Results from the Seven Percent Critical Experiment

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Outline

- **Sandia Critical Experiments – Some History**
- **The Seven Percent Critical Experiment**
  - **Design of the Experiment**
  - **Results from the Experiment**
- **The Future of the Sandia Critical Experiments**

We operated the SNTP CX in the late 80's

A critical experiment (CX) was run at Sandia as part of the Space Nuclear Thermal Propulsion (SNTP) program. The CX was designed to simulate the behavior of a nuclear rocket motor. It had:

• Stand-alone Authorization Basis

• New critical assembly hardware

• New critical assembly control system

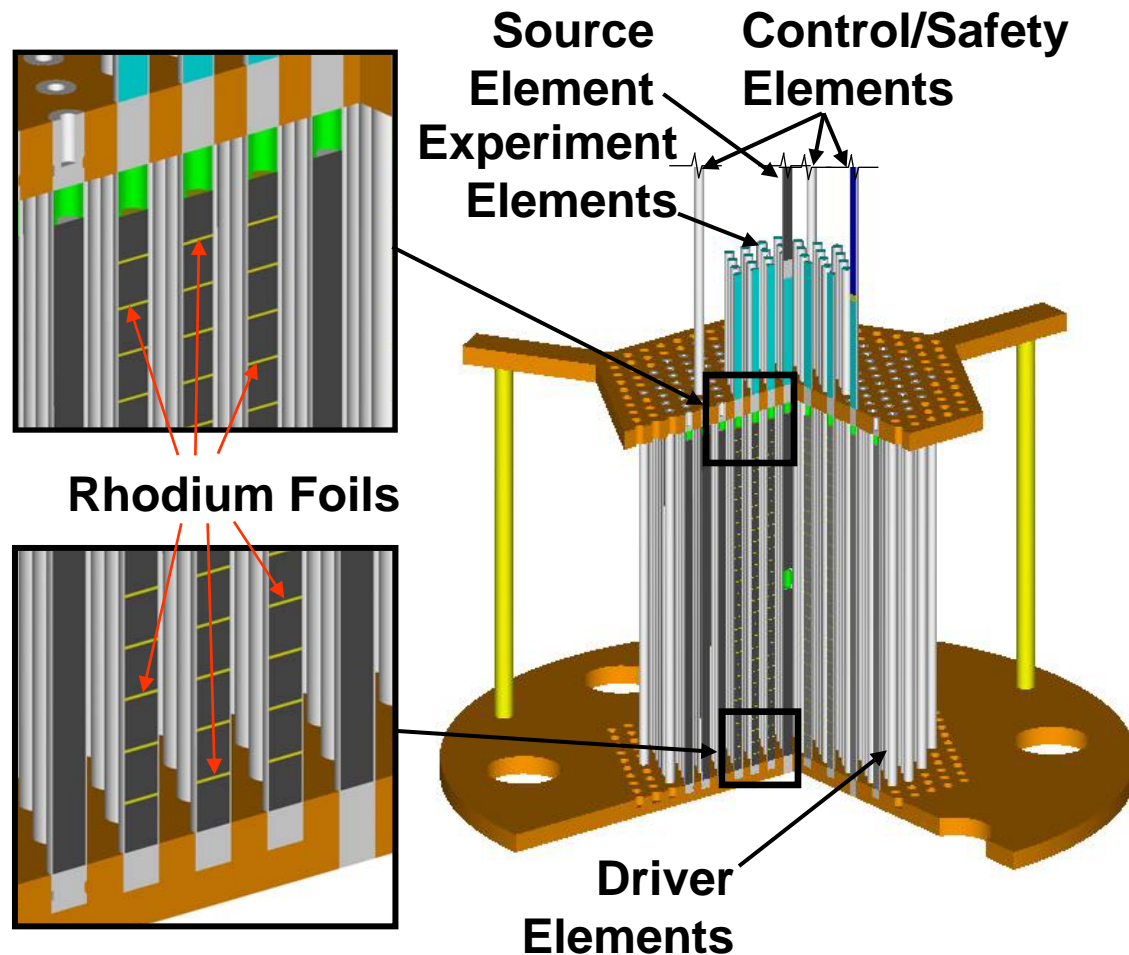Sandia National Laboratories

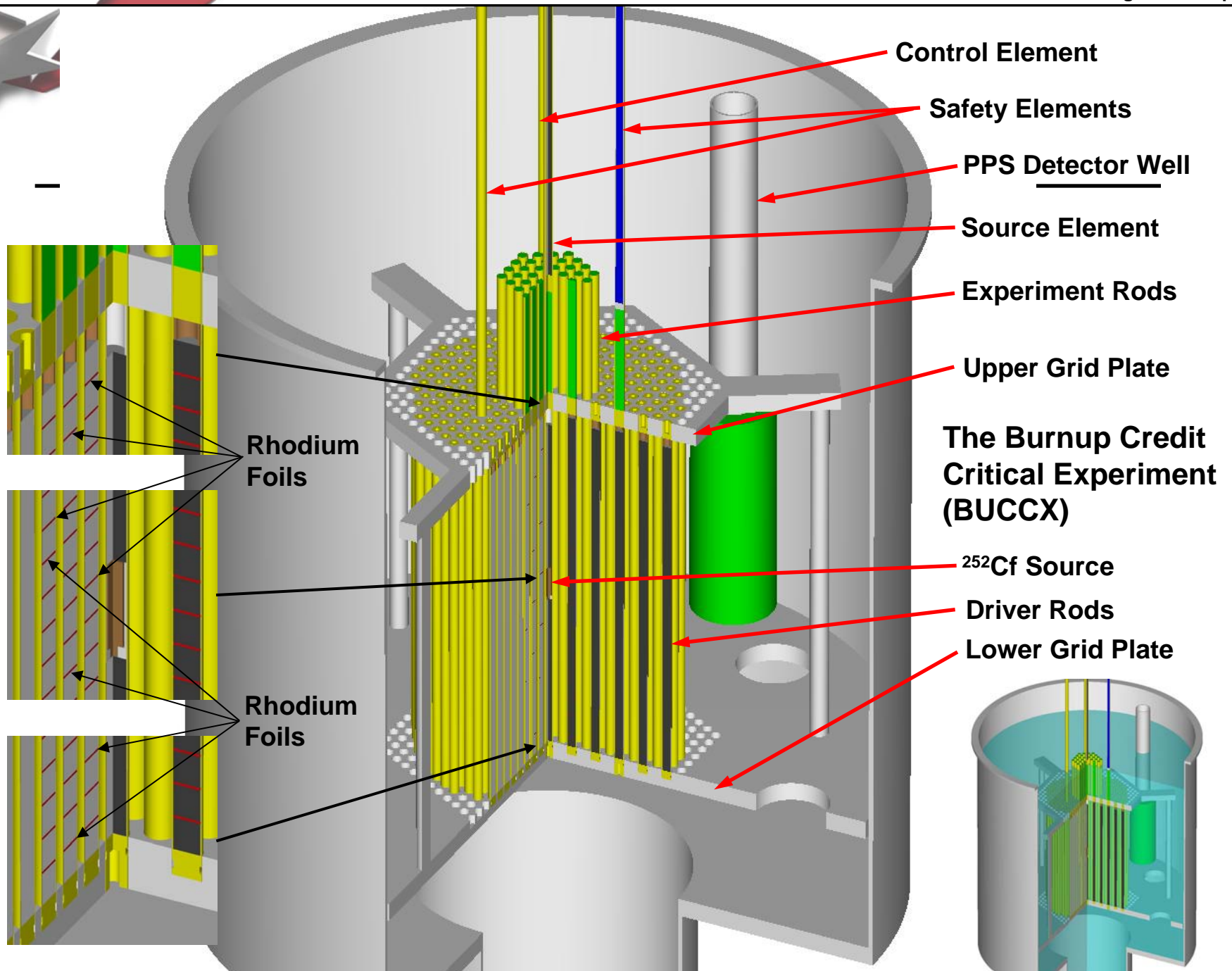# In 2002, we performed some critical experiments with rhodium
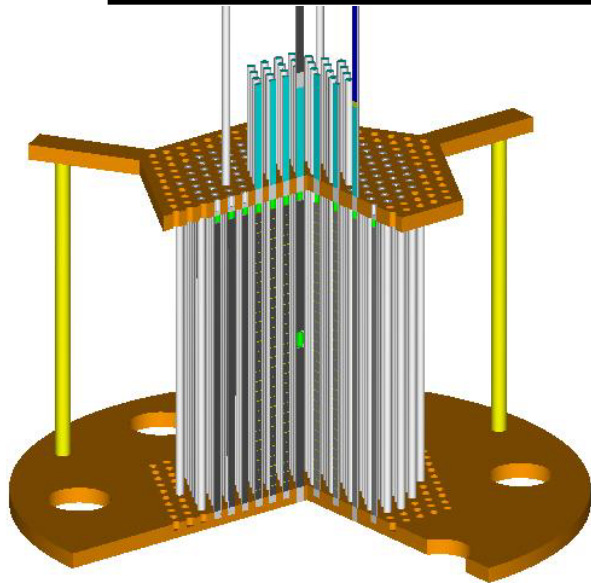
- **The Burnup Credit Critical Experiment (BUCCX) was funded by the Nuclear Energy Research Initiative (NERI)**
- **We built a critical assembly in which we could insert fission product materials to measure reactivity effects**
- **The NERI funding was used to bring the experiment capability up and perform 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 BUCCX core was designed to be easy to model

Source Element

Control/Safety Elements

Experiment Elements

Rhodium Foils

Driver Elements

- **The assembly is a triangular-pitched array of Zircaloy-4 clad $U(4.31\%)O_2$ fuel (driver) elements**
- **Test materials are placed between the fuel pellets in "experiment elements"**
- **The assembly has 3 control/safety elements**
  - **the B_4C absorber is decoupled from the assembly by a polyethylene spacer**
  - **the absorber is followed by a fuel rod**
- **The source is in the central fuel element**
- **The grid plates are aluminum**
- **The pitch of the array is modified by replacing the grid plates**

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Control Element

Safety Elements

PPS Detector Well

Source Element

Experiment Rods

Upper Grid Plate

The Burnup Credit Critical Experiment (BUCCX)

^{252}Cf Source

Driver Rods

Lower Grid Plate

Rhodium Foils

Rhodium Foils

The 7uPCX started as a NERI project

Reactor Physics and Criticality Benchmark Evaluations for Advanced Nuclear Fuel

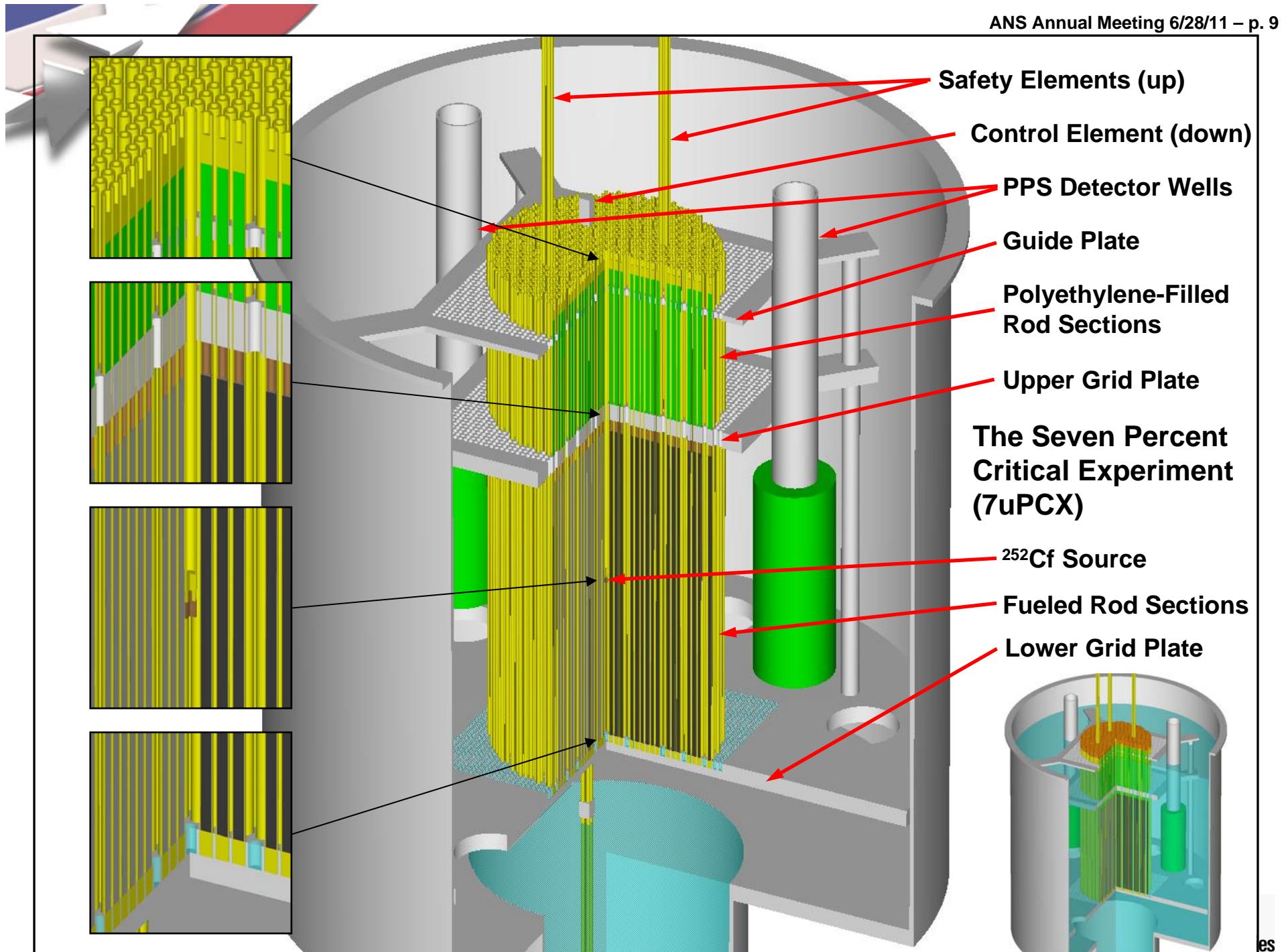- **The project was originally funded by the Nuclear Energy Research Initiative (NERI)**
- **The NERI project team:**
  - **AREVA Federal Services, LLC (Lynchburg, VA) – Conceptual Design, Analysis, Project Management**
  - **Sandia National Laboratories – Hardware Design, Transportation, Procurement,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

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The Seven Percent Critical Experiment (7uPCX) is a reactor physics experiment
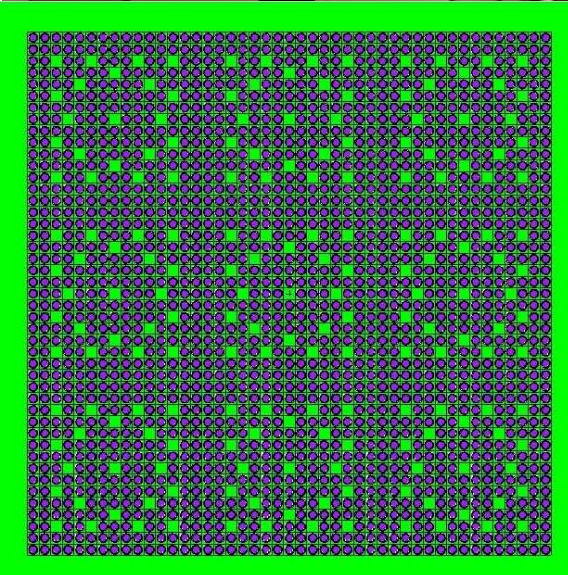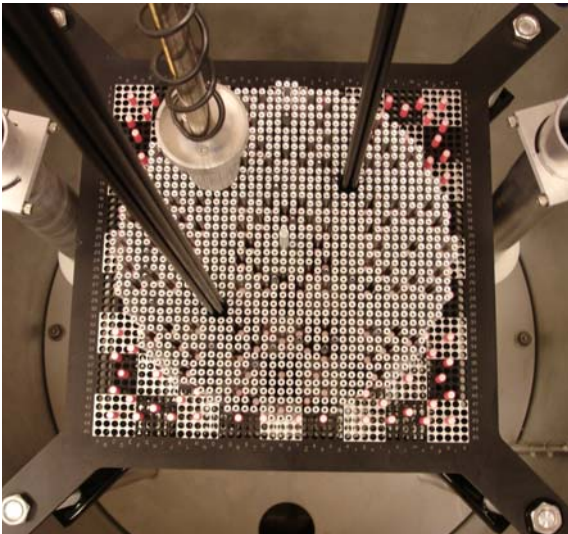
Project Objective: *Design, perform, and analyze critical benchmark experiments for validating reactor physics methods and models for fuel enrichments greater than 5-wt% ^{235}U*

- **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**
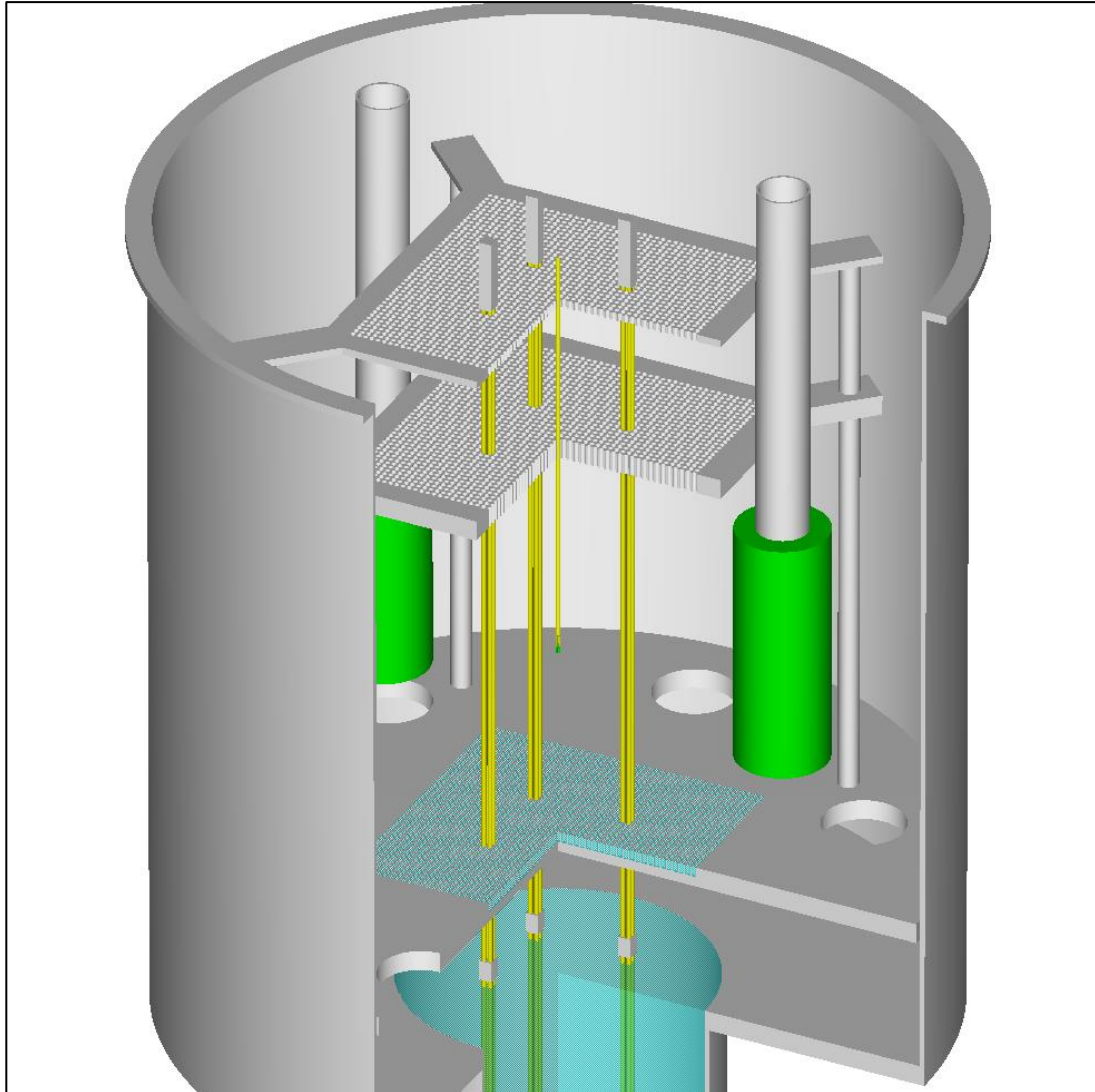
Safety Elements (up)

Control Element (down)

PPS Detector Wells

Guide Plate

Polyethylene-Filled
Rod Sections

Upper Grid Plate

**The Seven Percent
Critical Experiment
(7uPCX)**

^{252}Cf Source

Fueled Rod Sections

Lower Grid Plate

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.

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Raise the safety elements
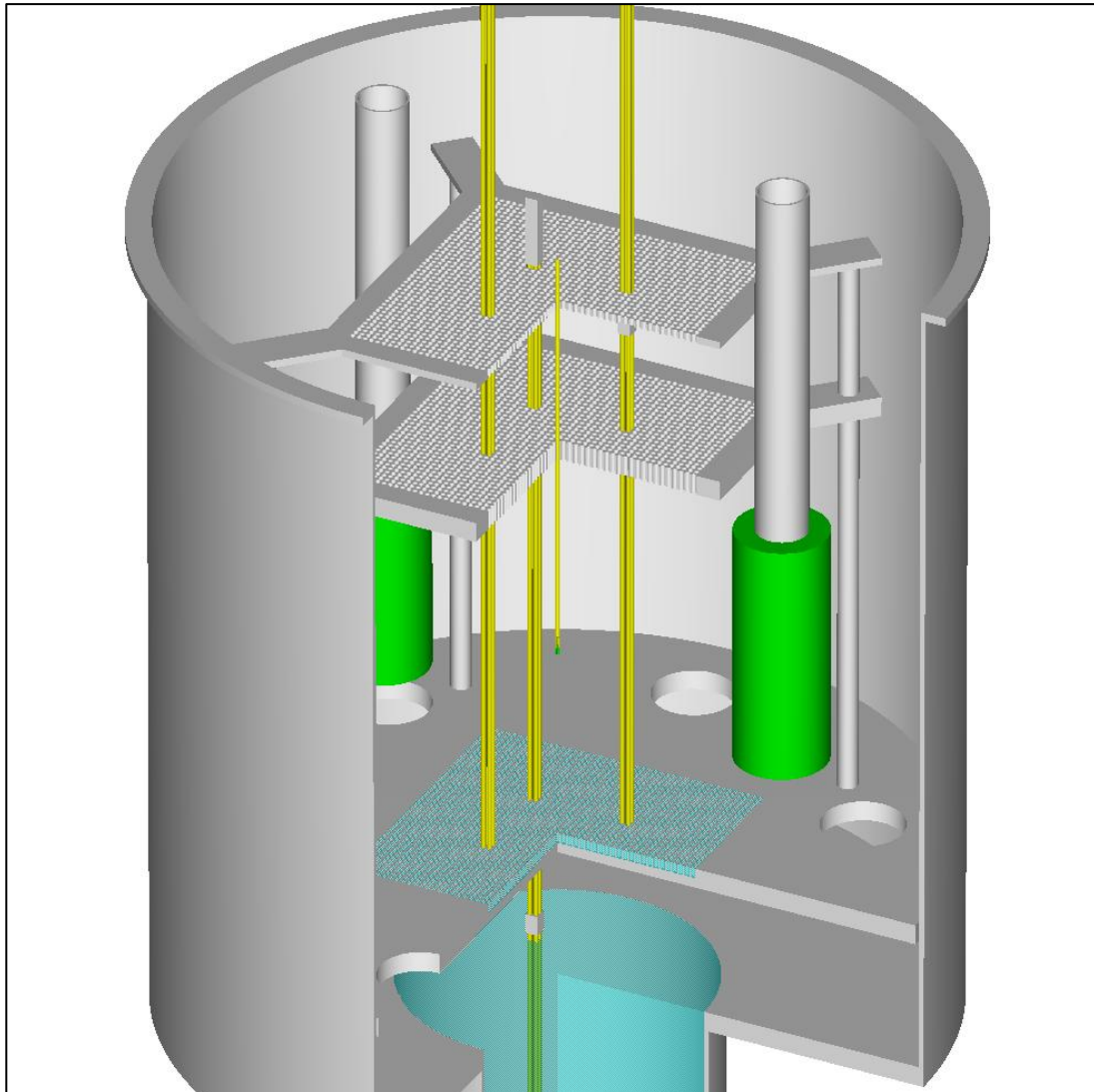
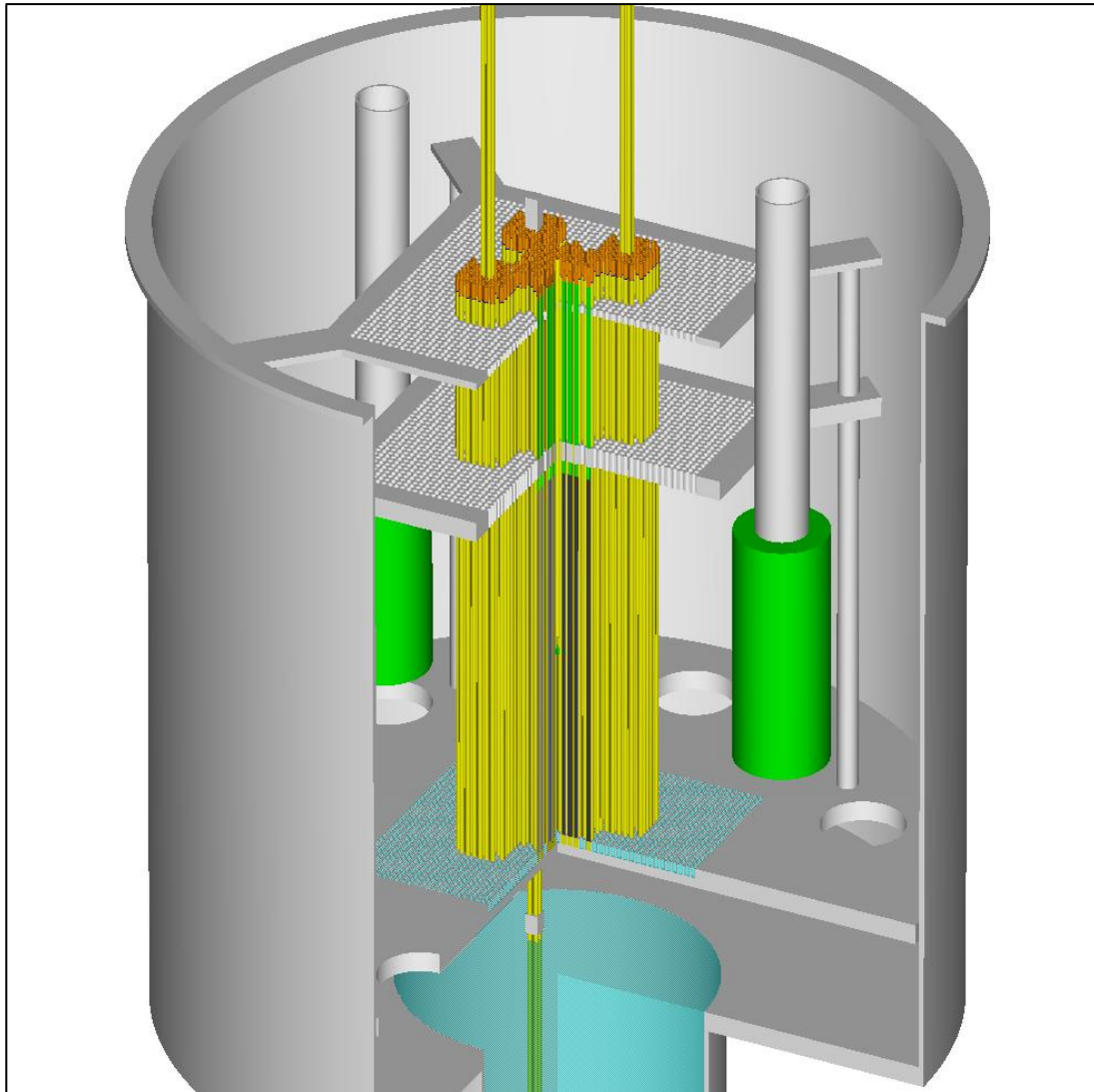**Fuel: 12 - CE/SE only**

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.

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Add fuel
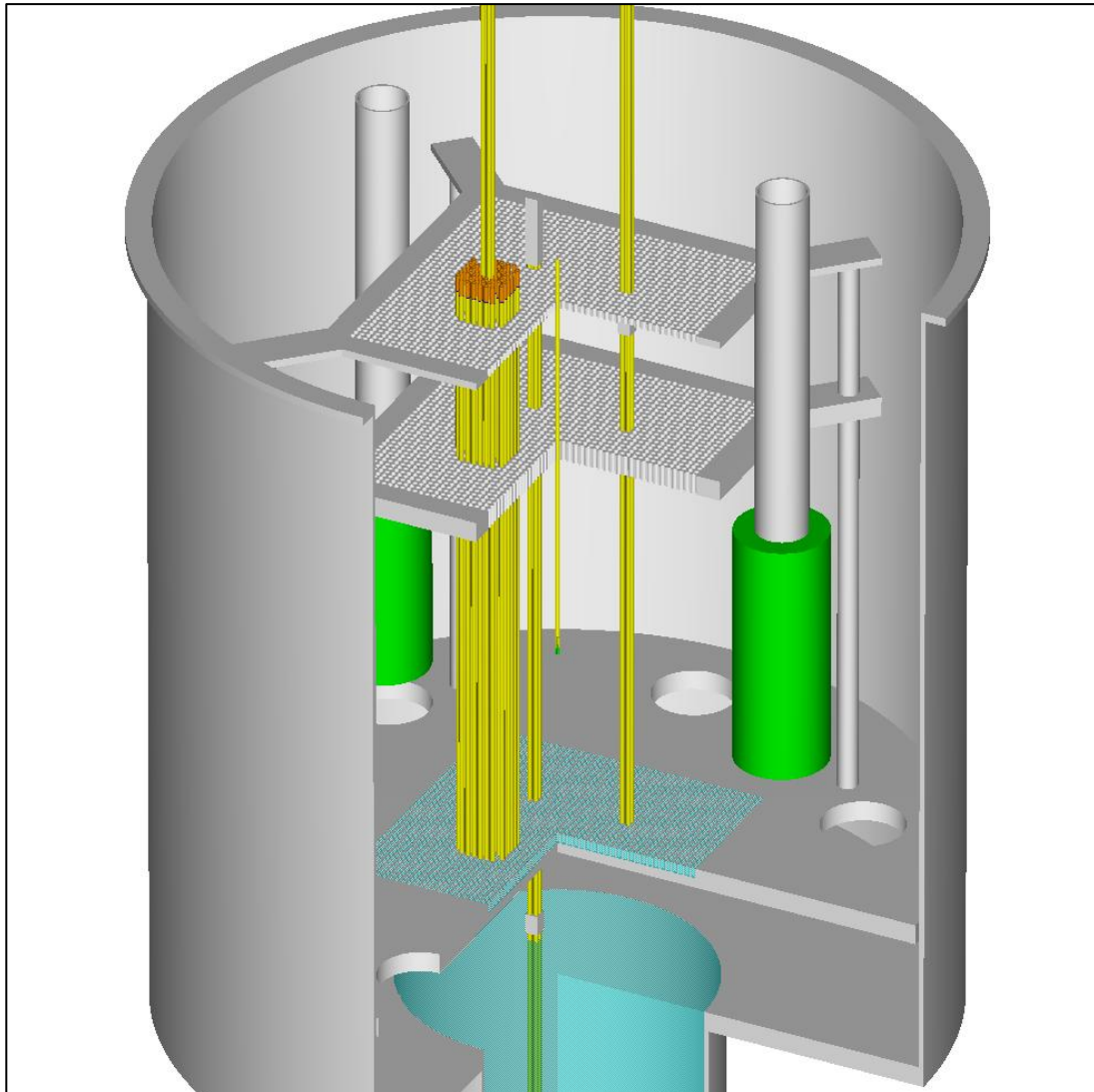
Fuel: 64

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.
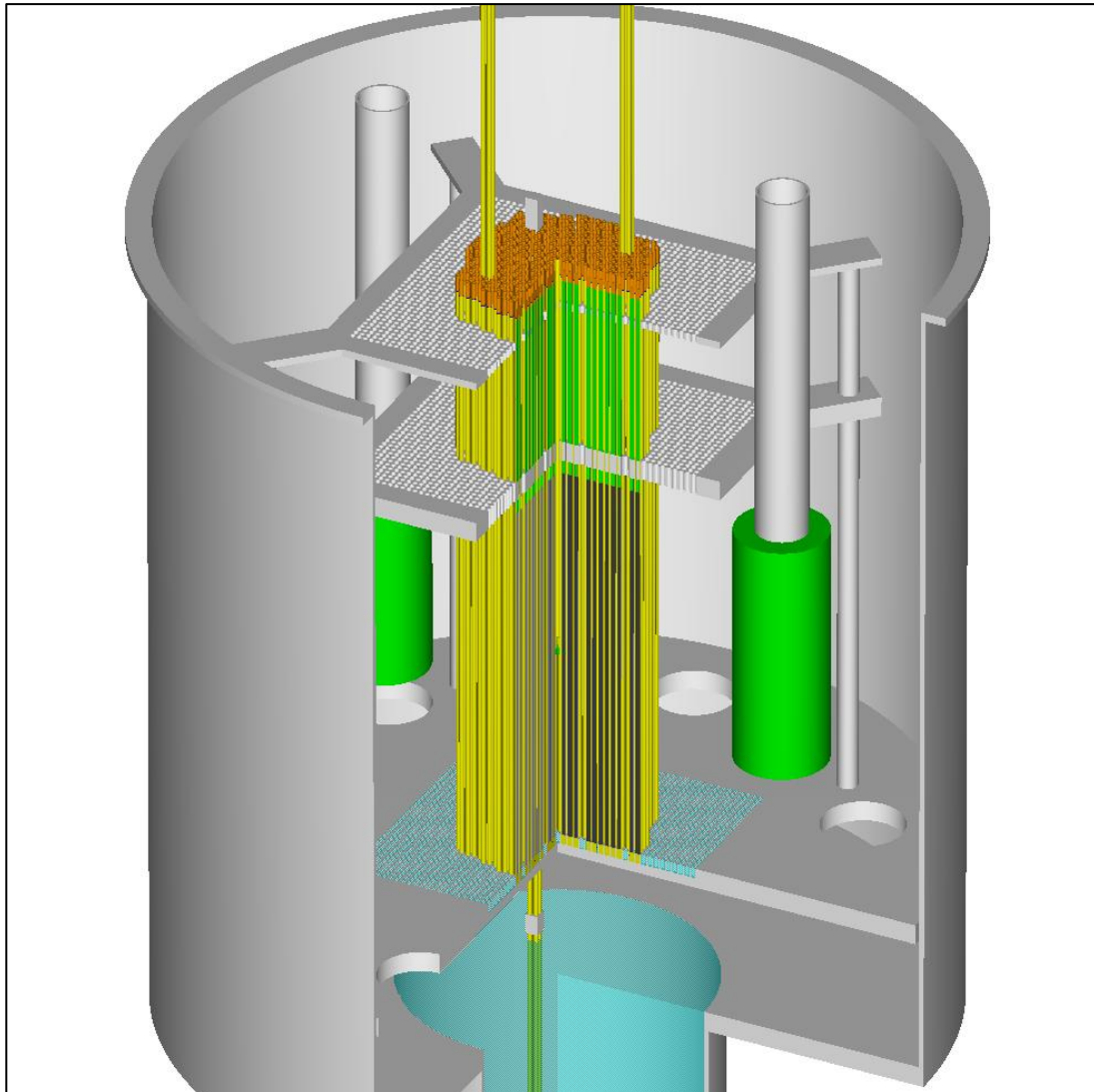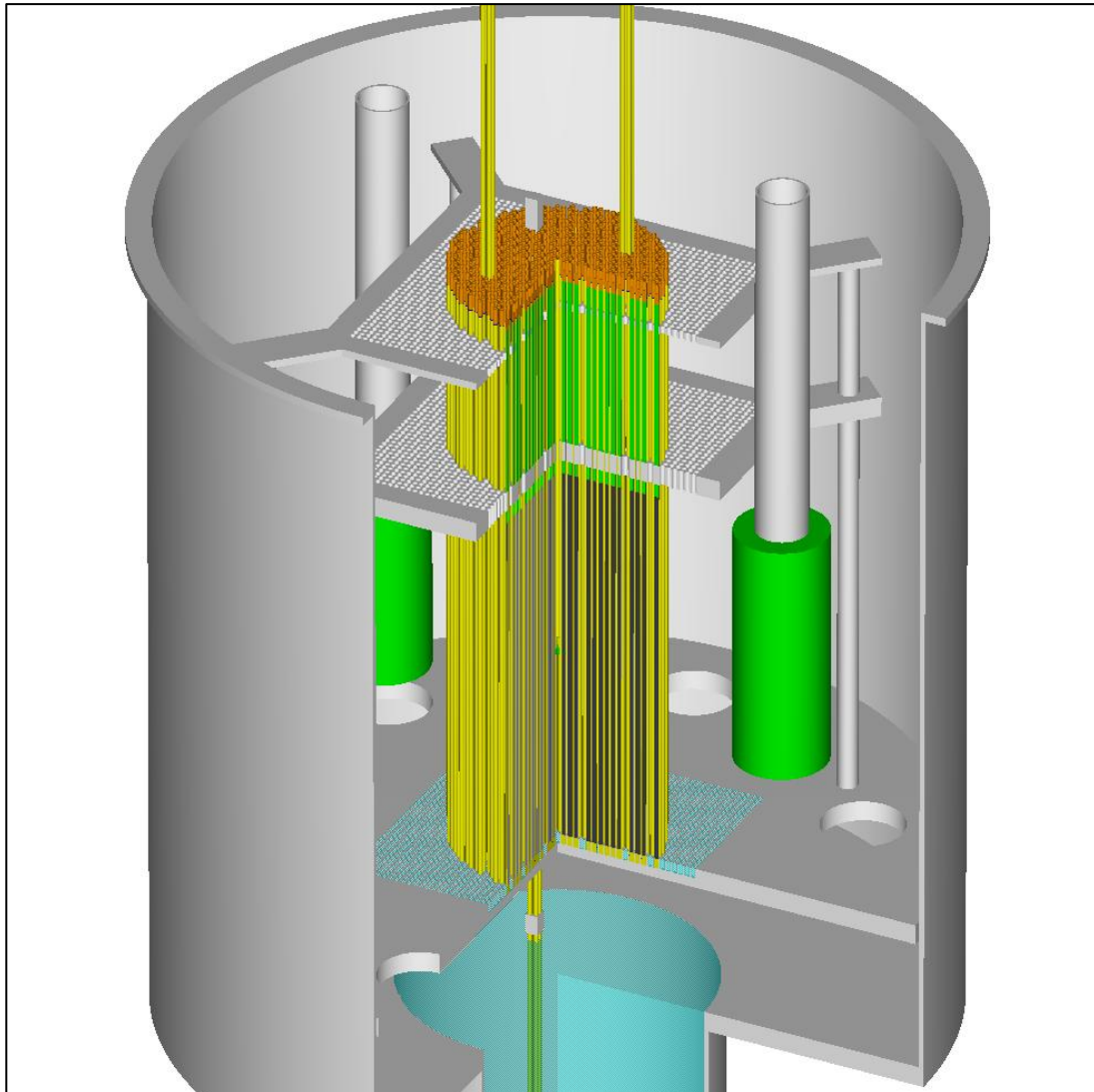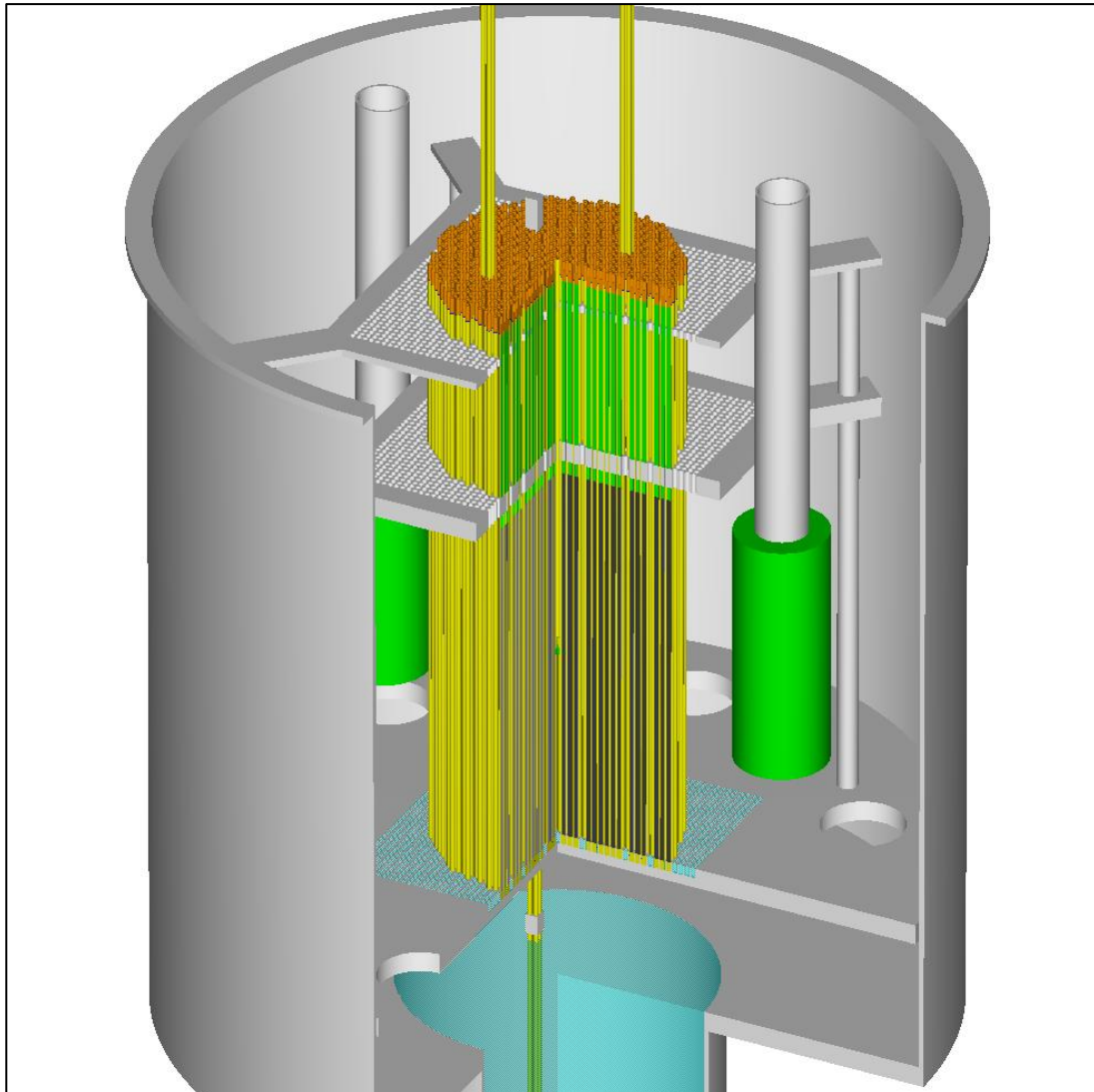
Add fuel
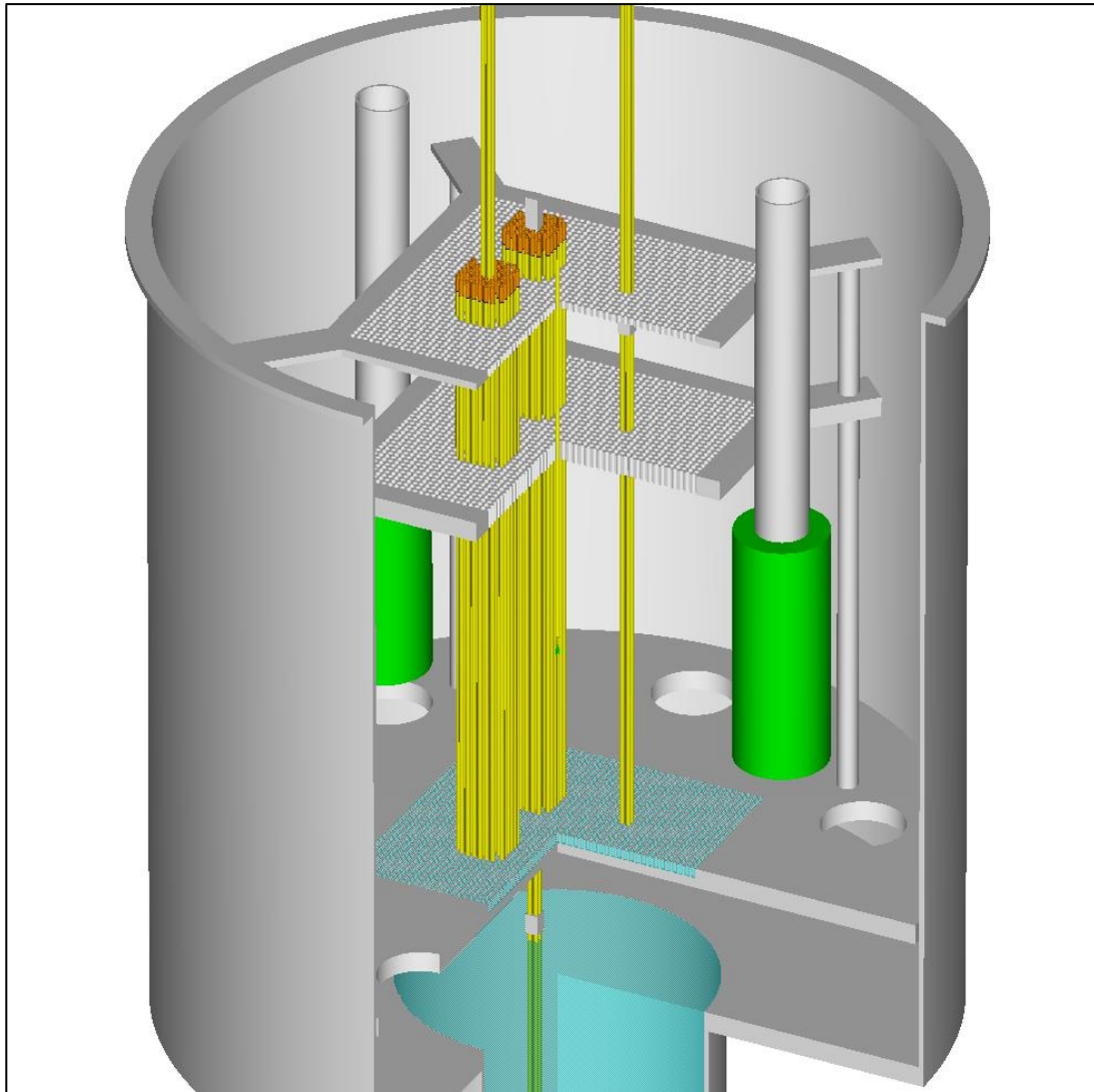
Fuel: 116

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.

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Add fuel
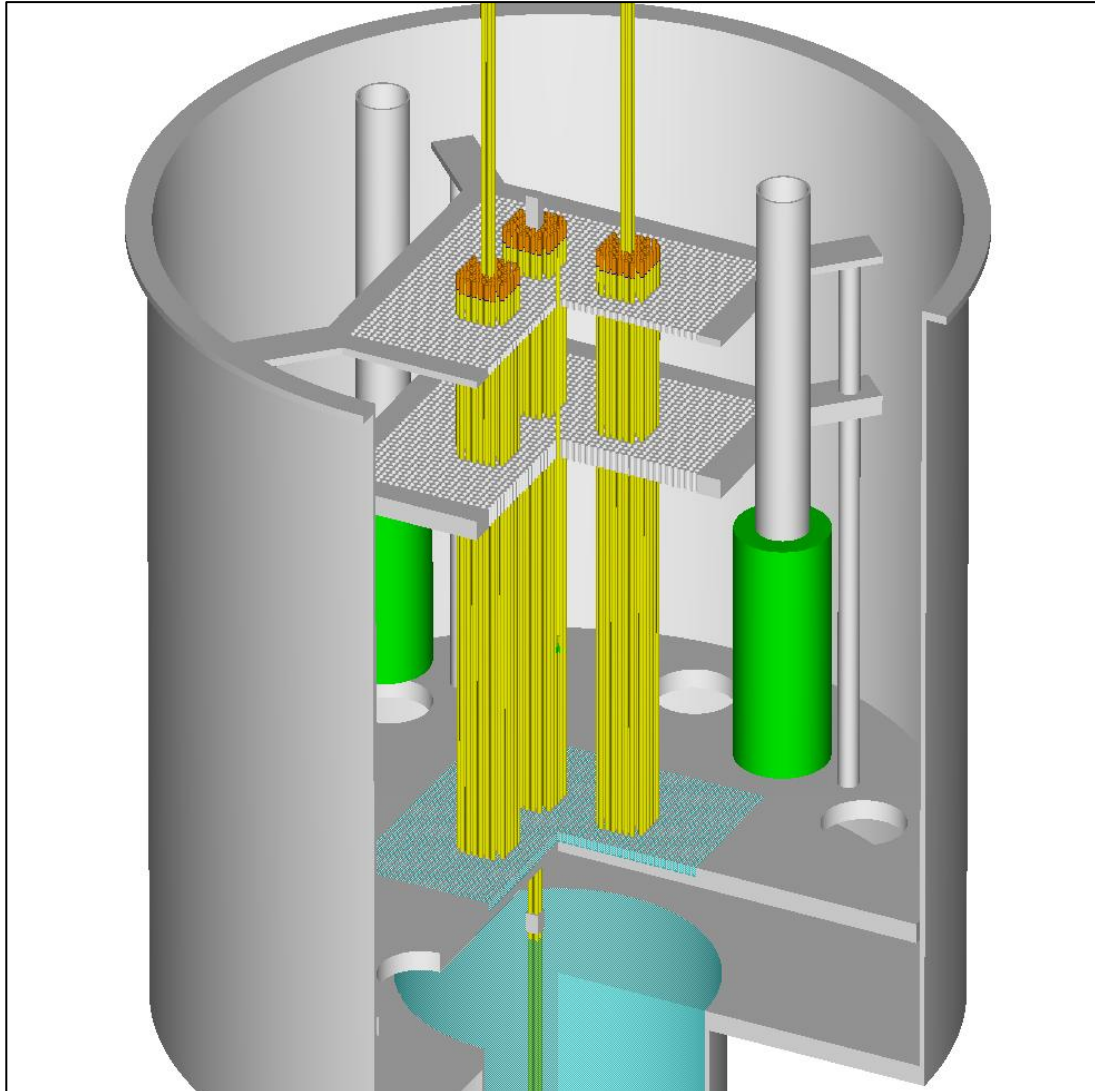
Fuel: 168

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.
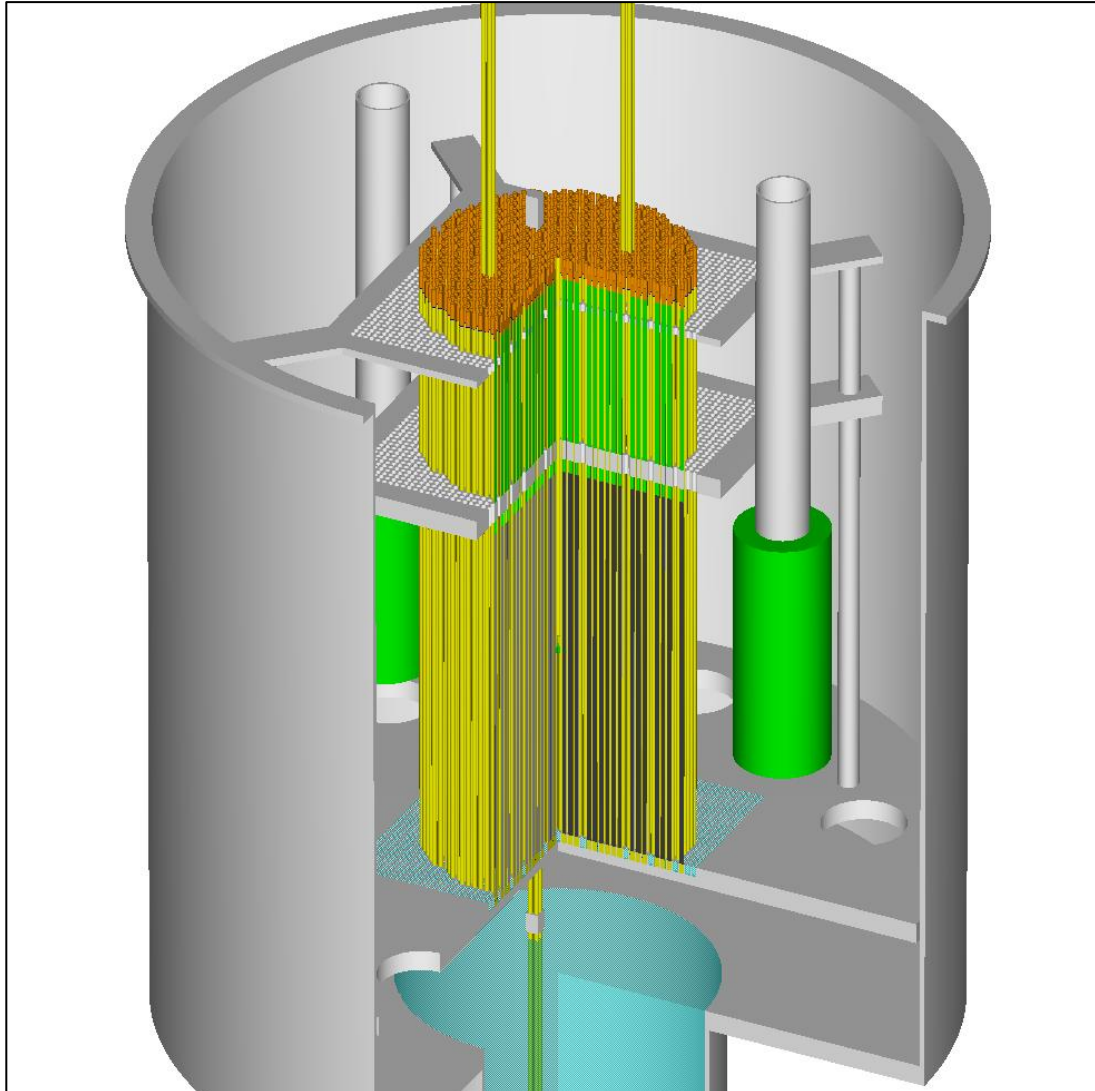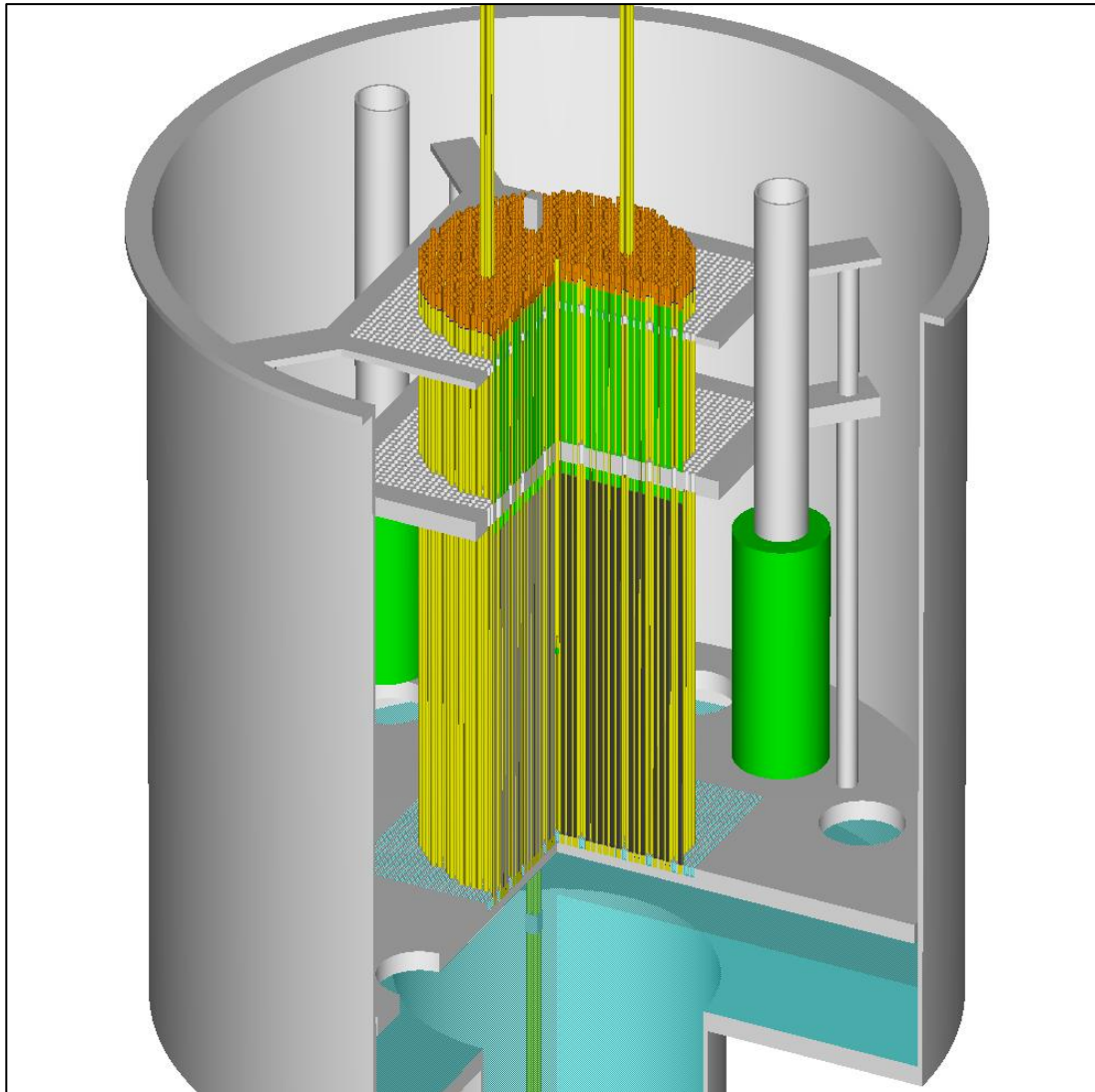
Add fuel

Fuel: 318
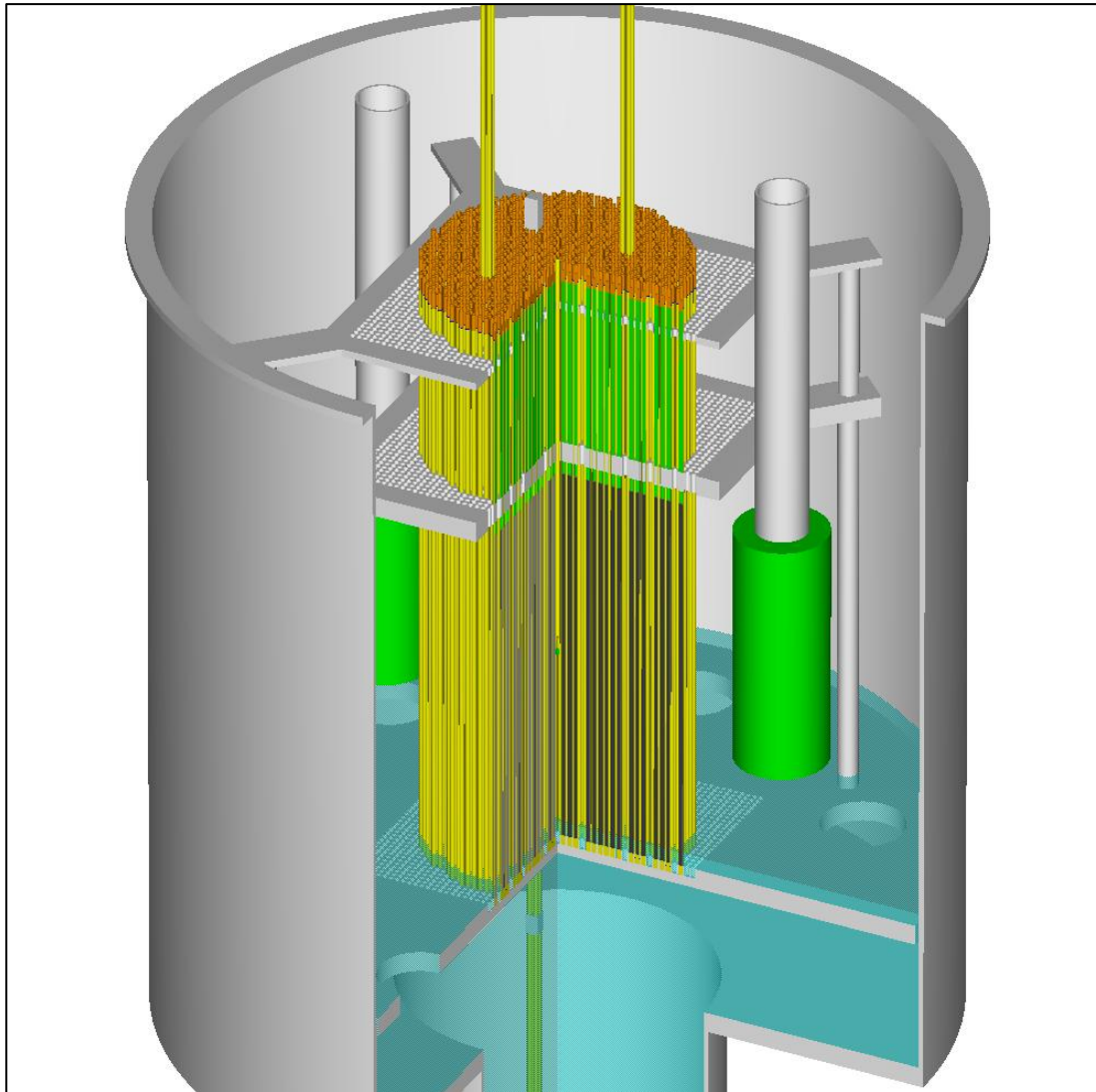
Safety Elements: Up

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.

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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.

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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.

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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.

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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.

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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.

Sandia National Laboratories

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.

Sandia National Laboratories

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.

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Laboratories

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.

Sandia National Laboratories

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.

Sandia National Laboratories

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.

Sandia National Laboratories

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.

Sandia National Laboratories

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.

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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.
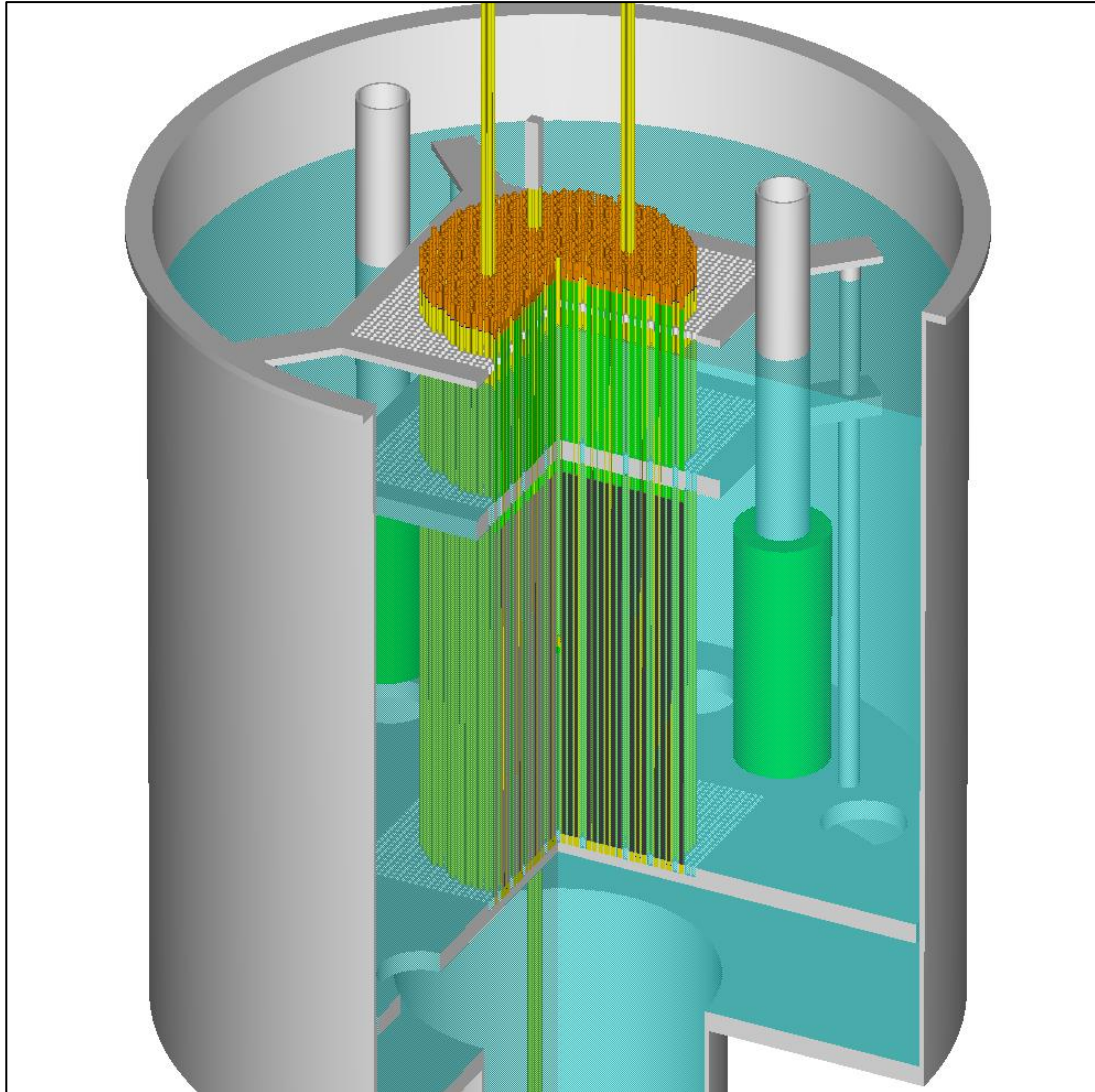
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Raise the control element

Fuel: 1136

Safety Elements: Up

Control Element: Raising

Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.

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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.
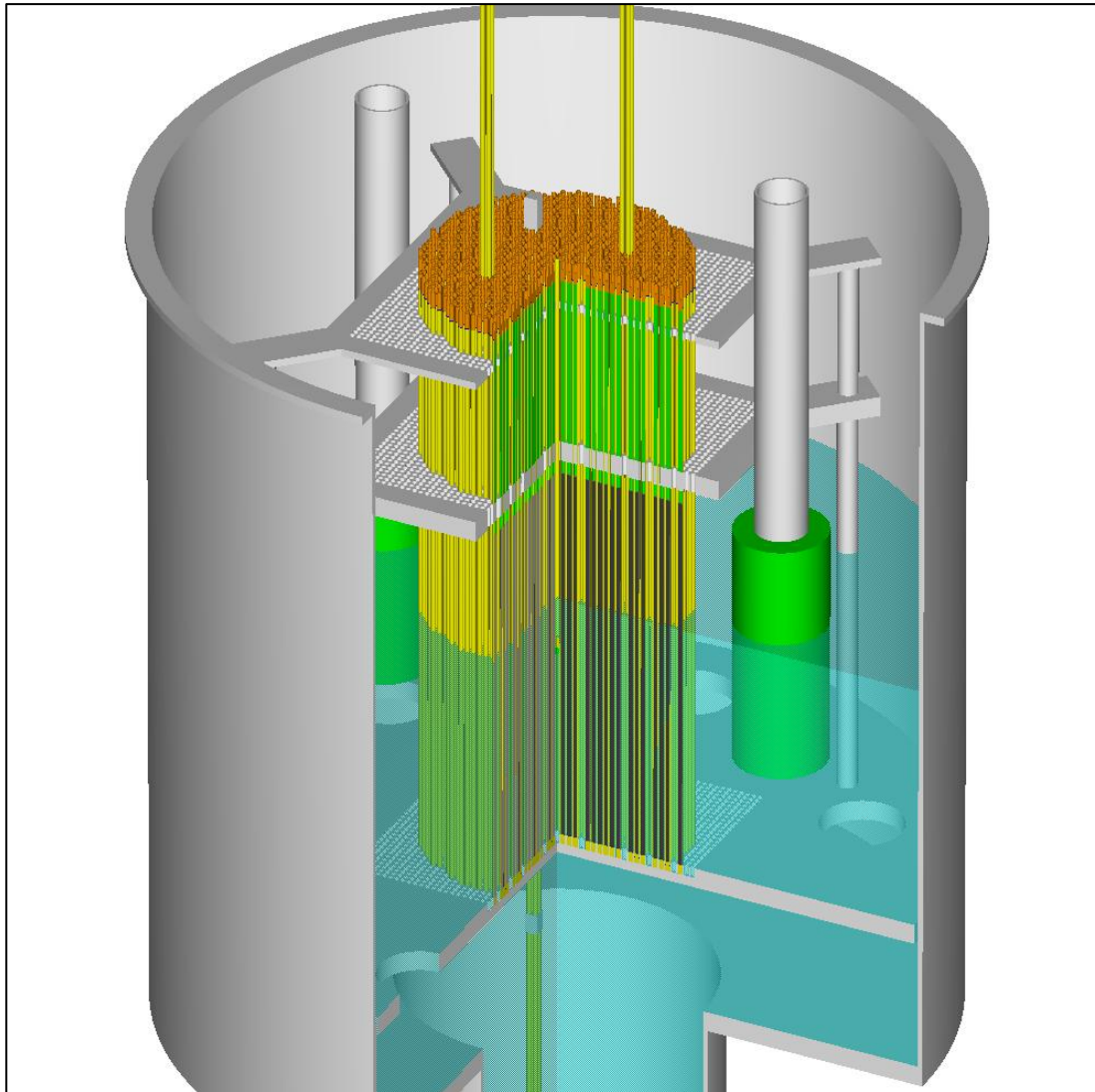
Raise the control element

Fuel: 1136

Safety Elements: Up

Control Element: Raising

Core Tank: Full

Personnel: Excluded

It takes about 90 seconds to raise the control element.

Sandia National Laboratories

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.

Sandia National Laboratories

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.

Sandia National Laboratories

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.

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The assembly reaches its most reactive state
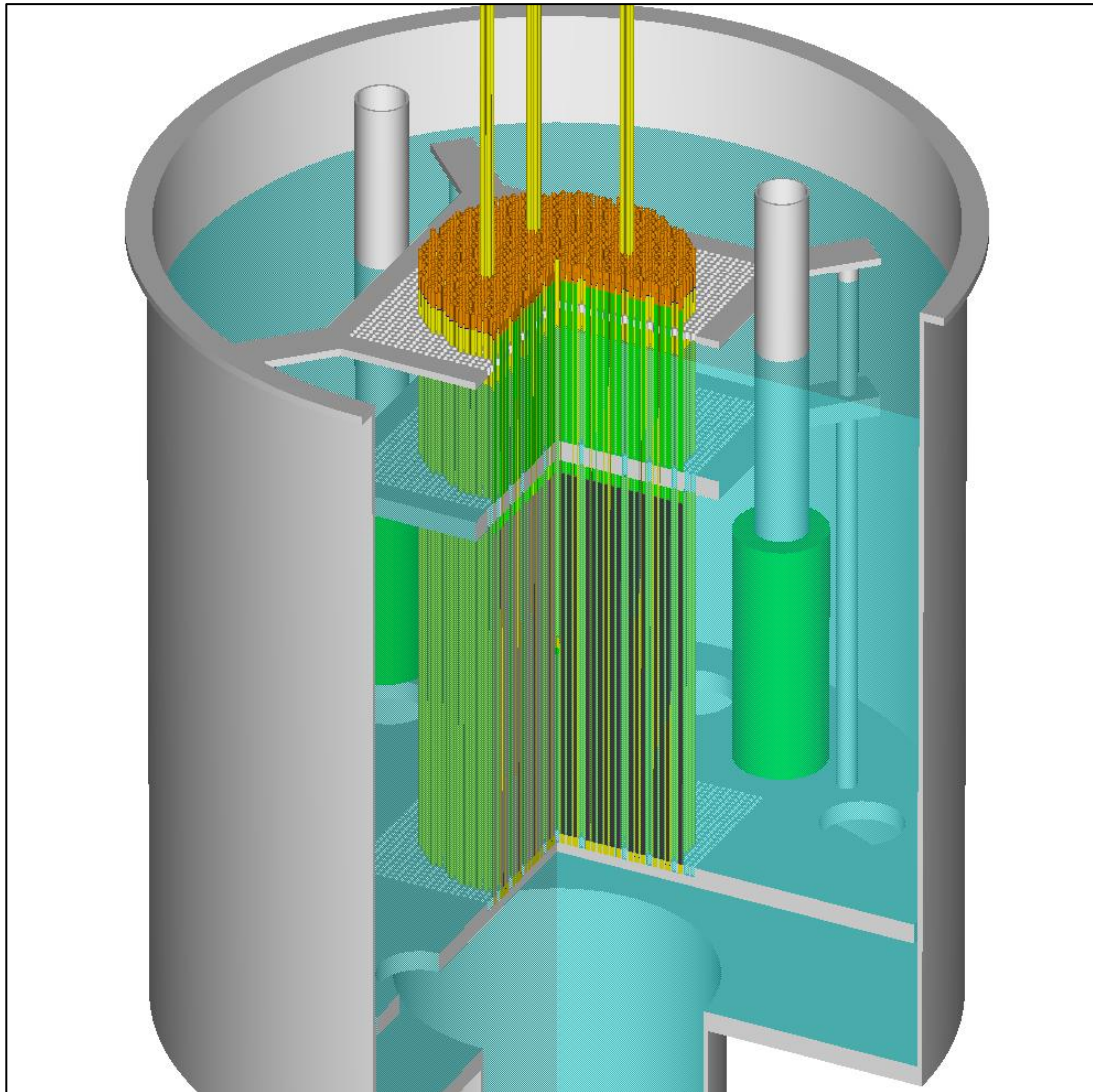
Fuel: 1136

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
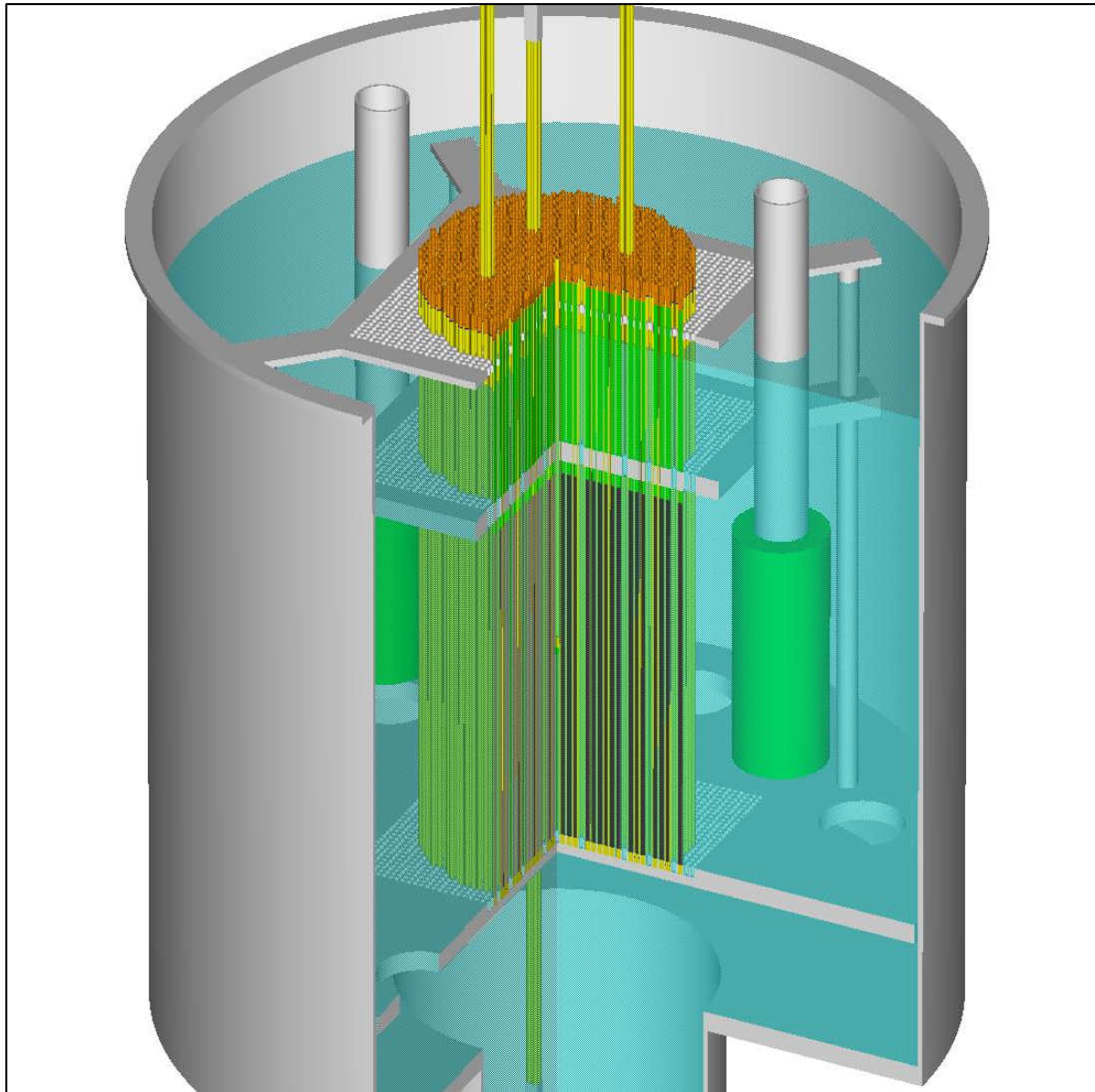
Fuel: 1136

Safety Elements: Up

Control Element: Lowering

Core Tank: Full

Personnel: Excluded

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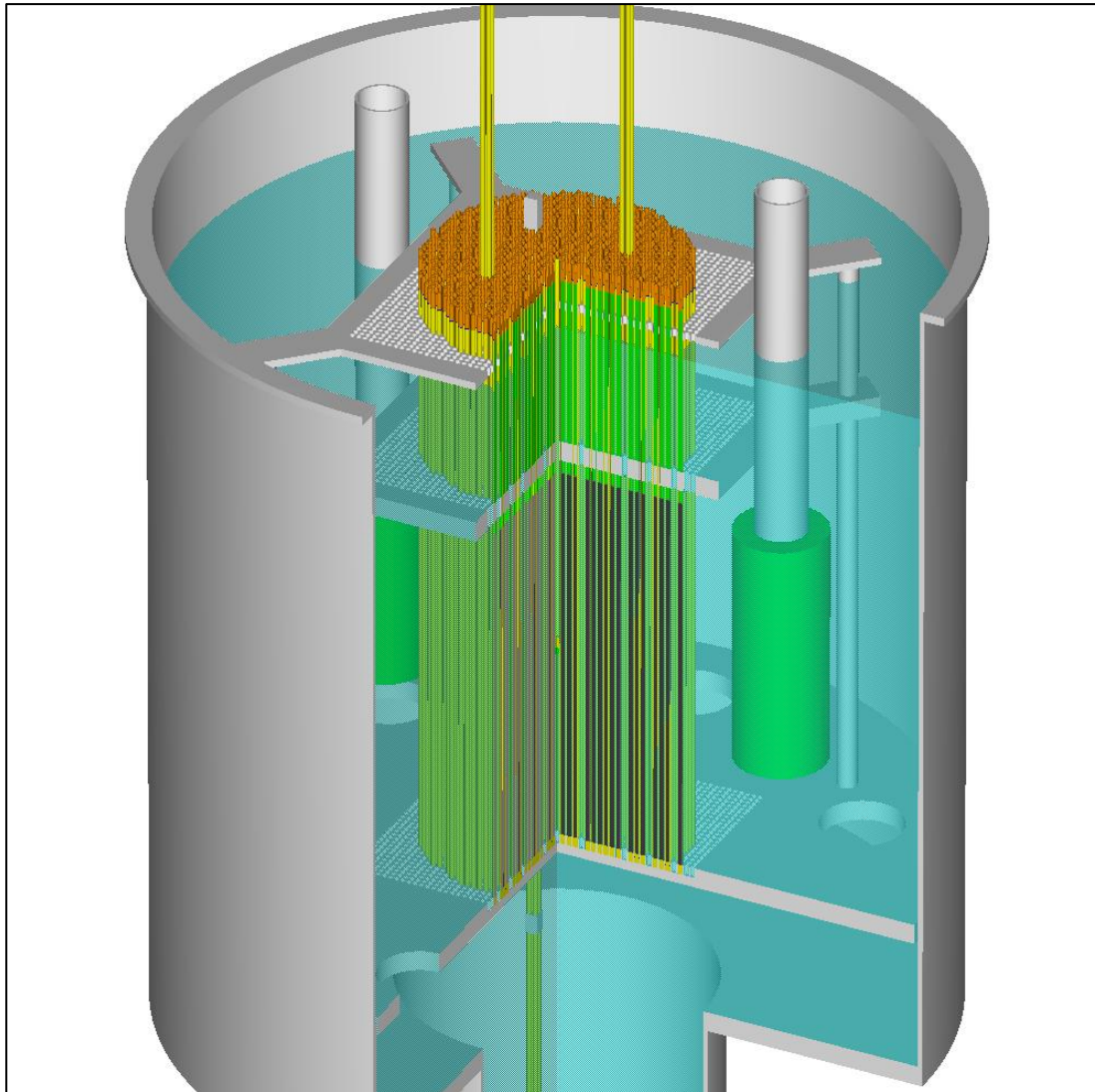
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Lower the control element

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.

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Drain the core tank
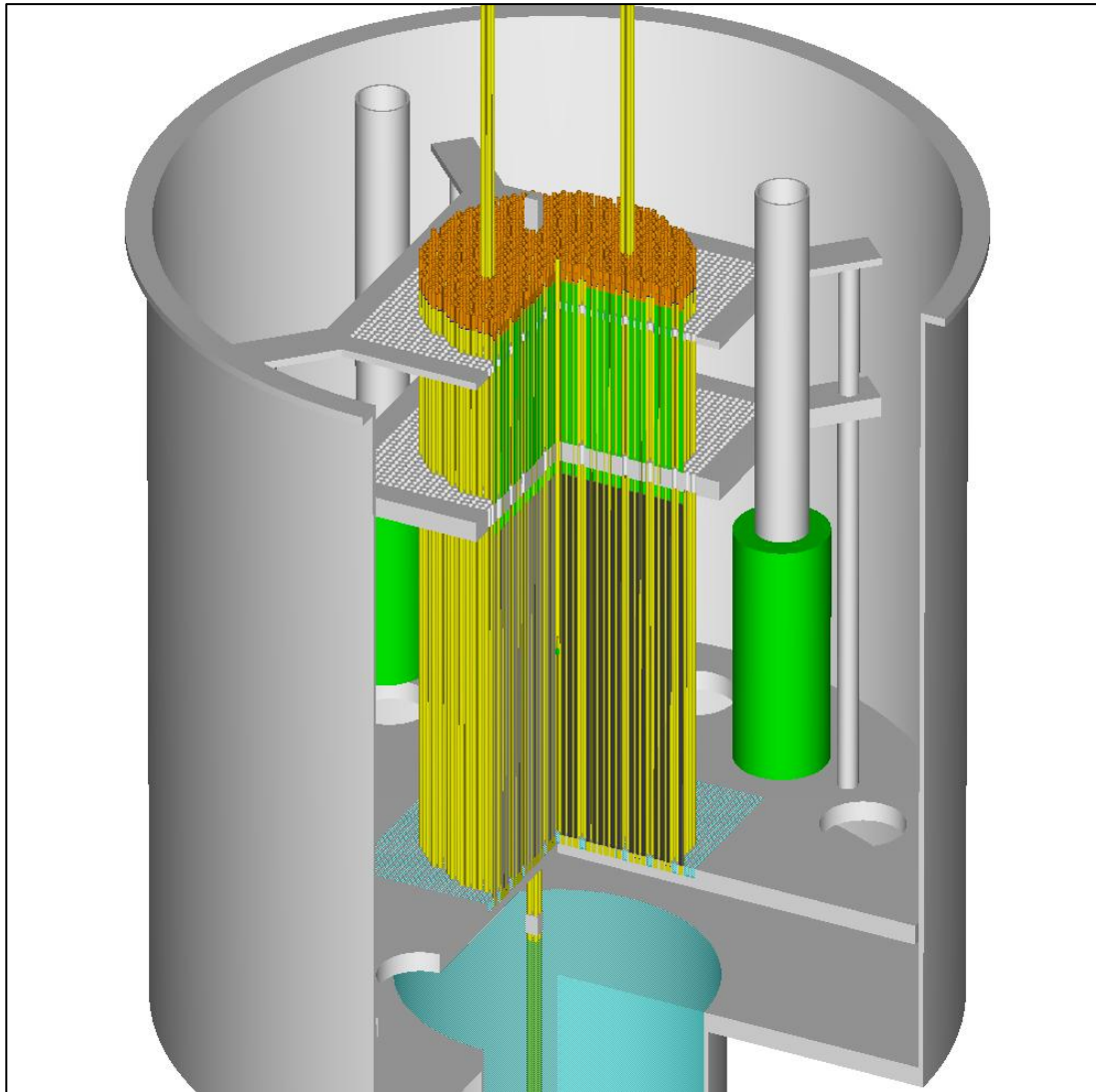
Fuel: 1136

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.
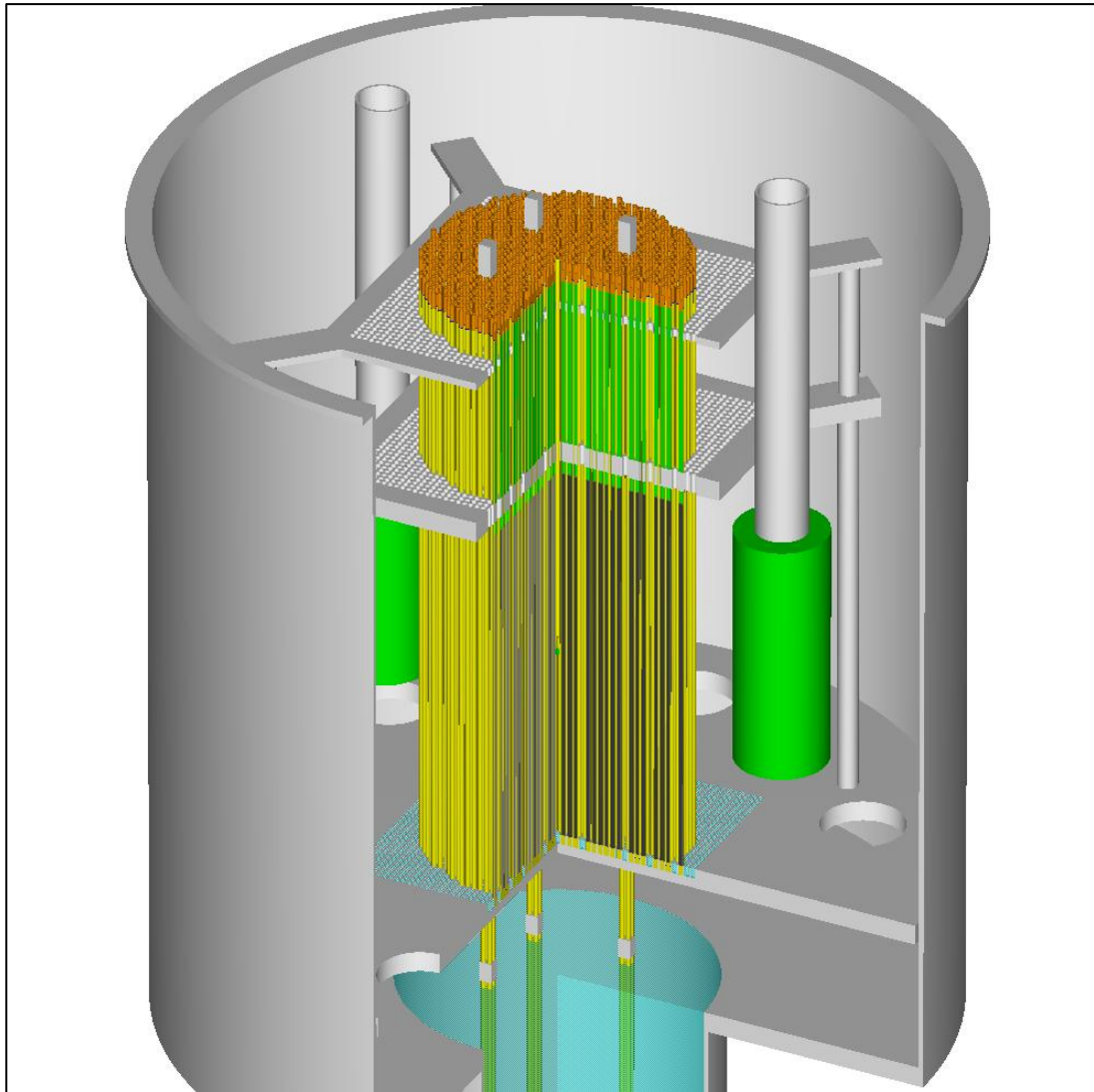
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The shut-down configuration of the assembly

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.

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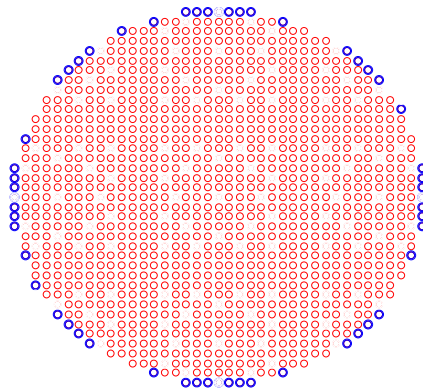# Core configurations during the first approach-to-critical experiment (1)
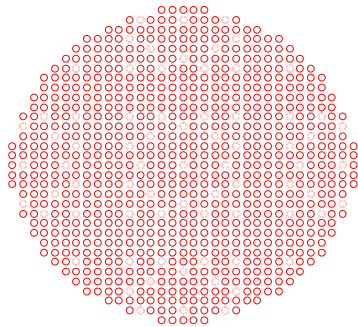
740
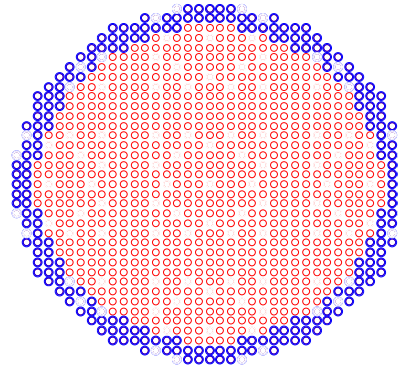
956

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

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

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

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

1063.4

Relative Inverse Multiplication

Fuel Rods in Assembly

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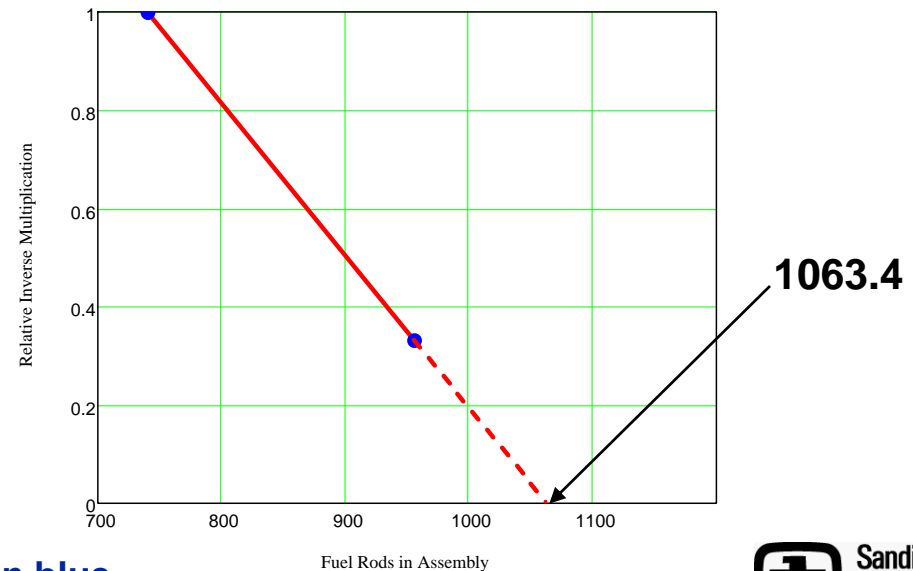
Core configurations during the first approach-to-critical experiment (2)

740

956

1009

1113.7
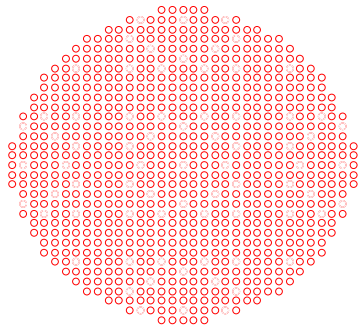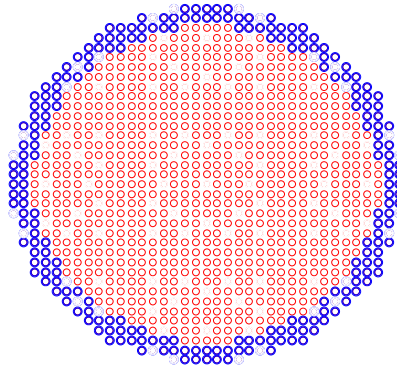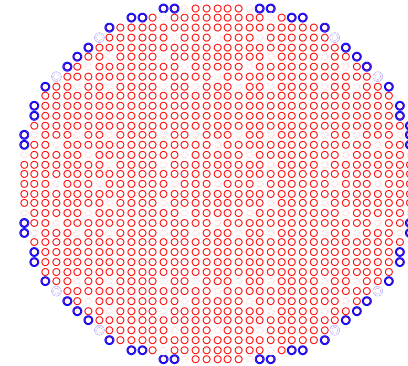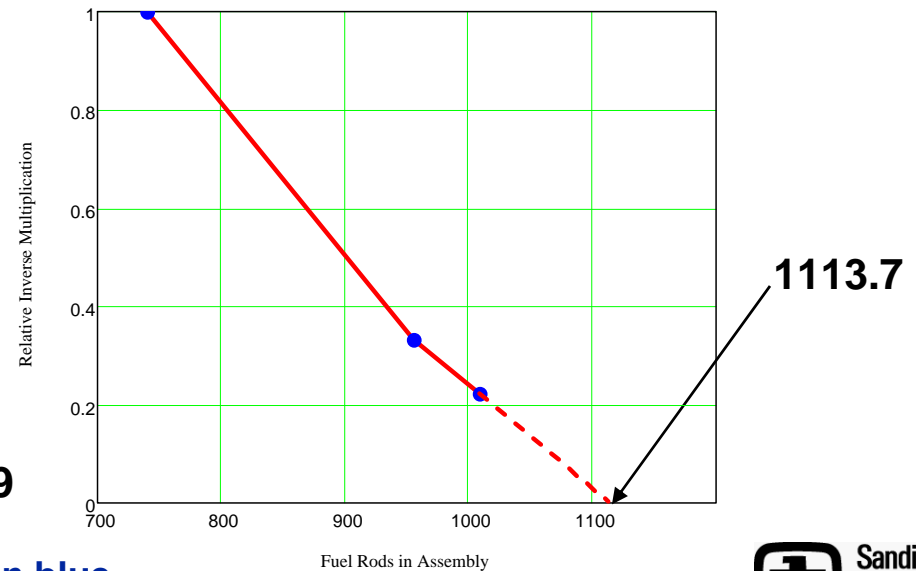
The next array: **1059**

The incremental fuel elements are shown in blue

Relative Inverse Multiplication

Fuel Rods in Assembly

Sandia National Laboratories

Core configurations during the first approach-to-critical experiment (3)
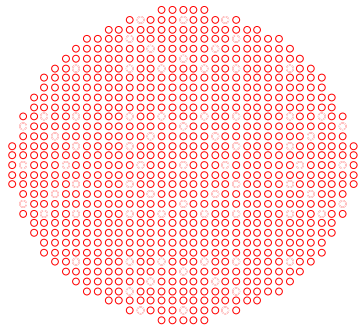
740
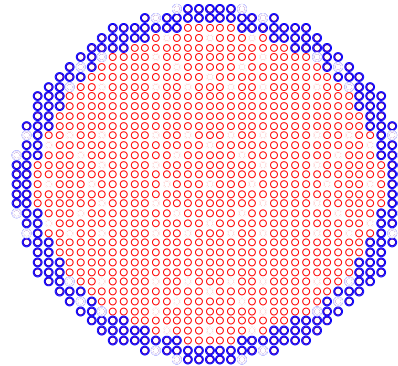
956
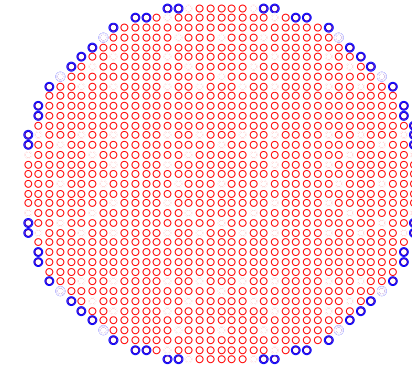
1009
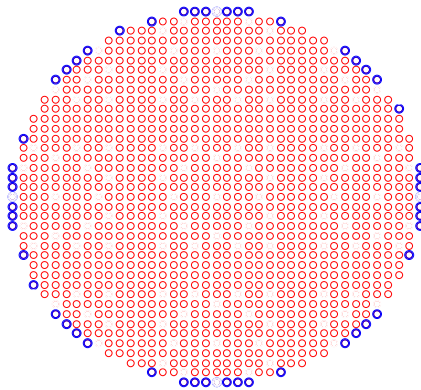
1059   **The next array: 1089**
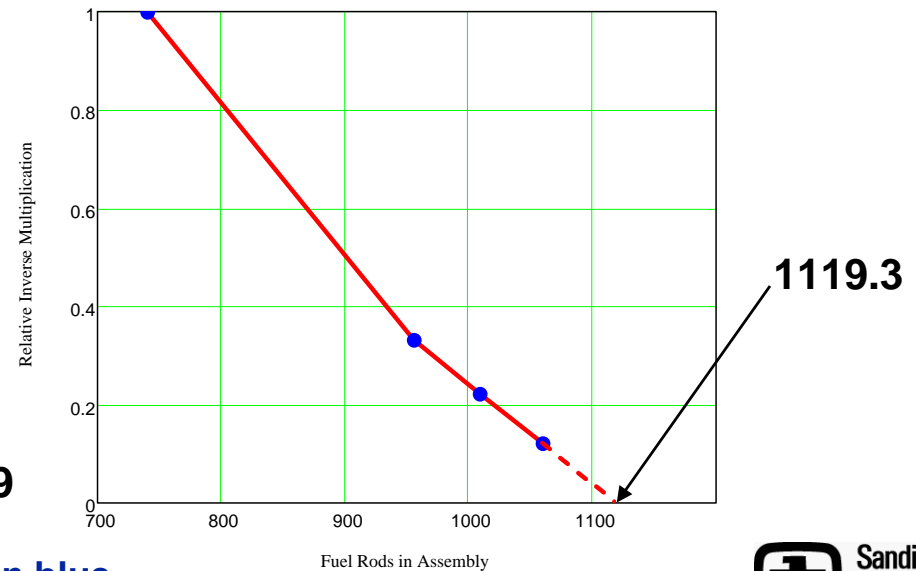
1119.3

Relative Inverse Multiplication

Fuel Rods in Assembly

The incremental fuel elements are shown in blue

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

1059

1089

The next array: 1115

1142.6

Relative Inverse Multiplication

Fuel Rods in Assembly

The incremental fuel elements are shown in blue

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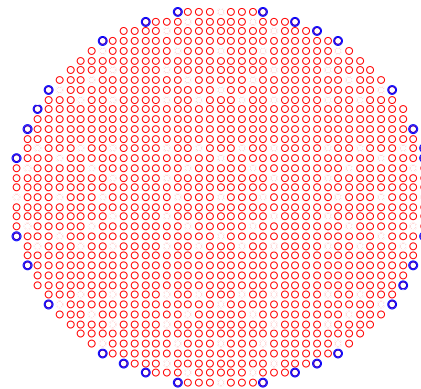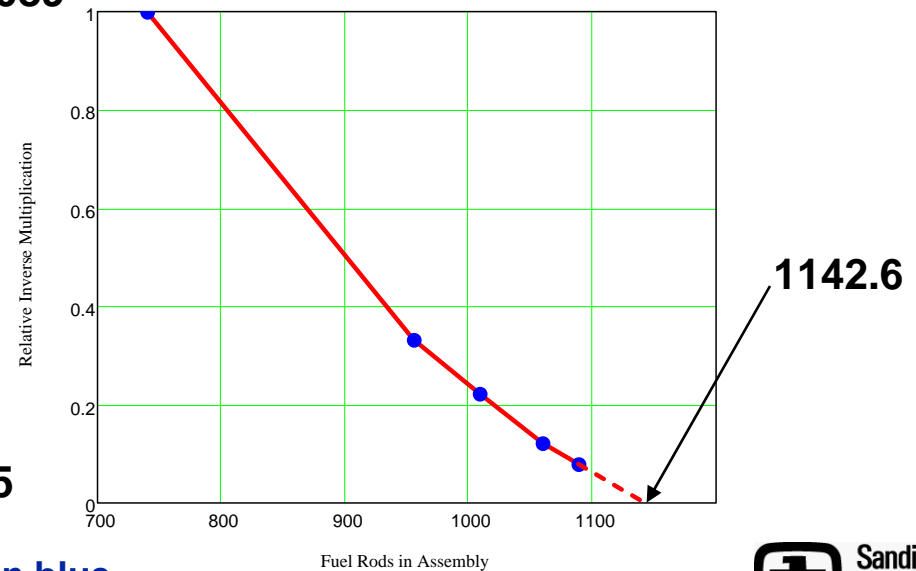
Core configurations during the first approach-to-critical experiment (4)
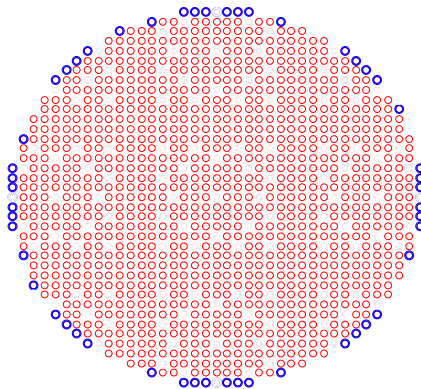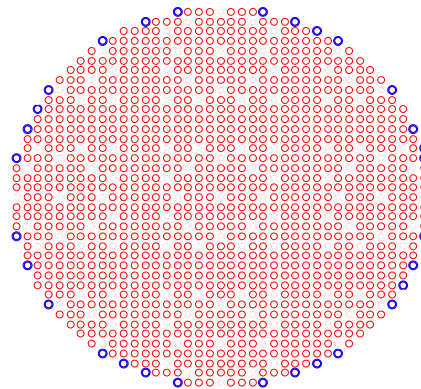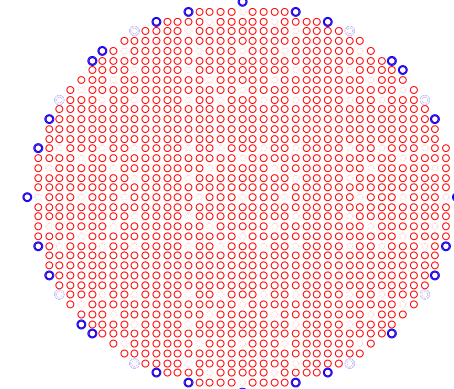
1059 **1089** **1115**

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

1139.1

The next array: 1127

The incremental fuel elements are shown in blue

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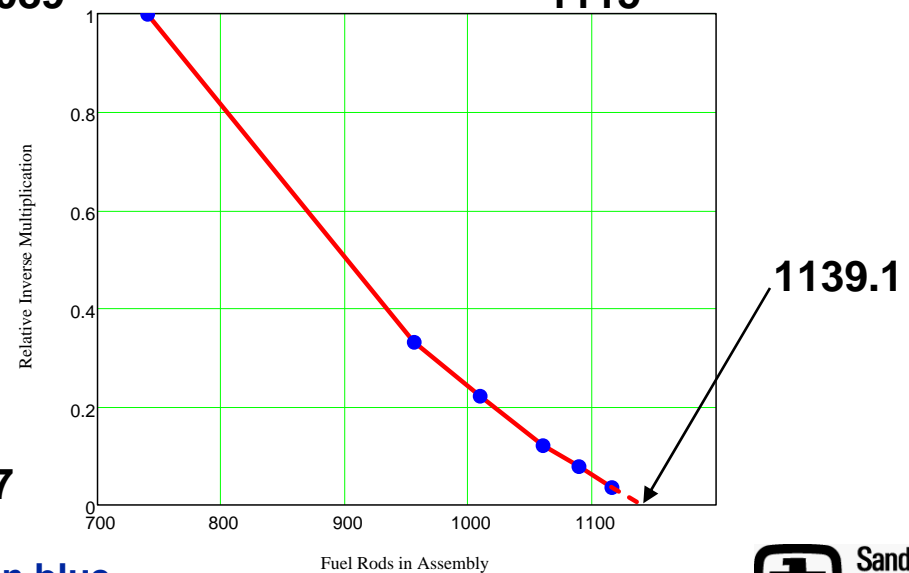
Core configurations during the first approach-to-critical experiment (5)
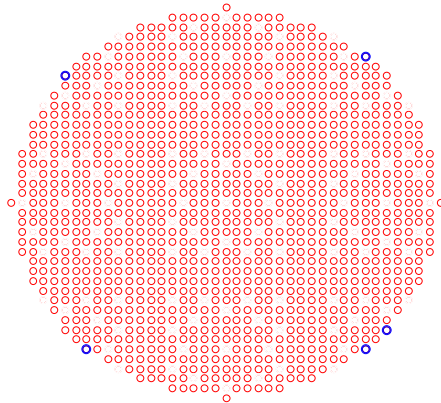
1120
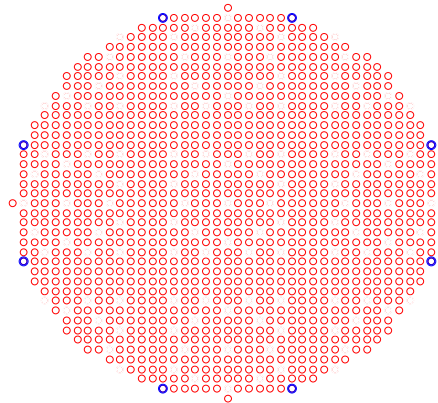
1128
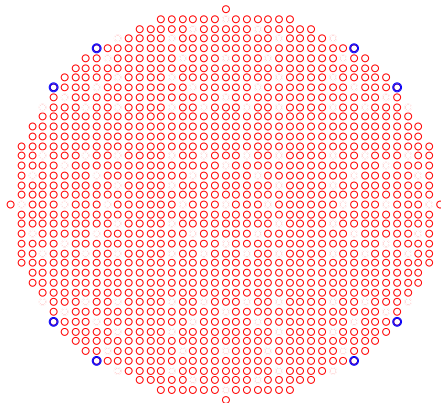
1136

The incremental fuel elements are shown in blue
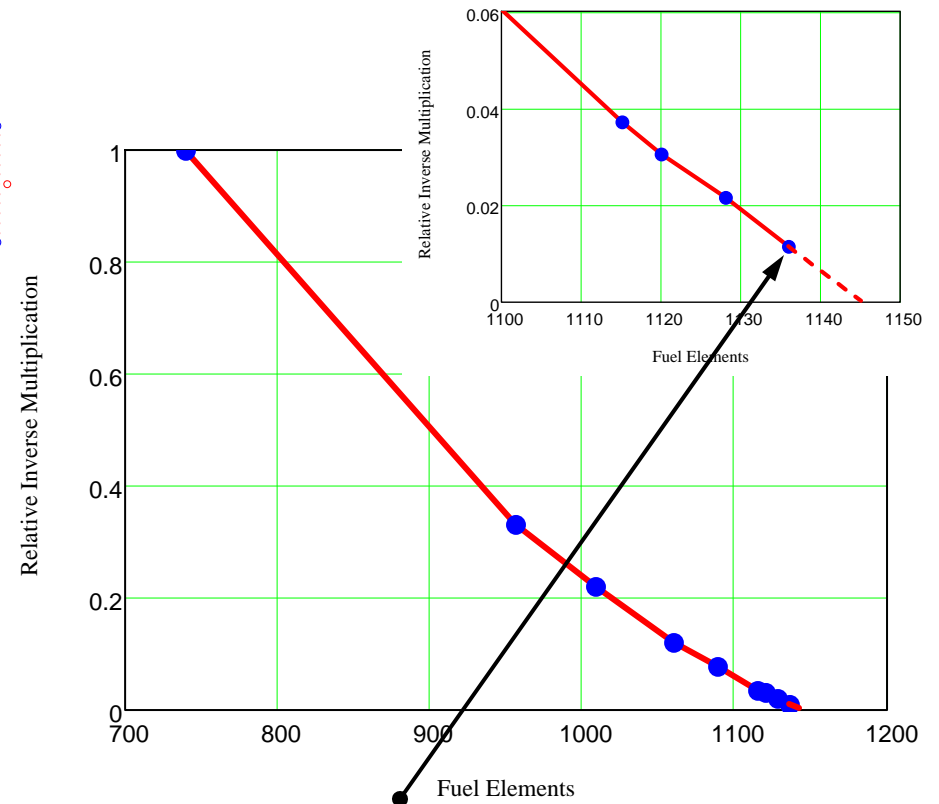
At 1136 fuel elements:

$N_{crit} = 1145.3$

$k_{eff} = 0.9984$

$M \sim 610$

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The first 7uPCX core
at the end of the approach
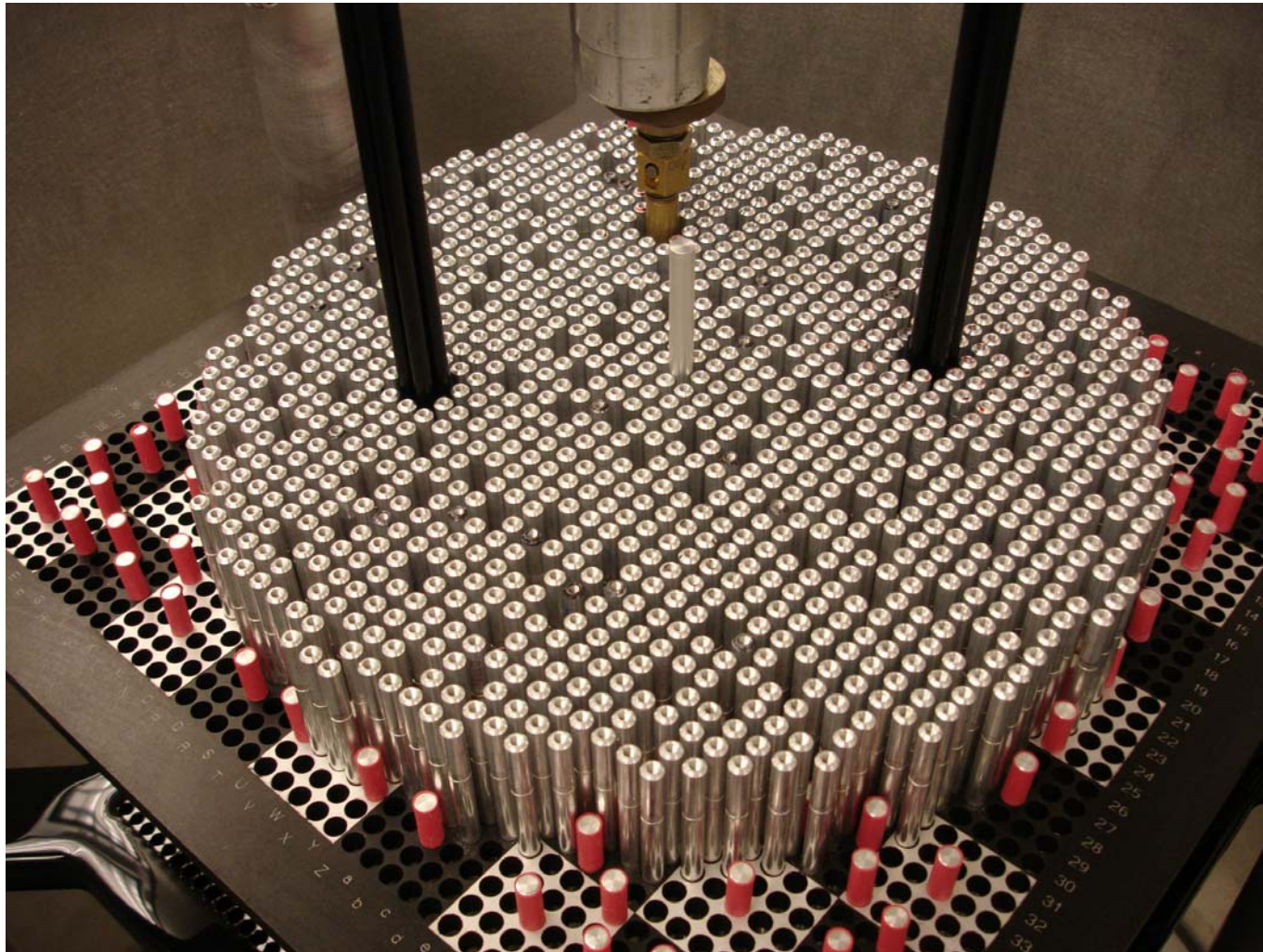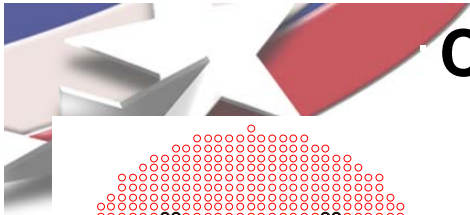
Core "A" Configurations Starting 2/9/10
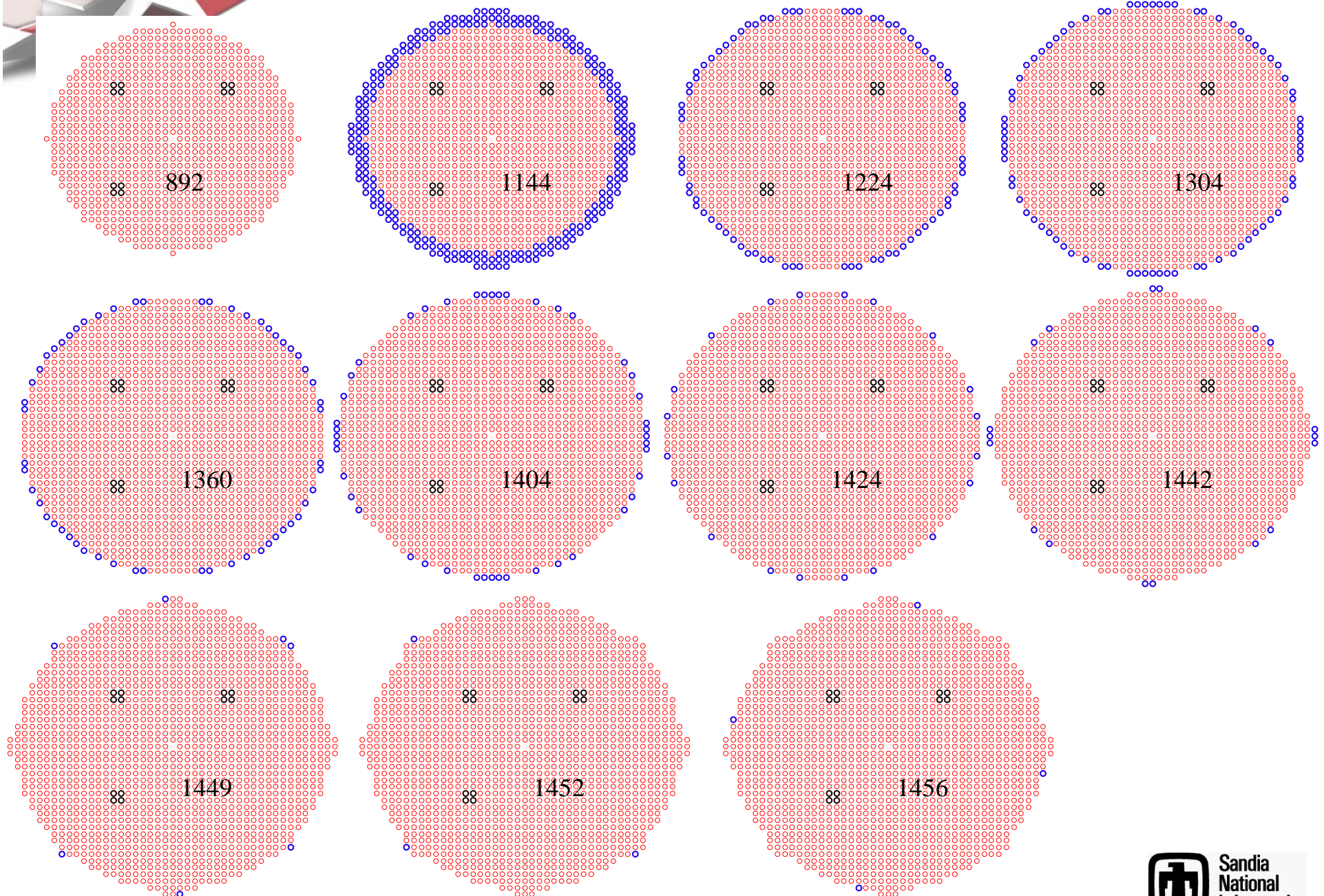
The "A" core

k$_{eff}$ from Approach Data

The Inverse Multiplication Plot

1425

1433

1437   k = 0.9964

1445   k = 0.9975

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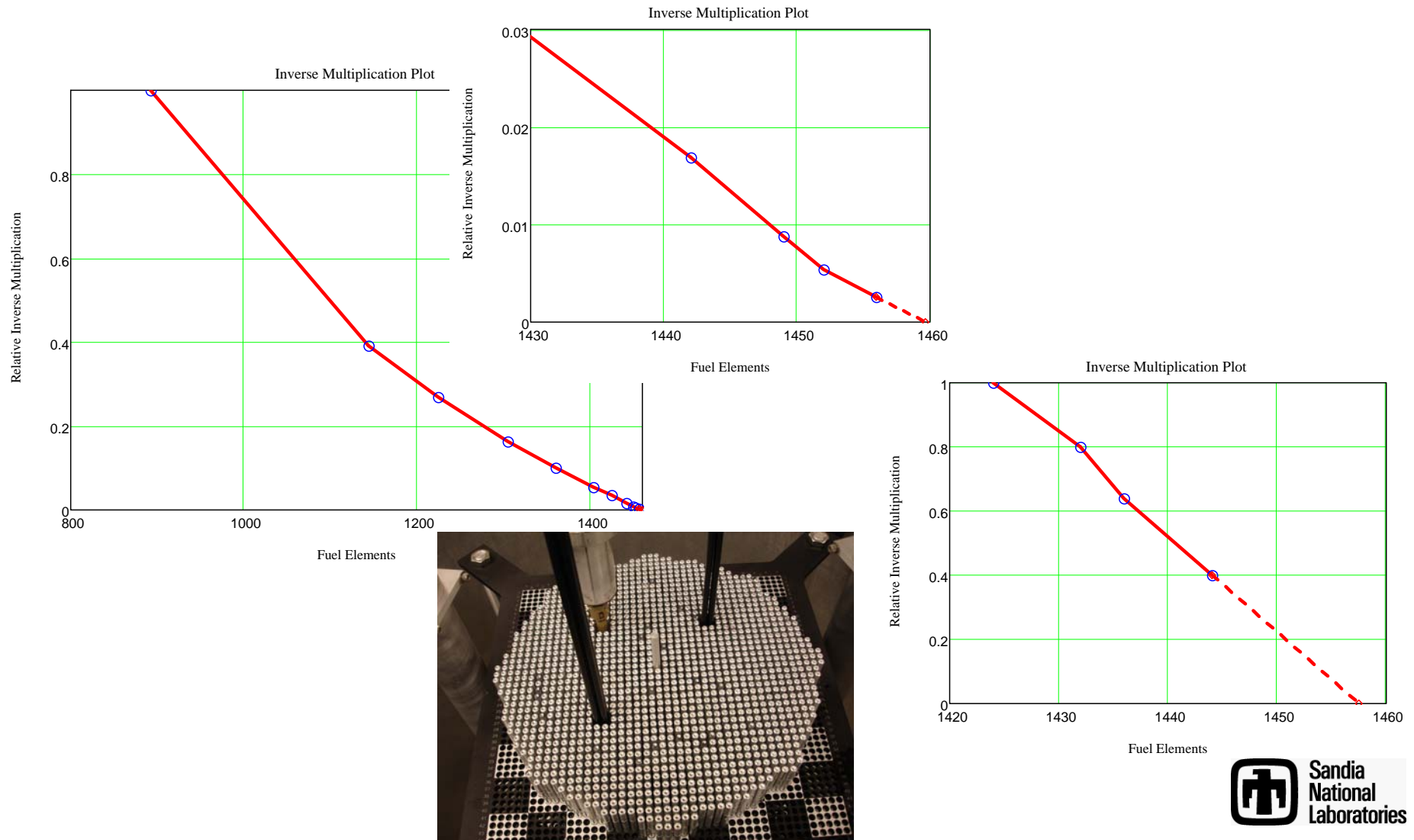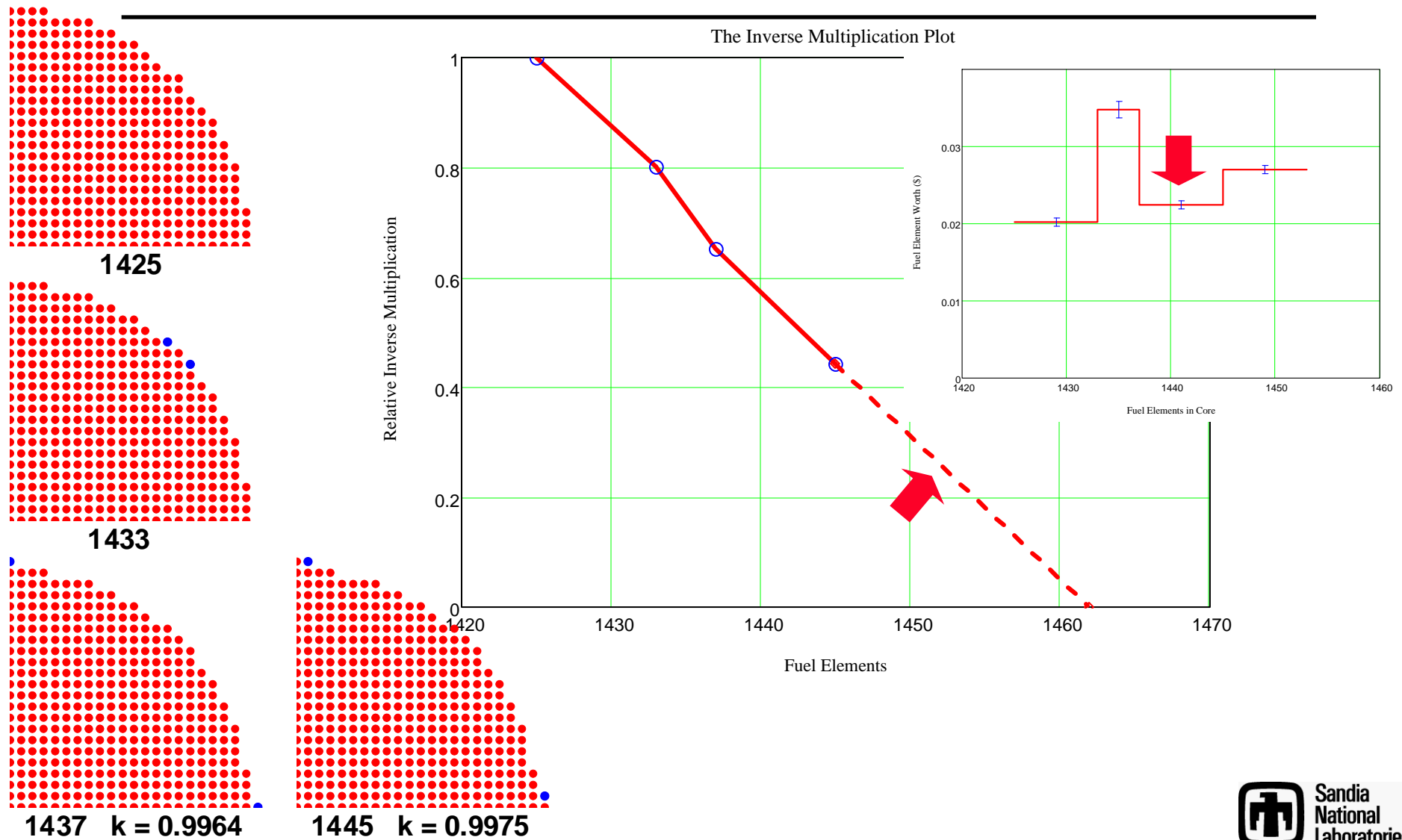
We have performed critical experiments on several 7uPCX configurations
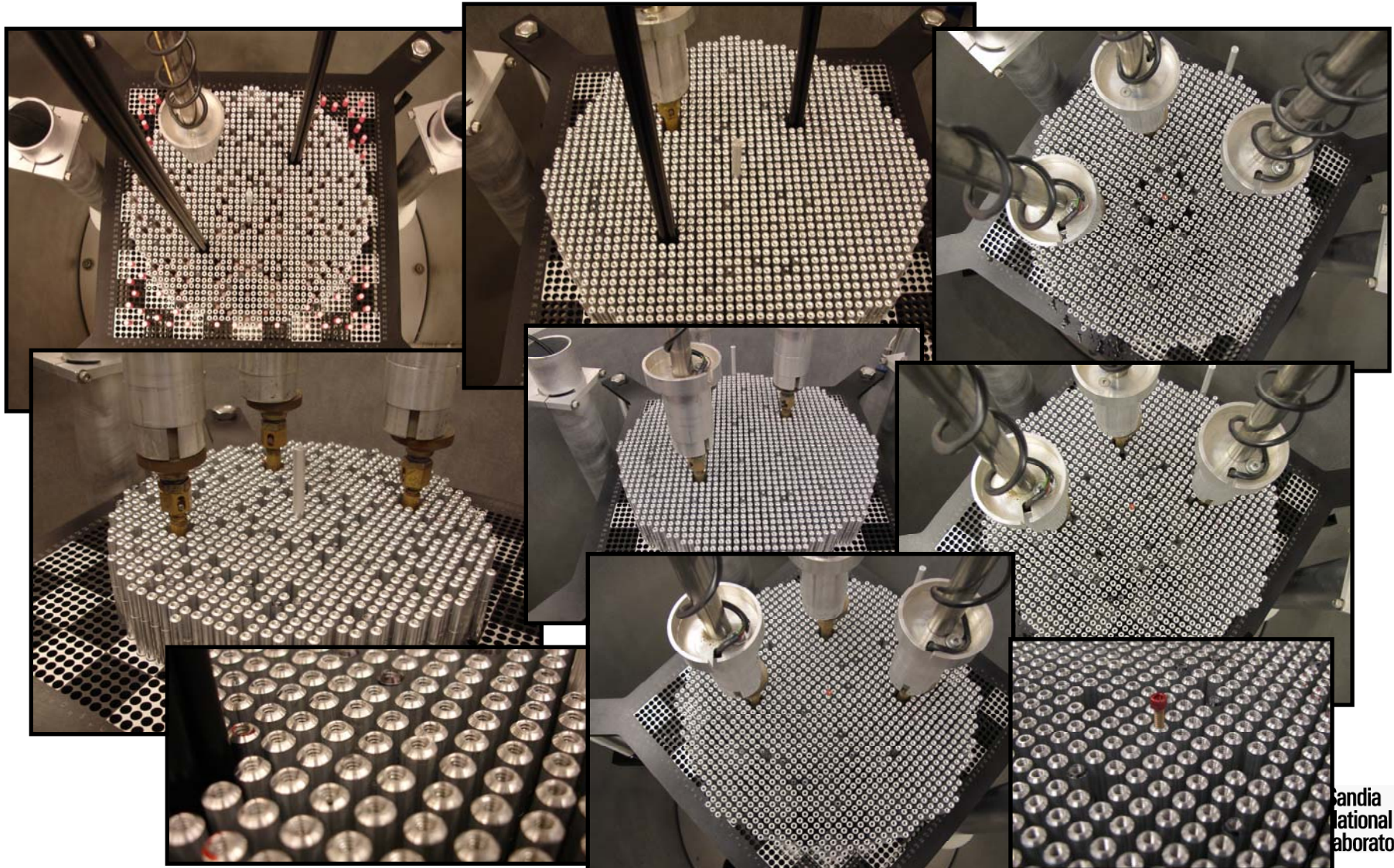
7uPCX Critical Configurations
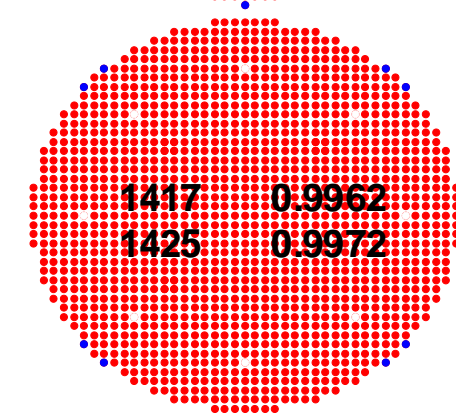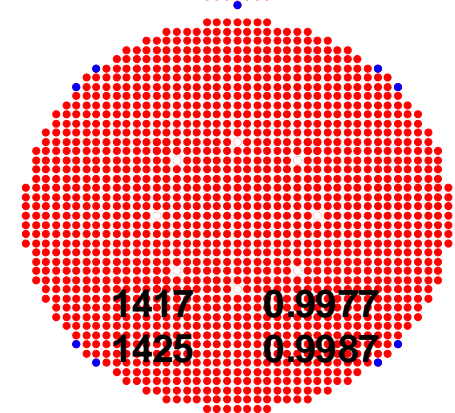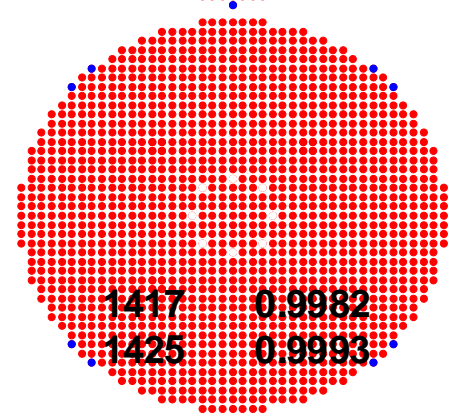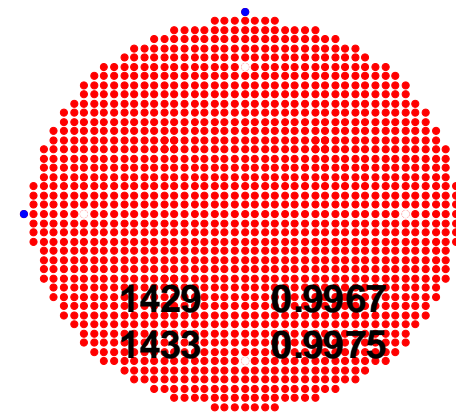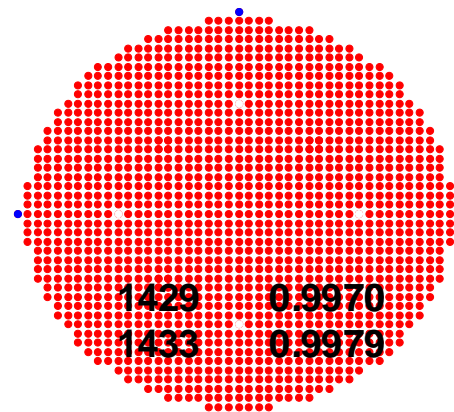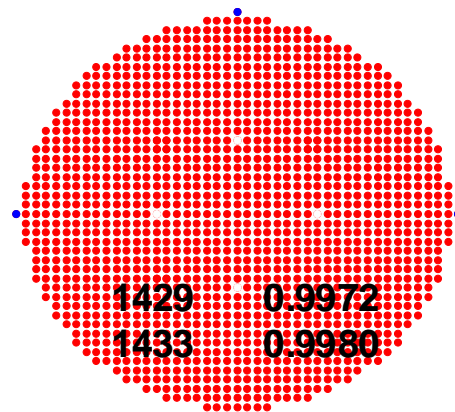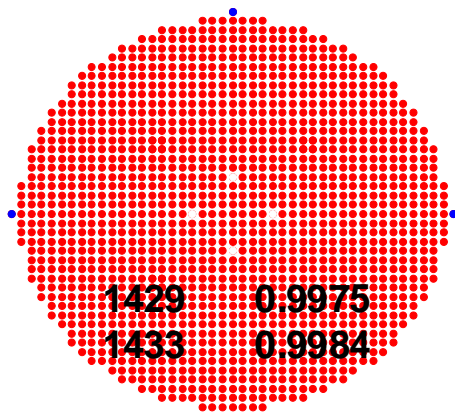
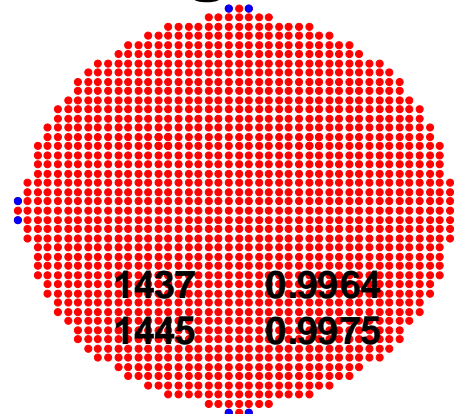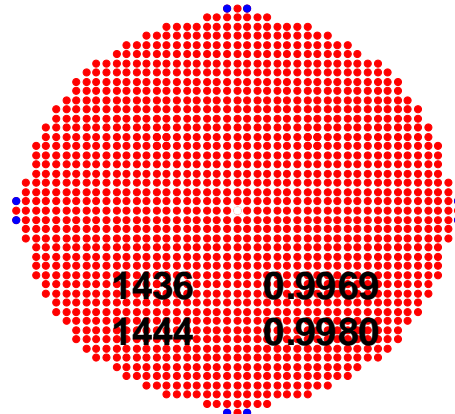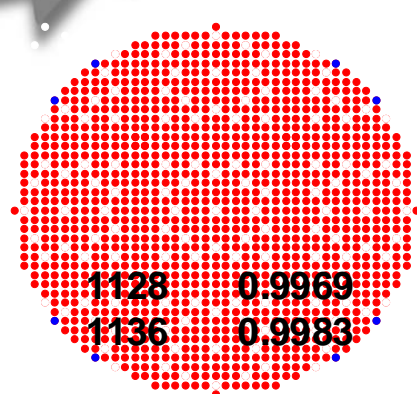# The 7uPCX experiment matrix

- **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**

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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**

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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

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