Critical Experiment Training at Sandia

Nuclear Criticality Safety Program Technical Seminar

Oak Ridge National Laboratory
March 14, 2011

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Sandia National Laboratories

SAND2012-XXXXC

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Colleagues

- **Reactor Operations**
  - **John Ford**
  - **Rafe Campbell**
- **Experiment, Class Materials**
  - **Allison Miller**
  - **John Miller**
- **Administrative Support**
  - **Mary Ellen Ratzer**
  - **Emily Fuller**
  - **Nancy Collins**

What is ahead

- We have developed a hands-on criticality experiments class
- It is part of the US DOE Nuclear Criticality Safety Program (NCSP) Training and Education Program for Nuclear Criticality Safety Engineers
- The class is a series of four experiments
  - Approach on fuel
  - Approach on moderator height
  - "Split table" approach
  - Fuel removal approach
- Lectures on various subjects are interspersed throughout the experiments

Classroom discussions are interspersed through the experiments

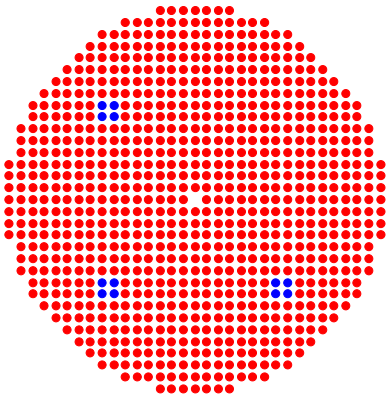
- The basics of criticality safety
- Criticality safety data and limits
- Historic critical experiments
- Subcritical multiplication
- Reactor theory and kinetics
- Description of selected critical mass accidents
- The design and operation of critical experiments at Sandia
- Radiation detection in the 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
Approach to Critical on Fuel Loading

Experiment 1 Overview

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

Core Loading Experiment Configuration 1



Fuel Rods: 836

k ~ 0.95

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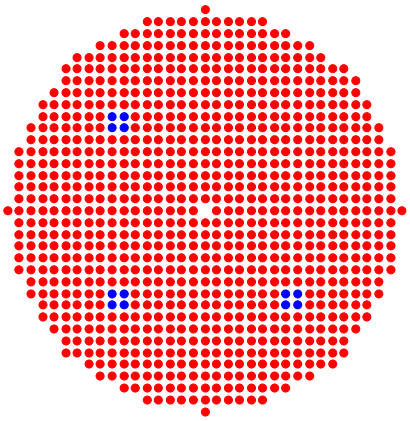
Core Loading Experiment Configuration 2



Fuel Rods: 895

k ~ 0.97

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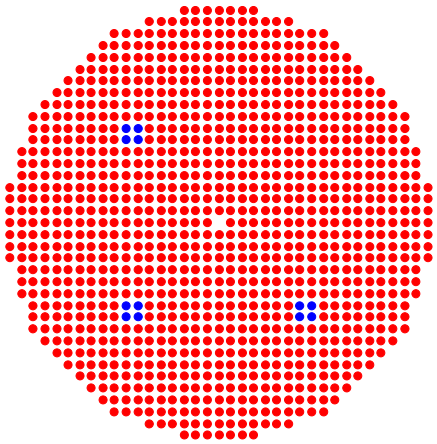
~Critical Core Loading



Fuel Rods: 1060

k ~ 1.00 (at 1059.6 rods)

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Mechanics of the Experiment

- The number of fuel rods in the core changes
- The fuel configurations are guided by the count rates
- The class sorts the fuel rods and passes them to the operations staff
- The operations staff places fuel rods in the core
- The minimum fuel increment is eight rods

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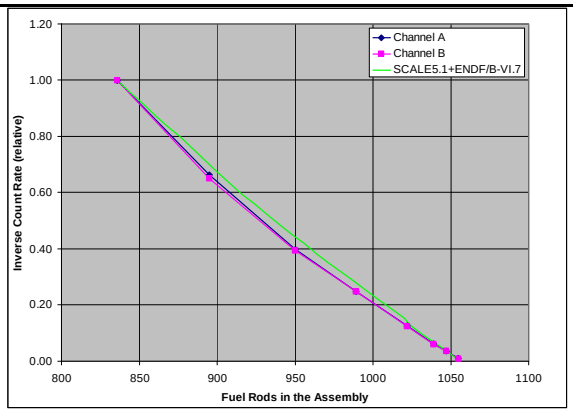
The Experiment Process

- The desired fuel rod array is loaded
- The safety rods are “cocked”
- The reactor room is cleared
- The core tank is filled with water
- The control rod is raised – this puts the assembly in its most reactive condition in this operational mode
- Counts are taken
- The core tank is drained
- The control rod is lowered
- The safety rods are dropped
- The next fuel increment is determined from the count rates
- The reactor room is opened
- Loop back to the first step on this page

8/16/2011 Approach on Fuel Loading



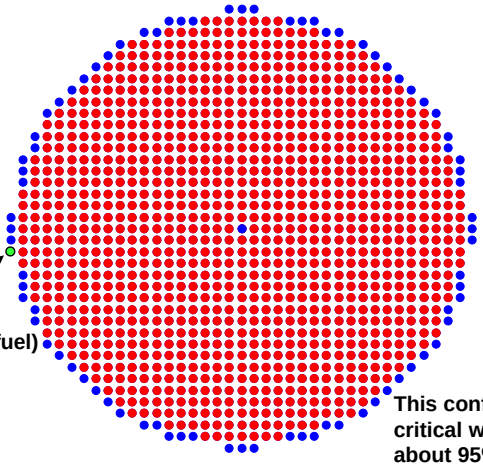
	Count Rate		Inverse Count Rate		Channel A		Channel B	
Rods	Ch. A	Ch. B	Ch. A	Ch. B	Projected	Next	Projected	Next
836	6130	5632	1.0000	1.0000				
895	9237	8655	0.6636	0.6507	1011.40	953.20	1004.92	949.96
950	15377	14292	0.3986	0.3941	1032.74	991.37	1034.45	992.22
989	24647	22716	0.2487	0.2479	1053.69	1021.35	1055.17	1022.08
1022	48744	45195	0.1258	0.1246	1055.75	1038.88	1055.35	1038.67
1039	98406	93457	0.0623	0.0603	1055.69	1047.34	1054.92	1046.96
1047	165607	156219	0.0370	0.0361	1058.71	1052.86	1058.91	1052.96
1055	626813	596754	0.0098	0.0094	1057.87	1056.44	1057.84	1056.42

Experiment 2
Approach to Critical on Moderator Height

Experiment 2 Overview

- **We perform an approach-to-critical experiment by increasing the moderator height in the assembly with a constant fuel loading**
- **Criticality safety parameters that are in play:**
  - **Moderation**
  - **Geometry**
  - **Mass**
- **Application to criticality safety:**
  - **What happens to an array that becomes flooded?**

The Fuel Rod Configuration



This configuration goes critical with the moderator at about 95% of the fuel height

1137 fuel rods

The blue rods are the difference from the fully-reflected critical array in the first experiment

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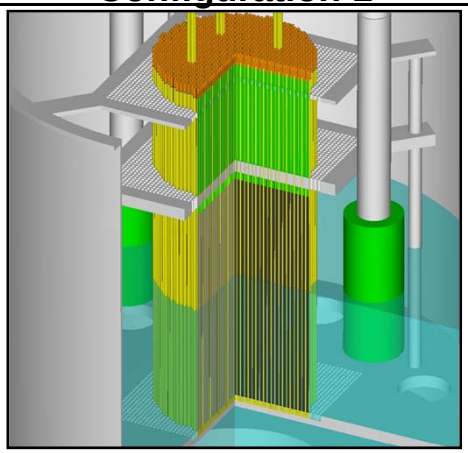
Moderator Height Experiment Configuration 1



Fuel Rods: 1137

k_{eff}: ~0.90

Water Depth: 271.6 mm

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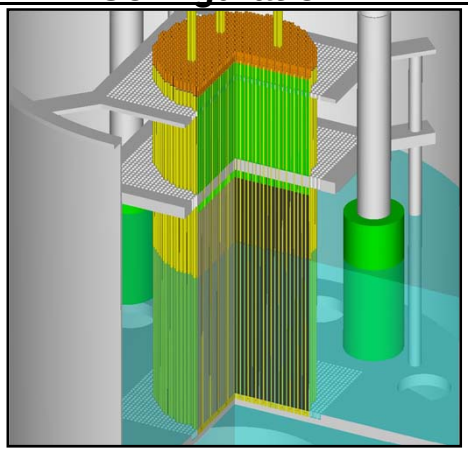
Moderator Height Experiment Configuration 2

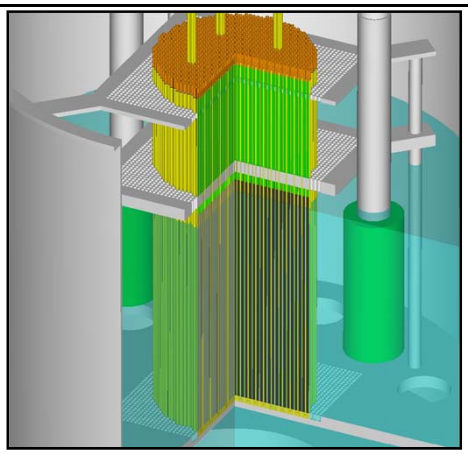


Fuel Rods: 1137

k_{eff}: ~0.95

Water Depth: 341.3 mm

Moderator Height Experiment at DC



Fuel Rods: 1137

k_{eff}: ~1.0

Water Depth: 461 mm

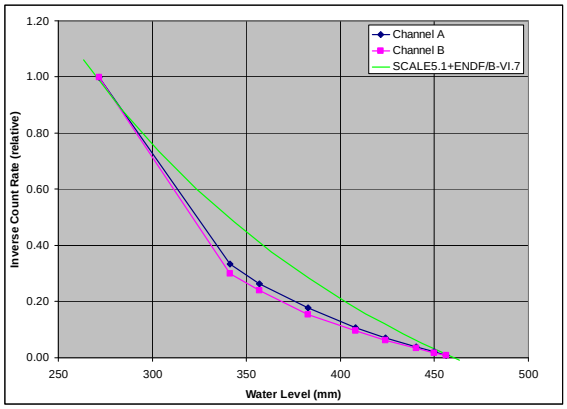
Mechanics of the Experiment

- The number of fuel rods in the core is constant
- The approach-to-critical is done with the depth of the moderator in the core tank as the free parameter
- The choice of water depth is guided by the count rates
- This approach is done remotely (we don't go into the reactor room)
- The minimum water height increment is 5 mm

The Experiment Process

- The desired fuel rod array is loaded
- The safety rods are "cocked"
- The reactor room is cleared
- The core tank is filled with water to the height that gives a calculated k_{eff} of about 0.90
- The control rod is raised
- The slow pump is turned on – the water height in the core is controlled by the setting of the overflow standpipe
- When the water level in the core tank reaches the standpipe, counts were taken [A]
- The next water level is determined from the previous two counts
- The standpipe is set for the new water level
- Loop back to the step marked [A]

8/17/2011 Approach on Moderator Level



$$M_1 = \frac{1}{1-0.9} = 10$$

$$I_1 = \frac{M_1}{M_1} = 1$$

The relative inverse multiplication

$$M_2 = \frac{1}{1-0.95} = 20$$

$$I_2 = \frac{M_1}{M_2} = \frac{10}{20} = 0.5$$

	Count Rate		Inverse Count Rate		Channel A		Channel B	
Water Level	Ch. A	Ch. B	Ch. A	Ch. B	Projected	Next	Projected	Next
271.7	1034	853	1.0000	1.0000				
341.4	3108	2847	0.3327	0.2996	376.15	358.77	371.22	356.31
357	3917	3565	0.2640	0.2393	416.93	386.97	418.86	387.93
382.9	5826	5521	0.1775	0.1545	436.04	409.47	430.11	406.50
408	9687	8939	0.1067	0.0954	445.87	426.94	448.54	428.27
424.1	14600	13547	0.0708	0.0630	455.84	439.97	455.33	439.72
440.2	26853	25241	0.0385	0.0338	459.38	449.79	458.85	449.53
450	50723	48777	0.0204	0.0175	461.02	455.51	460.51	455.25
456.1	113530	108681	0.0091	0.0078	461.03	458.56	461.07	458.58

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Experiment 3
Approach to Critical on Fuel Lump Separation

Experiment 3 Overview

- 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
- Criticality safety parameters that were in play:
  - Interaction
  - Moderation

- 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.

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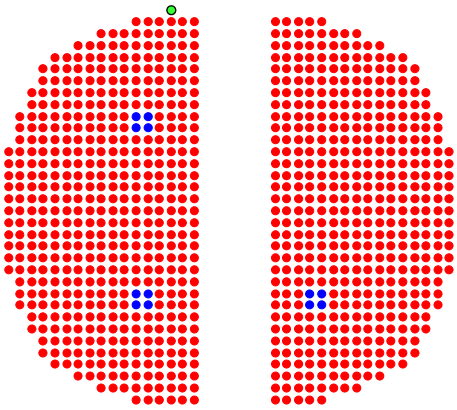
Core Separation Experiment Configurations



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

Separation: 5.130 cm

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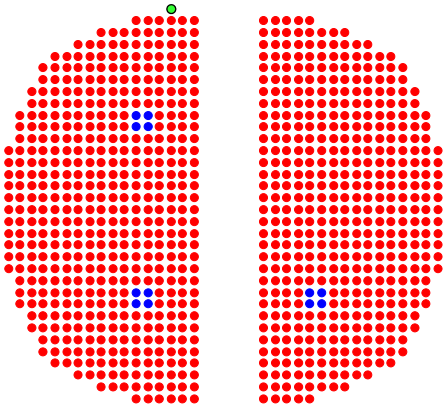
Core Separation Experiment Configurations



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

Separation: 4.275 cm

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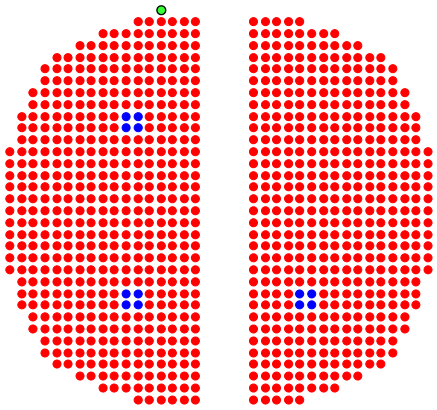
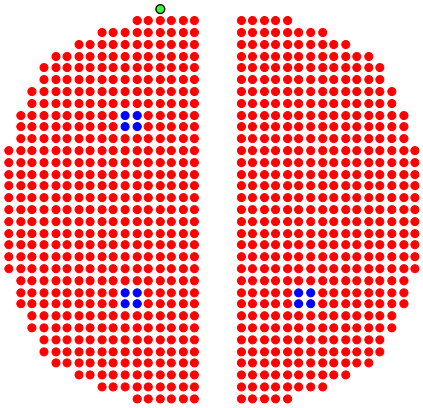
Core Separation Experiment Configurations



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

Separation: 3.420 cm

Core Separation Experiment Configurations



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

Separation: 2.565 cm

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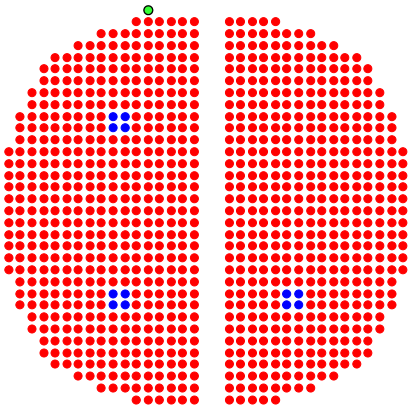
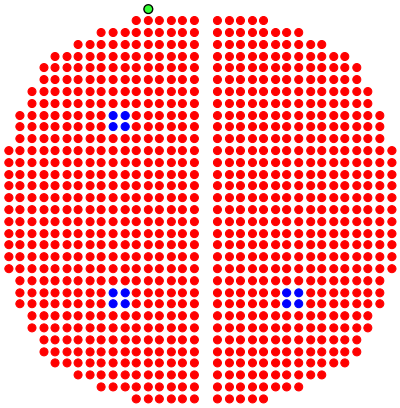
Core Separation Experiment Configurations



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

Separation: 1.710 cm

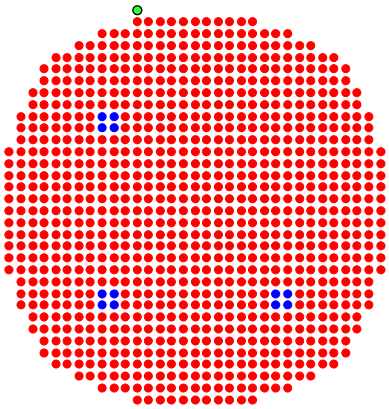
Core Separation Experiment Configurations



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

Separation: 0.855 cm

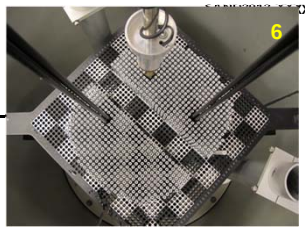
Core Separation Experiment Configurations

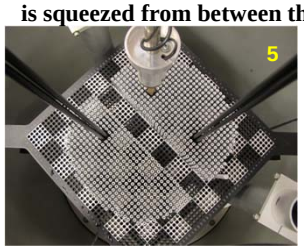


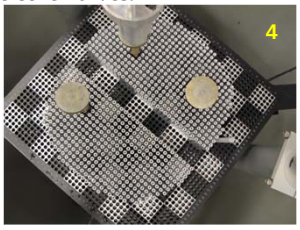
Fuel Rods: 921

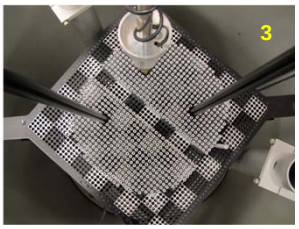
8/18/2011 Fuel Separation

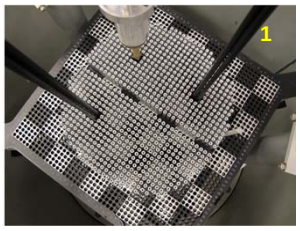
This experiment demonstrates the trade-off between increasing interaction between the core halves as they come together and decreasing moderation as the water is squeezed from between the core halves.

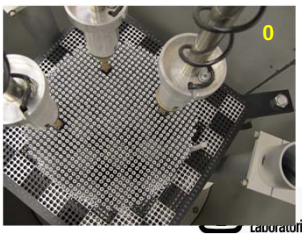




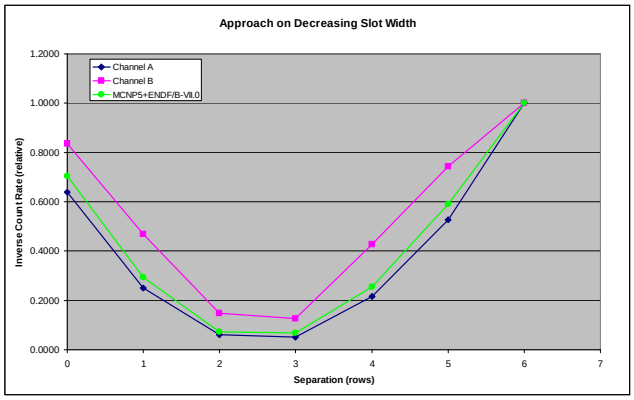








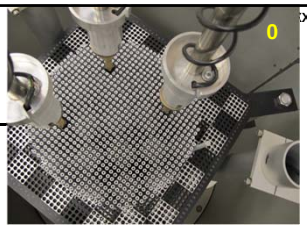
8/18/2011 Approach on Fuel Separation

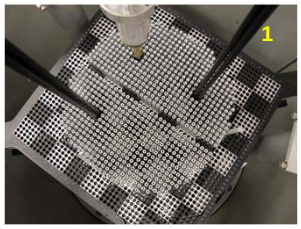


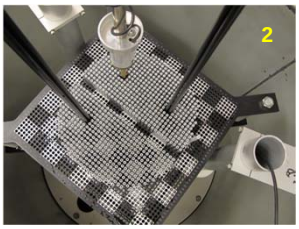
		Count Rate		Inverse Count Rate		Channel A		Channel B	
Rows	Holes	Ch. A	Ch. B	Ch. A	Ch. B	Projected	Next	Projected	Next
6	198	17957	45453	1.0000	1.0000				
5	165	34035	61171	0.5276	0.7430	3.88	4.44	2.11	3.55
4	132	82682	106178	0.2172	0.4281	3.30	3.65	2.64	3.32
3	99	346693	360622	0.0518	0.1260	2.69	2.84	2.58	2.79
2	66	290713	305421	0.0618	0.1488	8.19	5.10	8.53	5.27
1	33	71572	96942	0.2509	0.4689	2.33	1.66	2.46	1.73
0	0	28105	54327	0.6389	0.8367	1.65	0.82	2.27	1.14

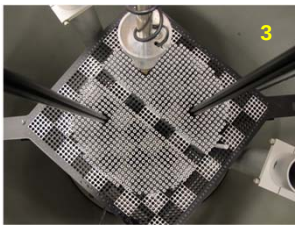
8/18/2011 Fuel Separation (2)

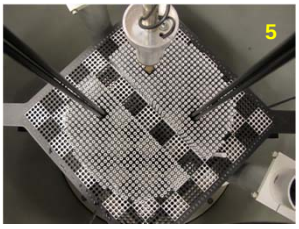
The reverse order demonstrates increasing moderation first and the decrease in reactivity as the core halves move "to far" apart.

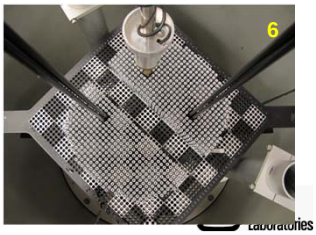




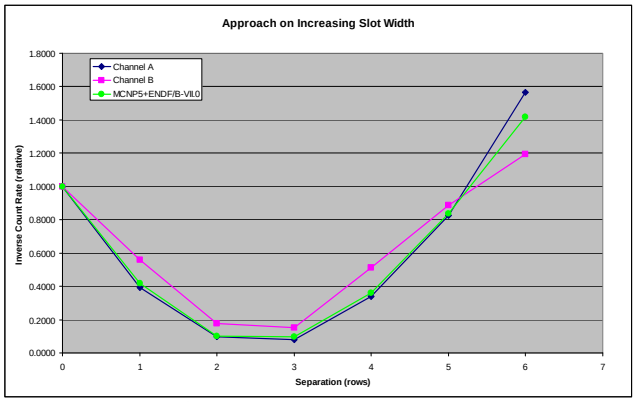








8/18/2011 Approach on Fuel Separation (2)



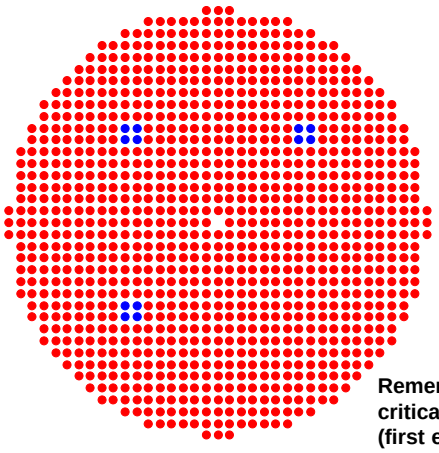
		Count Rate		Inverse Count Rate		Channel A		Channel B	
Rows	Holes	Ch. A	Ch. B	Ch. A	Ch. B	Projected	Next	Projected	Next
0	0	28105	54327	1.0000	1.0000				
1	33	71572	96942	0.3927	0.5604	1.65	1.32	2.27	1.64
2	66	290713	305421	0.0967	0.1779	2.33	2.16	2.46	2.23
3	99	346693	360622	0.0811	0.1506	8.19	5.60	8.53	5.77
4	132	82682	106178	0.3399	0.5117	2.69	3.34	2.58	3.29
5	165	34035	61171	0.8258	0.8881	3.30	4.15	2.64	3.82
6	198	17957	45453	1.5651	1.1952	3.88	4.94	2.11	4.05

Experiment 4
Interior Fuel Rod Removal

Experiment 4 Overview

- We determine the effect of removing fuel rods from the interior of the fuel array
- We are actually replacing fuel rods with water
- Criticality safety parameters that are in play:
  - Mass
  - Moderation
  - Reflection
  - Absorption
- Application to criticality safety:
  - What happens to a compact array of fuel lumps if the array becomes more spread out?

Fuel Replacement with Water Configuration 0



Remember that this core is critical with about 1060 rods (first experiment)

1032 Fuel Rods
0 Water Holes (the source doesn't count)

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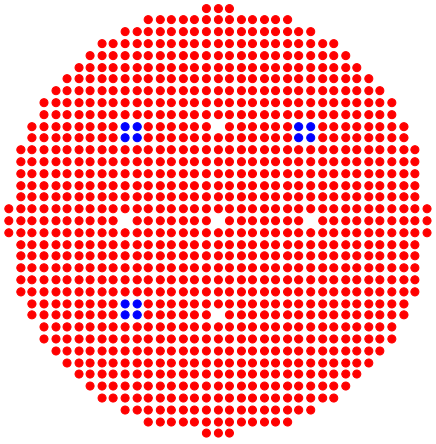
Fuel Replacement with Water Configuration 1



1028 Fuel Rods
4 Water Holes

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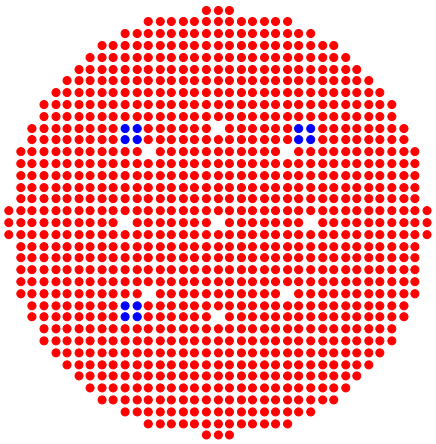
Fuel Replacement with Water Configuration 2



1024 Fuel Rods
8 Water Holes

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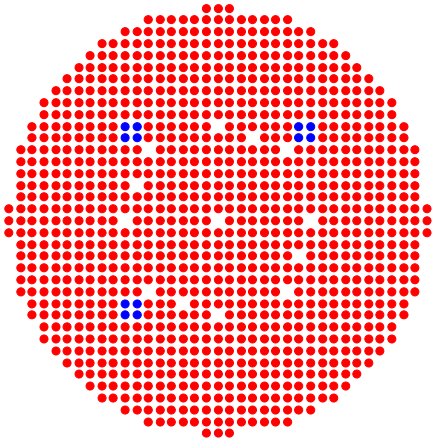
Fuel Replacement with Water Configuration 3



1020 Fuel Rods
12 Water Holes

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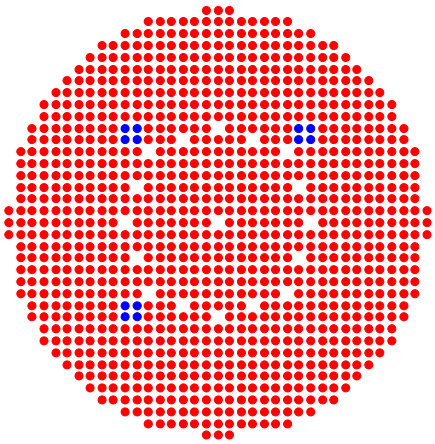
Fuel Replacement with Water Configuration 4



1016 Fuel Rods
16 Water Holes

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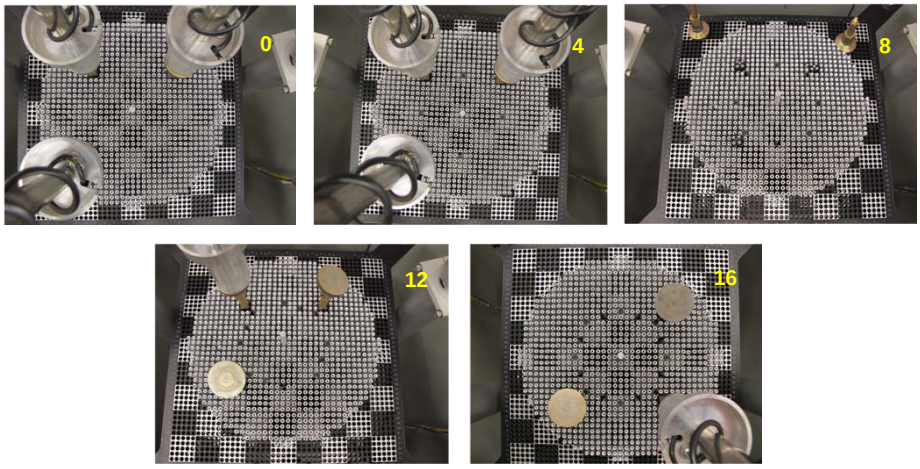
8/19/2011 Approach on Water Holes



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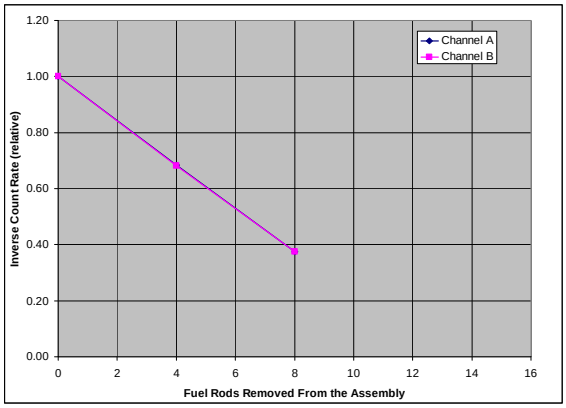
8/19/2011 Approach on Water Holes



	Count Rate		Inverse Multiplication		Channel A		Channel B	
Rods	Ch. A	Ch. B	Ch. A	Ch. B	Projected	Next	Projected	Next
0	73697	69113	1.0000	1.0000				
4	107895	101371	0.6830	0.6818	12.62	8.31	12.57	8.29
8	196099	184739	0.3758	0.3741	12.89	10.45	12.86	10.43

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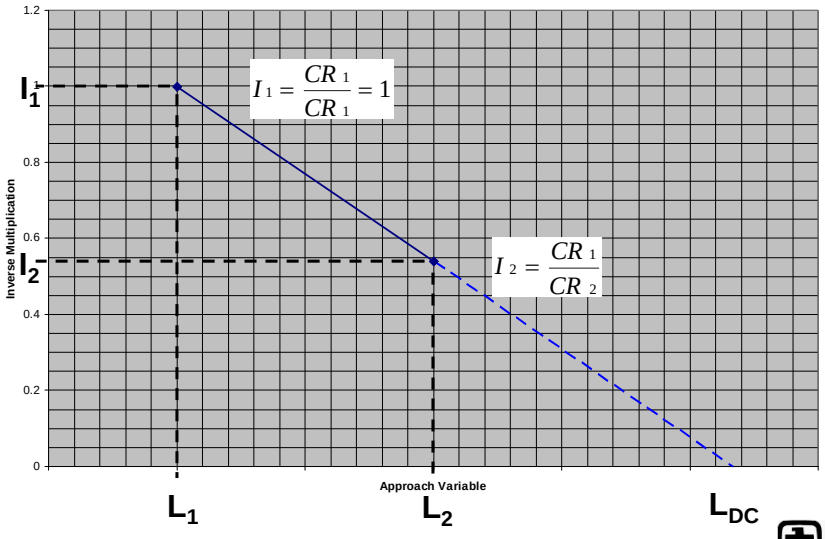
Determining the Next Fuel Increment



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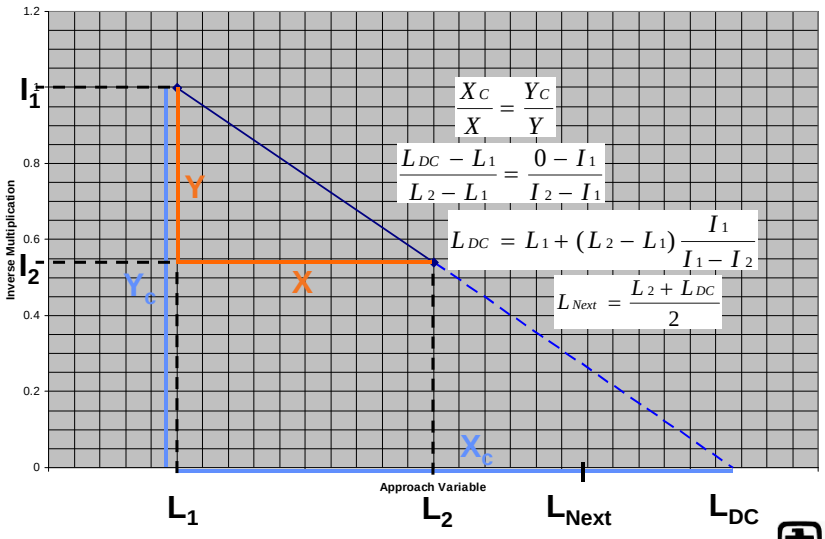
Determining the Next Fuel Increment



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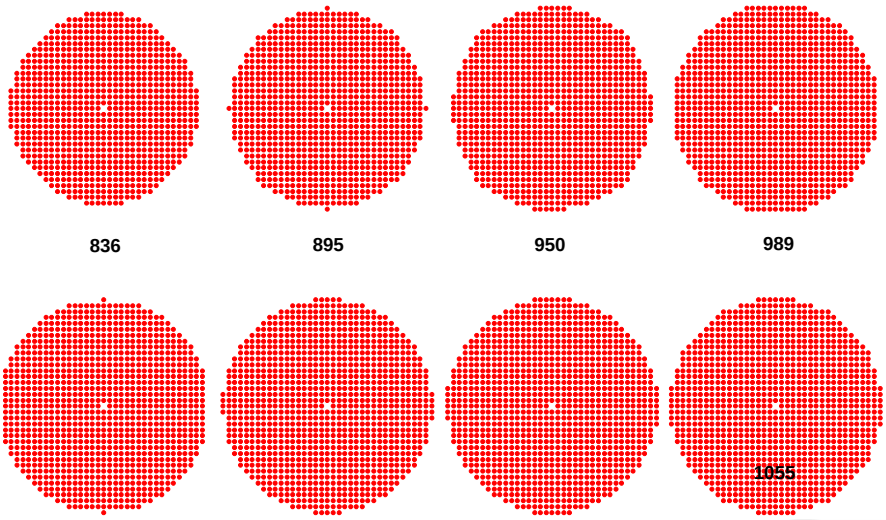
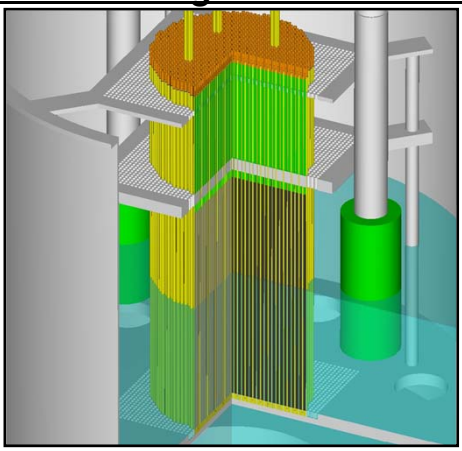
8/16/2011 Approach on Fuel Loading



Moderator Height Experiment Configuration 1



$$M_1 = \frac{1}{1-0.9} = 10$$

$$I_1 = \frac{M_1}{M_1} = 1$$

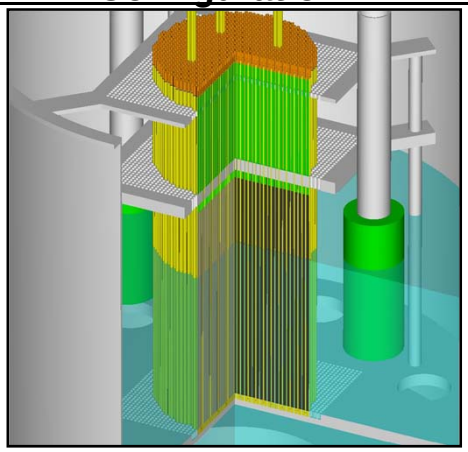
The relative inverse multiplication

Fuel Rods: 1137

k_{eff}: ~0.90

Water Depth: 271.6 mm

Moderator Height Experiment Configuration 2



$$M_1 = \frac{1}{1-0.9} = 10$$

$$I_1 = \frac{M_1}{M_1} = 1$$

$$M_2 = \frac{1}{1-0.95} = 20$$

$$I_2 = \frac{M_1}{M_2} = \frac{10}{20} = 0.5$$

Fuel Rods: 1137

k_{eff}: ~0.95

Water Depth: 341.3 mm

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Mechanics of the Experiment

- The number of fuel rods in the core is constant
- The separation of the fuel masses is adjusted by moving fuel rods from location to location in the core
- The operations staff performs all the fuel movements
- This is a DEMONSTRATION
  - We record data and make projections to critical as we would in an approach-to-critical experiment
  - We change the separation by full rows of fuel rods, not according to the results of our projections

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Mechanics of the Experiment

- The number of interior fuel rods replaced by water is increased
- We monitor the count rates
- The class takes the fuel rods from the operations staff and places them on the fuel table
- Each increment is four rods

The Experiment Process

- The desired fuel rod array is loaded
- The safety rods are “cocked”
- The reactor room is cleared
- The core tank is filled with water
- The control rod is raised – this puts the assembly in its most reactive condition in this operational mode
- Counts are taken
- The core tank is drained
- The control rod is lowered
- The safety rods are dropped
- We do projections to DC as before
- The reactor room is opened
- Loop back to the first step on this page