Development of a Research Reactor Protocol for Neutron Multiplication Measurements

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Rian Bahran[1], Jesson Hutchinson[1], Jennifer Arthur, Avneet Sood[1], Nick Thompson[3] and Sara Pozzi[3]

[1]Los Alamos National Laboratory
[2]University of Michigan
[3]Rensselaer Polytechnic Institute

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NCSP NUCLEAR CRITICALITY SAFETY PROGRAM Technical Program Review

Recent History of Neutron Multiplication Measurements

- **We have come a long way since the first sub-critical measurements at CP-1 in 1942.**
- **1980s - 2000s: Major Progress in Sub-critical Neutron Multiplication Measurements/Simulations**

See recent paper by J. Hutchinson, R. Bahran et al. “Sub-critical Multiplication Experiments & Simulations: Overview and Recent Advances” Proceedings of ANTPC 2016, Santa Fe, NM

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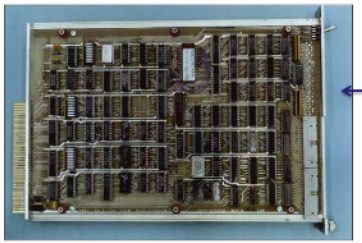
Electronic improvements.

Advances in electronics allowed for the ability to produce and store list-mode data (a time list of every recorded event).

- The majority of neutron multiplicity detection systems used today record list-mode data.



Programmable Multi-Channel Coincidence Module (PMCCM): 1st list-mode hardware at LANL in 1987.

1940s → 1950-1970 → 1980-2000 → 2000-Present

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Subcritical methods.

NEUTRON MULTIPLICATION MEASUREMENTS USING MOMENTS OF THE NEUTRON COUNTING DISTRIBUTION

A.A. ROBBA, E.J. DOWDY and H.F. ATWATER

In the 1980s, the methods introduced in the 1950s and 1960s were further refined.

Hansen-Dowdy and Hage-Cifarelli methods are still used to this day.

MODELS FOR A THREE-PARAMETER ANALYSIS OF NEUTRON SIGNAL CORRELATION MEASUREMENTS FOR FISSILE MATERIAL ASSAY

D.M. CIFARELLI

W. HAGE

1940s → 1950-1970 → 1980-2000 → 2000-Present

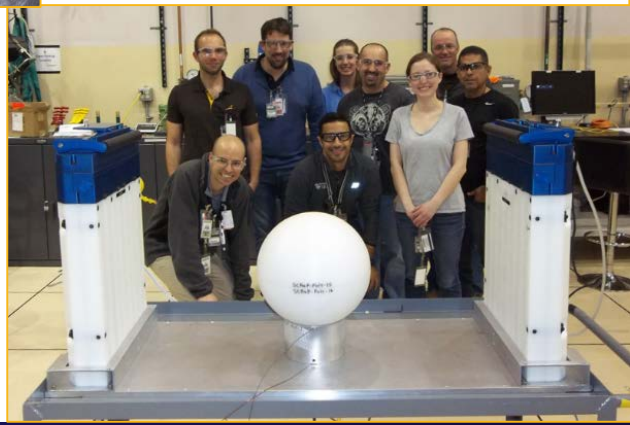
Sub-Critical Neutron Multiplication Benchmark Experiments

National Criticality Experiments Research Center (NCERC)

- **Growing dataset of neutron multiplication benchmarks experiments/evaluations**
  - Culmination of several years of sub-critical experiment research
  - Goal is to validate nuclear data and computational methods

Chronology: 2012 - Present

- **BeRP-Ni (published in 2014)**
  - Sub-critical nickel-reflected α-phase Pu
  - Executed in 2012, ICSBEP evaluation published in 2014
  - First benchmark of sub-critical measurements at NCERC
  - First benchmark w/ Feynman Variance-to-Mean method
- **BeRP-W (published in 2016)**
  - Sub-critical tungsten-reflected α-phase Pu
  - Executed in 2012, ICSBEP evaluation published in 2016
- **SCRαP (to be published in 2018)**
  - Sub-critical copper/poly-reflected α-phase Pu
  - Executed in 2016, ICSBEP evaluation published in 2018
- **Neptunium (to be published in 2020)**
  - Sub-critical Neptunium w/various reflectors, in design phase



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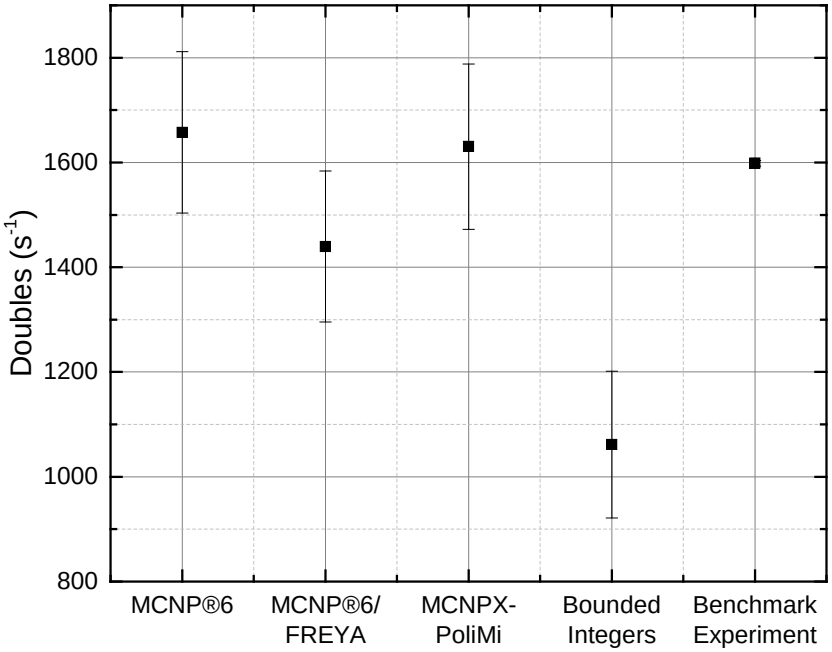

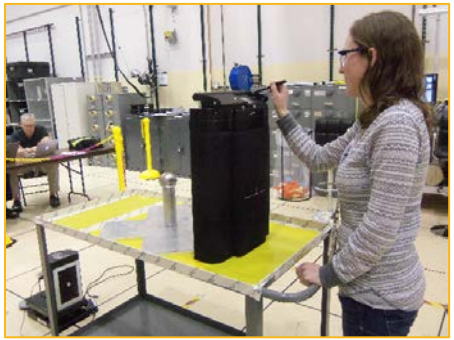

- **Can be used for benchmarking the performance correlated fission multiplicity implementation in transport codes [1].**
- **Un-reflected Pu benchmark experiment configuration is shown [1].**
- **Differences are more pronounced at higher multiplication (reflected) configurations.**

[1] Jennifer Arthur, R. Bahran, J. Hutchinson, A. Sood et al, *Comparison of the Performance of Various Correlated Fission Multiplicity Monte Carlo Codes*. Las Vegas, NV: ANS Winter Meeting and Nuclear Technology Expo, 2016 - LA-UR-16-24512

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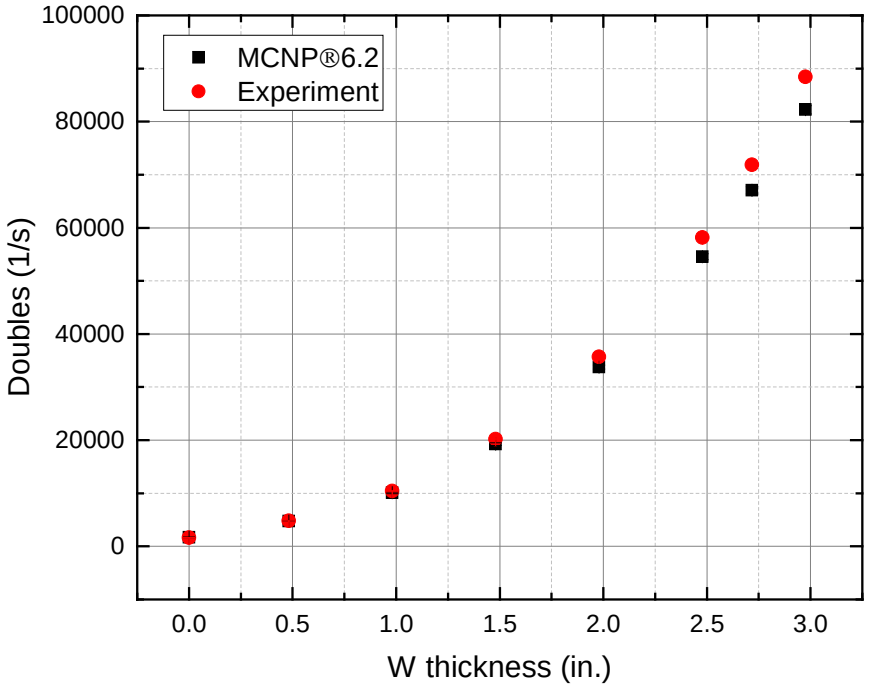

- **These trends had been observed in previous experiments [1], which provided a sense of urgency to perform/document ICSBEP benchmark-quality sub-critical measurements.**
- **Comparisons of BeRP-W to soon-to-be released MCNP®6.2 code shown.**

[1] A. Sood, C. J. Solomon, J. D. Hutchinson, R. Bahran "*A Review of Recent R&D Efforts in Sub-Critical Multiplication Measurements and Simulations*" Trans. Amer. Nucl. Soc., 111, 799-802 (2014)

Establishing a Research Reactor Protocol for Neutron Multiplication Measurements

- **Next step in advanced sub-critical neutron measurements is establishing research reactor measurement protocol.**
- **Obtain benchmark-quality integral measurements at different known reactivity states.**
- **Spatial complexity, different materials (fuel, moderator), and system-specific neutron cross-section sensitivities (various energy ranges and reactions)**
- **Expand upon previous LANL benchmark-quality sub-critical experiments**

Establishing a Research Reactor Protocol for Neutron Multiplication Measurements

- **History**
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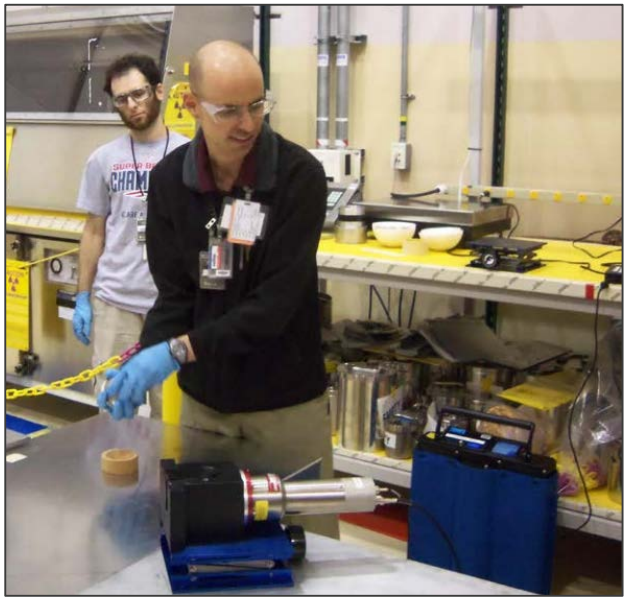

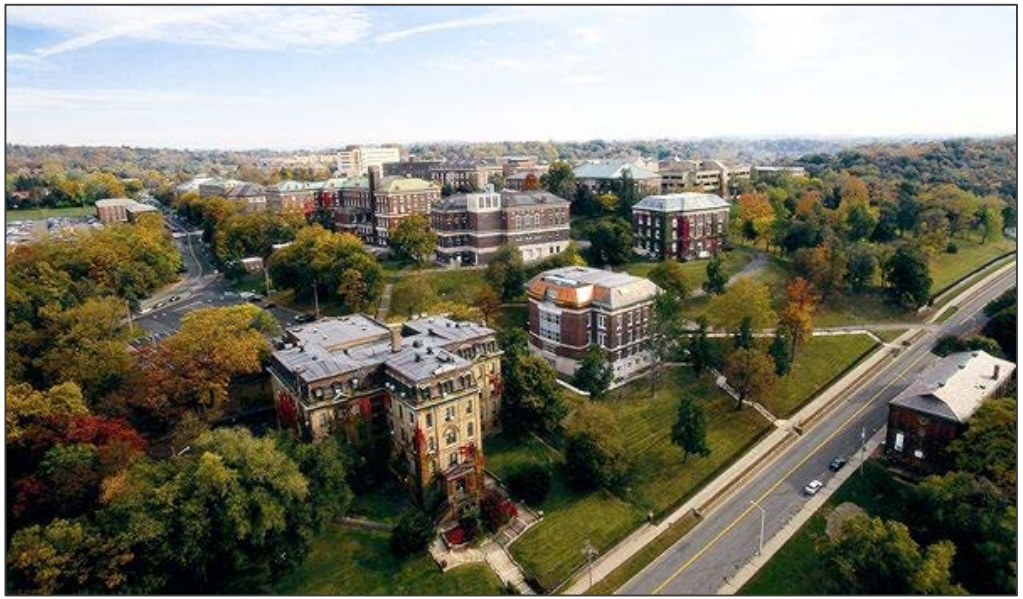

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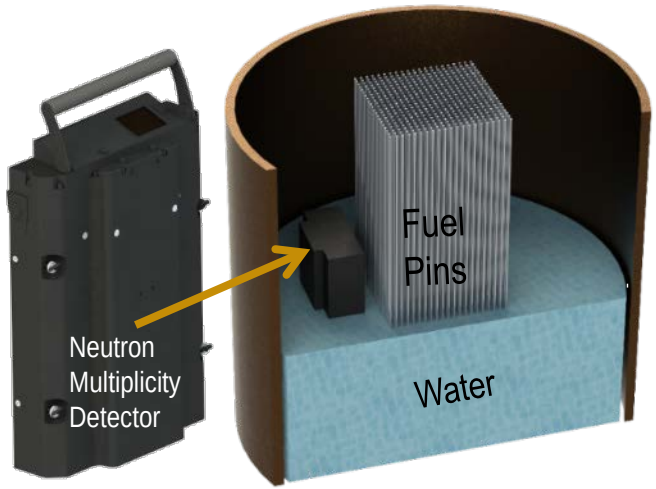

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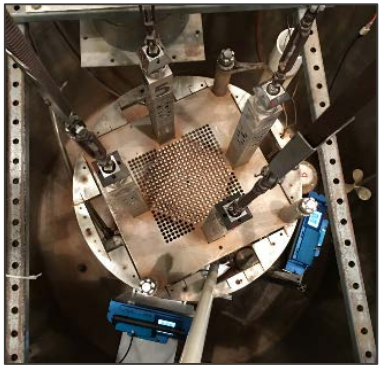
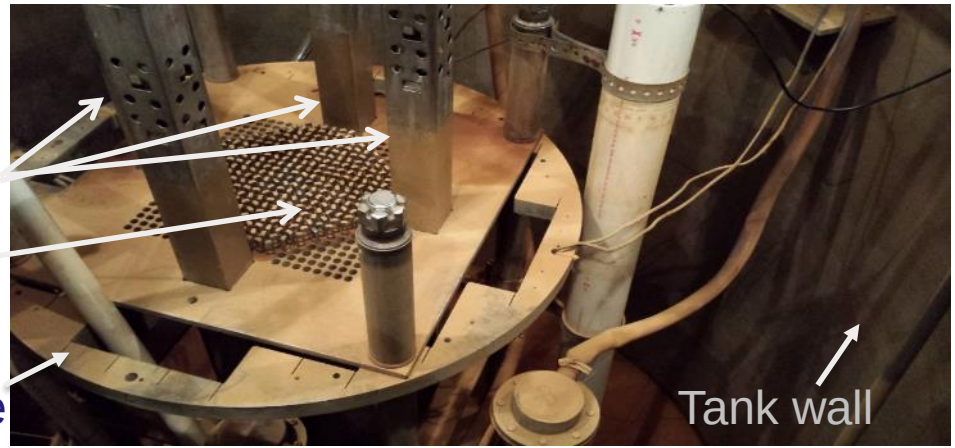
  - 2016: Execute first series of measurements at RPI Reactor Critical Facility



RPI Reactor Critical Facility

- **Located at Rensselaer Polytechnic Institute**
- **0-power reactor with negligible burn-up**
- **LEU SPERT-type F-1 fuel pins**
  - Enrichment of 4.82% U-235 by weight
- **Stainless steel cladding and B-impregnated Fe rods**
- **Water moderated**

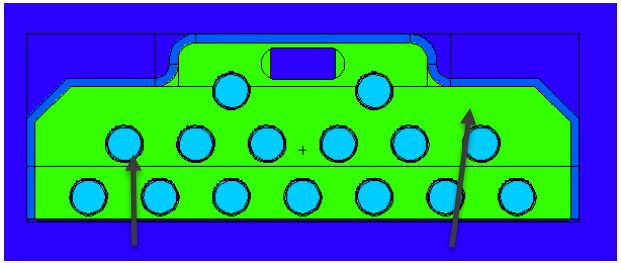


Neutron Instrumentation: LANL Multiplicity Detector (MC15)

- **15 He-3 tubes in poly**
- **Removable cadmium shield**
- **Time of arrival of pulse and detector of interaction are recorded**
  - o List-mode data

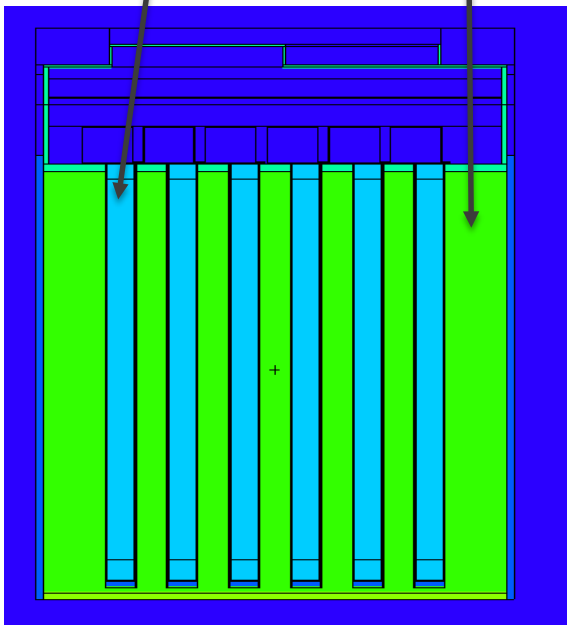
Table III. ^{3}He tube information	
Manufacturer	Reuter-Stokes
Model Number	RS-P4-0815-103
Body Material	Aluminum 1100
External Diameter	1.00 inch
Thickness	1/32 inch
Height (including cladding)	41.6 cm
^{3}He Pressure	150 psia
Active Length	15.0 inch

MC15 model – top view



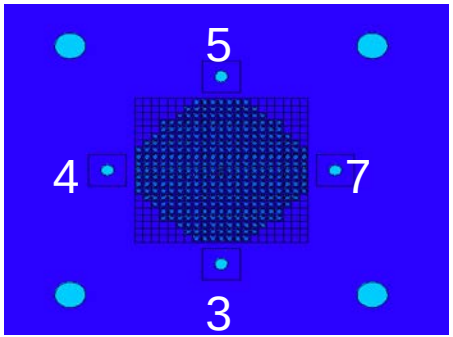
He-3 tubes

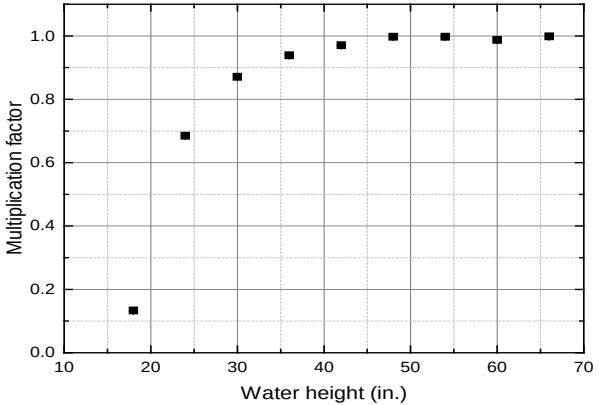
Poly

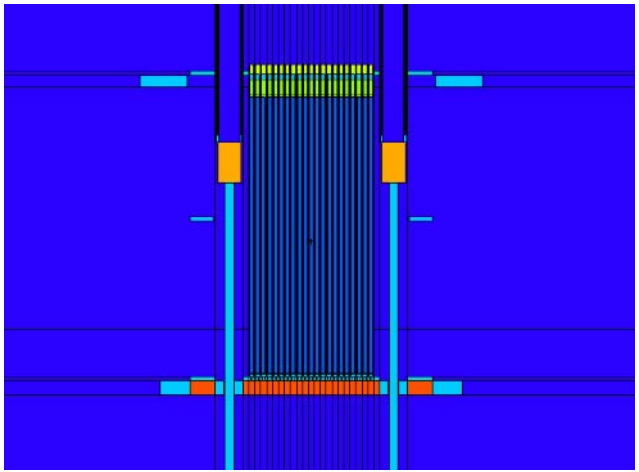


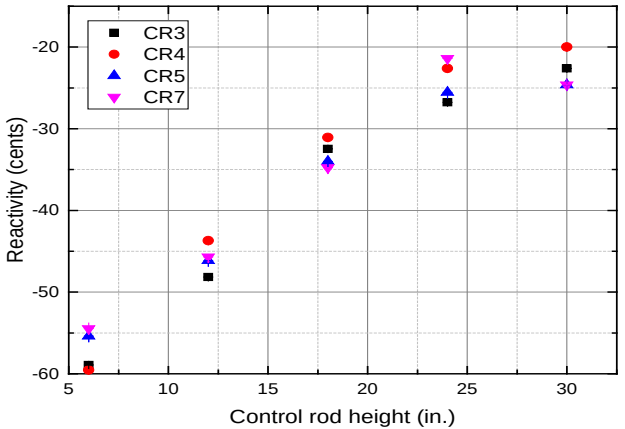
MC15 model – side view

Experiment Design in MCNP: model of RPI-RCF

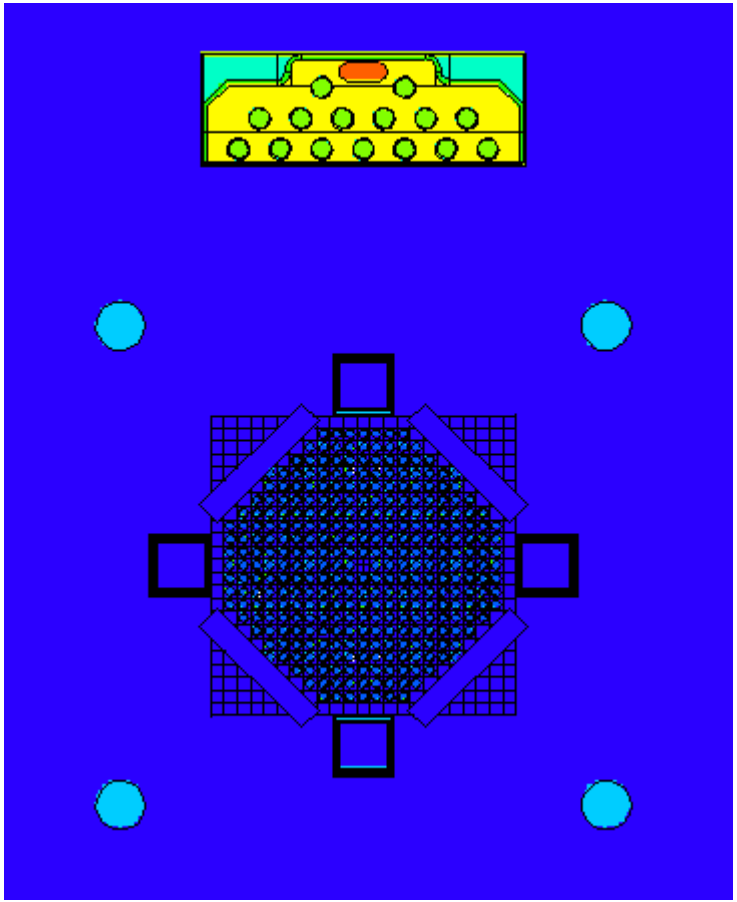


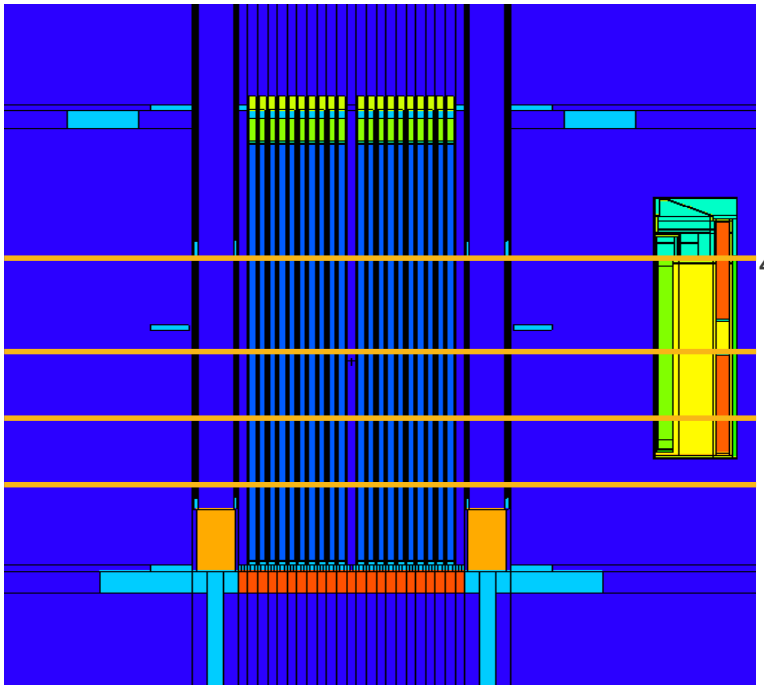






Experiment Design in MCNP: model of RPI-RCF + MC15





Experiment Design: Configuration Optimization

- **Optimized parameters:**
  - 10^3-10^5 s^{-1} singles rate
  - Good fit (quantified by χ^2) of doubles rate vs. gate width
- **Possible source positions**
  - **Center**: at axial centerline of fuel and in center of core
  - **Opposite**: at axial centerline of fuel and on opposite side of core from MC15
  - **Opposite offset**: near the bottom of the fuel pins and on opposite side of core from MC15

Detector distance (in.)	Source strength (n/s)	Source position	Water height (in.)	Singles rate (s^{-1})	Doubles rate (s^{-1})	χ^2
13.8 (35 cm)	**10^5**	**center**	**36**	**2733±6**	**545±44**	**0.293**
19.7 (50 cm)	10^5	center	36	1098±4	60±11	0.310
13.8	10^6	center	36	26693±62	5061±3576	0.662
13.8	10^7	center	36	247560±28	Unable to determine	65.12
13.8	10^5	opposite	36	687±3	175±12	0.202
13.8	10^5	opposite offset	36	658±2	304±8	0.207

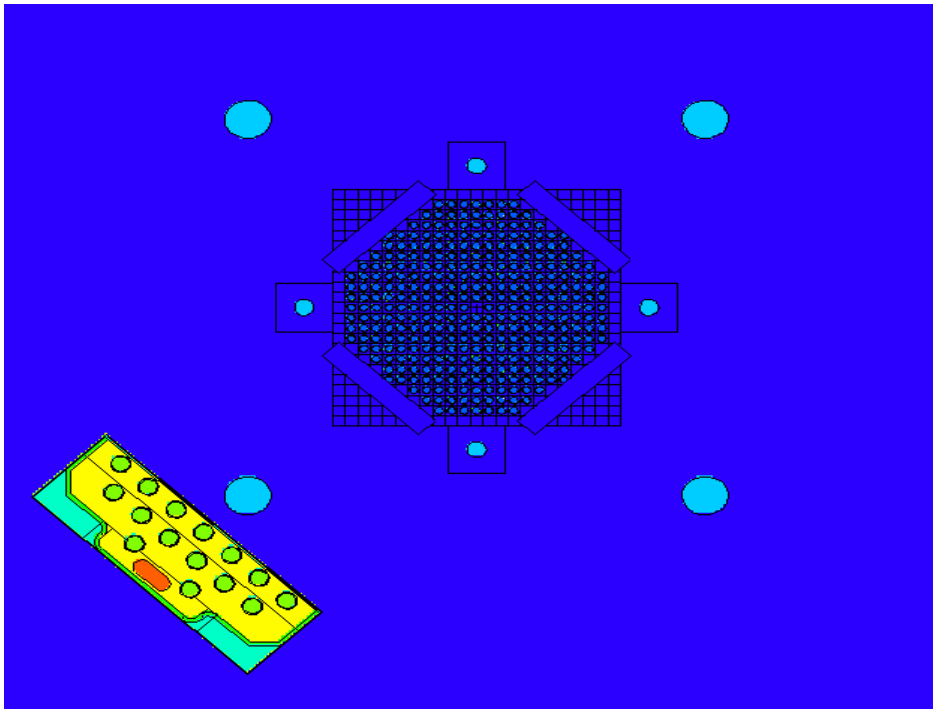
Experiment Design: Final Planned Configurations

- **MC15 13.8 in. (35 cm) from center of core, with vertical midpoint of active region at same height as axial midpoint of fuel rods**

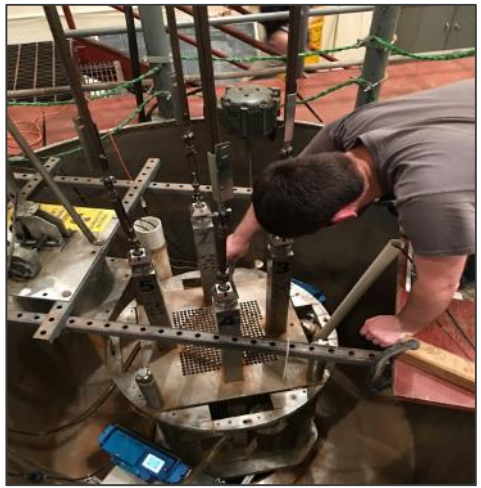
Water height (in.)	Fuel loading	Cf-252 source	MC15 detector
18	333 fuel pins, center pin absent	Replacing center fuel pin	13.8 in. (35 cm) from center of core
30	333 fuel pins, center pin absent	Replacing center fuel pin	13.8 in. from center of core
36	333 fuel pins, center pin absent	Replacing center fuel pin	13.8 in. from center of core
44	333 fuel pins, center pin absent	Replacing center fuel pin	13.8 in. from center of core
Variable	0 fuel pins	Replacing center fuel pin	13.8 in. from center of core

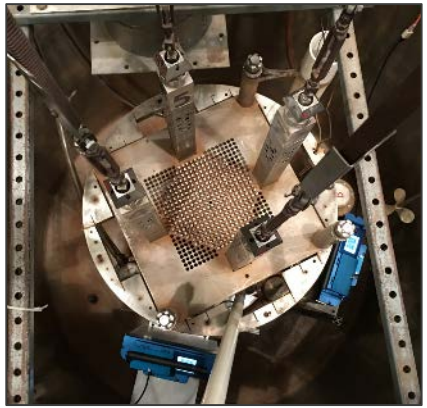
Experiment Design: Final Proposed Geometry

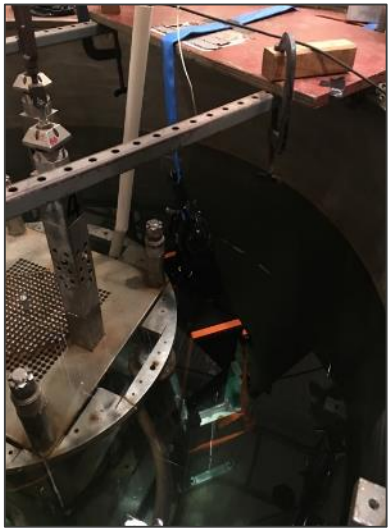
- **Only detector position changes (19.1 in. / 48.5 cm distance)**



Experiment Execution in July 2016







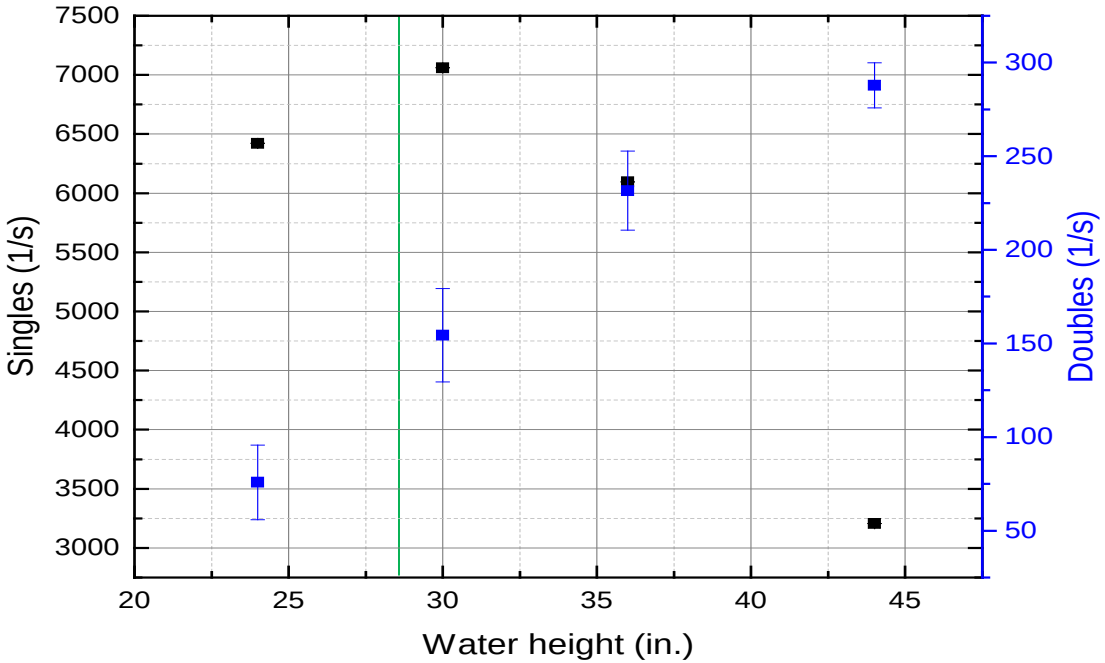
Experiment Execution: Completed Configurations

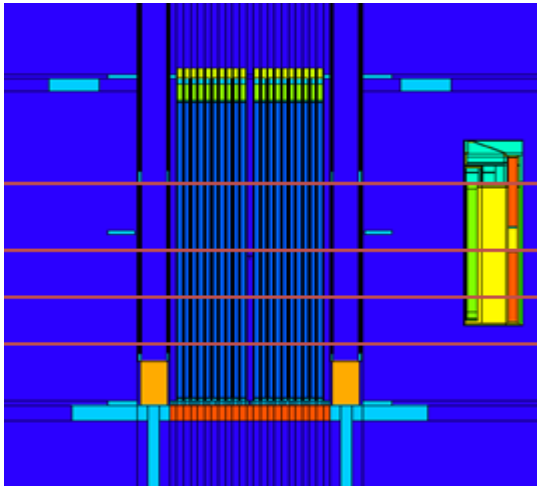
Configuration #	Water height	CR3 height	CR4 height	CR5 height	CR7 height	Intended reactivity
1	44 in.	36 in.	36 in.	36 in.	36 in.	-
2	36 in.	36 in.	36 in.	36 in.	36 in.	-
3	30 in.	36 in.	36 in.	36 in.	36 in.	-
4	24 in.	36 in.	36 in.	36 in.	36 in.	-
5	67 in.	0 in.	0 in.	0 in.	0 in.	-
6	67 in.	20 in.	20 in.	20 in.	20 in.	-$0.50
7	67 in.	16 in.	16 in.	16 in.	16 in.	-$1.00
8	67 in.	25 in.	25 in.	25 in.	25 in.	Delayed critical
9	67 in.	36 in.	36 in.	21 in.	21 in.	Delayed critical

Control rods completely withdrawn: 36 in.
Control rods completely inserted: 0 in.

Cf-252 source with strength of 125210 n/sec during measurements.

Preliminary Results: Singles/doubles vs water height

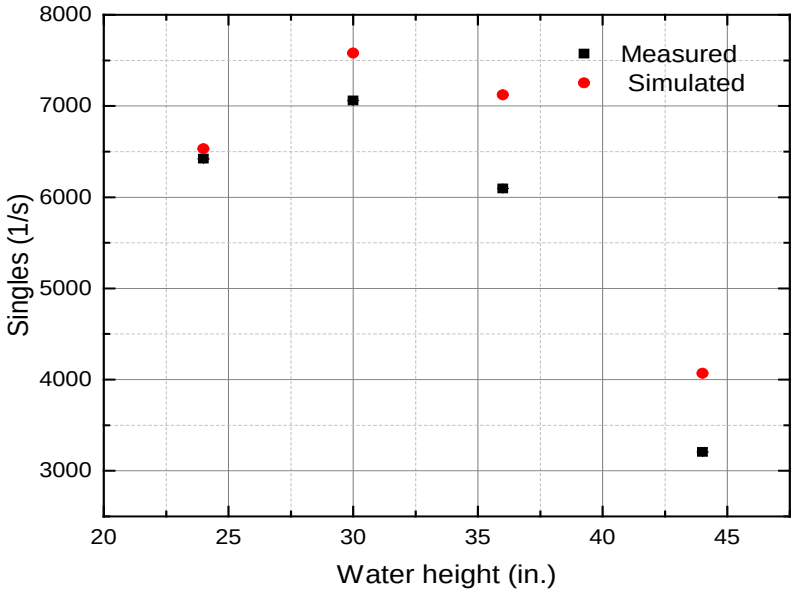


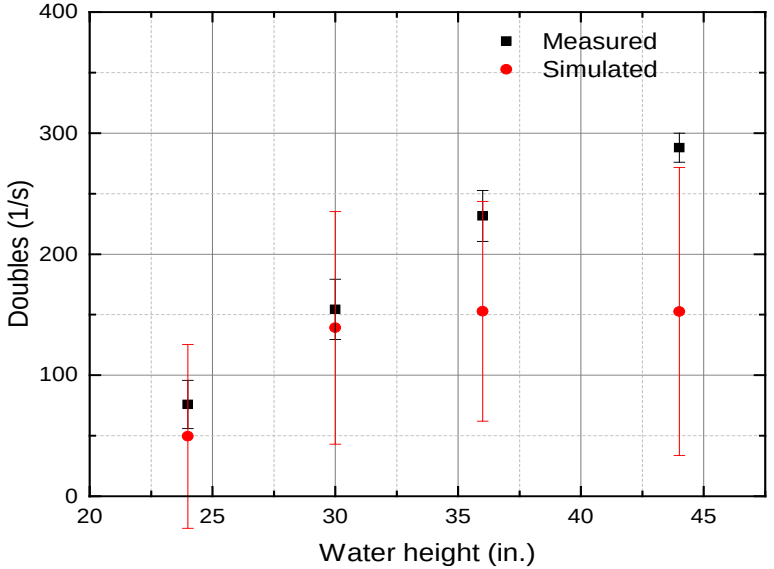


Note: All of the following results were obtained at a gate width of 3368 μs

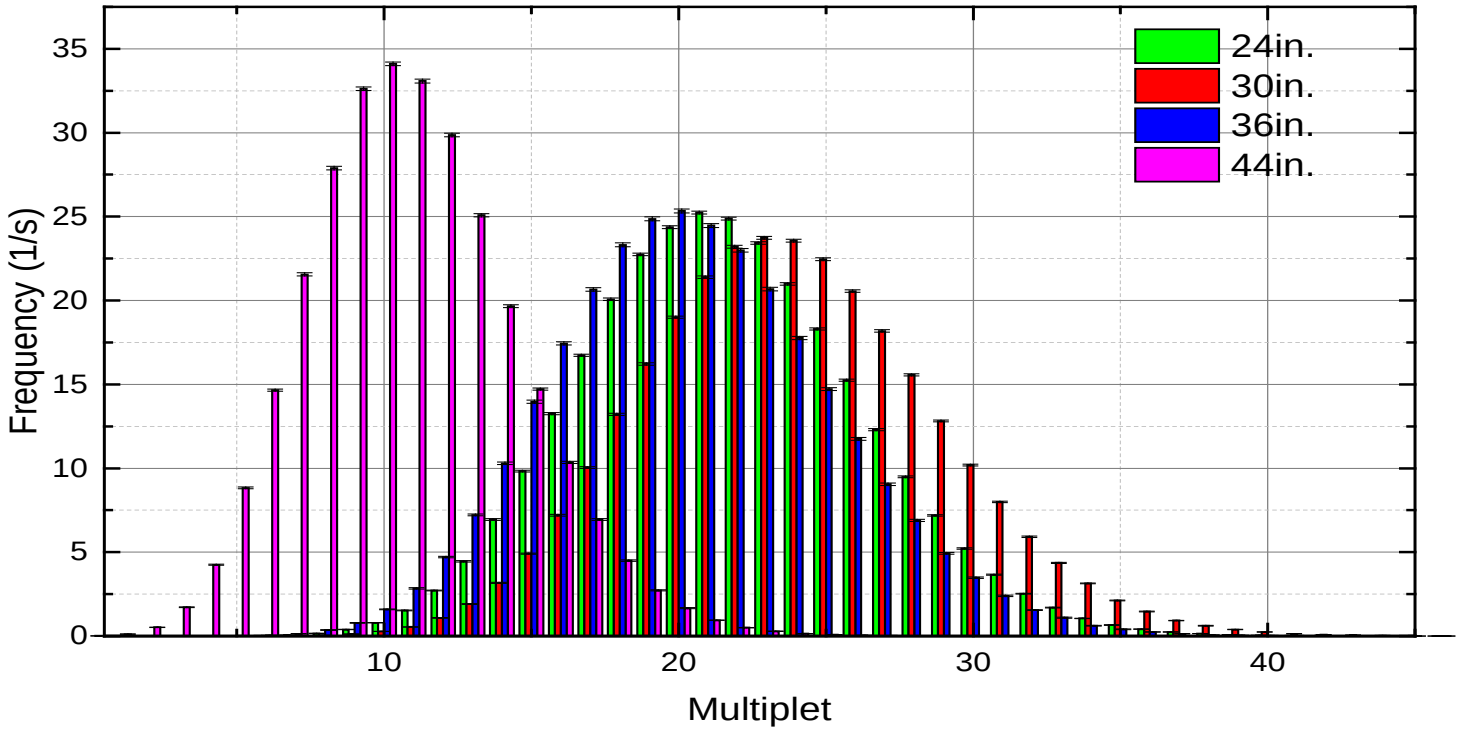
Preliminary Results: Singles/doubles vs water height

| Experiment + Simulation |





Preliminary Results: Feynman histograms



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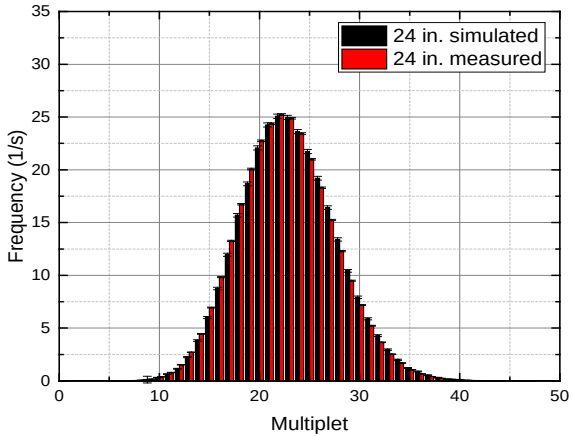
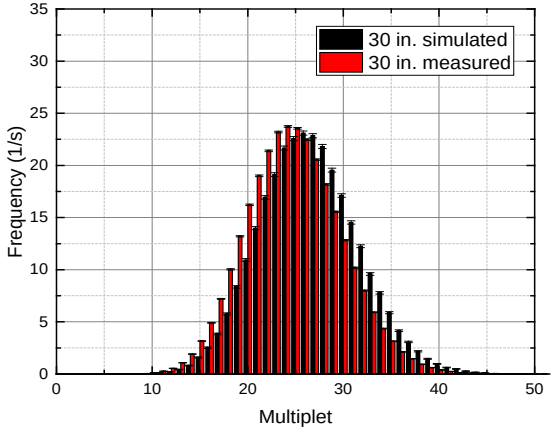
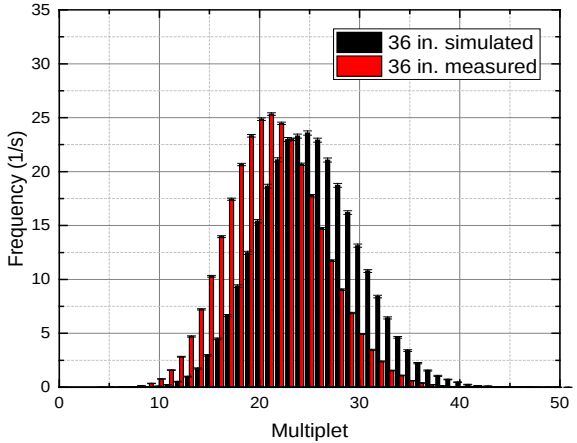
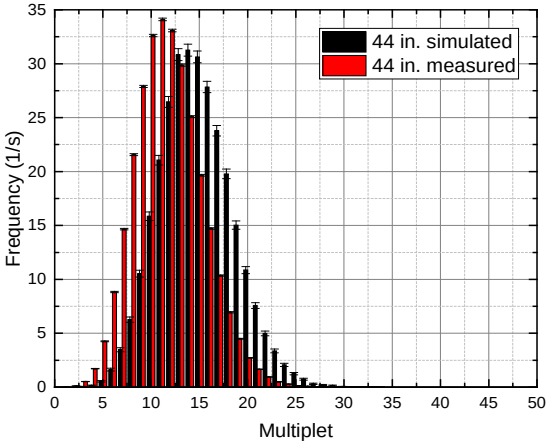
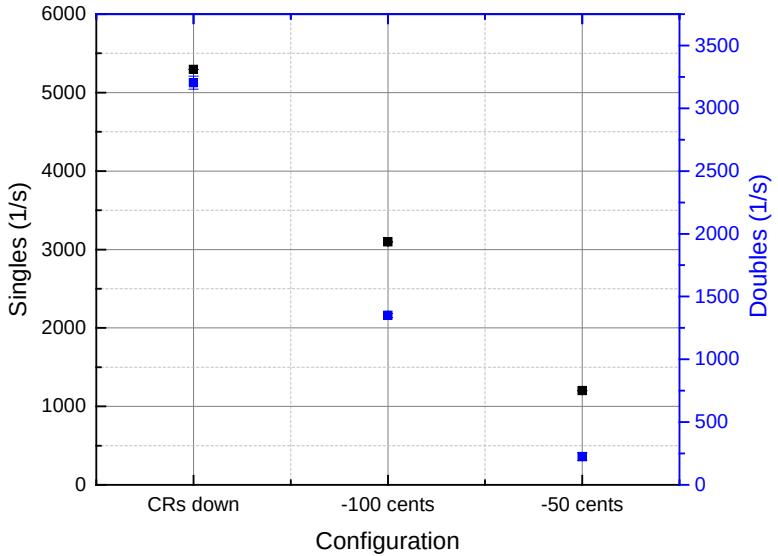


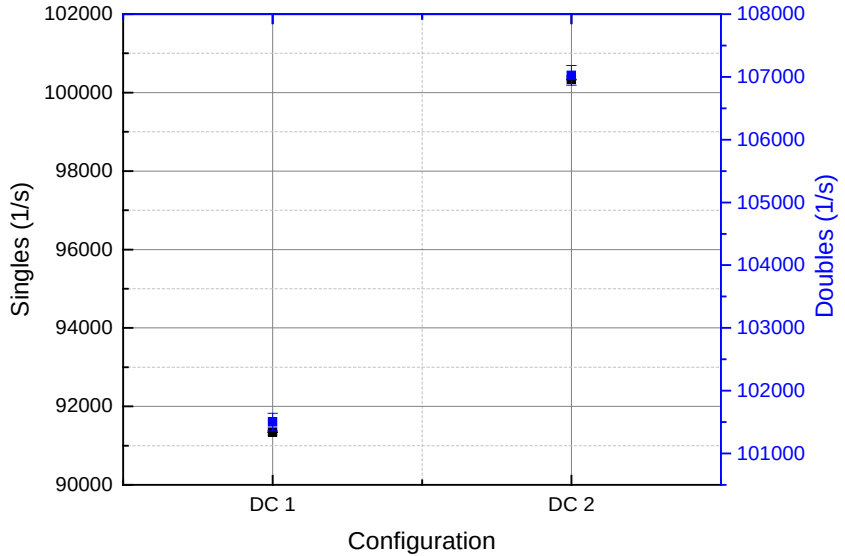






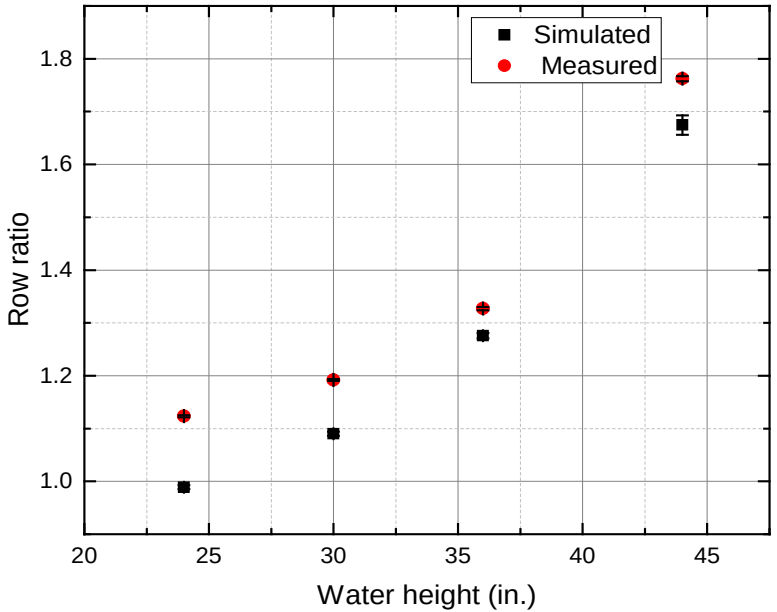
Preliminary Results: Singles/doubles at 67 in. water height and various reactivity states

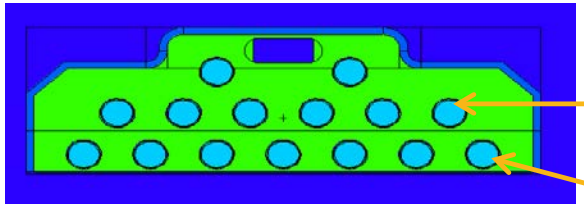




Preliminary Results: MC15 row ratio vs water height

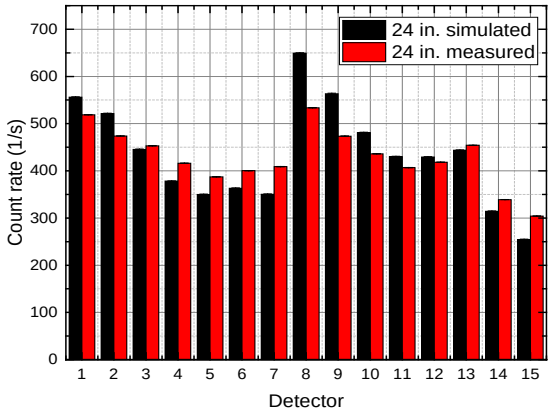
| Experiment + Simulation |

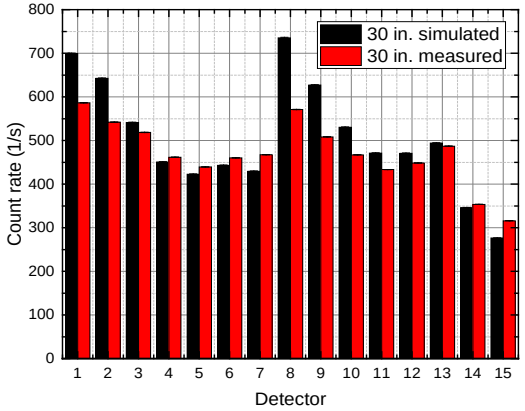


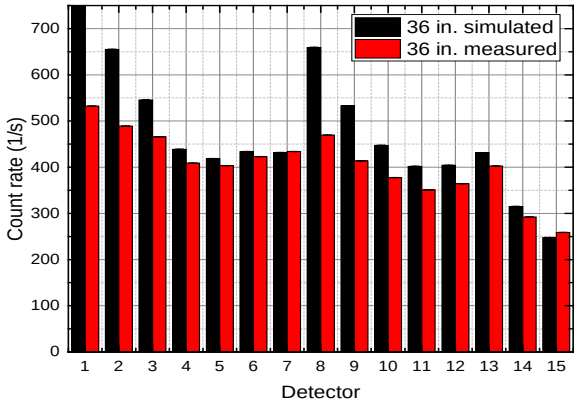


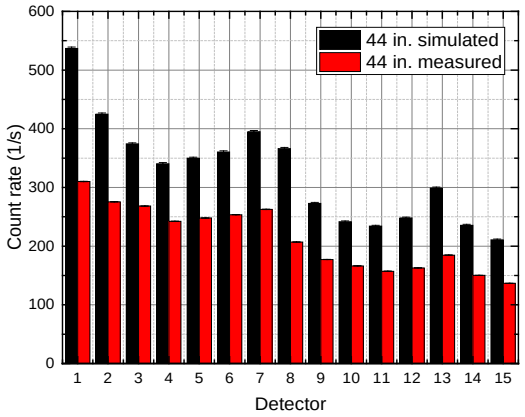
Preliminary Results: Counts per tube comparison

| Experiment + Simulation |

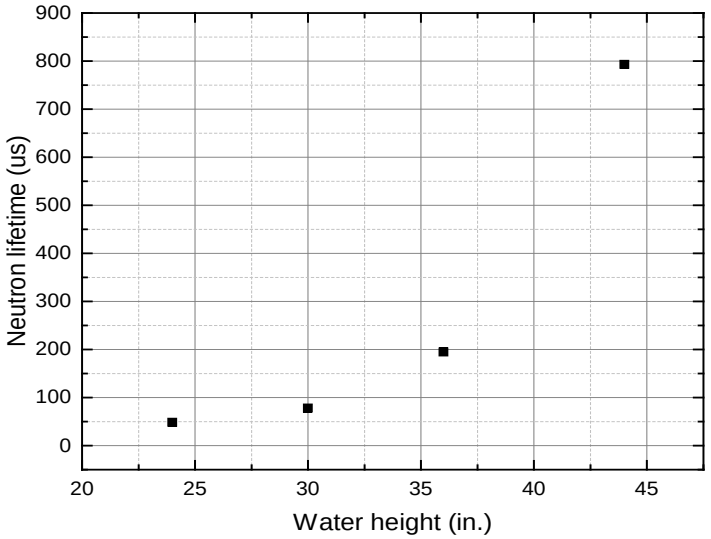


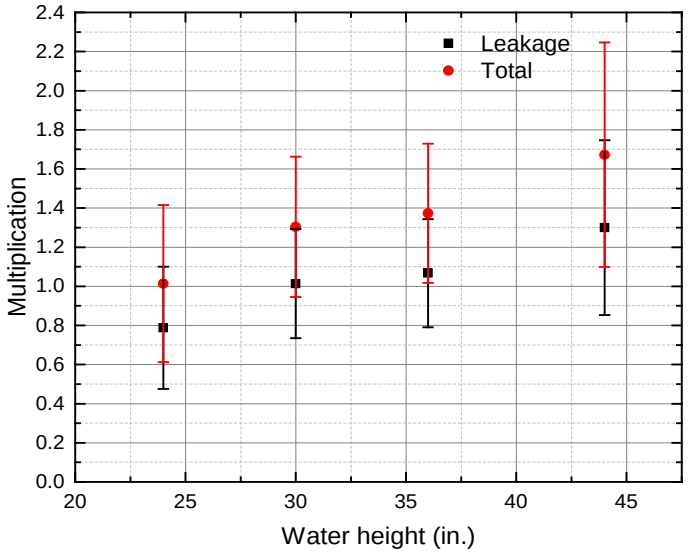






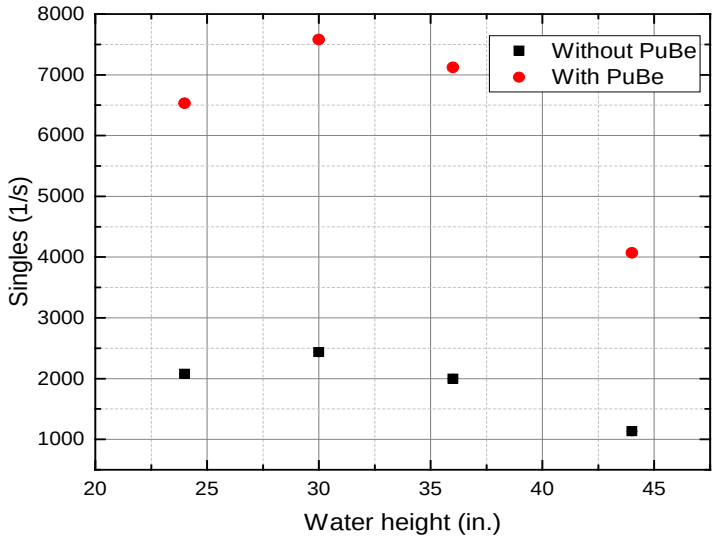
Preliminary Results:
Neutron lifetime and multiplication vs water height

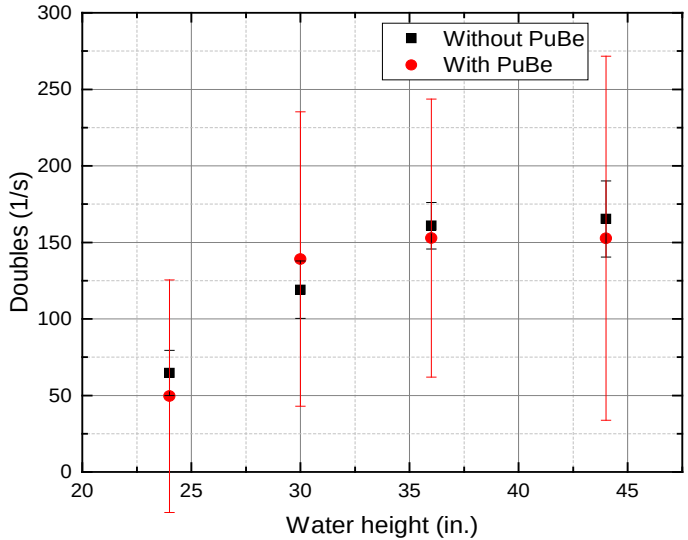




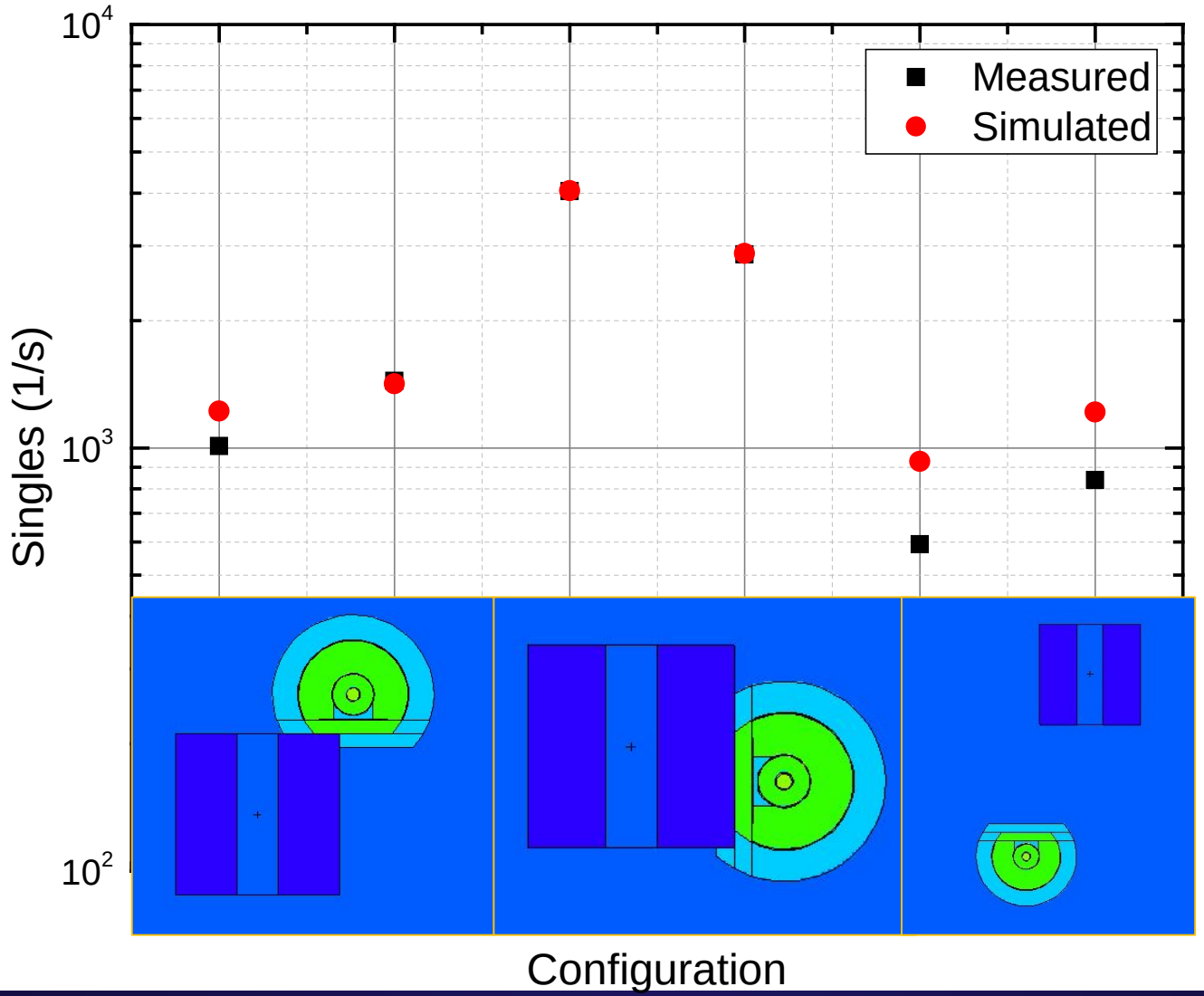
Preliminary Results: PuBe contribution to results

- **May artificially increase calculated efficiency**



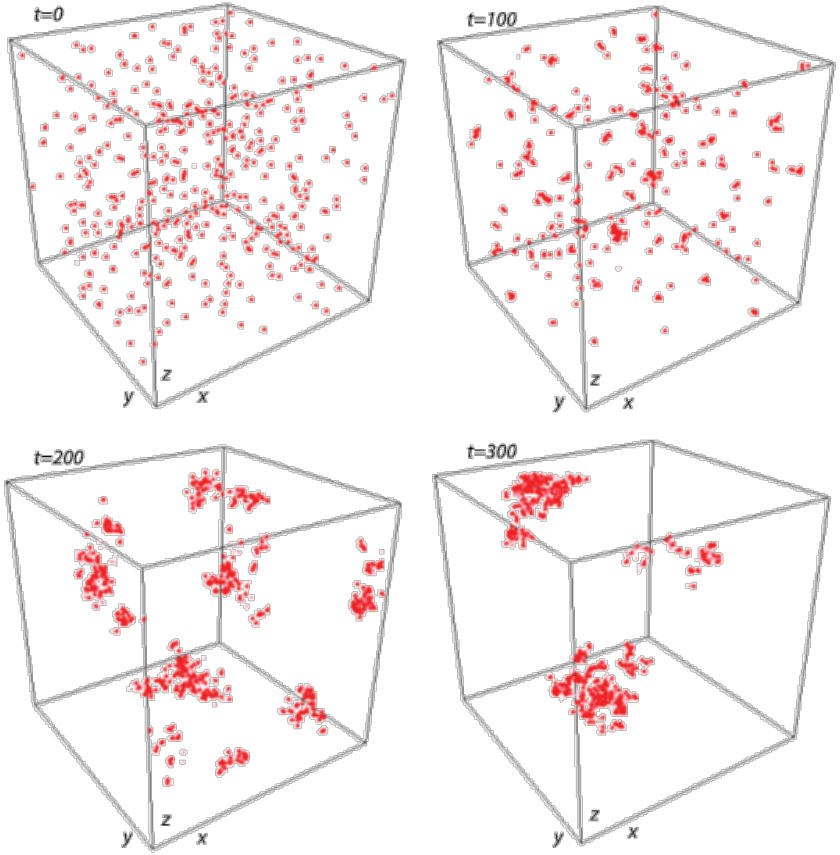


Additional PuBe Measurements Performed Feb. 2017


Measured
Simulated
Singles (1/s)
10^4
10^3
10^2
Configuration

Planned Spatial Correlations/Clustering Measurements

- **IRSN scientists (E. Dumonteil et al.) have been leading the way in advanced stochastic modelling, specifically as it relates to spatial correlations where neutron clustering has been observed in MC criticality simulations[1,2]**
- **Joint LANL-IRSN measurement campaign at RCF planned this summer2017:**
  - IRSN is performing the preliminary design simulations with the MORET, establishing a “spatial correlation function” as a parameter of interest.
  - Experimentally validate the clustering spatial effects at RCF with two LANL MC15 multiplicity detectors + small ^{3}He tubes placed directly in the fuel region.



[1] Dumonteil, E., Courau, T., 2010. Nuclear Technology 172, 120.
[2] Dumonteil, E. et al, 2014, Annals of Nuclear Energy 63, 612-618.

Thank you!

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Announcement: Critical & Sub-Critical Experiments Paper Session

2017 ANS Winter Meeting and Nuclear Technology Expo

Washington, DC

Marriott Wardman Park

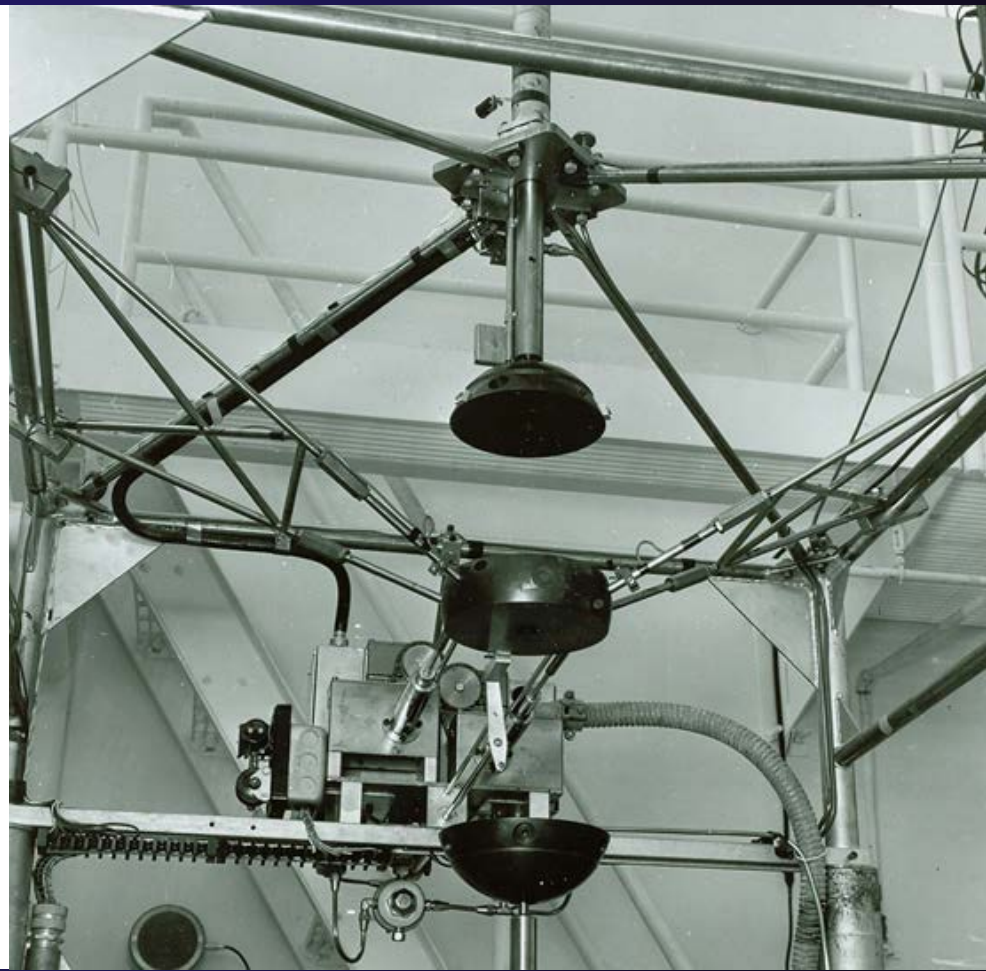
October 29-November 2, 2017

Session Organizer:

Jesson Hutchinson (LANL)

Co-sponsoring Divisions:

NCSD, NNPD, YMG



Questions?