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Results from the First Set of Criticals In the Seven Percent Critical Experiment

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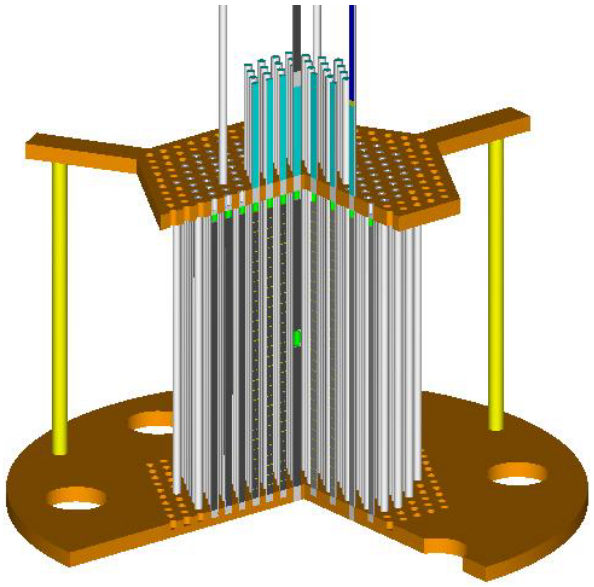
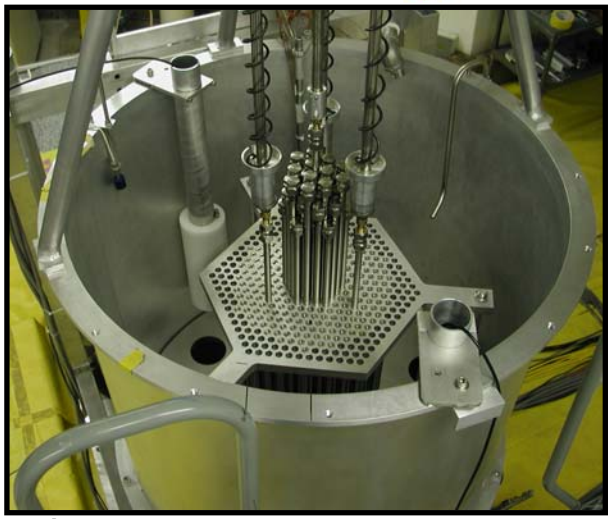
What is ahead

- The recent Sandia critical experiments
- Why 7uPCX?
- How we operate 7uPCX
- Some 7uPCX results
- Our plans for the critical experiments

In 2002, we performed some critical experiments with rhodium





- The Burnup Credit Critical Experiment (BUCCX) was funded by the Nuclear Energy Research Initiative (NERI)
- We built a critical assembly in which we could insert fission product materials to measure reactivity effects
- The NERI funding was used to bring the experiment capability up and perform the first set of experiments
- We completed a set of experiments with rhodium
- The experiment is documented as LEU-COMP-THERM-079 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments

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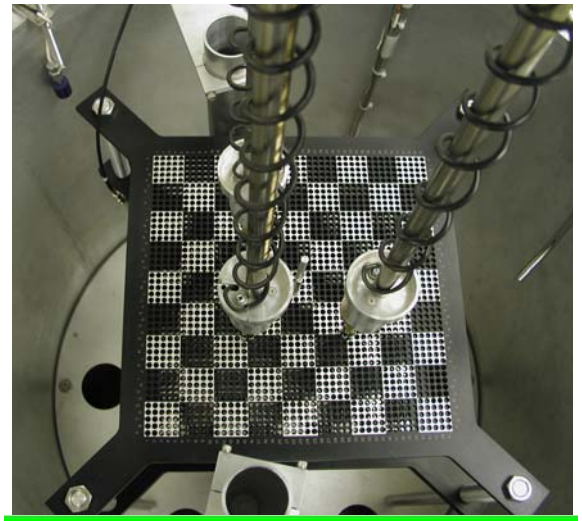
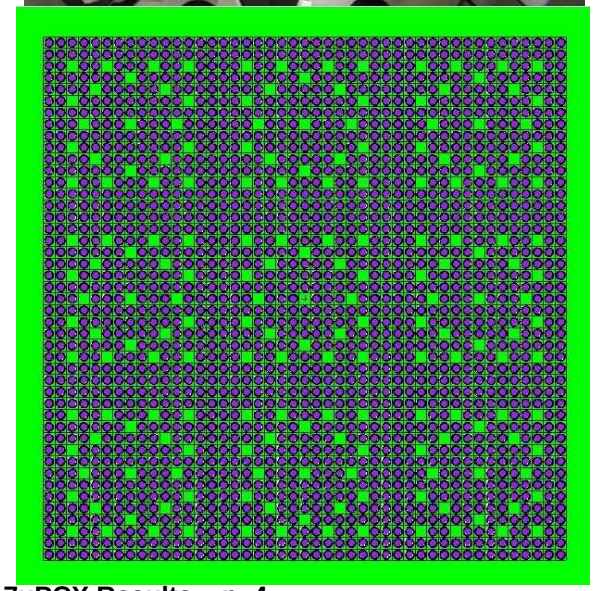
The Seven Percent Critical Experiment (7uPCX) is a NERI project





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 7% 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**

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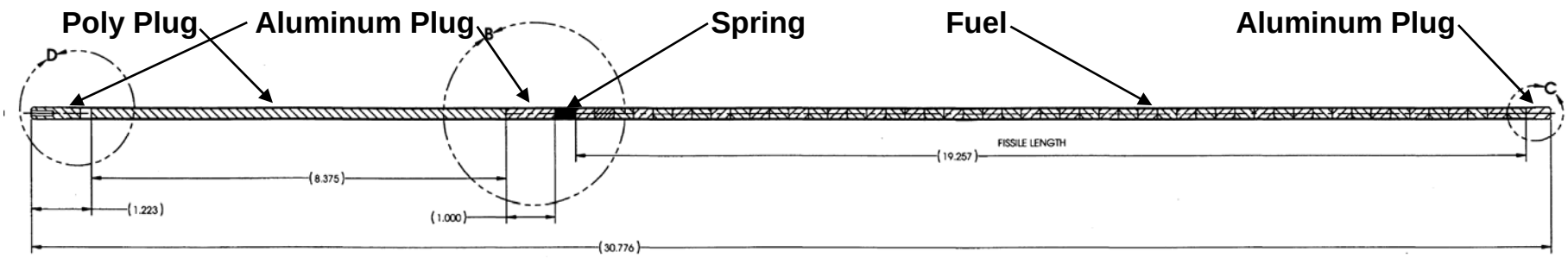
The 7uPCX experiment matrix

- 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 7uPCX core uses a new set of fuel rods



- The fuel is 6.90% enriched, 0.207” (0.536 cm) in diameter
- The fuel rods are 0.25” (0.635 cm) in diameter
- The fuel rod cladding and end plugs are aluminum
- The fuel rods extend above the upper grid plate – the upper plug is above the highest level of the moderator
- A polyethylene plug above the upper grid plate replaces the water

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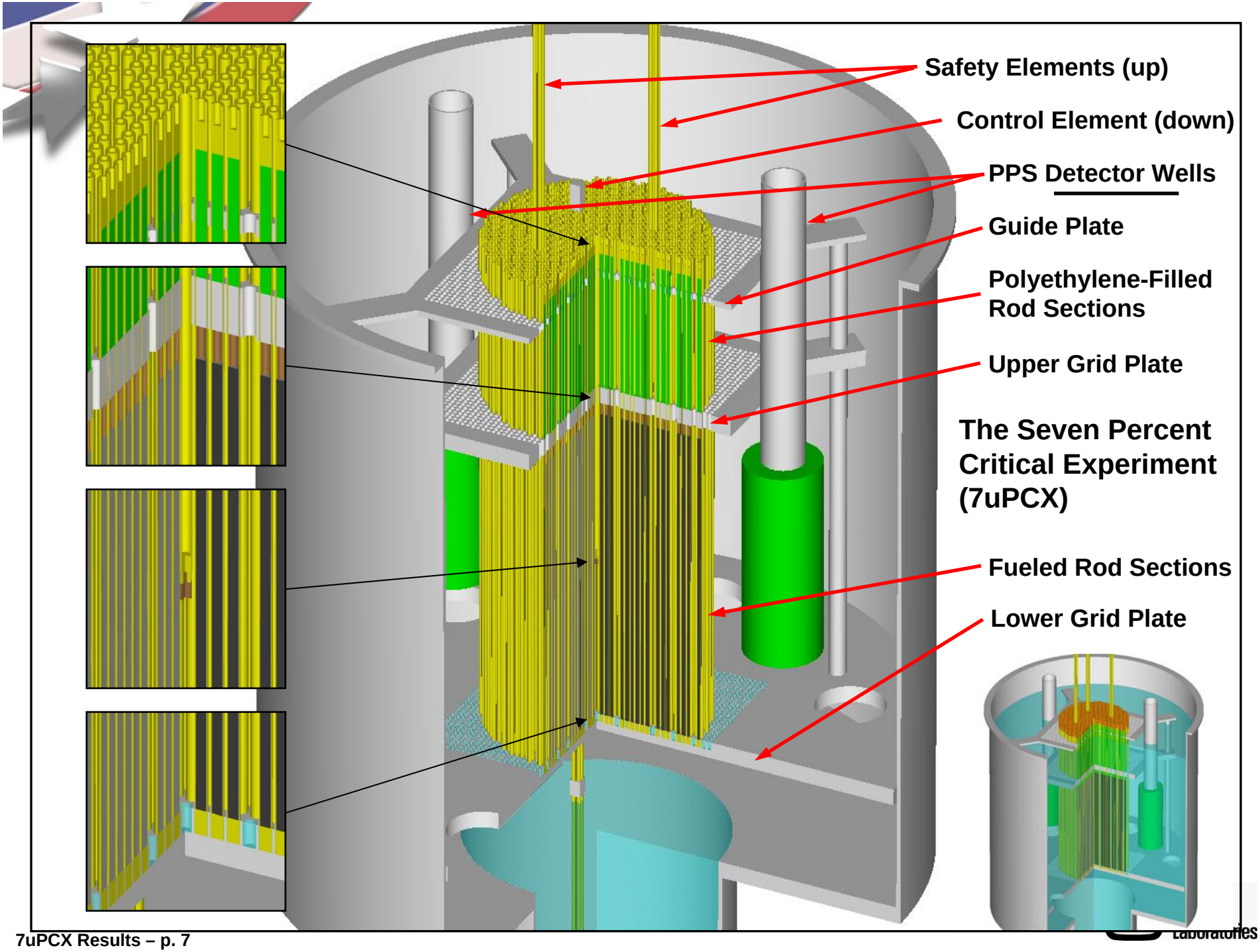
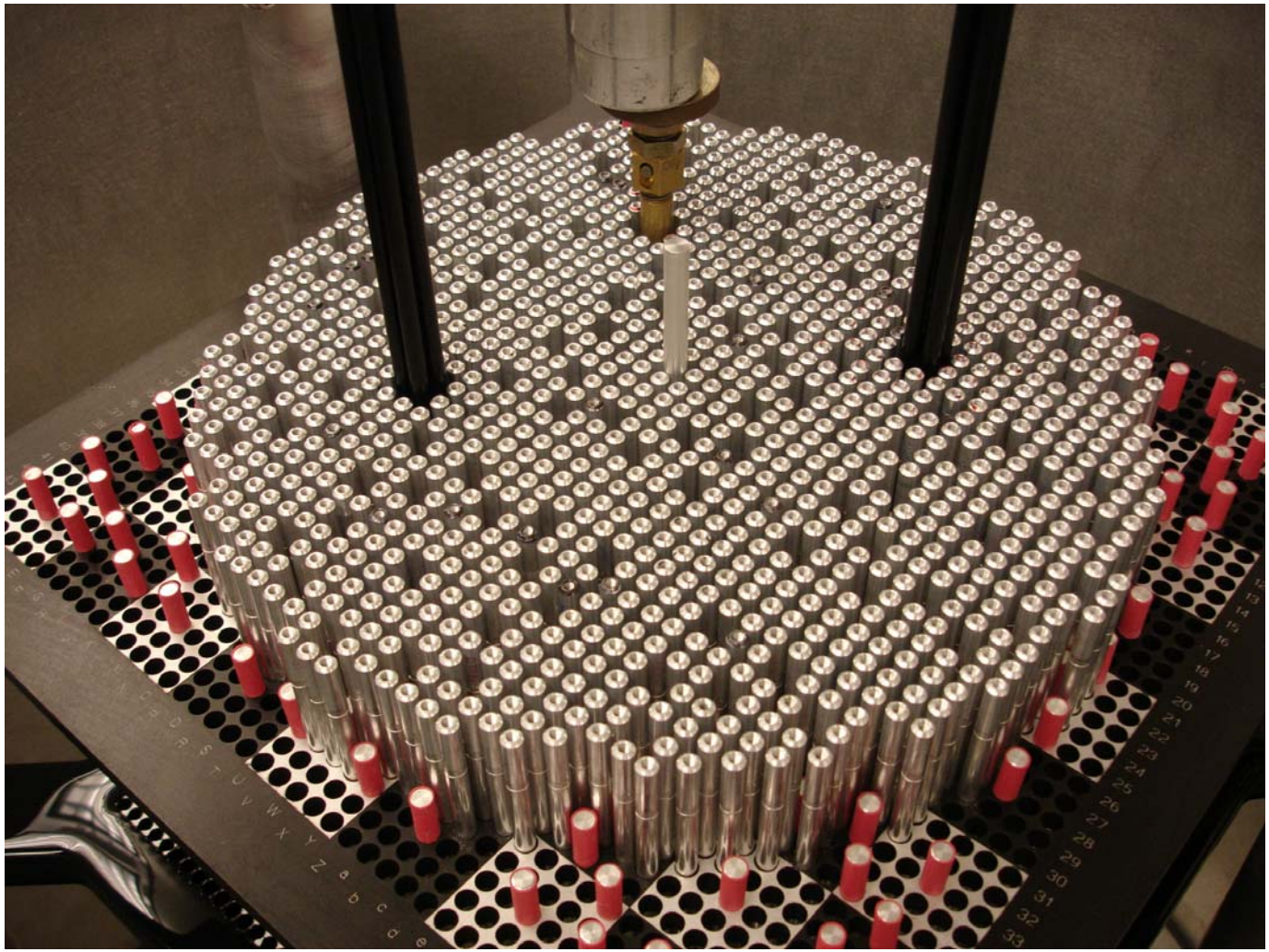

Safety Elements (up)
Control Element (down)
PPS Detector Wells
Guide Plate
Polyethylene-Filled Rod Sections
Upper Grid Plate
The Seven Percent Critical Experiment (7uPCX)
Fueled Rod Sections
Lower Grid Plate

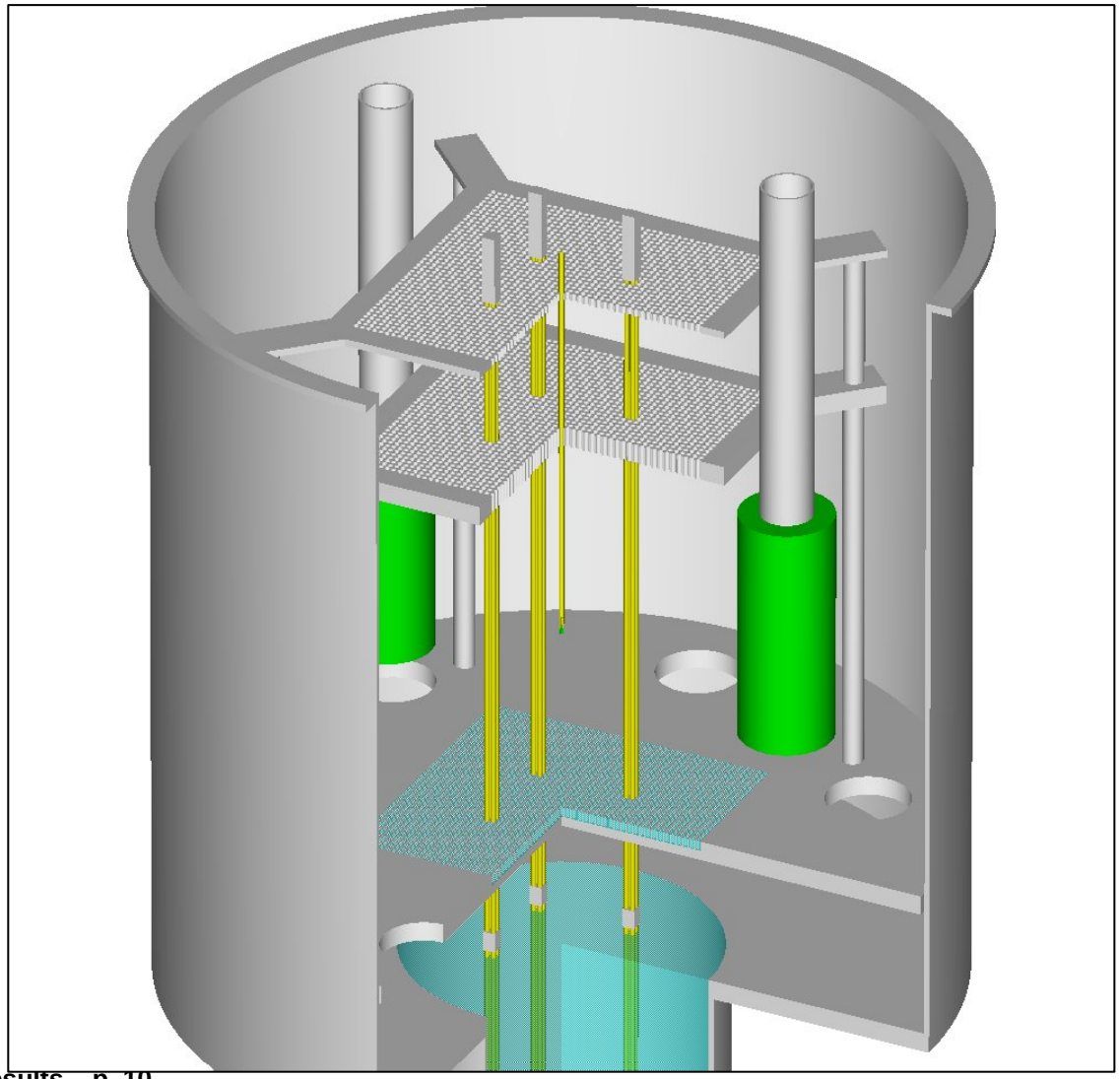
The first 7uPCX core at the end of the approach



Access controls ensure personnel safety

- We have limited ourselves to low-enriched (<20%) fuel
  - 1000 kg of the fuel is subcritical without water moderator
  - Reactor room is limited to 500 kg of fuel
  - The fuel cannot go critical without water
- The key that closes the dump valves and allows water to accumulate in the core tank is tied to the key to the facility door
  - When people are in the reactor room, the key is out of the console and the dump valves are open (core tank cannot hold water)
  - When the dump valves are closed, the reactor area is locked and people are excluded from the reactor room
  - FUEL – WATER – PEOPLE – pick any TWO

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 added to or removed from the array.

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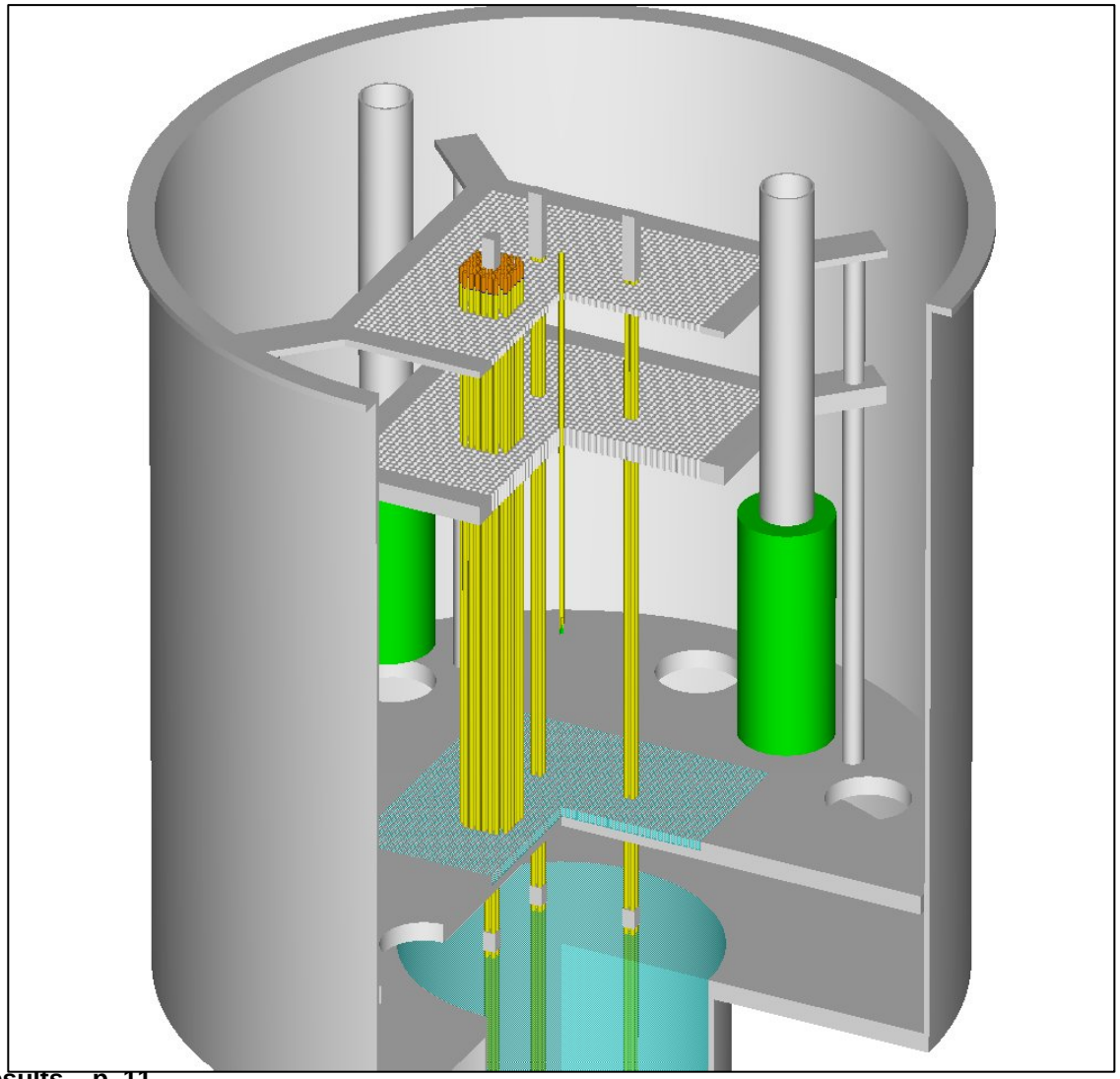
Load Fuel



Fuel: 64

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 added to or removed from the array.

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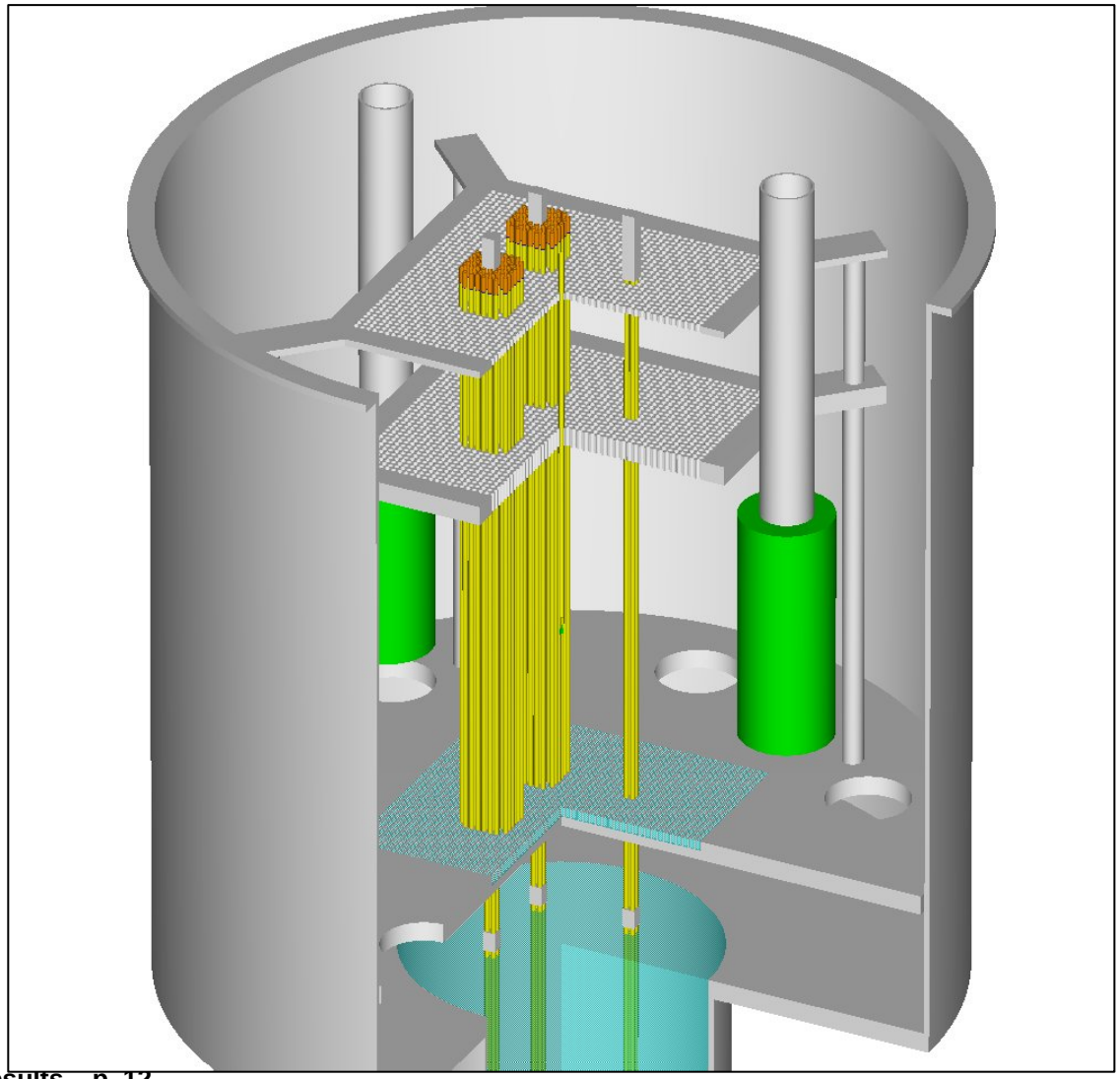
Load Fuel



Fuel: 116

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 added to or removed from the array.

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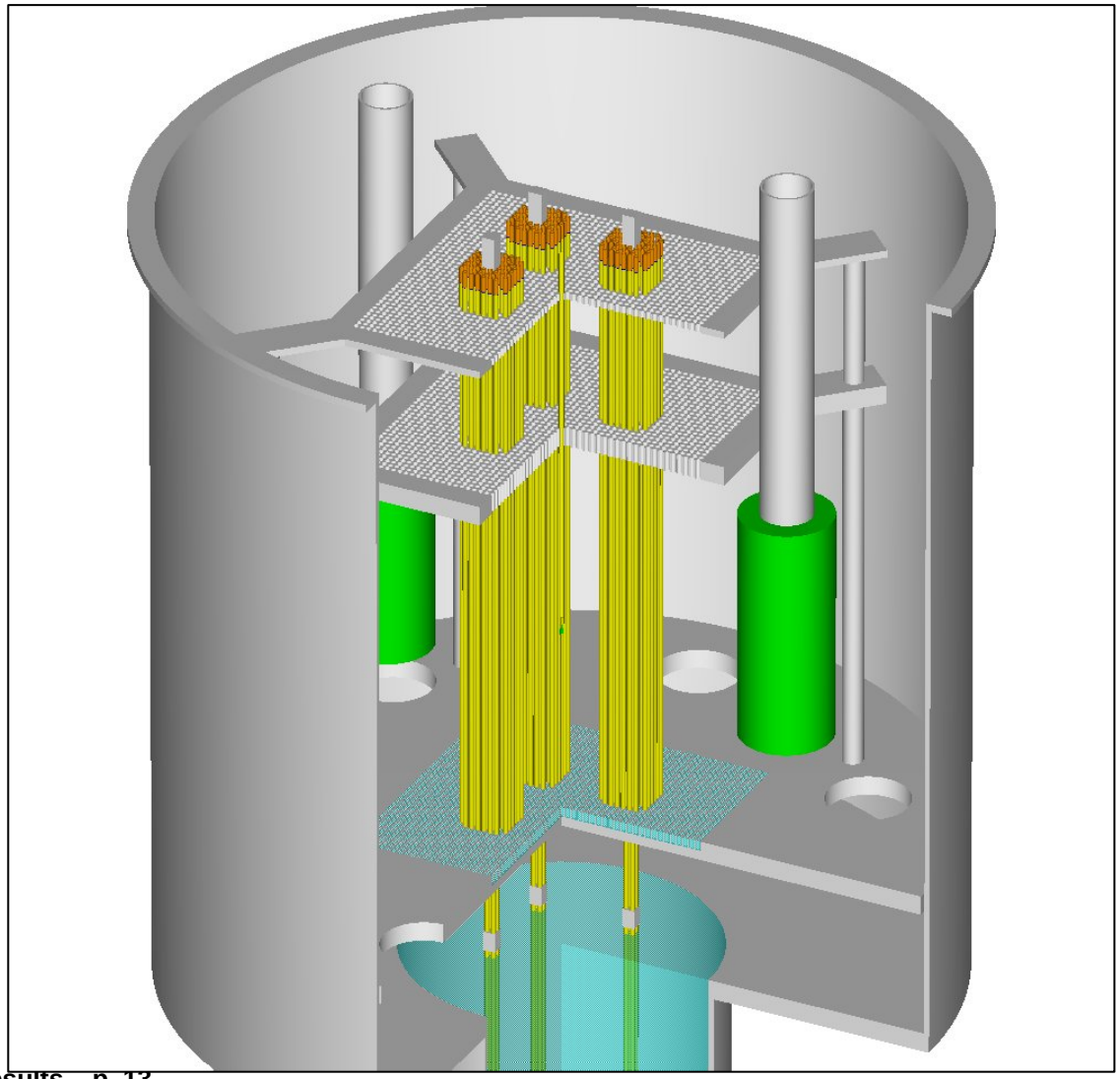
Load Fuel



Fuel: 168

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 added to or removed from the array.

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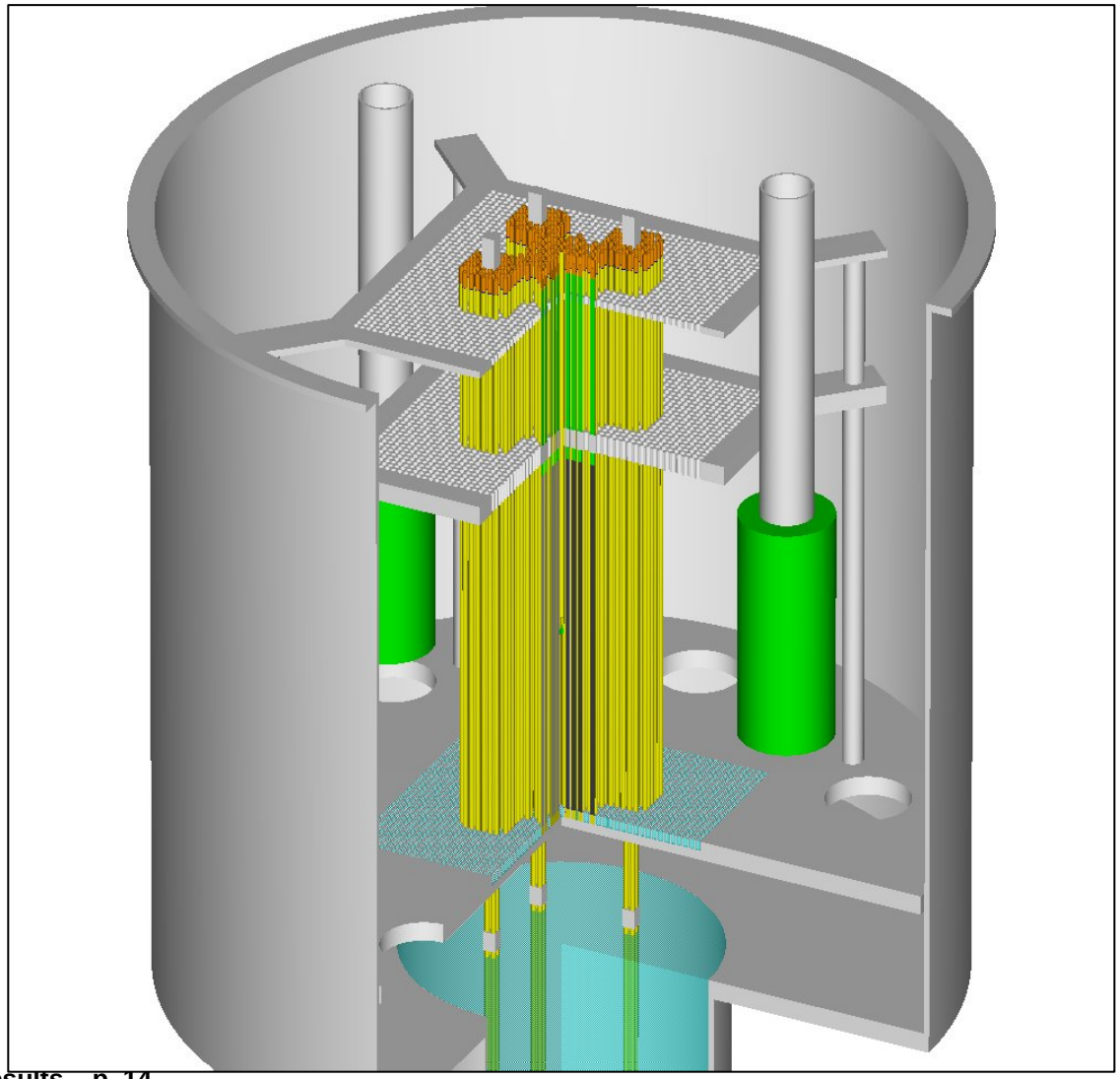
Load Fuel



Fuel: 318

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 added to or removed from the array.

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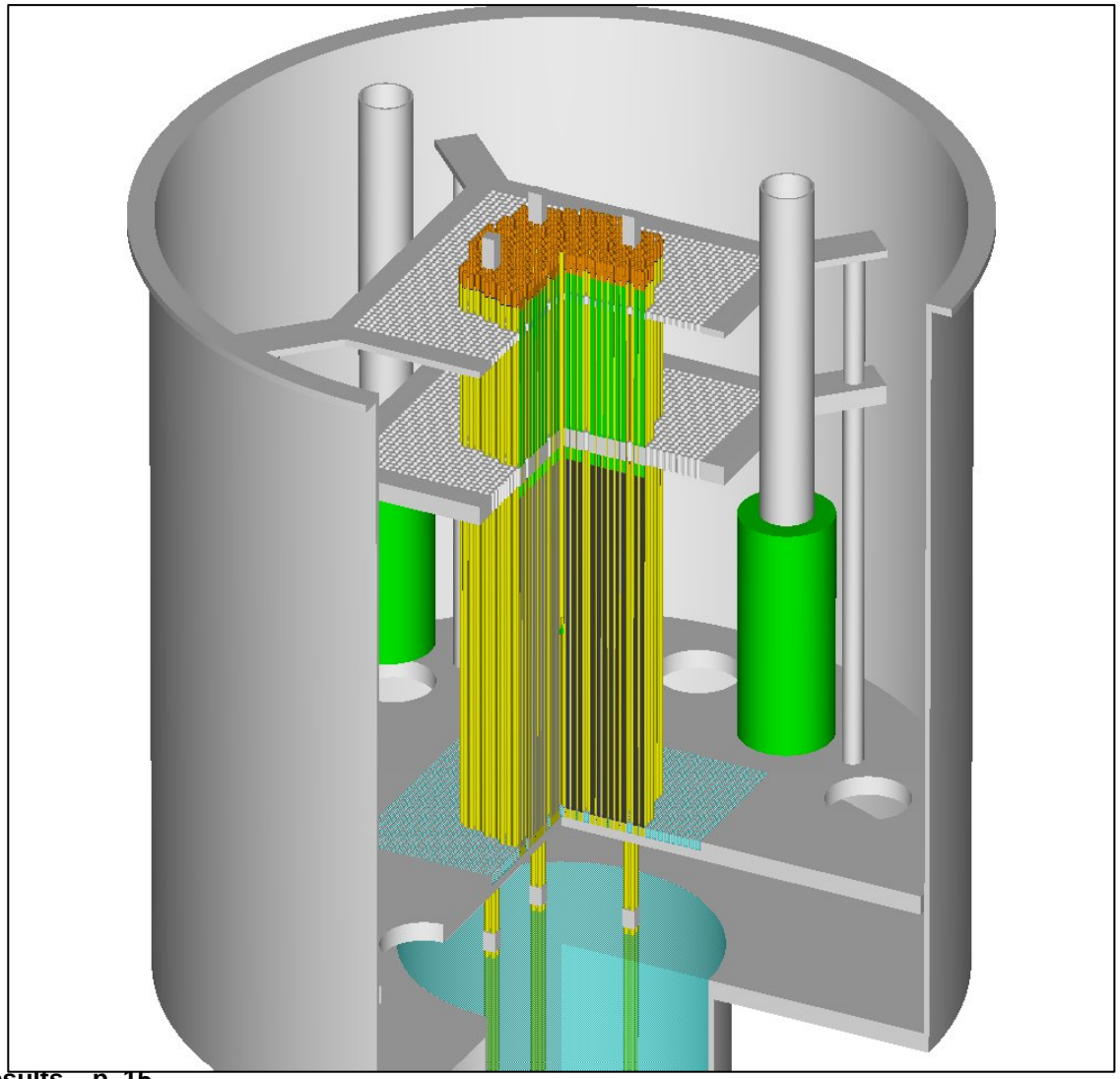
Load Fuel



Fuel: 548

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 added to or removed from the array.

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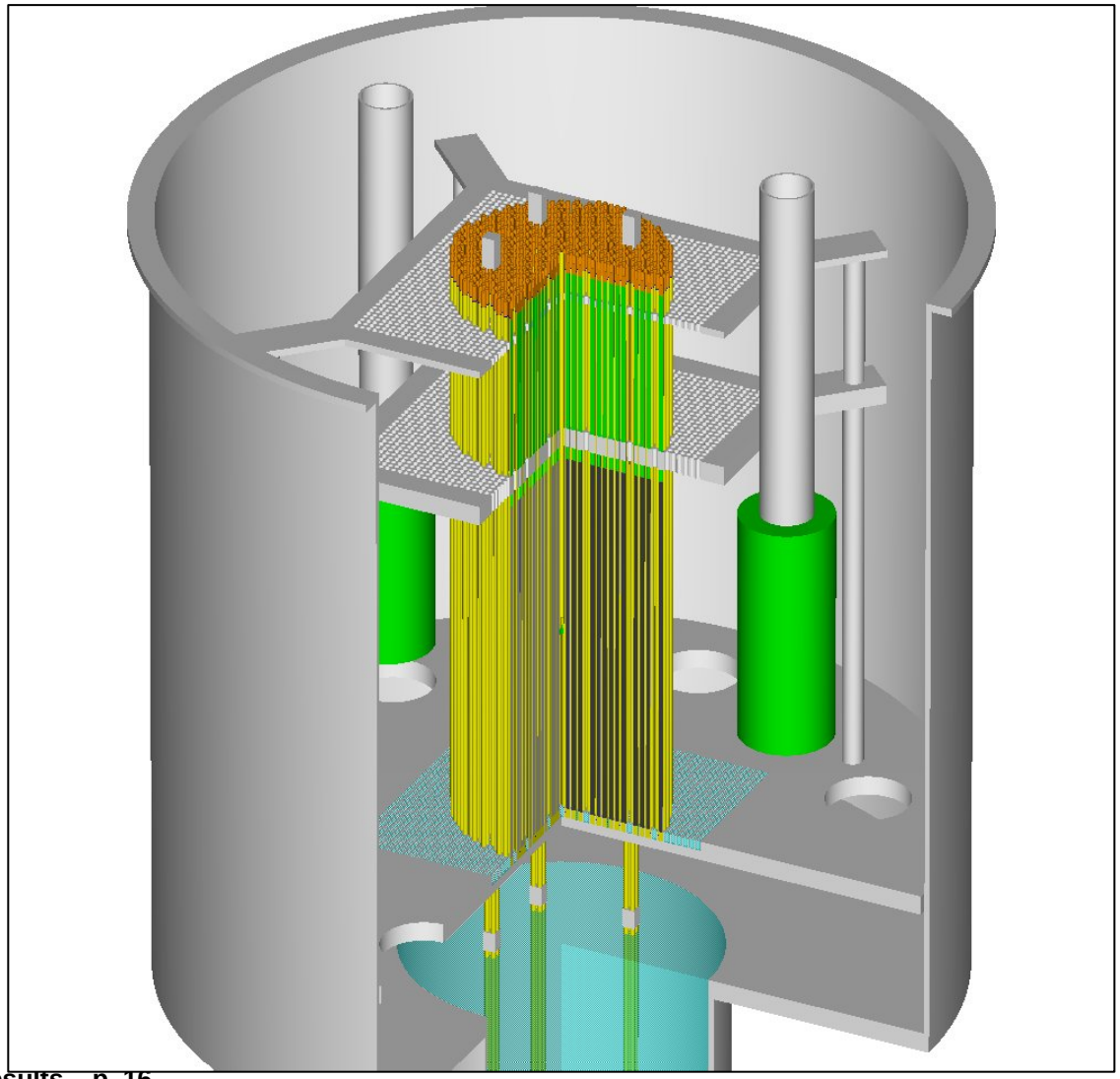
Load Fuel



Fuel: 740

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 added to or removed from the array.

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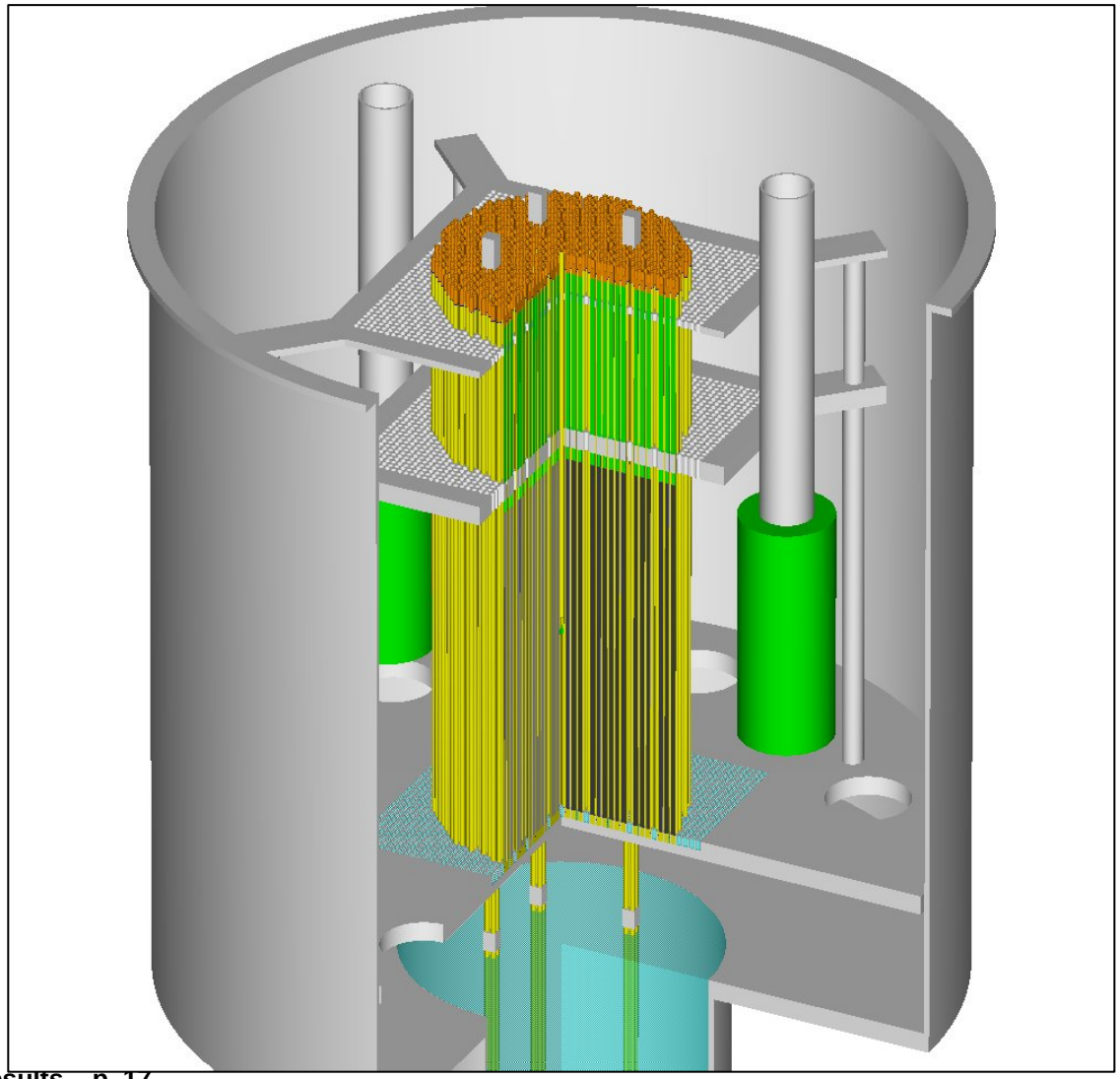
Load Fuel



Fuel: 956

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 added to or removed from the array.

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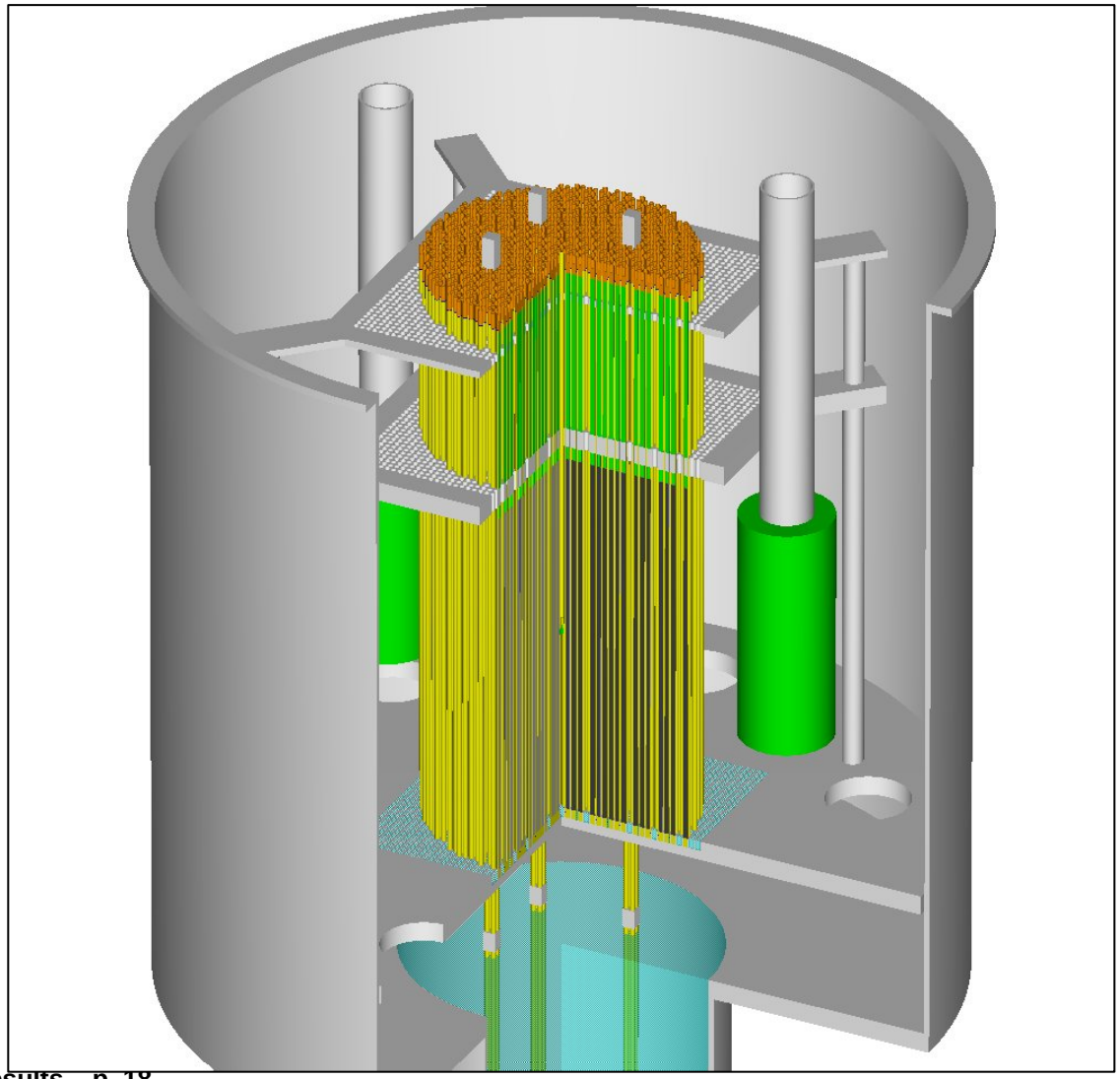
The Desired Fuel Array is Complete



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 added to or removed from the array.

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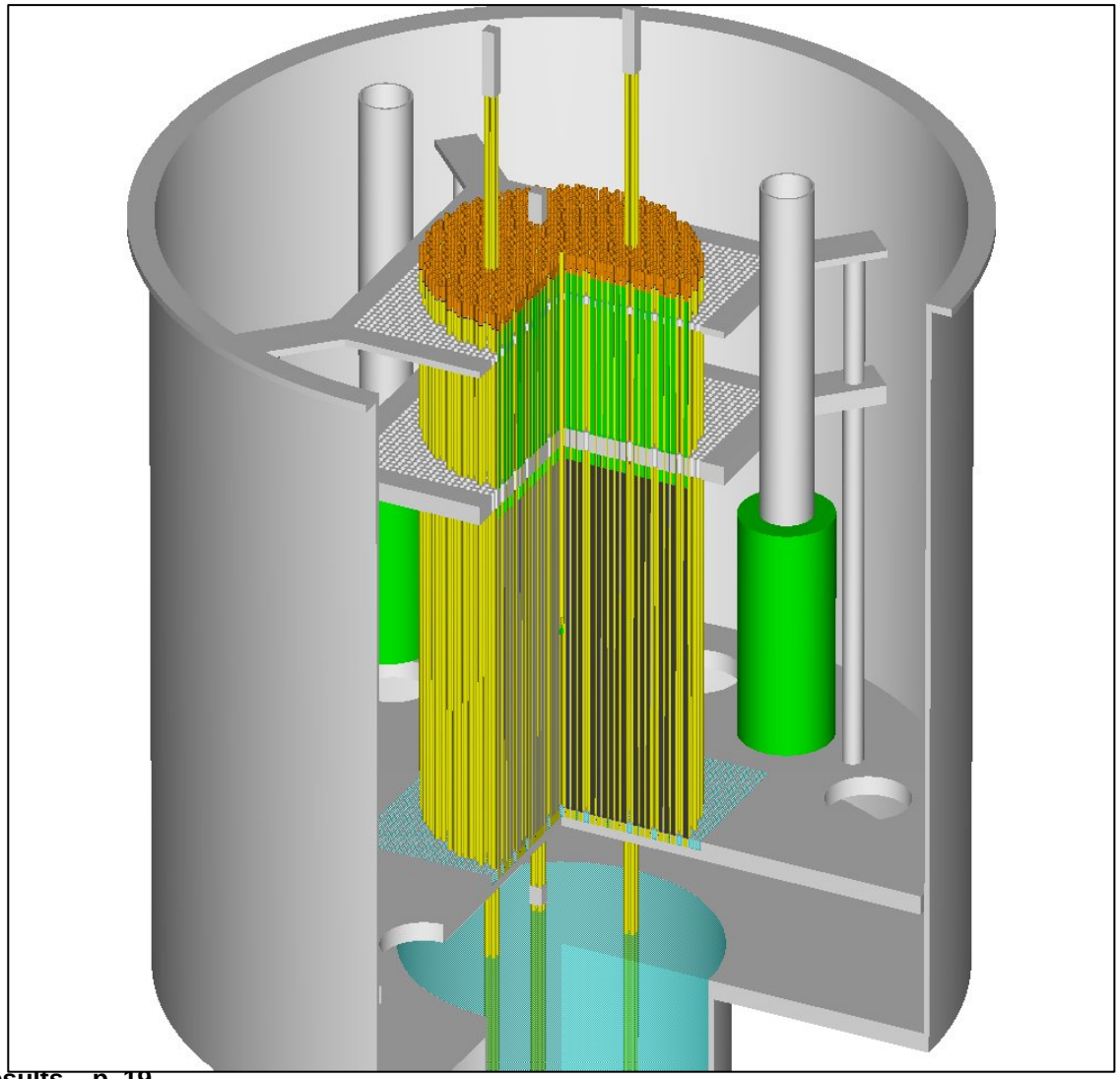
Raise the Safety Elements



Fuel: 1136

Safety Elements: Raising

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.

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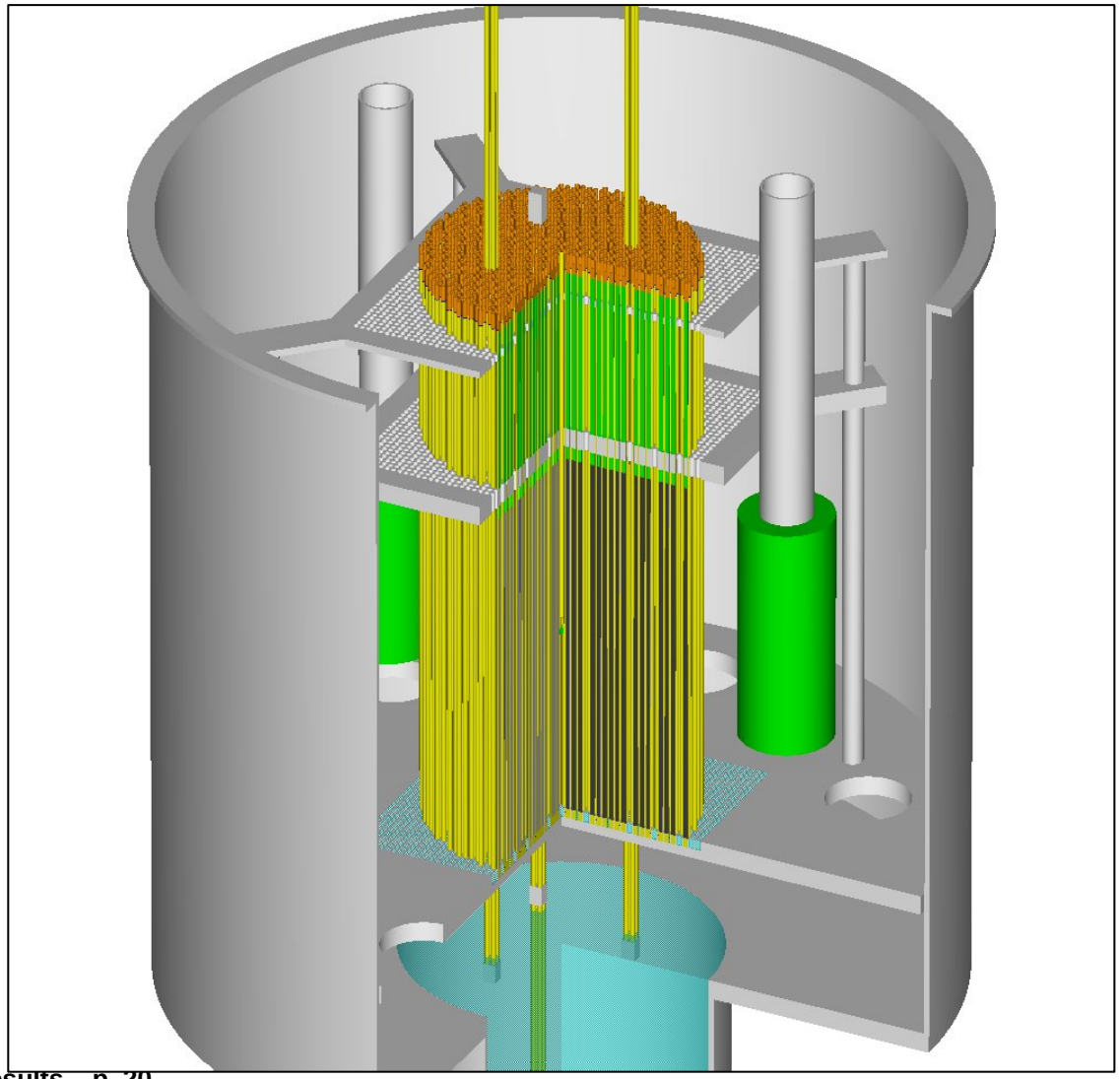
Raise the Safety Elements



Fuel: 1136

Safety Elements: Raising

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.

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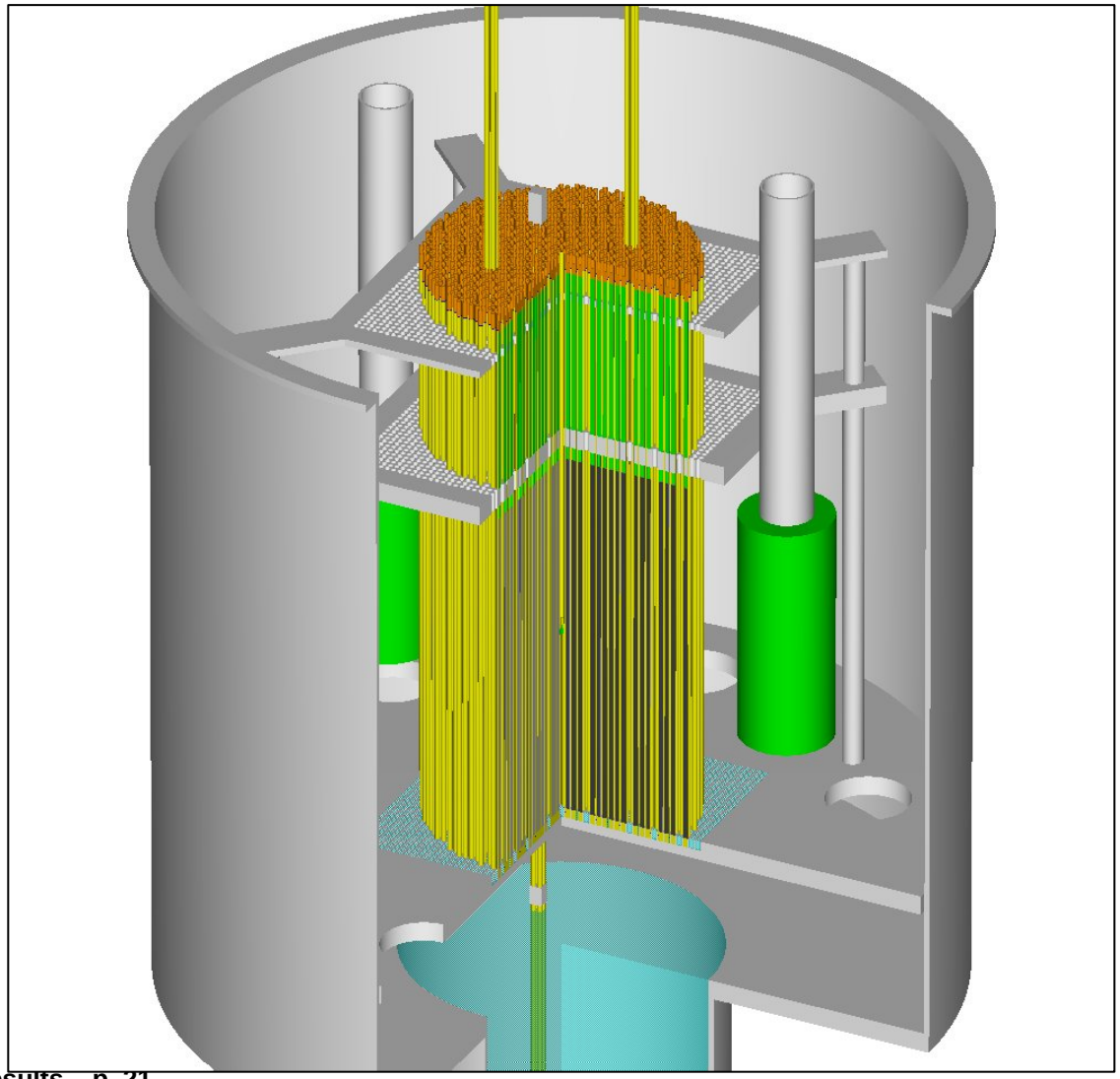
The Safety Elements are Up



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.

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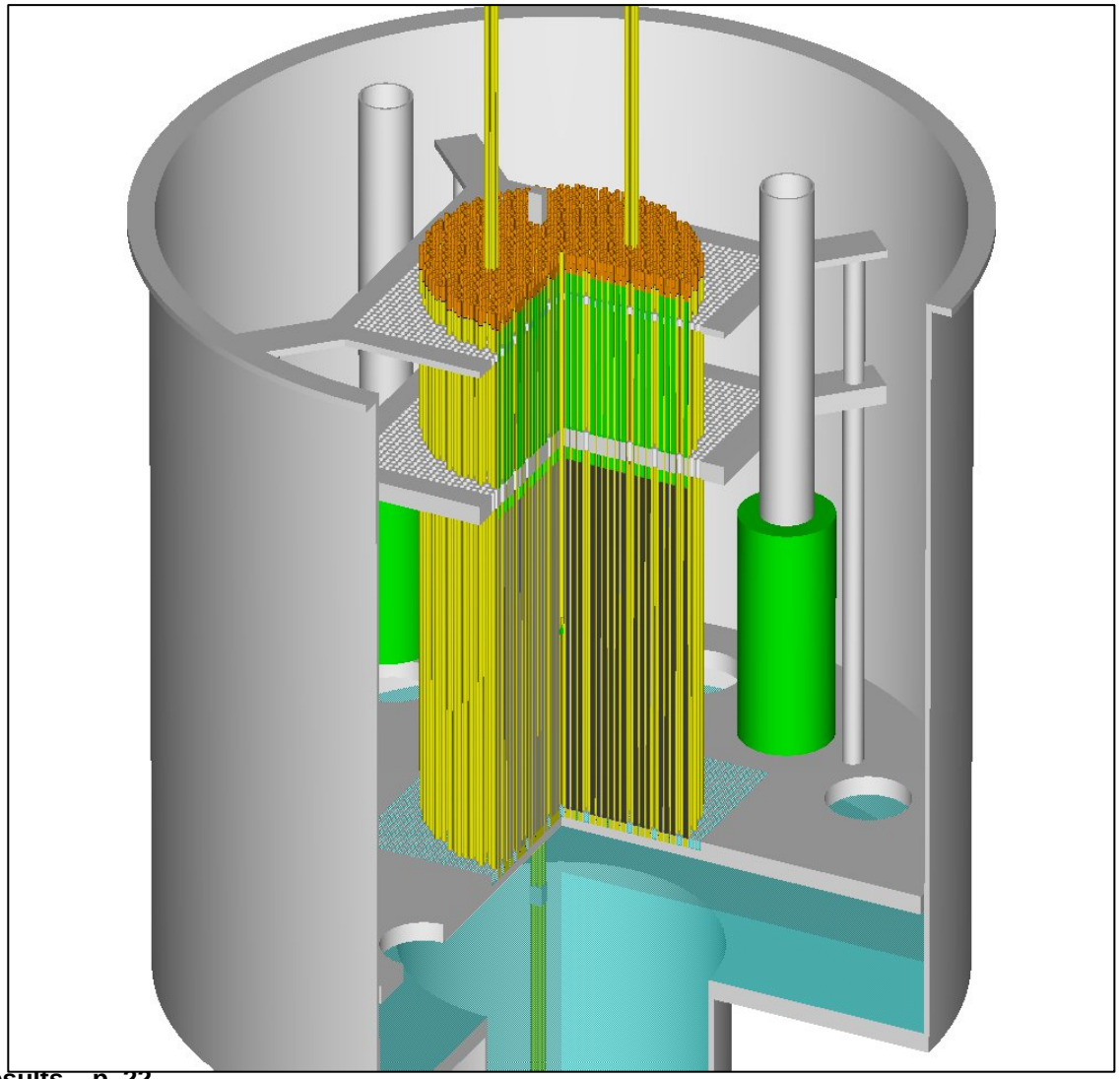
Fill the Core Tank



Fuel: 1136

Safety Elements: Up

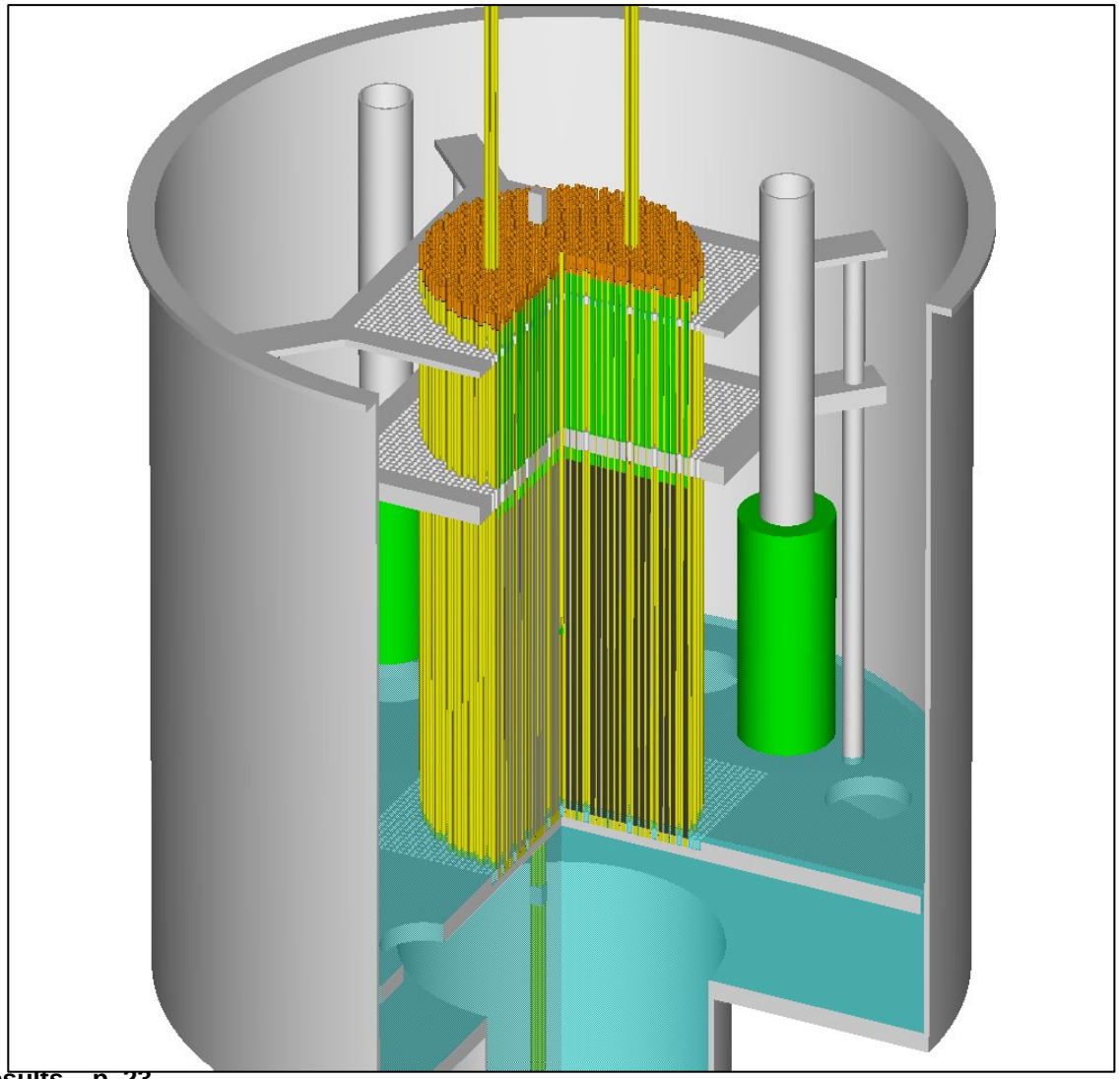
Control Element: Down

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

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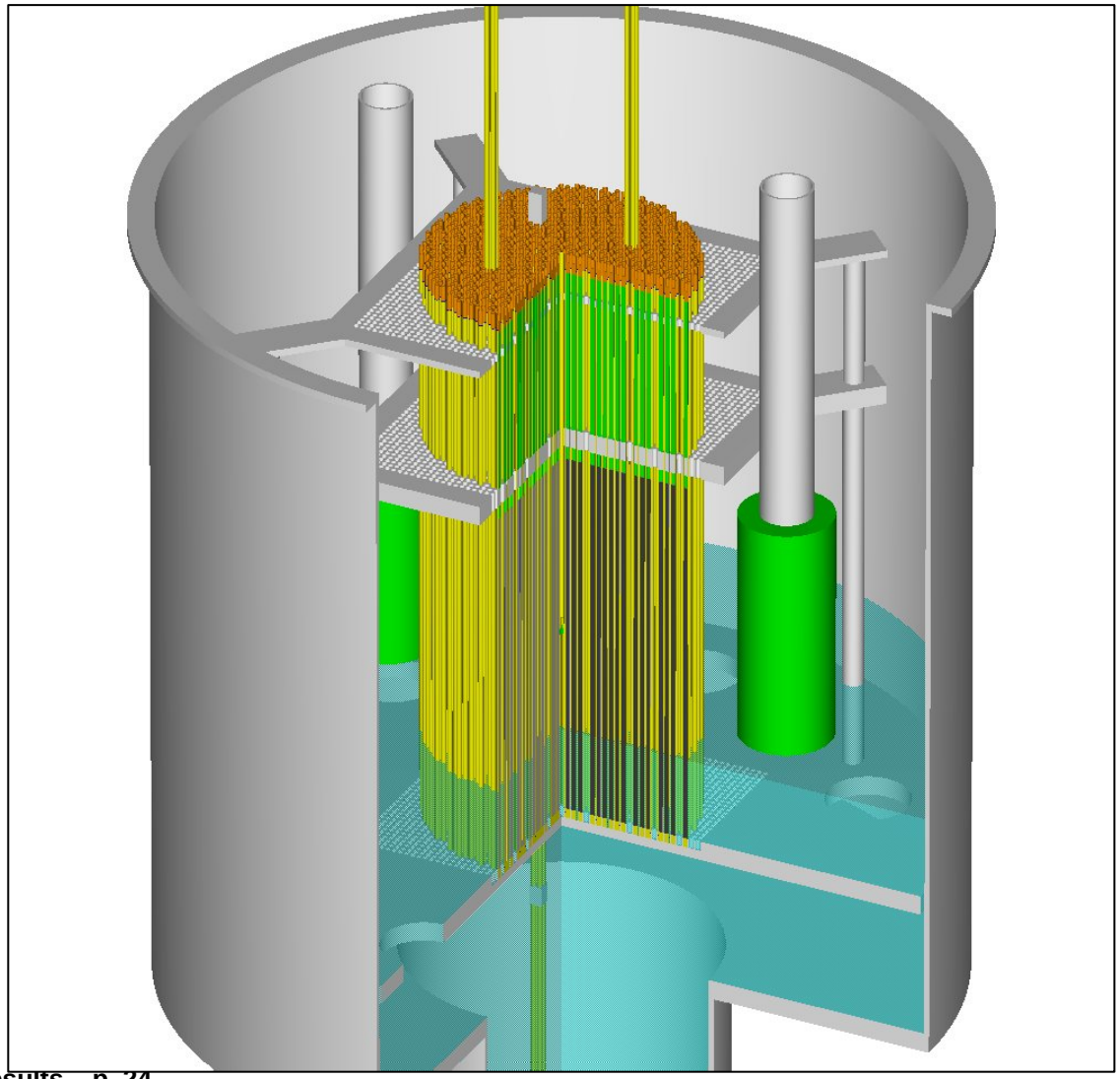

Fuel: 1136

Safety Elements: Up

Control Element: Down

Core Tank: Filling

Personnel: Excluded

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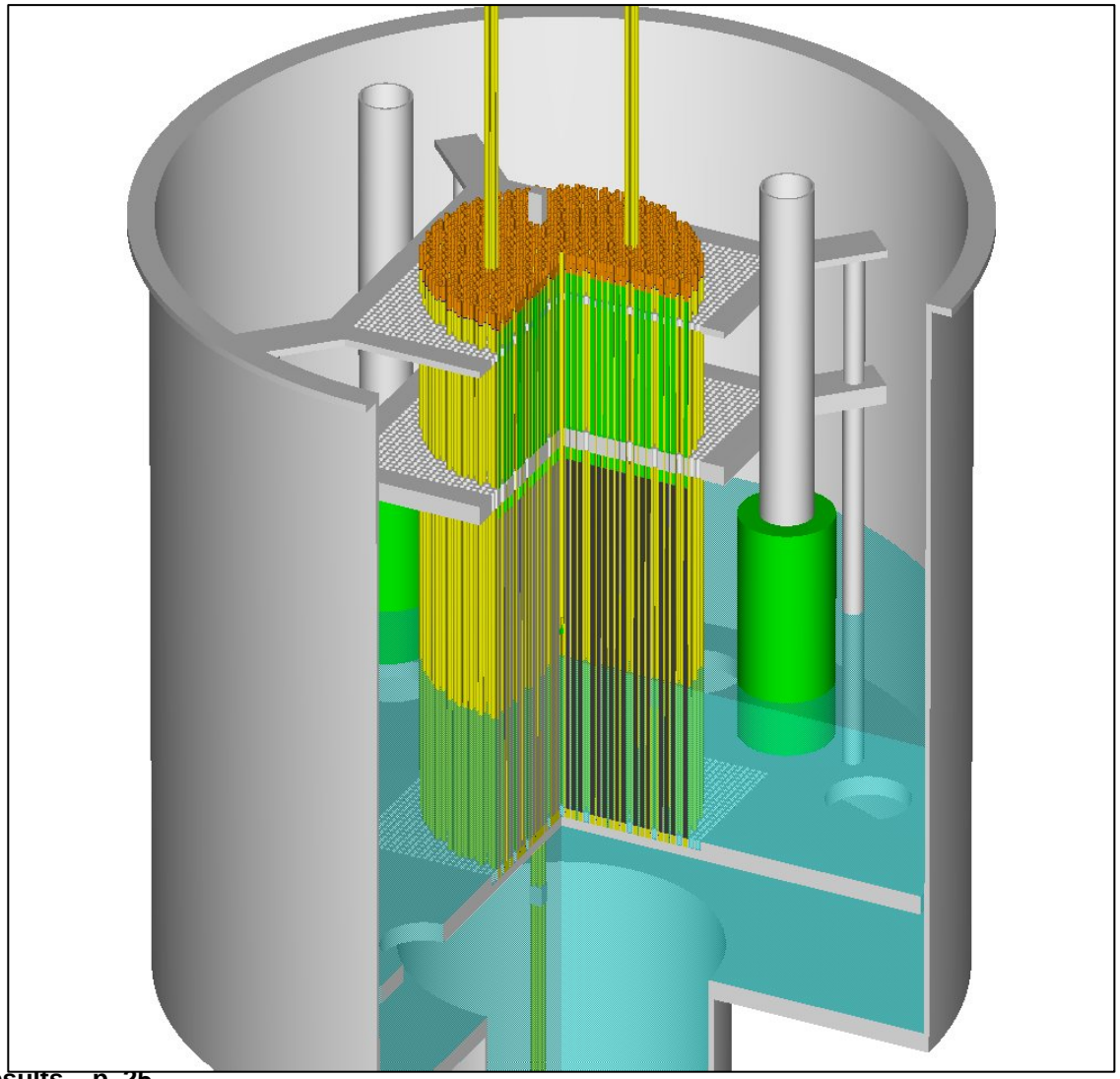
Fill the Core Tank



Fuel: 1136

Safety Elements: Up

Control Element: Down

Core Tank: Filling

Personnel: Excluded

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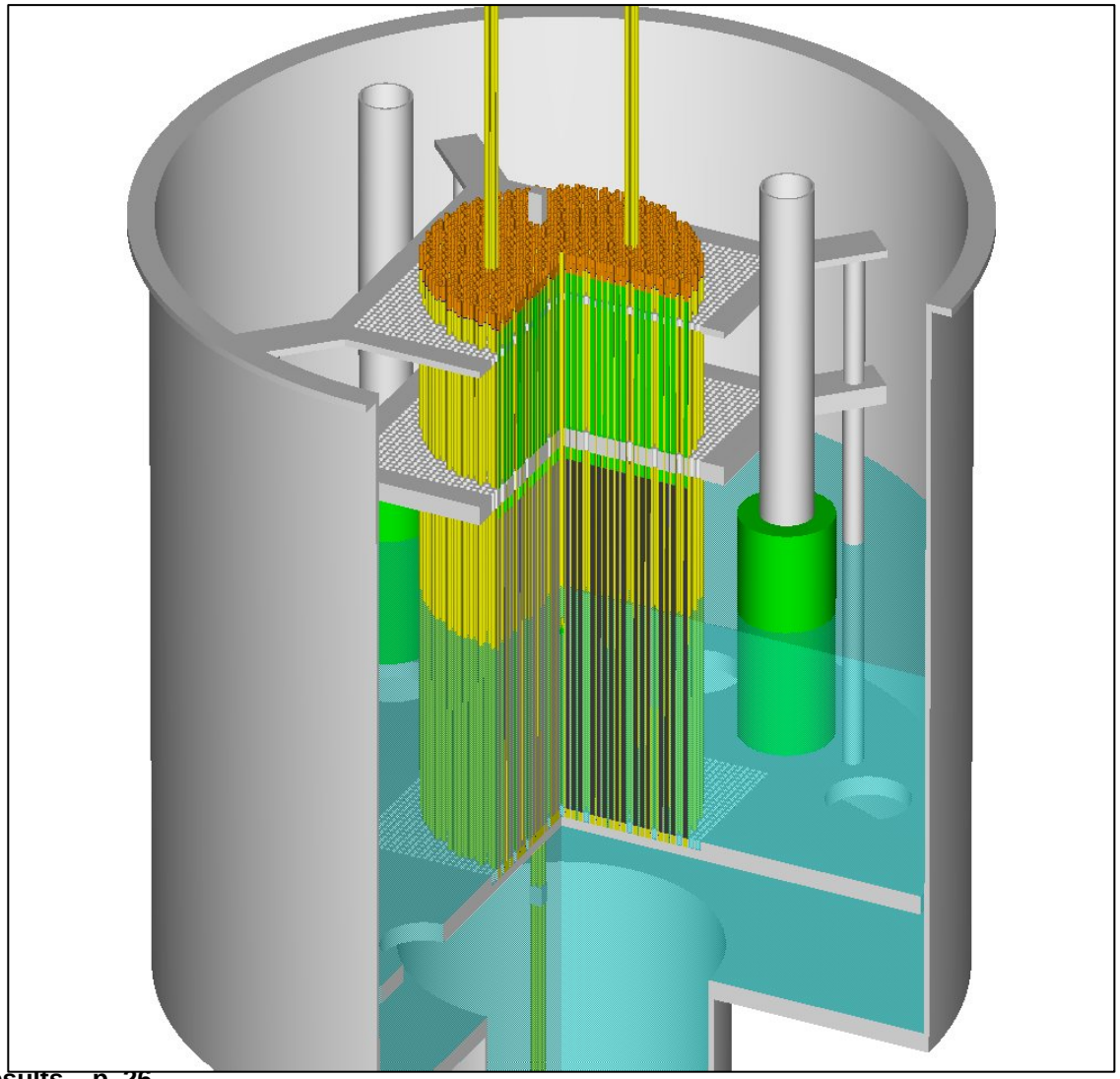
Fill the Core Tank



Fuel: 1136

Safety Elements: Up

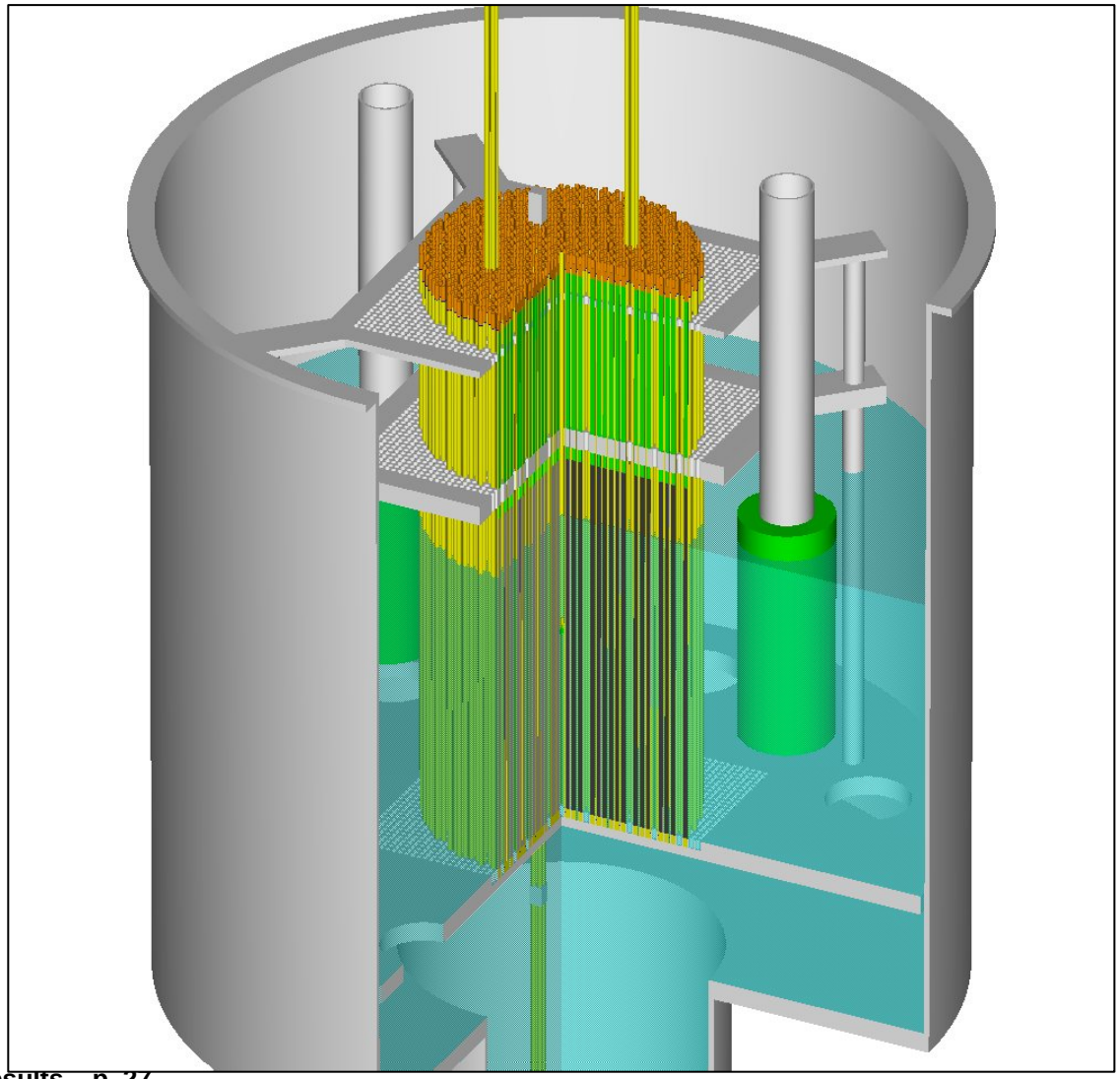
Control Element: Down

Core Tank: Filling

Personnel: Excluded

Filling the core tank requires about 15 minutes.

Fill the Core Tank



Fuel: 1136

Safety Elements: Up

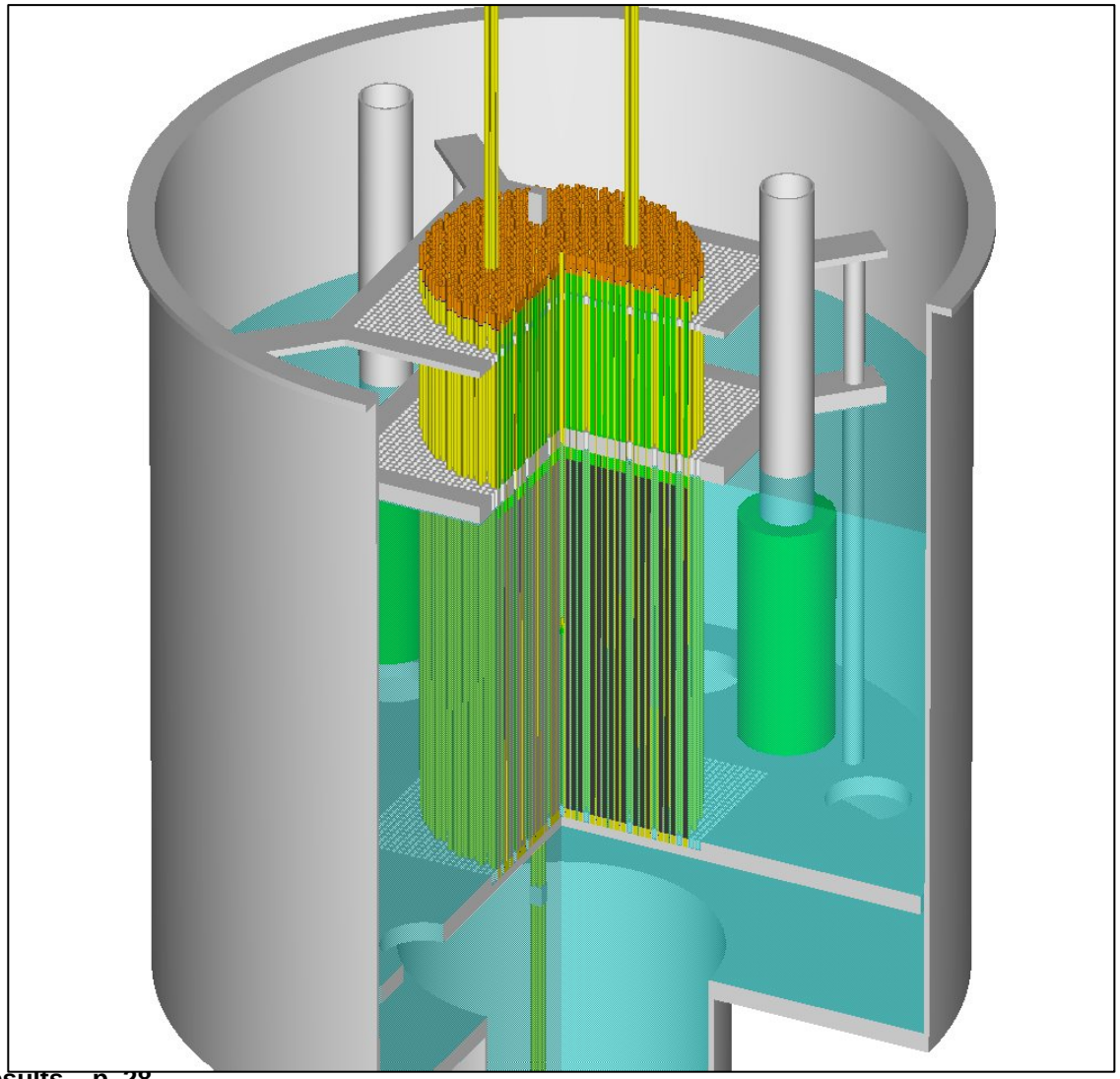
Control Element: Down

Core Tank: Filling

Personnel: Excluded

Filling the core tank requires about 15 minutes.

Fill the Core Tank



Fuel: 1136

Safety Elements: Up

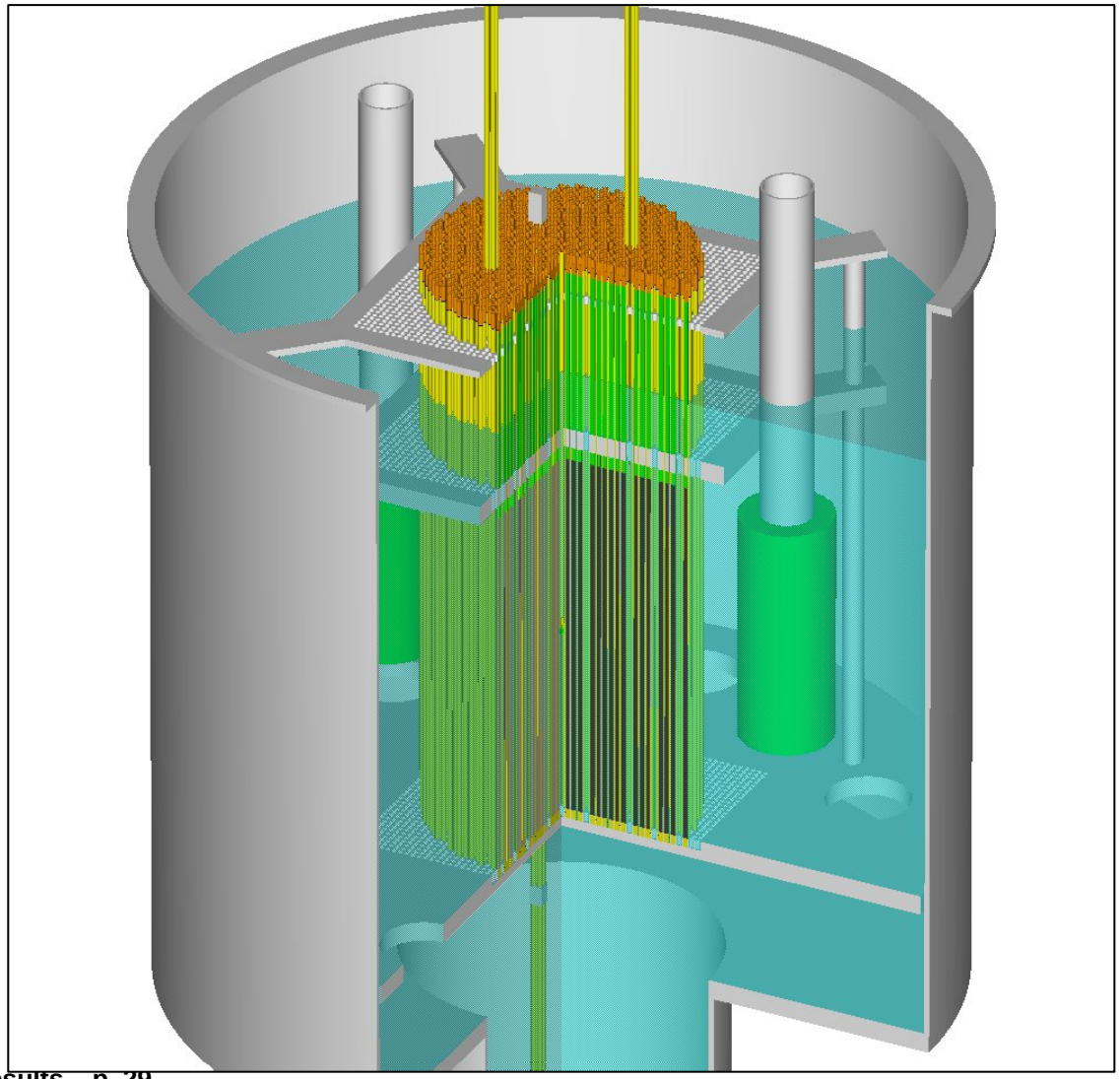
Control Element: Down

Core Tank: Filling

Personnel: Excluded

Filling the core tank requires about 15 minutes.

Fill the Core Tank



Fuel: 1136

Safety Elements: Up

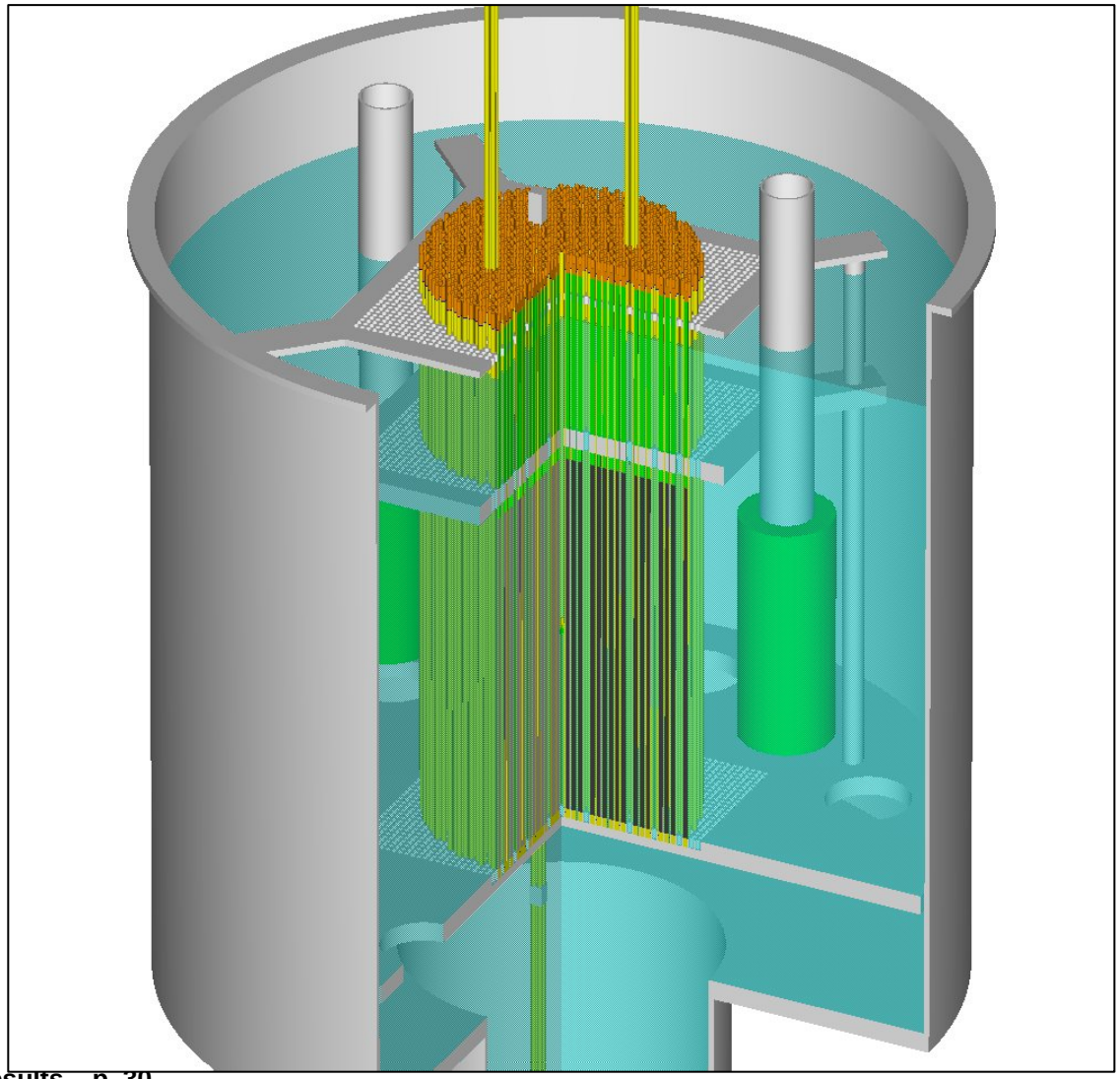
Control Element: Down

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 standpipe.

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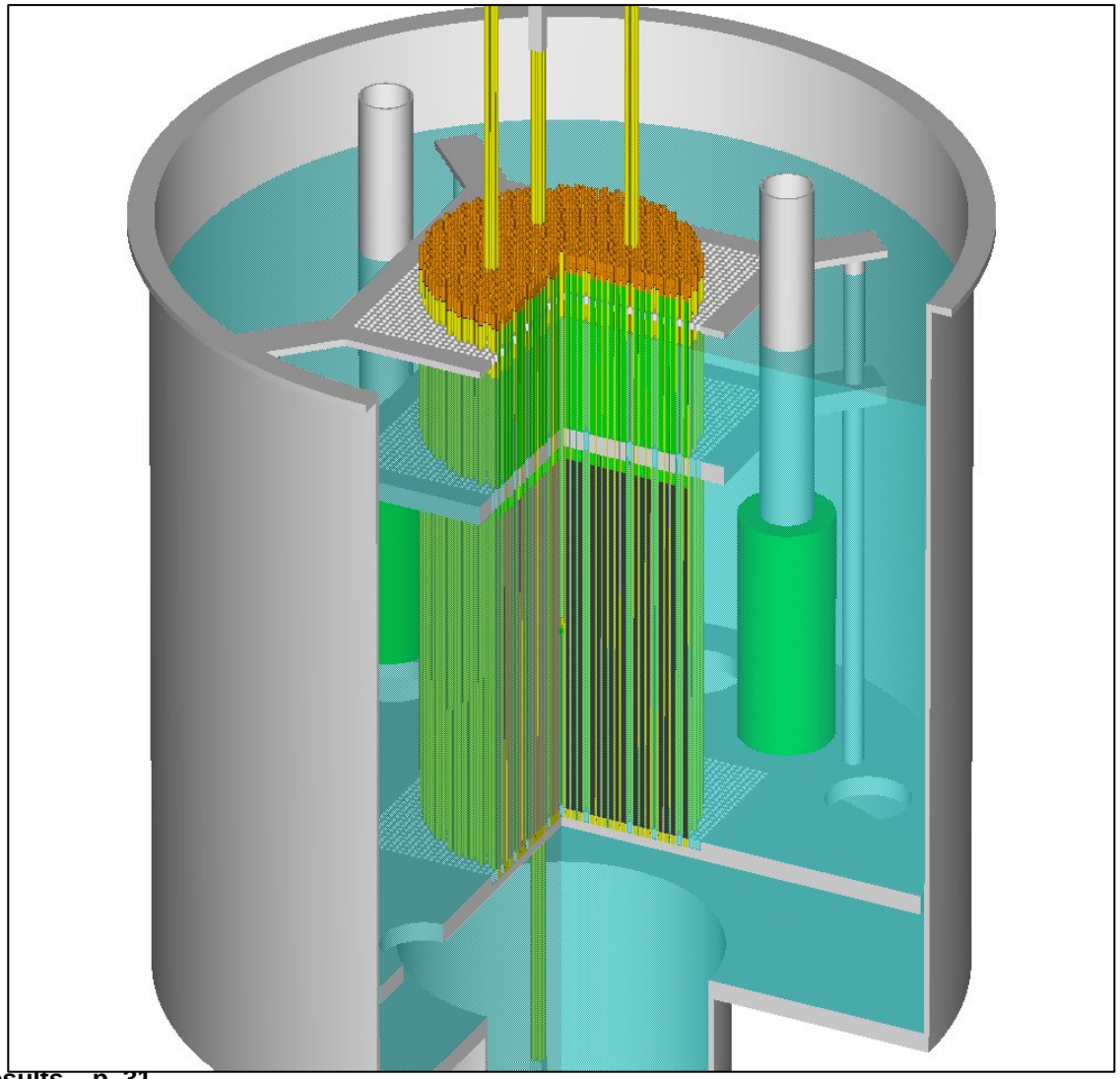
Raise the Control Element



Fuel: 1136

Safety Elements: Up

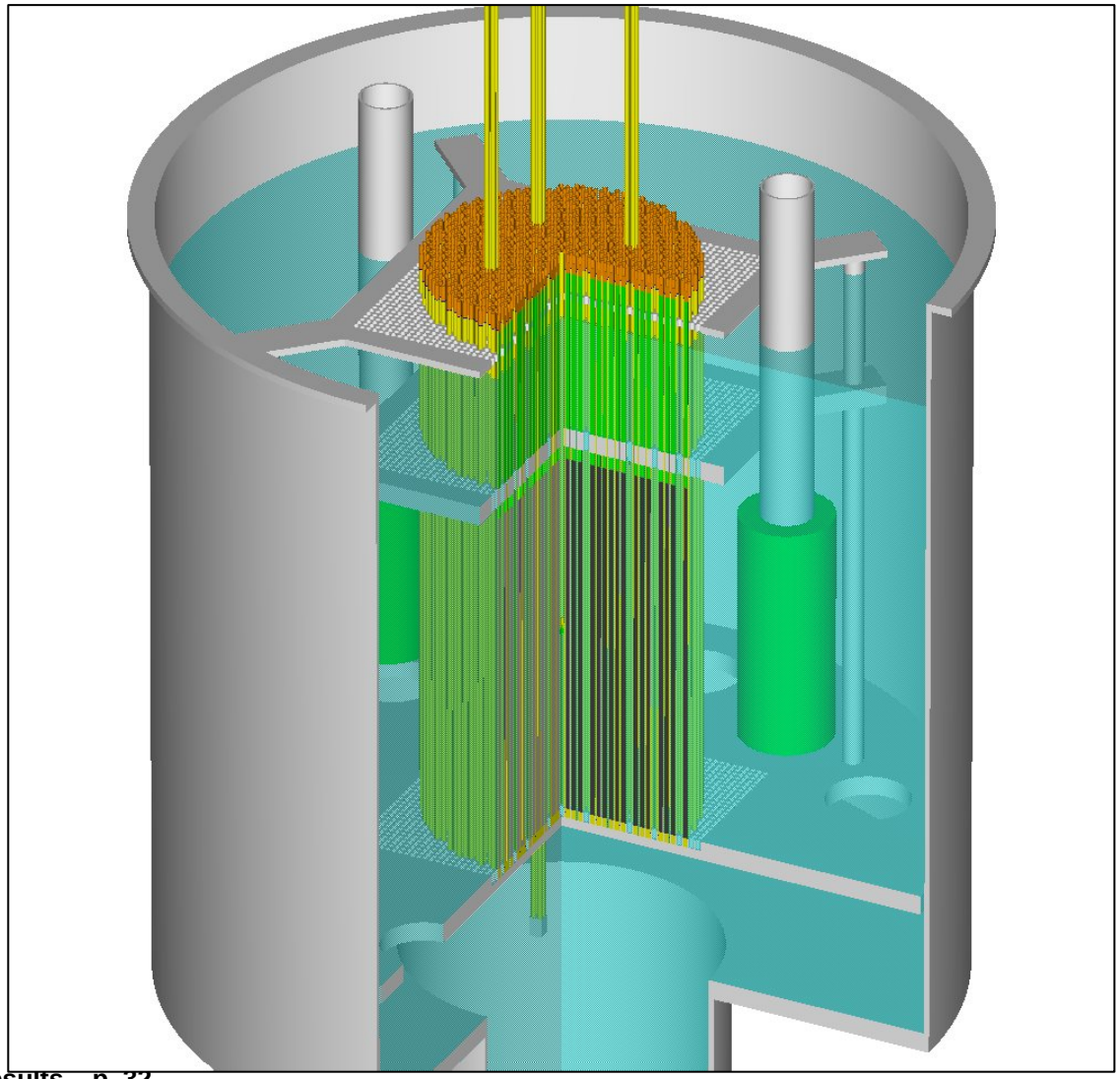
Control Element: Raising

Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.

Raise the Control Element



Fuel: 1136

Safety Elements: Up

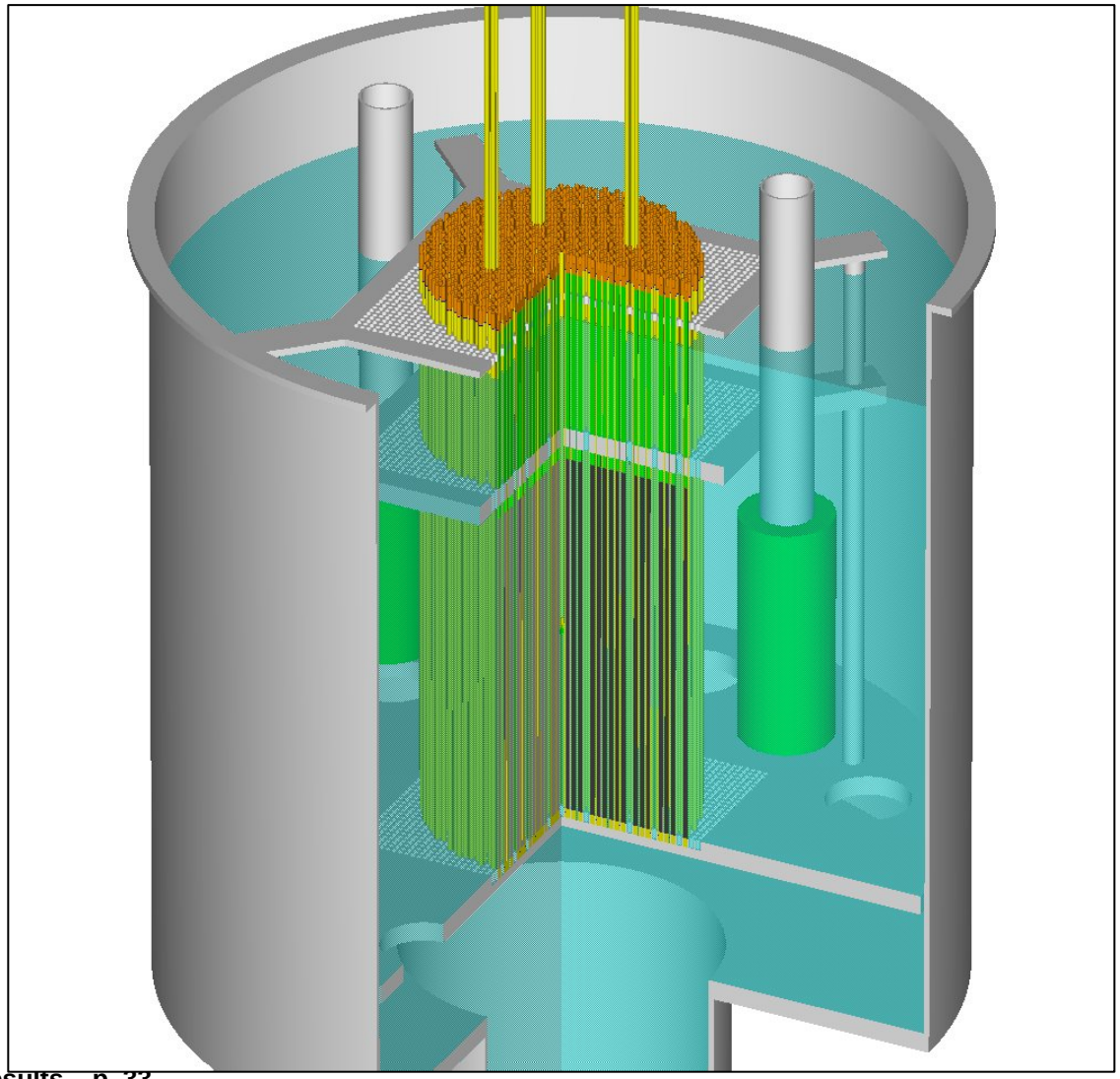
Control Element: Raising

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.

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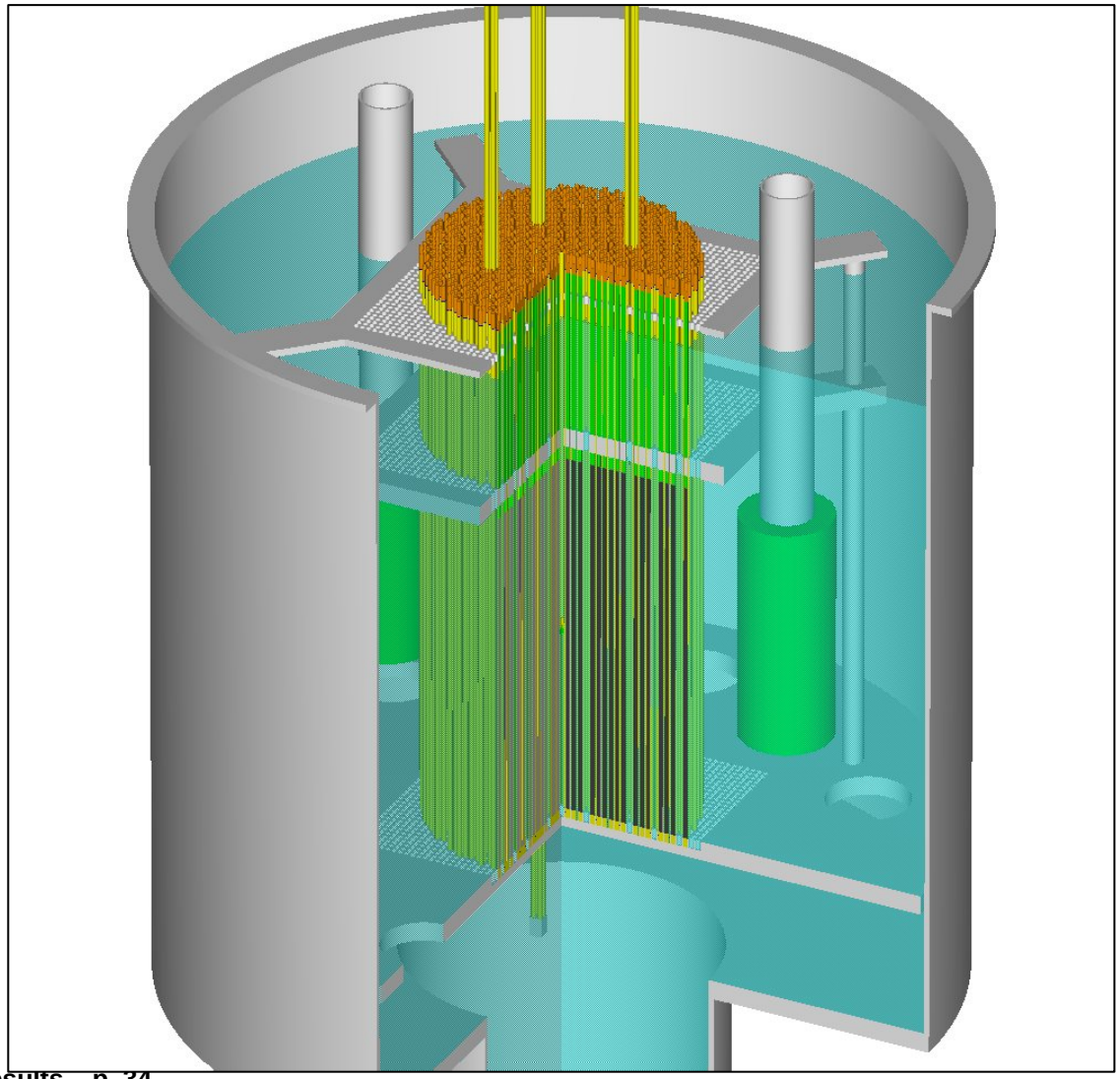
Lower the Control Element



Fuel: 1136

Safety Elements: Up

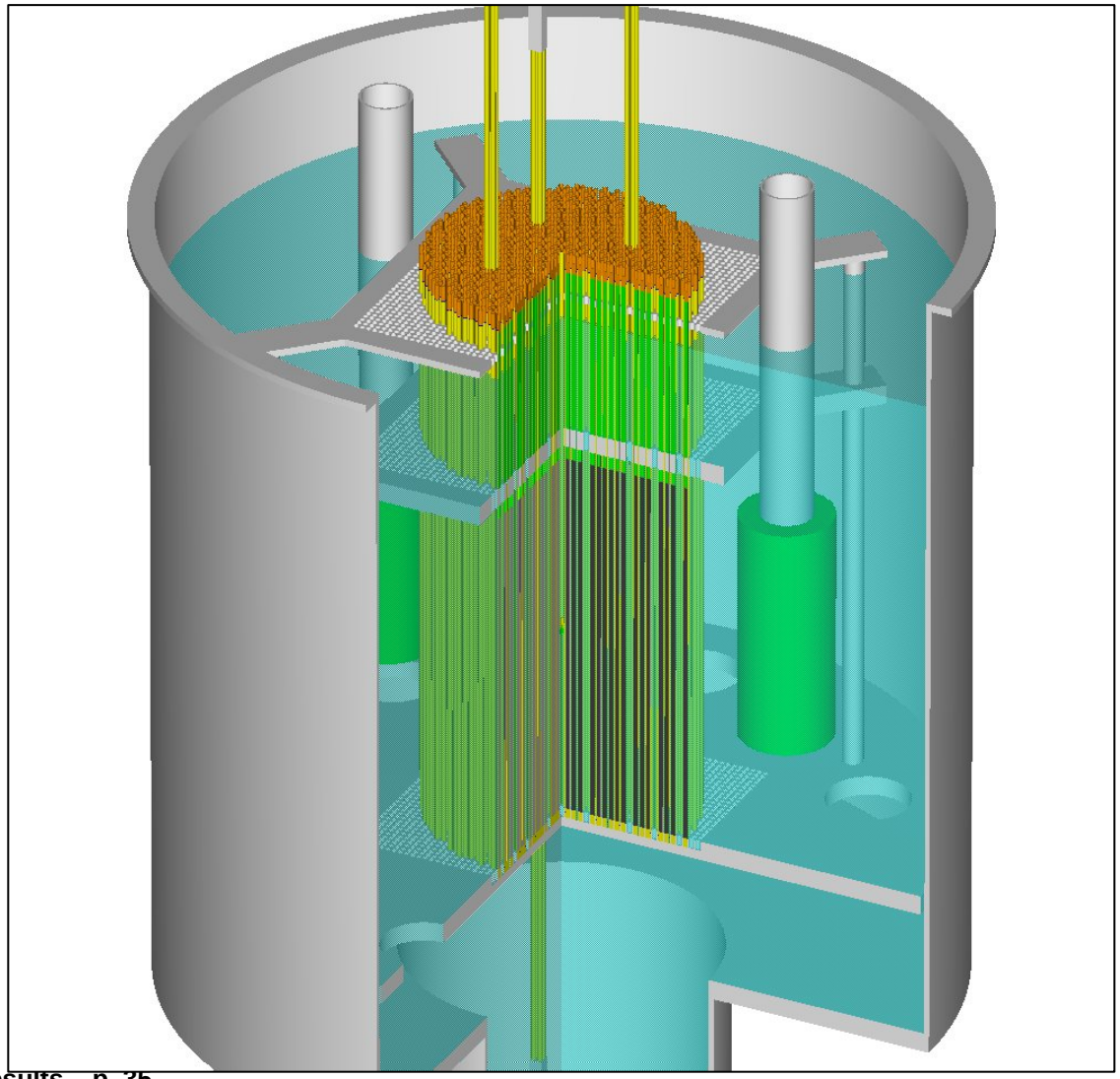
Control Element: Lowering

Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to lower the control element.

Lower the Control Element



Fuel: 1136

Safety Elements: Up

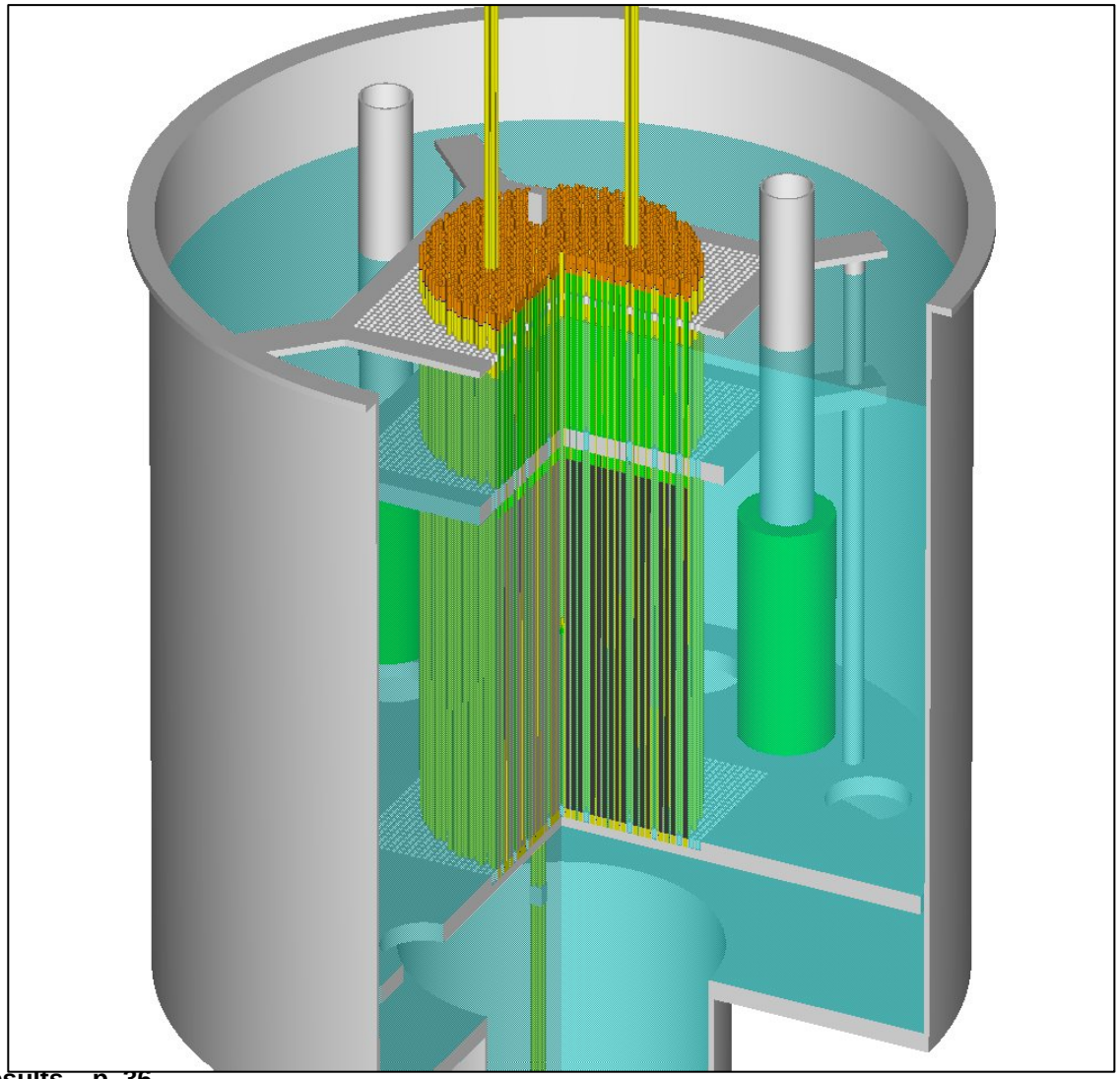
Control Element: Lowering

Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to lower the control element.

Lower the Control Element



Fuel: 1136

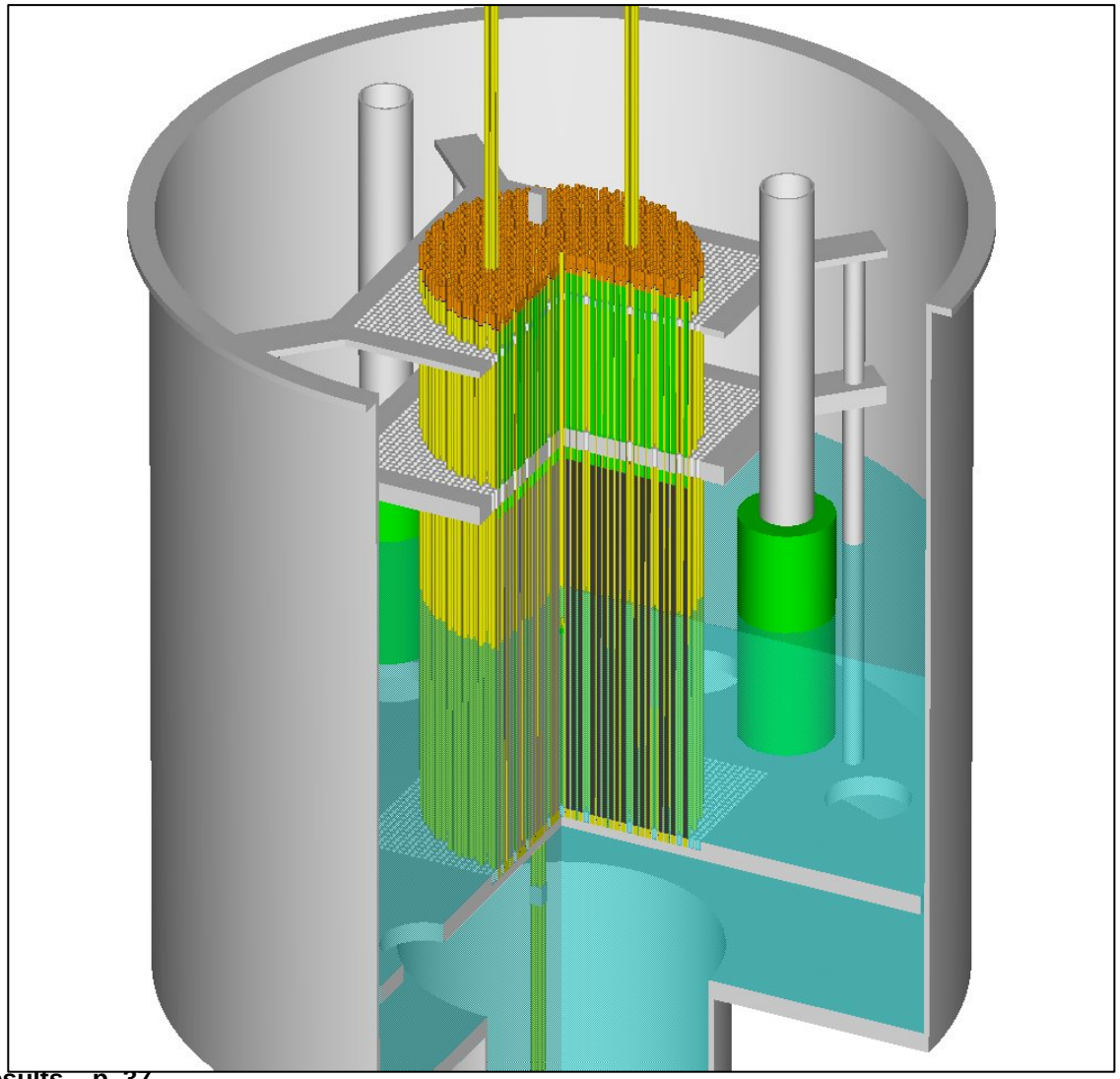
Safety Elements: Up

Control Element: Down

Core Tank: Full

Personnel: Excluded

Drain the Core Tank



Fuel: 1136

Safety Elements: Up

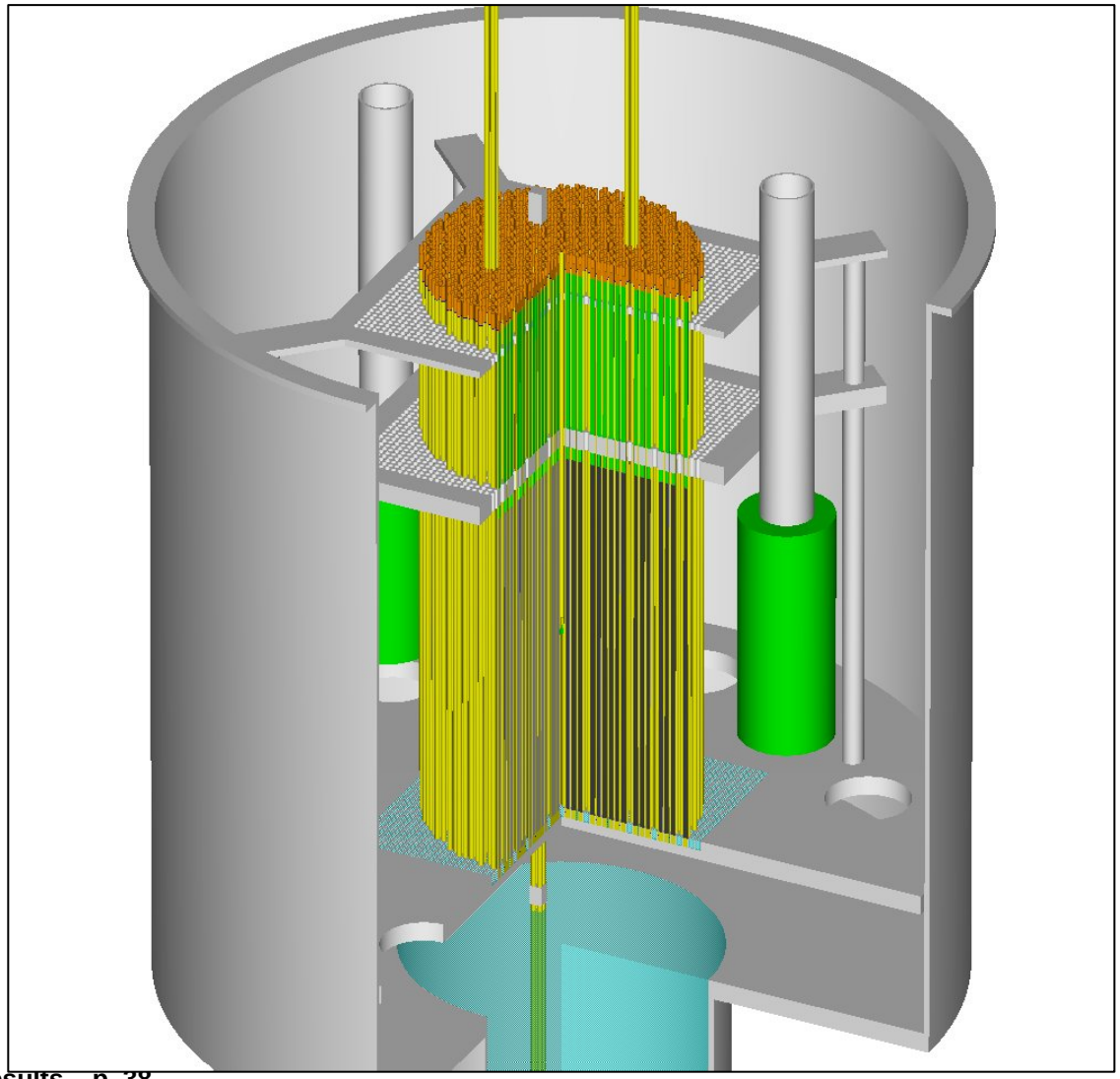
Control Element: Down

Core Tank: Draining

Personnel: Excluded

Draining the core tank requires only a few seconds.

Drain the Core Tank



Fuel: 1136

Safety Elements: Up

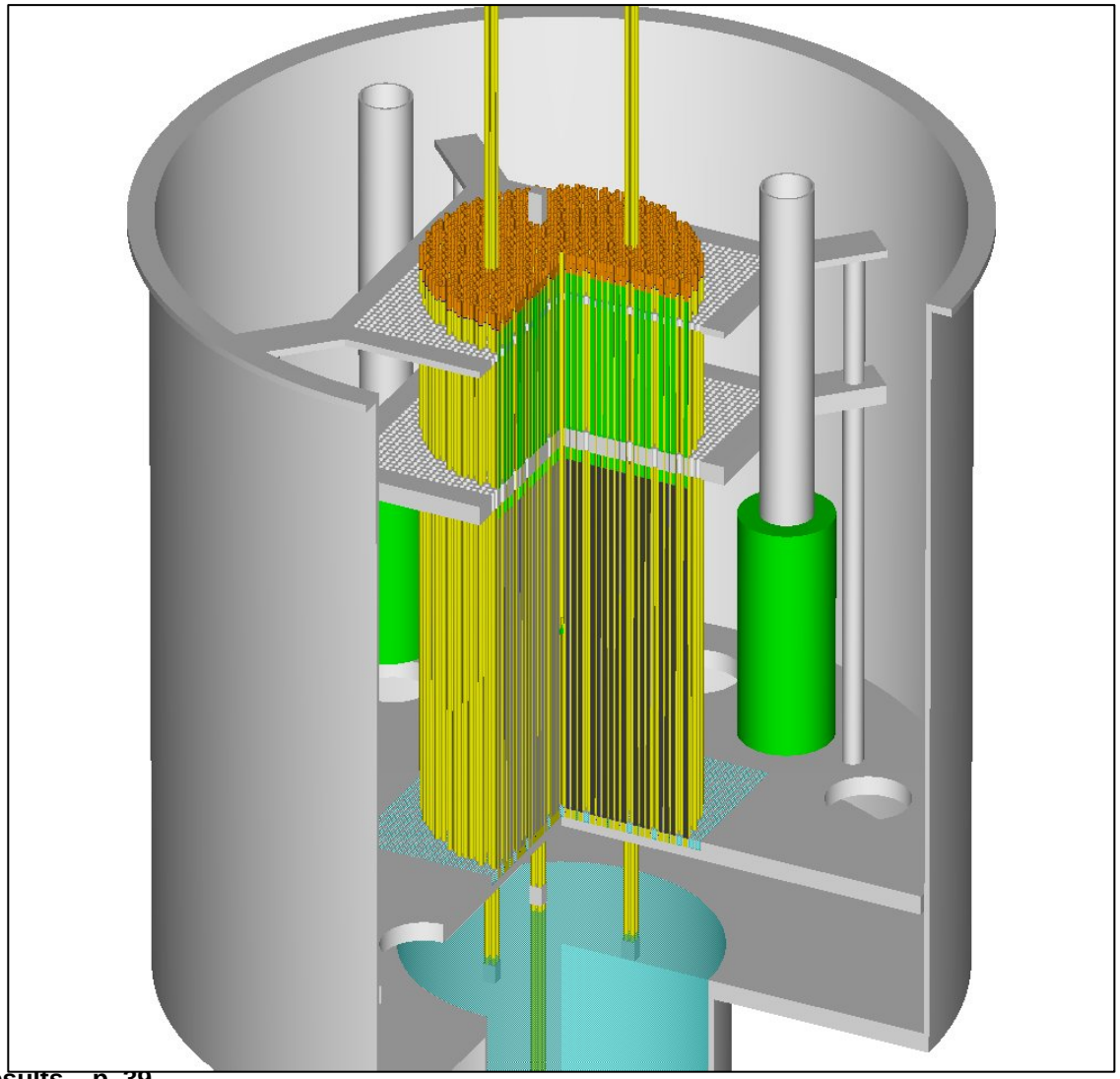
Control Element: Down

Core Tank: Empty

Personnel: Allowed

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

Lower the Safety Elements



Fuel: 1136

Safety Elements: Lowering

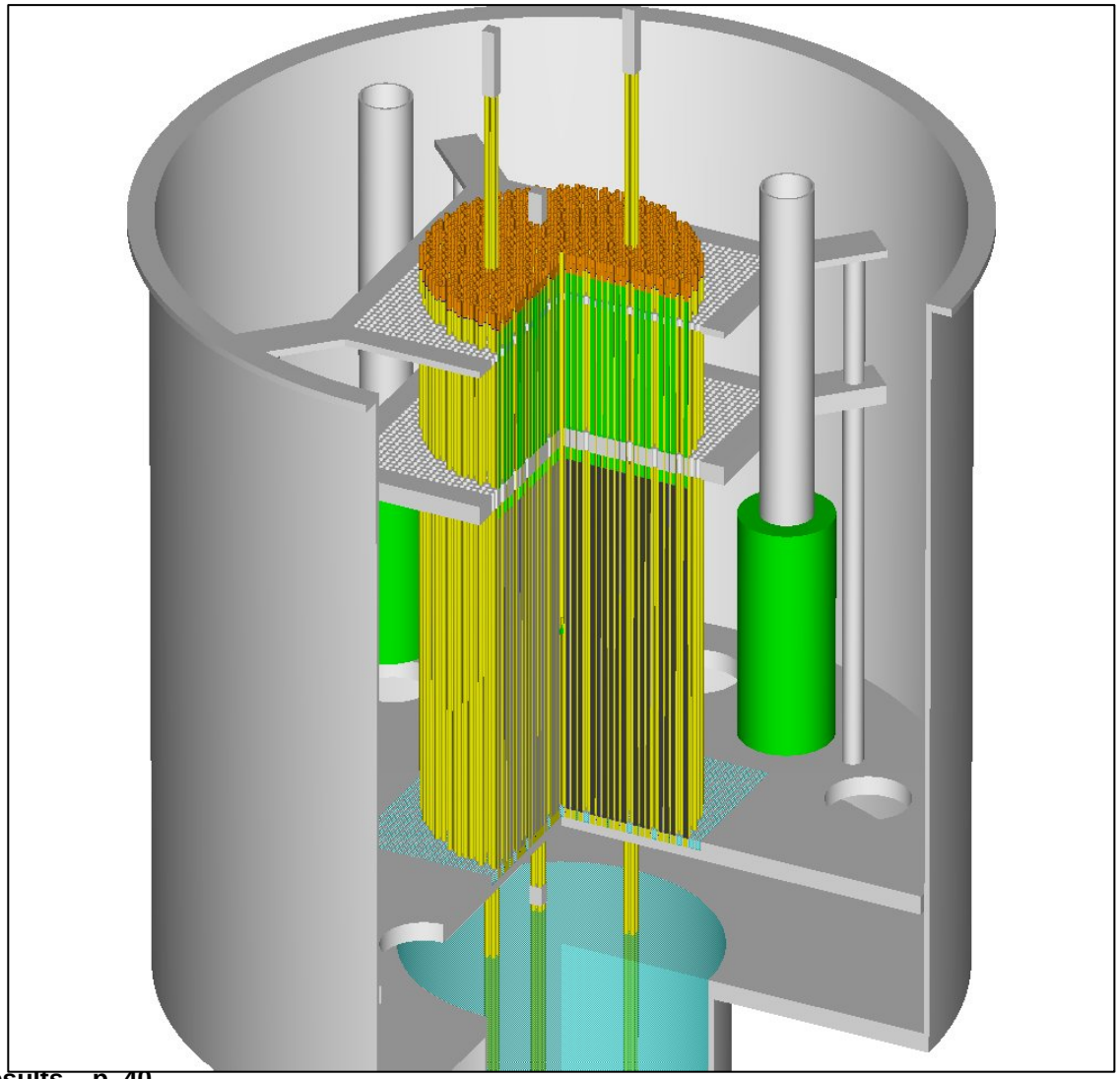
Control Element: Down

Core Tank: Empty

Personnel: Allowed

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

Lower the Safety Elements



Fuel: 1136

Safety Elements: Lowering

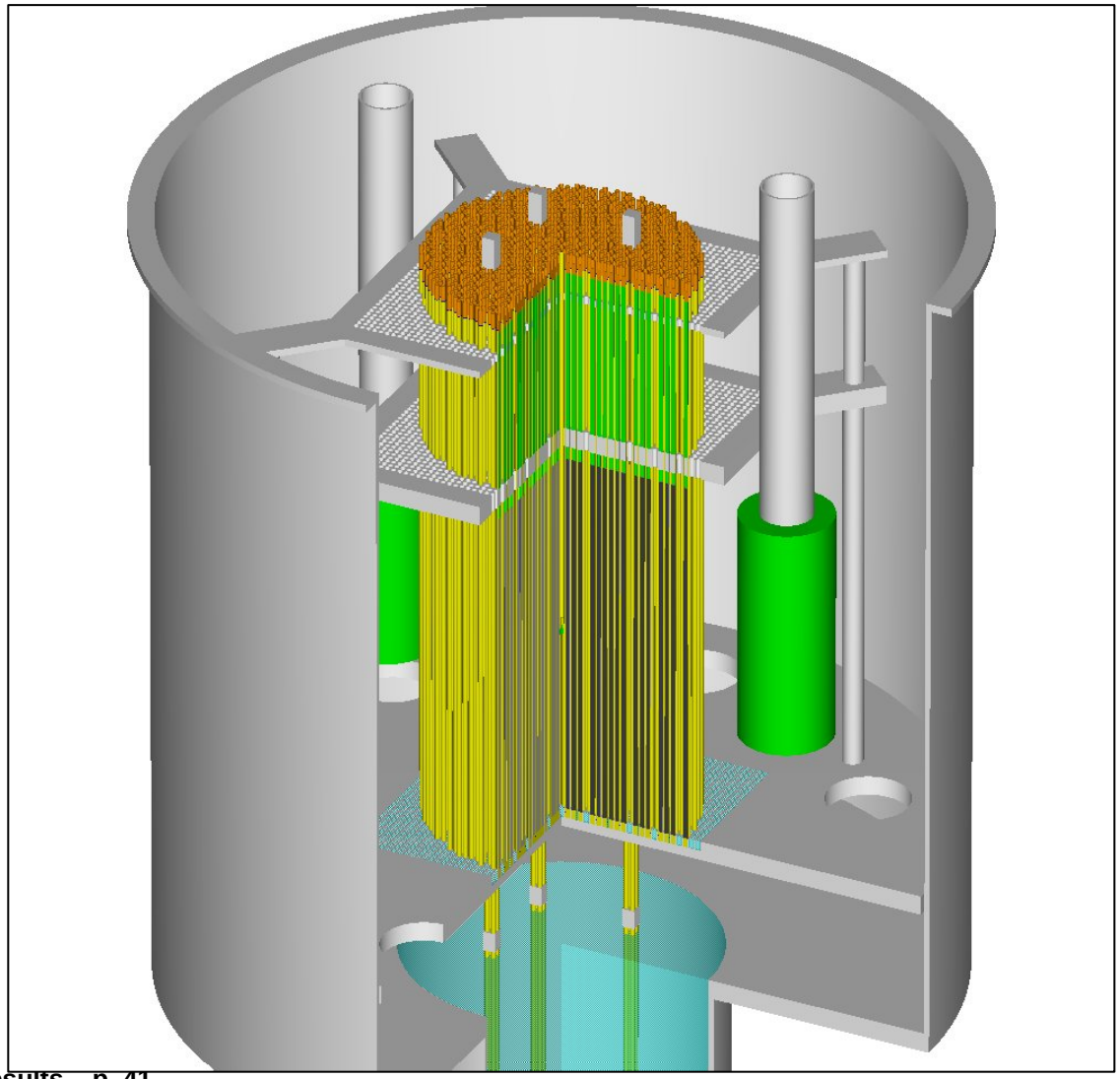
Control Element: Down

Core Tank: Empty

Personnel: Allowed

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

The Assembly Reaches its Shutdown Condition



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 added to or removed from the array.

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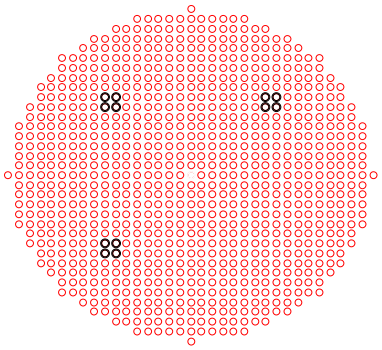
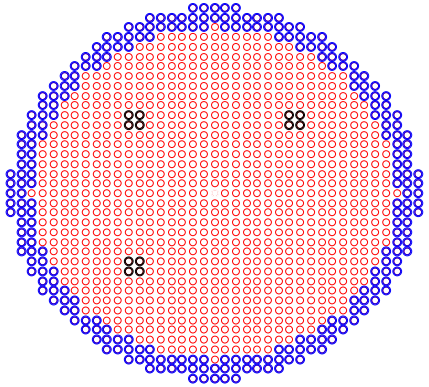
Approach to Critical

- We determine critical conditions for a given set of assembly conditions in an “approach-to-critical” experiment
- The goal of the experiment is to find the conditions where the multiplication of the assembly is infinite
- Under those conditions, the inverse of the multiplication is zero
- Count-rate measurements are made on the assembly as the approach variable is changed to make the system more reactive
- When the assembly is nearly critical, the count rates follow the assembly multiplication
- Estimates are made of the critical condition of the assembly from the measurements

Core configurations during the 800B0000A approach-to-critical experiment (1)



892

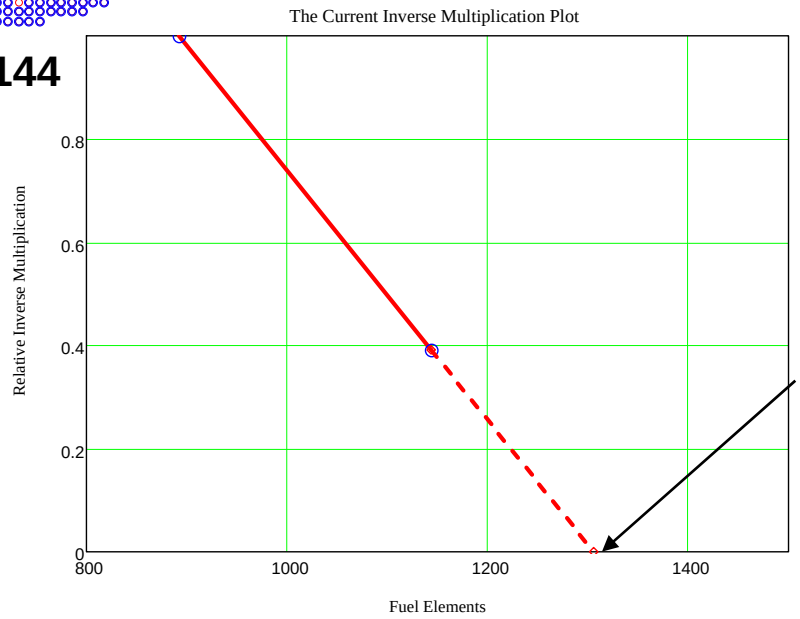


1144

The first two arrays have k_{eff} ~ 0.9 and k_{eff} ~ 0.95 (calculated)

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

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



1307.5

Project the two inverse multiplication measurements to zero and add half the increment to get the next array – in this case 1224 elements

The incremental fuel elements are shown in blue

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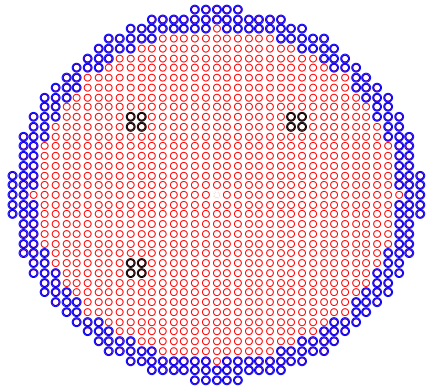
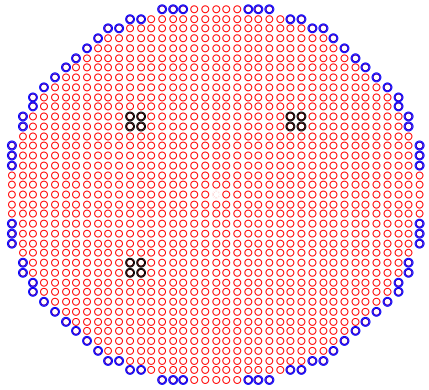
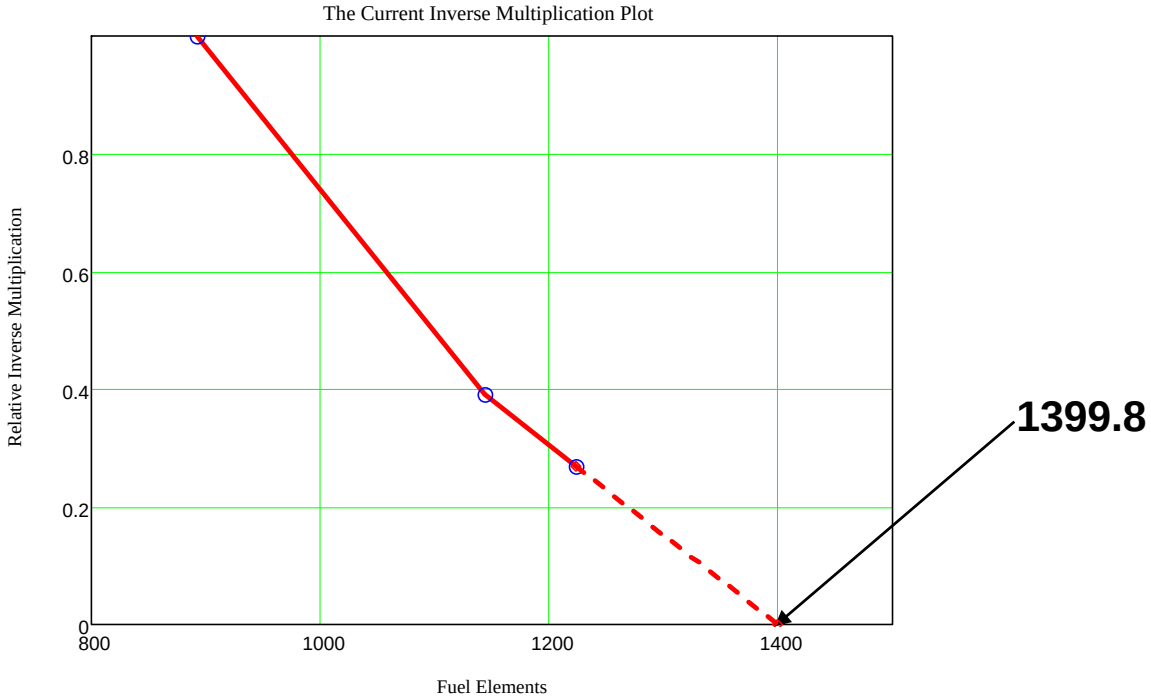
Core configurations during the 800B0000A approach-to-critical experiment (2)



1144



1224



The next array: 1304

The incremental fuel elements are shown in blue

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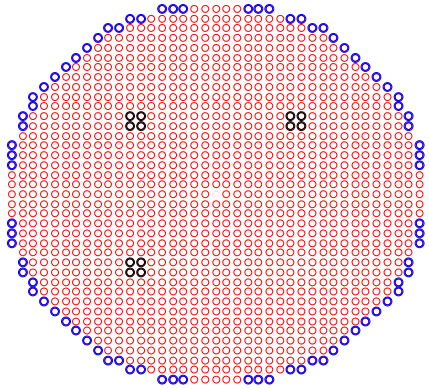
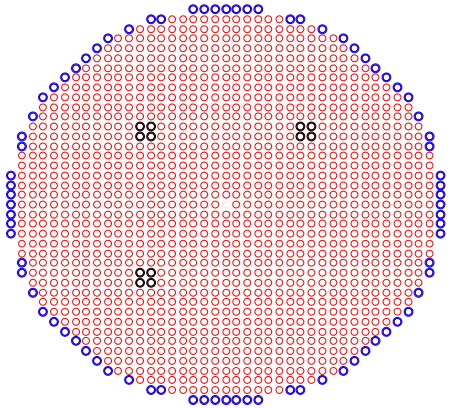
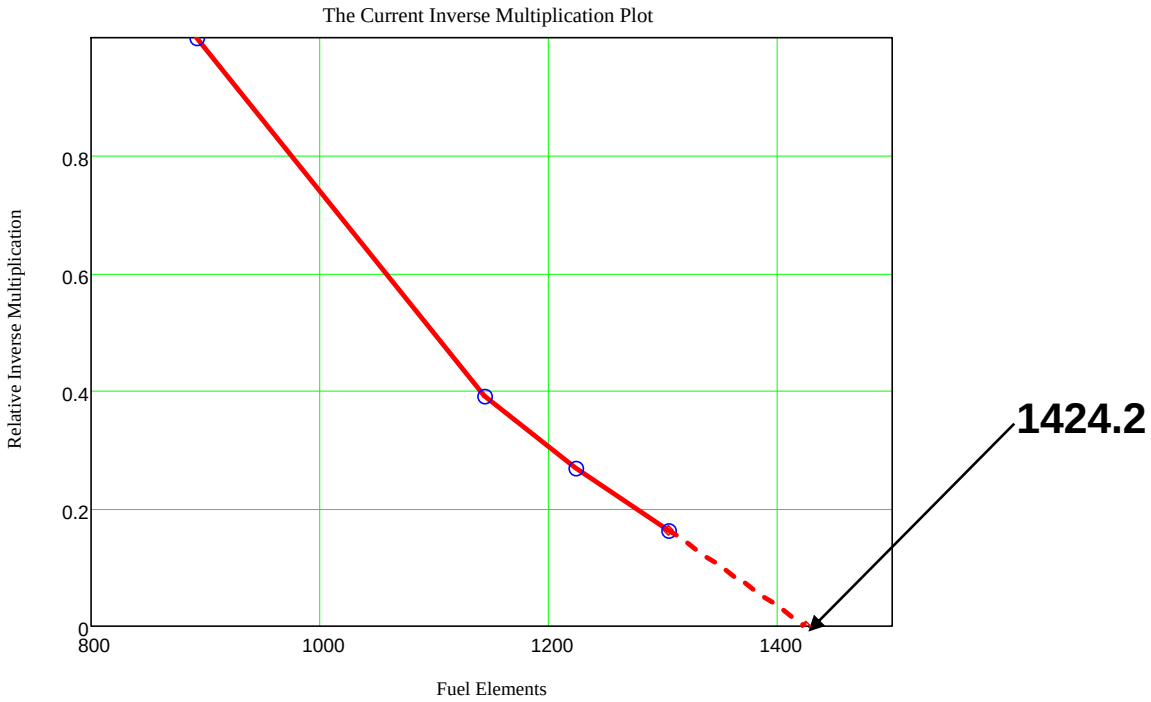
Core configurations during the 800B0000A approach-to-critical experiment (3)



1224



1304



The next array: 1360

The incremental fuel elements are shown in blue

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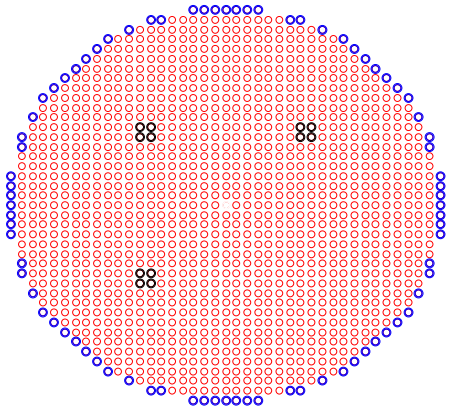
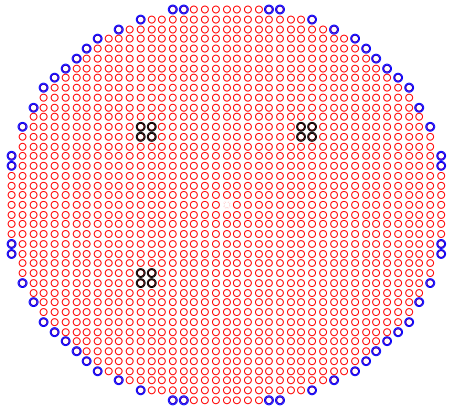
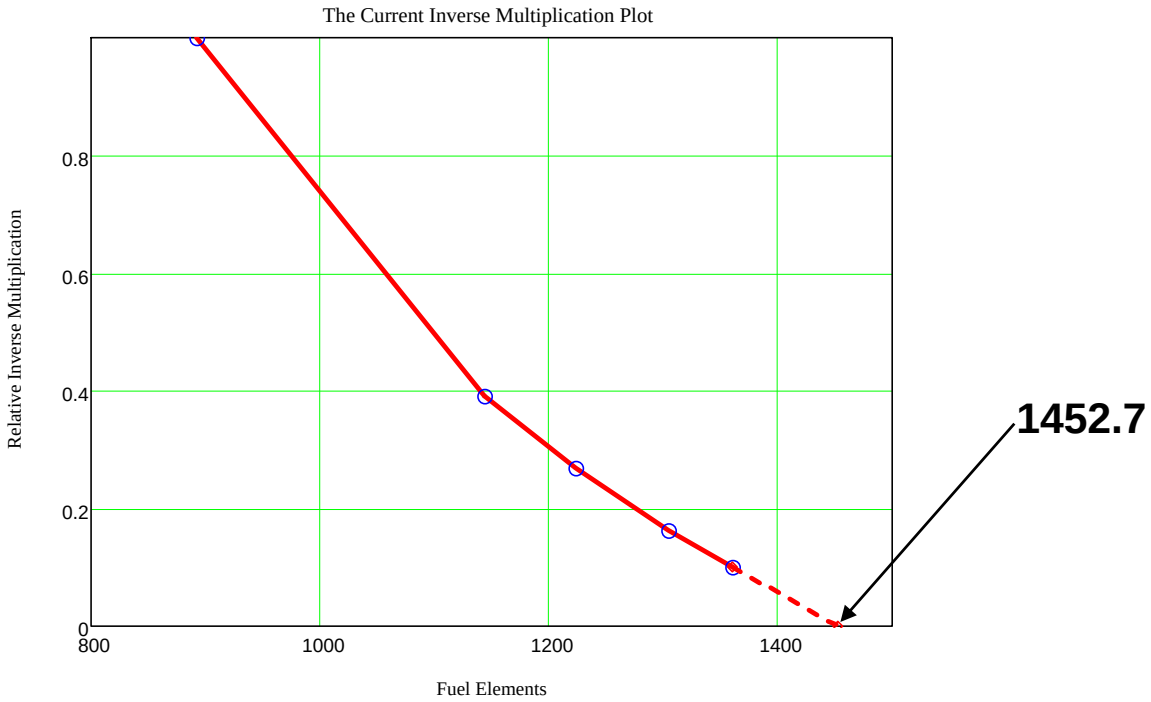
Core configurations during the 800B0000A approach-to-critical experiment (4)



1304



1360



The next array: 1404

The incremental fuel elements are shown in blue

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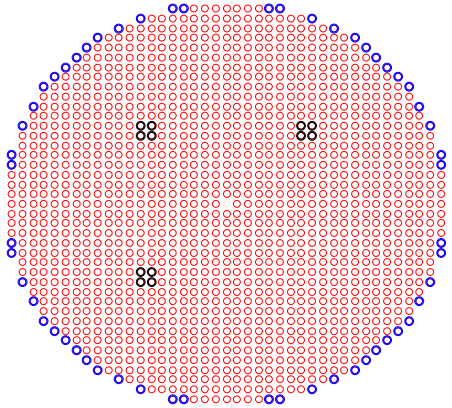
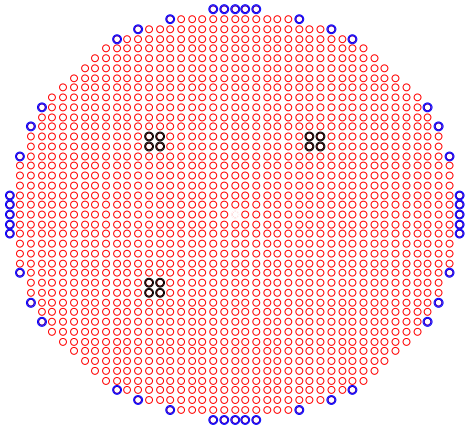
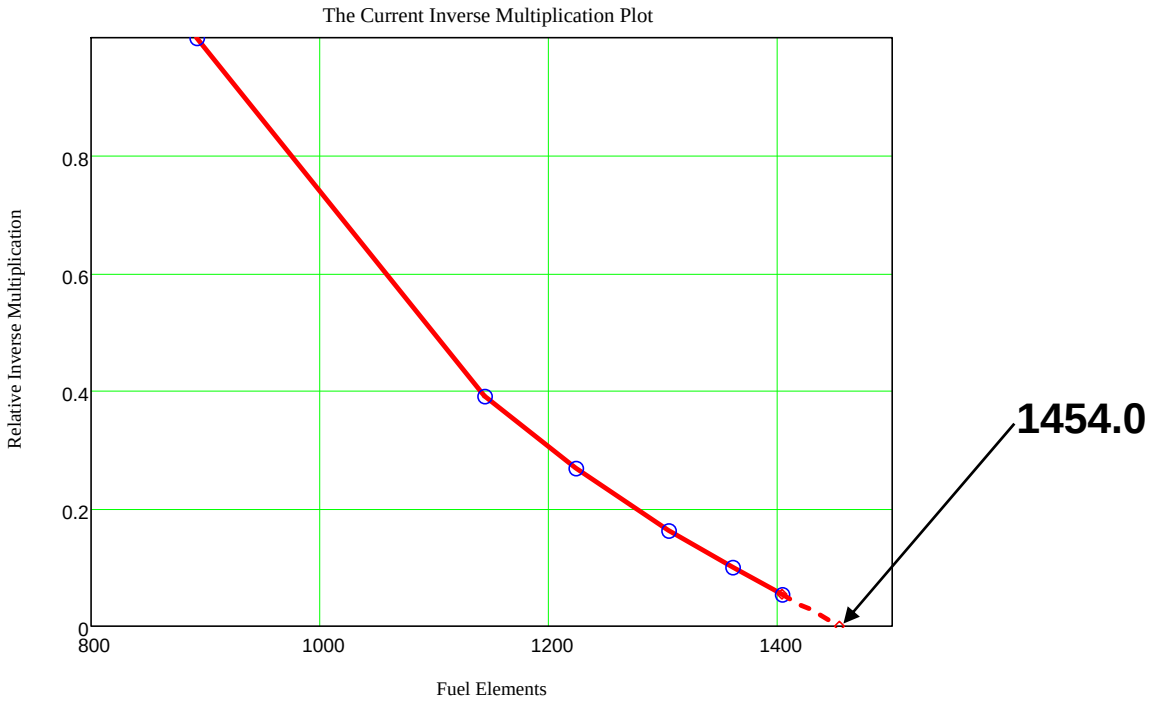
Core configurations during the 800B0000A approach-to-critical experiment (5)



1360



1404



The next array: 1424

The incremental fuel elements are shown in blue

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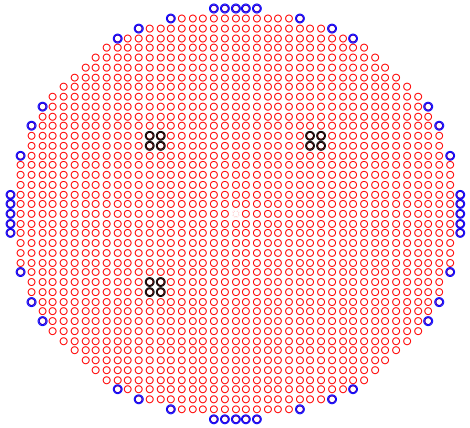
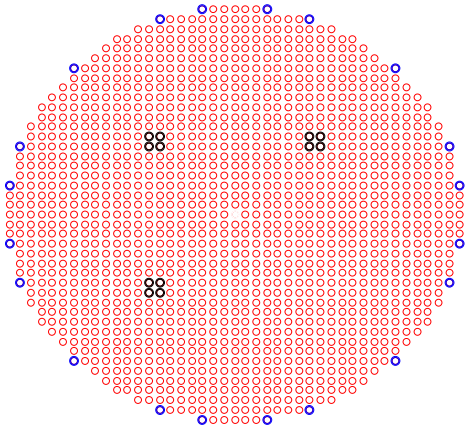
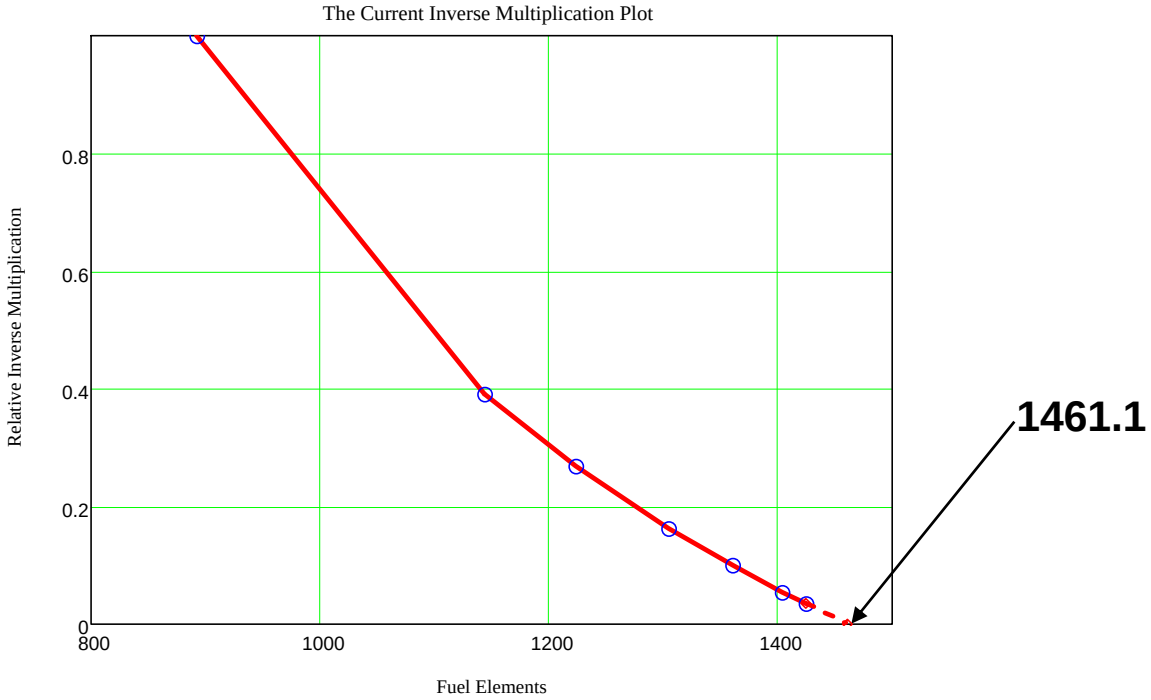
Core configurations during the 800B0000A approach-to-critical experiment (6)



1404



1424



The next array: 1442

The incremental fuel elements are shown in blue

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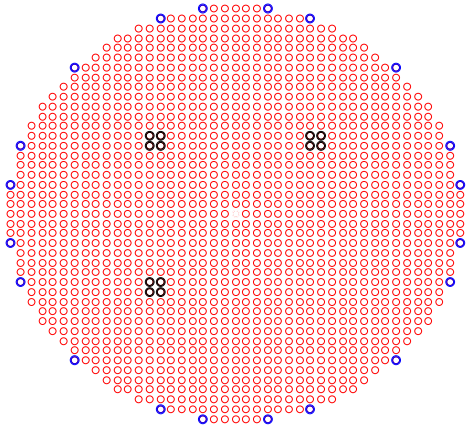
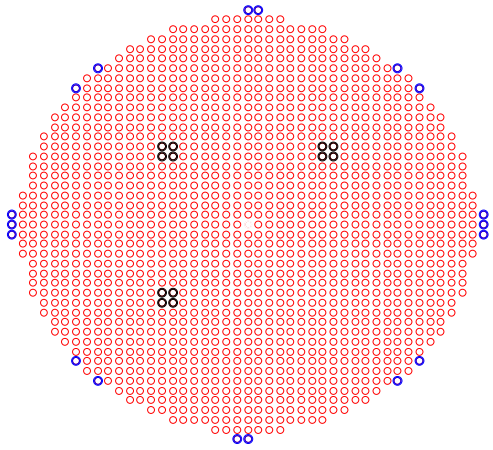
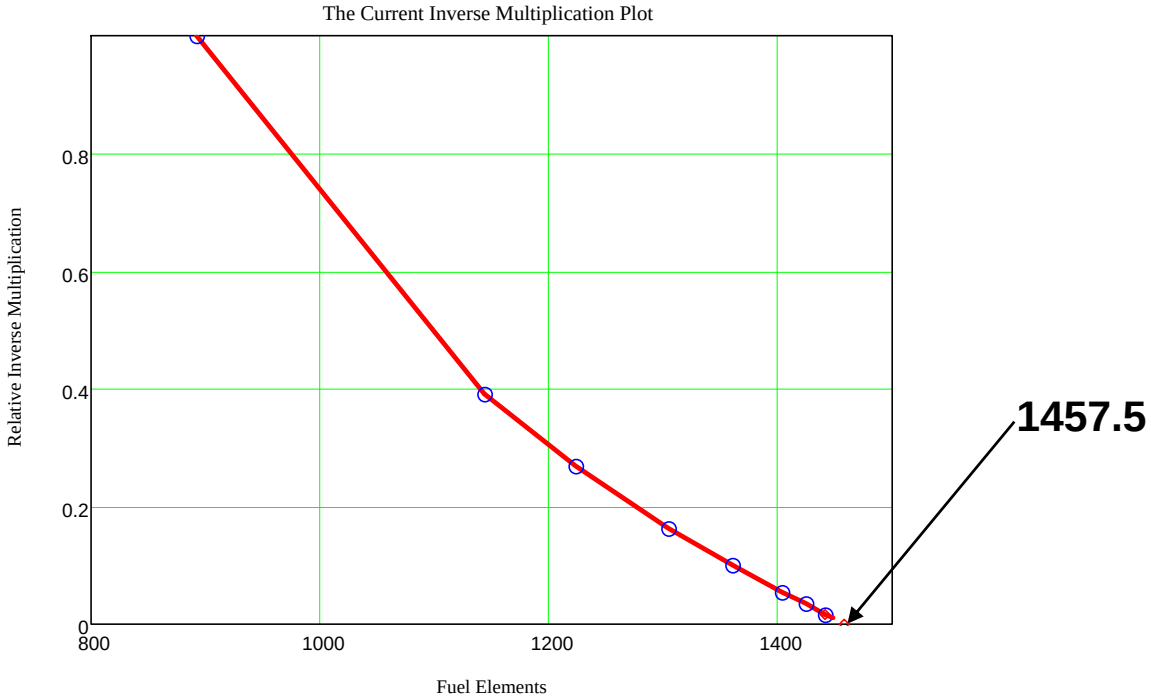
Core configurations during the 800B0000A approach-to-critical experiment (7)



1424



1442



The next array: 1449

The incremental fuel elements are shown in blue

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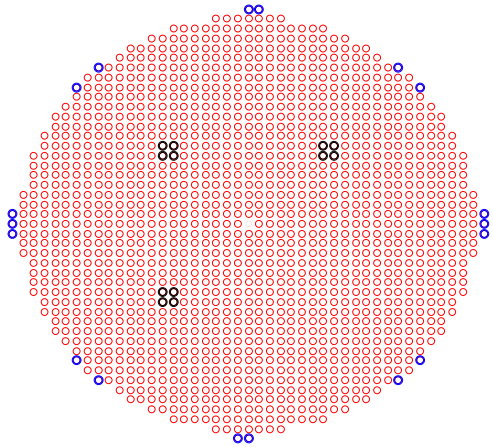
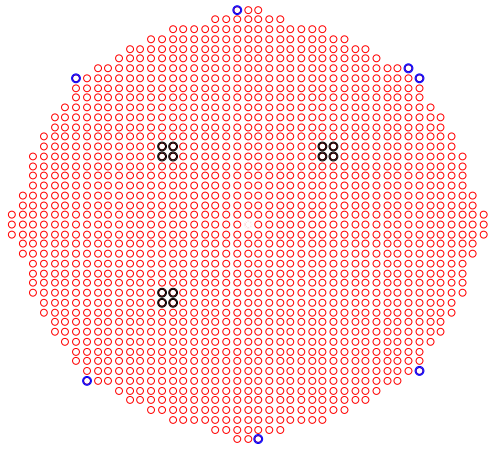
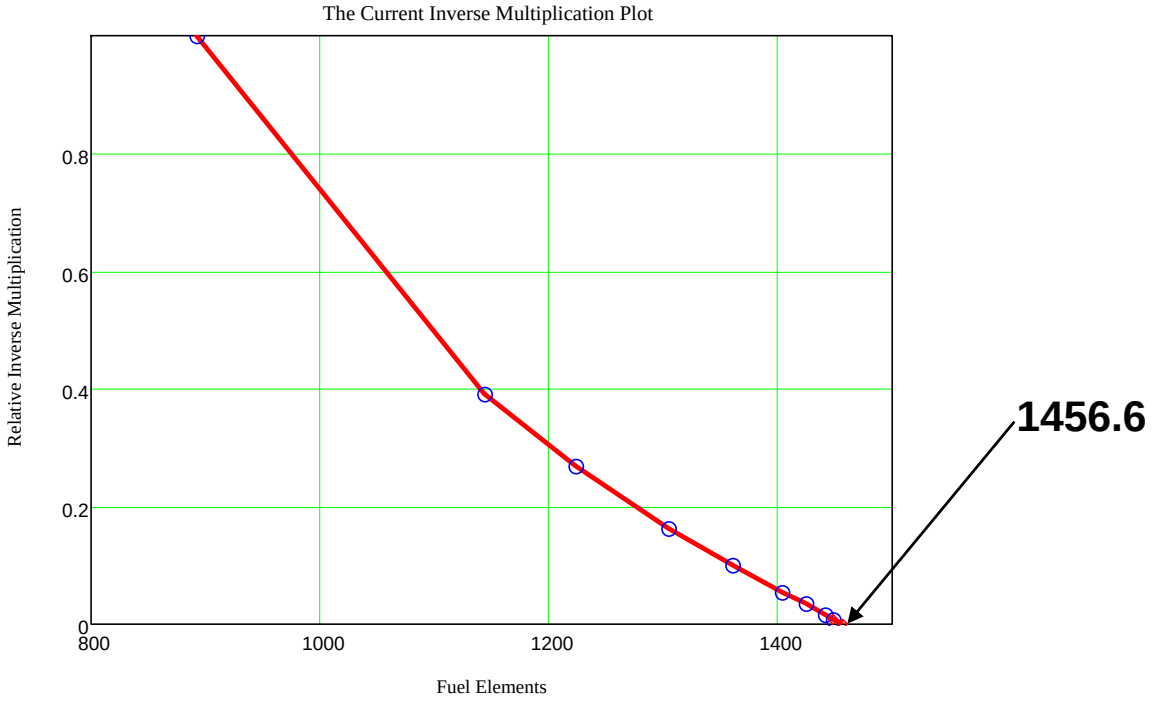
Core configurations during the 800B0000A approach-to-critical experiment (8)



1442



1449



The next array: 1452

The incremental fuel elements are shown in blue

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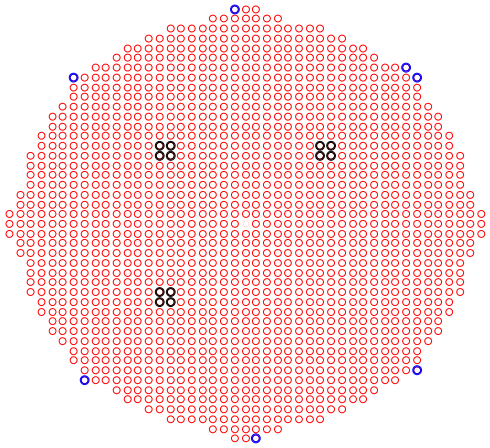
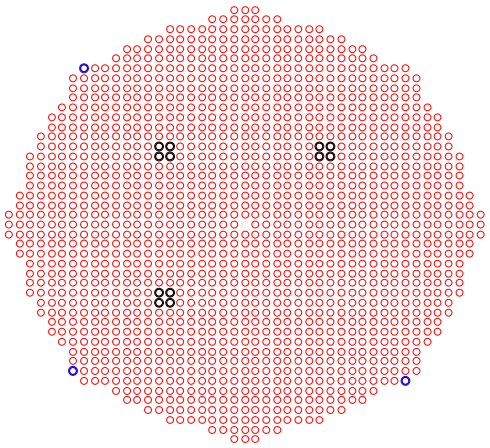
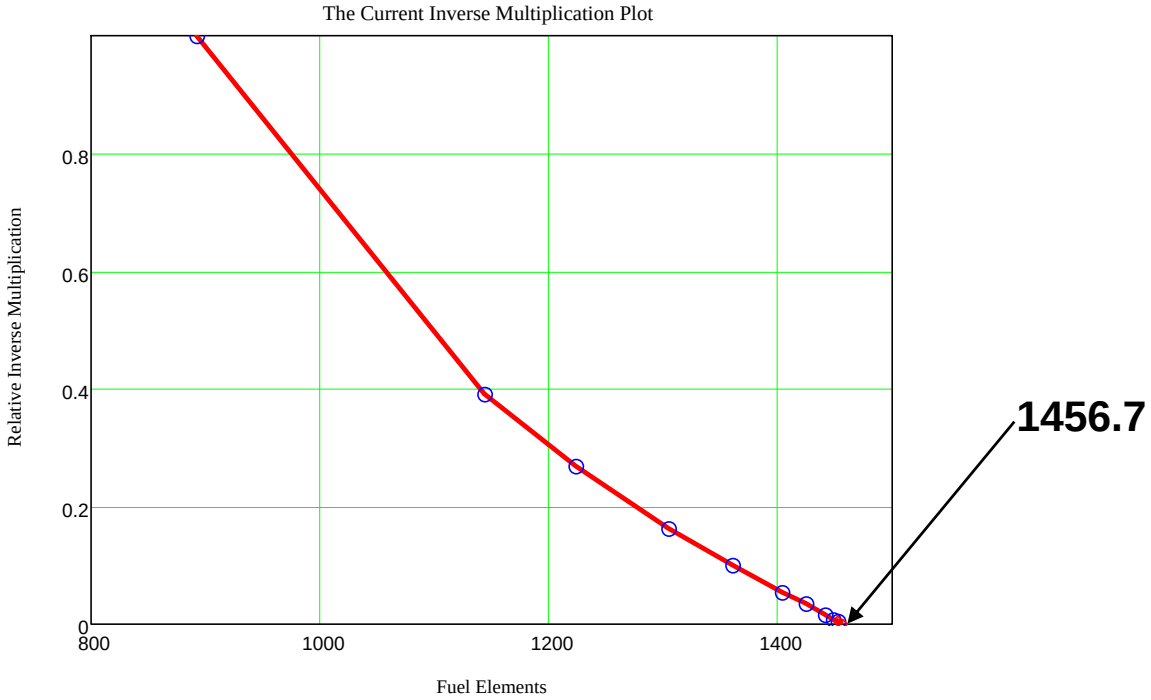
Core configurations during the 800B0000A approach-to-critical experiment (9)



1449



1452



The next array: 1456

The incremental fuel elements are shown in blue

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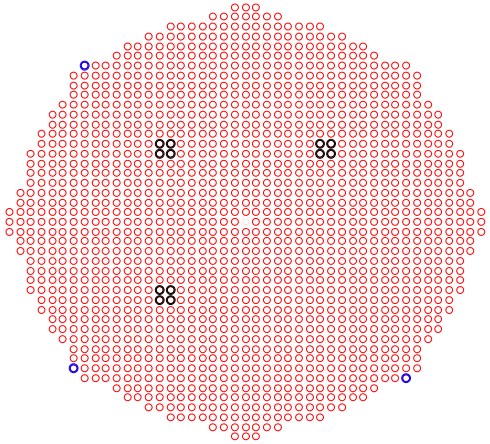
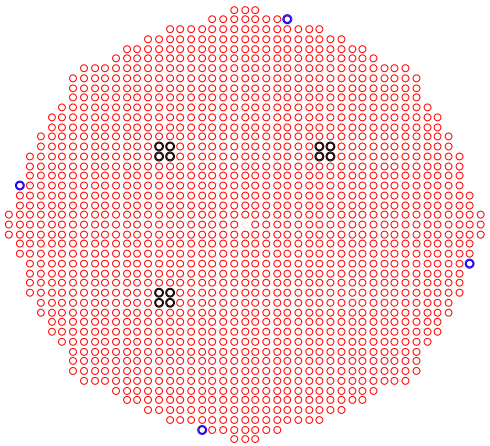
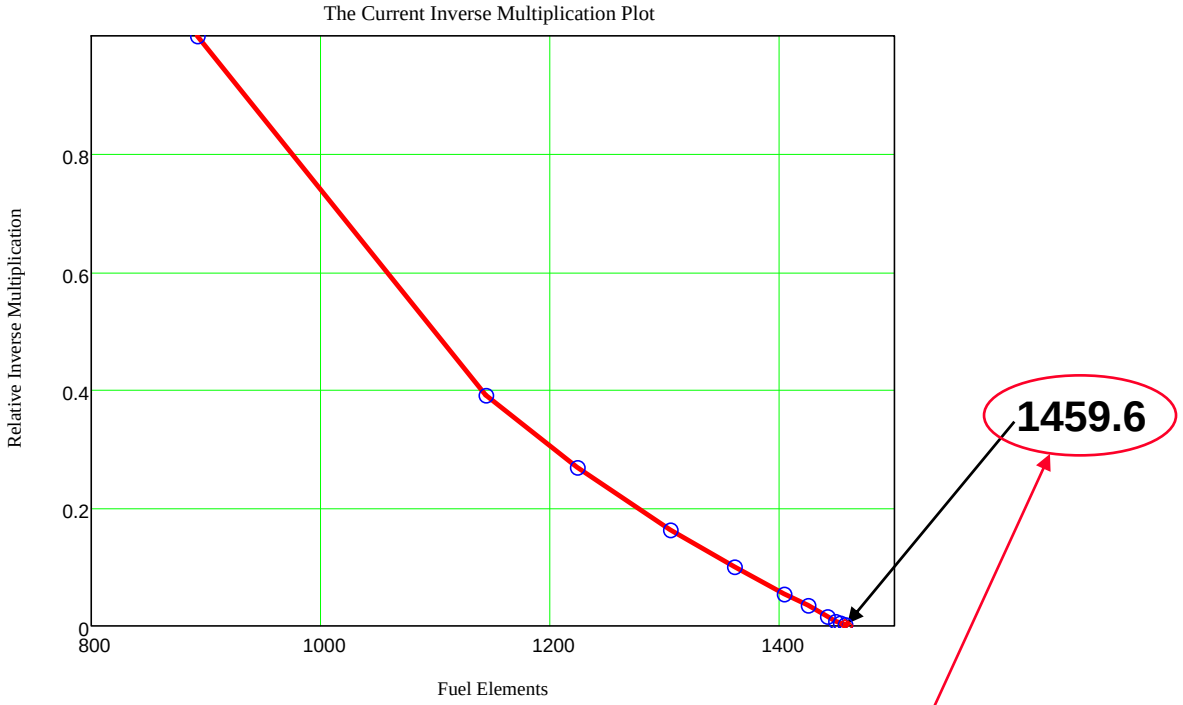
Core configurations during the 800B0000A approach-to-critical experiment (10)



1452



1456



1459.6

The next array: 1460

Should be just critical??

The incremental fuel elements are shown in blue

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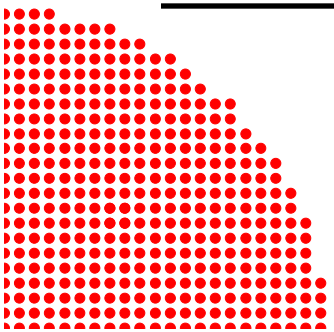
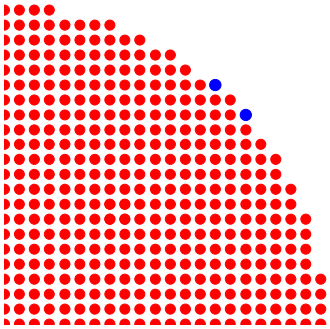
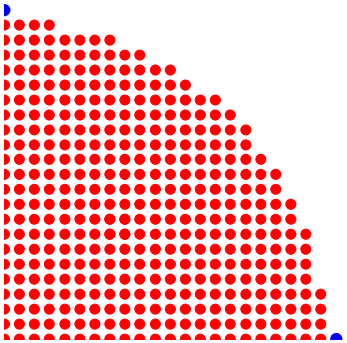
k_{eff} from Approach Data



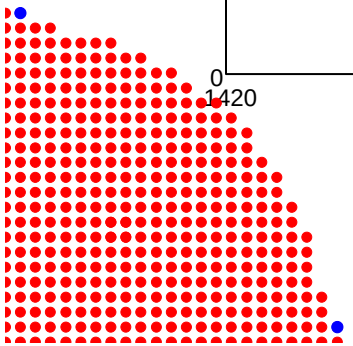
1425



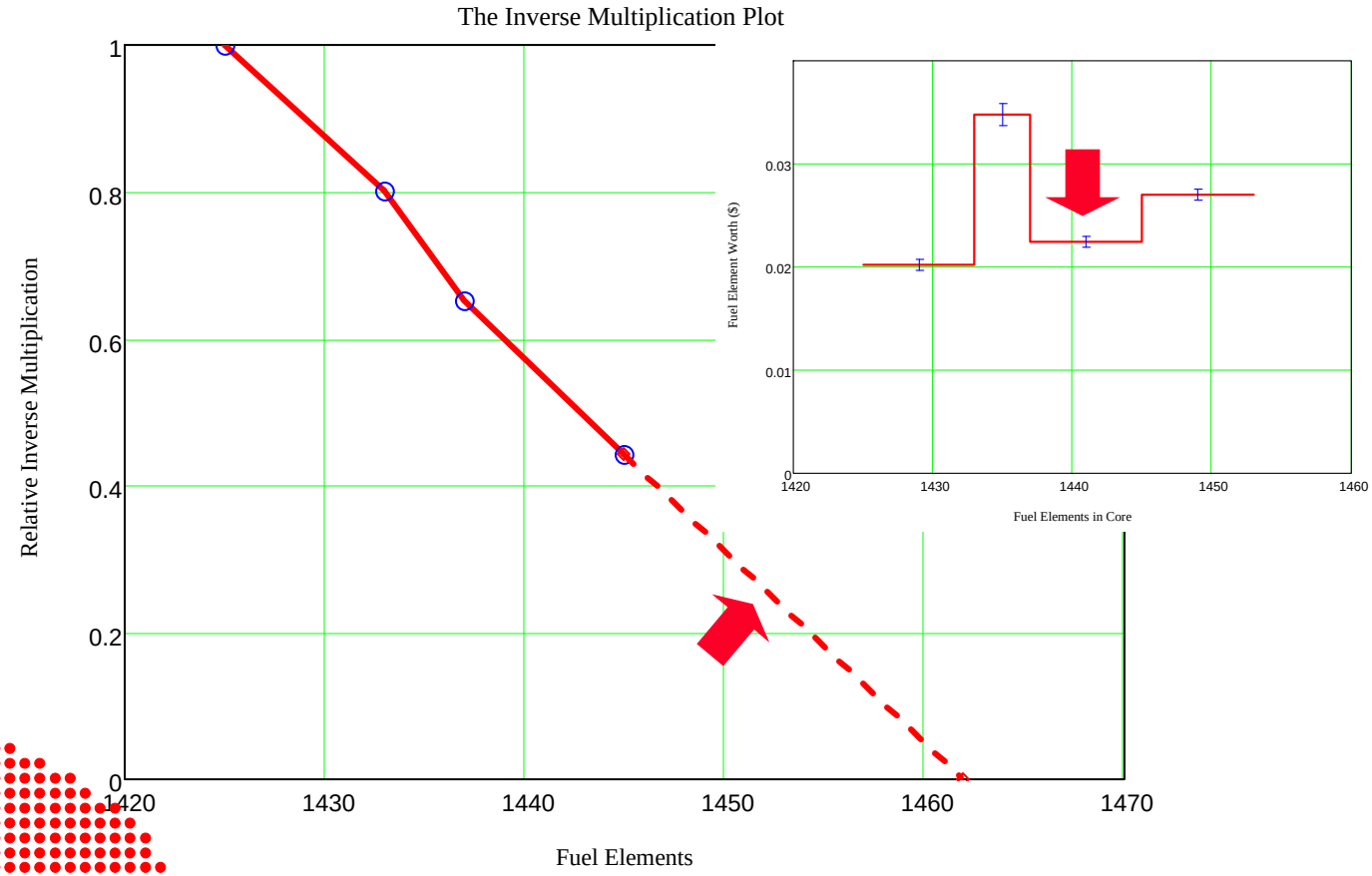
1433



1437 k = 0.9964



1445 k = 0.9975



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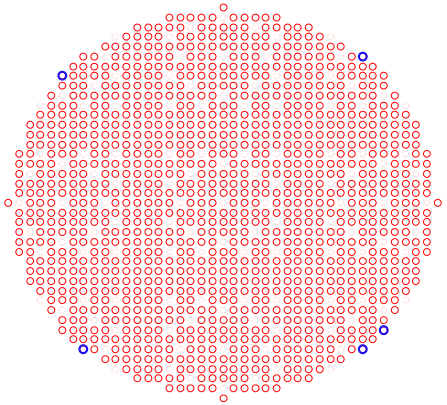
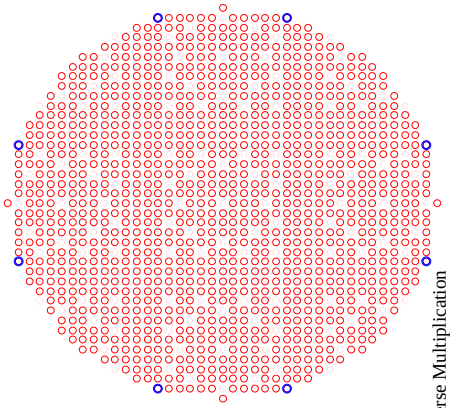
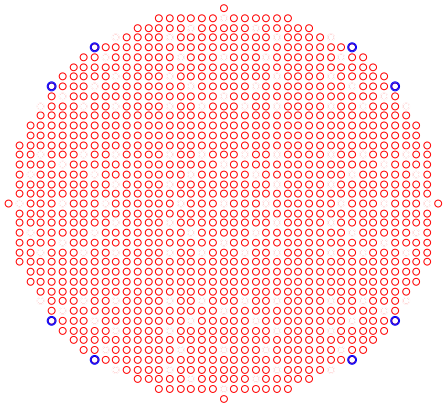
Core 800B0000 configurations during the first approach-to-critical experiment



1120



1128

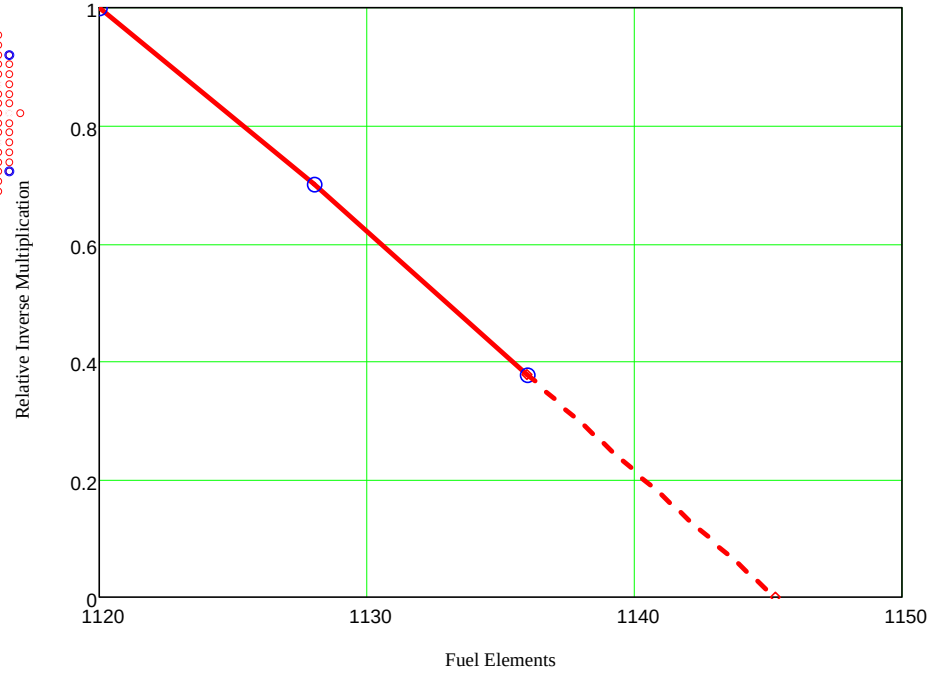


1136

At 1128 fuel elements:

k_{eff} = 0.9970

M ~ 330



At 1136 fuel elements:

k_{eff} = 0.9984

M ~ 620

The incremental fuel elements are shown in blue

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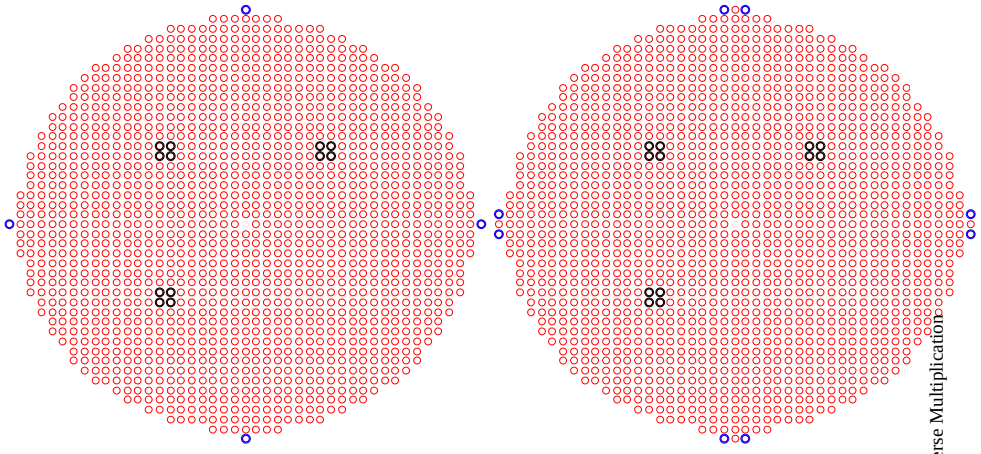
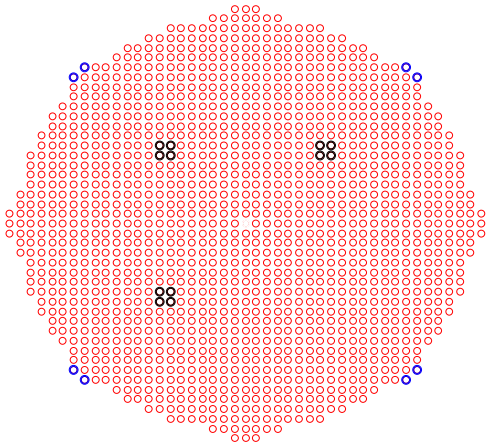
Core 800B0000A configurations near delayed critical



1436

1444

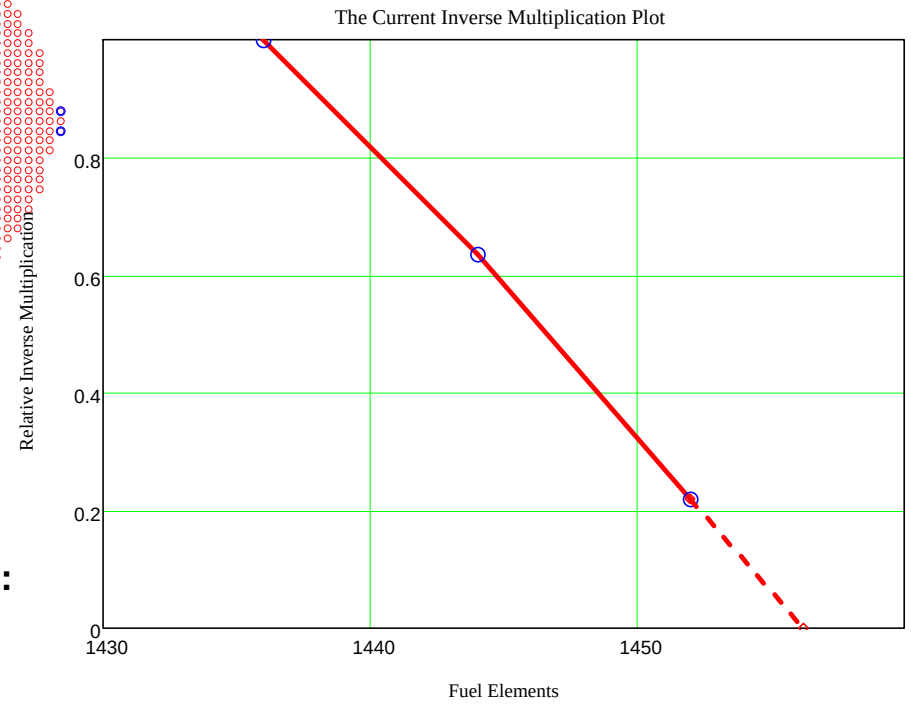


1452

At 1444 fuel elements:

k_{eff} = 0.9980

M ~ 490



At 1452 fuel elements:

k_{eff} = 0.9992

M ~ 1340

The incremental fuel elements are shown in blue

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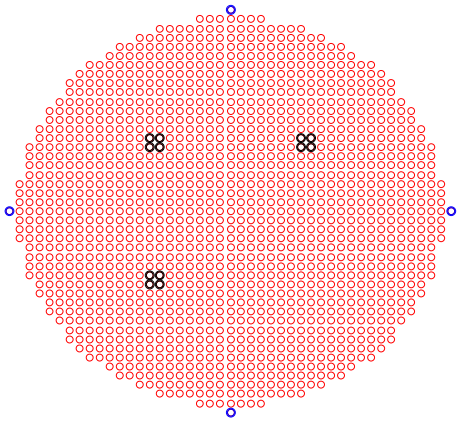
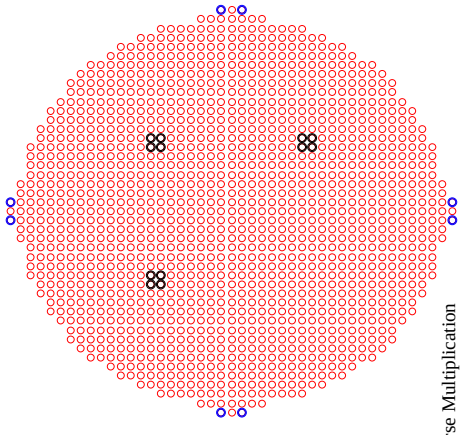
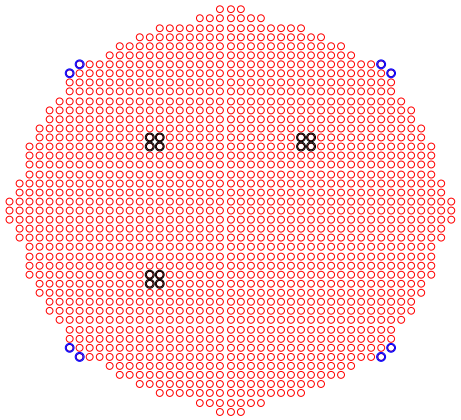
Core 800B0000B configurations during the first approach-to-critical experiment



1437



1445

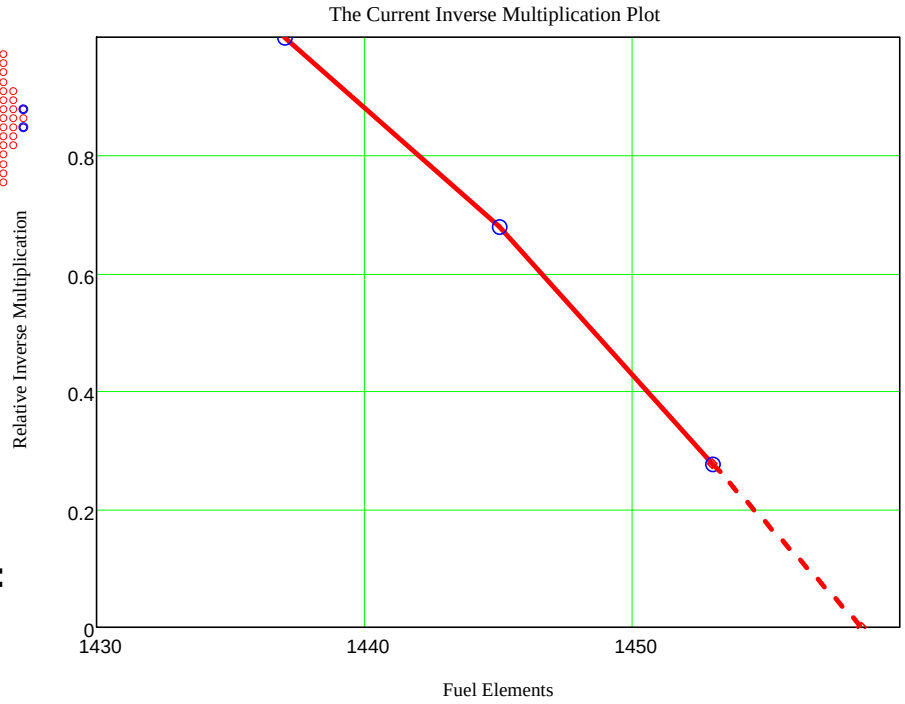


1453

At 1445 fuel elements:

k_{eff} = 0.9975

M ~ 400



At 1453 fuel elements:

k_{eff} = 0.9990

M ~ 1020

The incremental fuel elements are shown in blue

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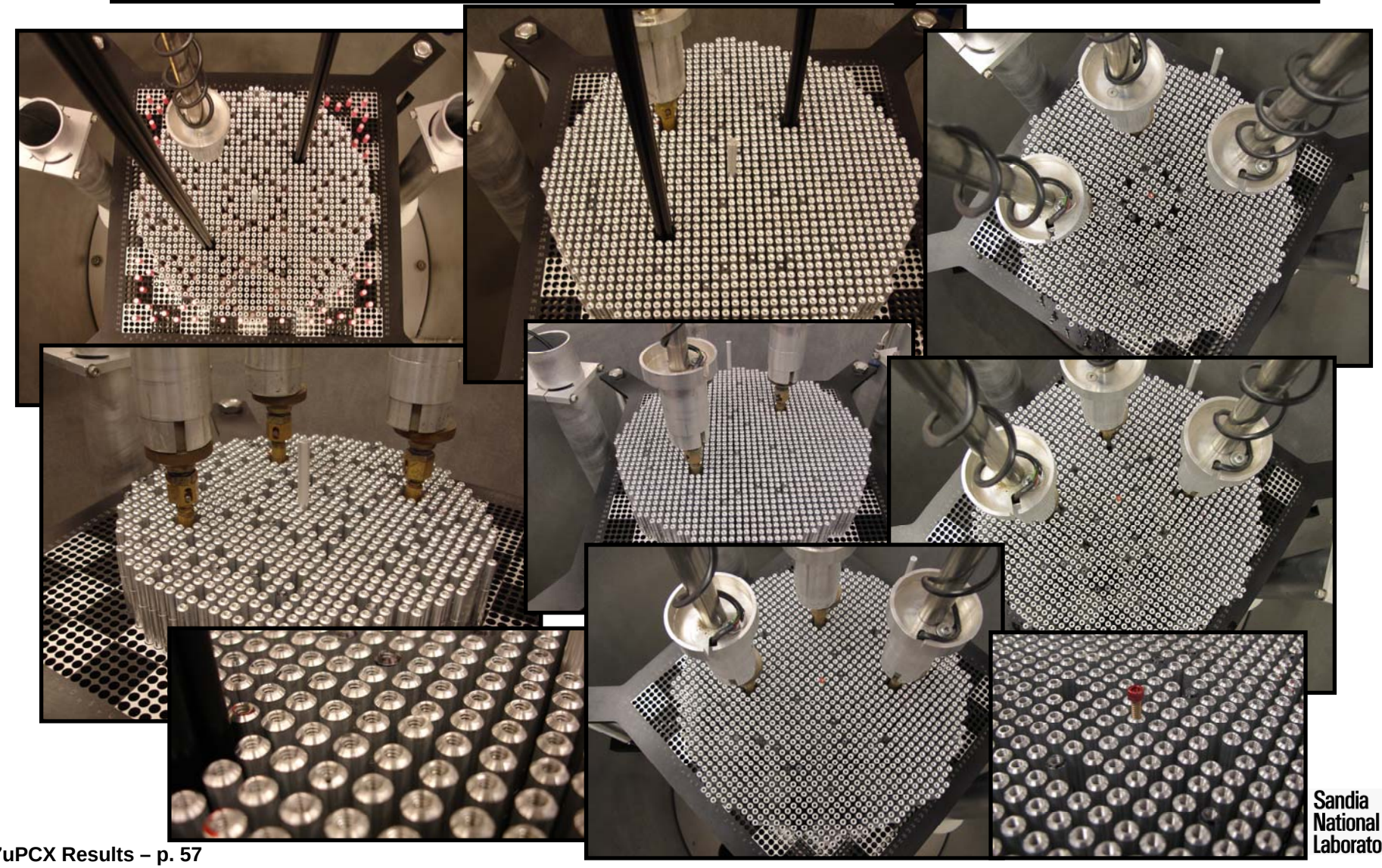
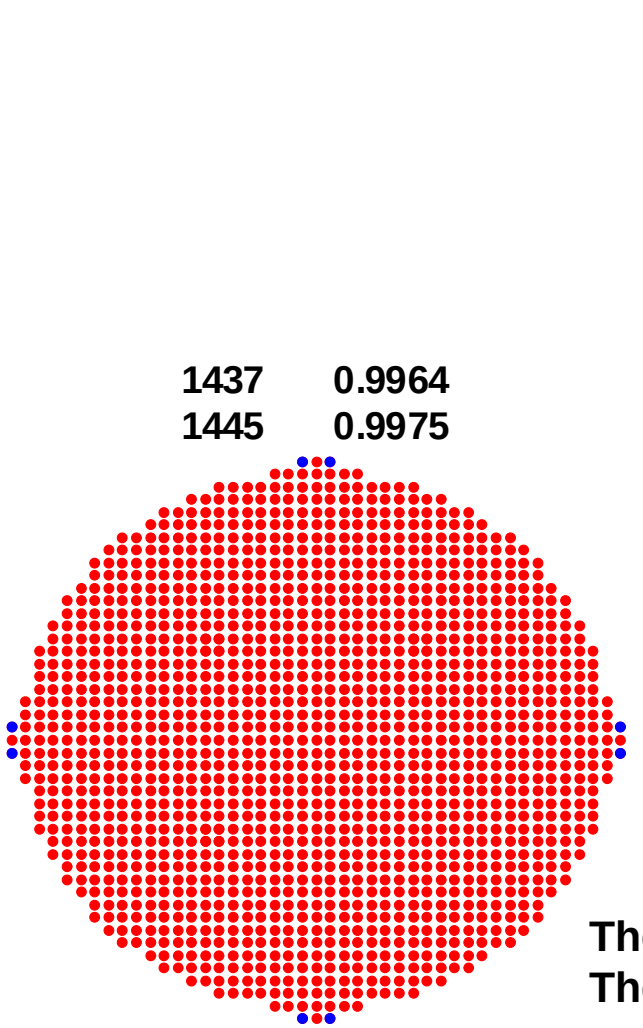
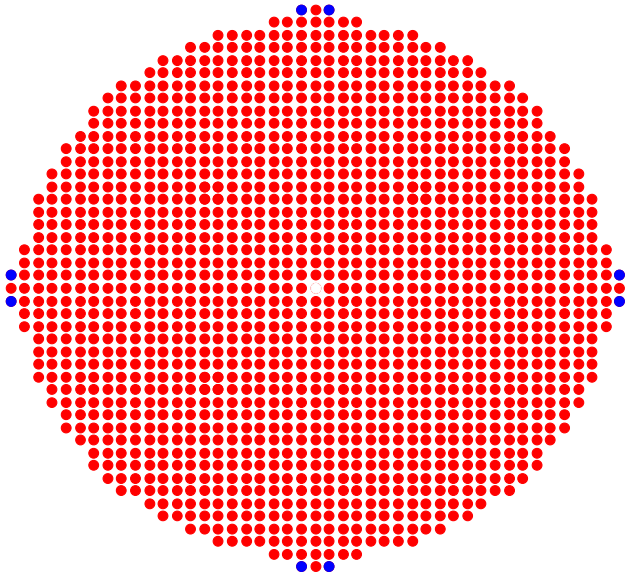
We have performed critical experiments on several 7uPCX configurations



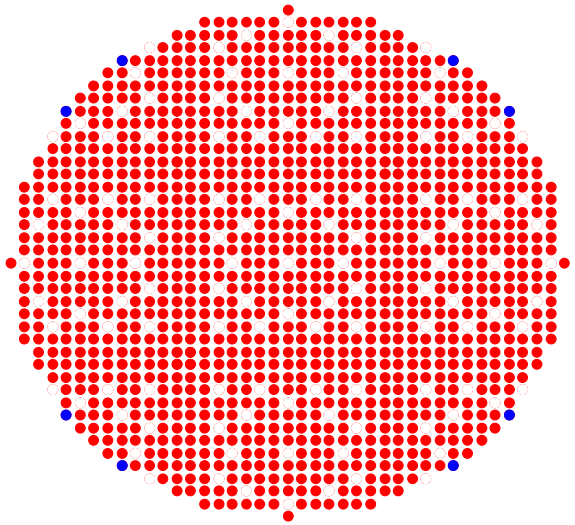
7uPCX Critical Configurations (1)



1437 0.9964
1445 0.9975



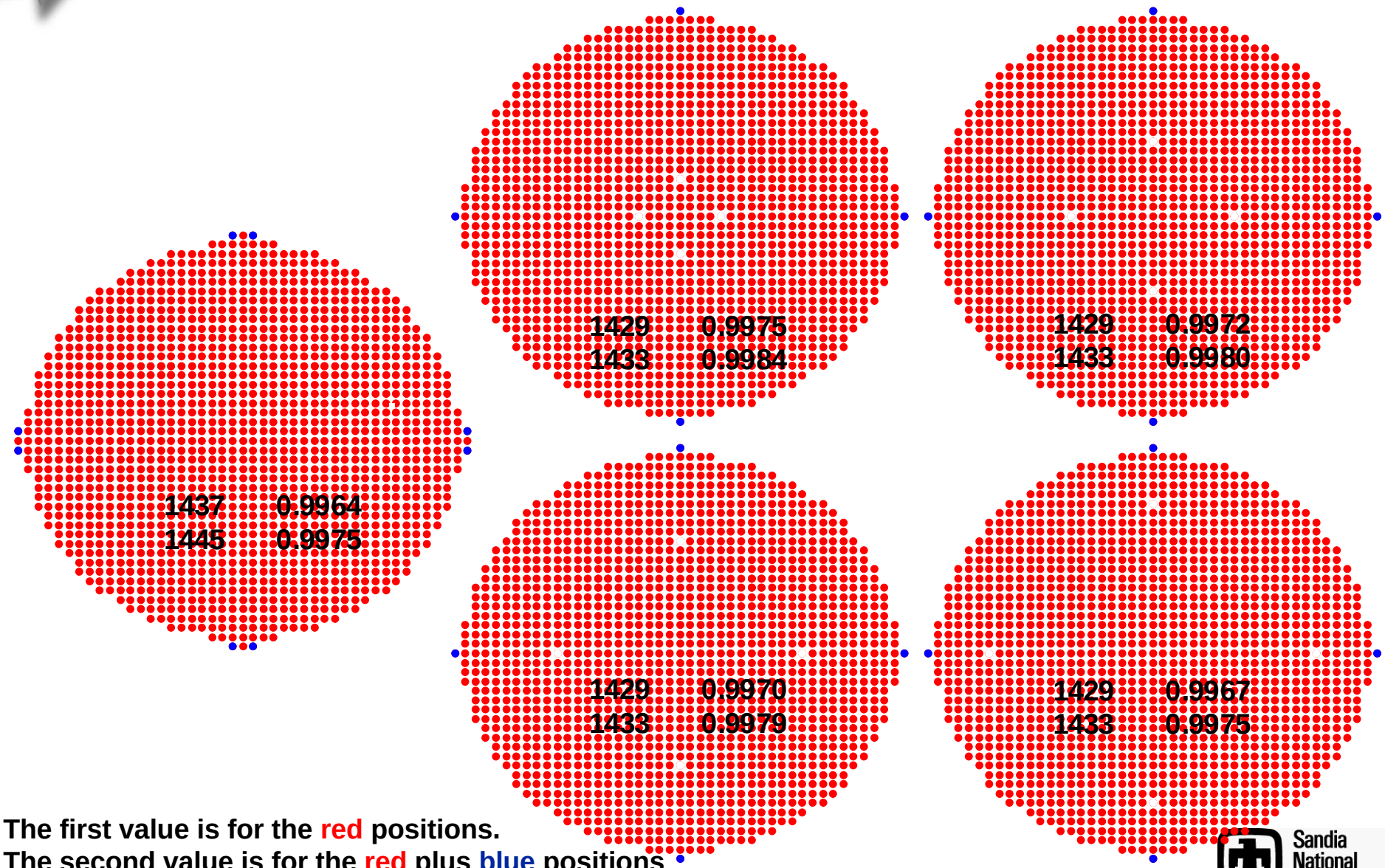
1436 0.9969
1444 0.9980



1128 0.9970
1136 0.9984

The first value is for the red positions.
The second value is for the red plus blue positions

7uPCX Critical Configurations (2)



The first value is for the red positions.
The second value is for the red plus blue positions

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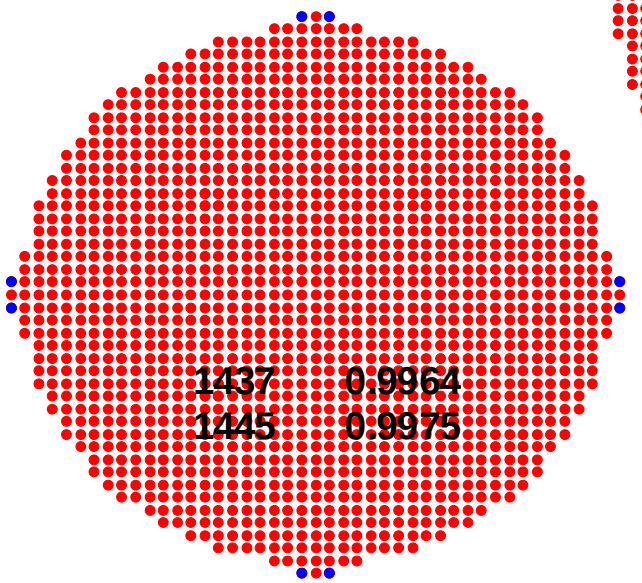
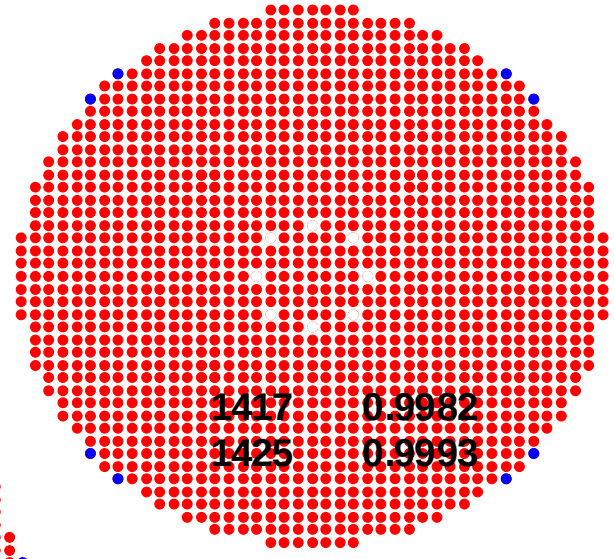
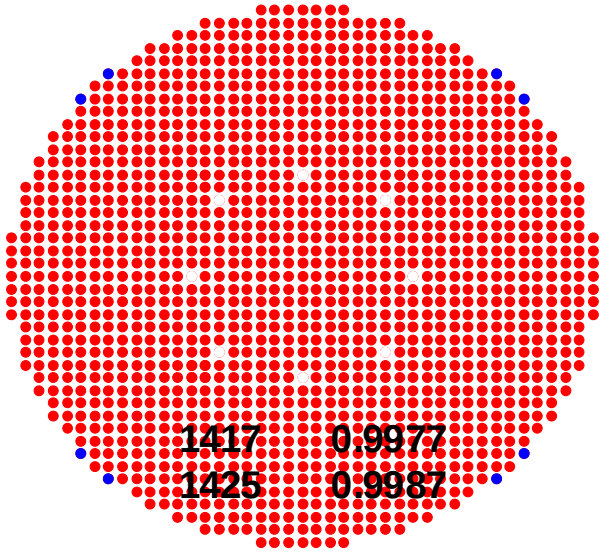
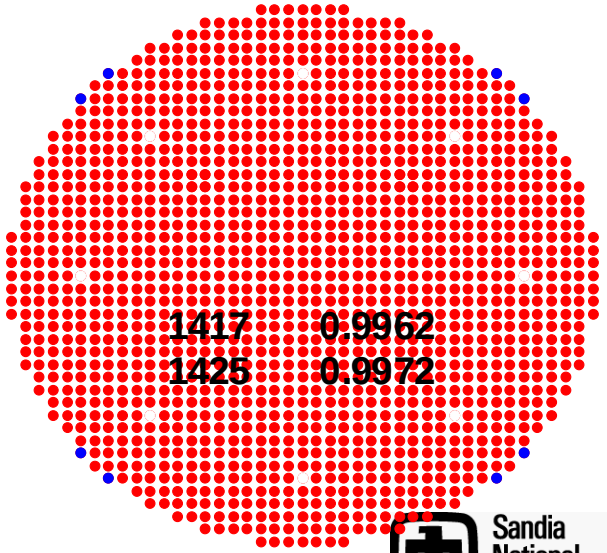
7uPCX Critical Configurations (3)









The first value is for the red positions.
The second value is for the red plus blue positions

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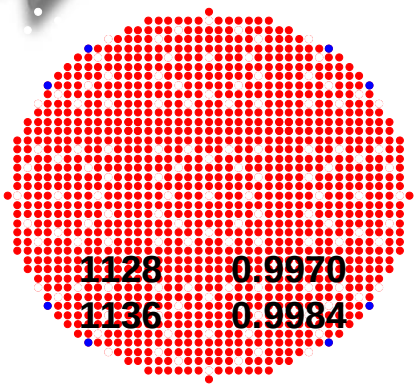
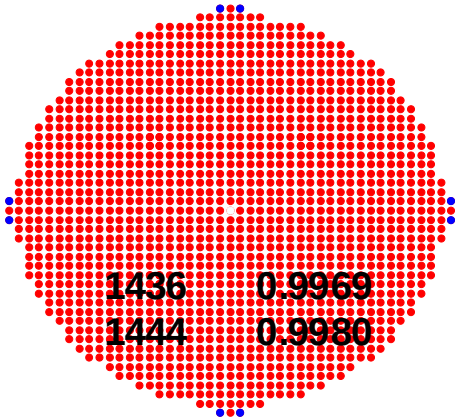
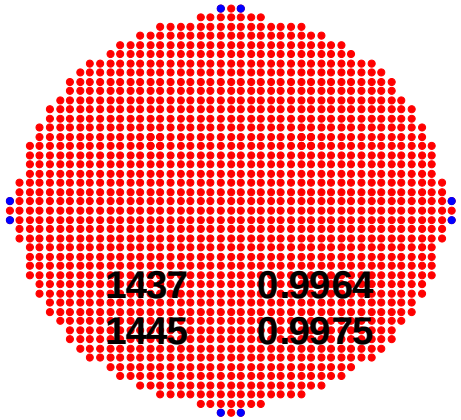
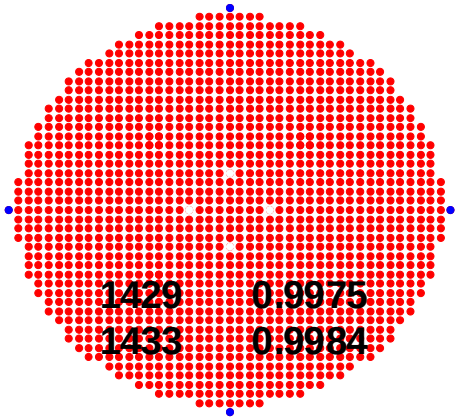
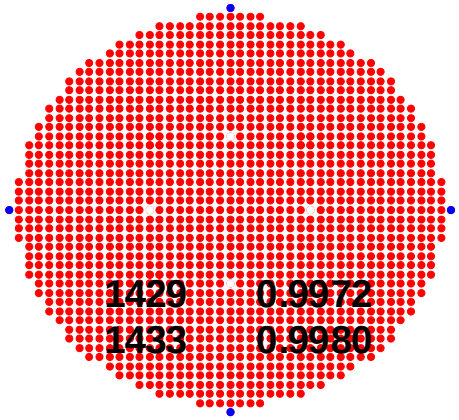
7uPCX Critical Configurations

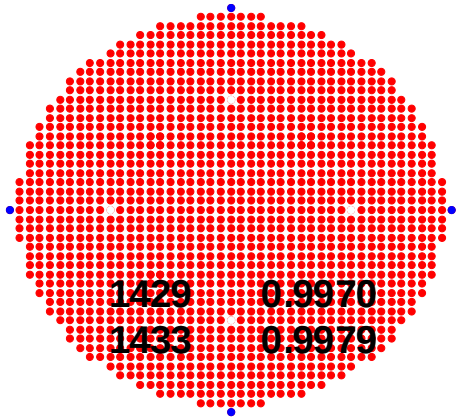


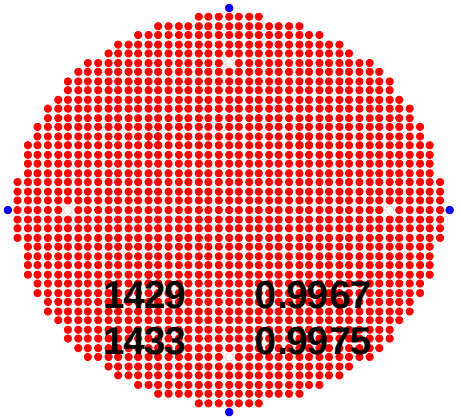


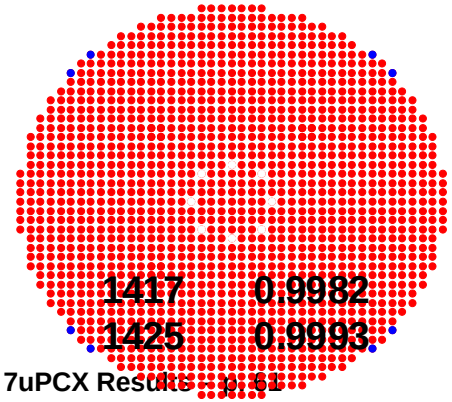


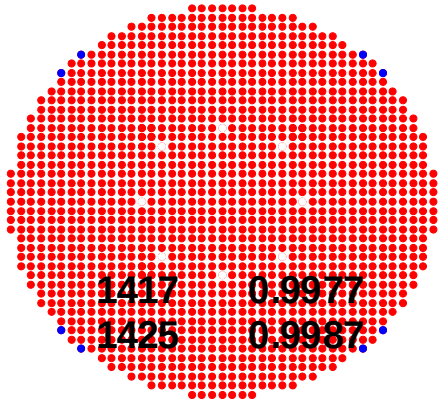




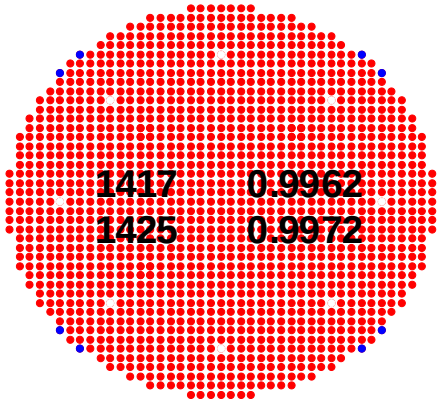








The first value is for the **red** positions.
The second value is for the **red** plus **blue** positions



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 have developed 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**

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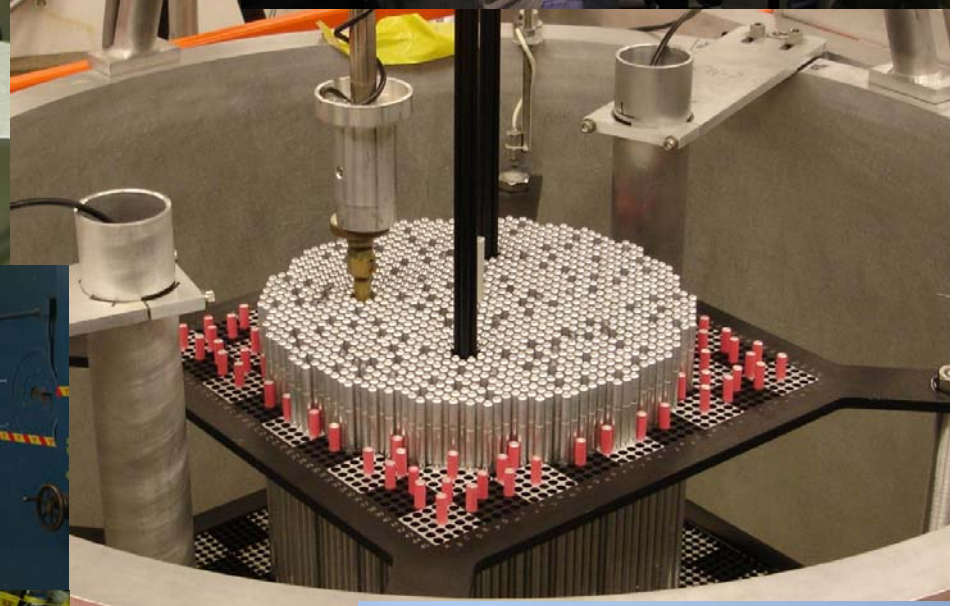
The Phase Space our Authorization Basis Allows is Large

- **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**

Critical Experiments at Sandia

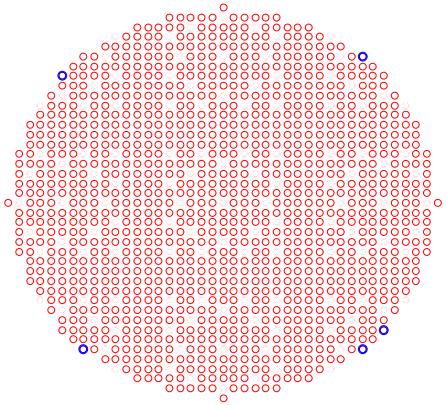




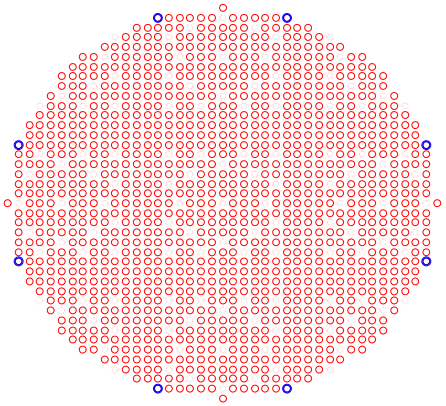




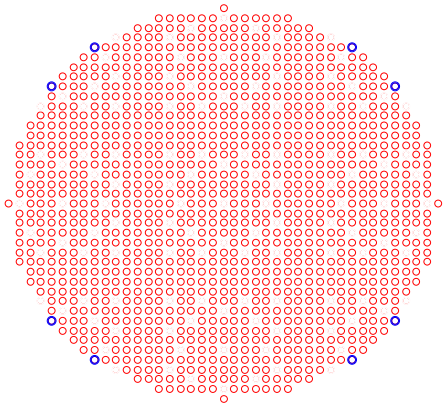

Core 800B0000 configurations during the first approach-to-critical experiment



1120

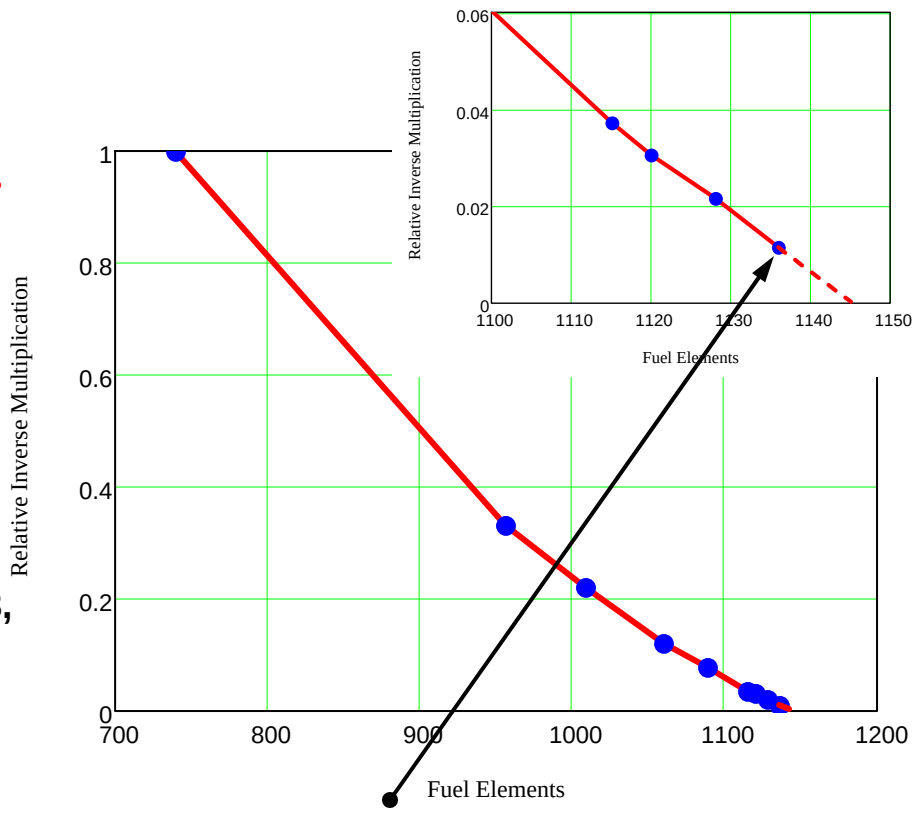


1128



1136

We also made measurements with 1138, 1140, and 1144 elements (all subcritical). A core with 1148 elements was supercritical.



At 1136 fuel elements:

N_{crit} = 1145.3

k_{eff} = 0.9984

M ~ 610

The incremental fuel elements are shown in blue

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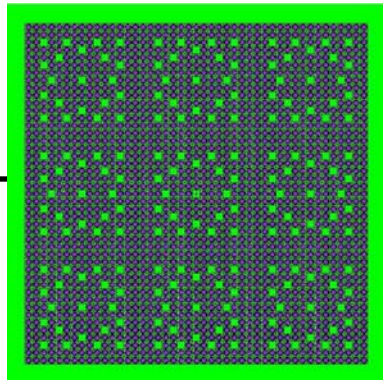
The 7uPCX experiment matrix



- 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