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Restart of the Sandia Pulsed Reactor Facility Critical Experiments

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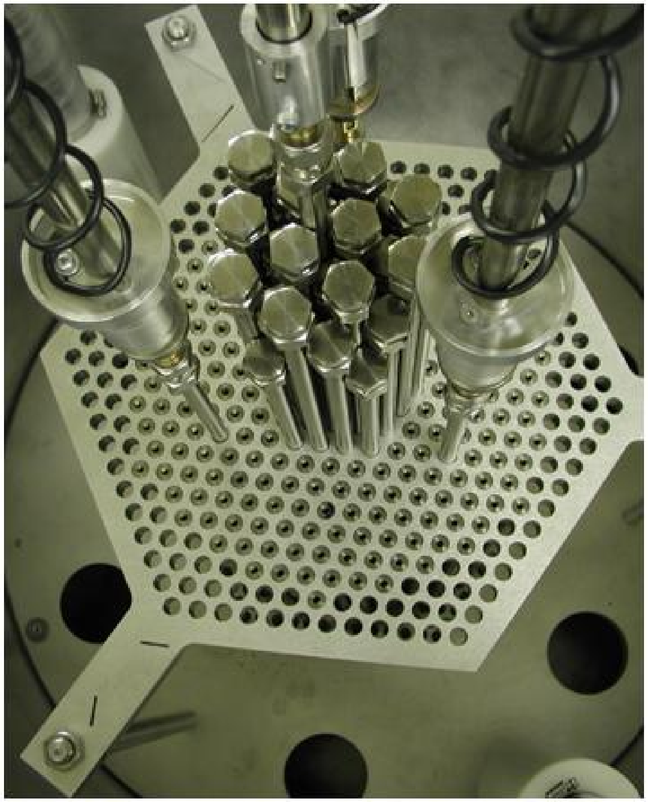
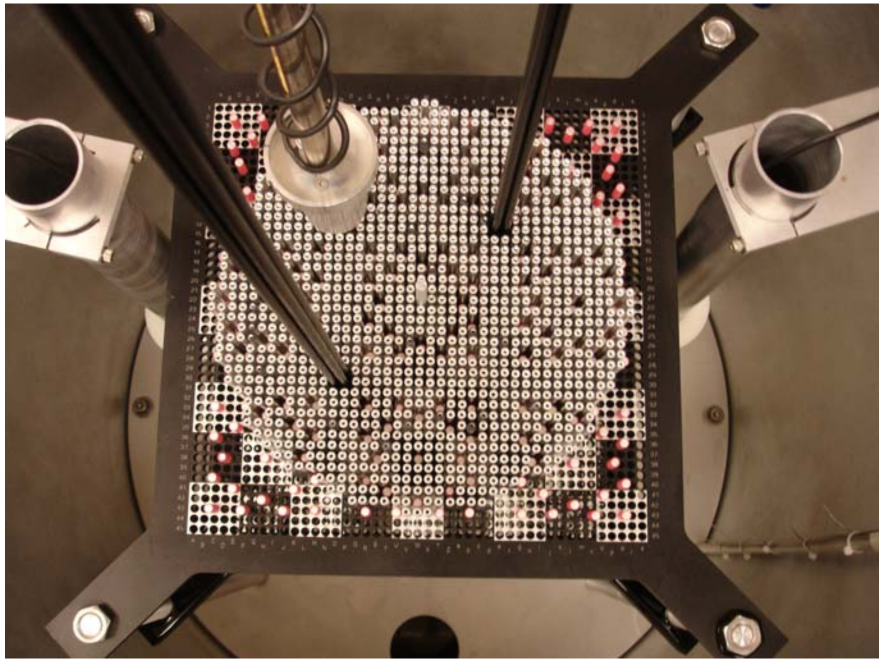
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

We have restarted our critical experiment capability

BUCCX – fission product effects

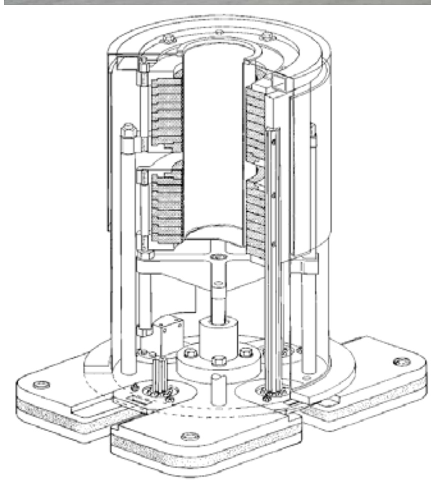




7uPCX – physics of higher-enrichment cores (5-10%)

This is the first core investigated after the restart

We operate our critical experiments in the Sandia Pulsed Reactor Facility



Sandia Pulsed Reactor III (SPR-III)

- The SPRF is an operating Nuclear Facility
- The SPRF has:
  - ✓ a professional operating staff and supporting infrastructure
  - ✓ an existing Authorization Basis (AB)
  - ✓ room in its schedule – the HEU SPR fuel has been removed
- We modify the AB as needed for the critical experiments
- The AB is current – SER 1/18/08
- We restarted our critical experiments capability in May, 2009
  - 7uPCX for DOE-NE and NCSP
  - BUCCX for DOE-RW (YMP)

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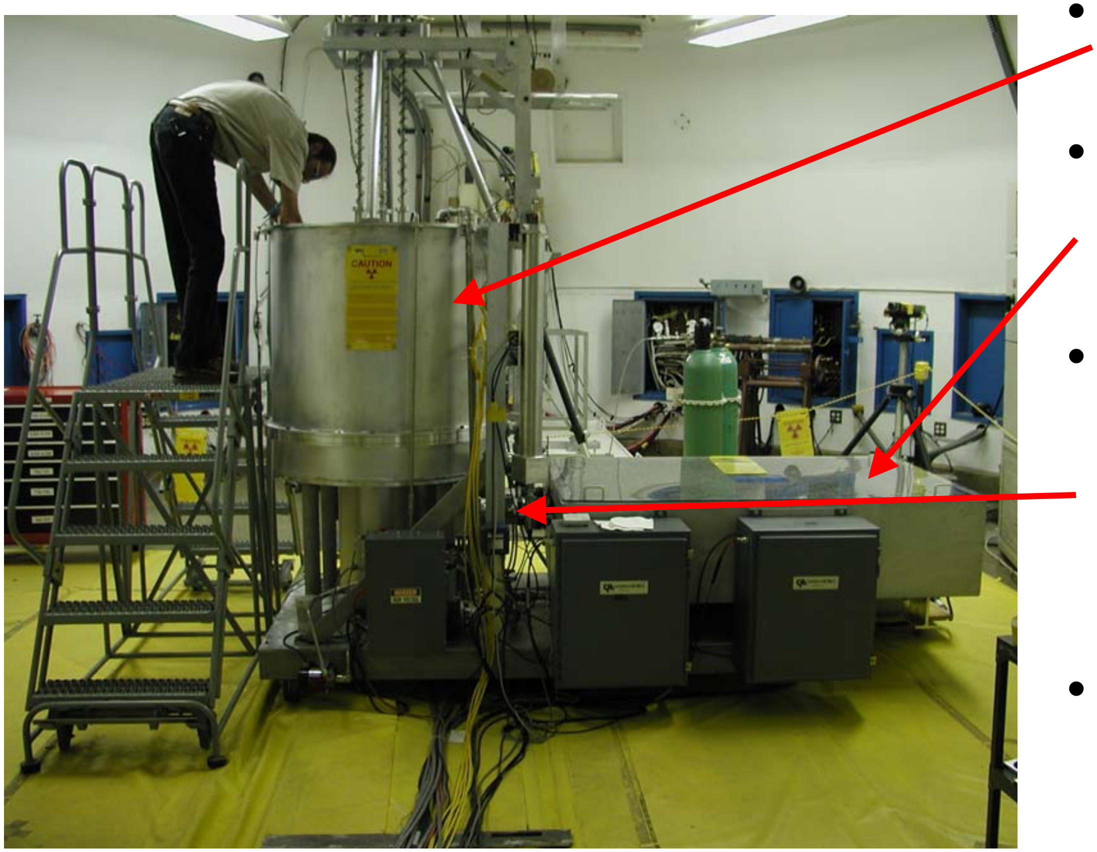
The design of the critical assembly uses gravity to promote safety



- The fuel array is in the elevated core tank
- The water moderator is normally stored in the dump tank
- The core tank is connected to the dump tank by two 4" lines with normally-open remotely-controlled dump valves
- To close the dump valves, a key must be inserted into the console and turned – the key cannot be removed if activated

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The safety case is simple

- Low-enriched (<20%) fuel is used
  - 1000 kg of the fuel cannot go critical without water moderator
- Access controls ensure personnel safety – 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
- The fission product inventory is kept low by limiting the energy deposition in the fuel
  - Allows manual handling of fuel during experiments
  - Limits accident source term
- The control system includes power and period scrams for asset protection

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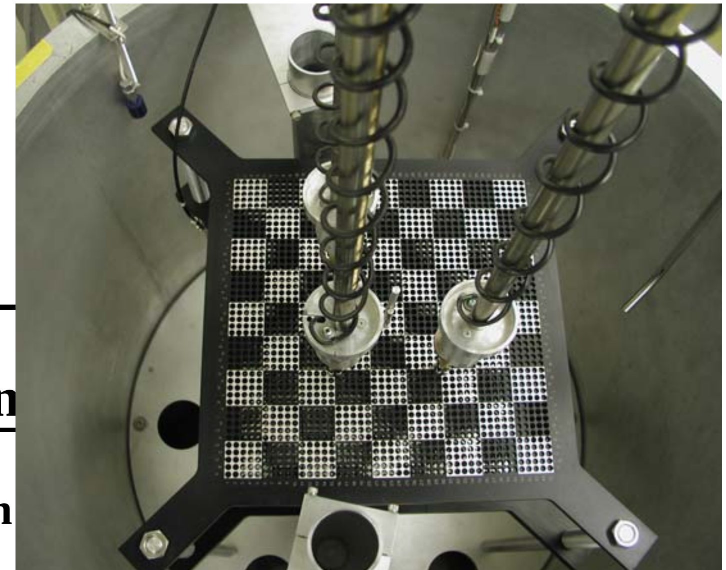
Starting a core load



The first fuel addition

Step	Fuel Elements	SE	CE	Water in Core?	People Allowed?	Action
1	0	Down	Down	No	Yes	Start new core load here.
2	0	Up	Down	No	Yes	Raise the safety elements.
3	0	Up	Up	No	Yes	Raise the control element.
4	N_1	Up	Up	No	Yes	Add the first fuel increment.
5, 6*	N_1	Up	Up	No	No	Leave and lock the reactor room.
	N_1	Up	Down	No	No	Lower the control element.
7	N_1	Up	Down	Yes	No	Close dump valves and fill the core tank.
8	N_1	Up	Up	Yes	No	Raise control element, measure count rates.
9, 10*	N_1	Up	Down	Yes	No	Lower the control element.
	N_1	Up	Down	No	Yes	Open the dump valves.
11	N_1	Up	Down	No	Yes	Jump to "C" below for the next fuel increment.

* Steps can be done in any order.

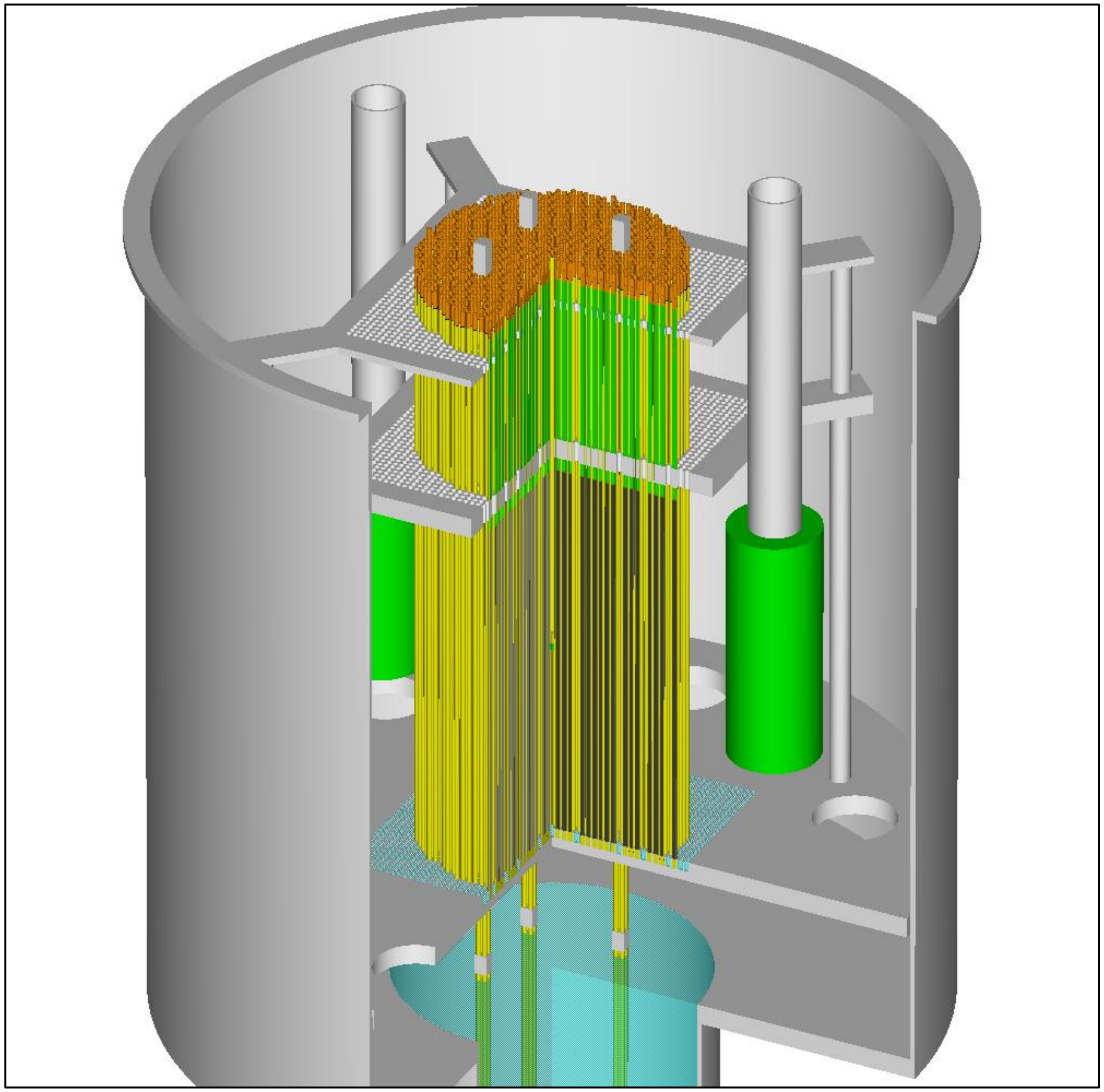
Loading to critical is a repetitive process

All fuel additions after the first

Step	Fuel Elements	SE	CE	Water in Core?	People Allowed?	Action
A	N_1	Down	Down	No	Yes	Perform the necessary startup actions.
B	N_1	Up	Down	No	Yes	Condition after startup actions.
C	N_2	Up	Down	No	Yes	Add fuel increment.
D	N_2	Up	Down	No	No	Leave and lock the reactor room.
E	N_2	Up	Down	Yes	No	Close dump valves and fill the core tank.
F	N_2	Up	Up	Yes	No	Raise control element, measure count rates.
G, H, I*	N_2	Up	Down	Yes	No	Lower the control element.
	N_2	Up	Down	No	Yes	Open the dump valves.
	N_2	Up	Down	No	Yes	Determine the next fuel increment. Loop to "C" unless done.

* Steps can be done in any order.

Start of a multiplication measurement



Safety Elements: Down

Control Element: Down

Core Tank: Empty

Personnel: Allowed

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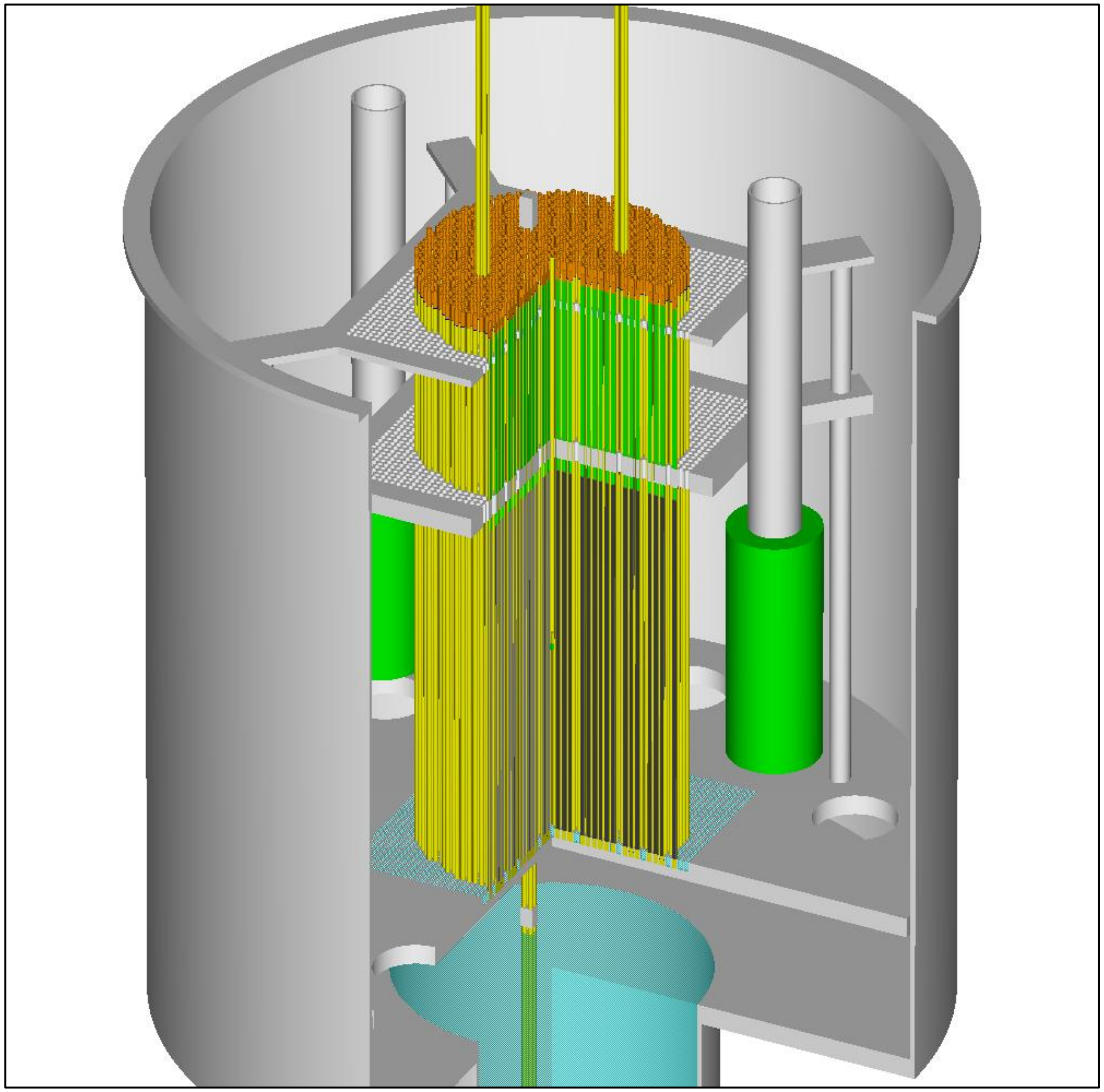
Raise the safety elements



Safety Elements: Up

Control Element: Down

Core Tank: Empty

Personnel: Allowed

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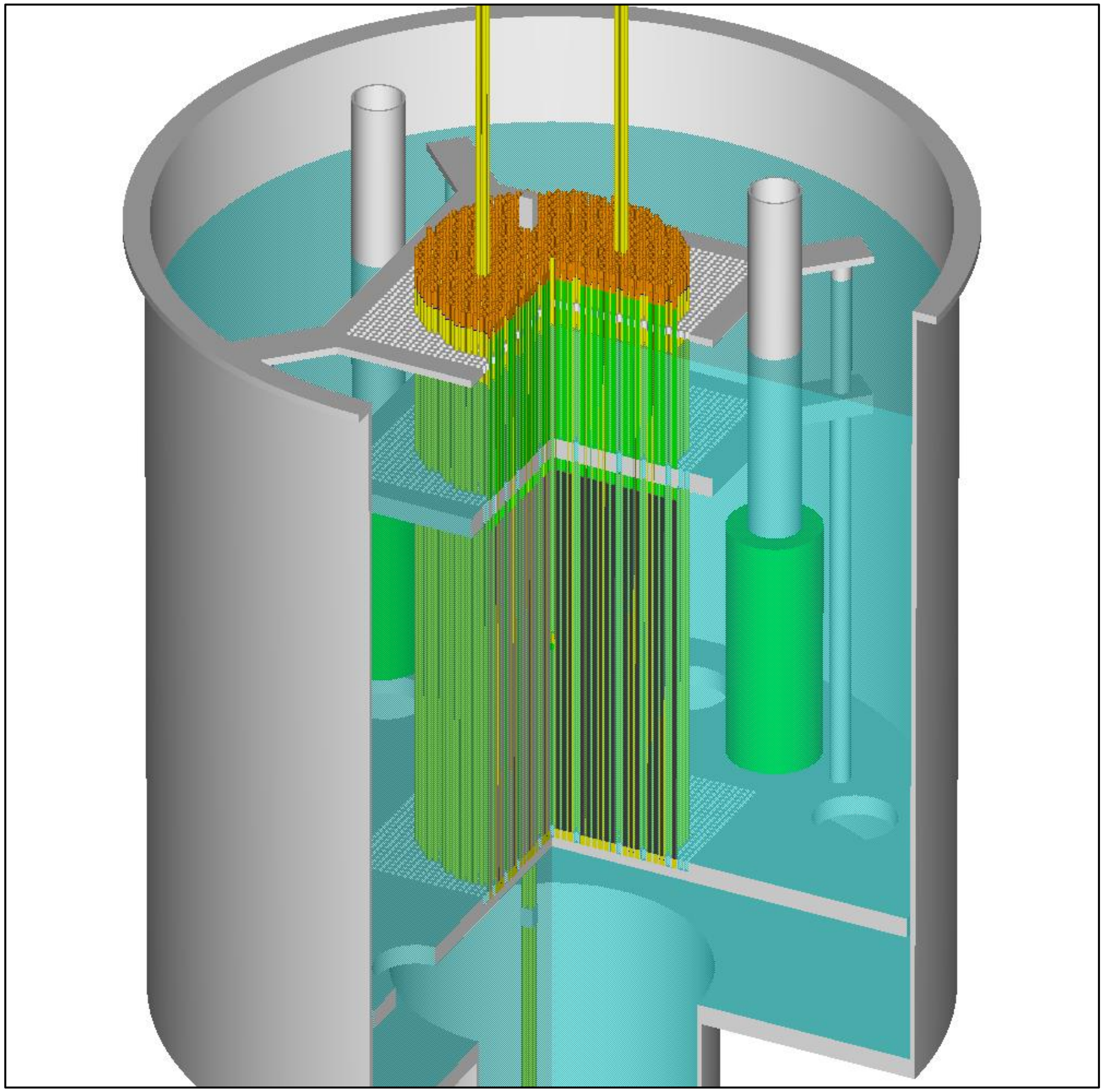
Fill the core tank



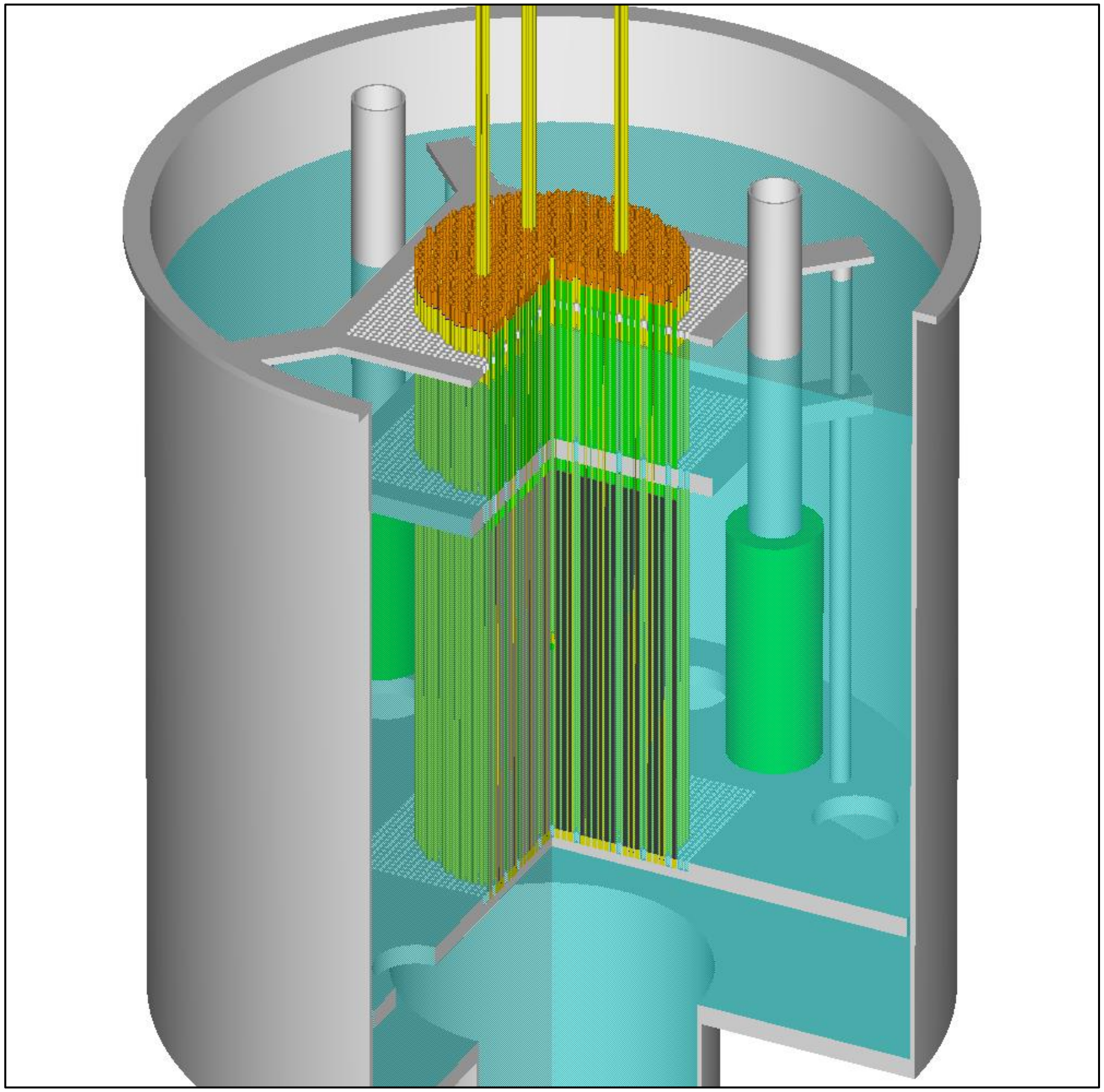
Safety Elements: Up

Control Element: Down

Core Tank: Full

Personnel: Excluded

Raise the control element



Safety Elements: Up

Control Element: Up

Core Tank: Full

Personnel: Excluded

Multiplication measurements are made in this configuration

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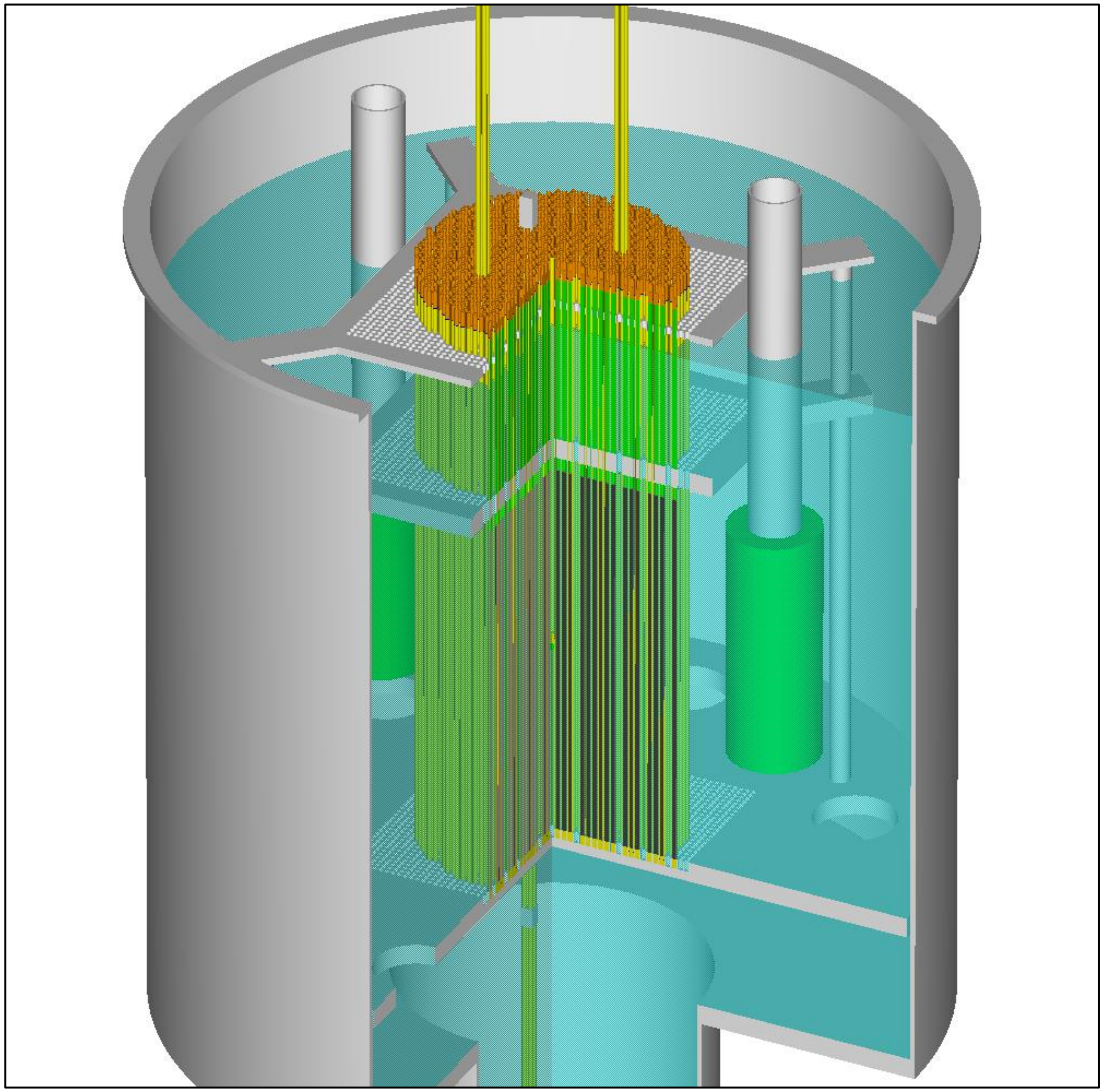
Lower the control element



Safety Elements: Up

Control Element: Down

Core Tank: Full

Personnel: Excluded

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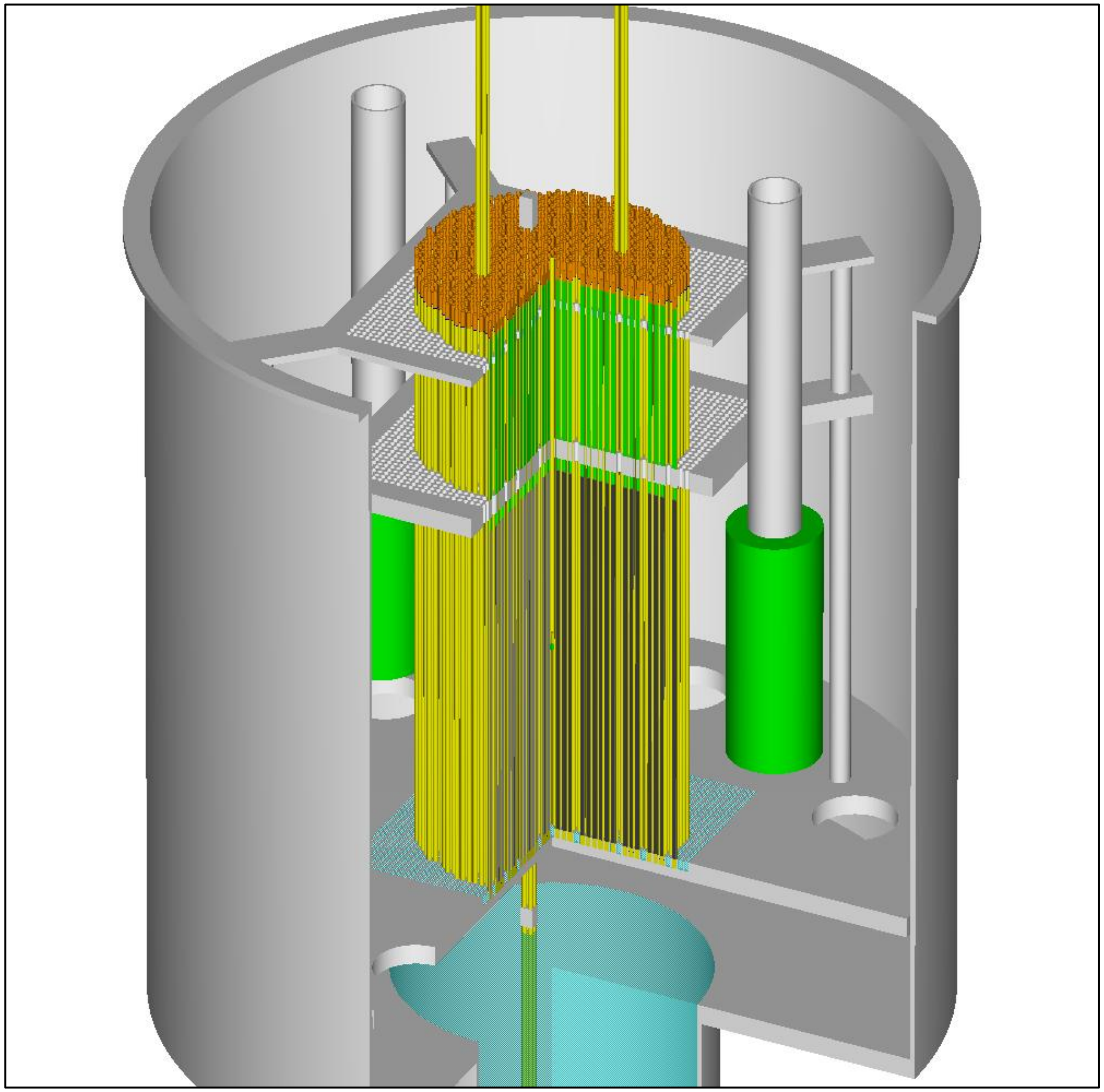
Drain the core tank



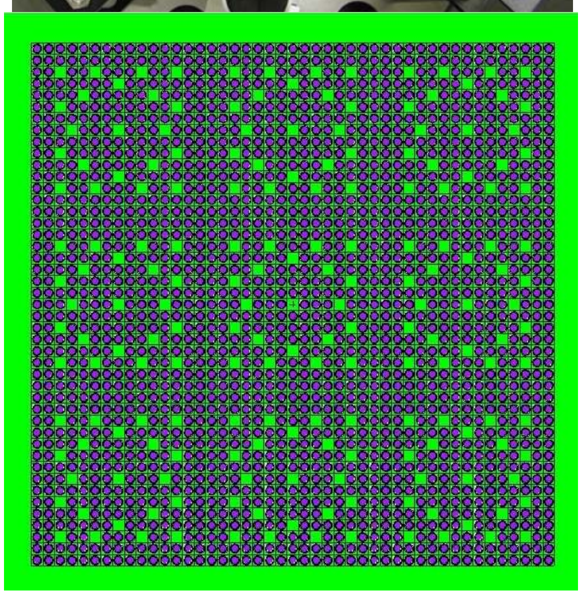
Safety Elements: Up

Control Element: Down

Core Tank: Empty

Personnel: Allowed

The 7uPCX core simulates a 3x3 array of commercial fuel assemblies



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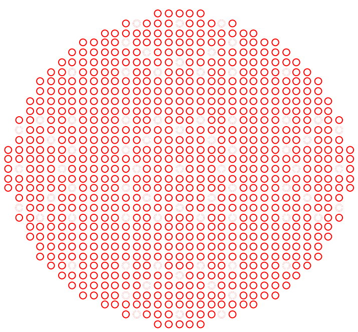
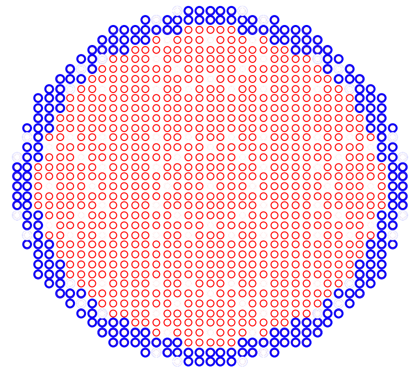
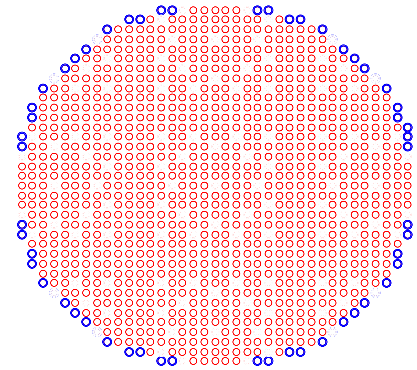
Core configurations during the first approach-to-critical experiment (1)



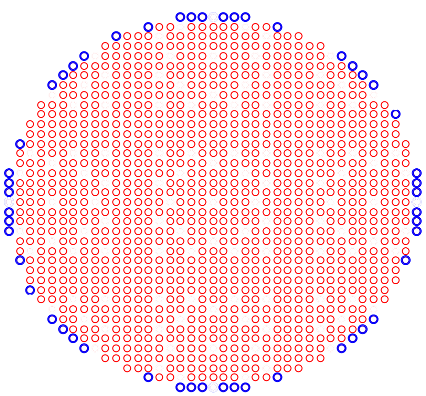
740



956



1009



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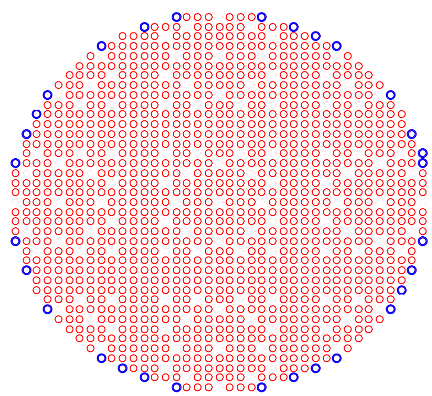

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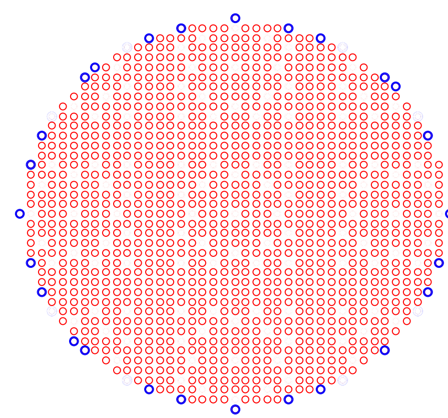
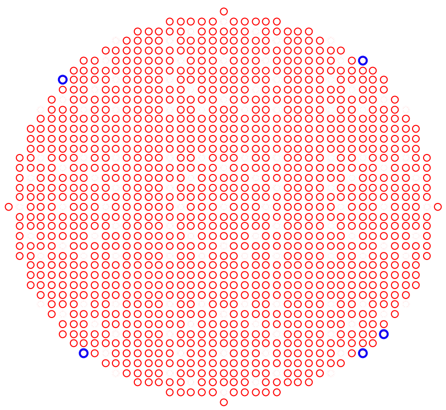


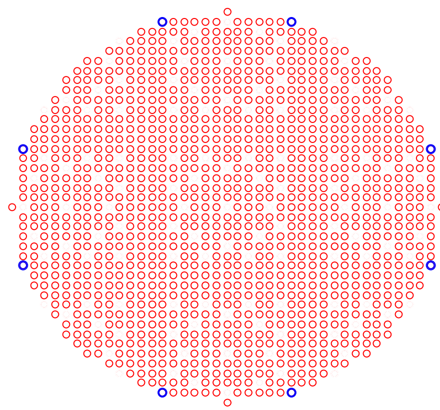
1115

The incremental fuel elements are shown in blue

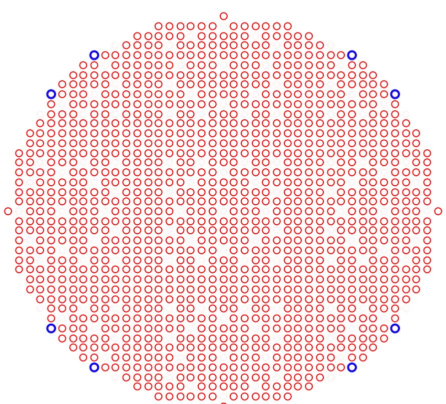
Core configurations during the first approach-to-critical experiment (2)



1120

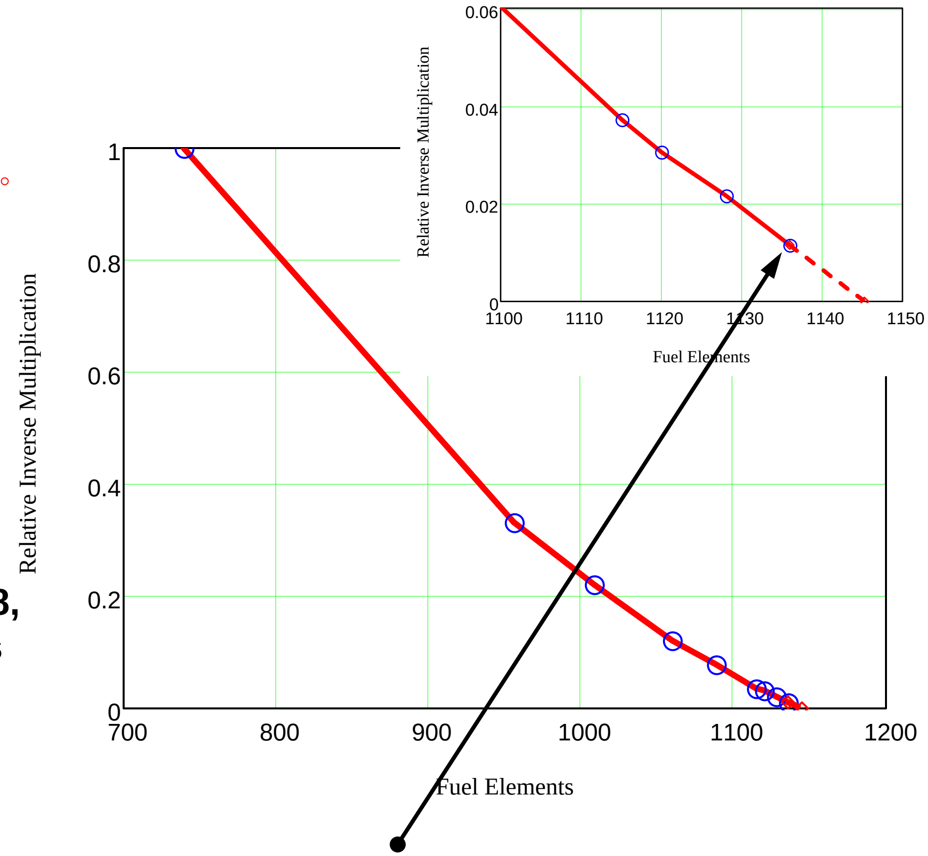


1128



1136

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



At 1136 fuel elements:

k_{eff} = 0.9984

M ~ 610

The incremental fuel elements are shown in blue

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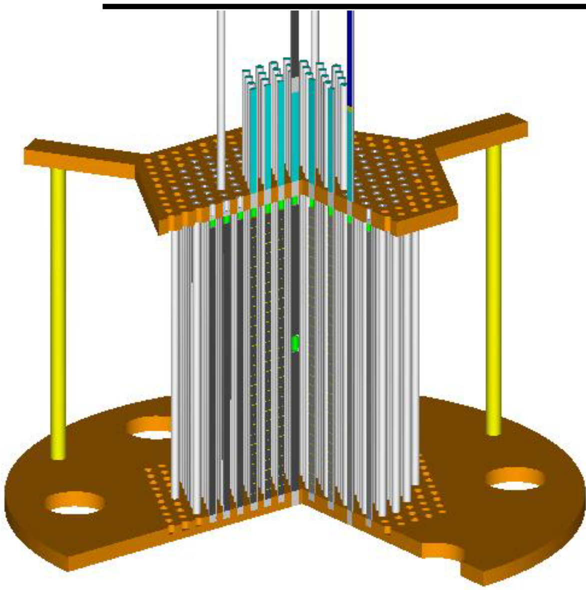
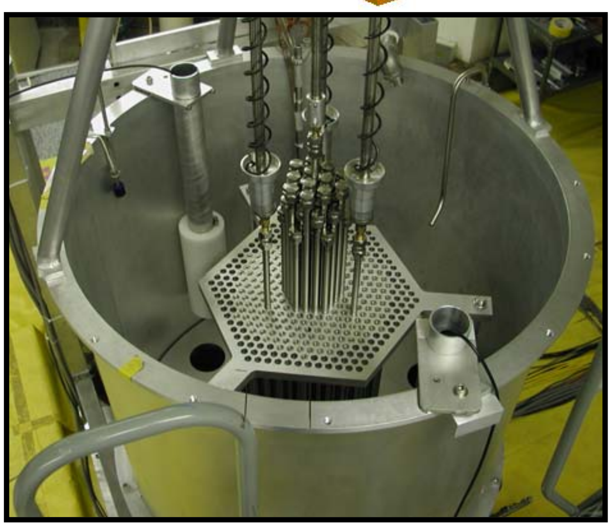
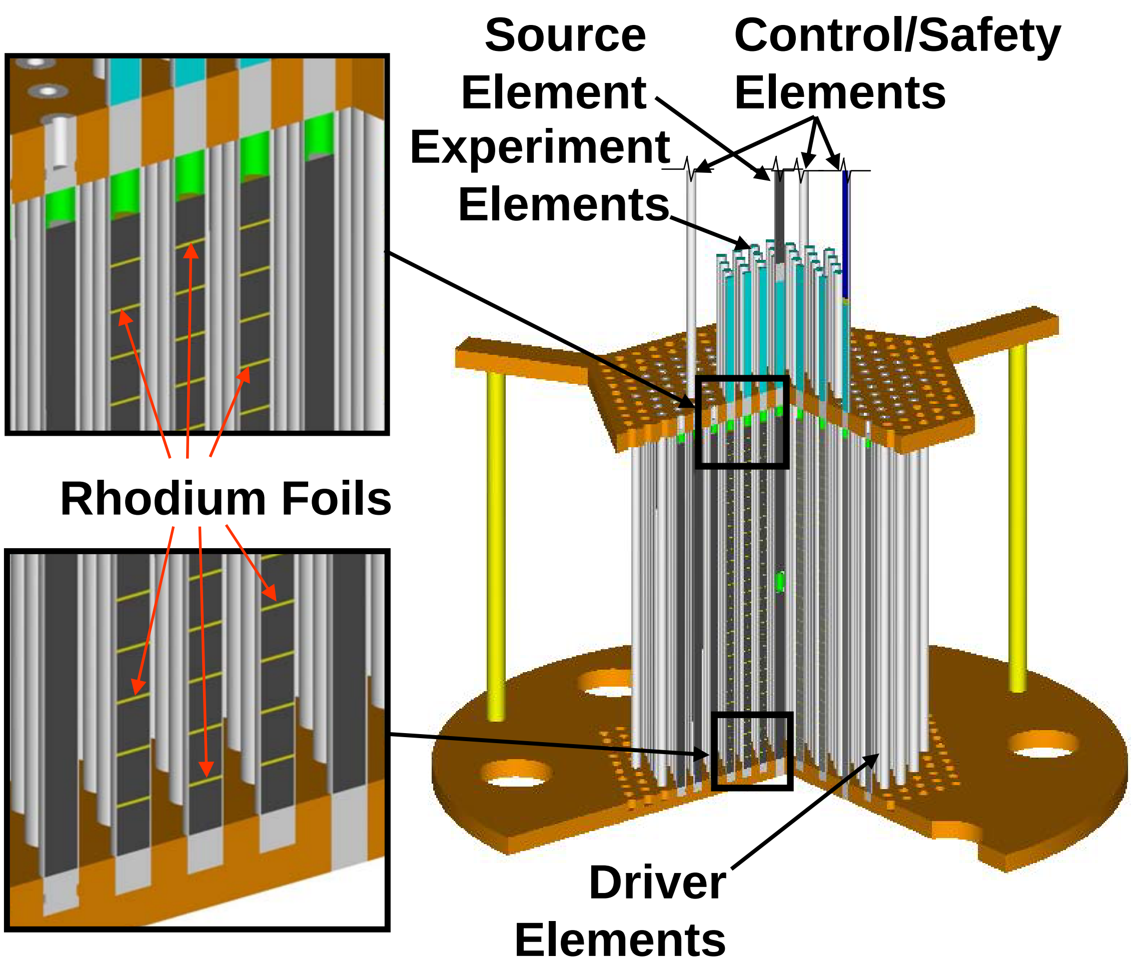
In 2002, we performed some critical experiments with rhodium





- 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

The BUCCX core was designed to be easy to model



- 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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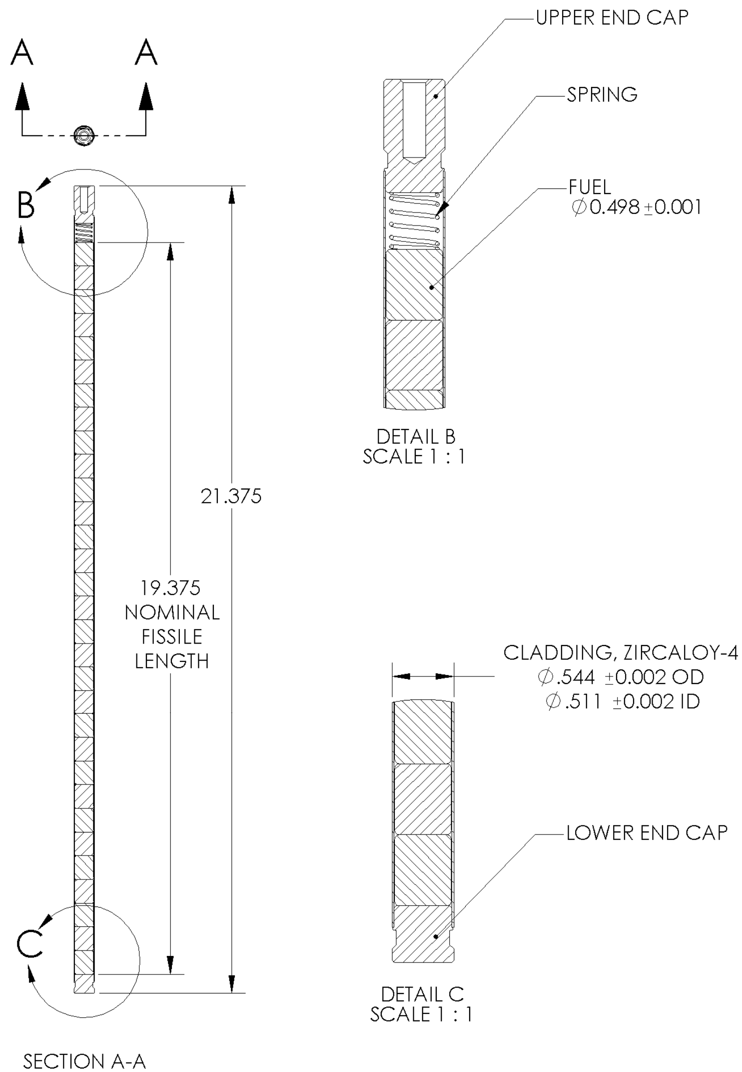
We used driver fuel rods that were fabricated for an earlier critical experiment



The fuel was built for an earlier critical experiment. The UO_2 pellets come from fuel that was used in experiments at the Critical Mass Laboratory at Pacific Northwest Laboratories (now PNNL) documented in the *<u>International Handbook of Evaluated Criticality Safety Benchmark Experiments</u>*, NEA/NSC/DOC/95 (experiment LEU-COMP-THERM-002 and others). The uranium is 4.31% enriched and was well characterized at PNNL. Originally in aluminum tubes, the pellets were rebuilt into Zircaloy-4 tubes.

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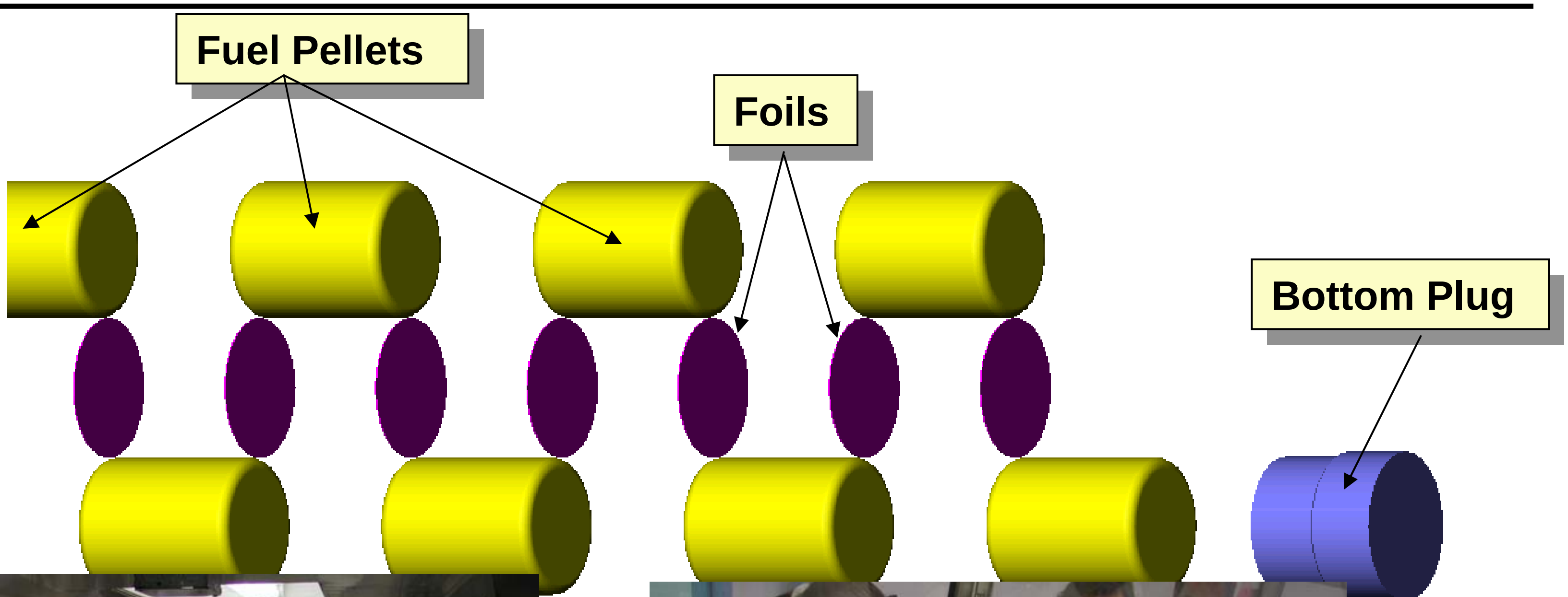
We built special experiment fuel rods that give us access to the fuel pellets



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The BUCCX core shown at the end of an approach-to-critical experiment

We completed ten critical experiments

- We used two grid plate sets
  - 2.0 cm pitch – gives fuel-to-water ratio about the same as a PWR fuel element
  - 2.8 cm pitch – gives a softer spectrum (nearly optimum moderation)
- We did five experiments at each pitch
  - Driver fuel only
  - 36 experiment elements with no foils
  - 36 experiment elements each with 31 Rh foils (25 micron) between the 32 fuel pellets (1116 foils total)
  - 36 experiment elements each with 31 Rh foils (50 micron)
  - 36 experiment elements each with 31 Rh foils (100 micron)
- The critical fuel array size was determined at the highest reactivity state of the assembly (fully reflected)

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The experimental uncertainties are relatively small

Uncertainty	2.0 cm Pitch (under-moderated)	2.8 cm Pitch (~optimum moderation)
Assembly Dimensions	0.00147 ←	0.00029
Fuel Effects	0.00054	0.00064 ←
Composition Effects	0.00034	0.00028
Assembly Temperature	0.00008	0.00002
Sum in Quadrature	**0.0016**	**0.0008**

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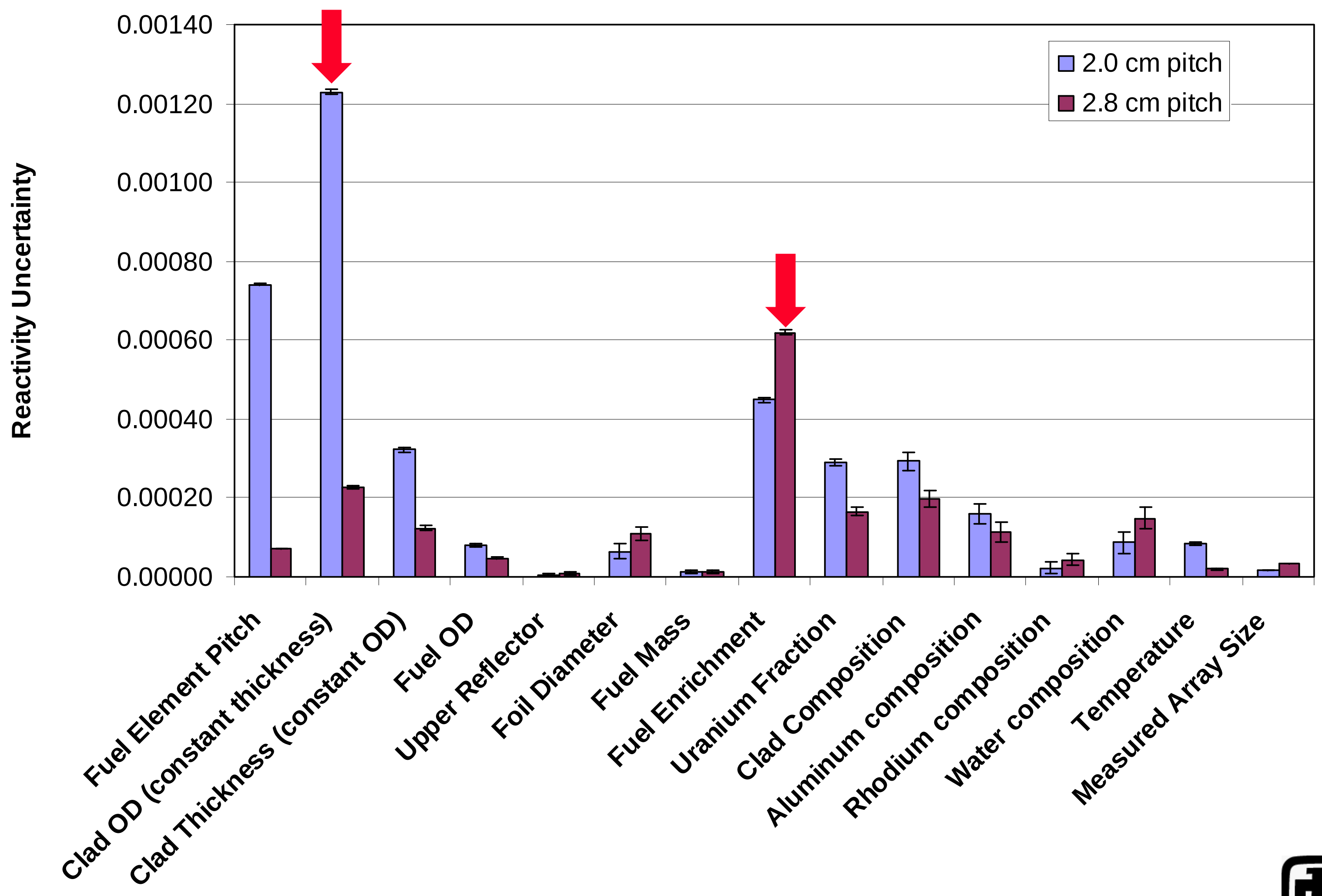
The experimental uncertainties are relatively small



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The details of the experiment are given in the “benchmark book”

International Handbook of Evaluated Criticality Safety Benchmark Experiments

NEA/NSC/DOC/(95)03 – updated annually in September

LEU-COMP-THERM-079

These experiments first appeared in September, 2005

Our plans for the critical experiments

We are now funded by the DOE Nuclear Criticality Safety Program

- Restarted the critical experiment capability in May, 09
- Maintain the capability in FY10 and beyond
  - Perform at least four approach-to-critical experiments per year
  - We have considerable excess capability for other experiments
- Develop a hands-on nuclear criticality safety engineer training course using our CX capability in FY10
- Begin offering the hands-on class in later years
  - DOE security clearance NOT required
  - Available to both DOE- and NRC-regulated entities

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Status of the Sandia critical experiments capability

- First approach-to-critical experiment started May 11
- First supercritical core measured on May 15
- We will perform one critical experiment per quarter to maintain the capability of the facility and the proficiency of the staff

Critical Experiments at Sandia