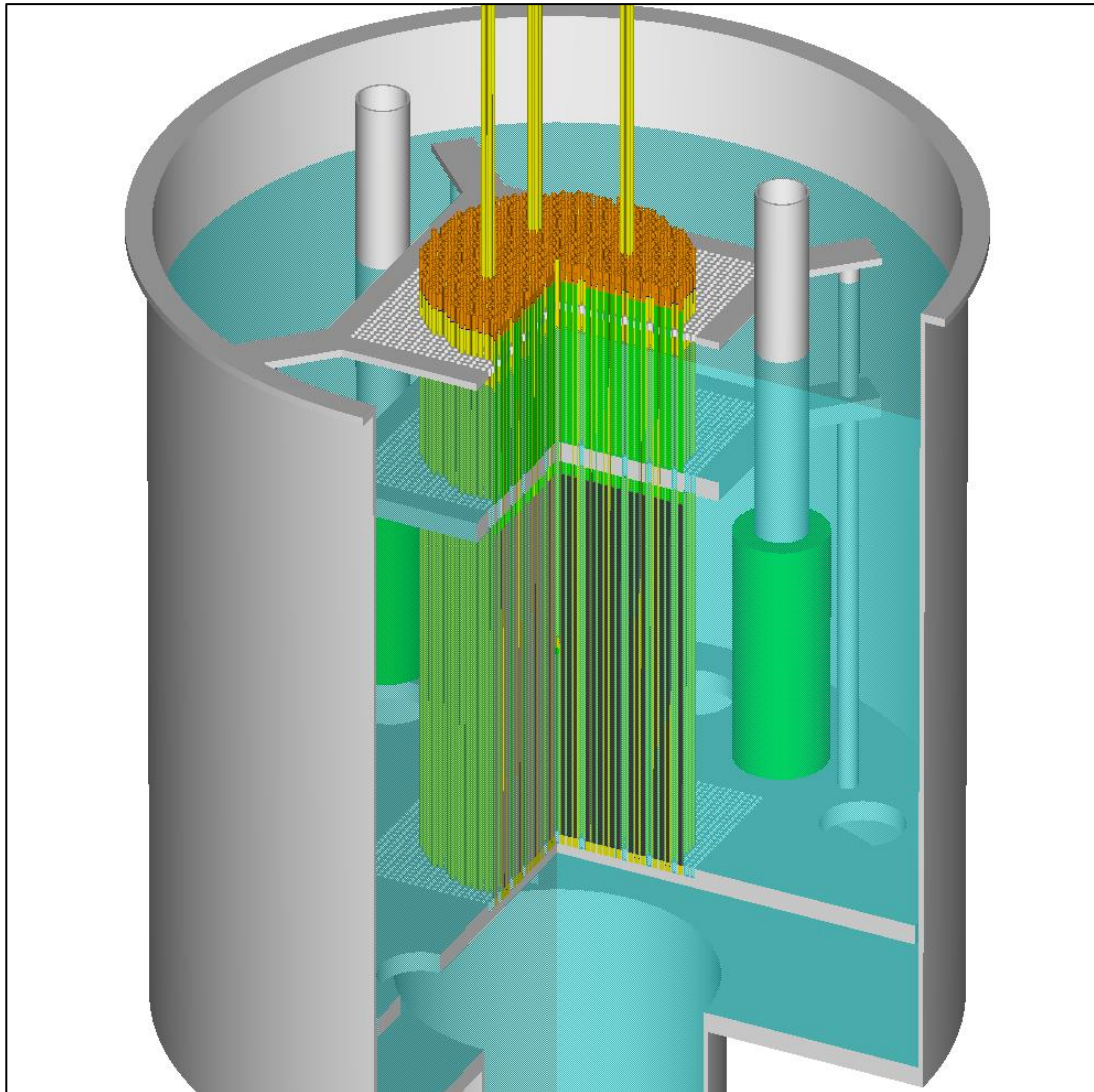
**Core Tank: Full**

**Personnel: Excluded**

**It takes about 90 seconds to raise the control element.**



## Raise the control element



**Fuel: 1136**

**Safety Elements: Up**

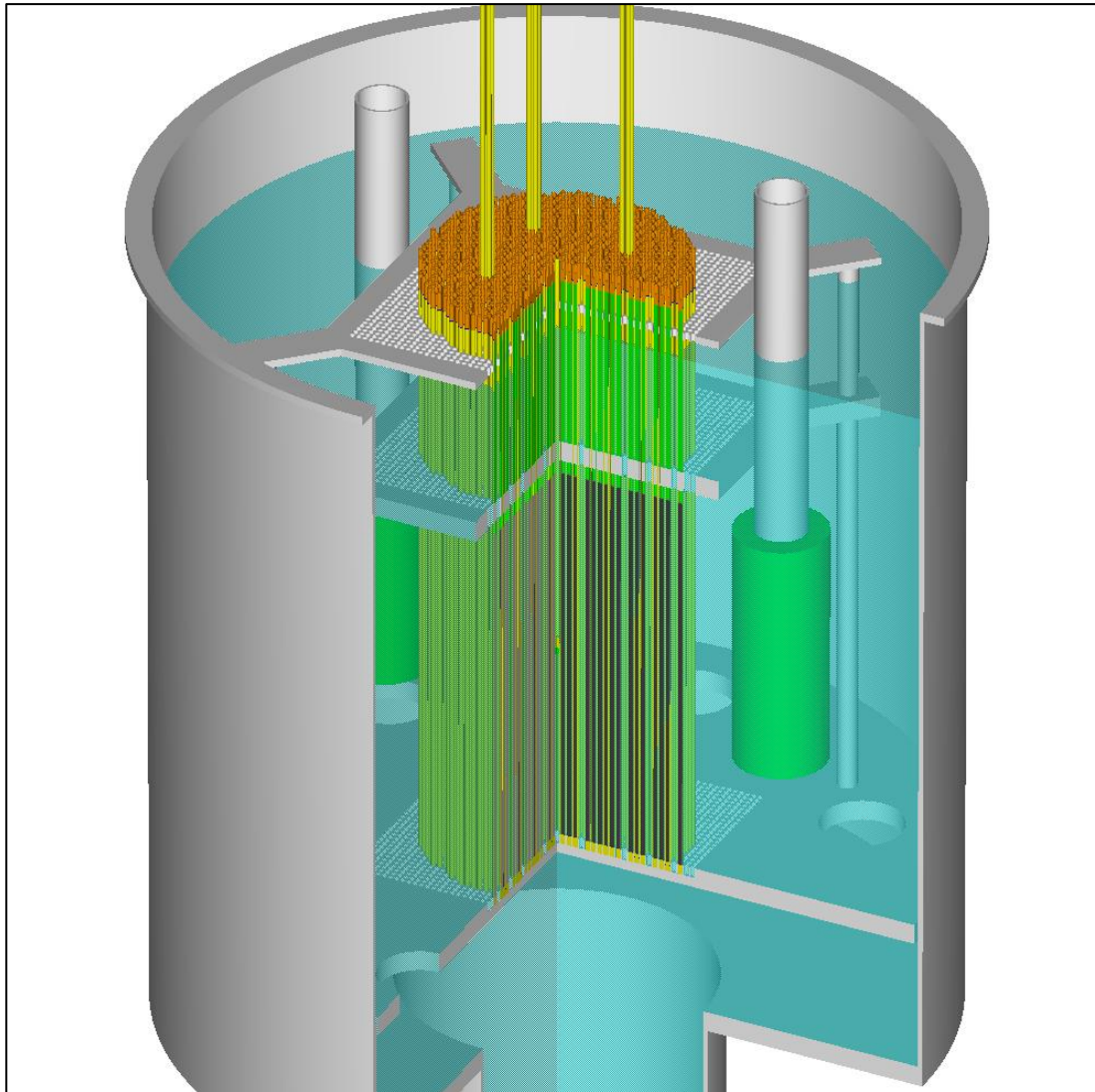
**Control Element: Raising**

**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**

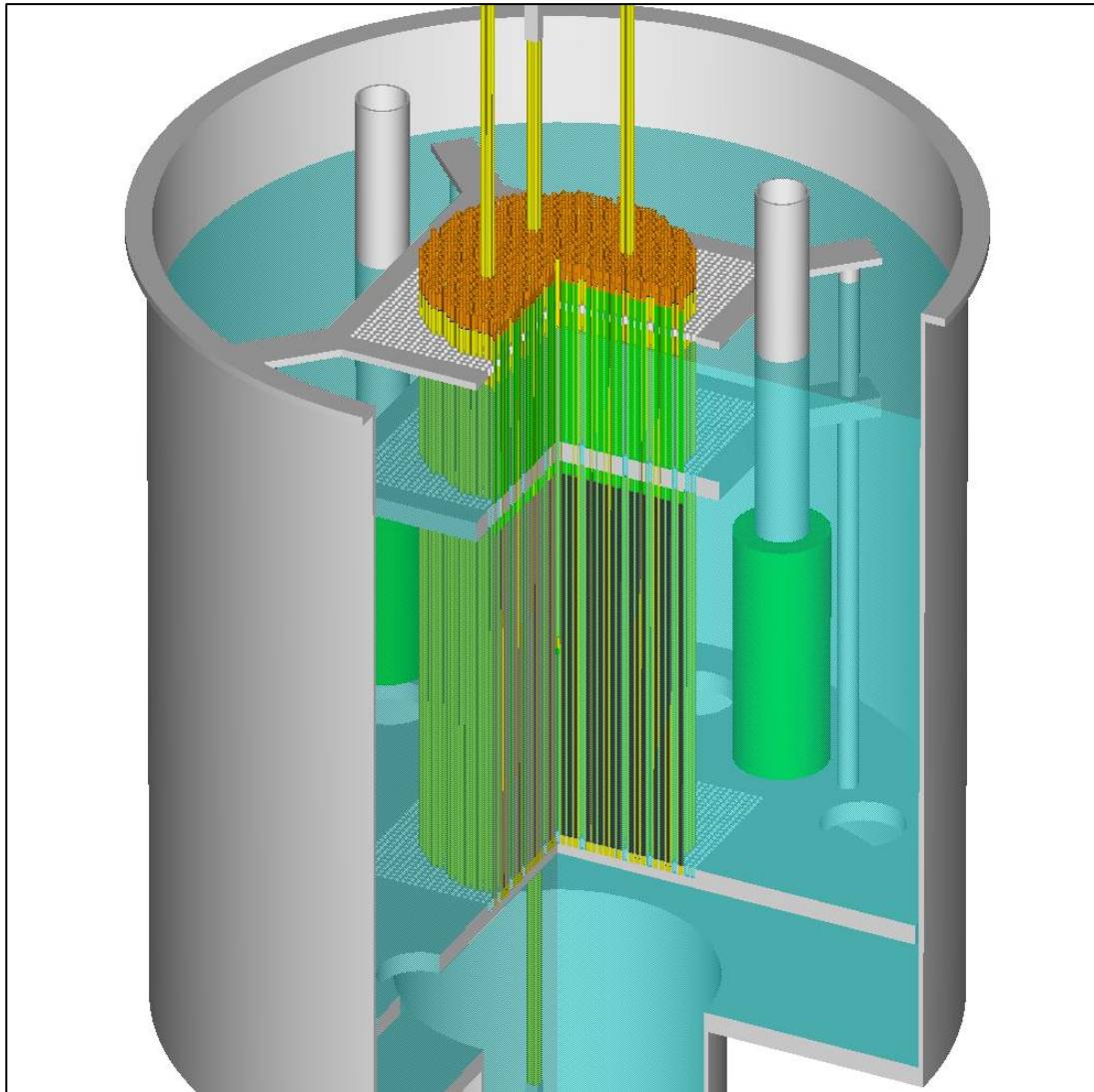
**Core Tank: Full**

**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**

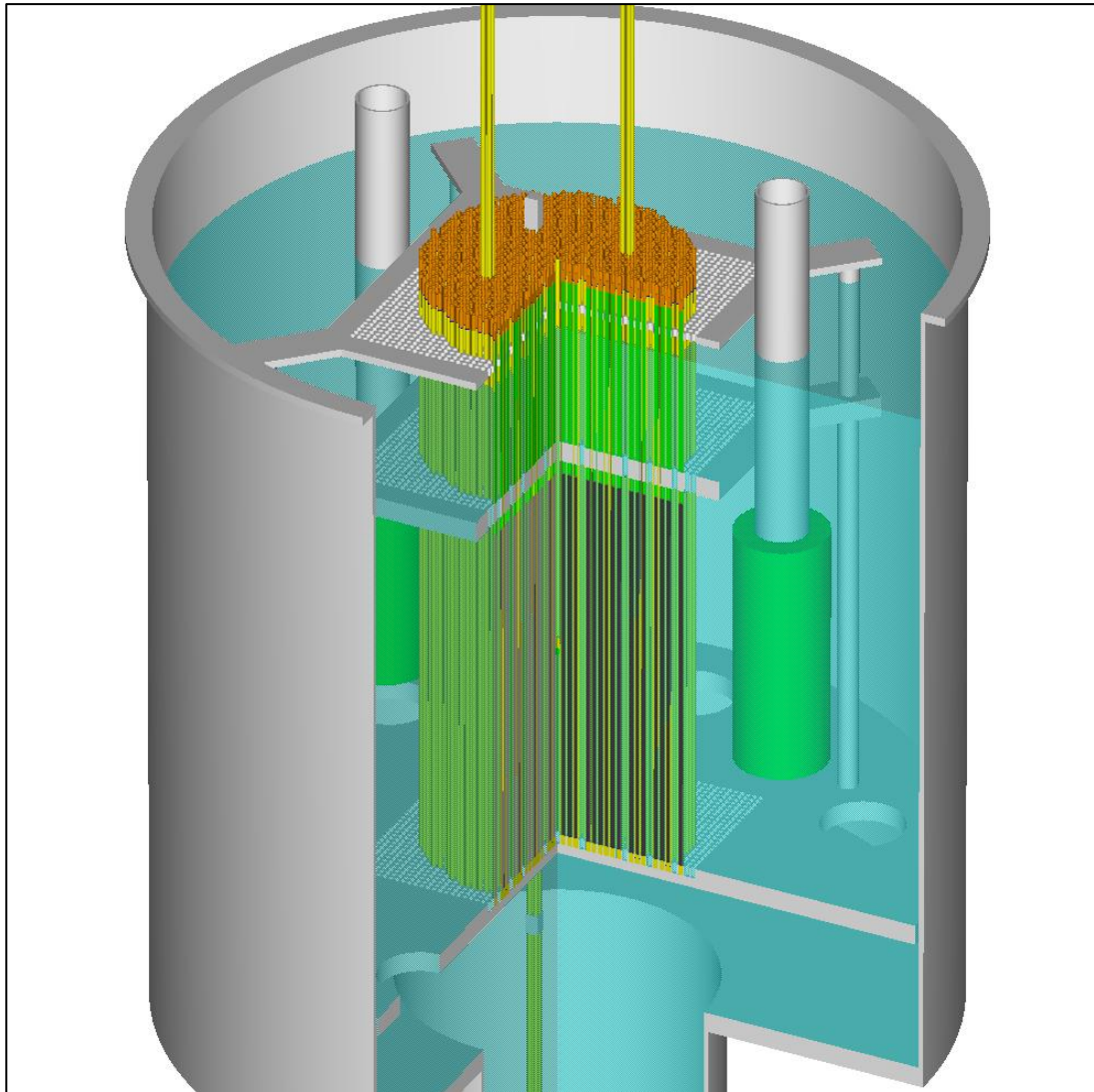
**Core Tank: Full**

**Personnel: Excluded**

**It takes about 90 seconds to  
lower the control element.**



## Lower the control element



**Fuel: 1136**

**Safety Elements: Up**

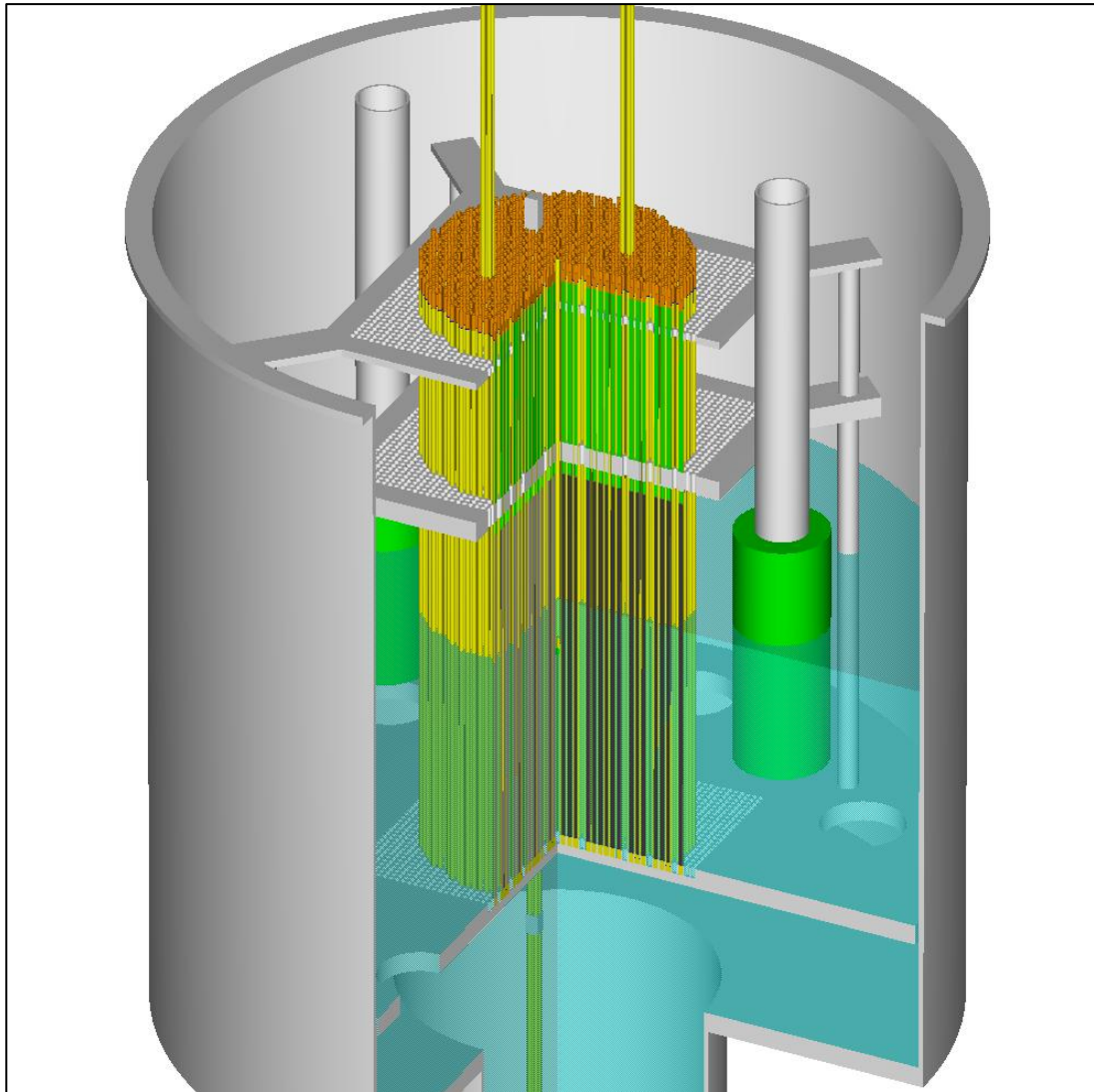
**Control Element: Down**

**Core Tank: Full**

**Personnel: Excluded**



## Drain the core tank



**Fuel: 1136**

**Safety Elements: Up**

**Control Element: Down**

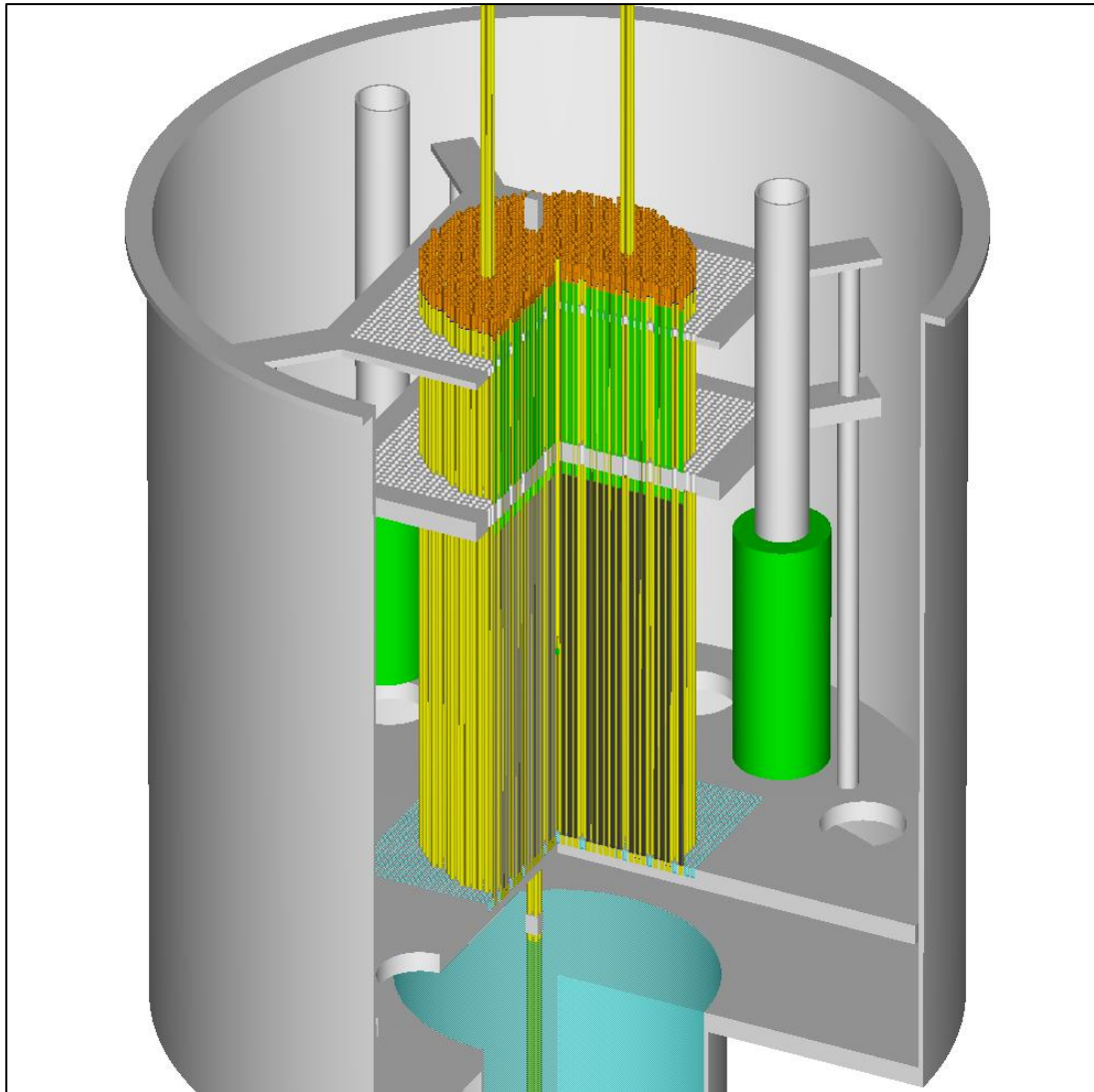
**Core Tank: Draining**

**Personnel: Excluded**

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



## Drain the core tank



**Fuel: 1136**

**Safety Elements: Up**

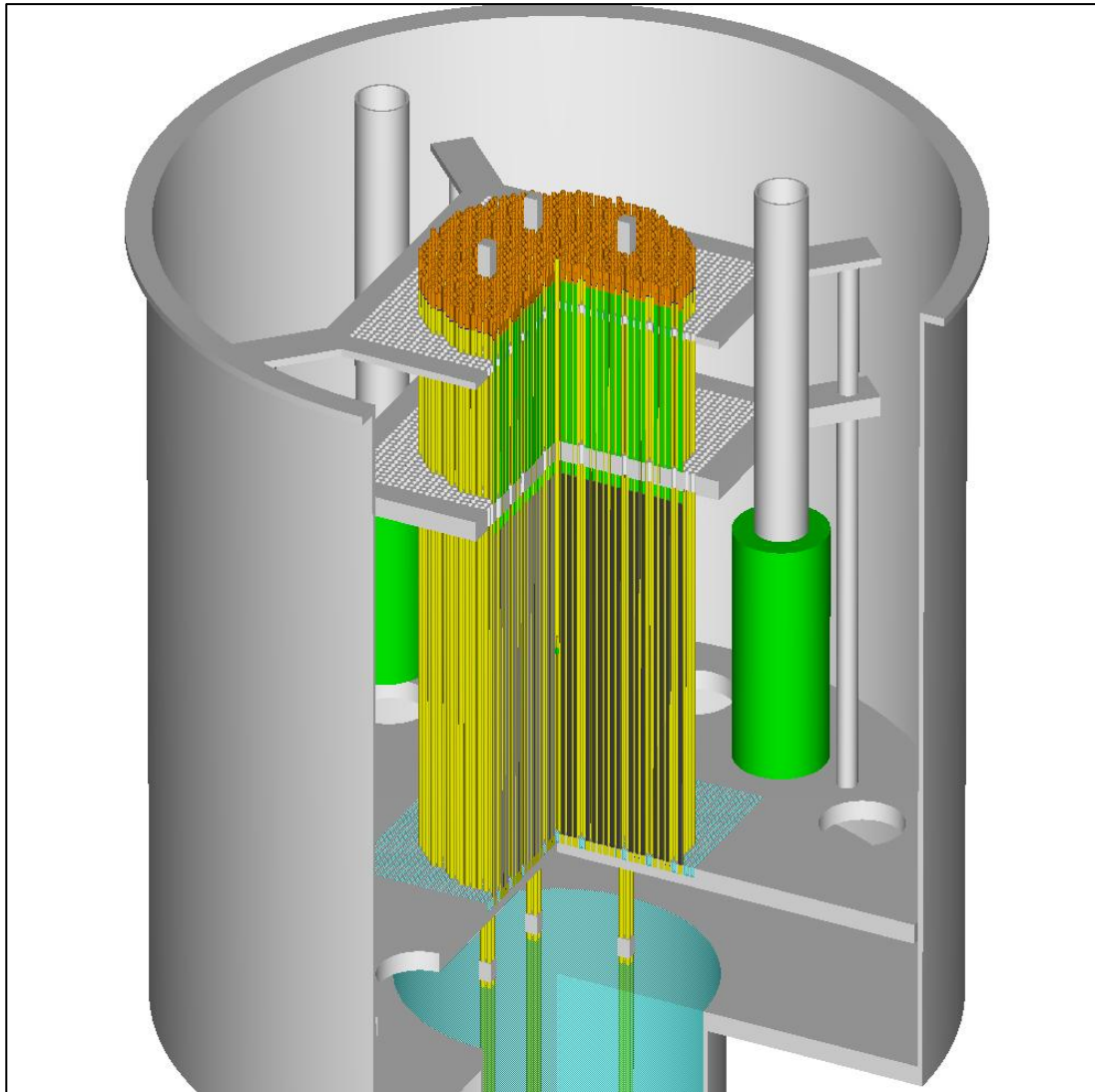
**Control Element: Down**

**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**

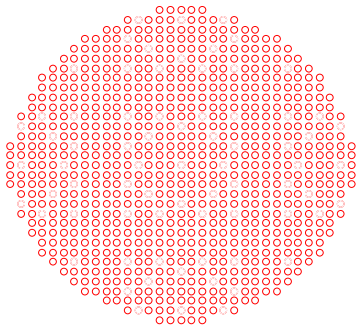
**Control Element: Down**

**Core Tank: Empty**

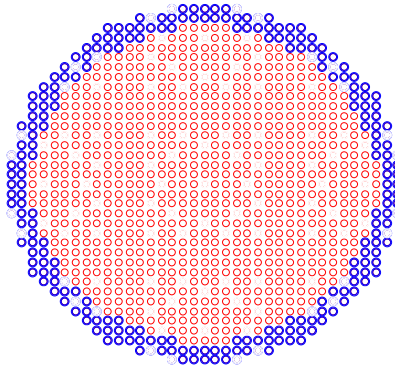
**Personnel: Allowed**

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

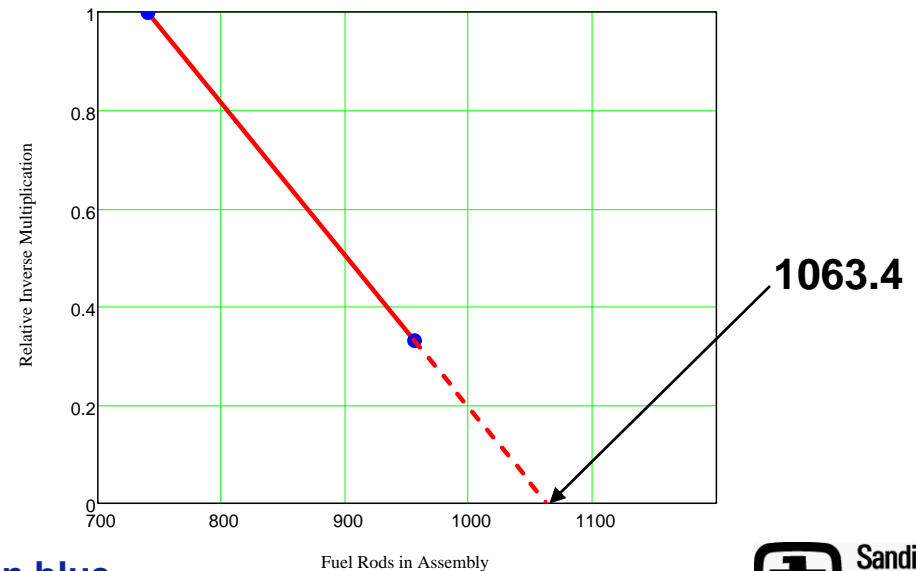
The first two arrays have  
 $k_{\text{eff}} \sim 0.9$  and  $k_{\text{eff}} \sim 0.95$   
 (calculated)

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

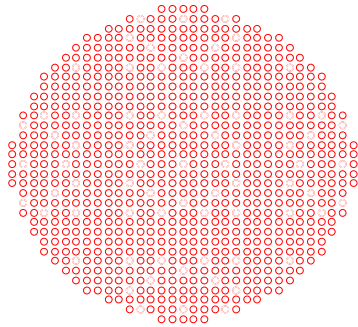
$$\frac{1}{M} = 1 - k_{\text{eff}}$$

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

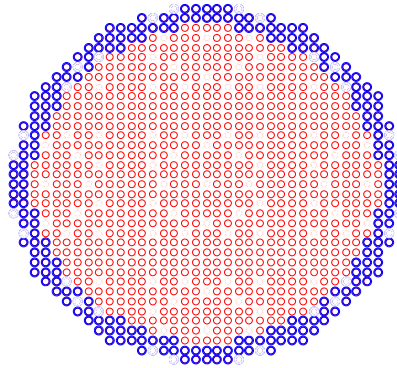
The incremental fuel elements are shown in blue



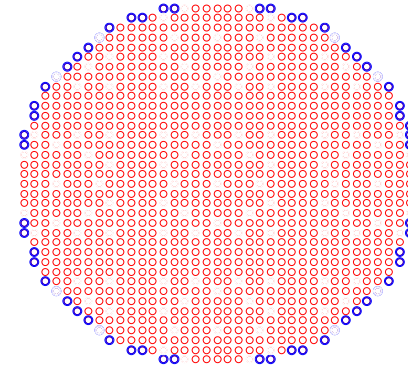
# Core configurations during the first approach-to-critical experiment (2)



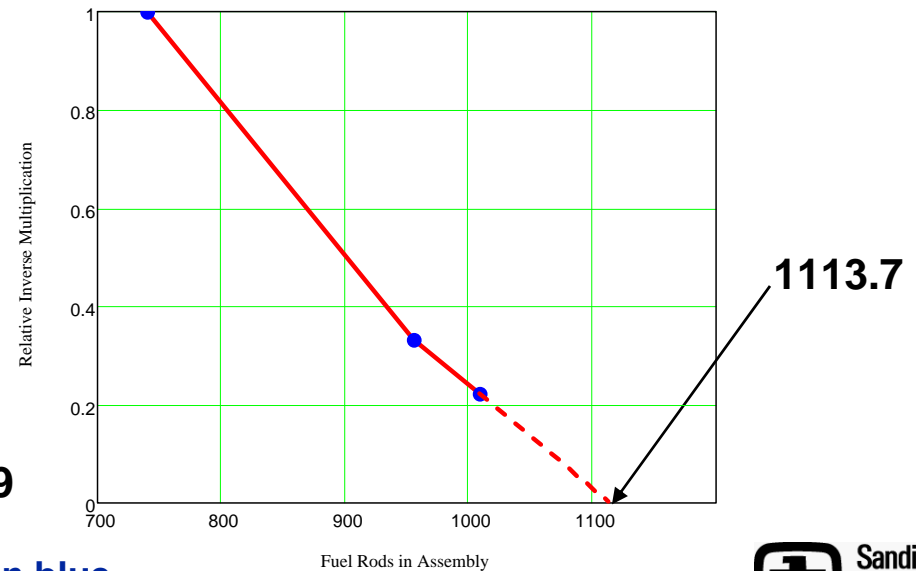
740



956



1009

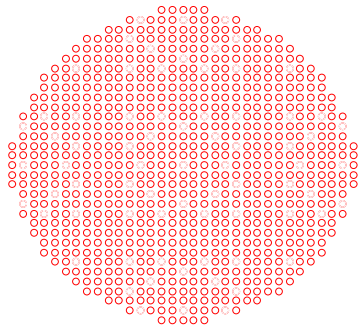


The next array: 1059

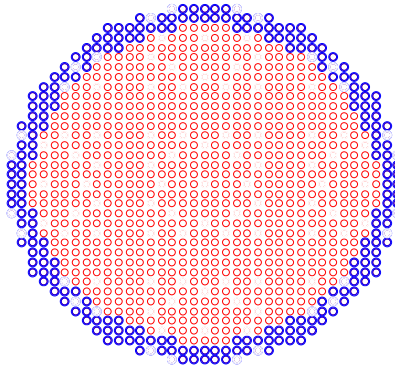
The incremental fuel elements are shown in blue



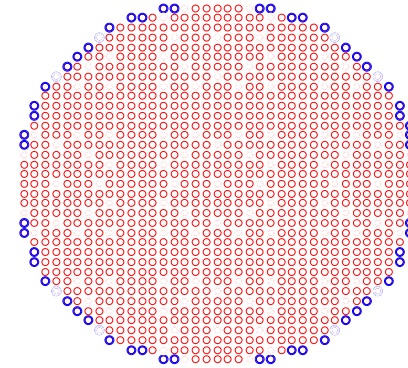
# Core configurations during the first approach-to-critical experiment (3)



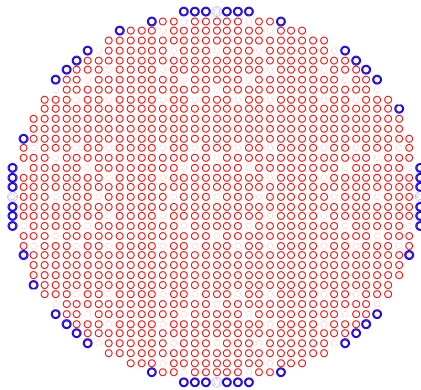
740



956

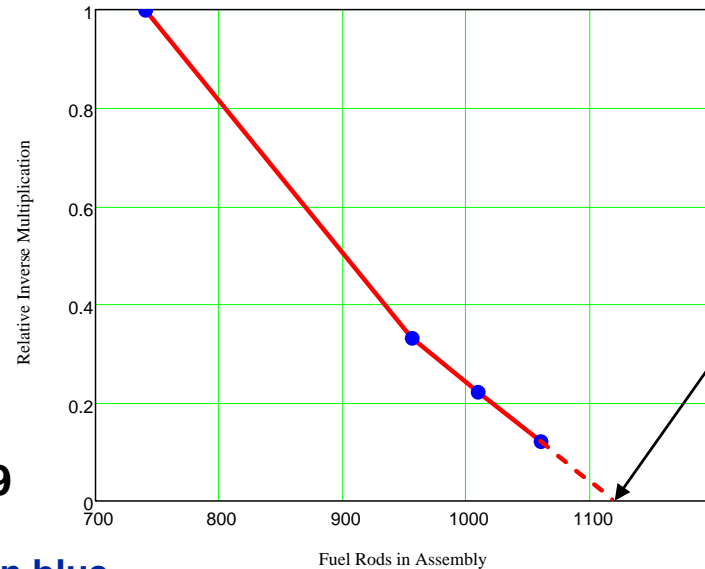


1009



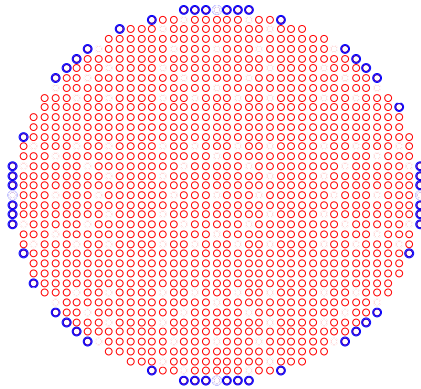
1059

The next array: 1089

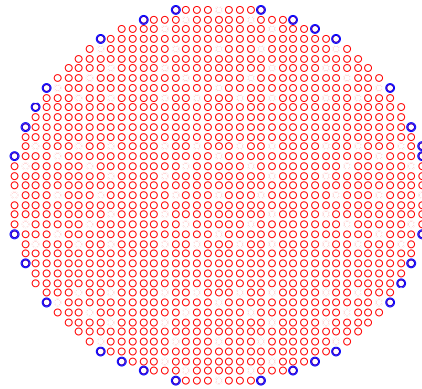


The incremental fuel elements are shown in blue

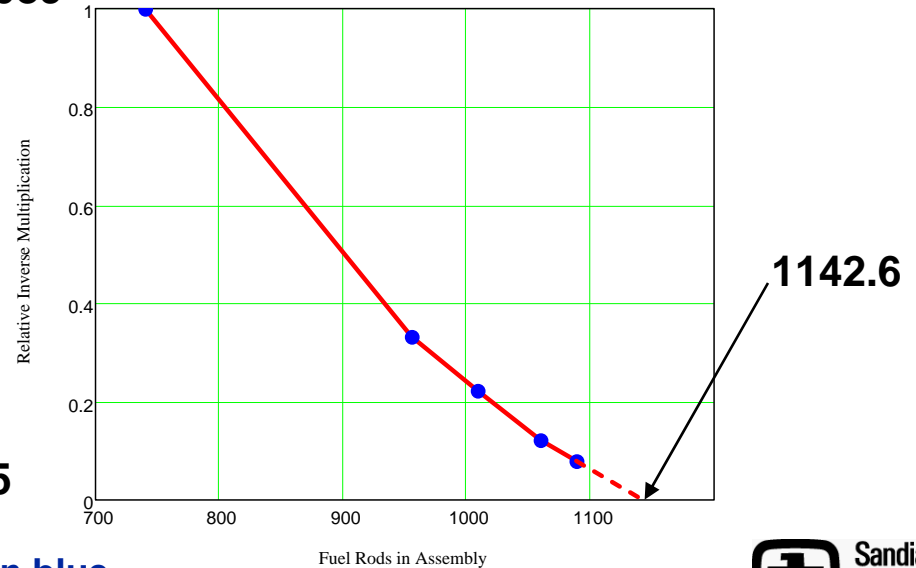
# Core configurations during the first approach-to-critical experiment (4)



1059



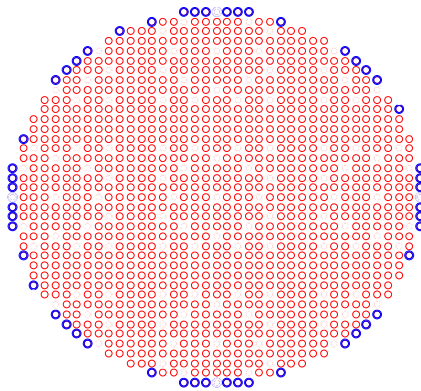
1089



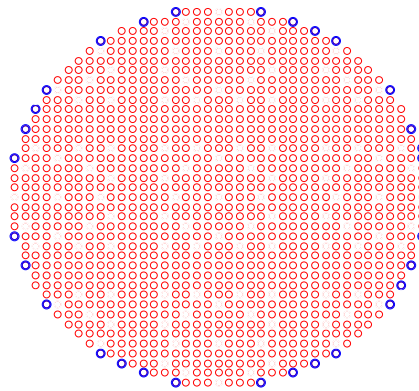
The next array: 1115

The incremental fuel elements are shown in blue

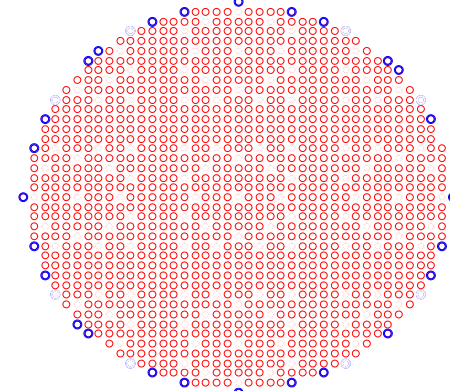
# Core configurations during the first approach-to-critical experiment (4)



1059



1089

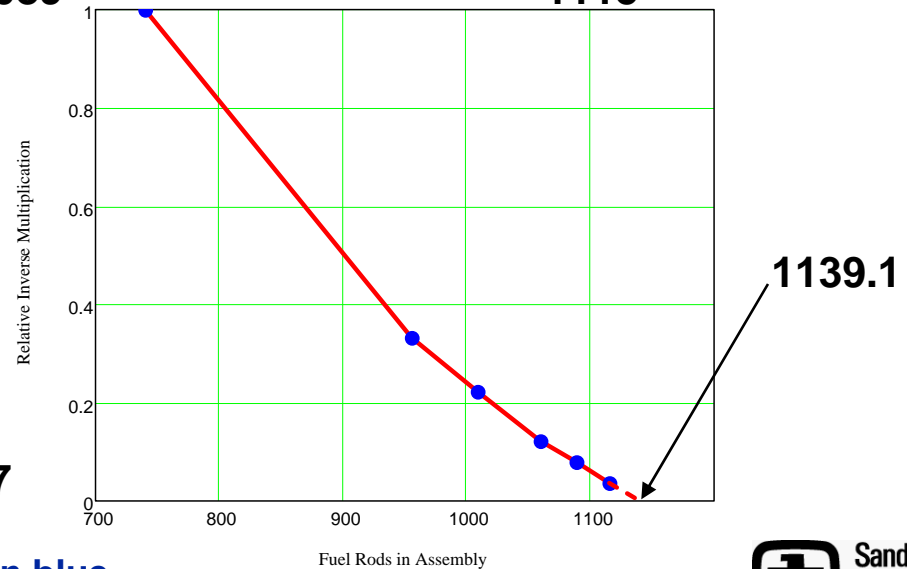


1115

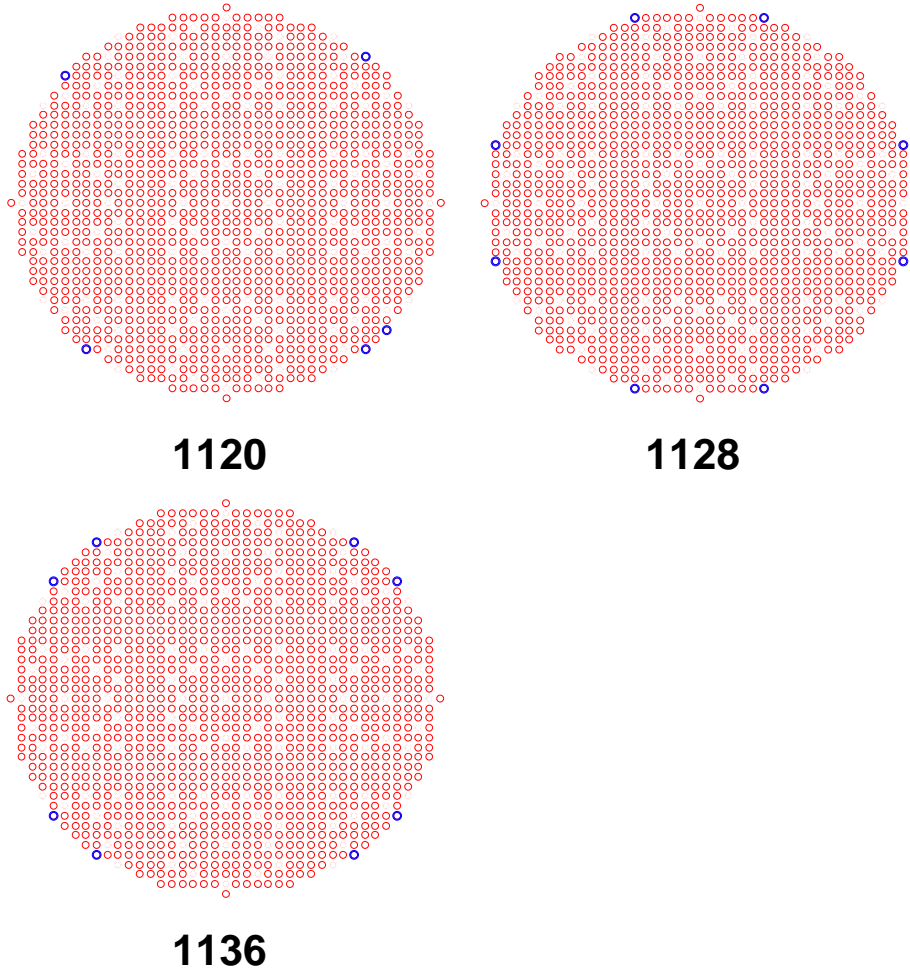
We also made measurements with 1127, 1136, 1140, and 1144 elements (all subcritical). A core with 1148 elements was supercritical.

The next array: 1127

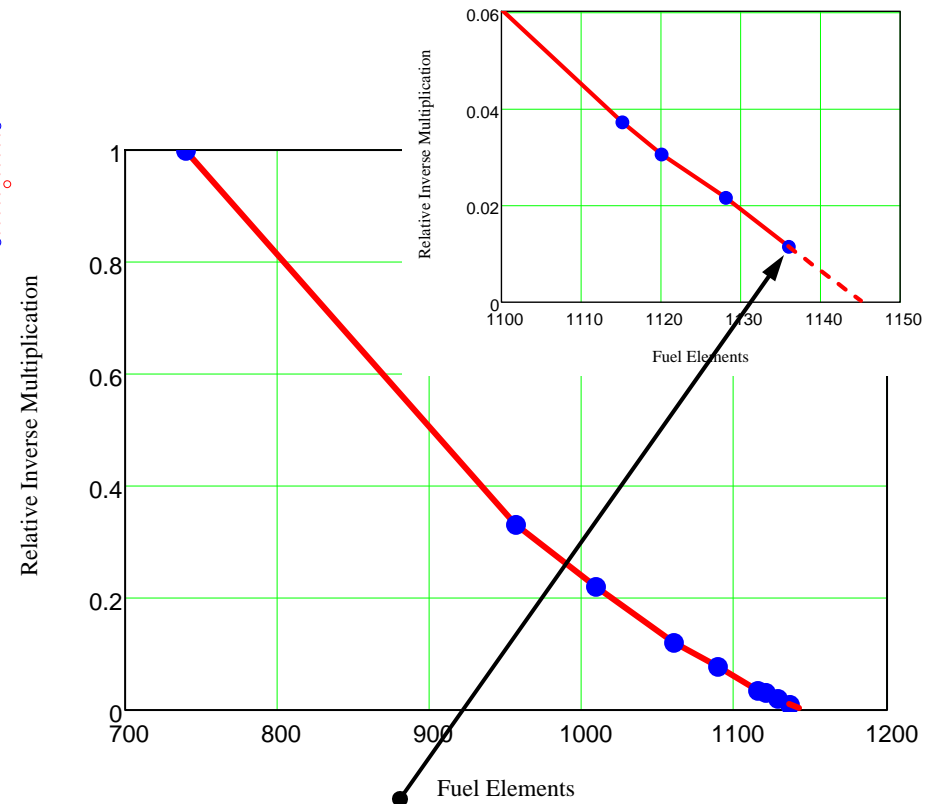
The incremental fuel elements are shown in blue



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



The incremental fuel elements are shown in blue



At 1136 fuel elements:

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

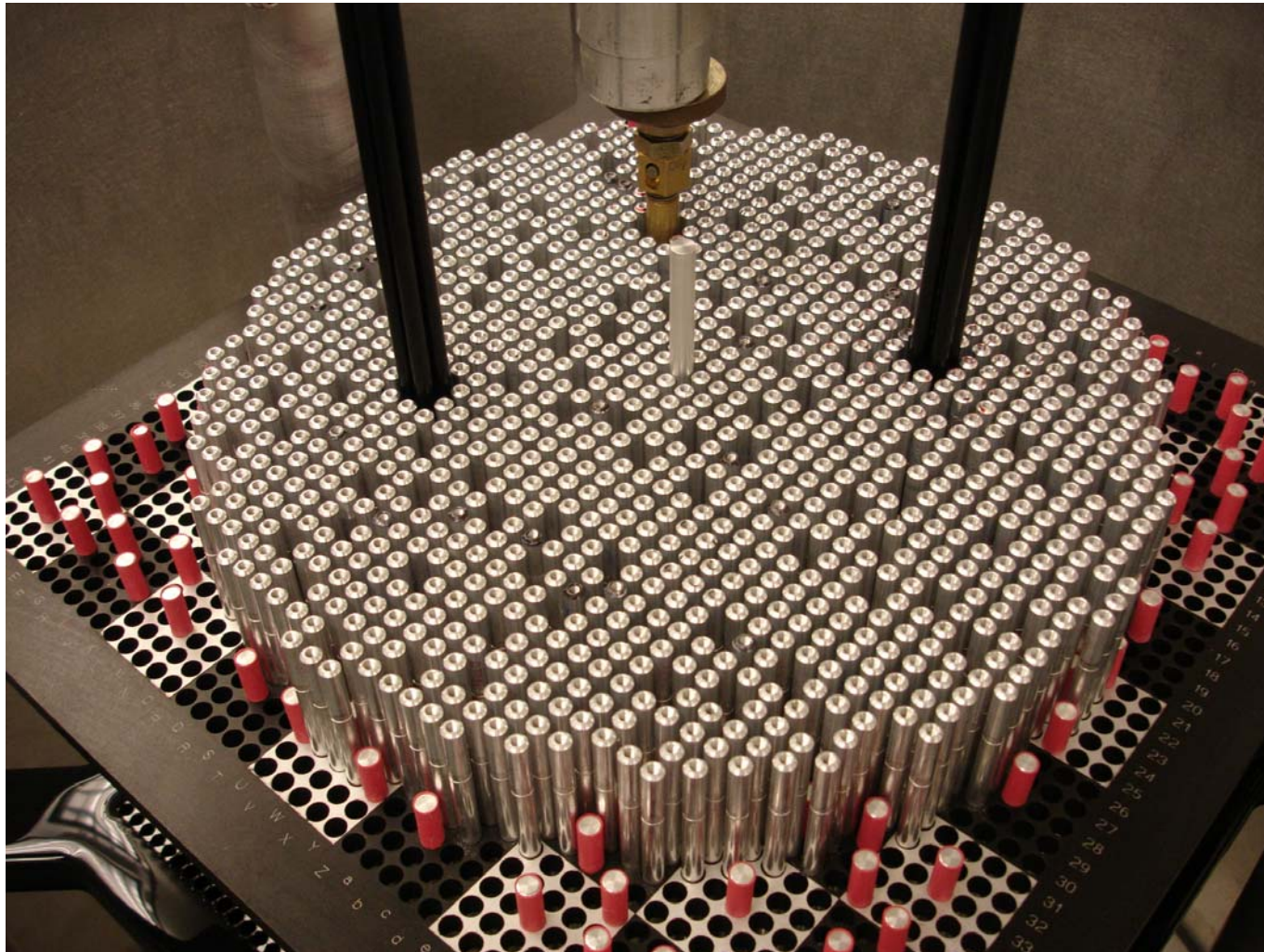
$$k_{\text{eff}} = 0.9984$$

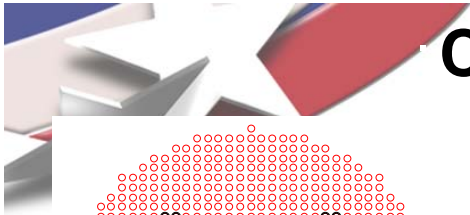
$$M \sim 610$$



## The first 7uPCX core at the end of the approach

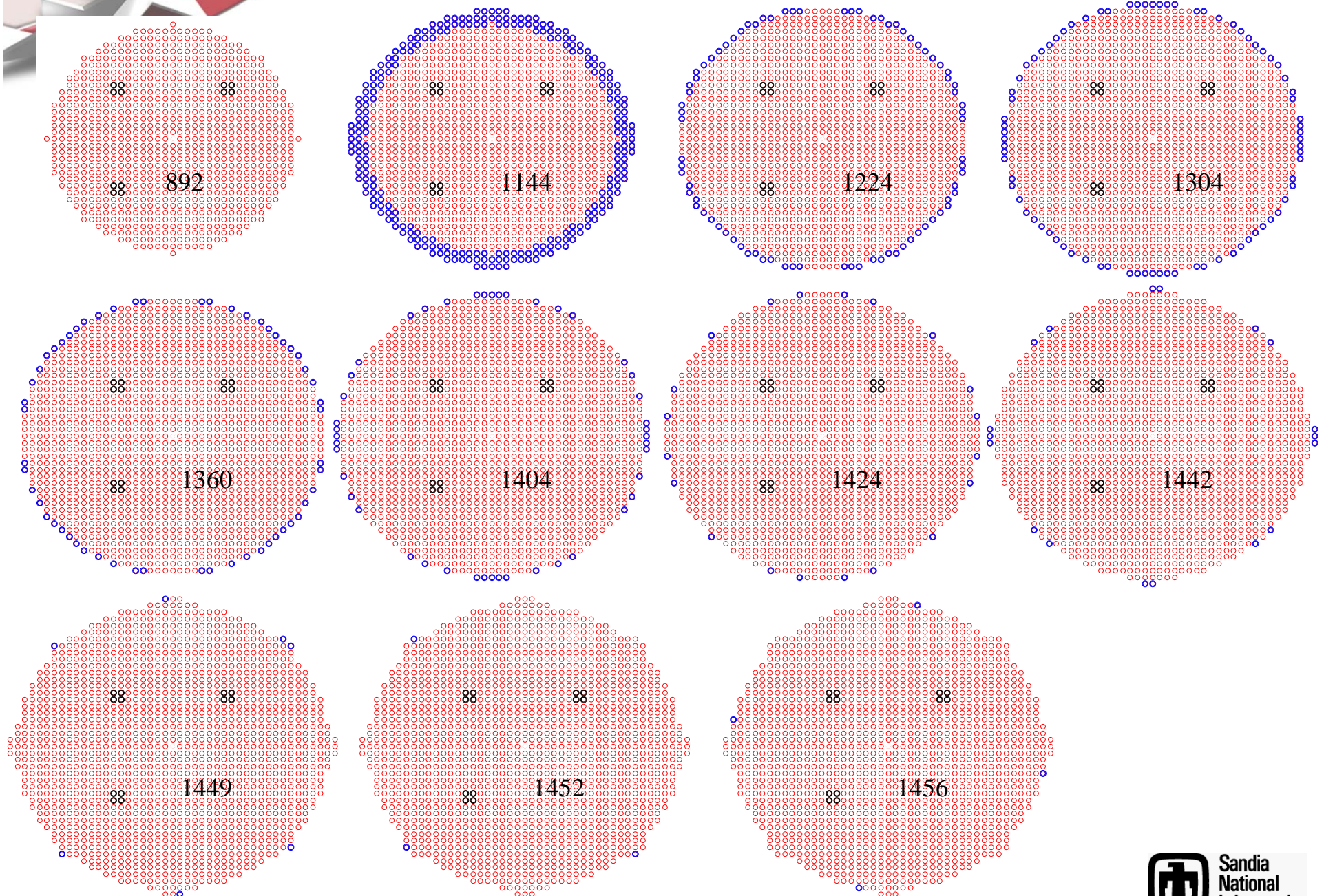
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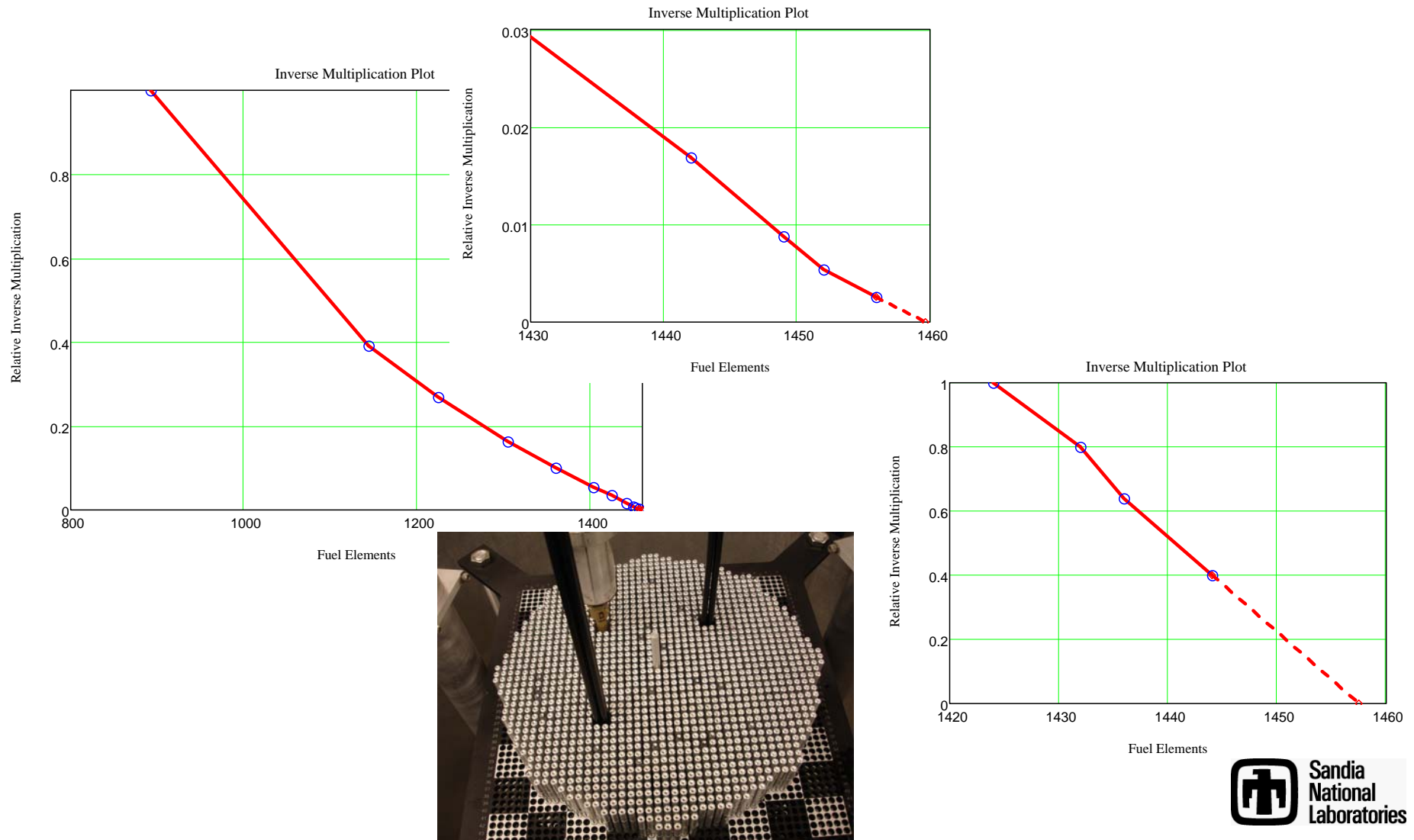
# Core “A” Configurations Starting 2/9/10

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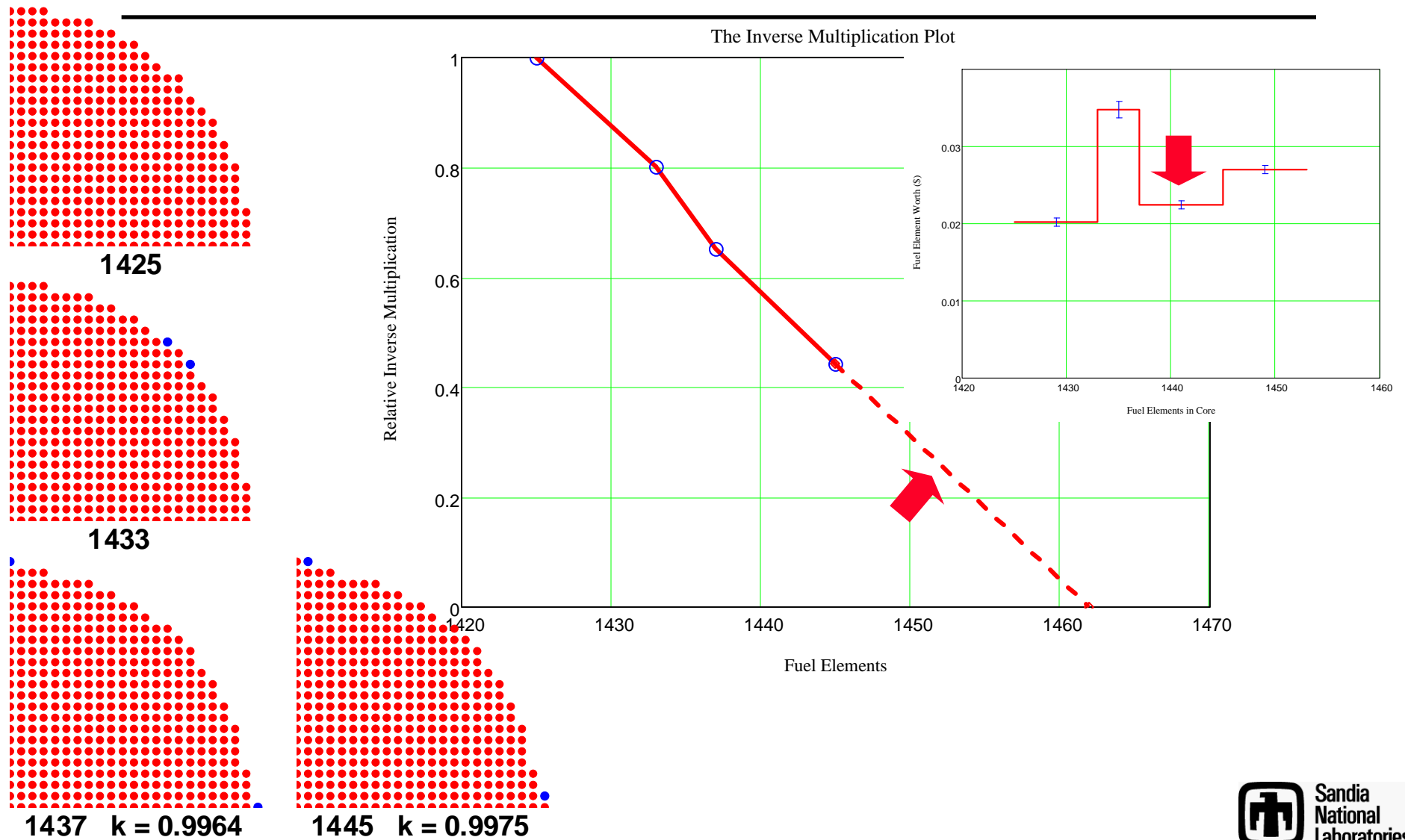


# The “A” core

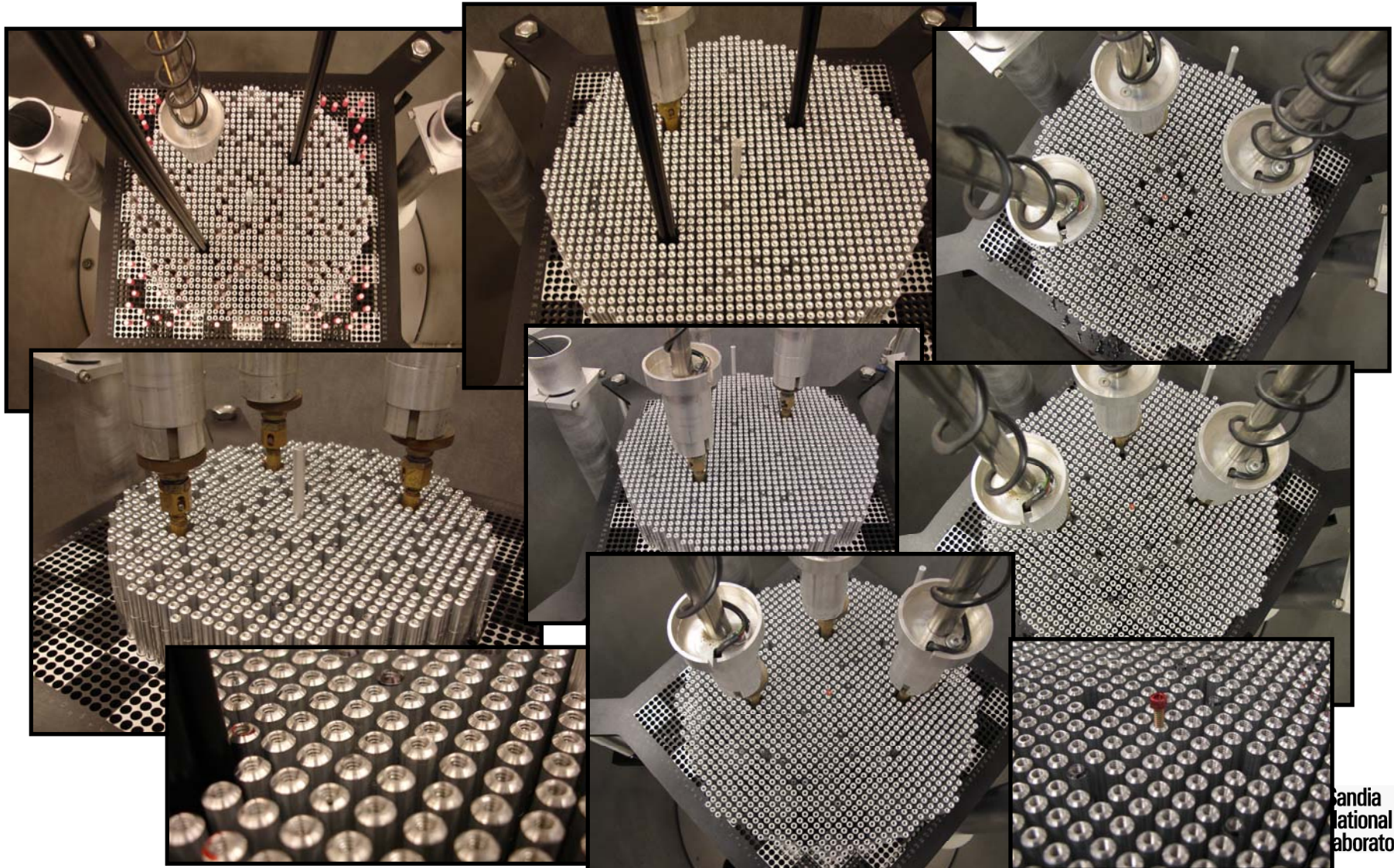




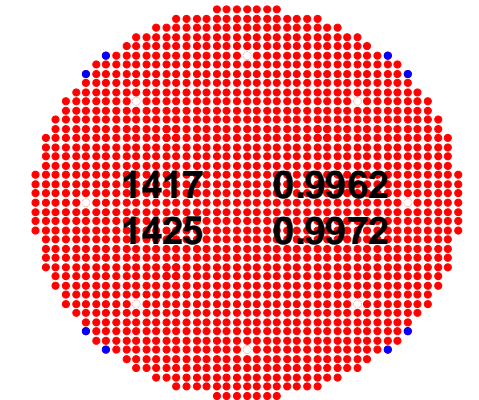
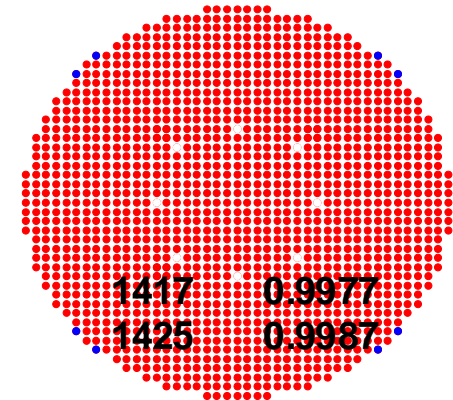
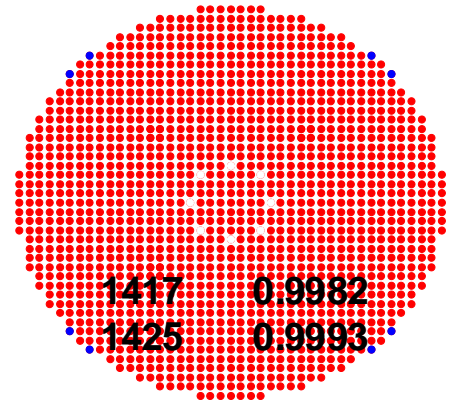
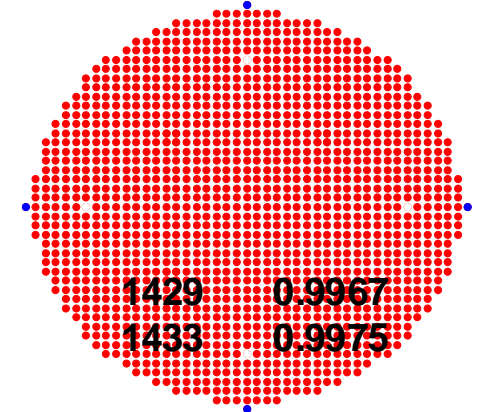
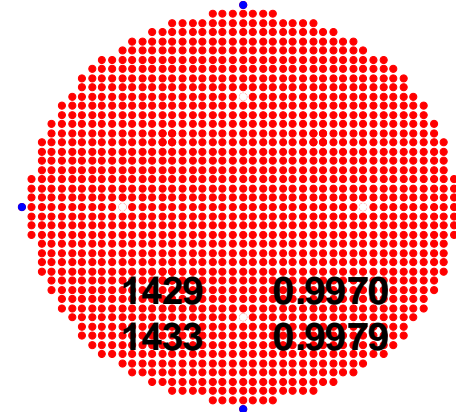
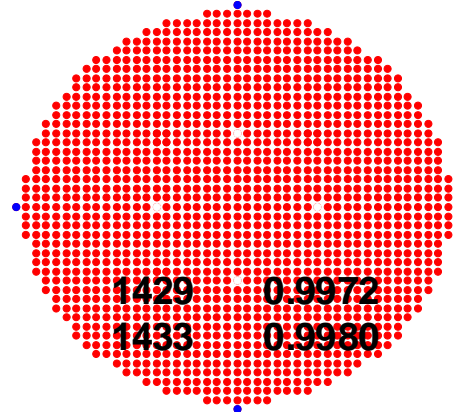
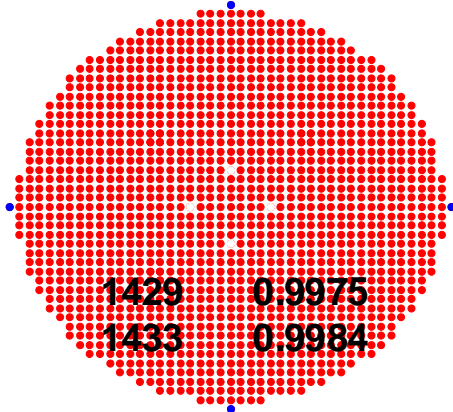
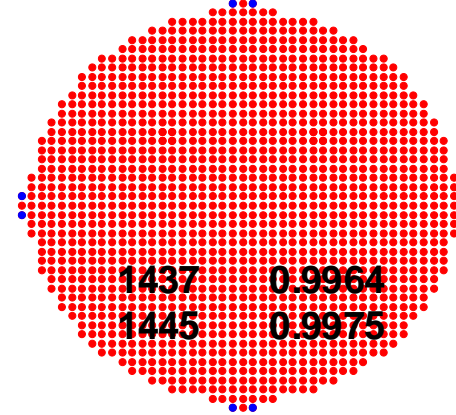
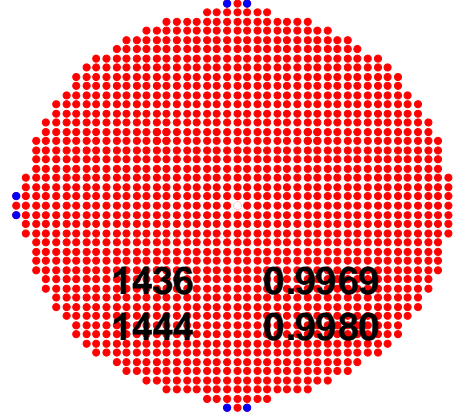
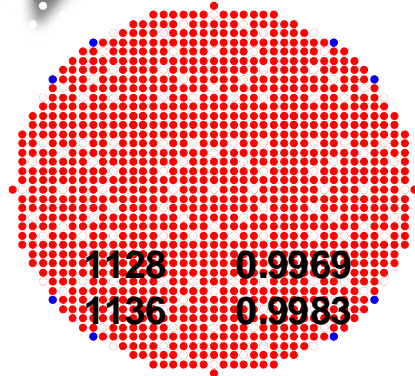
# $k_{\text{eff}}$ from Approach Data



# We have performed critical experiments on several 7uPCX configurations



# 7uPCX Critical Configurations





## The 7uPCX experiment matrix

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- **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

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- **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

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- Our design space:
  - $\text{UO}_2$  fuel
  - Metal Cladding
  - Light Water Moderator
  - $<20\%$  Enrichment
  - $<500$  kg of  $\text{UO}_2$  in the reactor room
  - $>50$  kg of  $\text{UO}_2$  in a critical configuration