Progress at Sandia on NCSP Integral Experiments

Nuclear Criticality Safety Program Technical Review Meeting

Washington, D. C.

May 30, 2013

Gary A. Harms
Sandia National Laboratories

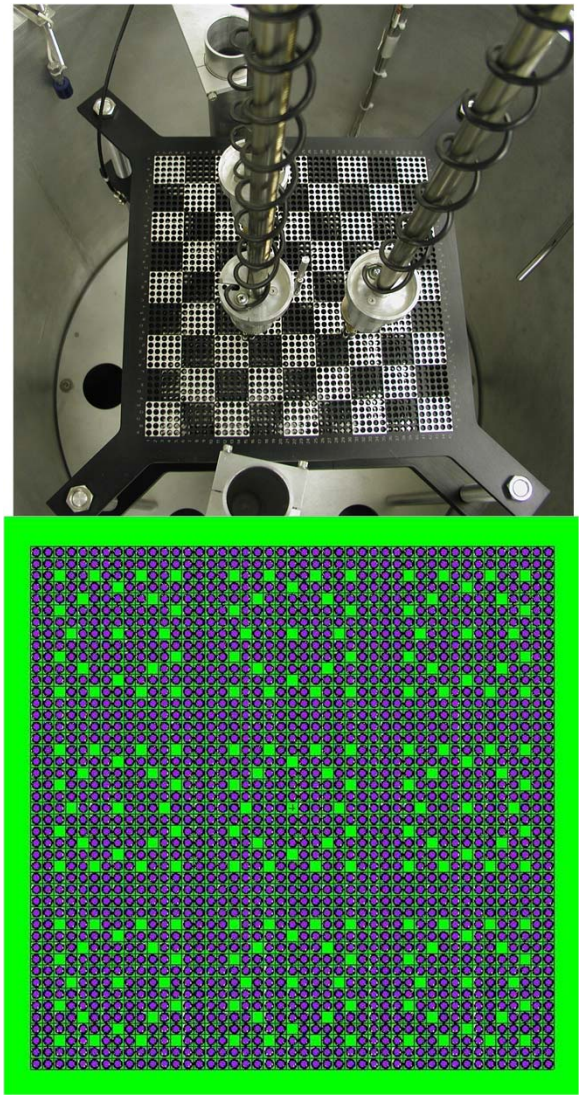
SAND2013-4370P

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

What is ahead

- The evaluation of the experiments we completed last year
- The experiments we are working on now
- Our plans for the future

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**
  - **Poison worth**
  - **Effect of water holes**

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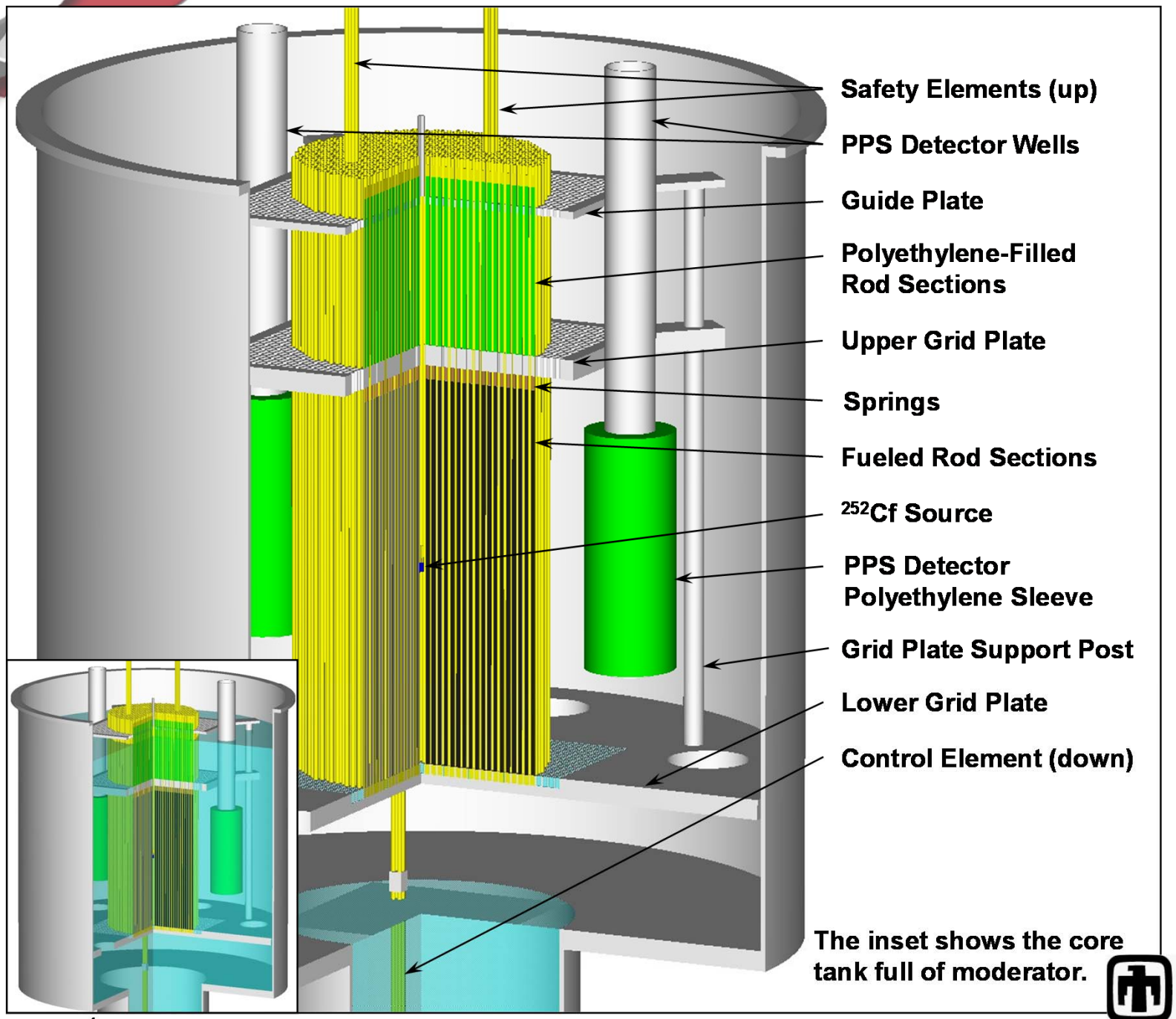

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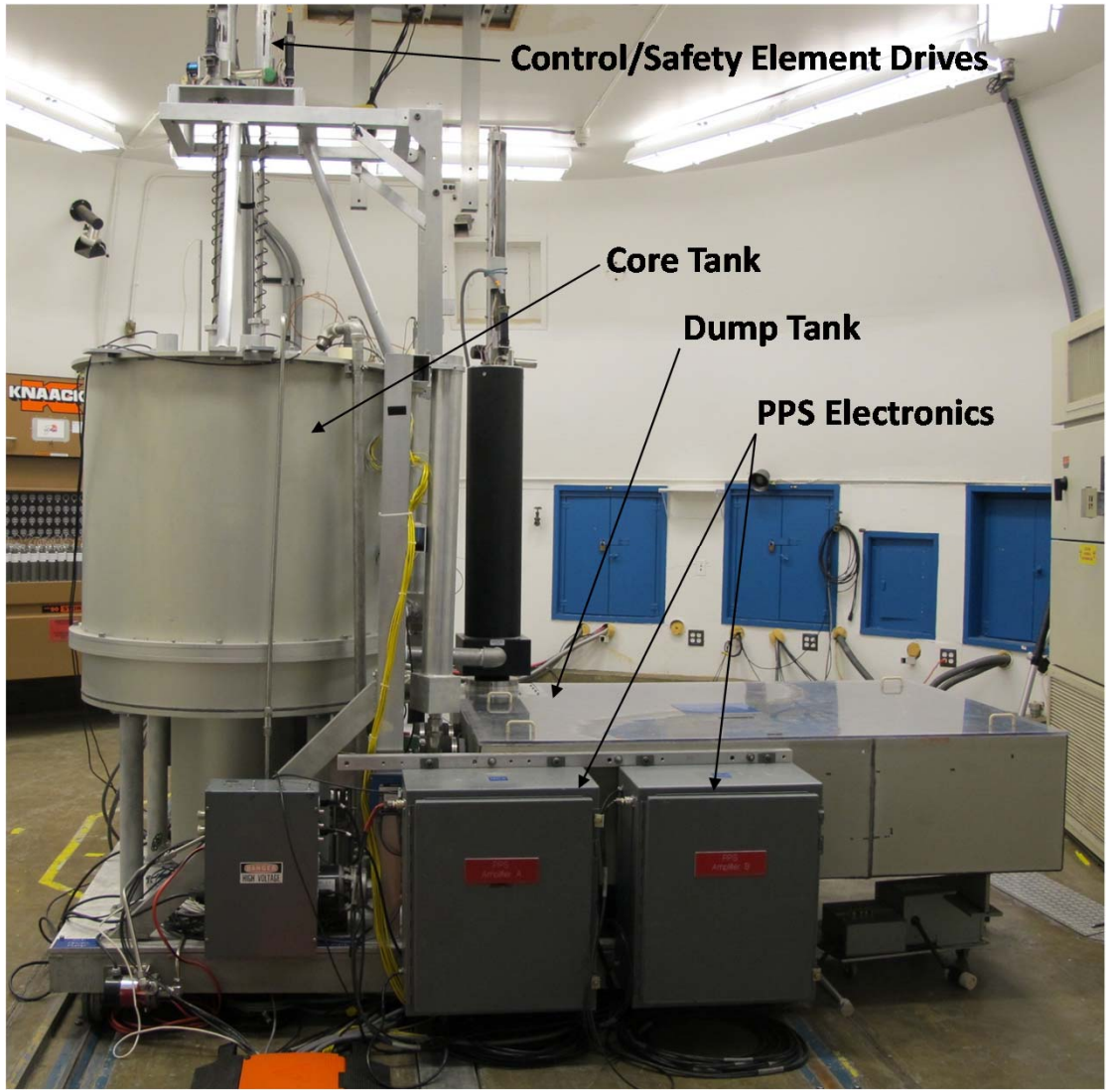
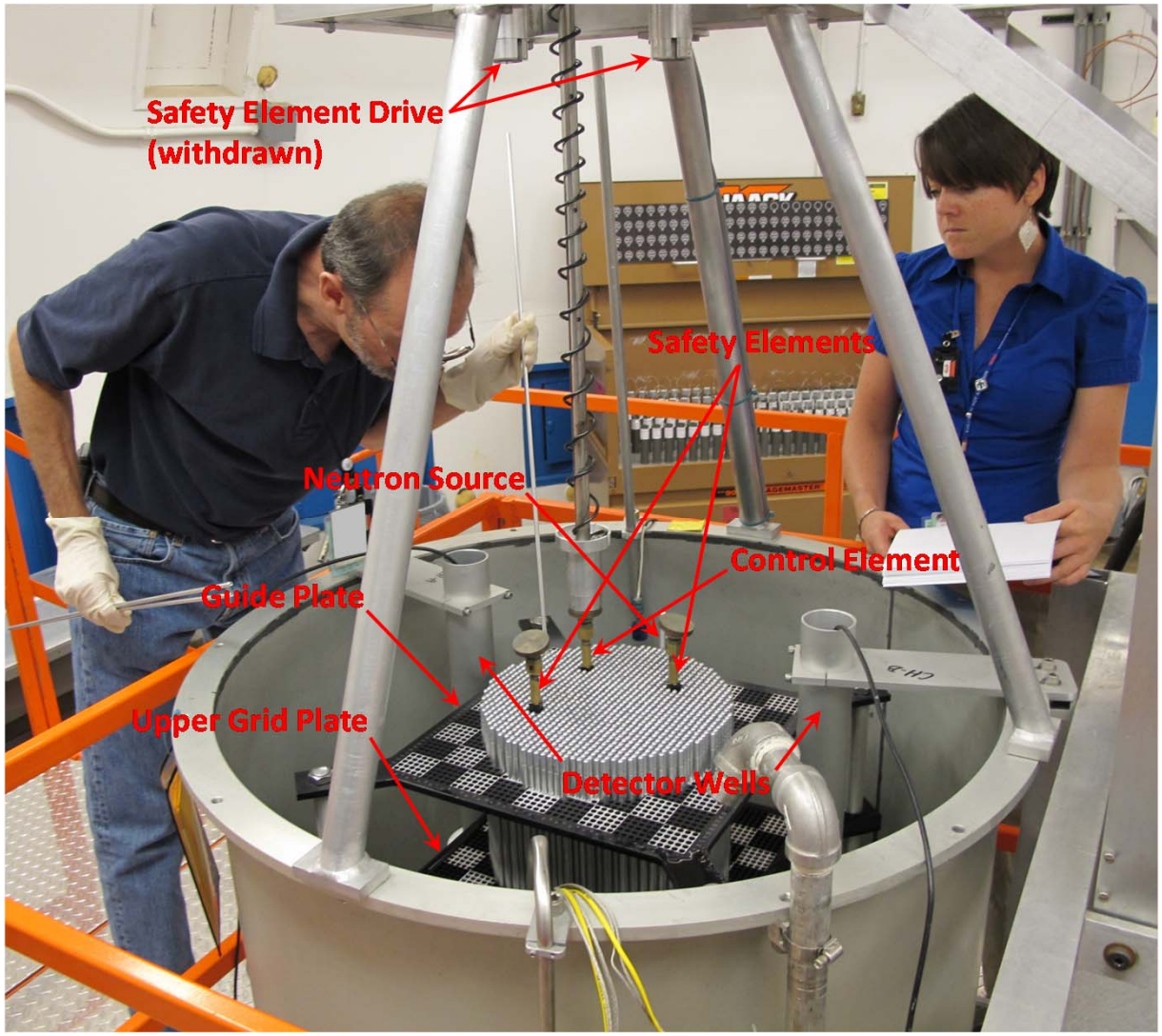
The assembly in person



Loading the core



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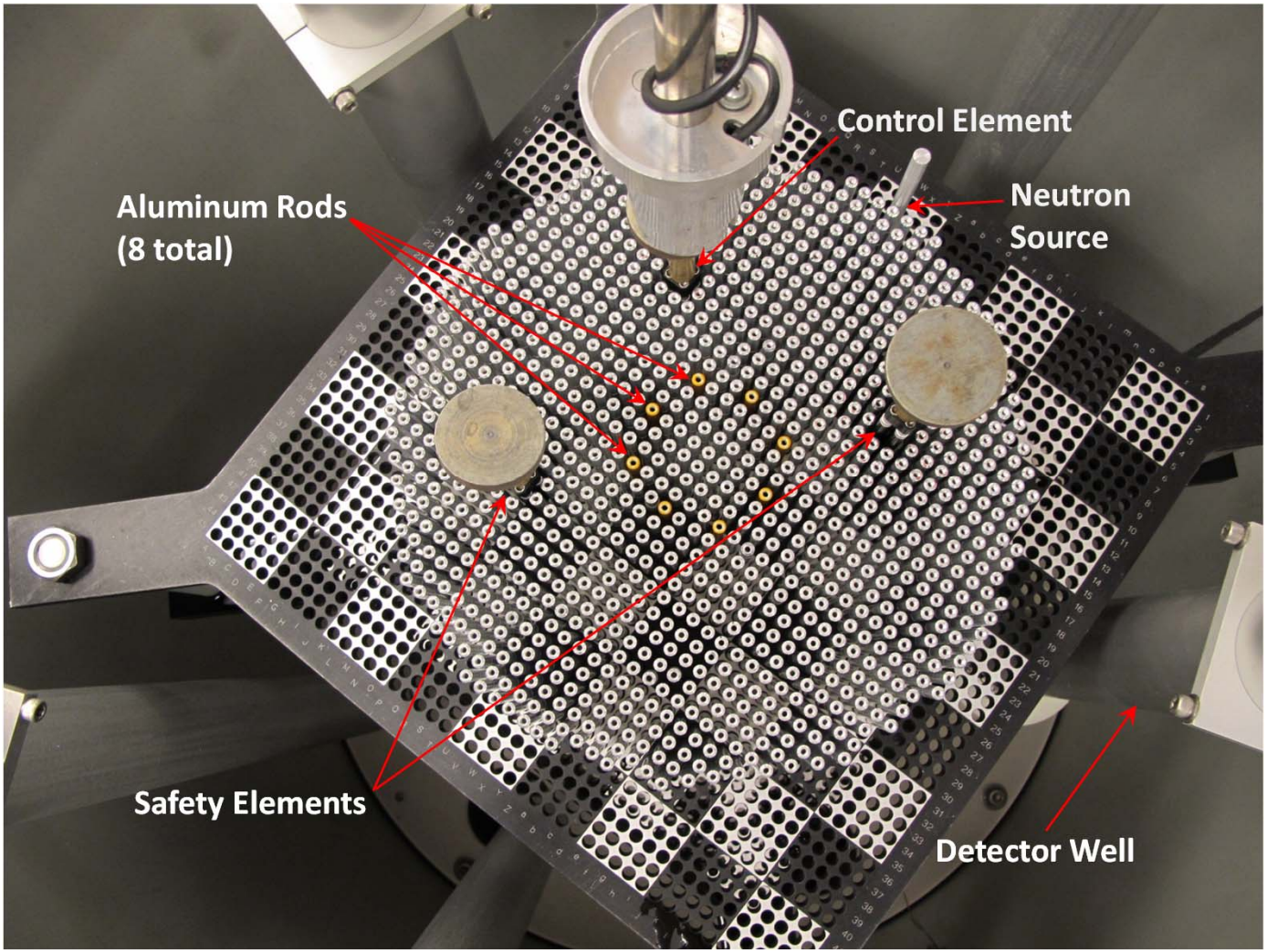
A completed core (LCT078 Case 11)



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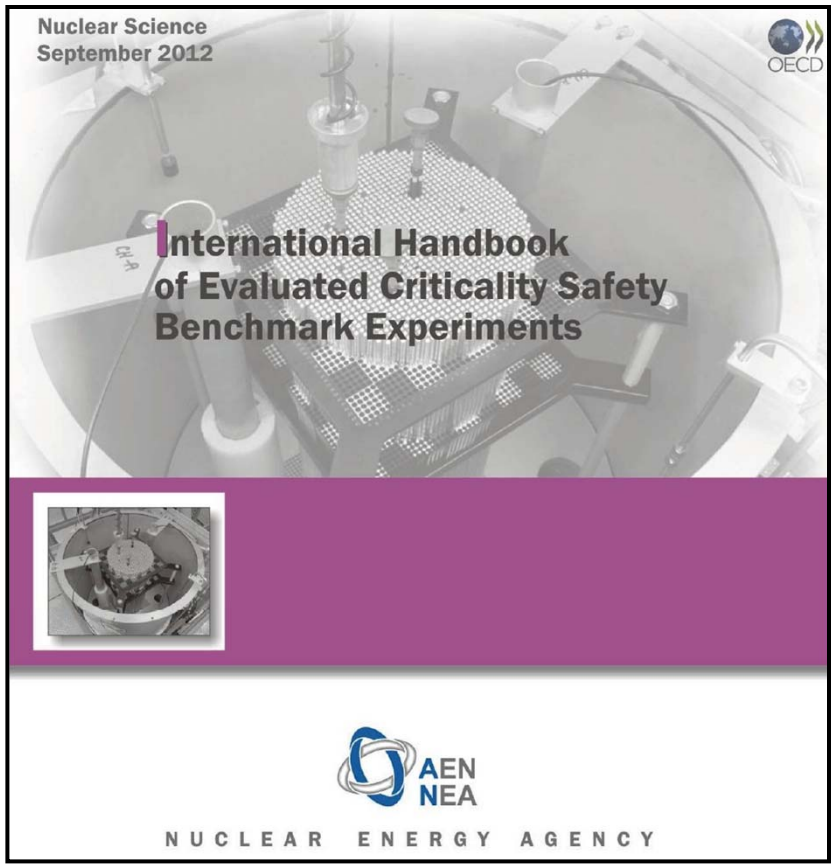
LEU-COMP-THERM-080 is in the book



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

LEU-COMP-THERM-080

WATER-MODERATED SQUARE-PITCHED U(6.90)O_2 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

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LEU-COMP-THERM-078 is in review

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

LEU-COMP-THERM-078

WATER-MODERATED SQUARE-PITCHED U(6.90)O_2 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

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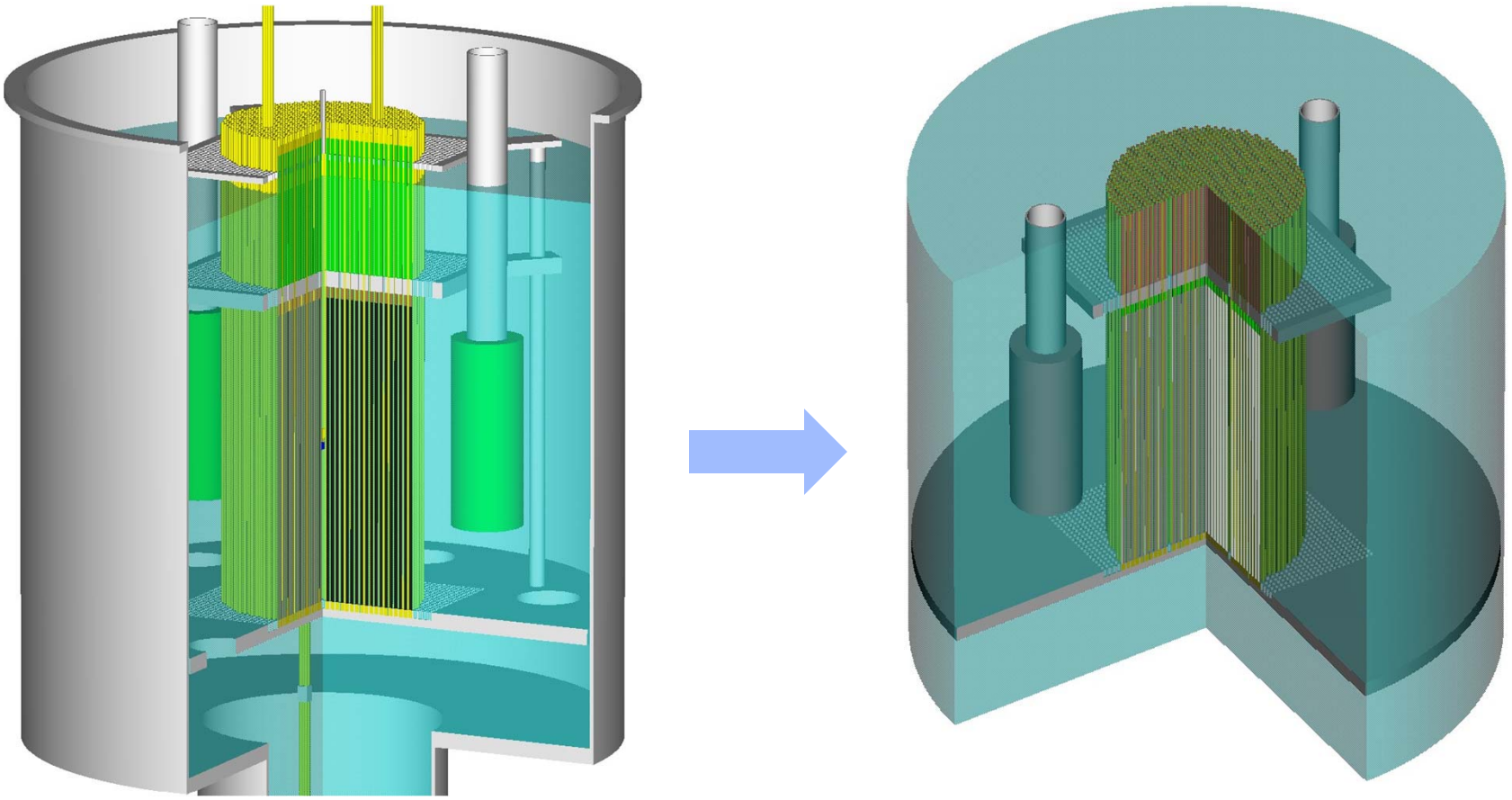
A comparison of the detailed assembly with the benchmark model

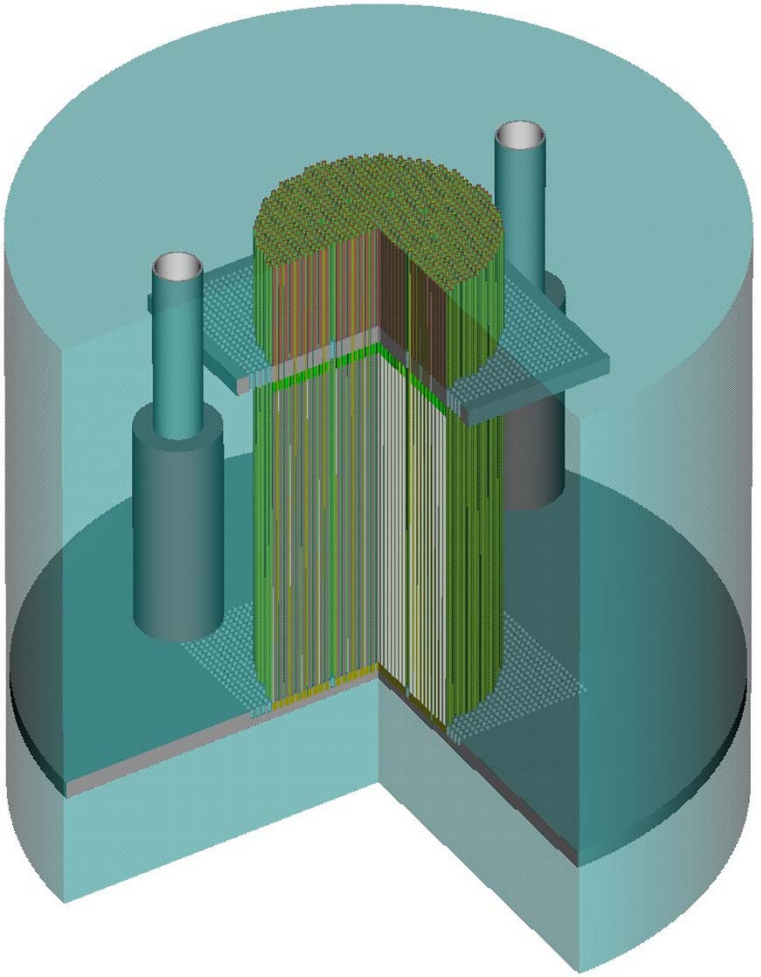


LEU-COMP-THERM-078 Case 8 Benchmark Model

k_{eff} = 0.9987

Each Case includes a total bias of 0.00001 to 0.00012 from:

- Temperature Difference
- Fuel Mass Difference
- Fuel Stack Length Difference
- Fuel Rod OD Difference
- Source Removal
- Convert CE/SE to Fuel Rods
- Remove everything above the water level
- Regularize Design Irregularities



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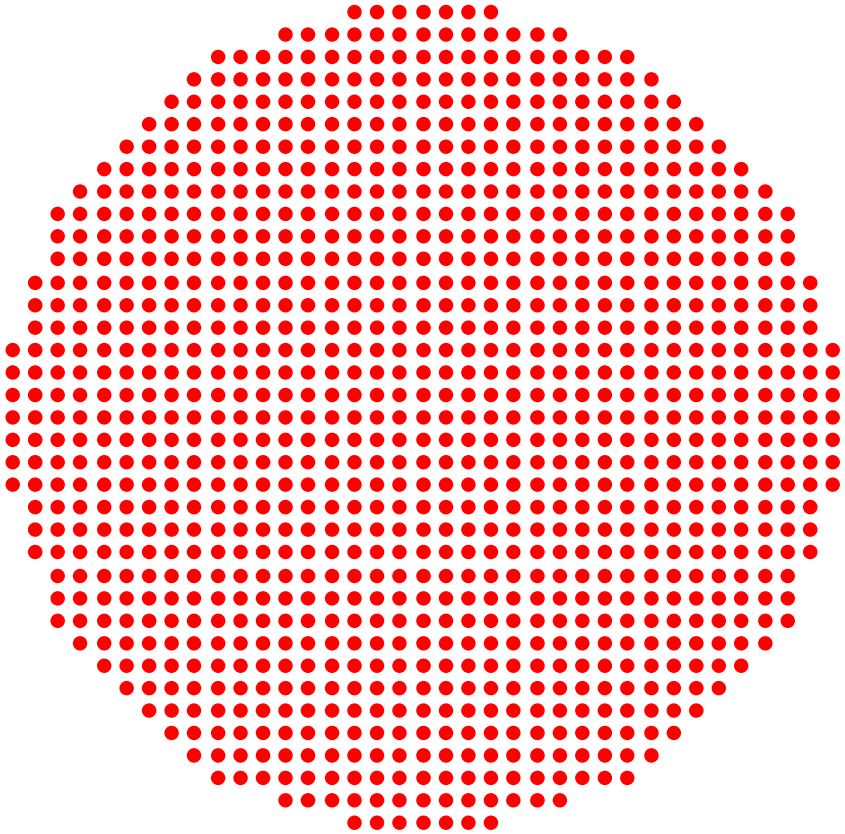
LEU-COMP-THERM-078 Case 1



1057 rods

k_{eff} = 0.9995

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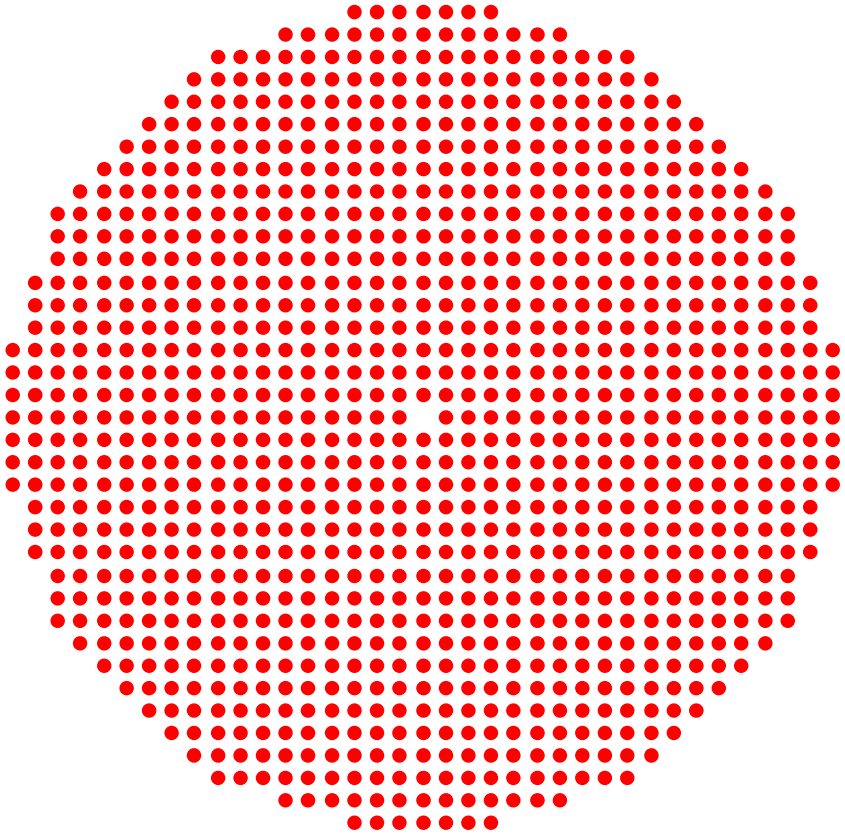
LEU-COMP-THERM-078 Case 2



1056 rods

k_{eff} = 0.9999

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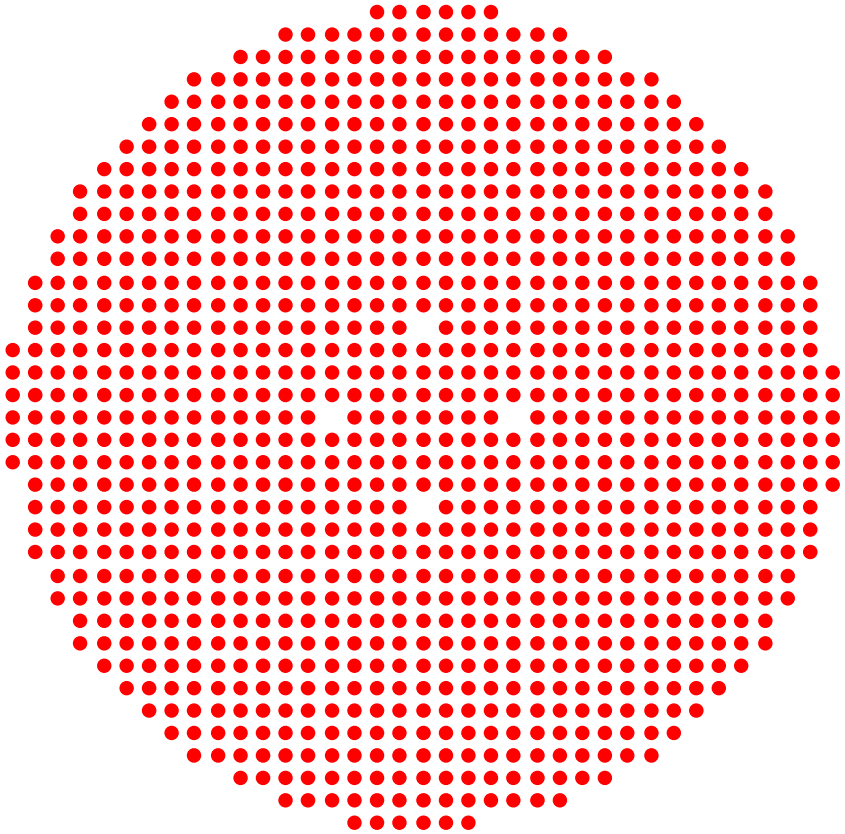
LEU-COMP-THERM-078 Case 3



1041 rods

k_{eff} = 0.9990

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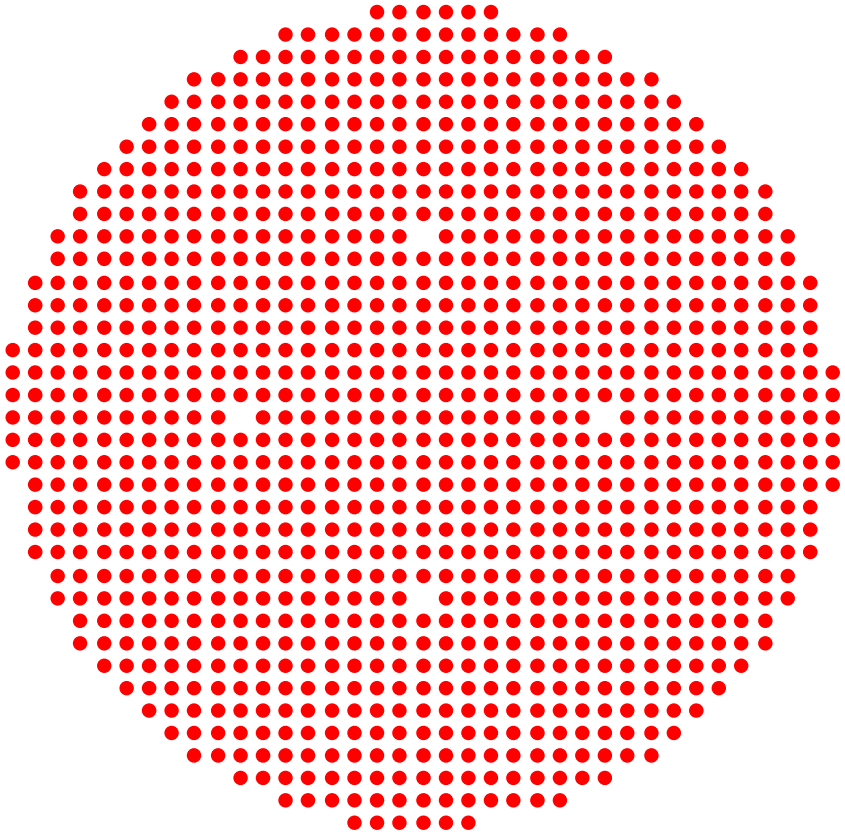
LEU-COMP-THERM-078 Case 4



1041 rods

k_{eff} = 0.9986

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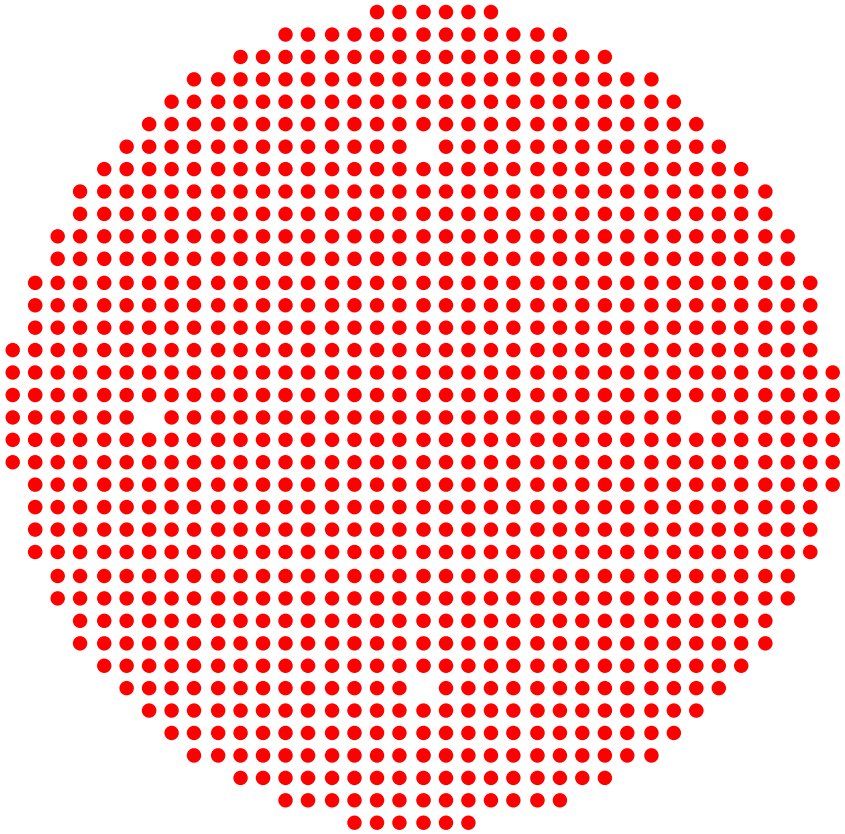
LEU-COMP-THERM-078 Case 5



1041 rods

k_{eff} = 0.9980

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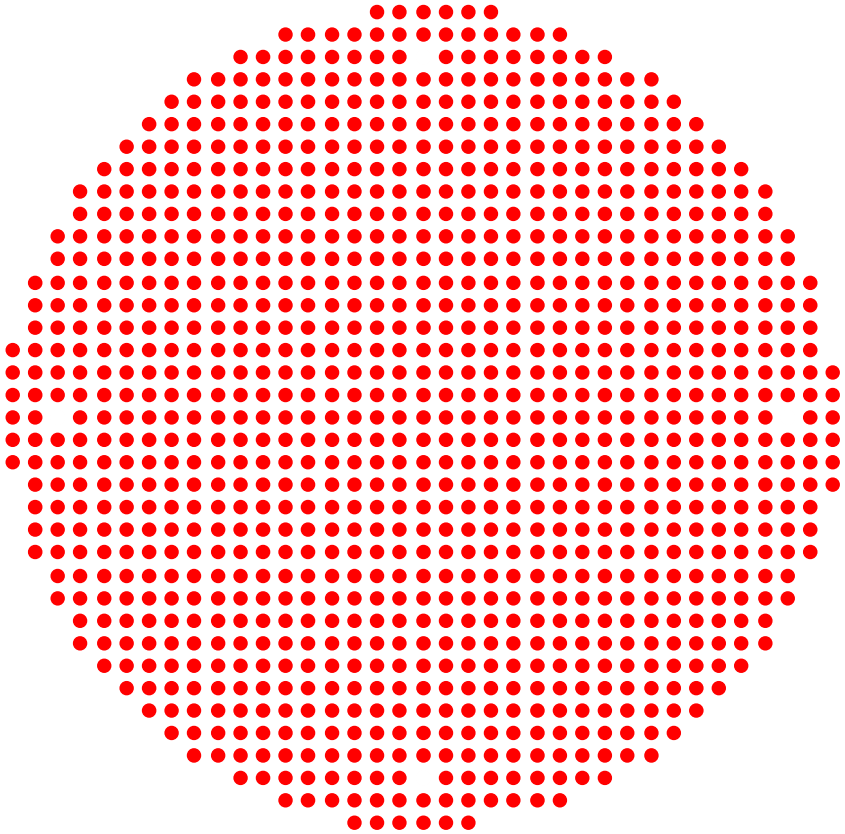
LEU-COMP-THERM-078 Case 6



1041 rods

k_{eff} = 0.9974

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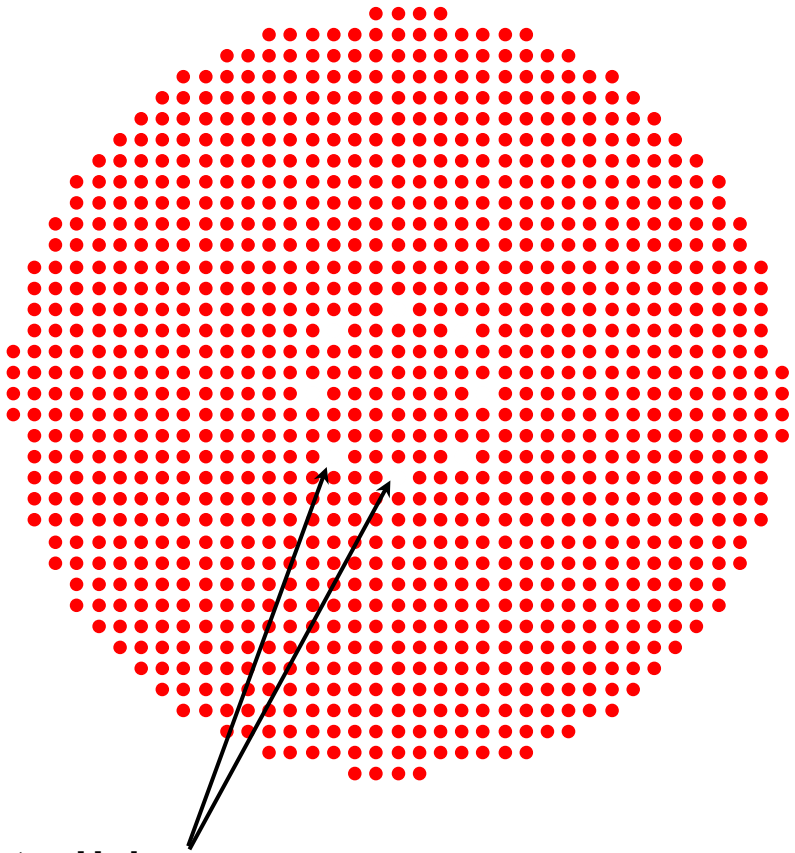
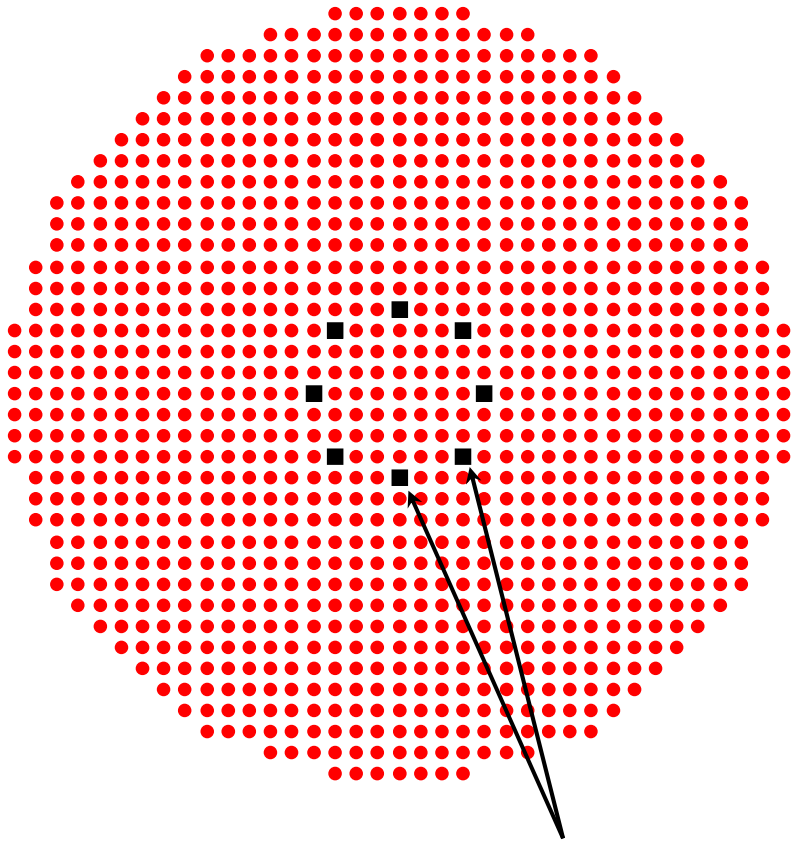
LEU-COMP-THERM-078 Cases 7 and 11



Case 7
1029 rods
k_{eff} = 0.9994



Case 11
1049 rods
k_{eff} = 0.9994

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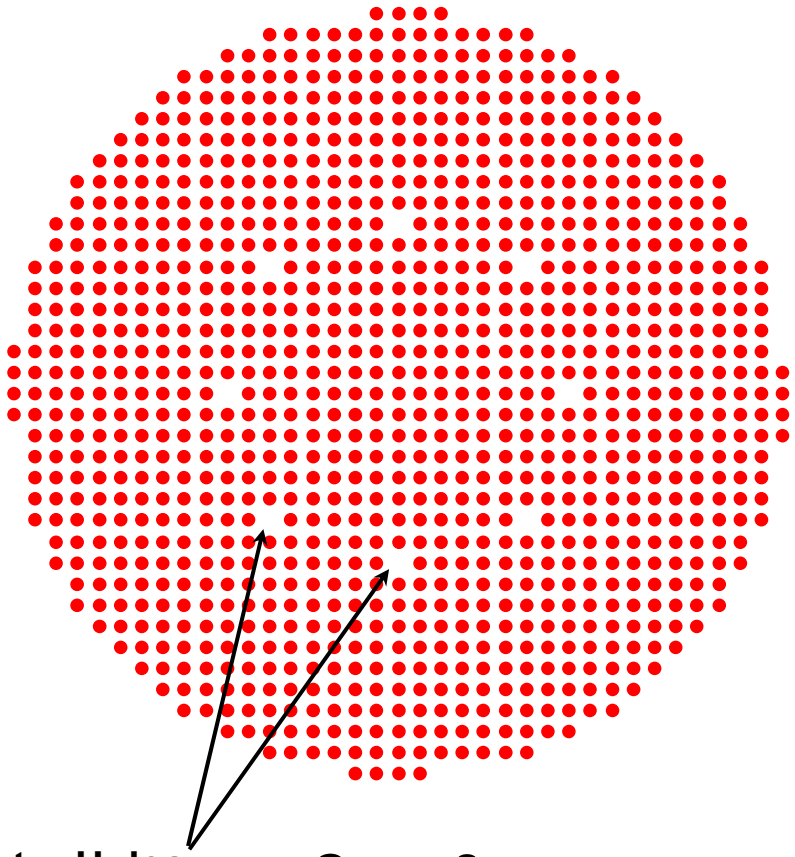
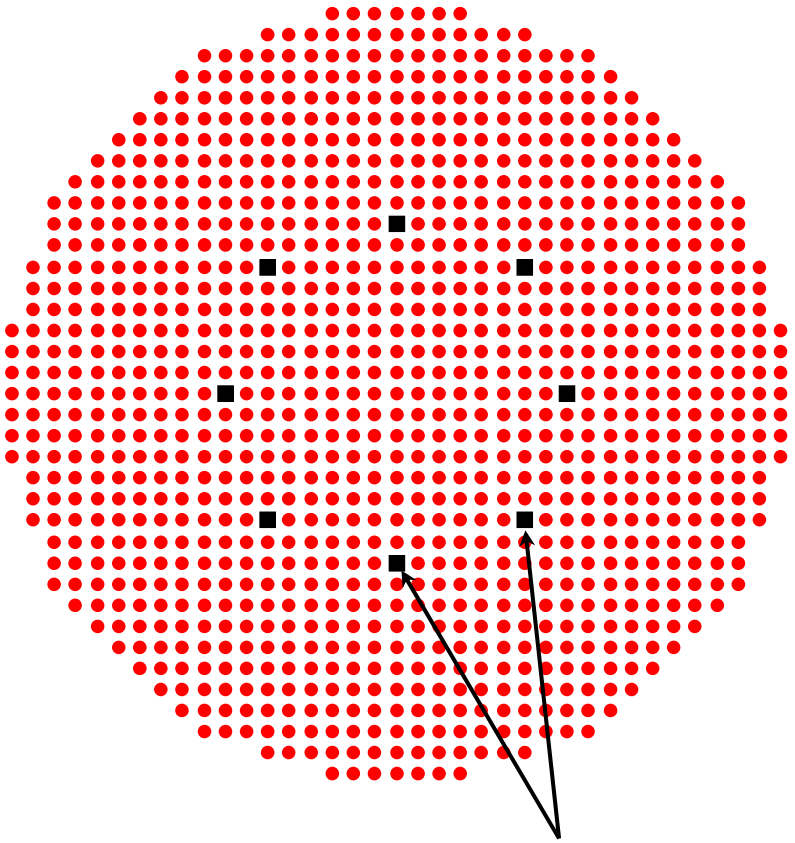
LEU-COMP-THERM-078 Cases 8 and 12



Case 8
1029 rods
k_{eff} = 0.9987



Case 12
1049 rods
k_{eff} = 0.9993

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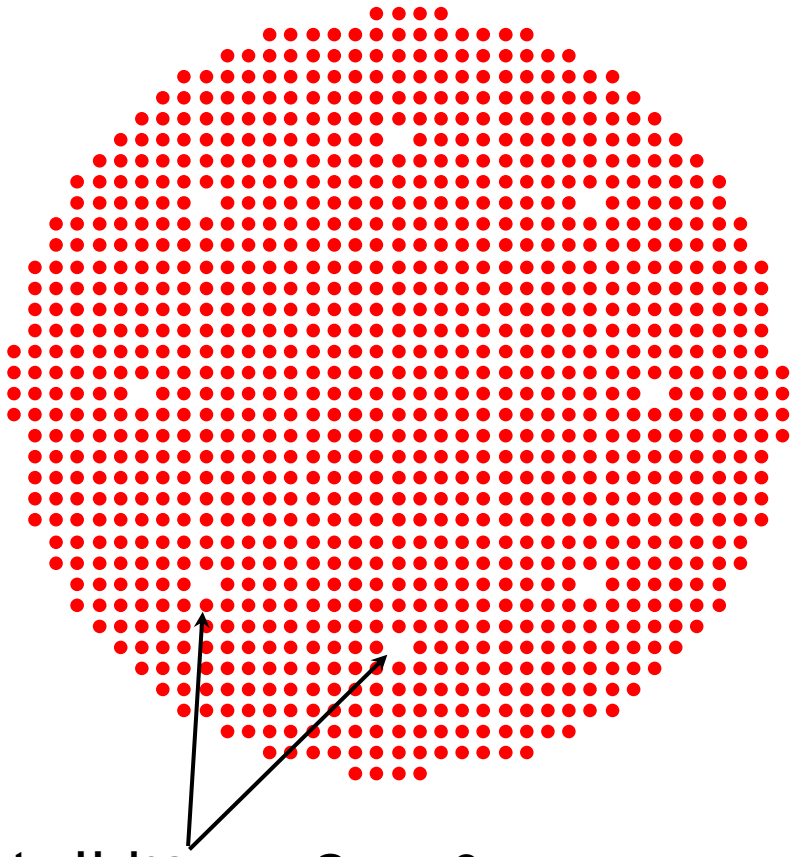
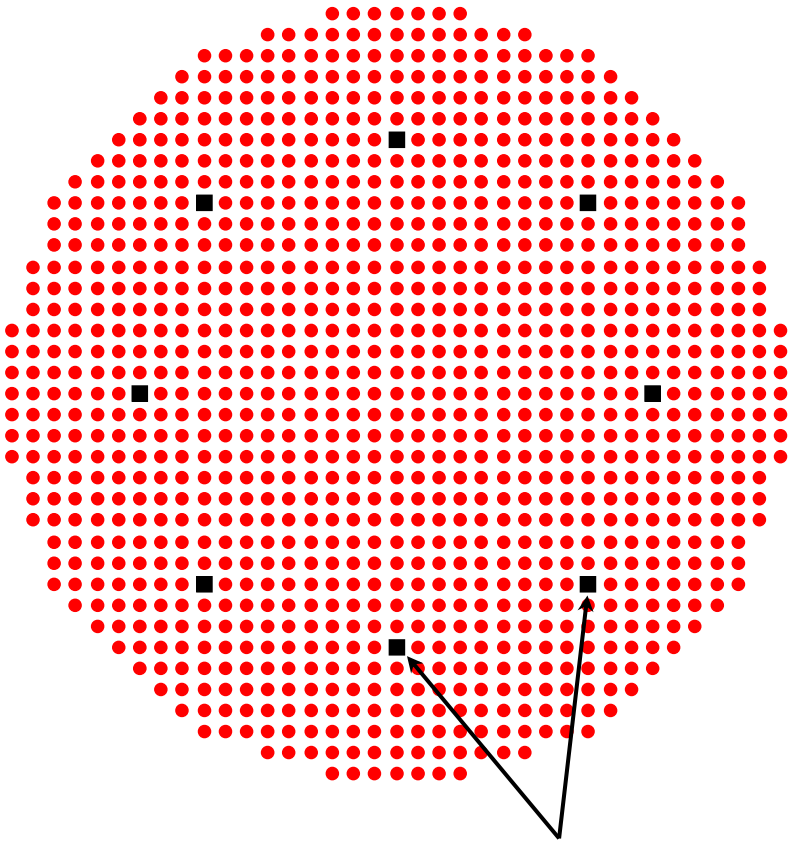
LEU-COMP-THERM-078 Cases 9 and 13



Case 9
1029 rods
k_{eff} = 0.9978



Case 13
1049 rods
k_{eff} = 0.9993

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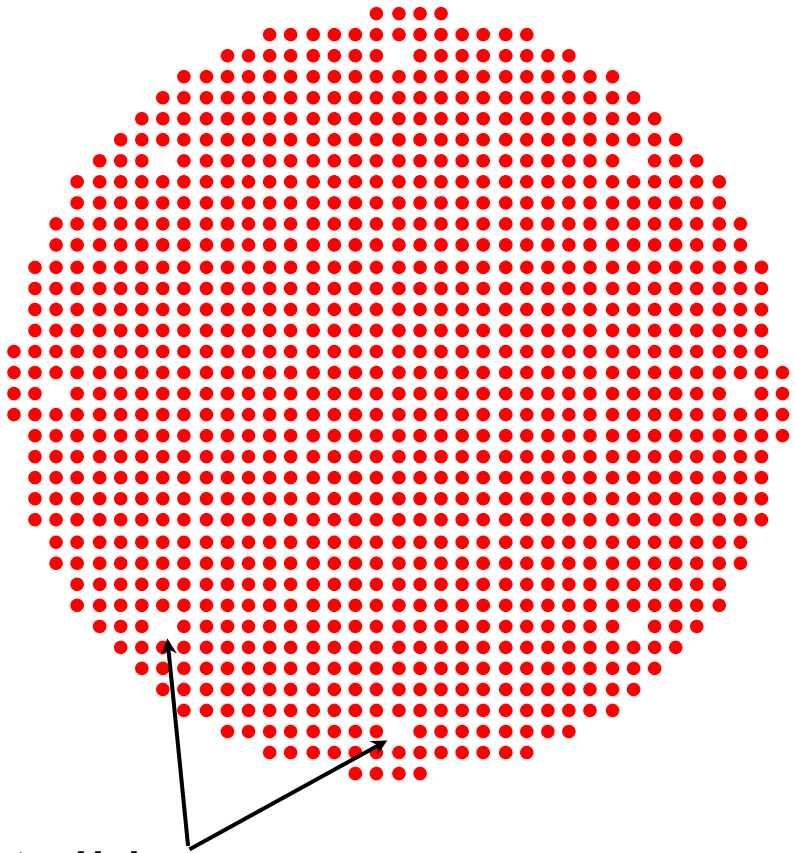
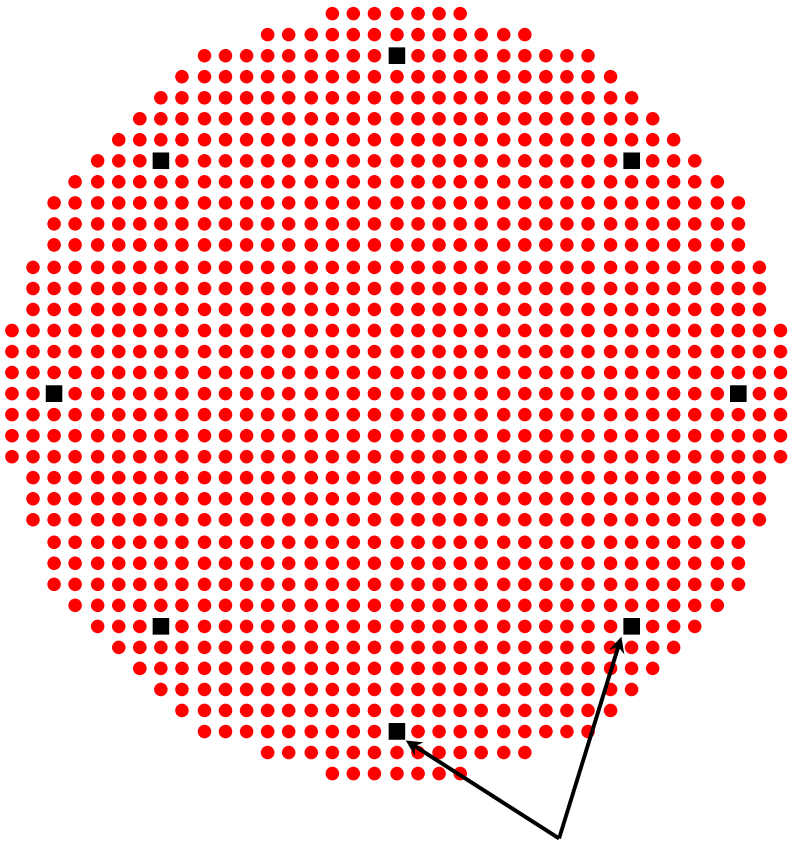
LEU-COMP-THERM-078 Cases 10 and 14



Case 10
1029 rods
k_{eff} = 0.9969



Case 14
1049 rods
k_{eff} = 0.9991

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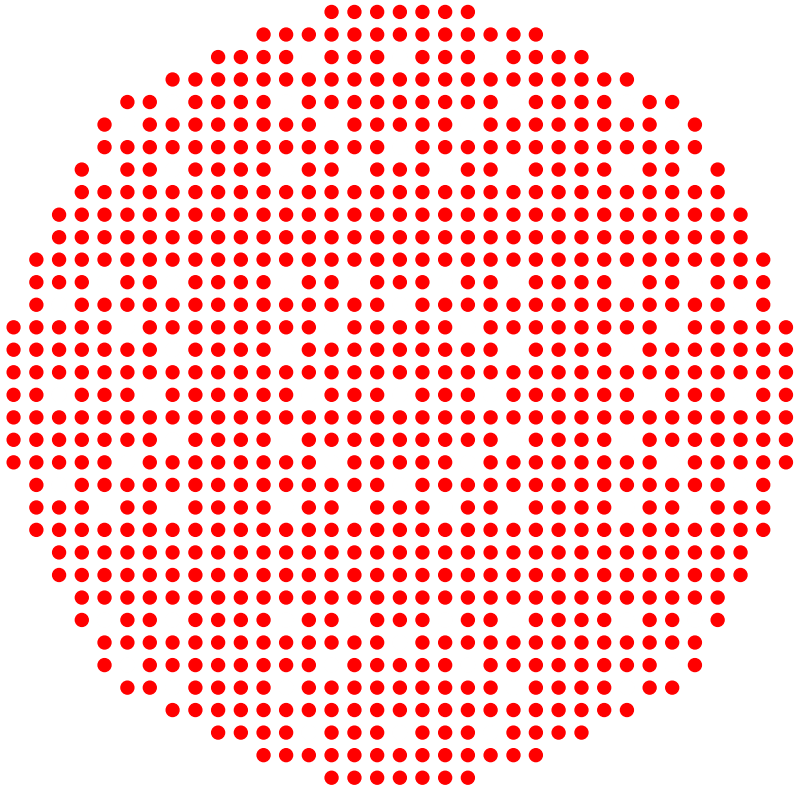
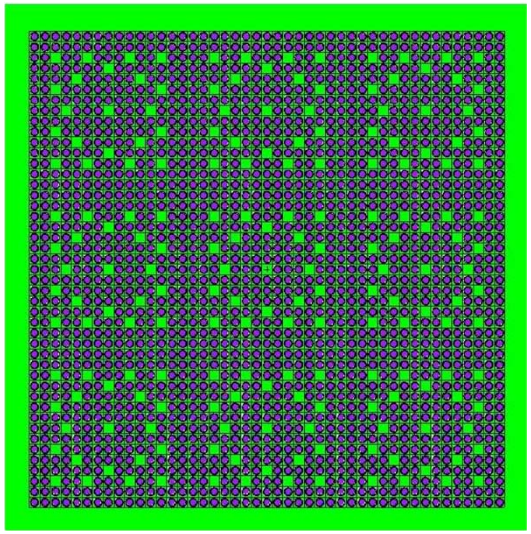
LEU-COMP-THERM-078 Case 15

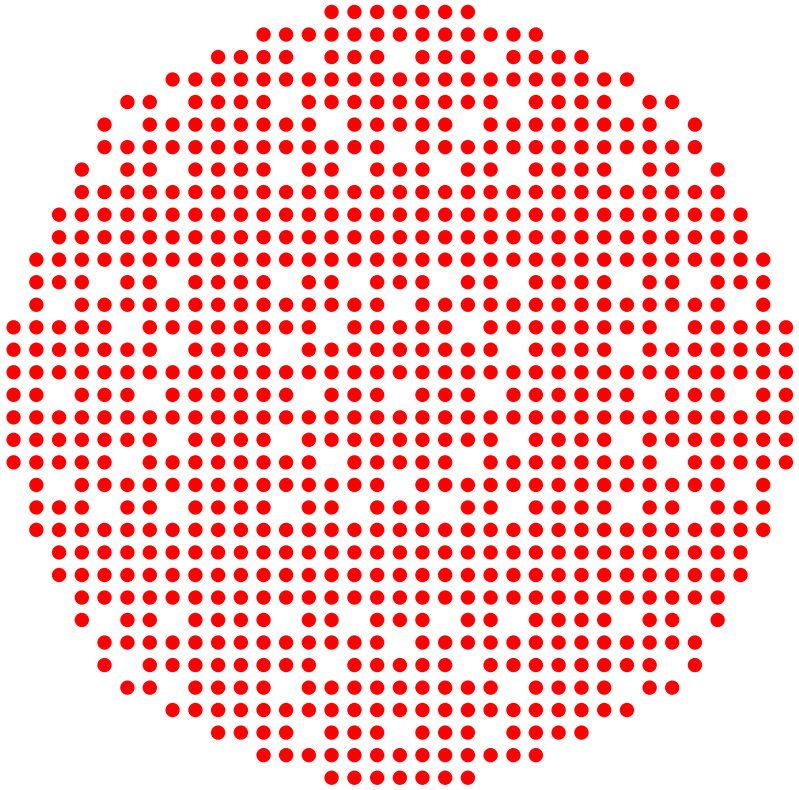


872 rods

k_{eff} = 0.9996

LEU-COMP-THERM-078 Case 15





872 rods

k_{eff} = 0.9996

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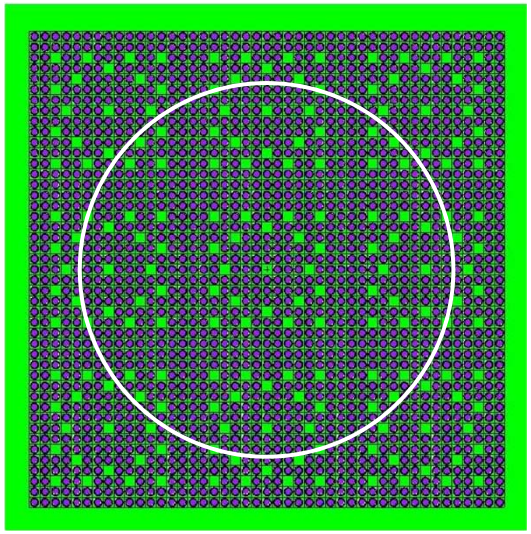
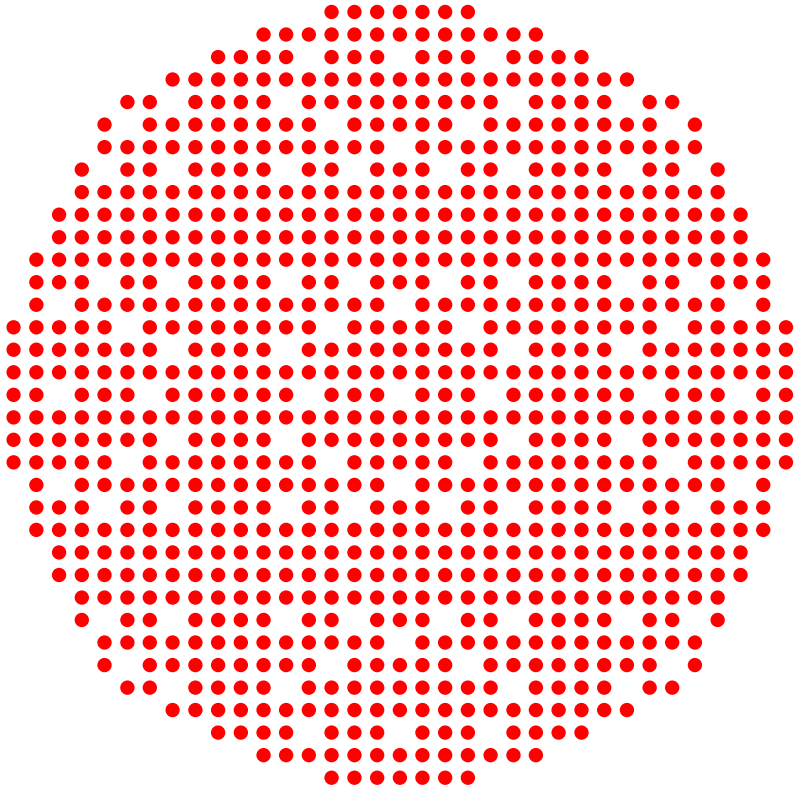
LEU-COMP-THERM-078 Case 15





872 rods

k_{eff} = 0.9996

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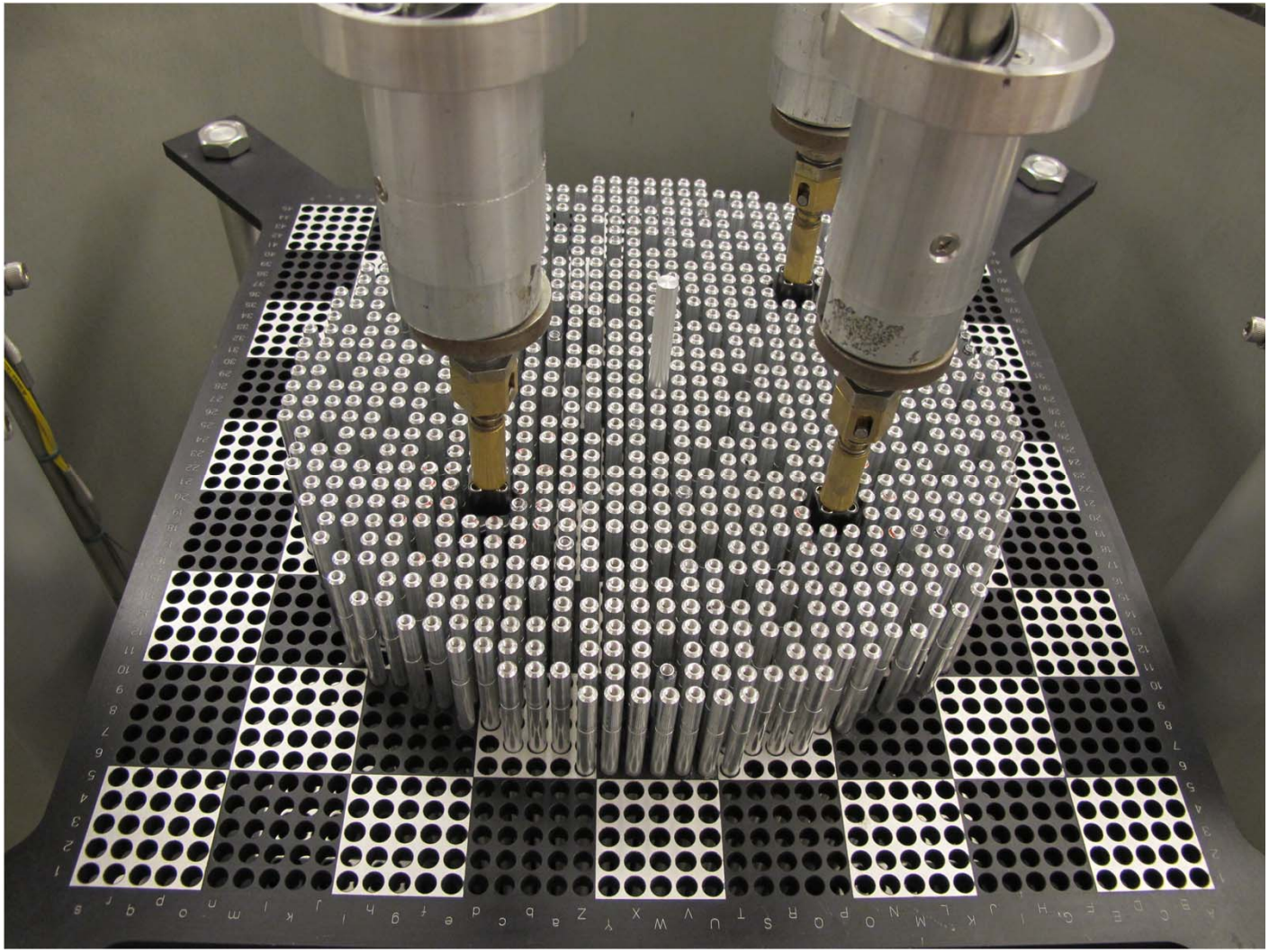
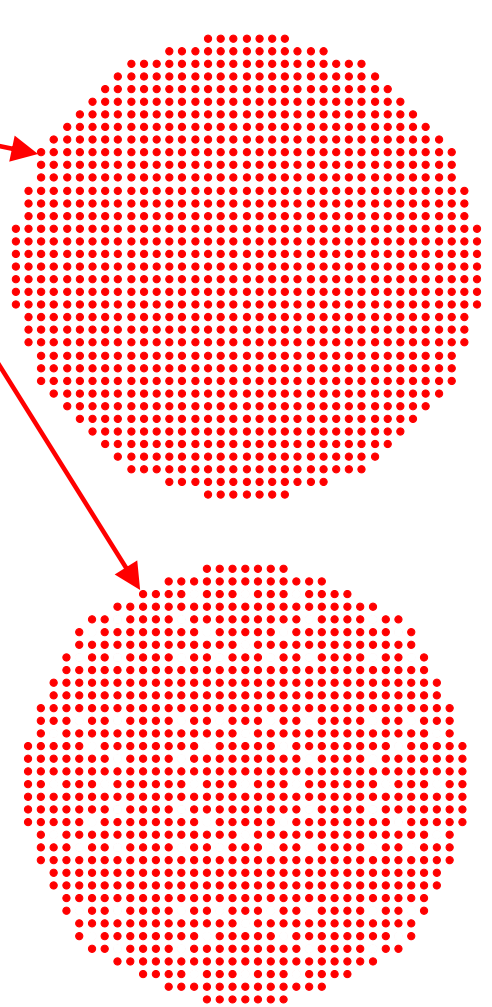
The 7uPCX core at the end of an approach – LCT078 Case 15



The uncertainties in the benchmarks are relatively small

Uncertainty Source	Case 1 Δk_{eff}	Case 15 Δk_{eff}
Pitch of Fuel Rods	0.00073	0.00069
Clad OD	-0.00010	-0.00008
Clad ID	-0.00001	-0.00001
Fuel Pellet OD	0.00000	0.00000
Water Depth	0.00000	0.00000
Rod Fuel Mass	0.00002	0.00002
Rod Fuel Length	0.00004	0.00003
Enrichment	0.00012	0.00013
^{234}U	-0.00001	-0.00001
^{236}U	-0.00001	-0.00001
UO_2 Stoichiometry	-0.00049	-0.00055
Measured Fuel Impurities	-0.00012	-0.00011
Undetected Fuel Impurities	-0.00010	-0.00007
Clad Composition	-0.00027	-0.00026
Grid Plate Composition	-0.00011	-0.00012
Water Composition	-0.00021	-0.00024
Temperature	-0.00005	-0.00004
Sum in Quadrature	**0.0010**	**0.0010**



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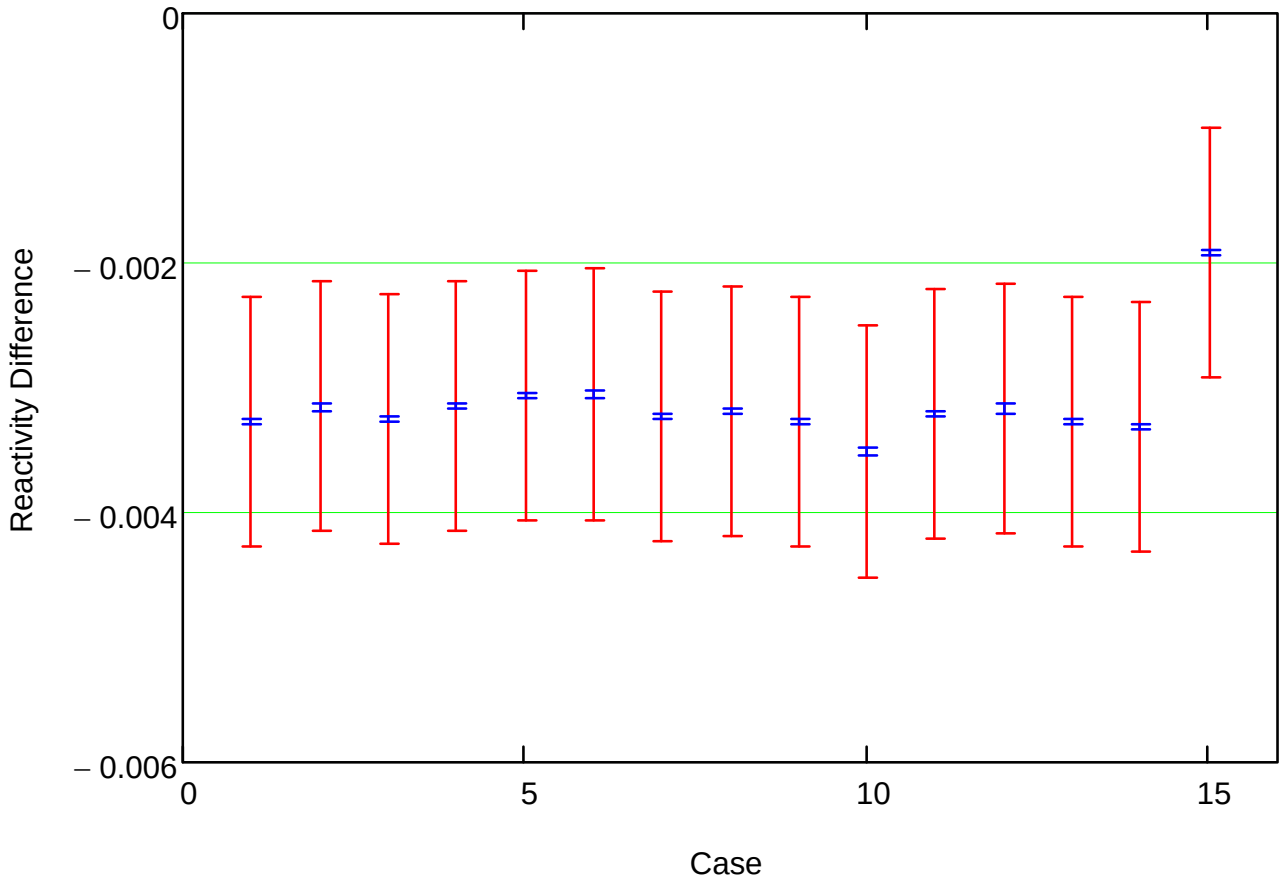
Reactivity Difference – KENO V.a + ENDF/B-VII.0 (MG) vs Benchmark Model k_{eff}



The mean reactivity difference is about 3.2 × experiment uncertainty.
The red error bars show the benchmark uncertainties.
The blue error bars show the stochastic uncertainties in the calculations.

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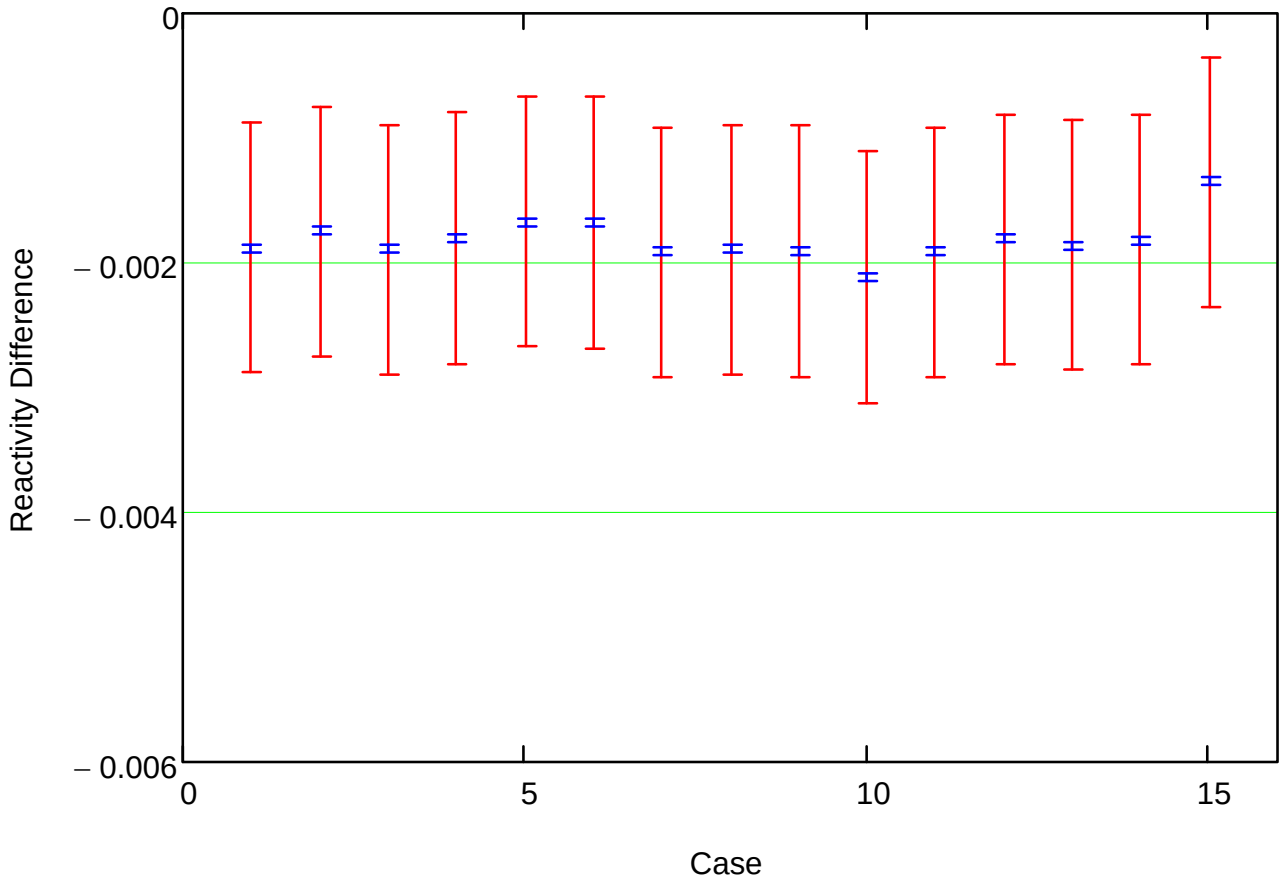
Reactivity Difference – KENO V.a + ENDF/B-VII.0 (CE) vs Benchmark Model k_{eff}



The mean reactivity difference is about 1.8 × experiment uncertainty.
The red error bars show the benchmark uncertainties.
The blue error bars show the stochastic uncertainties in the calculations.

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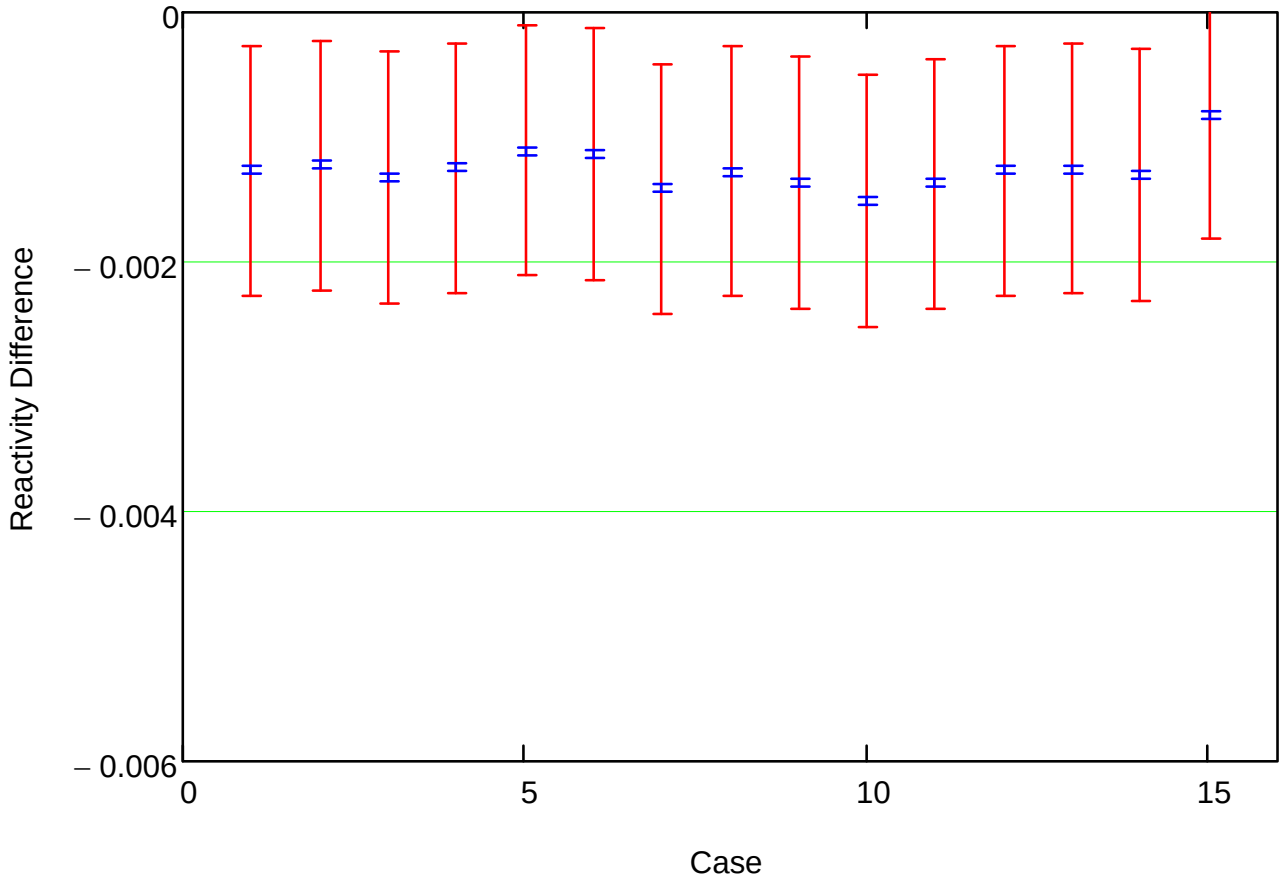
Reactivity Difference – MCNP5 + ENDF/B-VII.0 (CE) vs Benchmark Model k_{eff}



The mean reactivity difference is about 1.3 × experiment uncertainty.
The red error bars show the benchmark uncertainties.
The blue error bars show the stochastic uncertainties in the calculations.

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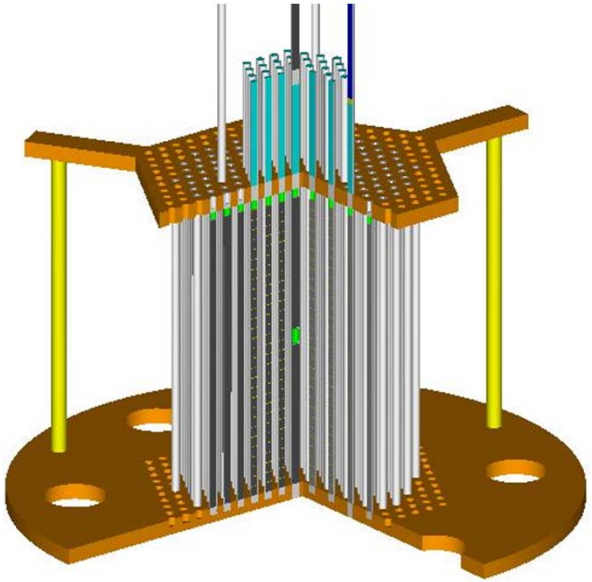
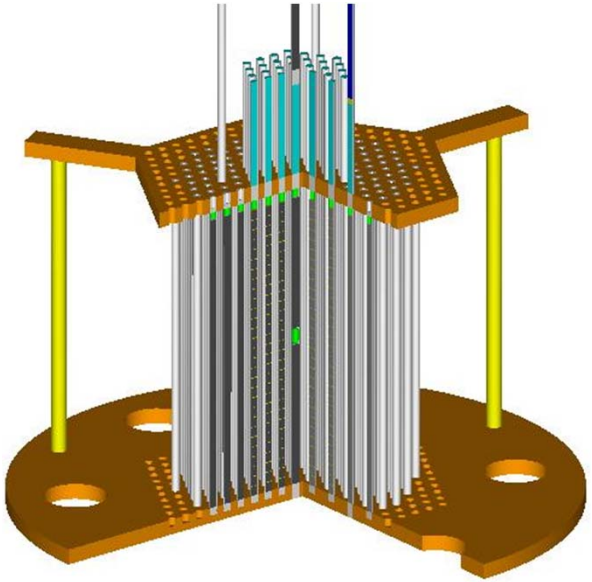
What are We Up To Now?

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



- $C_E dT$:
  - Dick McKnight (ANL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)

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%)O2 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

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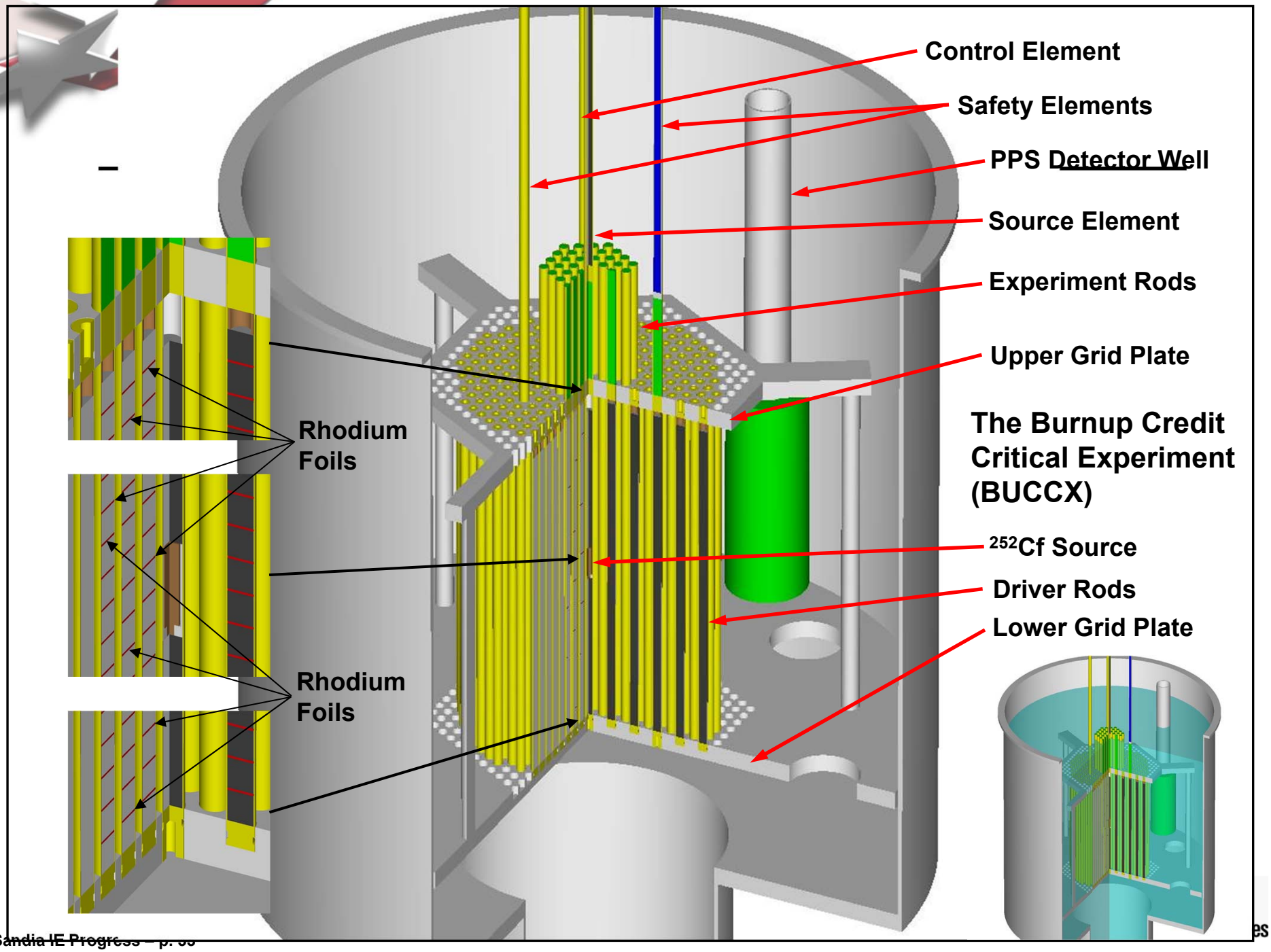
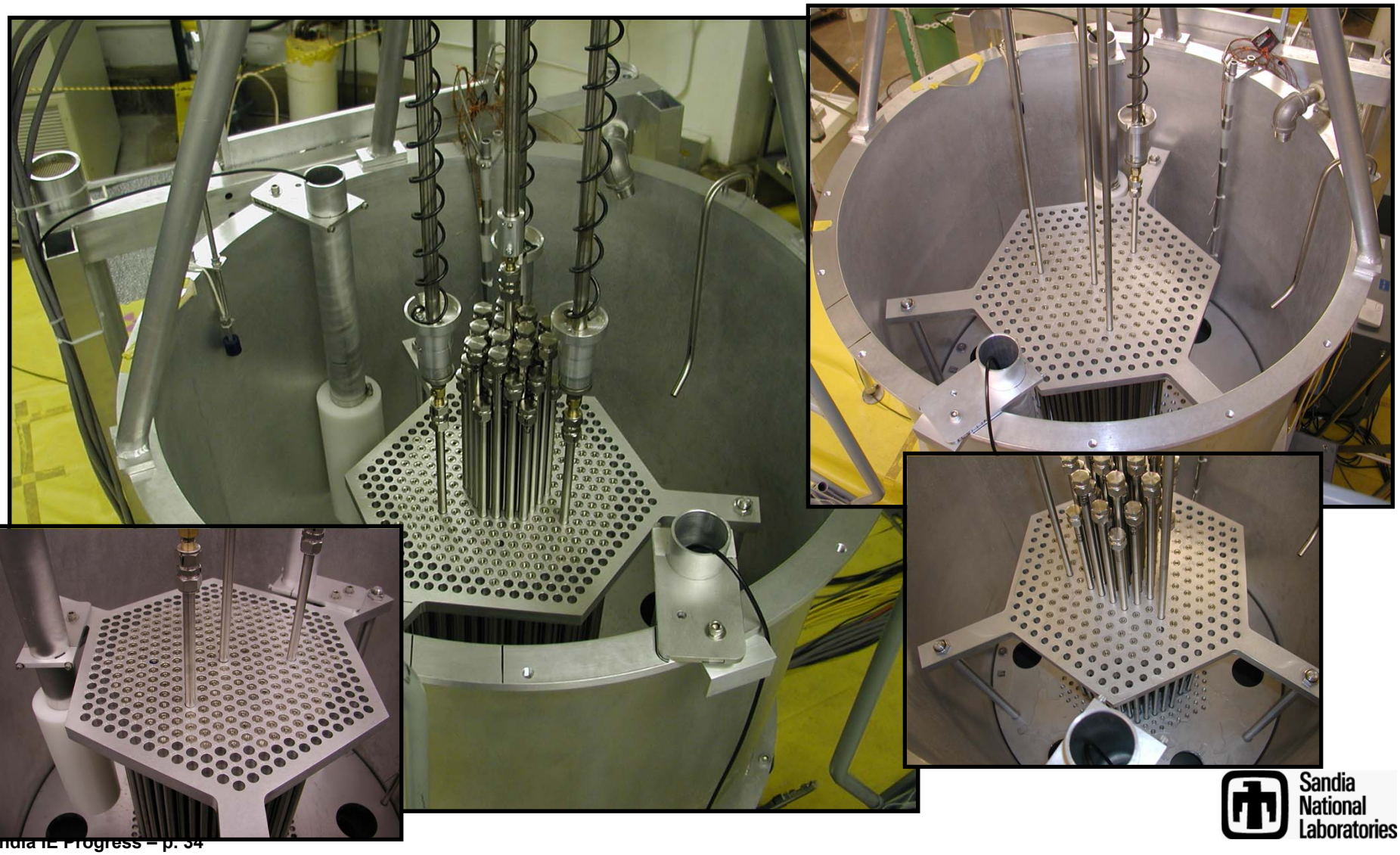

Control Element
Safety Elements
PPS Detector Well
Source Element
Experiment Rods
Upper Grid Plate
The Burnup Credit Critical Experiment (BUCCX)
252Cf Source
Driver Rods
Lower Grid Plate
Rhodium Foils
Rhodium Foils

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



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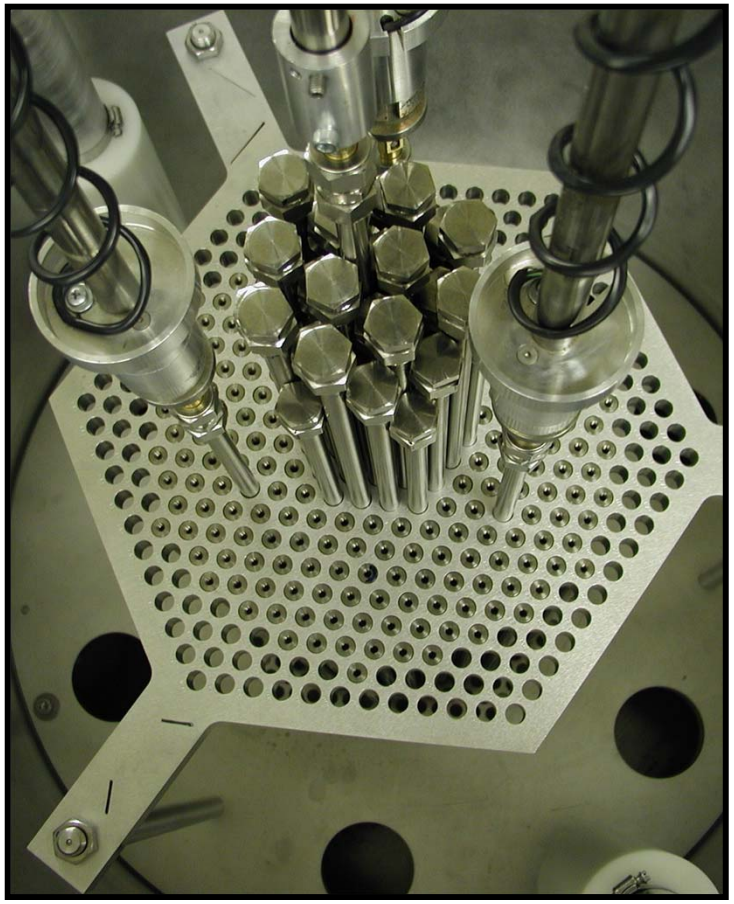
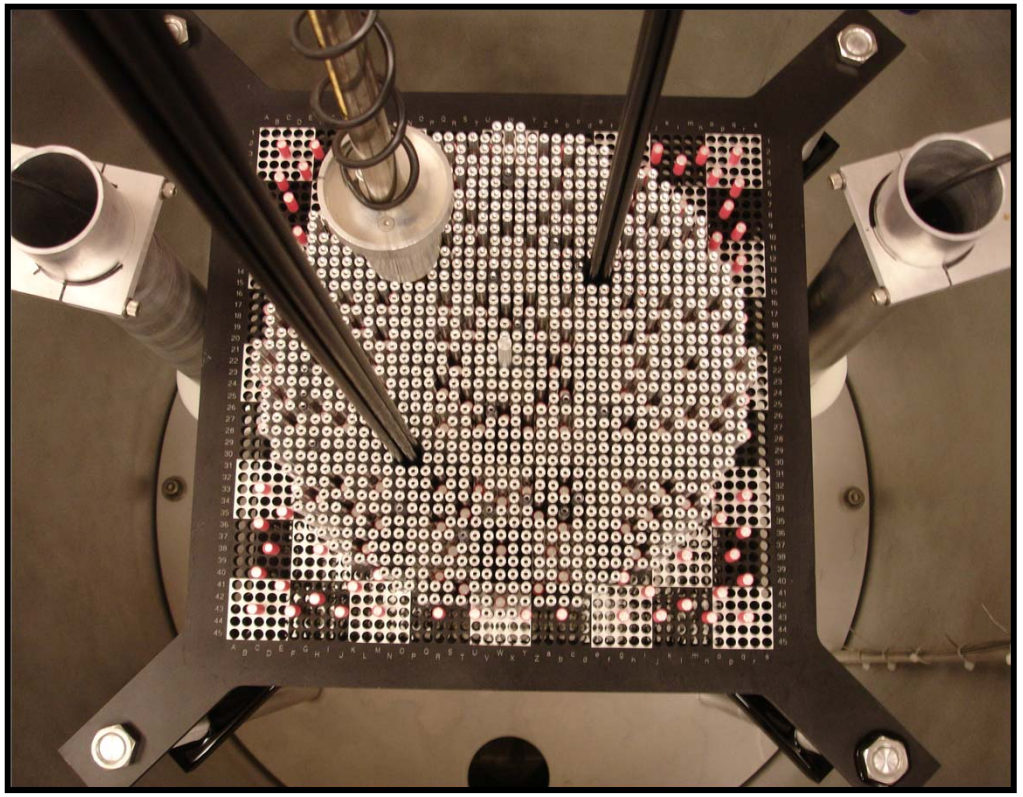
A Comparison of the BUCCX and 7uPCX Cores



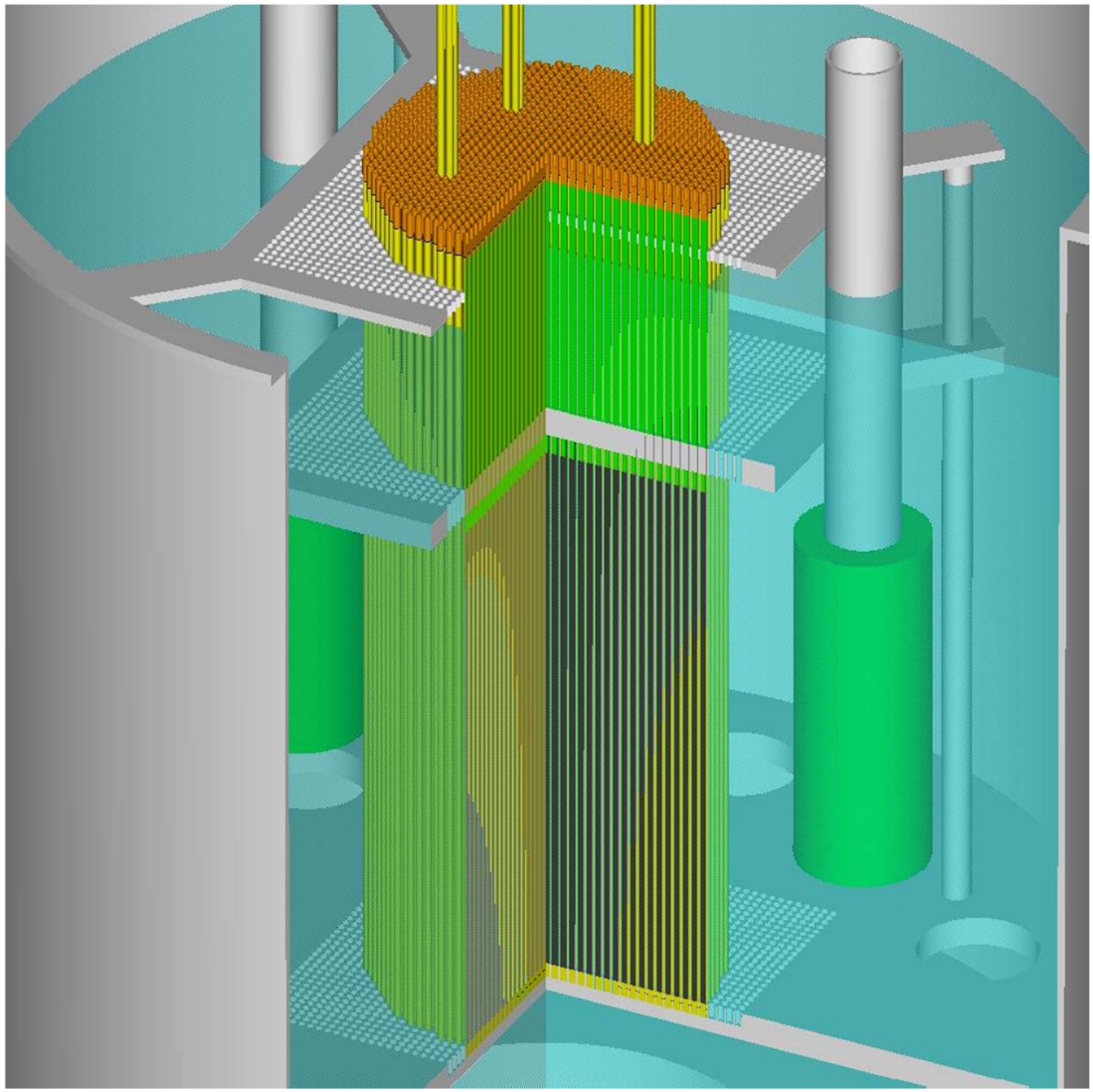


The cores (fuel, grid plates, etc.) are different. The balance of the assembly hardware is the same

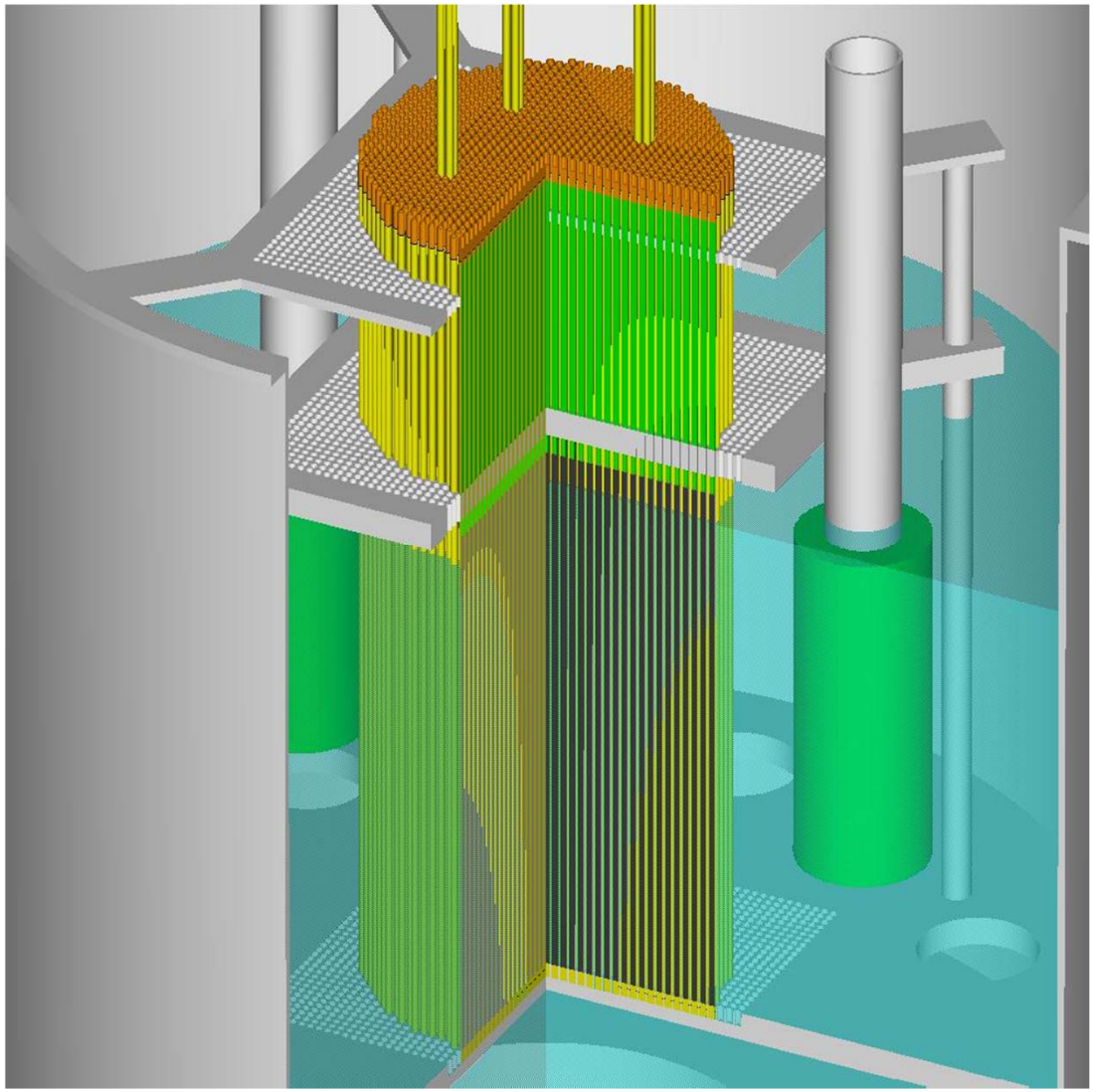
Measure Critical Water Depth as a Function of Fuel Loading – IER-208, -209

- $C_E dT$:
  - Dick McKnight (ANL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)

Fully-Reflected Critical Array With 1057 Fuel Rods – 0.855 cm Pitch



An Array with 1137 Fuel Rods Needs a Water Depth That Covers Most of the Fuel



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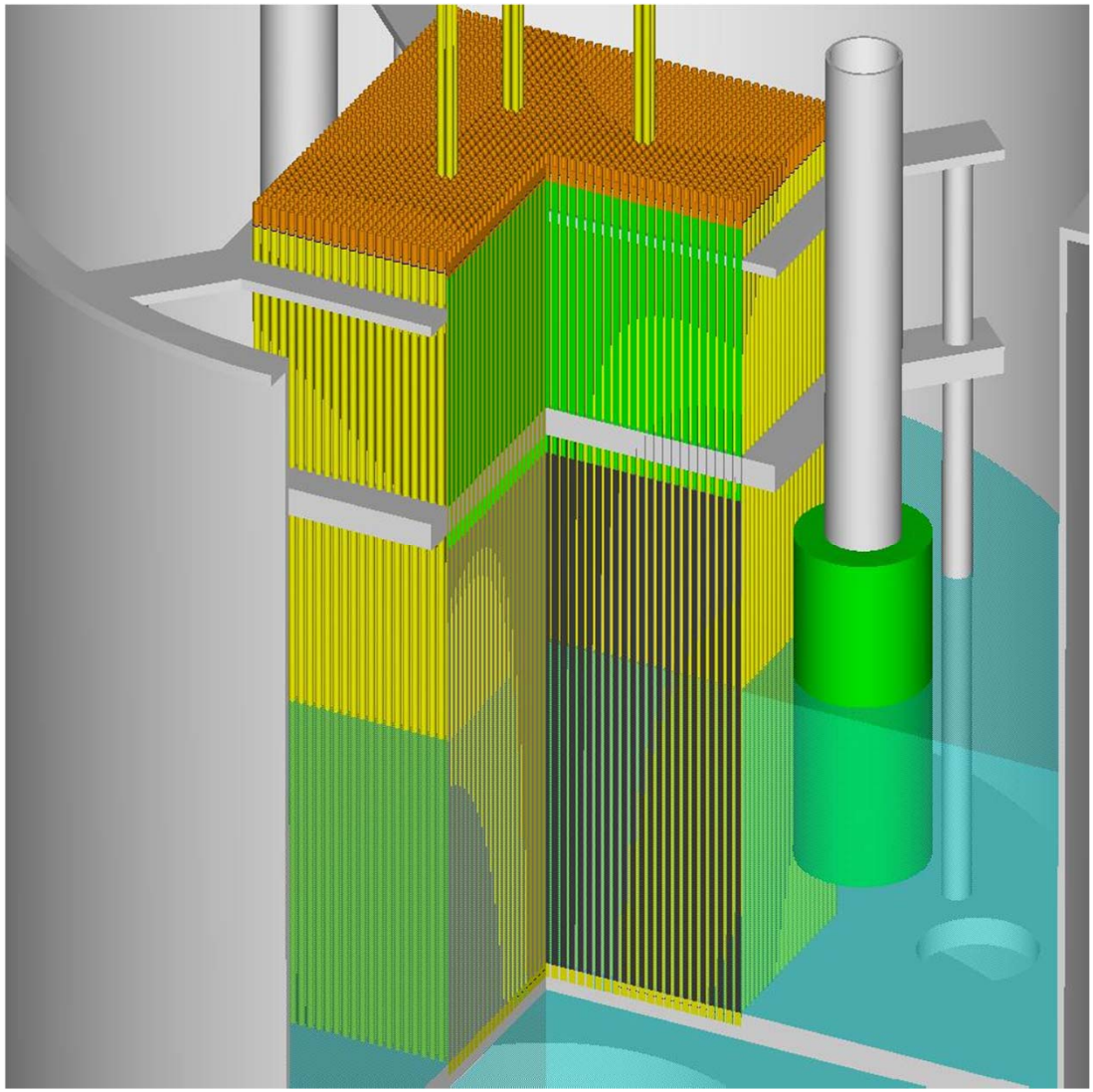
A 2025 Rod Array is Critical with the Water Level Slightly Above the Fuel Midplane



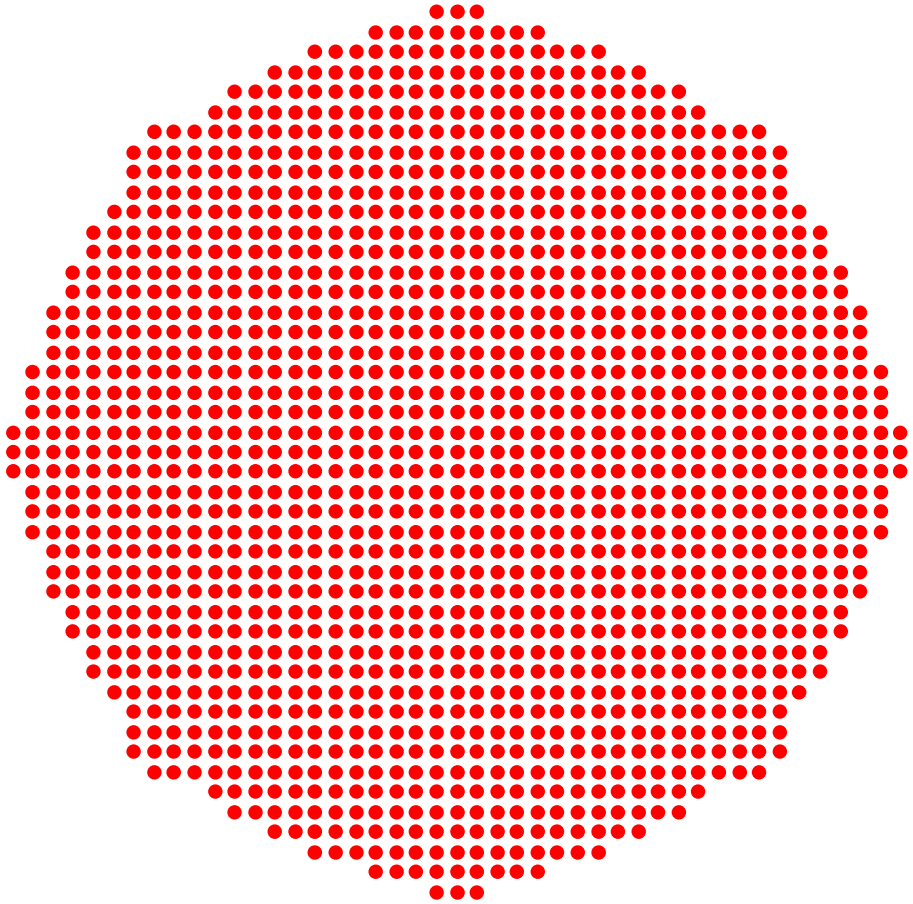
Low-Enriched General-Purpose Split-Table Critical Assembly – IER-226

- $C_E dT$:
  - Allison Miller (SNL)
  - Dick McKnight (ANL)
  - Thomas Miller (ORNL)
  - Dave Heinrichs (LLNL)
  - Gary Harms (SNL)
- CED-1 Conceptual Design is in progress

Measure Critical Fuel Loading as a Function of Pitch (Fully Reflected)

IER-230 (not yet started)

LCT080 Case 1 Configuration
Pitch 0.800 cm – Critical with ~1461 Rods



p800B0000B
1461

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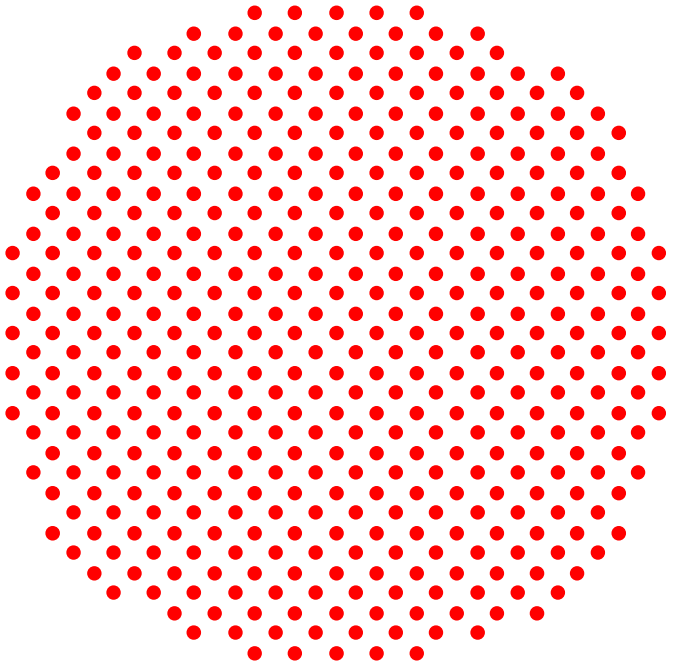
Remove 1 in 2 Rods – Pitch 1.132 cm
Critical with ~454 Rods

Leave Every Other Position Open in a Checkerboard Pattern



p1132B0000B
454

Pitch Increases by a Factor of √2
The Diagonals Become the Fuel Rows

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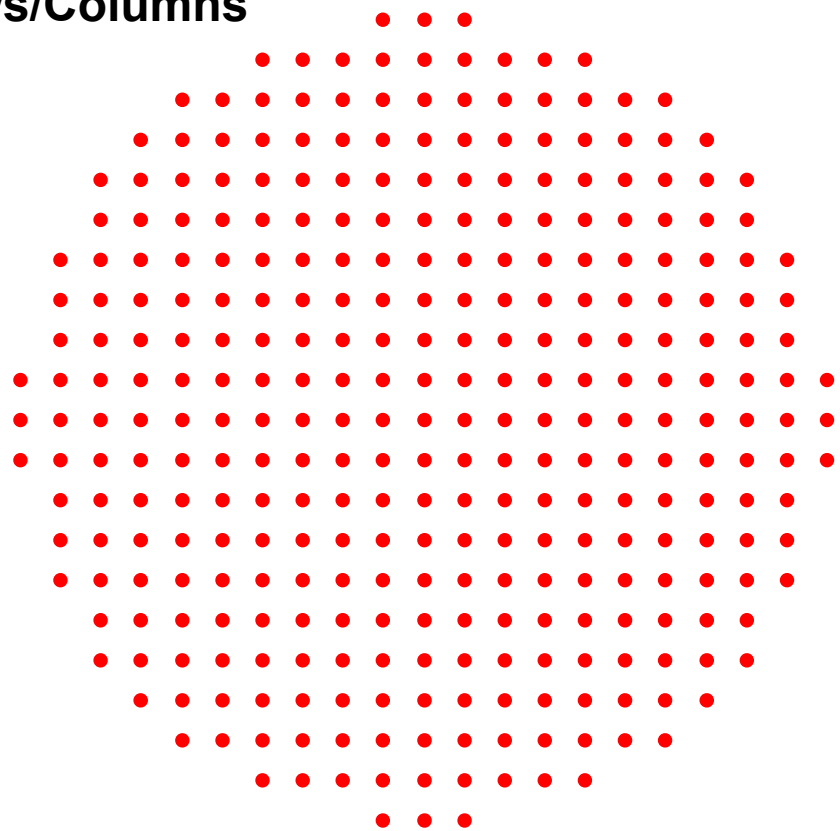
Remove 3 in 4 Rods – Pitch 1.600 cm
Critical with ~328 Rods

Leave Three of Four Positions Open

Remove Alternate Rows/Columns



p1600B0000B
328

Pitch Increases by a Factor of 2

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Changing the Pitch by Removing Rods from the Grid

Grid Plate Pitch (cm)	Effective Pitch (cm)	Rods Removed from Grid	Critical Array Size (rods)	Critical Array Volume (m^3)
0.800	0.800	None	1461	0.0468
0.855	0.855	None	1059	0.0387
0.800	1.132	1 in 2	454	0.0291
0.855	1.209	1 in 2	403	0.0295
0.800	1.600	3 in 4	328	0.0420
0.855	1.710	3 in 4	340	0.0497

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Concluding Remarks

- We have evaluated two 7uPCX experiment series
  - LEU-COMP-THERM-080 using a 0.800 cm pitch array with full reflection is in the 2012 edition of the benchmark book
  - LEU-COMP-THERM-078 using a 0.855 cm pitch array with full reflection has been accepted for inclusion in the 2013 edition
- We are working on future directions for our experiments
  - 7uPCX experiments with larger arrays and the approach done on moderator/reflector depth
  - BUCCX
  - Low-enriched general-purpose split-table critical assembly
  - Characterize capabilities with the 7uPCX fuel

Critical Experiments at Sandia