



# **NCSP IE and T&E Activities at Sandia**

## **Nuclear Criticality Safety Program Technical Program Review**

**Los Alamos, NM**

**March 27, 2014**

**Presented by  
Gary A. Harms  
Sandia National Laboratories**

**SAND2014-2264P**



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## Summary of the paper

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- **The paper outlines our IE activities**
  - IER-208/209 – Measure the critical water depth in the 7uPCX as a function of fuel loading
  - IER-206 – Restart the BUCCX
  - IER-230 – Measure the critical core size of the 7uPCX as a function of rod pitch
  - IER-227 – Build a general-purpose vertical-lift critical assembly for low-enriched experiments
  - IER-226 – Build a general-purpose horizontal split-table critical assembly for low-enriched experiments
- **And describes our T&E activities**
  - NCSE hands-on training class
  - Hands-on training class for nuclear material managers

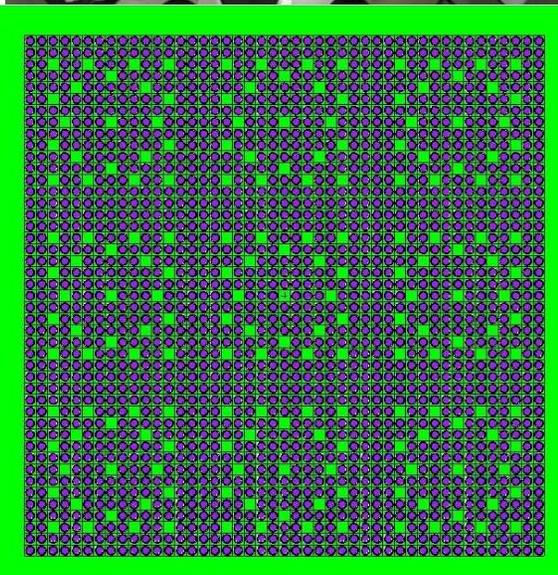
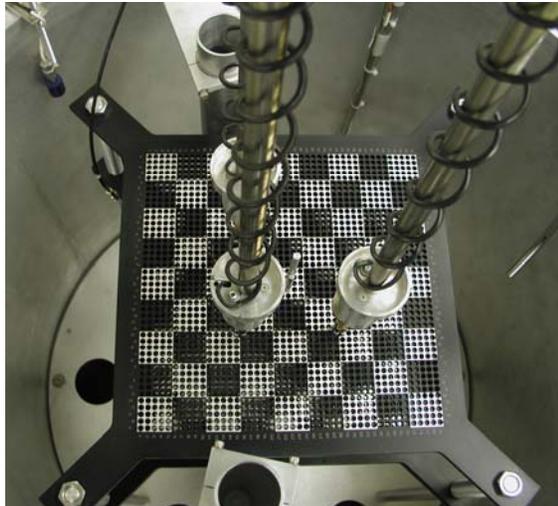


# Critical Experiments at Sandia

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- **The primary purpose of the reactor facilities at Sandia is to support our nuclear weapons mission**
- **The facilities and staff necessary to enable that work are exactly what are needed to support critical experiments.**

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

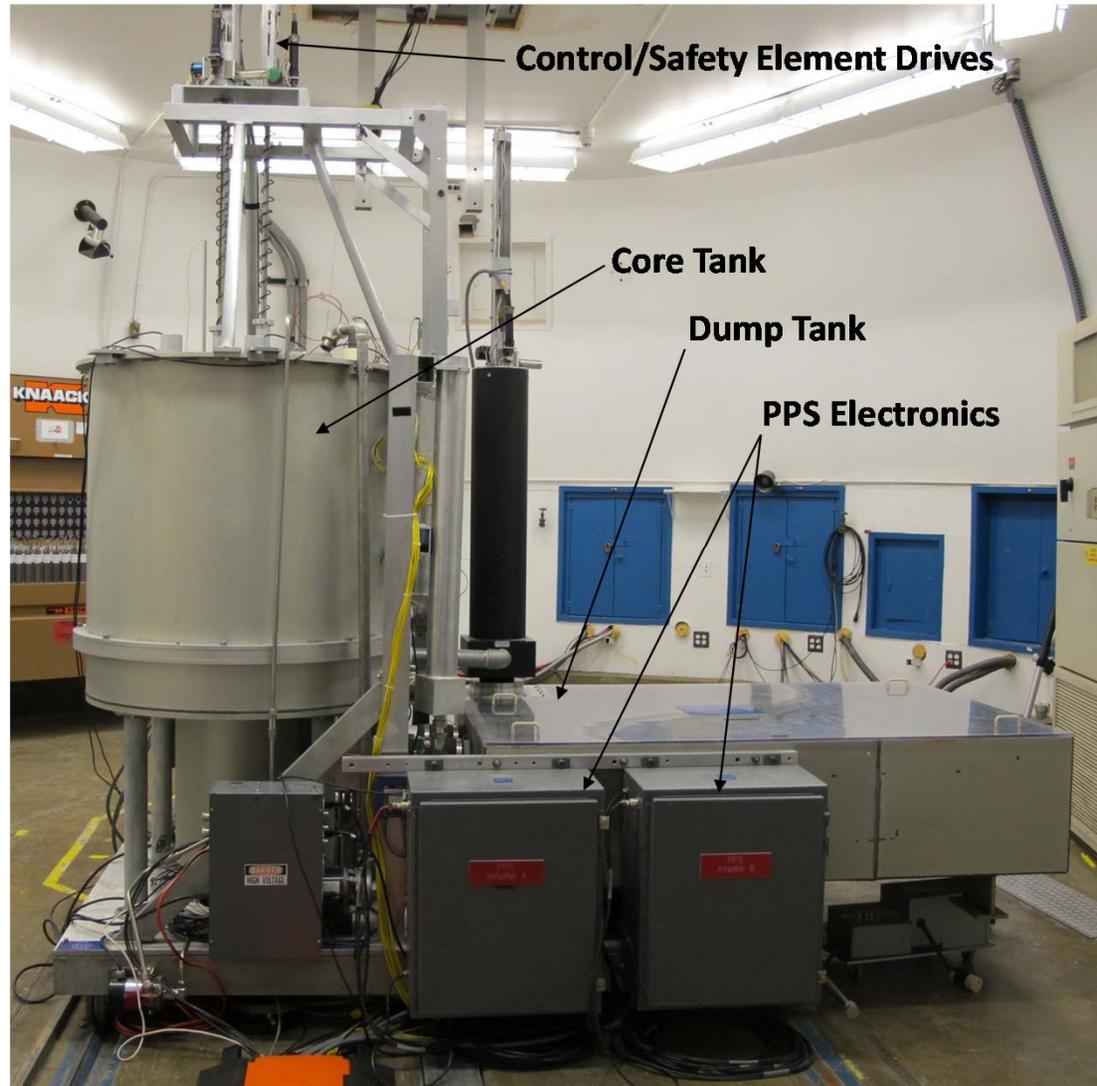


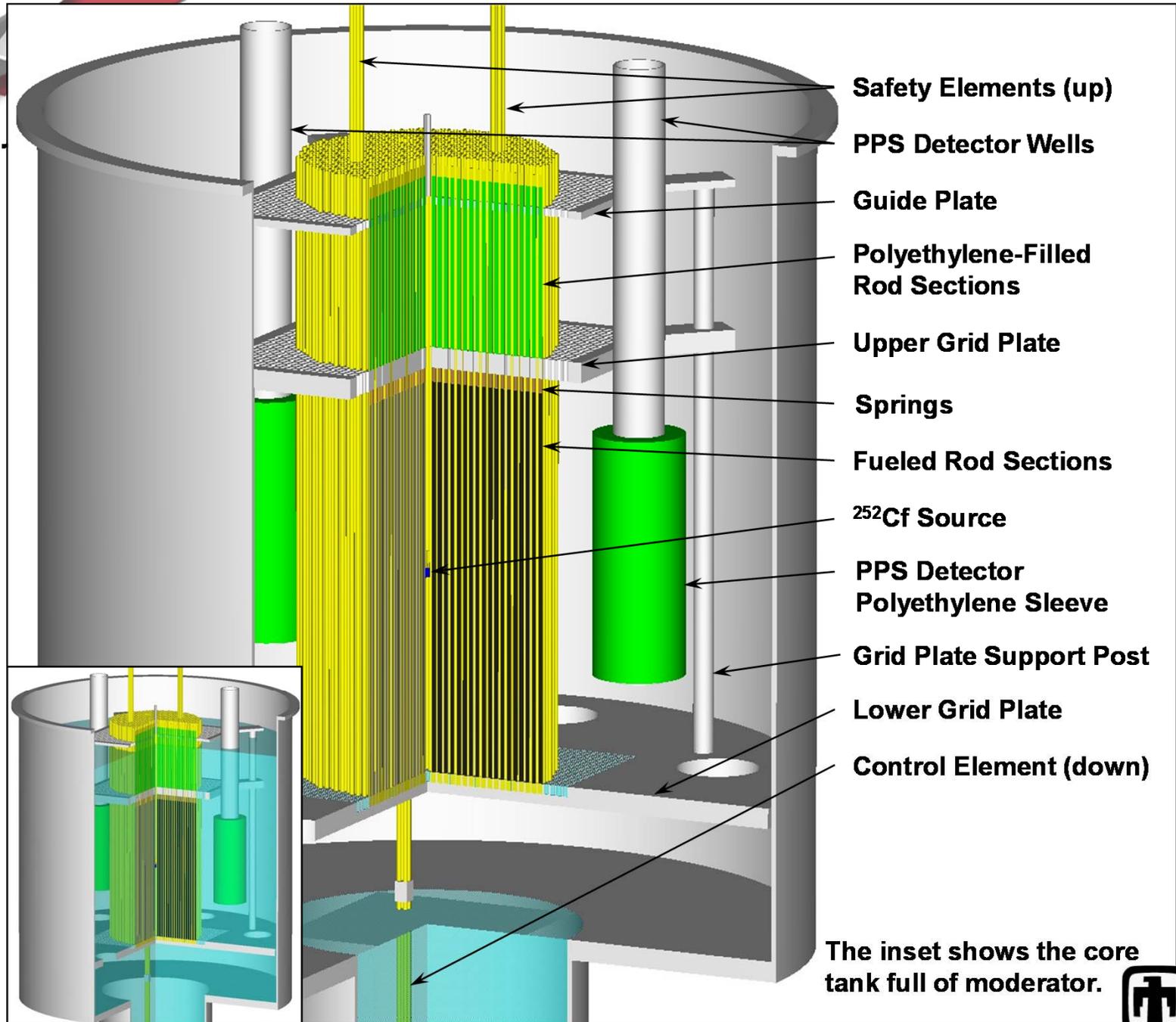
**Project Objective:** *Design, perform, and analyze critical benchmark experiments for validating reactor physics methods and models for fuel enrichments greater than 5-wt%  $^{235}\text{U}$*

- 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 can be made
  - Fission density profiles
  - Poison worth
  - Effect of water holes



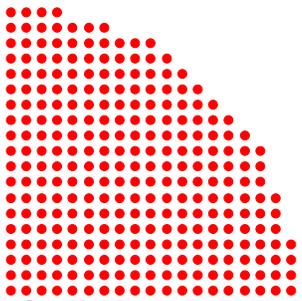
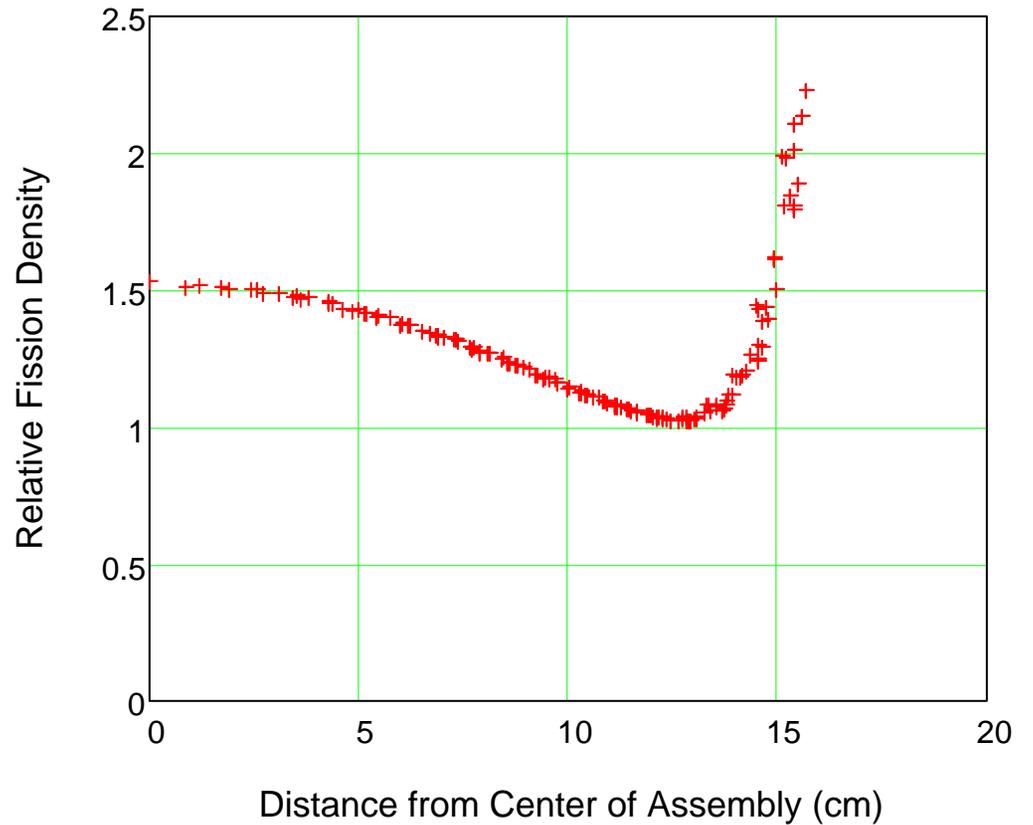
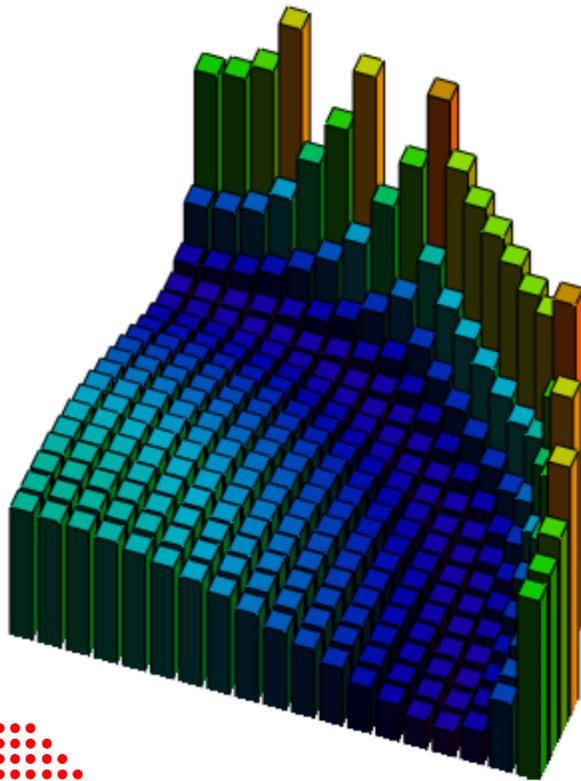
# The critical assembly in person







# Calculated Fission Densities in the Core – LCT078 Case 1



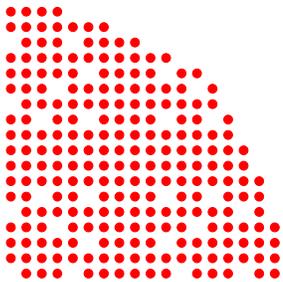
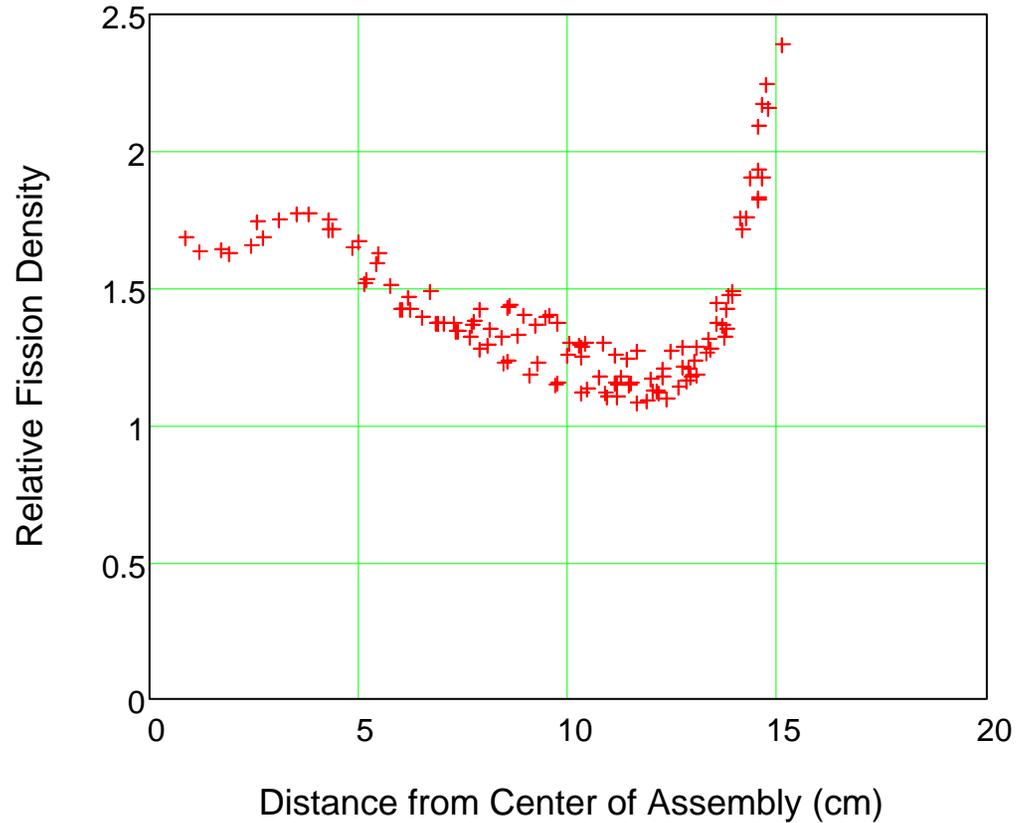
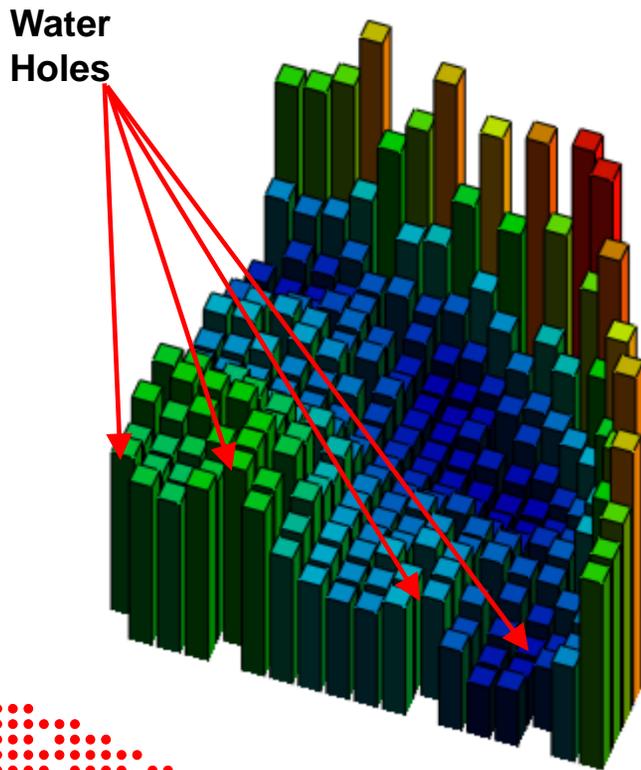
Zero Suppressed

MCNP5.1.60 – ENDF/B-VII.0



# Calculated Fission Densities in the Core – LCT078 Case 15

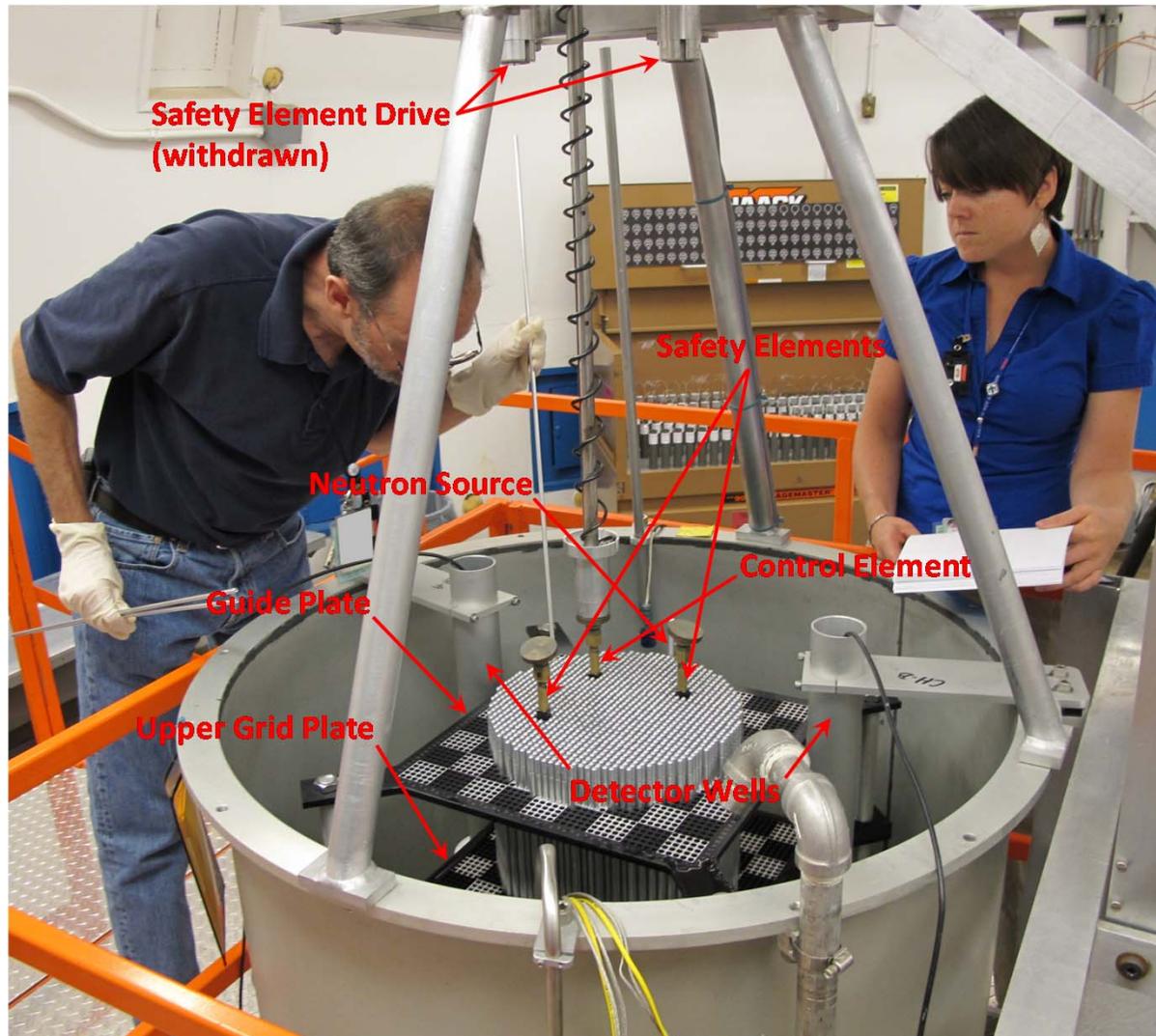
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Zero Suppressed

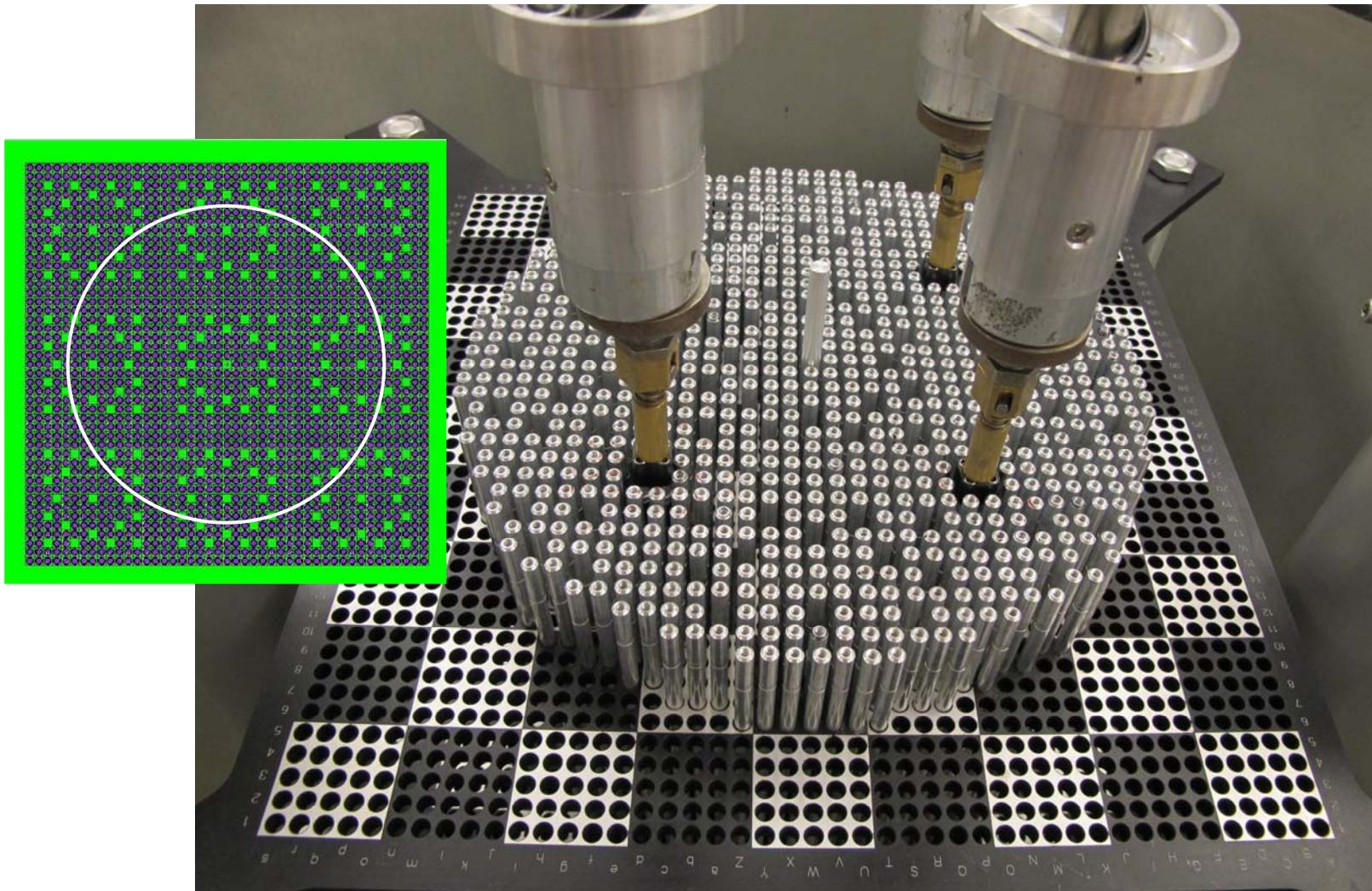
MCNP5.1.60 – ENDF/B-VII.0

# Loading the core





# The 7uPCX core at the end of an approach – LCT078 Case 15





# LEU-COMP-THERM-078 and LEU-COMP-THERM-080 are in the book

NEA/NSC/DOC/(95)03/IV  
Volume IV

LEU-COMP-THERM-078

**WATER-MODERATED SQUARE-PITCHED U(6.90)O<sub>2</sub> FUEL ROD  
LATTICES WITH 0.52 FUEL-TO-WATER VOLUME RATIO**

**Evaluator**

Gary A. Harms  
Sandia National Laboratories

**Internal Reviewer**

Allison D. Miller

**Independent Reviewers**

Nicolas Leclaire  
François-Xavier Le Dauphin  
Institut de Radioprotection et de Sûreté Nucléaire, IRSN

David P. Heinrichs  
Allan W. Krass  
Lawrence Livermore National Laboratory

NEA/NSC/DOC/(95)03/IV  
Volume IV

LEU-COMP-THERM-080

**WATER-MODERATED SQUARE-PITCHED U(6.90)O<sub>2</sub> FUEL ROD  
LATTICES WITH 0.67 FUEL TO WATER VOLUME RATIO**

**Evaluator**

Gary A. Harms  
Sandia National Laboratories

**Internal Reviewer**  
Allison D. Miller

**Independent Reviewer**

Nicolas Leclaire  
Institut de Radioprotection et de Sûreté Nucléaire, IRSN





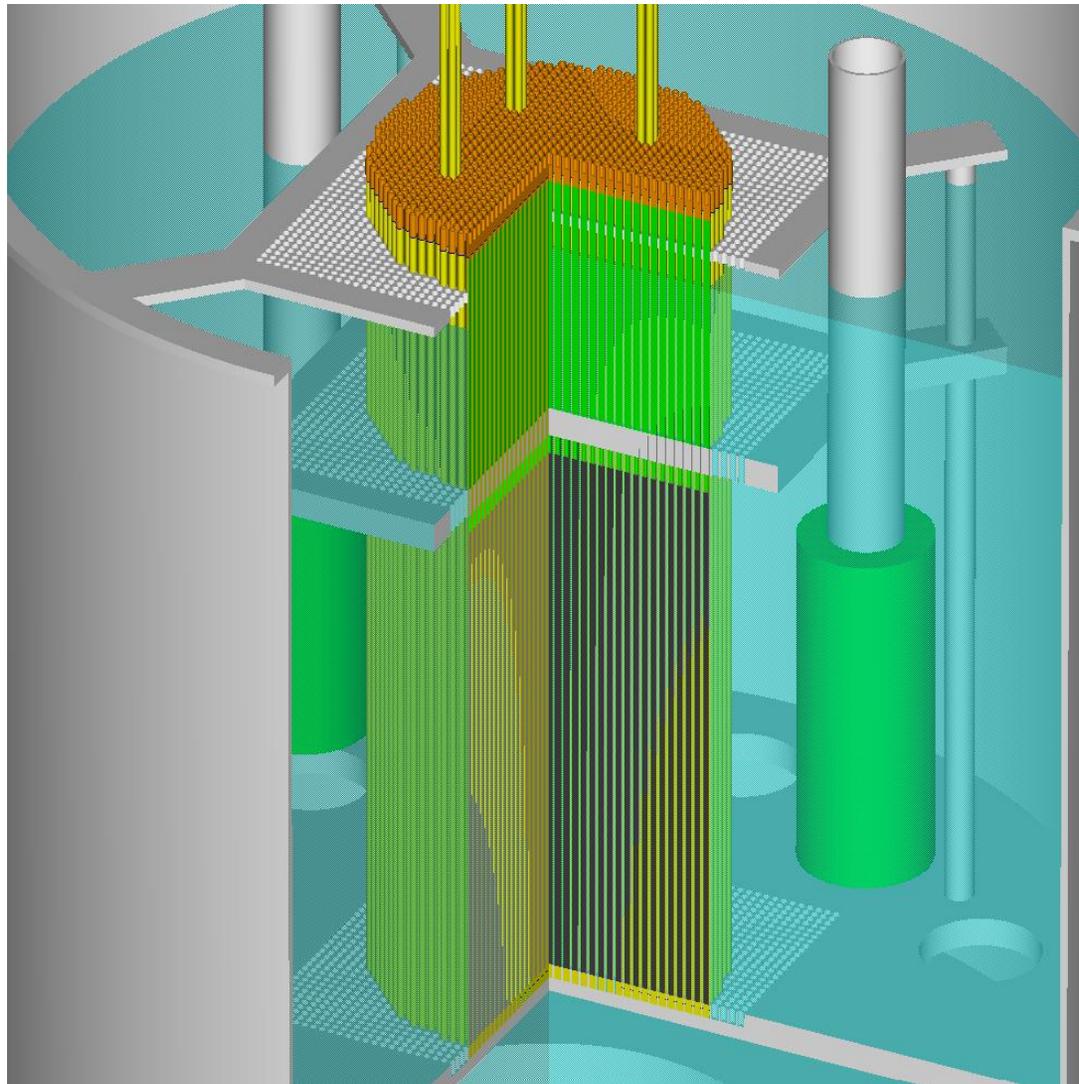
# Measure Critical Water Depth as a Function of Fuel Loading – IER-208, -209

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- $C_{EdT}$ :
  - Allison Miller (SNL)
  - Mike Dunn (ORNL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)
- IER-208 (0.800 cm pitch)
  - CED-1 Conceptual Design complete
  - CED-2 Final Design complete
  - CED-3a Experiment Planning/Cost Estimation complete
  - CED-3b Experiment Execution is next
- IER-209 (0.855 cm pitch)
  - CED-1 Conceptual Design is complete
  - CED-2 Final Design is next



# Measure Critical Water Depth as a Function of Fuel Loading – IER-208, -209



0.855 cm Pitch

1057 Rods

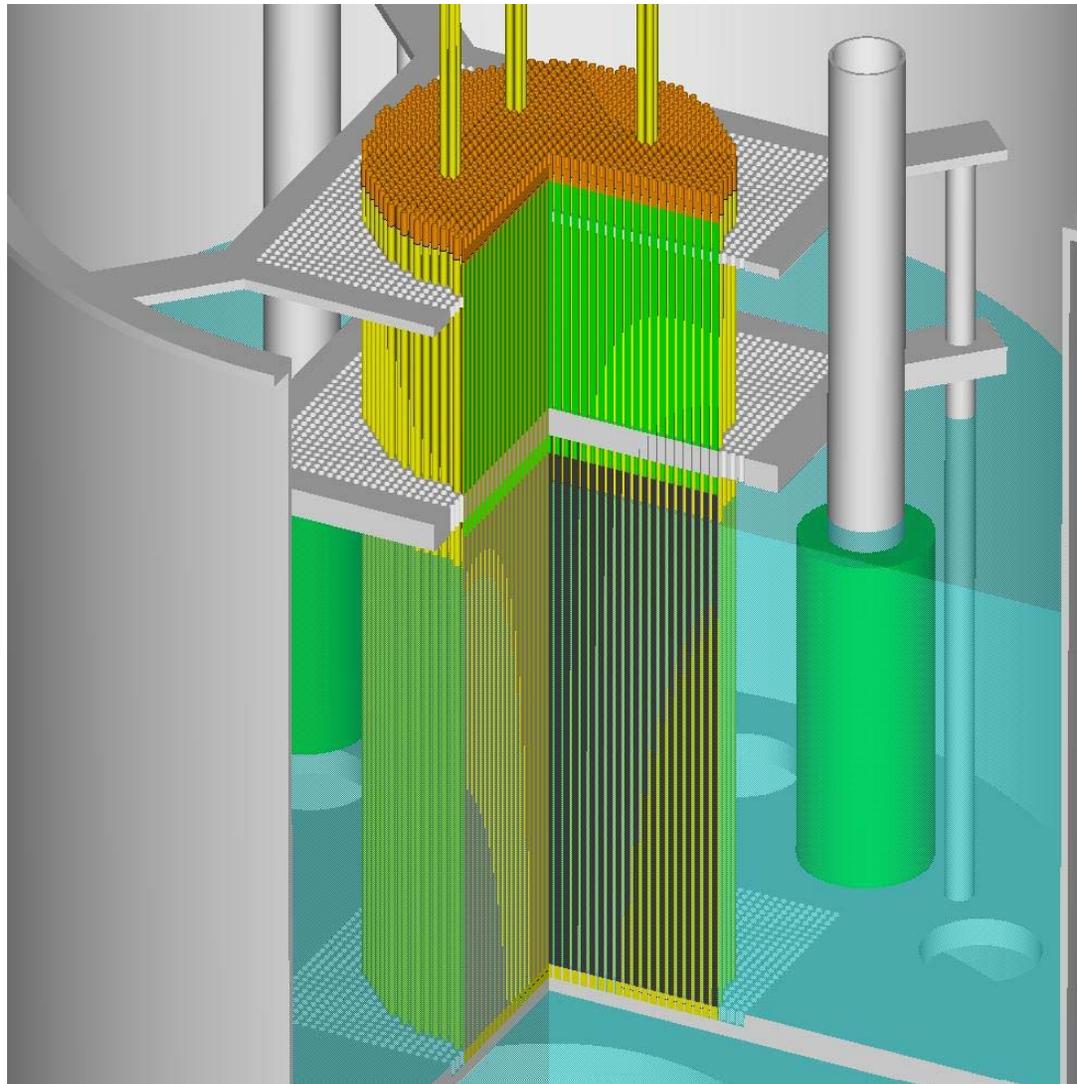
Full Reflection

# Measure Critical Water Depth as a Function of Fuel Loading – IER-208, -209

0.855 cm Pitch

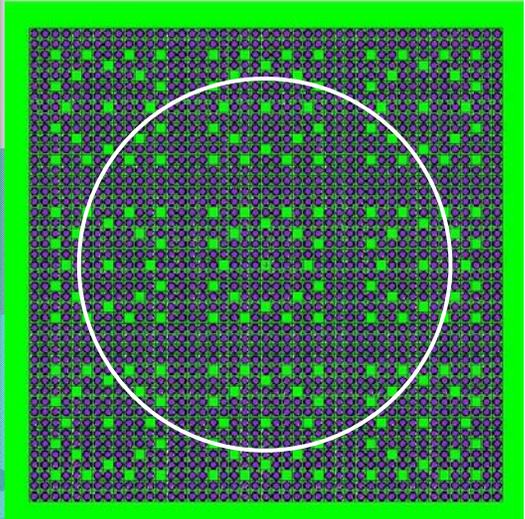
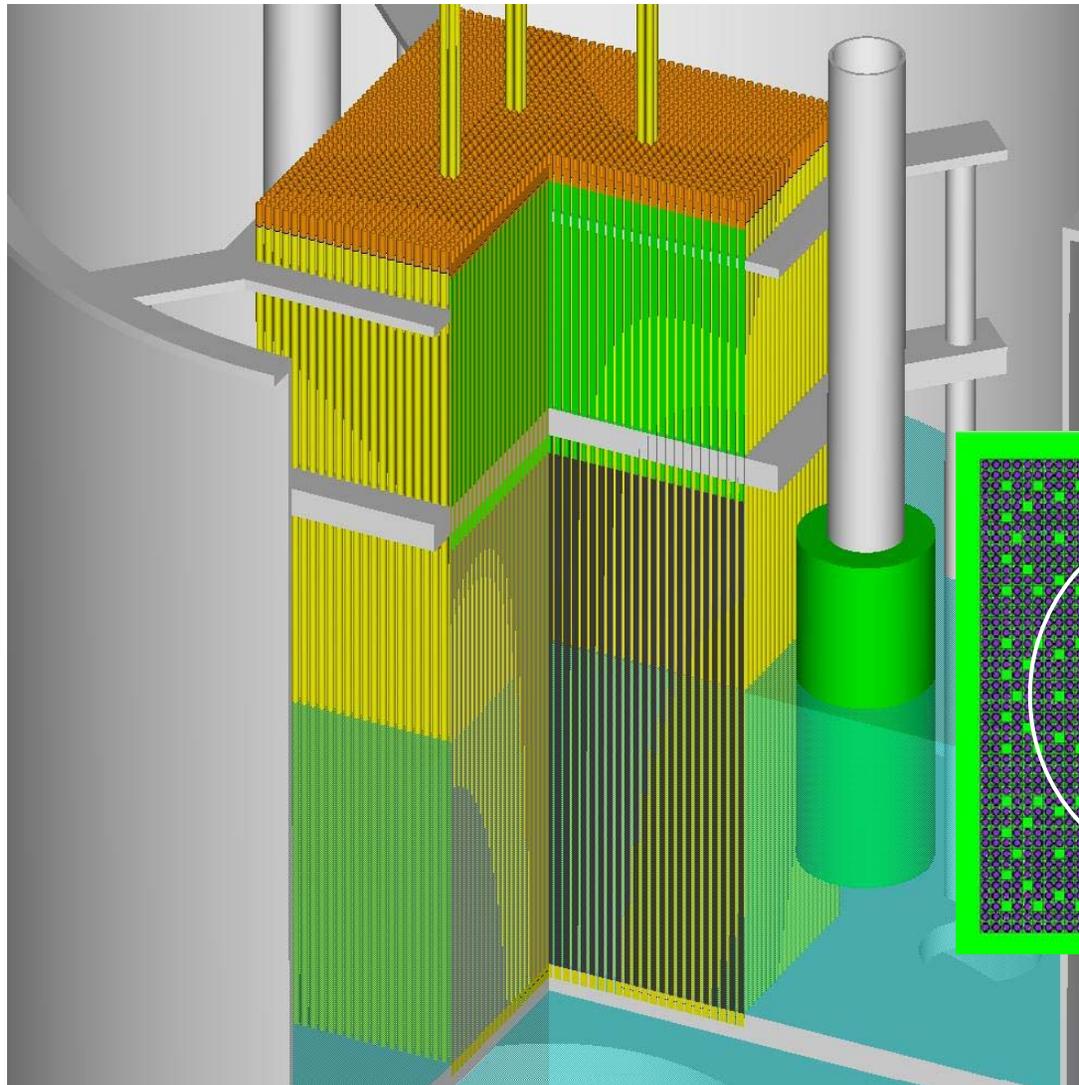
1137 Rods

Water 95% Up the Fuel





# Measure Critical Water Depth as a Function of Fuel Loading – IER-208, -209

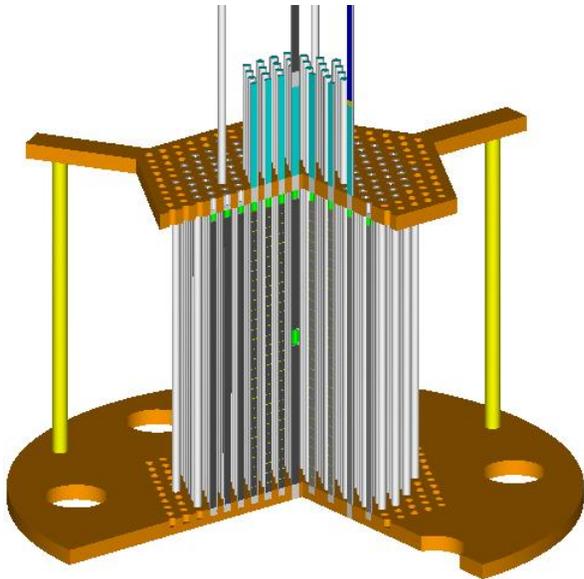


0.855 cm Pitch

2025 Rods

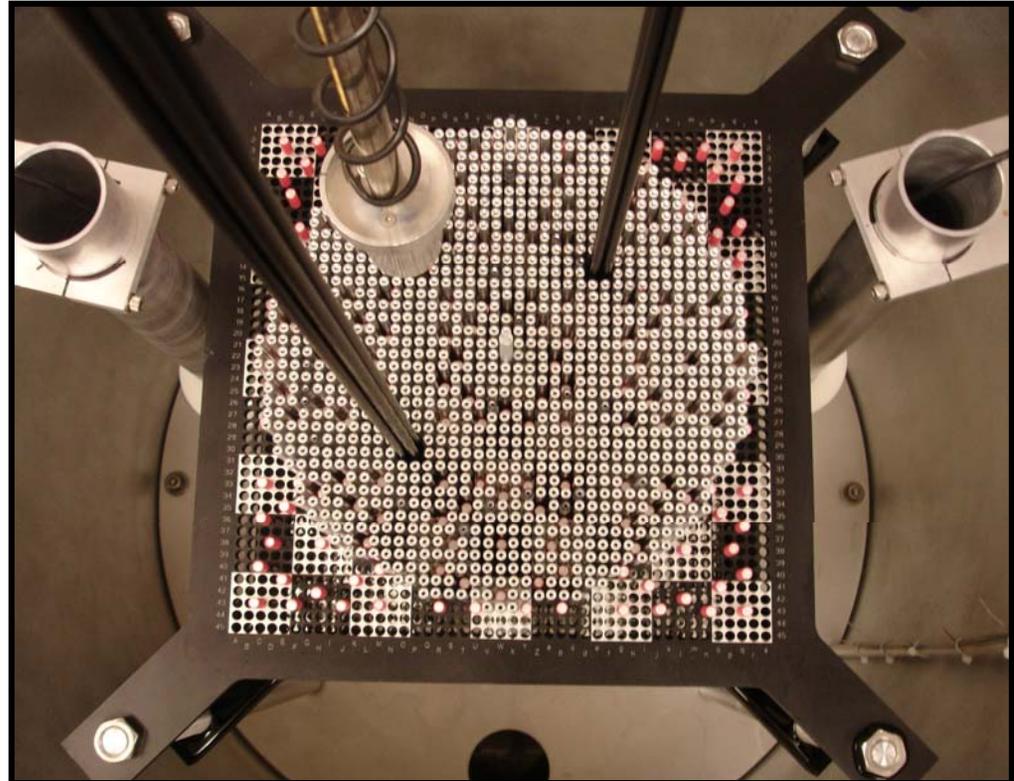
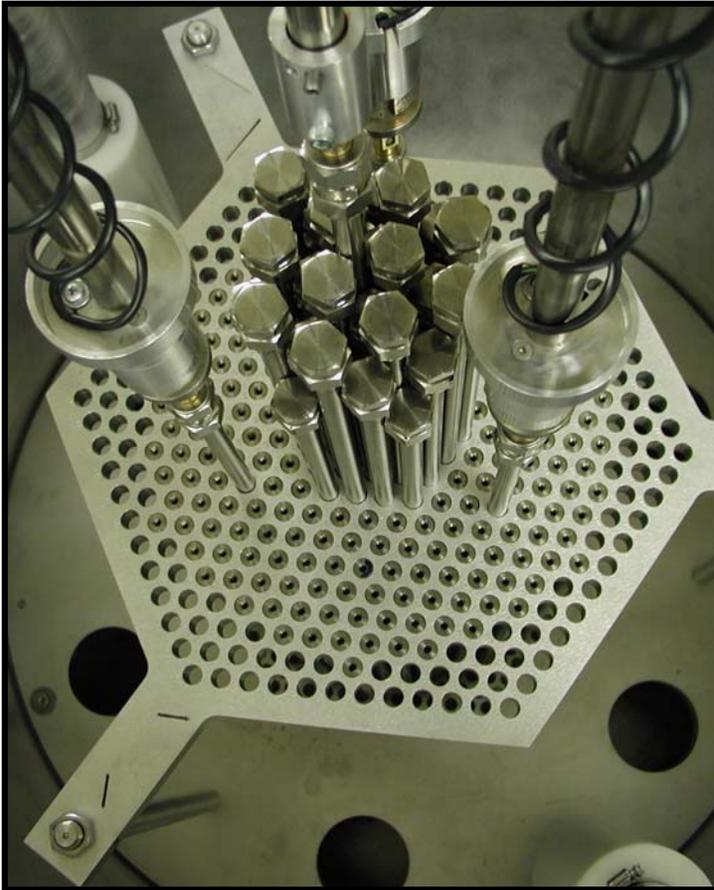
Water Slightly  
above the Fuel  
Midplane

# Restart the 4.3% Enriched Burnup Credit Critical Assembly – IER-206



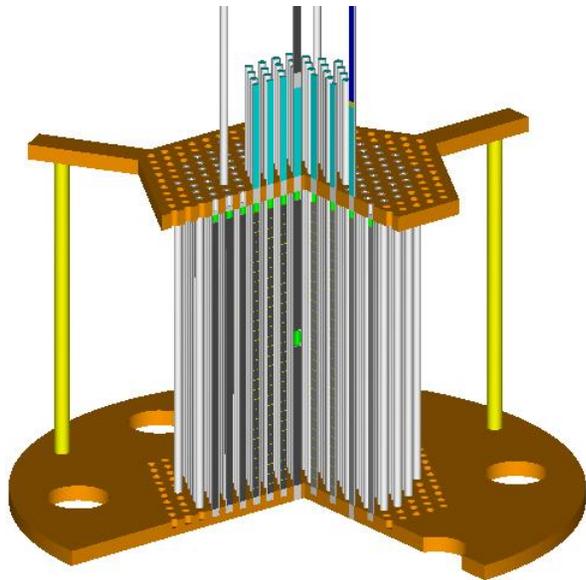
- $C_{EdT}$ :
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  - Mike Dunn (ORNL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)
- CED-1 Conceptual Design is complete
- CED-2 Final Design is complete
- CED-3a Experiment Planning/Cost Estimation is next

# Restart the 4.3% Enriched Burnup Credit Critical Assembly – IER-206

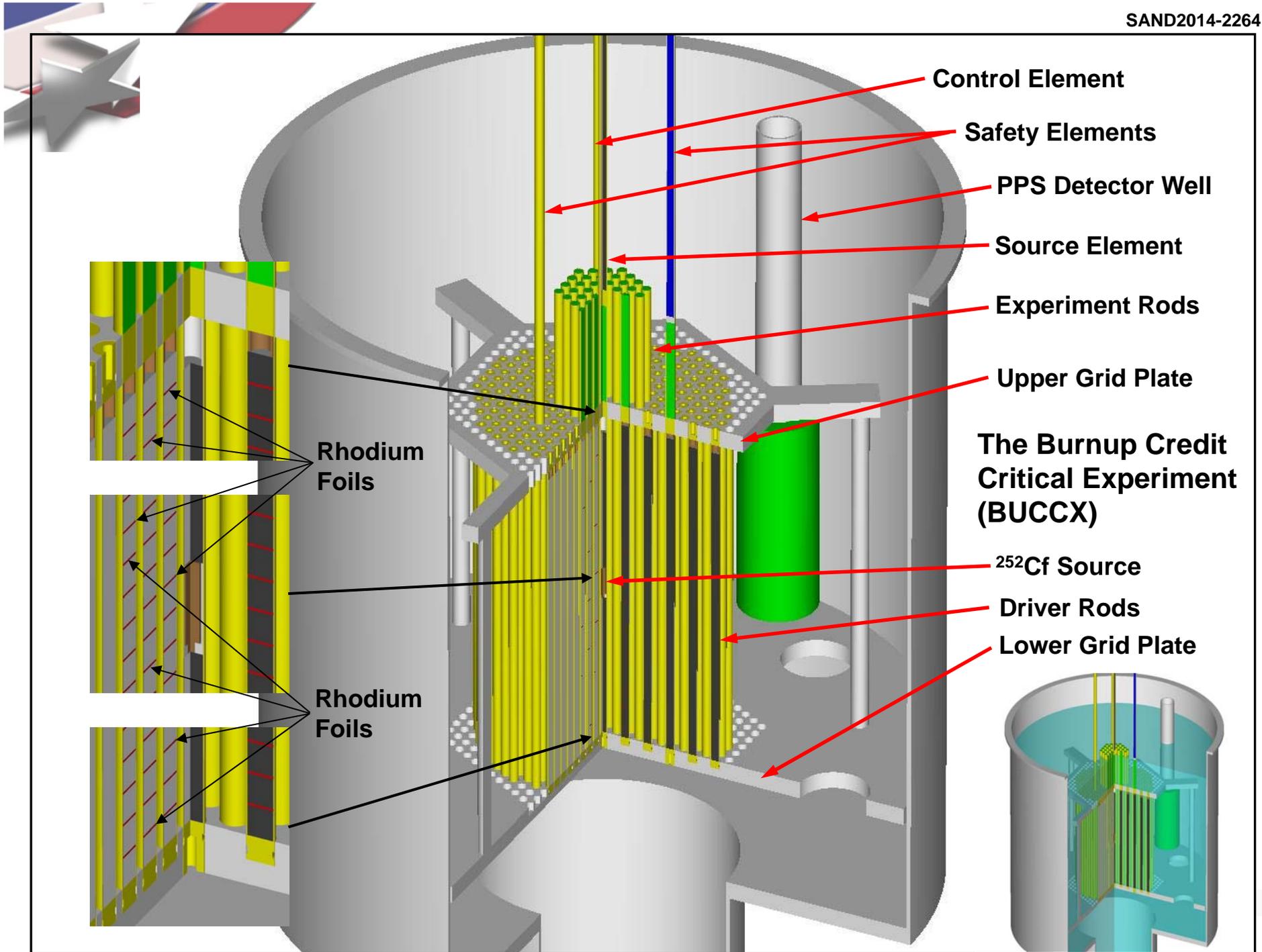


The cores (fuel, grid plates, etc.) are different. The balance of the assembly hardware is the same.

# Restart the 4.3% Enriched Burnup Credit Critical Assembly – IER-206

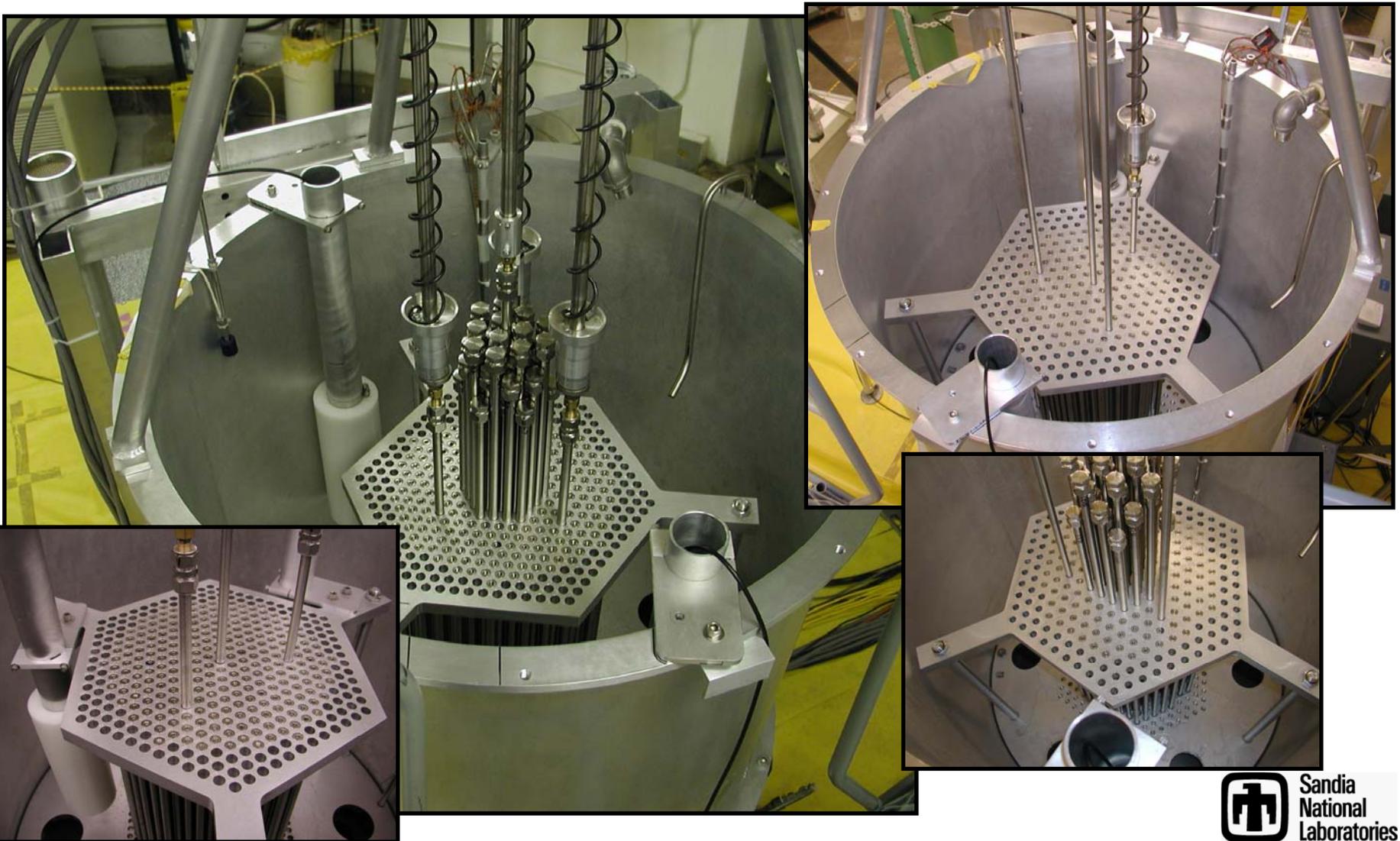


- In 2002, we built a critical assembly in which we could insert fission product materials to measure reactivity effects
- The assembly was a triangular-pitched array of Zircaloy-4 clad U(4.31%)O<sub>2</sub> fuel (driver) elements
- Test materials were placed between the fuel pellets in “experiment elements”
- We completed a set of experiments with rhodium as the test material
- The experiment is documented as LEU-COMP-THERM-079 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments





# The BUCCX core shown at the end of approach-to-critical experiments





# Measure Critical 7uPCX Fuel Loading as a Function of Pitch (Fully Reflected) – IER-230

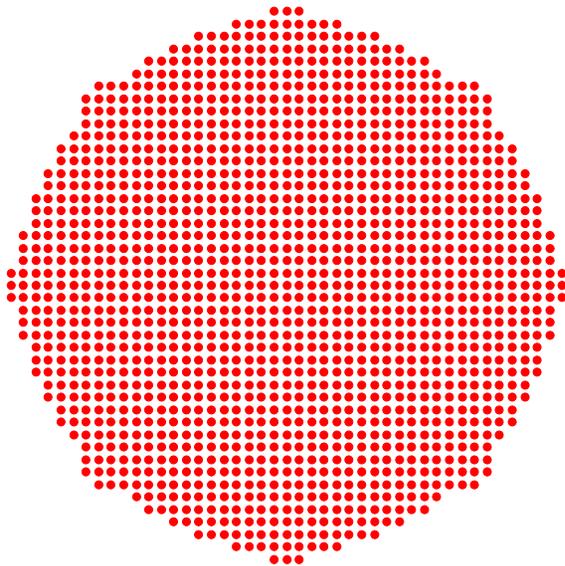
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- $C_{EdT}$ :
  - Allison Miller (SNL)
  - Mike Dunn (ORNL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)
- Initiated in October, 2013
- CED-1 Conceptual Design is in progress

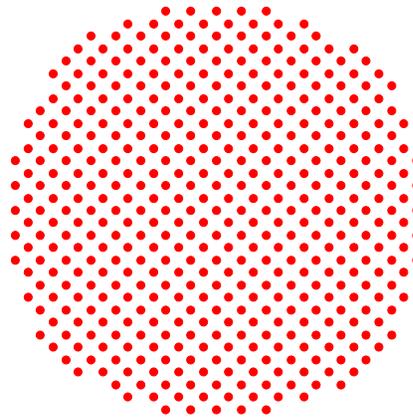


# Characterize the Capabilities of the 7uPCX – IER-230

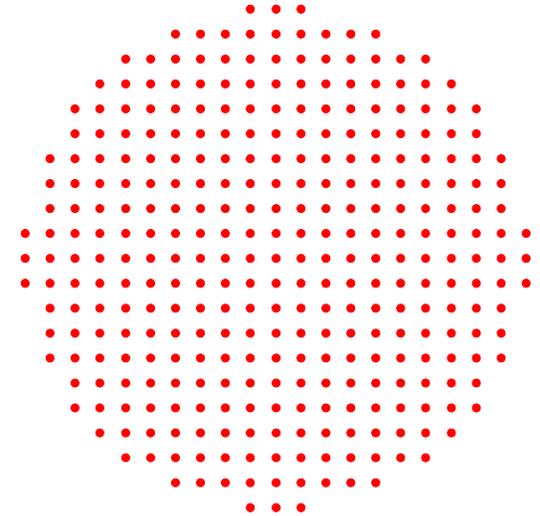
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**0.800 cm Pitch**  
**1461 Rods at DC**

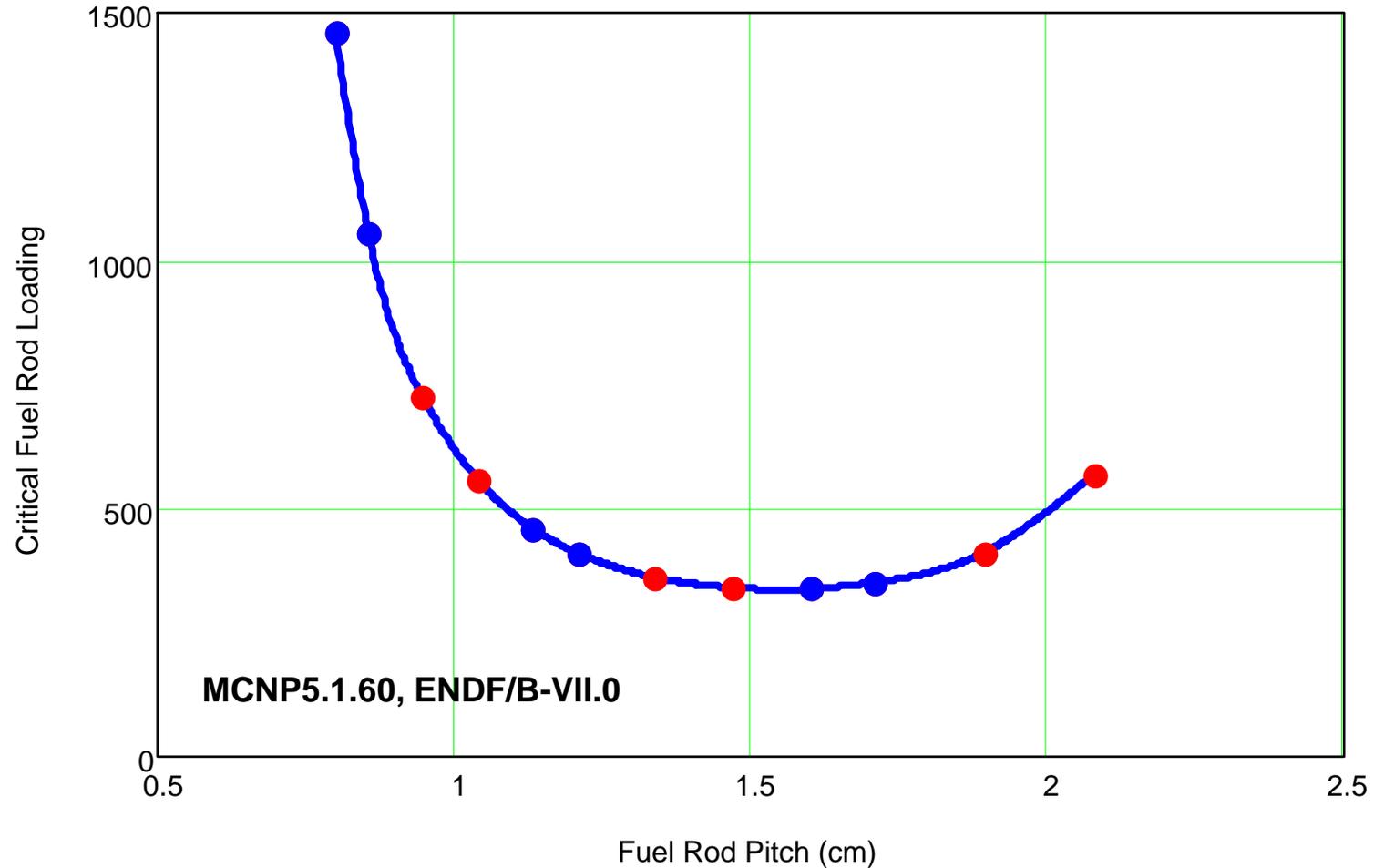


**1.132 cm Pitch**  
**454 Rods at DC**



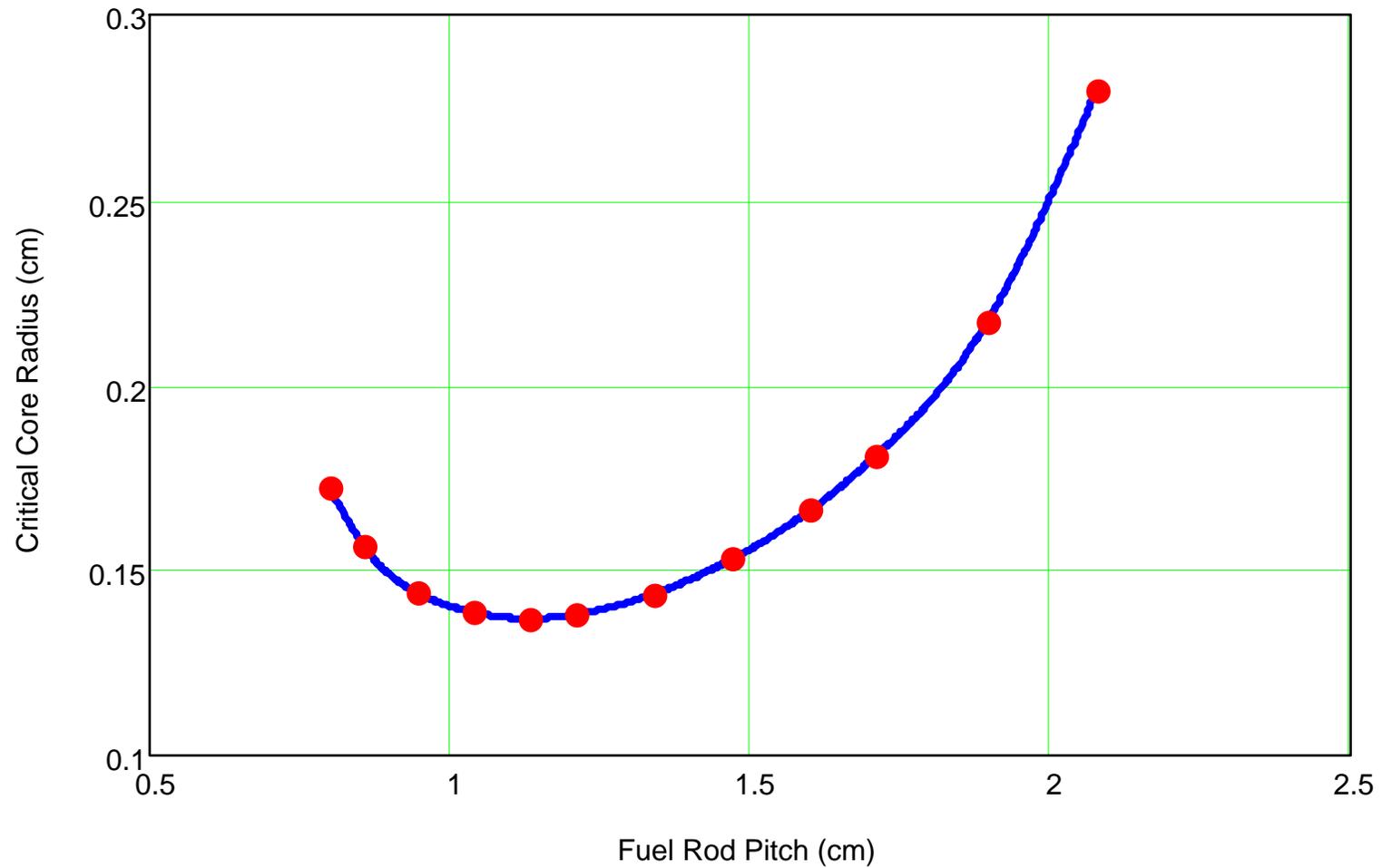
**1.600 cm Pitch**  
**328 Rods at DC**

# Number of Fuel Rods at DC vs Pitch



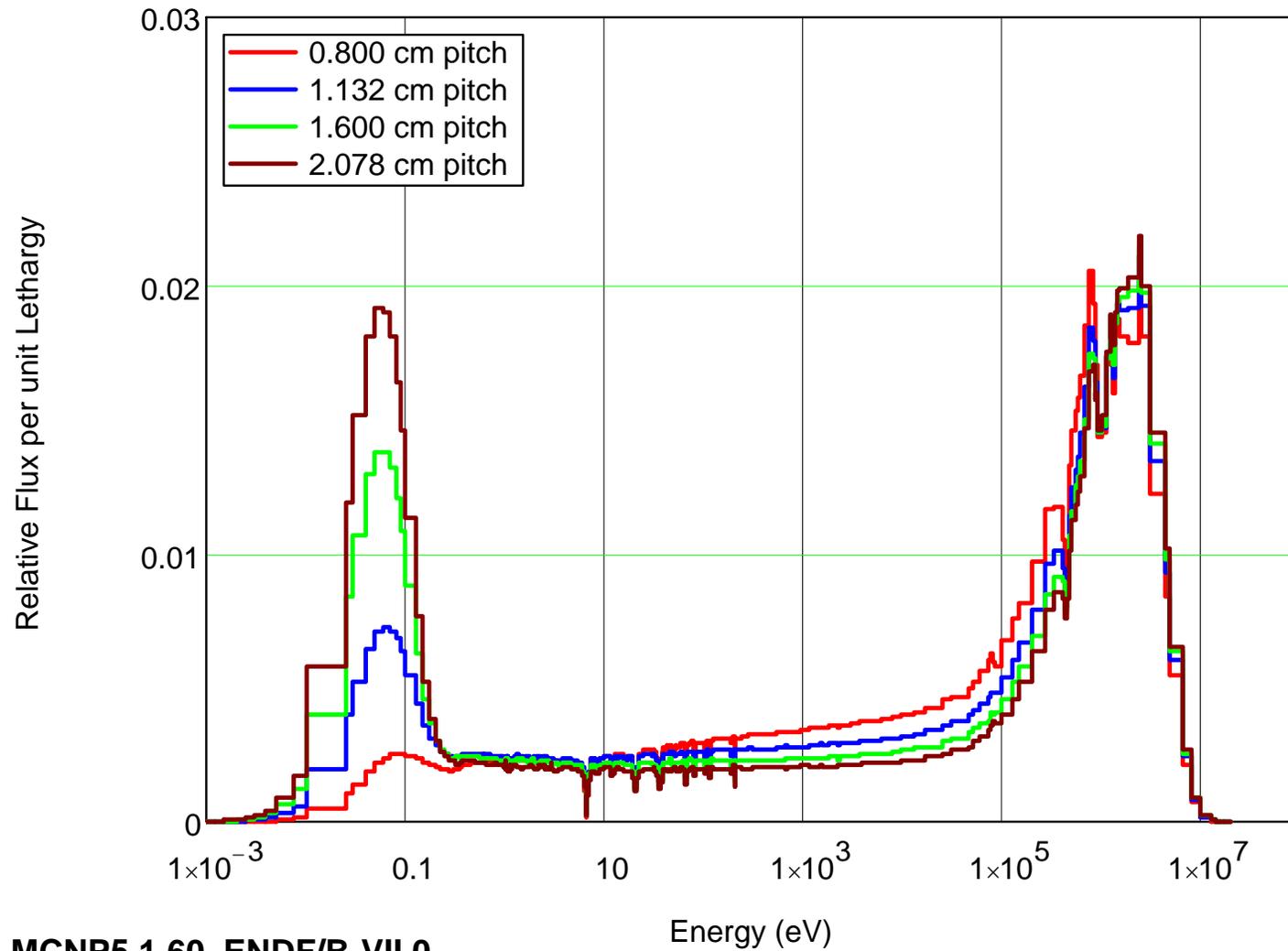
The blue points are for existing grid plates (0.800 and 0.855 cm pitch).  
The red points are for new grid plates (0.947 and 1.039 cm pitch)

# Critical Core Radius vs Pitch



MCNP5.1.60, ENDF/B-VII.0

# The Neutron Spectrum vs Pitch



MCNP5.1.60, ENDF/B-VII.0



# Low-Enriched General-Purpose Vertical-Lift Critical Assembly – IER-227

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- $C_{EdT}$ :
  - Allison Miller (SNL)
  - Mike Dunn (ORNL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)
- Initiated in October, 2013
- CED-1 Conceptual Design is in progress

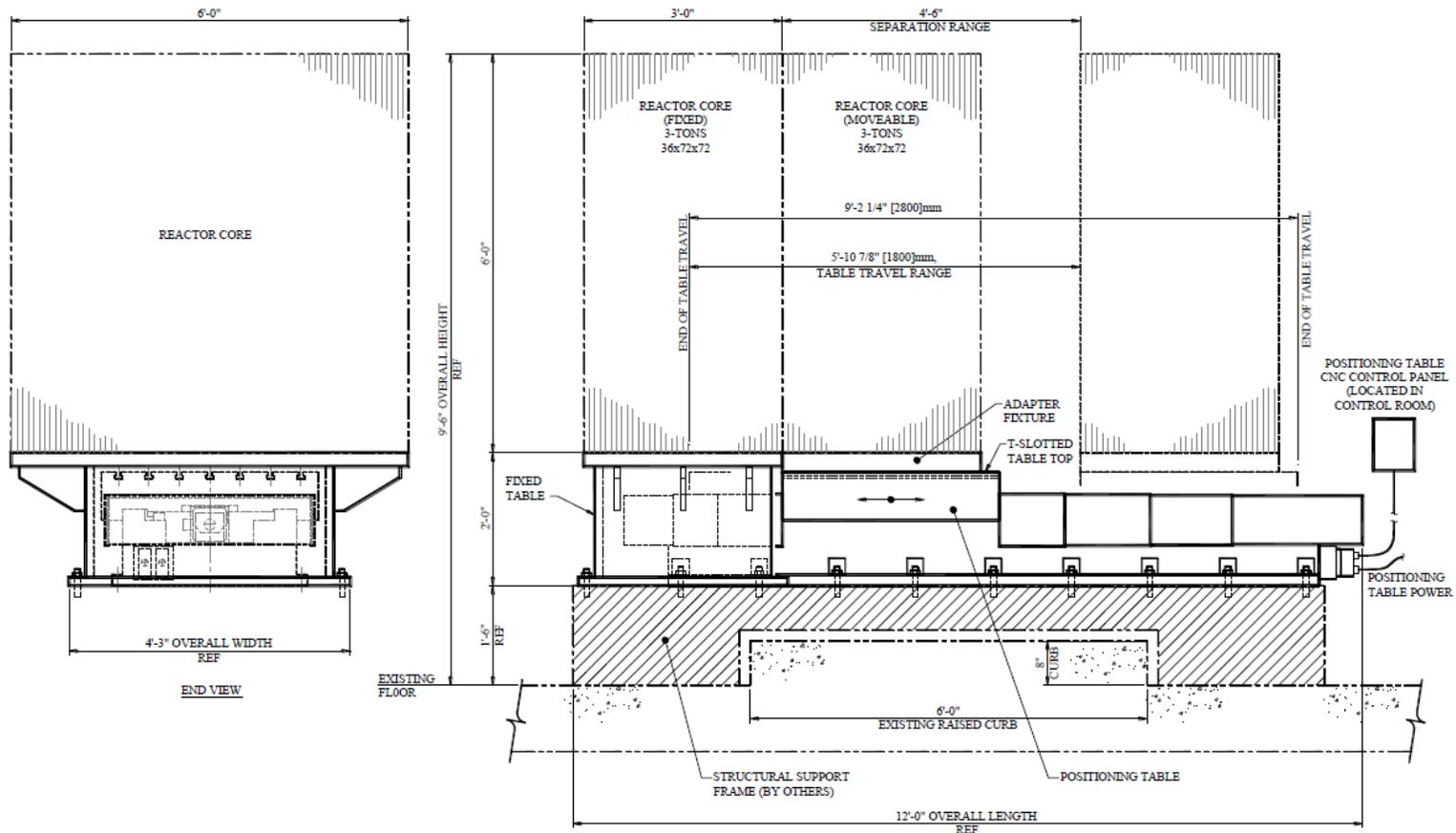


# Low-Enriched General-Purpose Split-Table Critical Assembly – IER-226

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- $C_{EdT}$ :
  - Allison Miller (SNL)
  - Mike Dunn (ORNL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)
- CED-1 Conceptual Design is complete
- CED-2 Final Design has been initiated

# Low-Enriched General-Purpose Split-Table Critical Assembly – IER-226



Allison Miller will present a paper on this IER next.



# Hands-On Criticality Safety Training at Sandia

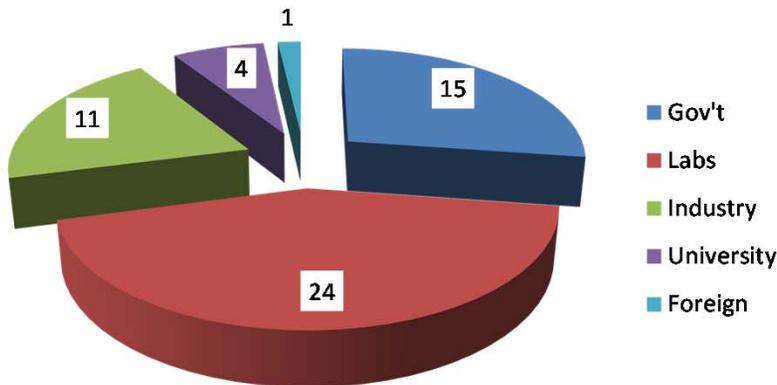
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- Two hands-on critical experiment classes are currently offered.
- The first is part of a two-week class for Nuclear Criticality Safety Professionals, 1 week at LANL and one week at Sandia or at NCERC.
- The other is a one-week class at Sandia for Nuclear Material Managers.
- Information about the classes and how to register is at <http://ncsp.llnl.gov/classMain.html>

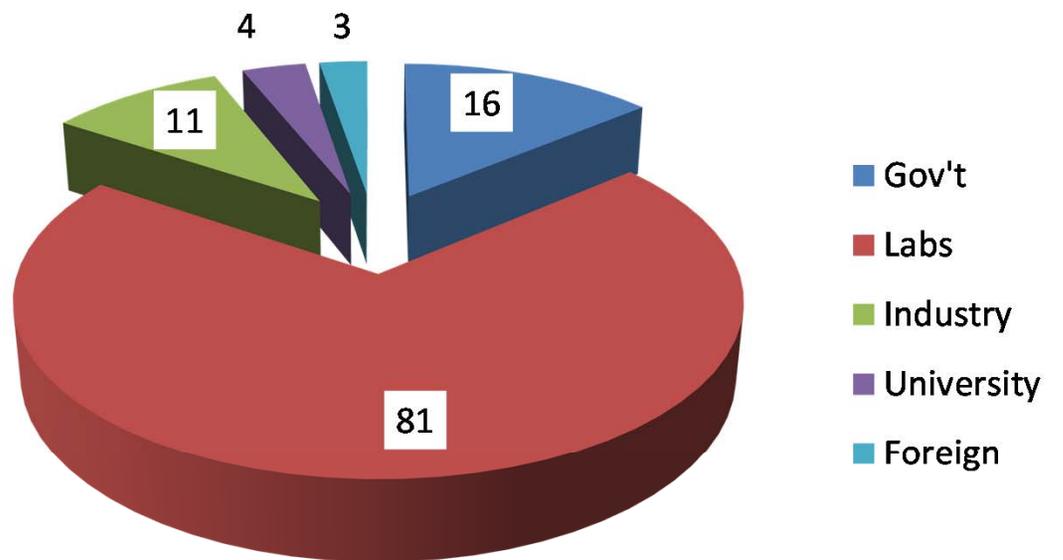


# The Class Serves a Diverse Audience

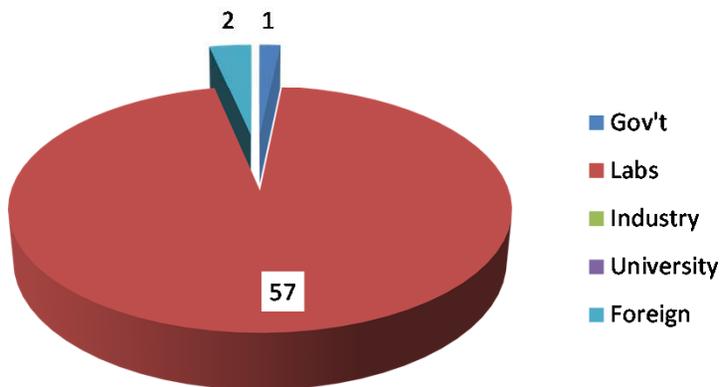
### NCSE (6 Sessions, 55 Students)



### Both (10 Sessions, 115 Students)



### Managers (4 Sessions, 60 Students)





# The Sandia Classes

- **The Sandia classes are a series of four experiments**
  - Approach on fuel
  - Approach on moderator height
  - “Split table” approach
  - Fuel removal approach
- **Lectures on various subjects are integrated with the experiments**



# Classroom discussions are interspersed through the experiments

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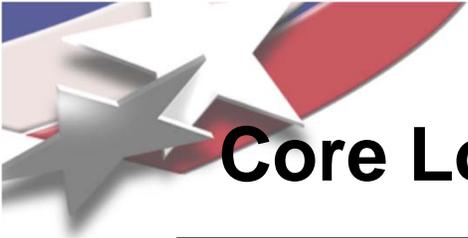
- The basics of criticality safety
- Criticality safety data and limits
- Historic critical experiments
- Subcritical multiplication
- Reactor theory and kinetics
- Identify lessons from historic critical-assembly accidents
- The design and operation of critical experiments at Sandia
- Radiation detection in the experiments
- Results of Sandia critical experiments
- The development and use of critical experiment benchmarks
- Light water reactor concepts as applied to the Sandia experiments



# Experiment 1 Overview

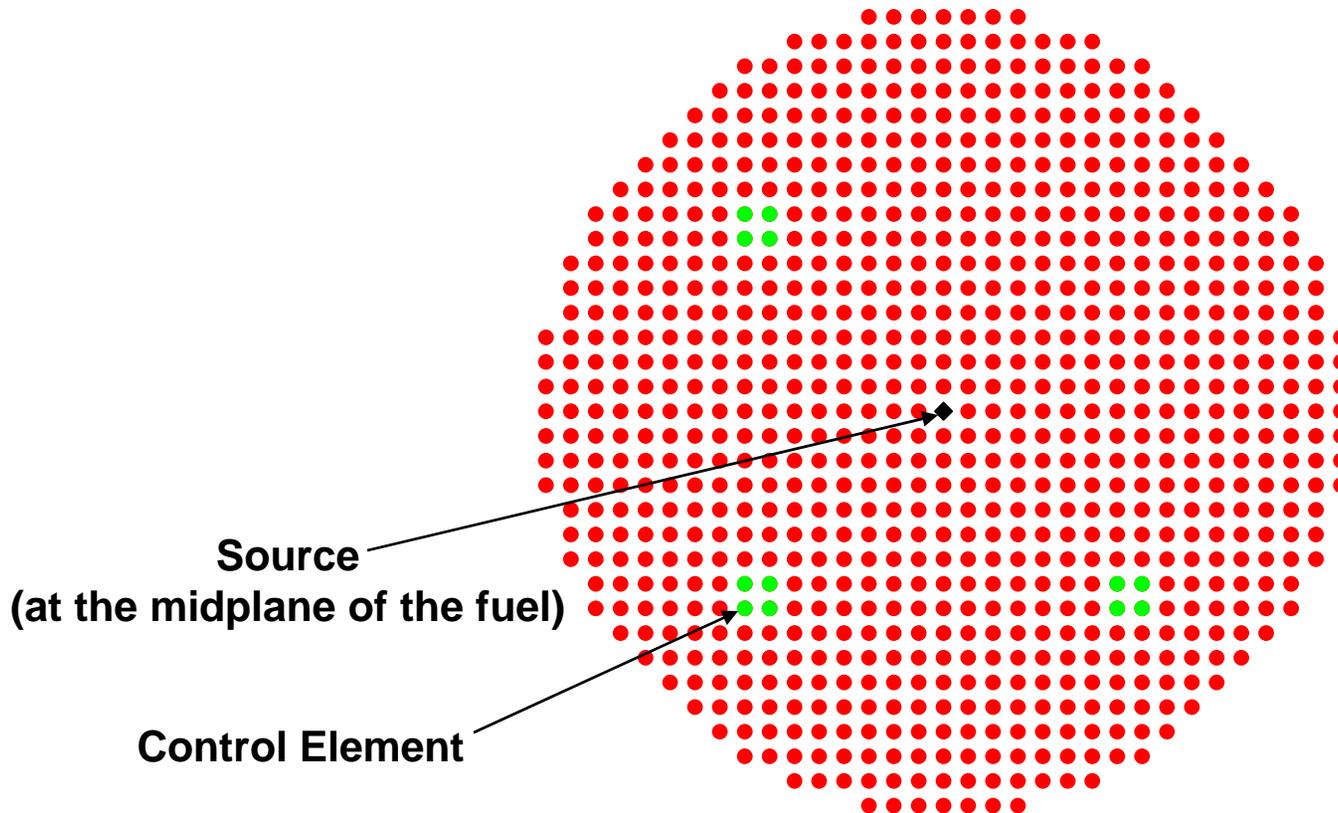
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- **We perform an approach-to-critical experiment by loading fuel into the fully-reflected assembly**
- **This is the way we normally perform experiments**
- **The primary criticality safety parameter investigated is the fissile MASS**
- **Other parameters in play are:**
  - Moderation
  - Reflection
  - Absorption
- **Application to criticality safety:**
  - What happens when the number of fuel lumps in an array increases?



# Core Loading Experiment Configuration 1

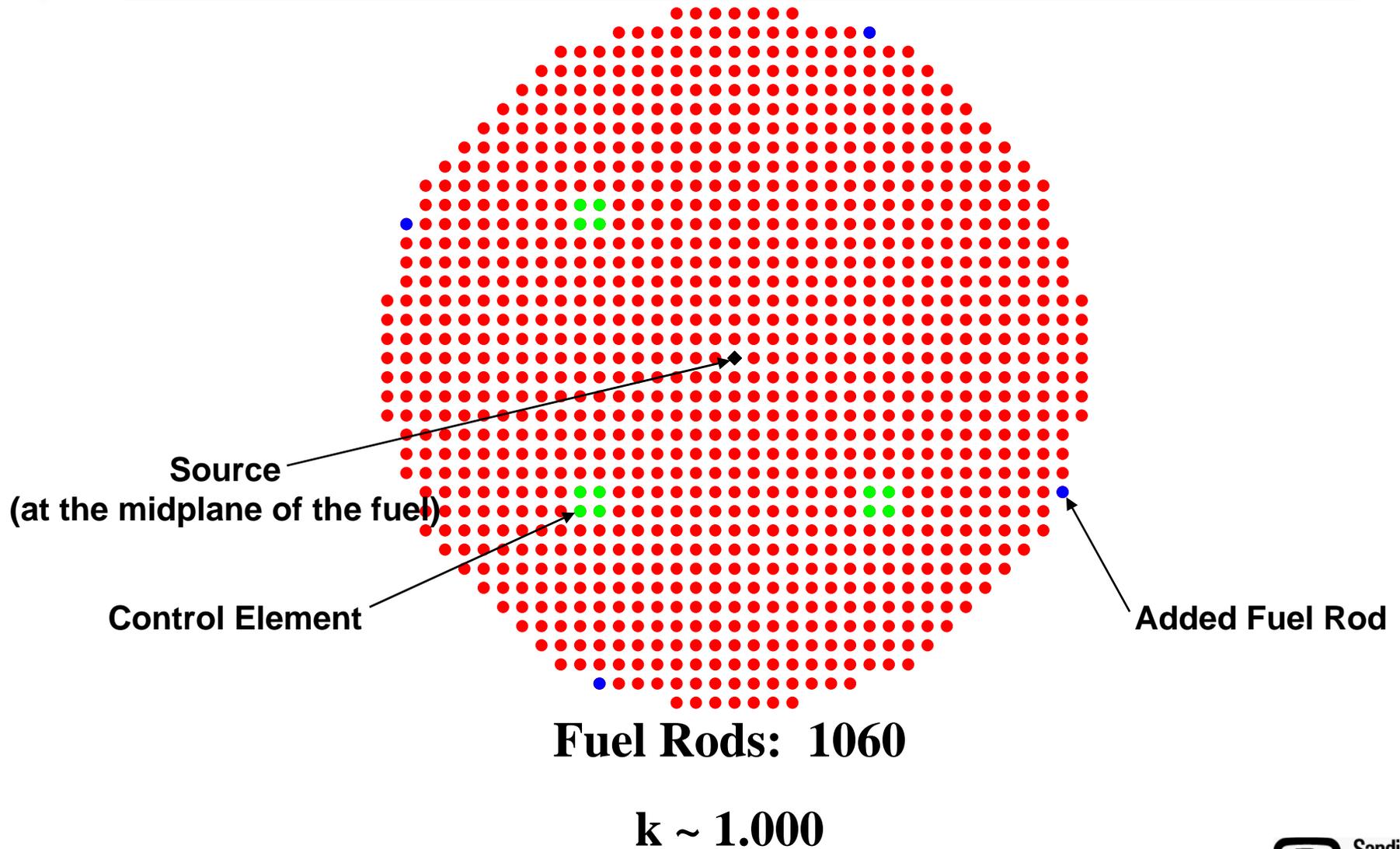
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**Fuel Rods: 836**

**$k \sim 0.950$**

# Supercritical Core Loading





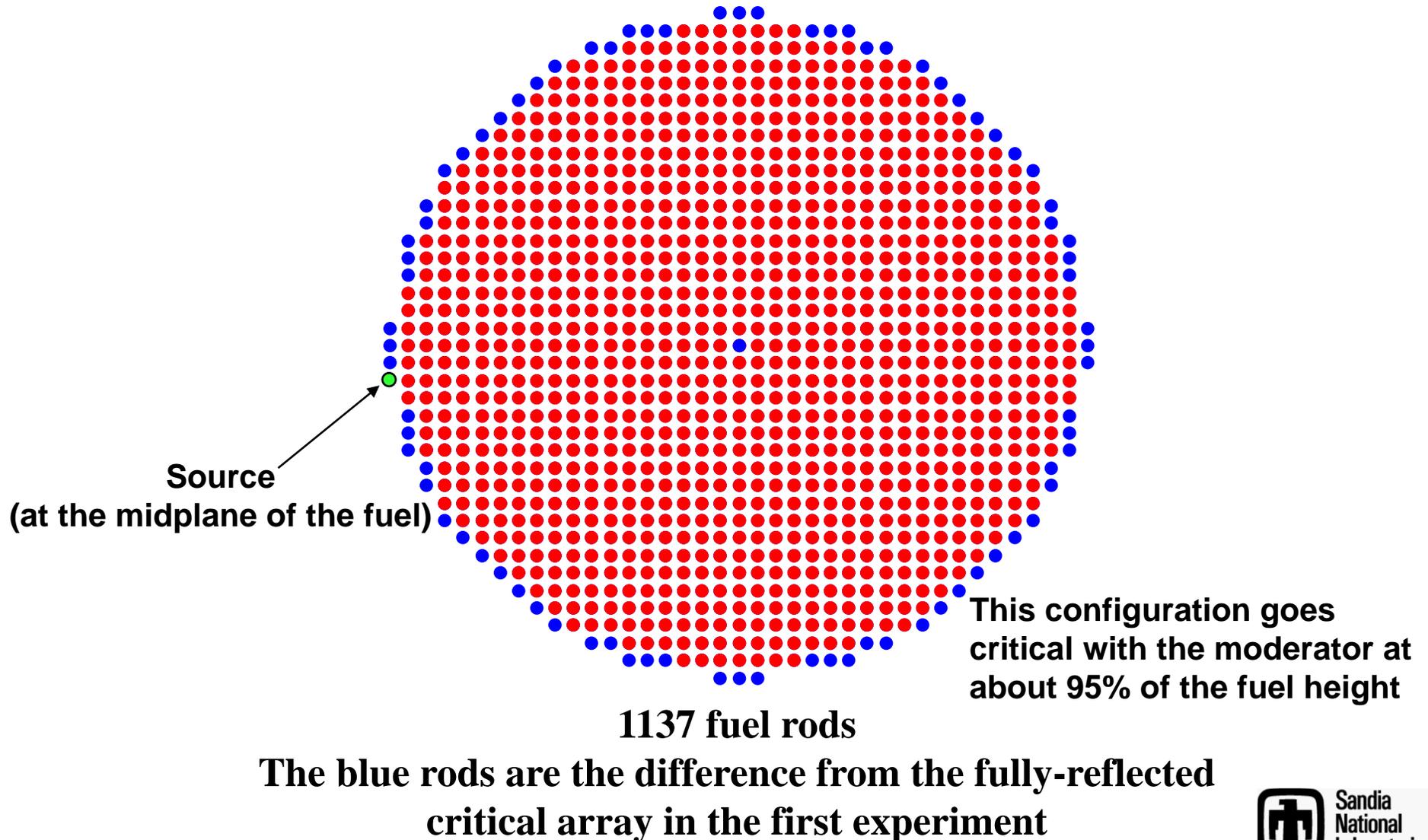
## Experiment 2 Overview

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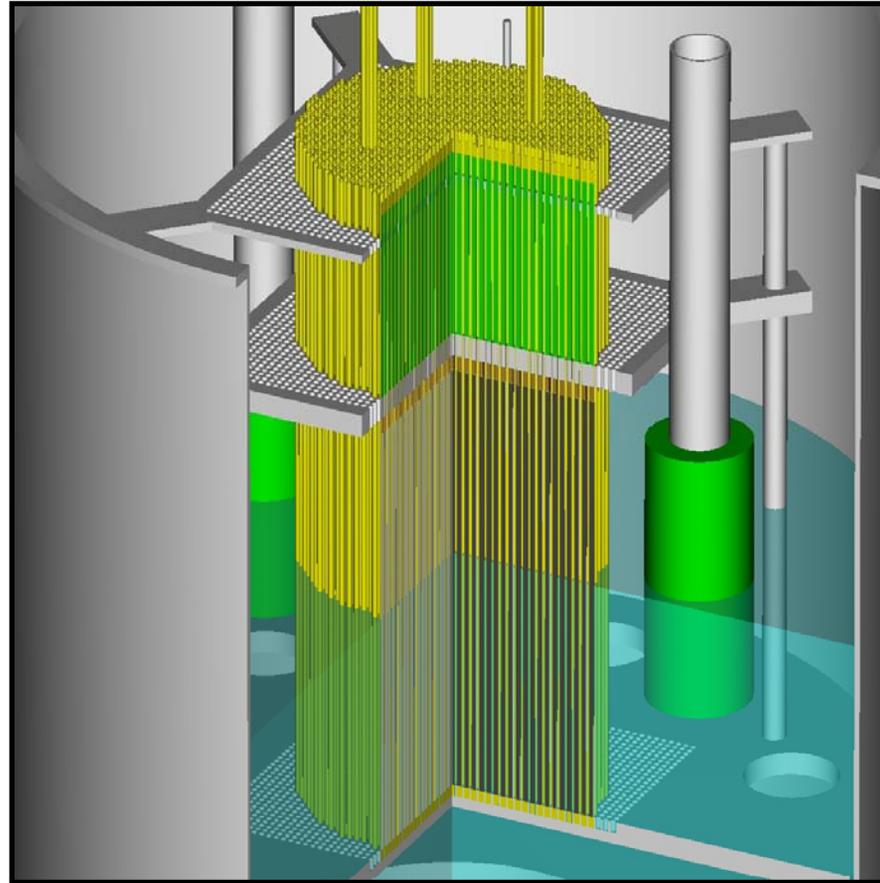
- We perform an approach-to-critical experiment by increasing the moderator height in the assembly with a constant fuel loading
- The primary criticality safety parameter investigated is MODERATION
- Other parameters that are in play:
  - Reflection
  - Geometry
  - Mass
- Application to criticality safety:
  - What happens to an array that becomes flooded?



# The Fuel Rod Configuration



# Moderator Height Experiment First Step

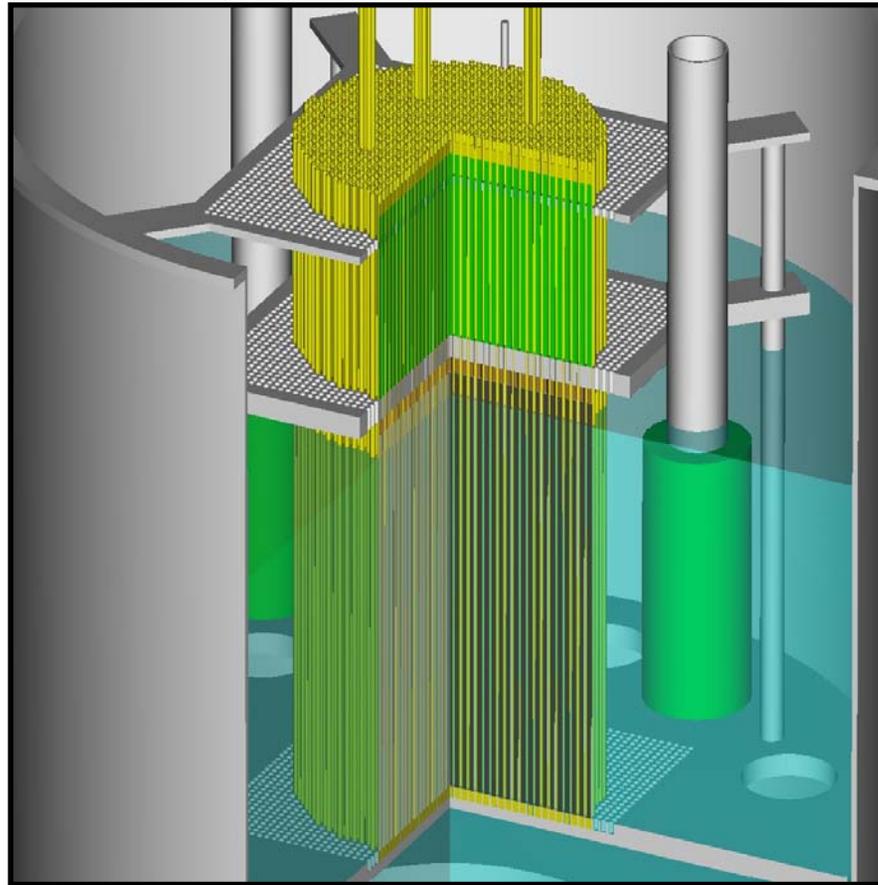


**Fuel Rods: 1137**

**$k_{\text{eff}}$ : ~ 0.900**

**Water Depth: 271.6 mm**

# Moderator Height Experiment at Critical



**Fuel Rods: 1137**

**$k_{\text{eff}}$ : ~ 1.000**

**Water Depth: 461.0 mm**

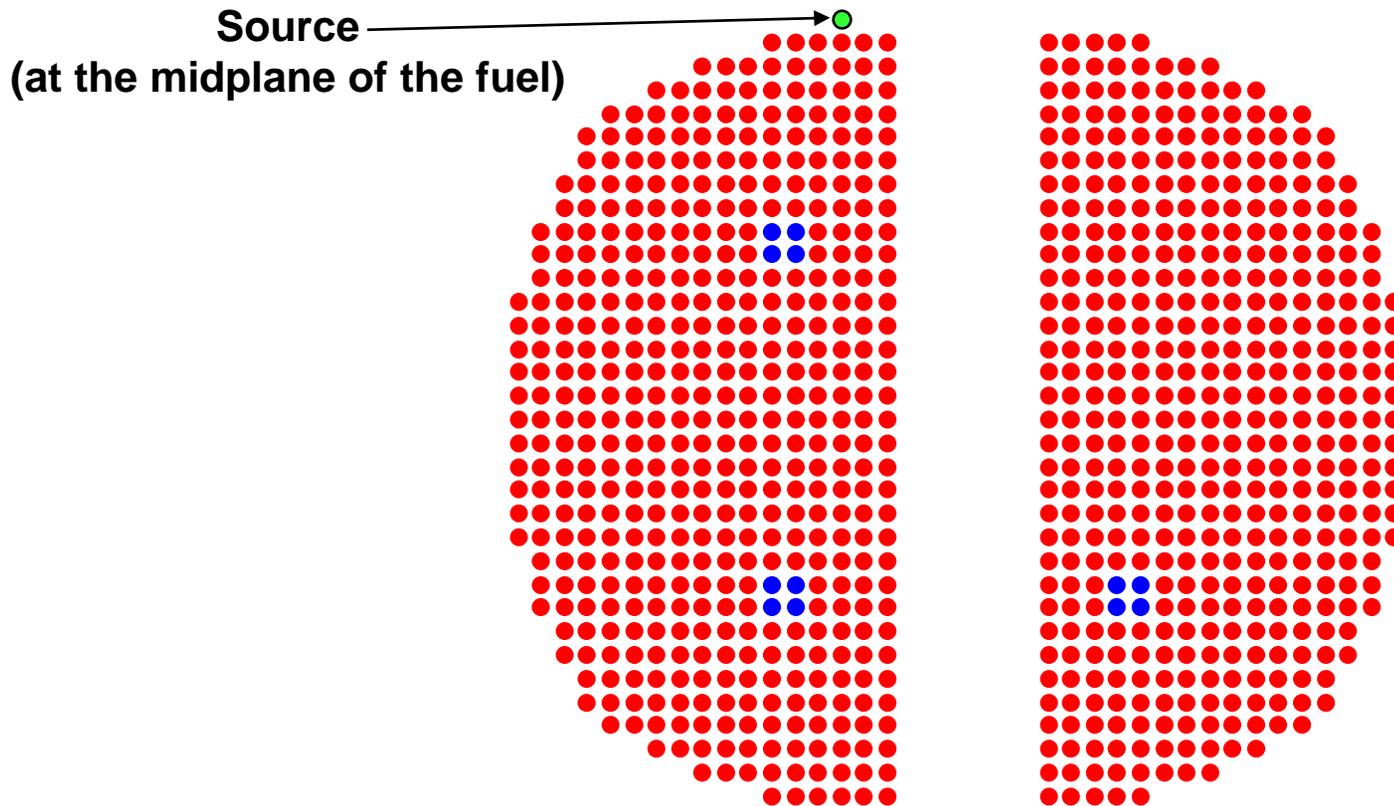


## Experiment 3 Overview

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- We perform an approach-to-critical experiment by moving two roughly equal (and unchanging) fuel lumps toward each other
- This simulates experiments done with a horizontal split table machine
- The primary criticality safety parameter that is investigated is **INTERACTION**
- Moderation is also in play
- Application to criticality safety:
  - What happens as two fuel masses are moved progressively closer to one another?
  - What happens when two neighboring fuel masses are moved apart?
  - This experiment is applicable to many accident configurations.

# Core Separation Experiment Configuration 1

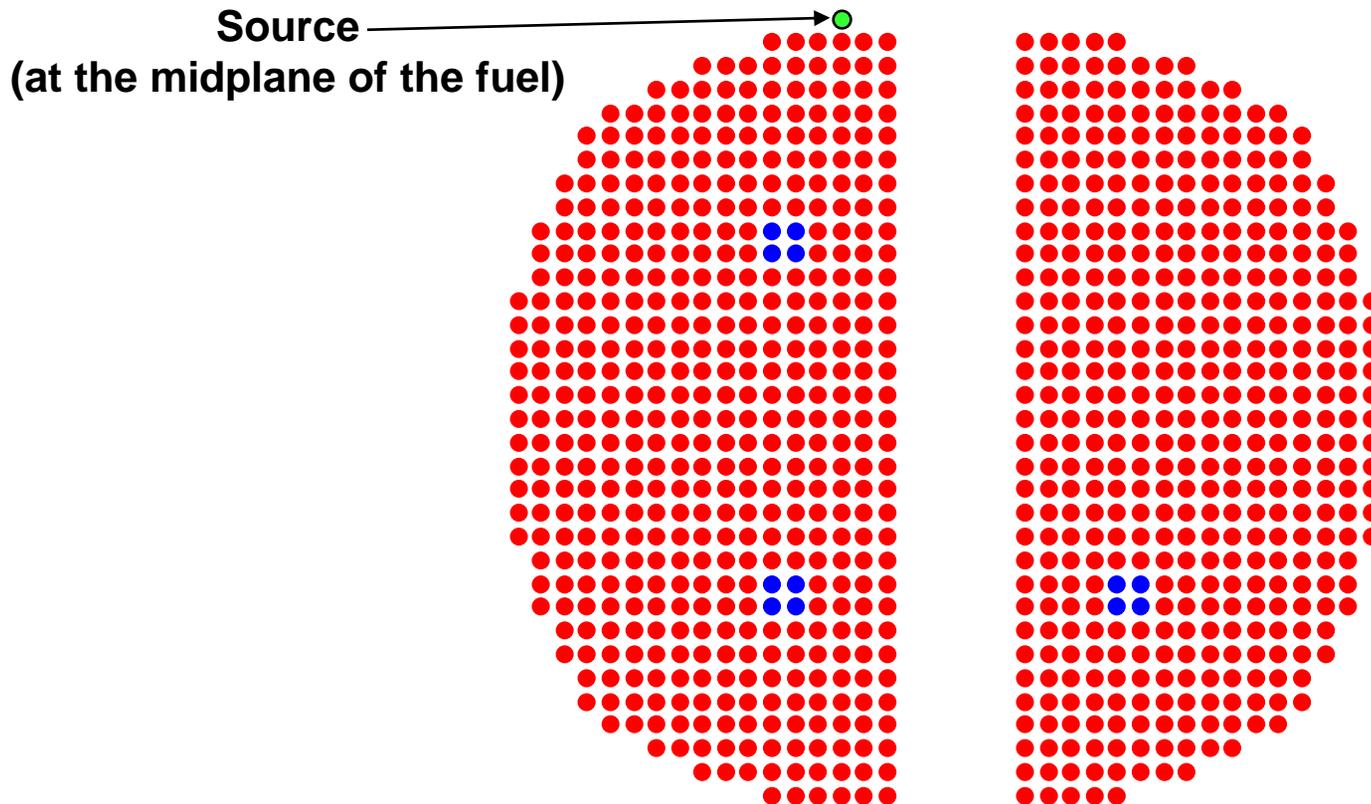


**Fuel Rods: 477 (left) + 444 (right) = 921 (total)**

**$k_{\text{eff}}$ : ~ 0.958**

**Separation: 5.130 cm**

# Core Separation Experiment Configuration 2

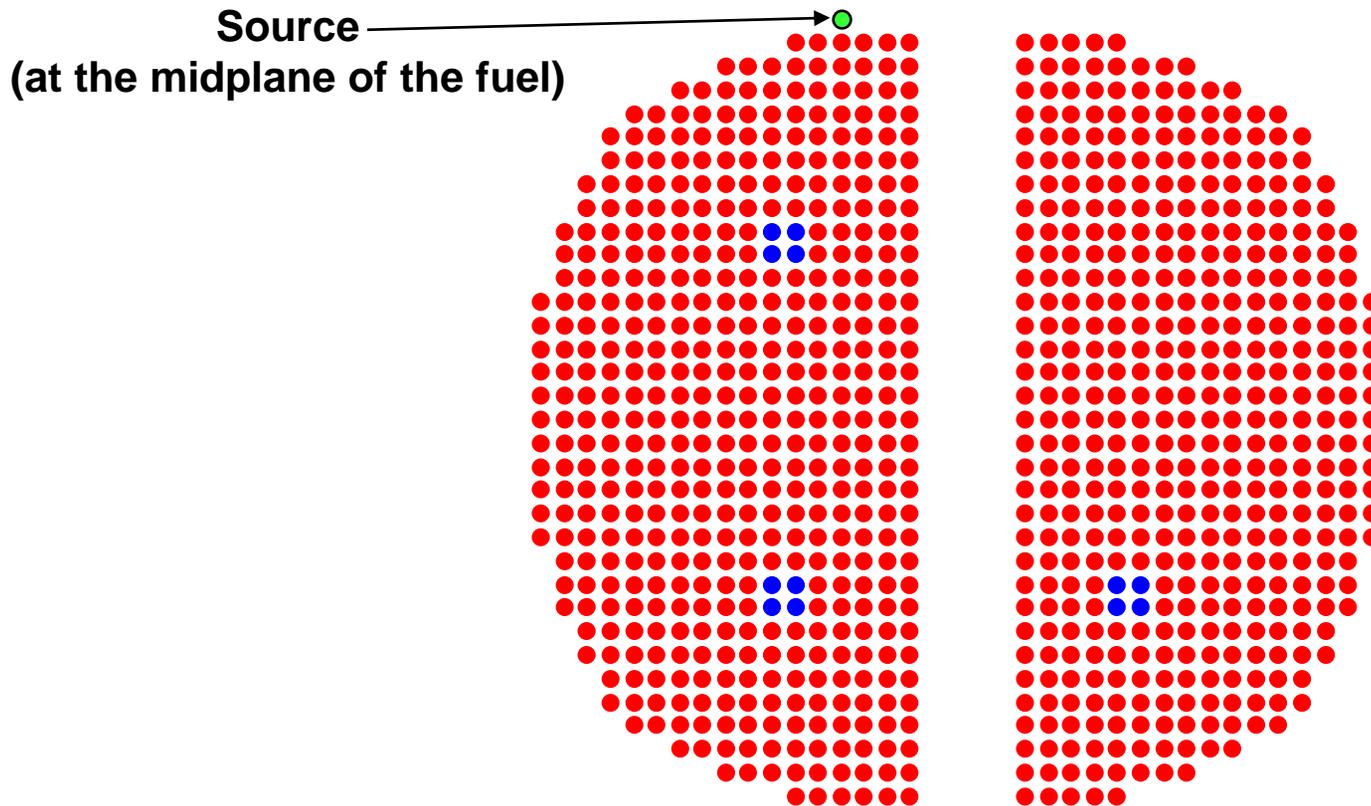


**Fuel Rods: 477 (left) + 444 (right) = 921 (total)**

**$k_{\text{eff}}$ : ~ 0.975**

**Separation: 4.275 cm**

# Core Separation Experiment Configuration 3

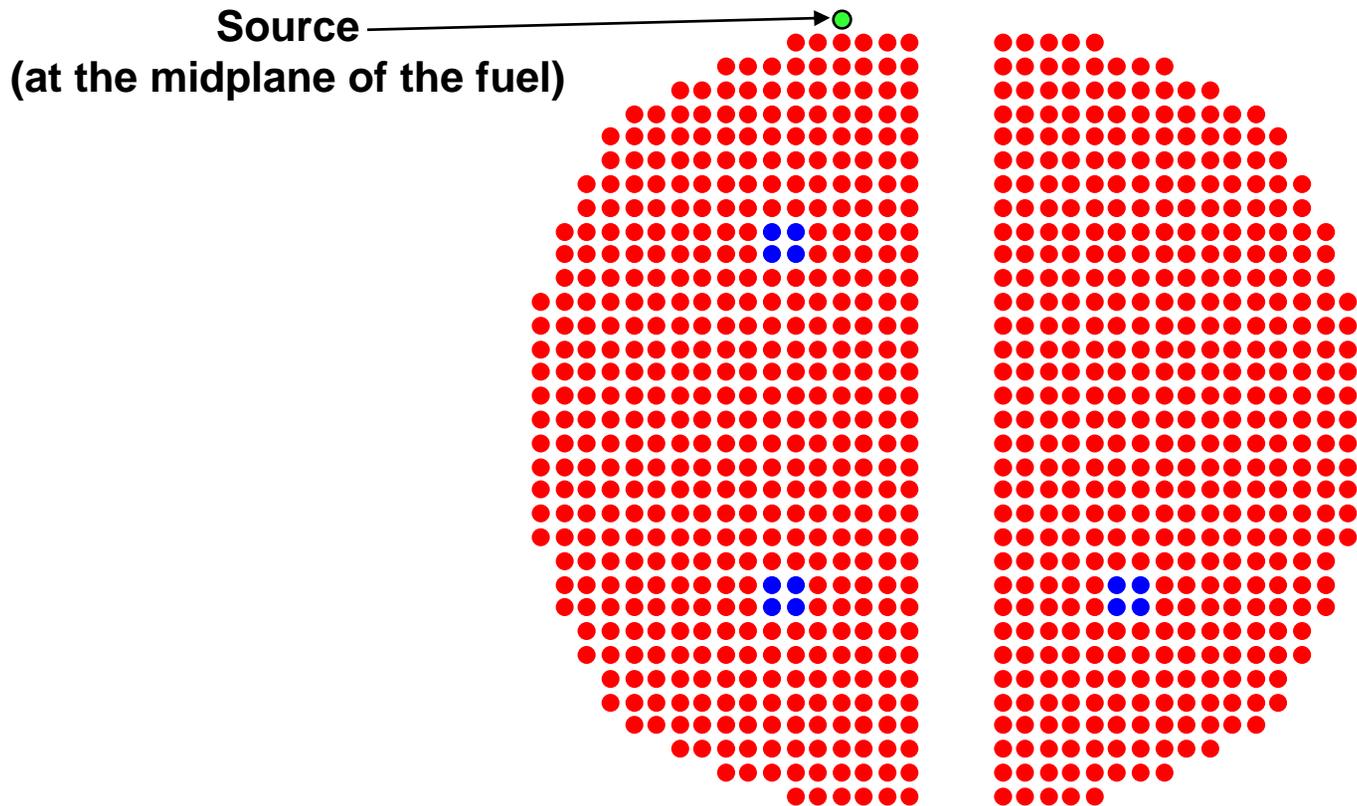


**Fuel Rods: 477 (left) + 444 (right) = 921 (total)**

**$k_{\text{eff}}$ : ~ 0.989**

**Separation: 3.420 cm**

# Core Separation Experiment Configuration 4

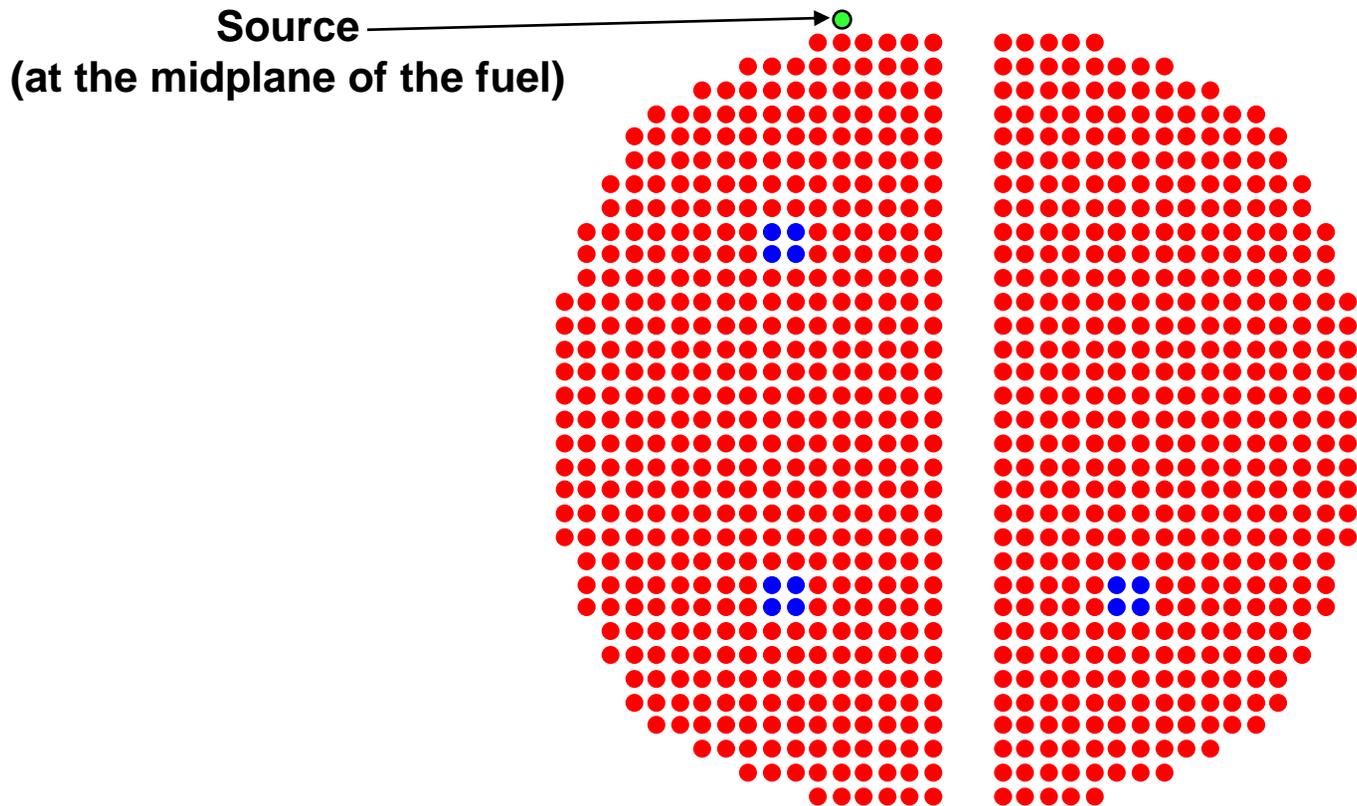


**Fuel Rods: 477 (left) + 444 (right) = 921 (total)**

**$k_{\text{eff}}$ : ~ 0.997**

**Separation: 2.565 cm**

# Core Separation Experiment Configuration 5

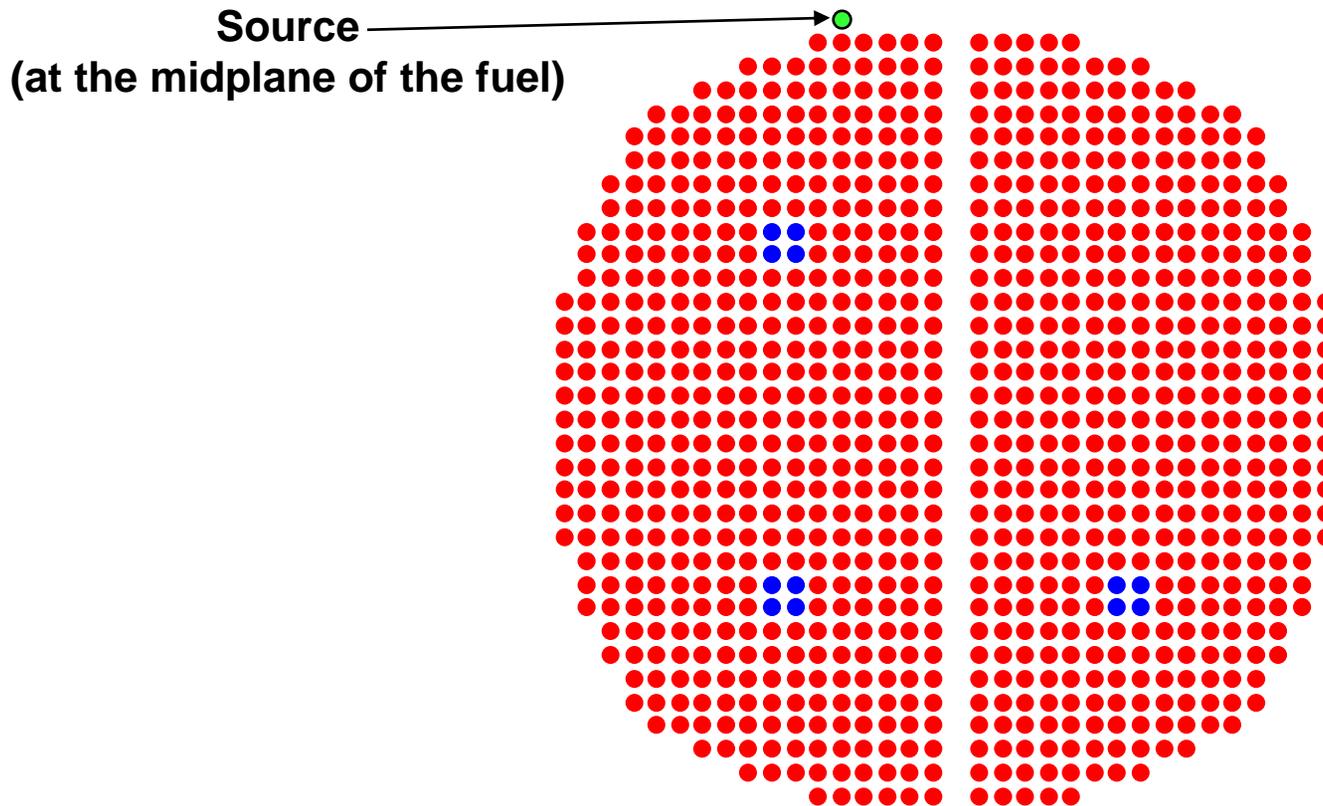


**Fuel Rods: 477 (left) + 444 (right) = 921 (total)**

**$k_{\text{eff}}$ : ~ 0.997**

**Separation: 1.710 cm**

# Core Separation Experiment Configuration 6



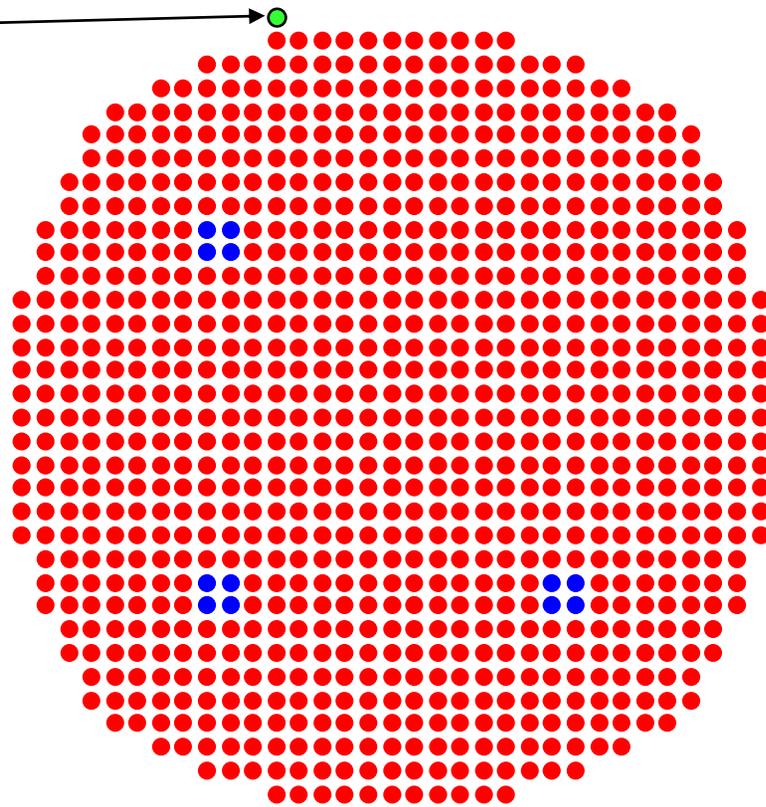
**Fuel Rods: 477 (left) + 444 (right) = 921 (total)**

**$k_{\text{eff}}$ : ~ 0.988**

**Separation: 0.855 cm**

# Core Separation Experiment Configuration 7

Source  
(at the midplane of the fuel)



**Fuel Rods: 921**

**$k_{\text{eff}}$ : ~ 0.958**



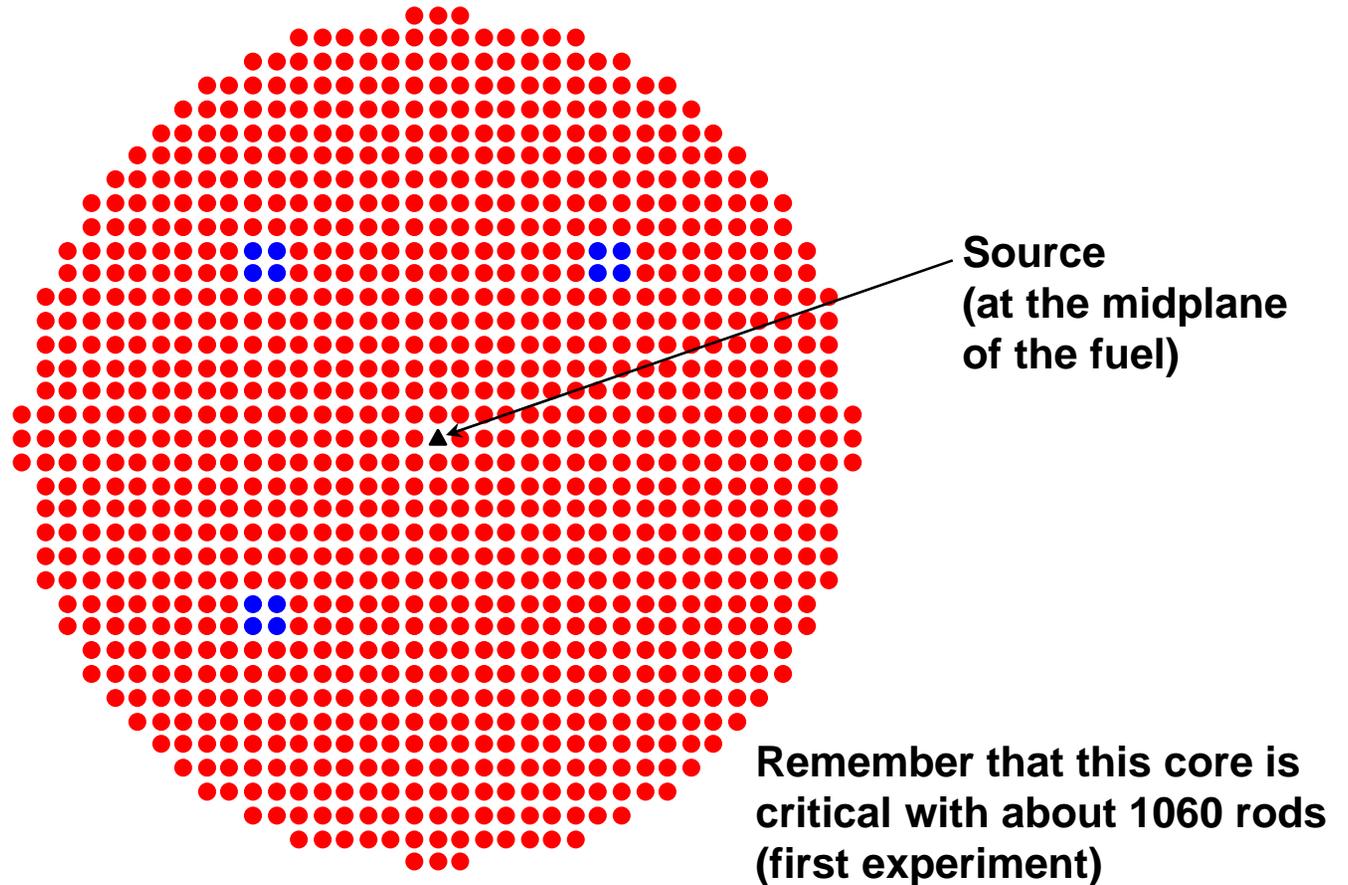
## Experiment 4 Overview

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- **We determine the effect of removing fuel rods from the interior of the fuel array**
- **We are actually replacing fuel rods with water**
- **The primary criticality safety parameters that are investigated are fissile MASS and MODERATION**
- **Other parameters that are in play:**
  - Reflection
  - Absorption
- **Application to criticality safety:**
  - Fuel mass is the most important parameter, right?
  - What happens to a compact array of fuel lumps if the array becomes more spread out?



# Fuel Replacement with Water Configuration 0

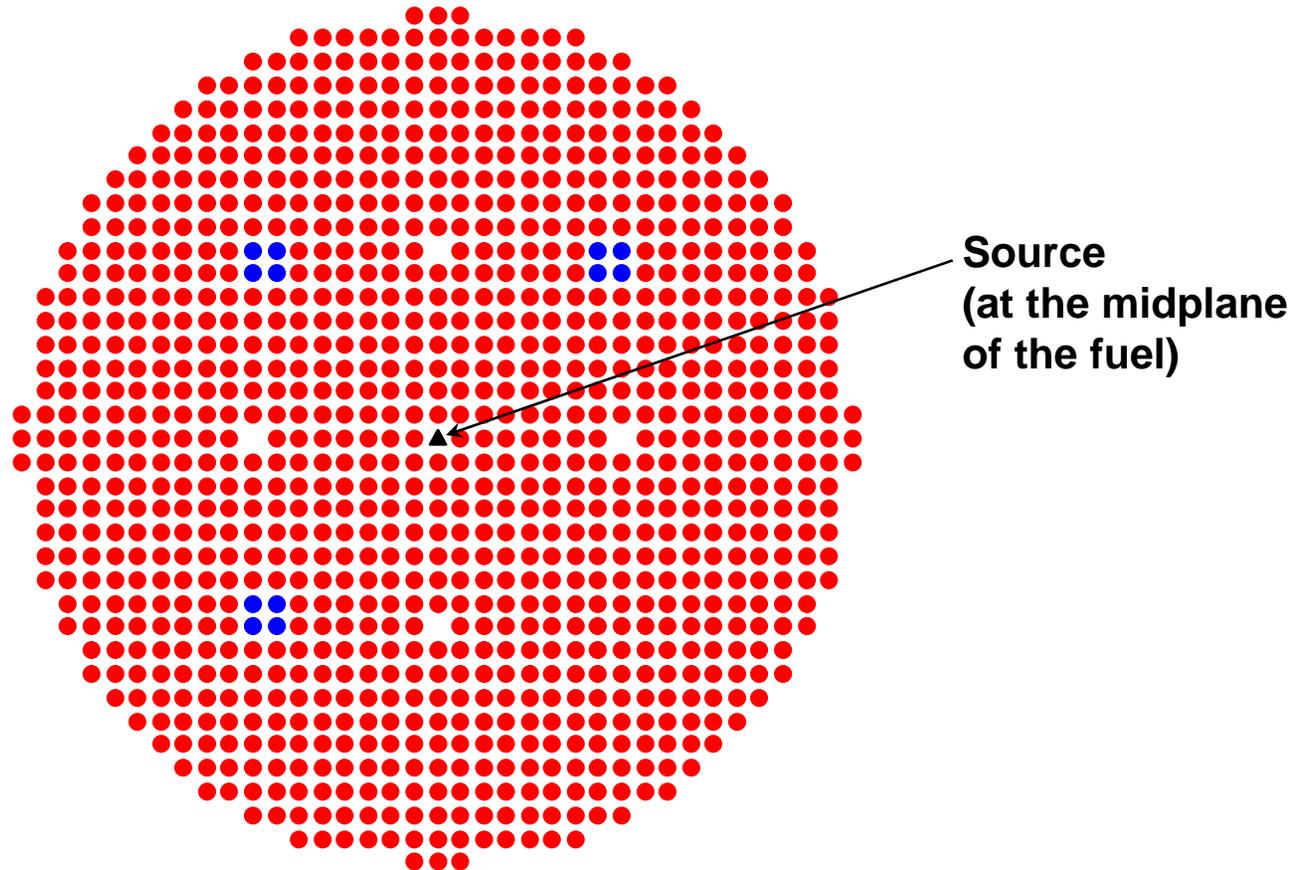


**1032 Fuel Rods**  
**0 Water Holes**  $k_{\text{eff}}: \sim 0.9953$



# Fuel Replacement with Water Configuration 1

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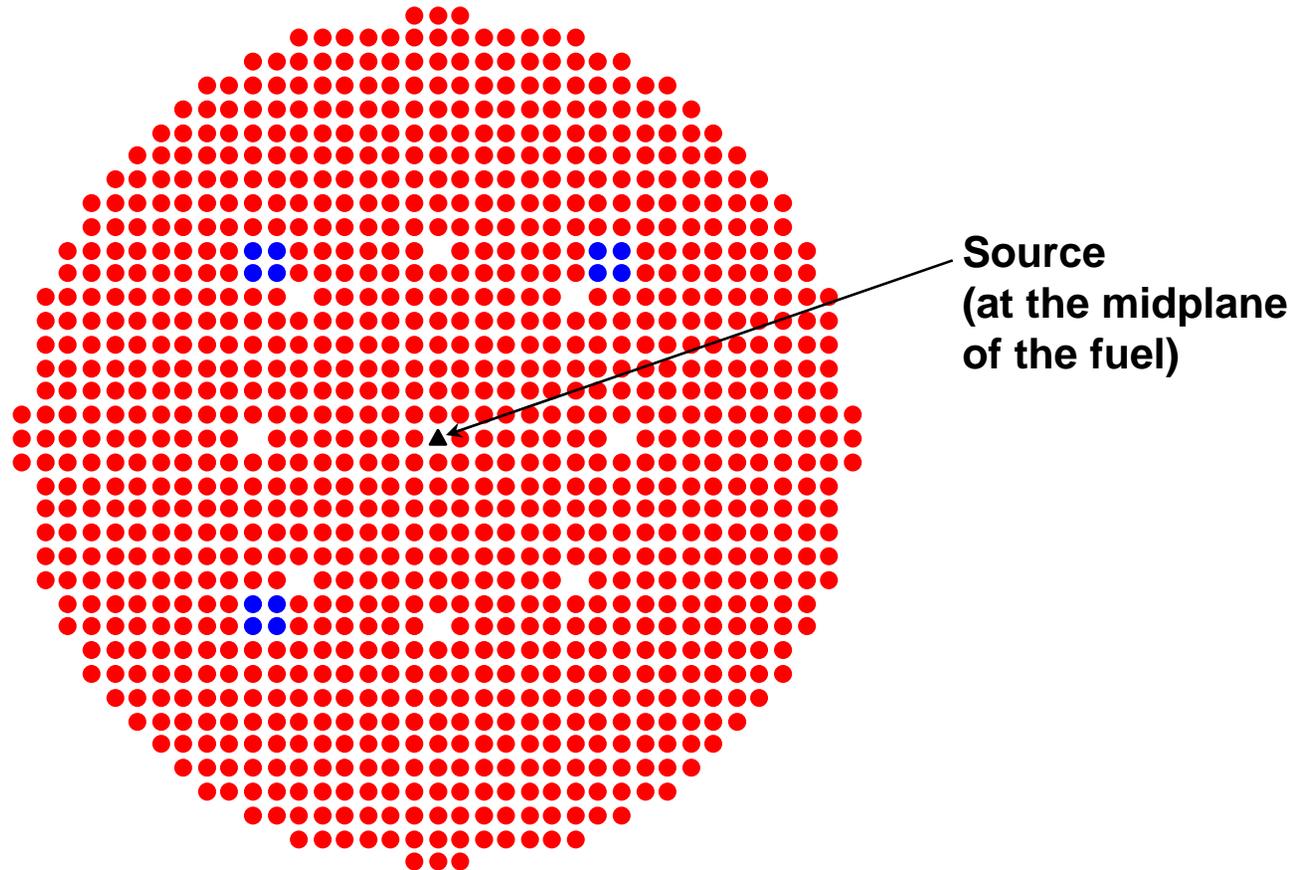


1028 Fuel Rods  
4 Water Holes  $k_{\text{eff}}: \sim 0.9967$



# Fuel Replacement with Water Configuration 2

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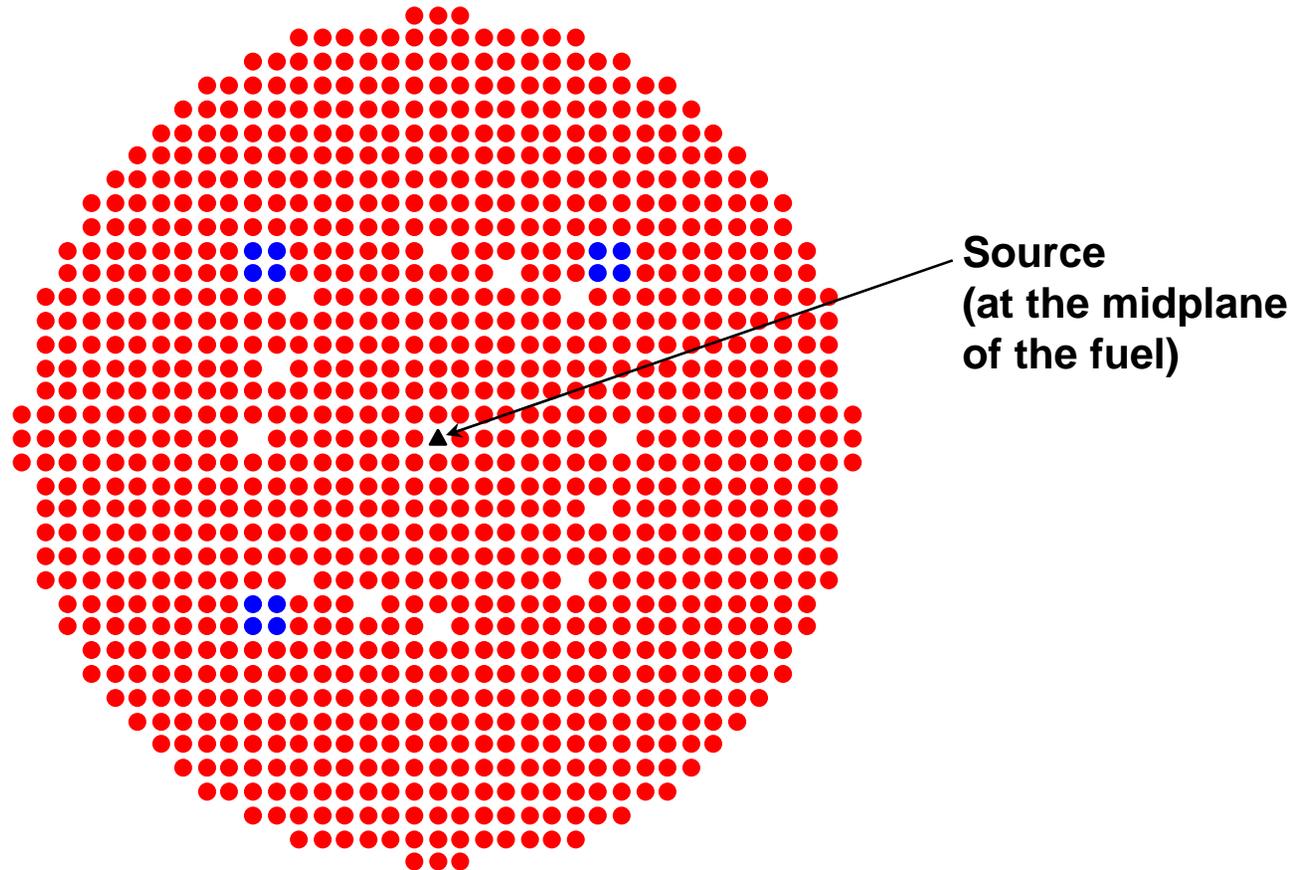


1024 Fuel Rods  
8 Water Holes  $k_{\text{eff}}: \sim 0.9983$



# Fuel Replacement with Water Configuration 3

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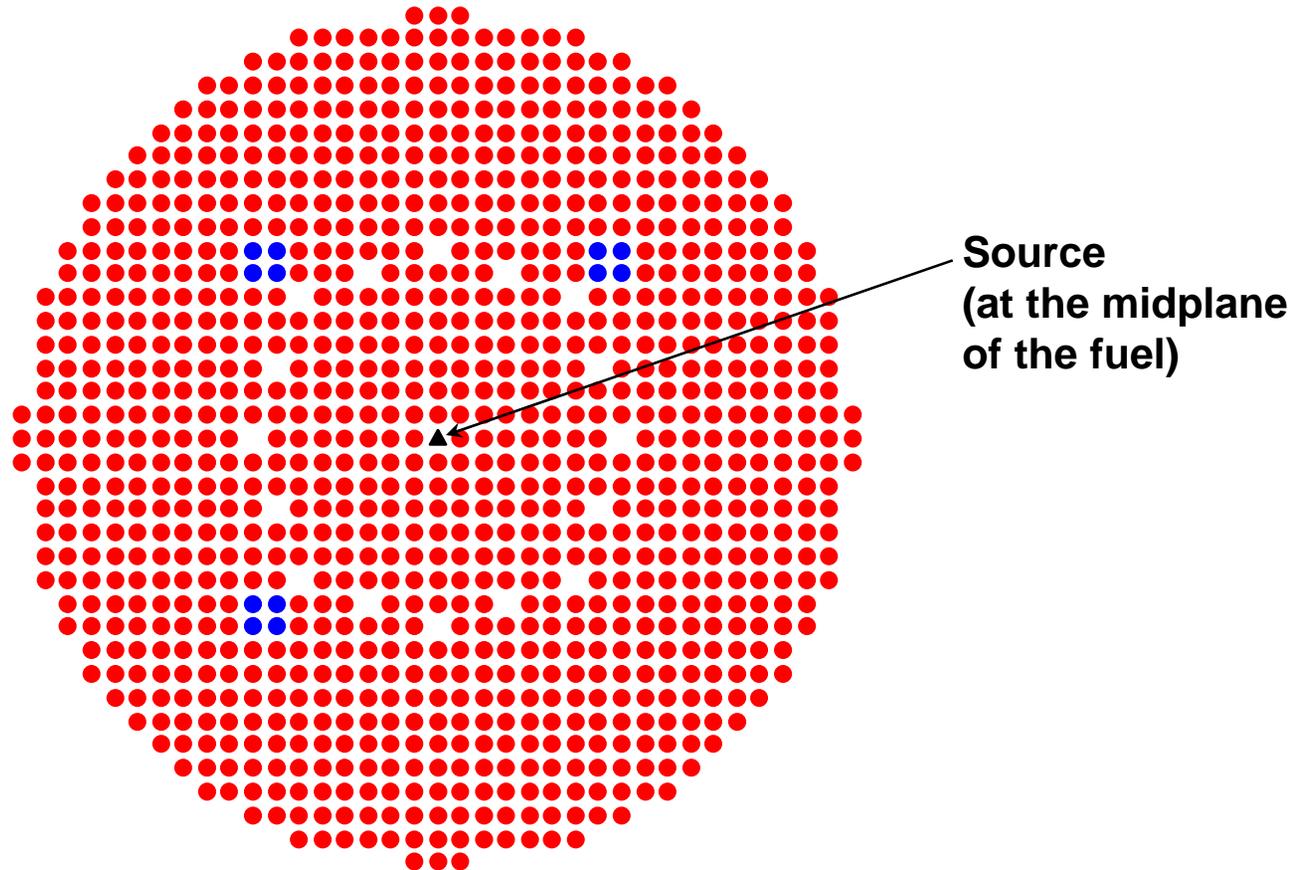


**1020 Fuel Rods**  
**12 Water Holes  $k_{\text{eff}}: \sim 0.9999$**



# Fuel Replacement with Water Configuration 4

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**1016 Fuel Rods**  
**16 Water Holes  $k_{\text{eff}}: \sim 1.0014$**



## Concluding Remarks

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- **The paper discussed our IE activities and where we are on each one**
  - IER-208/209 – Measure the critical water depth in the 7uPCX as a function of fuel loading
  - IER-206 – Restart the BUCCX
  - IER-230 – Measure the critical core size of the 7uPCX as a function of rod pitch
  - IER-227 – Build a general-purpose vertical-lift critical assembly for low-enriched experiments
  - IER-226 – Build a general-purpose horizontal split-table critical assembly for low-enriched experiments
- **And described our T&E activities and how our classes are doing**
  - NCSE hands-on training class
  - Hands-on training class for nuclear material managers

# Critical Experiments at Sandia

