Kansas State University Libraries

New Prairie Press

Symposium on Advanced Sensors and Modeling Techniques for Nuclear Reactor Safety

Preliminary Assessment of Steady-state and Transient Reaction-Rate Measurements at the University of Wisconsin Nuclear Reactor

J. A. Roberts
Kansas State University, jaroberts@ksu.edu

T. R. Ochs
Kansas State University

D. M. Nichols
Kansas State University

W. Fu
Kansas State University

Y. Cheng
Kansas State University

See next page for additional authors

Follow this and additional works at: https://newprairiepress.org/asemot

Part of the Mechanical Engineering Commons, and the Nuclear Engineering Commons

Recommended Citation

Roberts, J. A.; Ochs, T. R.; Nichols, D. M.; Fu, W.; Cheng, Y.; Boyington, J. C.; McGregor, D. S.; Wilson, P. P.H.; Agasie, R. J.; Edwards, C. S.; and Park, Y-H. (2018). "Preliminary Assessment of Steady-state and Transient Reaction-Rate Measurements at the University of Wisconsin Nuclear Reactor," *Symposium on Advanced Sensors and Modeling Techniques for Nuclear Reactor Safety*. https://newprairiepress.org/asemot/2018/fullprogram/31

This Invited is brought to you for free and open access by the Conferences at New Prairie Press. It has been accepted for inclusion in Symposium on Advanced Sensors and Modeling Techniques for Nuclear Reactor Safety by an authorized administrator of New Prairie Press. For more information, please contact cads@k-state.edu.

Presenter Information

J. A. Roberts, T. R. Ochs, D. M. Nichols, W. Fu, Y. Cheng, J. C. Boyington, D. S. McGregor, P. P.H. Wilson, R. J. Agasie, C. S. Edwards, and Y-H. Park

This invited is available at New Prairie Press: https://newprairiepress.org/asemot/2018/fullprogram/31

Preliminary Assessment of Steady-State and Transient Reaction-Rate Measurements at the University of Wisconsin Nuclear Reactor

J.A. Roberts, T.R. Ochs, D.M. Nichols, W. Fu,
Y. Cheng, J.C. Boyington, D.S. McGregor
Dept. of Mechanical and Nuclear Engineering
Kansas State University

P.P.H. Wilson, R.J. Agasie,
C.S. Edwards, Y-H. Park
Dept. of Engineering Physics
University of Wisconsin – Madison

Indo-US Science and Technology Forum
Symposium on Advanced Sensors and Modeling Techniques for Nuclear Reactor Safety
Mumbai, India December 15-19, 2018

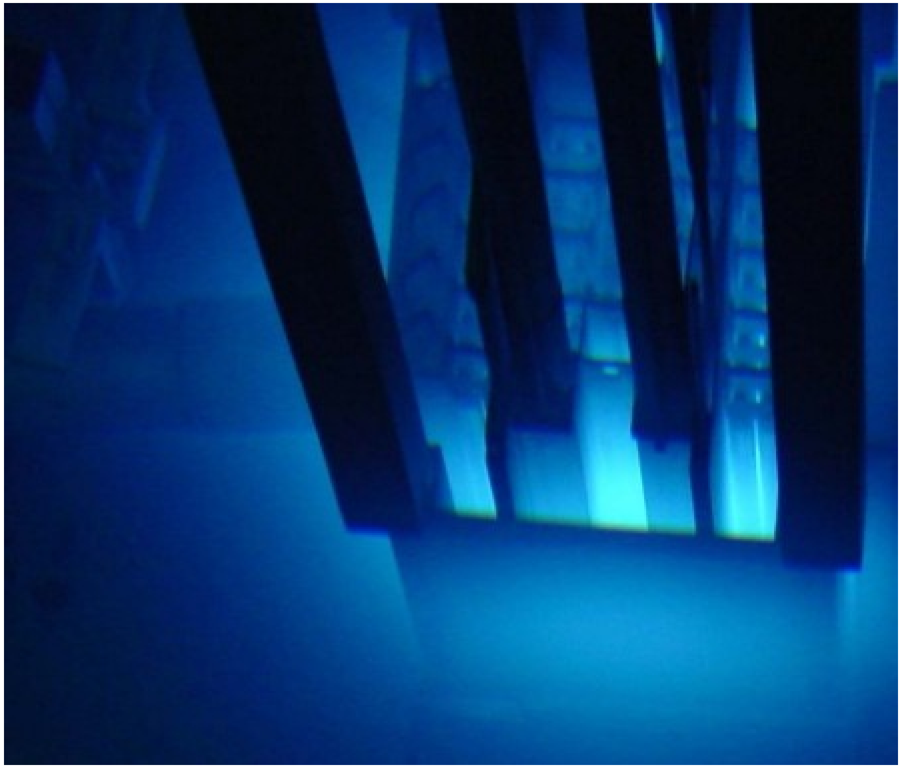
KANSAS STATE UNIVERSITY

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

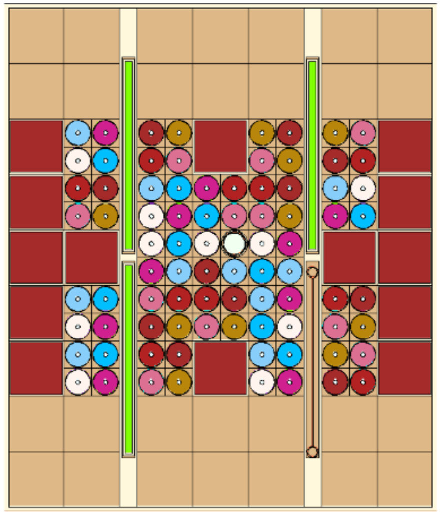
Motivation

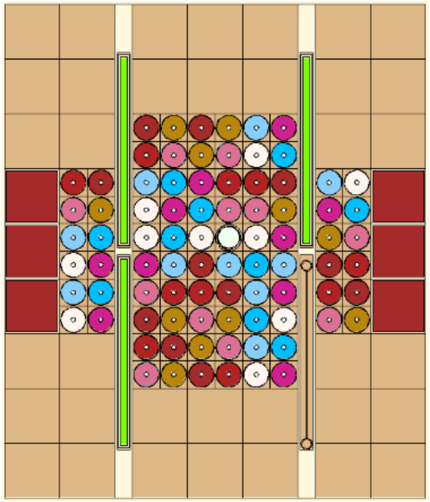
- Growing interest in high-fidelity models of all relevant physics; ongoing development of
  - NEAMS ToolKit (PROTEUS, and others)
  - MOOSE-enabled MAMMOTH/Rattlesnake
- Recognized need to conduct new experiments and to generate new data that for validation of such models
- Focus of this work was to generate first-of-a-kind, transient, reaction-rate measurements.

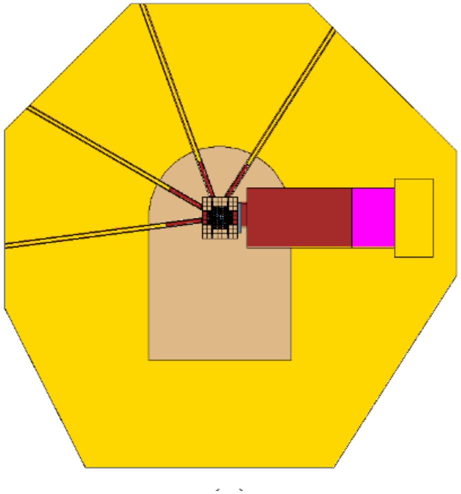
Where to Generate Date? UWNR.



- TRIGA-fueled MTR conversion with 2x2 bundles in square lattice
- Conversion to LEU (from HEU FLIP) fuel completed in 09/2009
- 1 MW licensed power with pulsing capability to ~ 1 GW

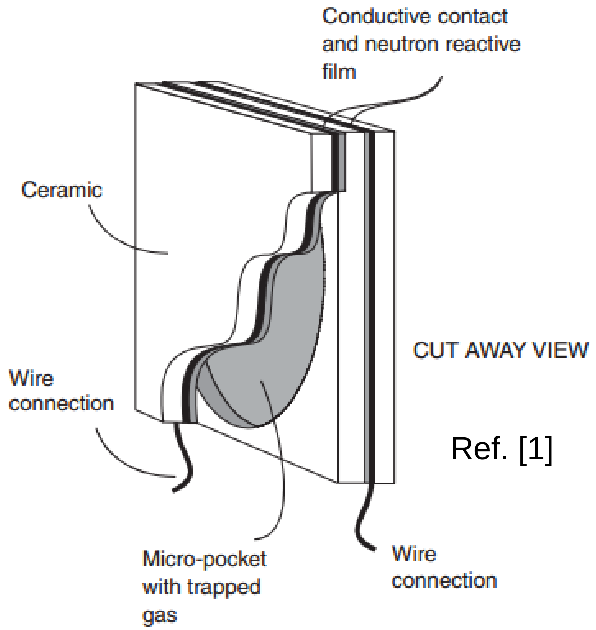




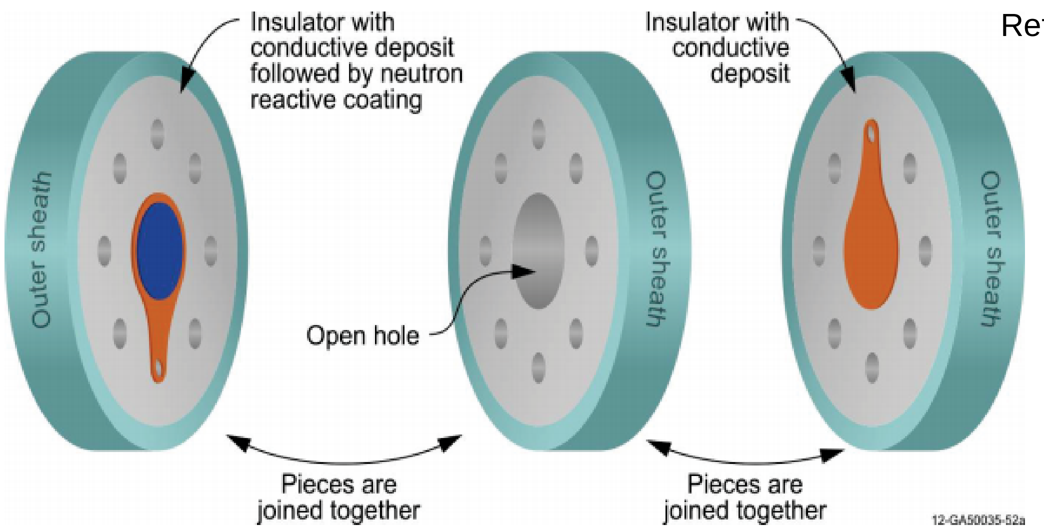


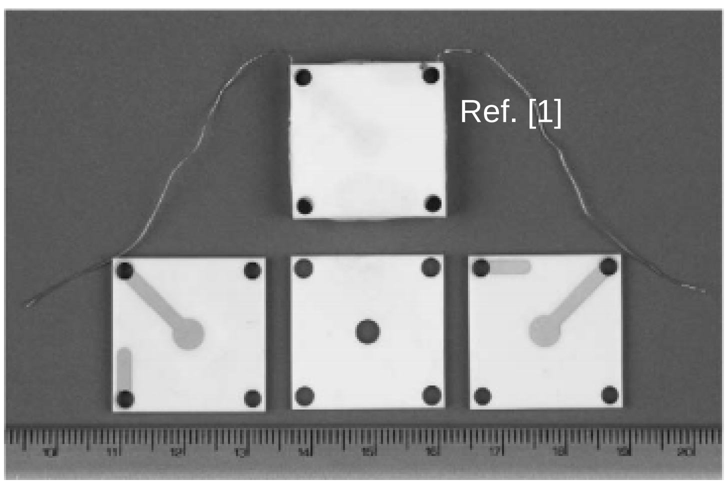
(micro-pocket fission detector)

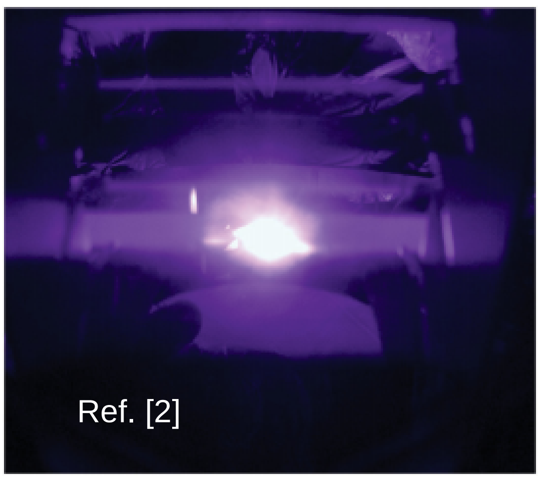
So What is a MPFD?

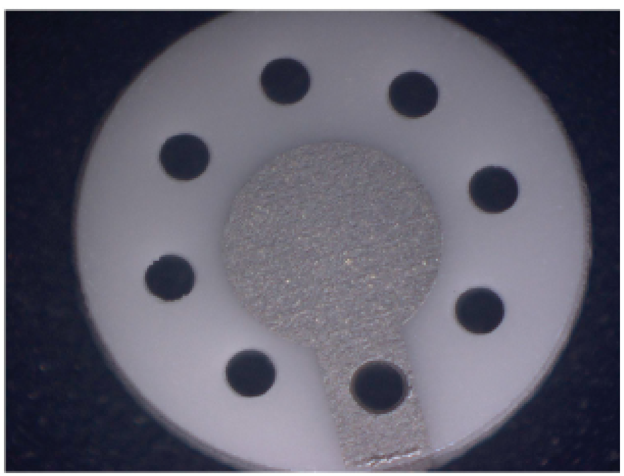


Ref. [2]



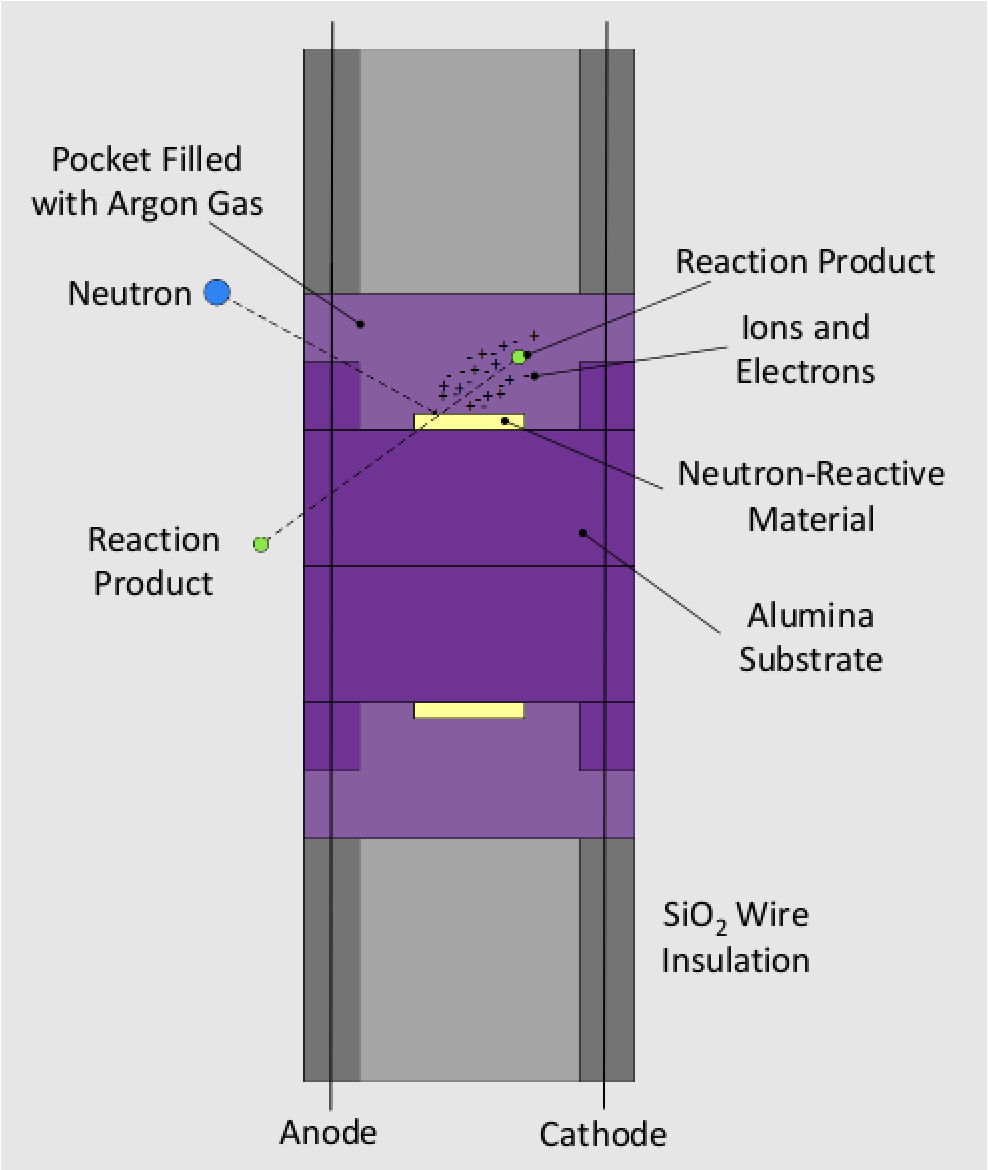




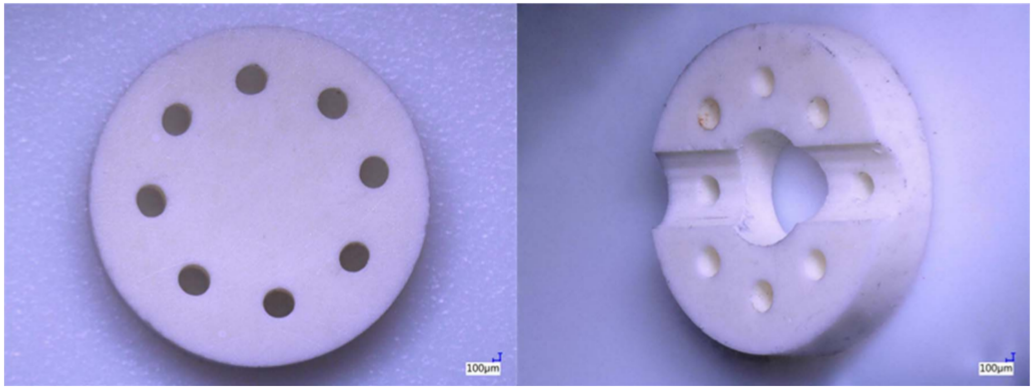


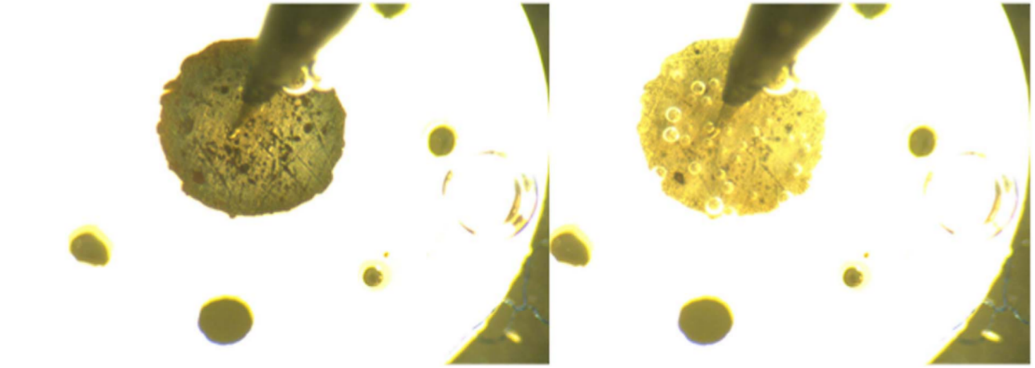
[1] McGregor, D. S., Ohmes, M. F., Ortiz, R. E., Ahmed, A. S., & Shultis, J. K. (2005). Micro-pocket fission detectors (MPFD) for in-core neutron flux monitoring. NIM A, 554(1), 494-499.
[2] Unruh, T., Rempe, J., McGregor, D., Ugorowski, P., Reichenberger, M., & Ito, T. (2012). NEET Micro-Pocket Fission Detector-FY 2012 Status Report. INL/EXT-12-27274

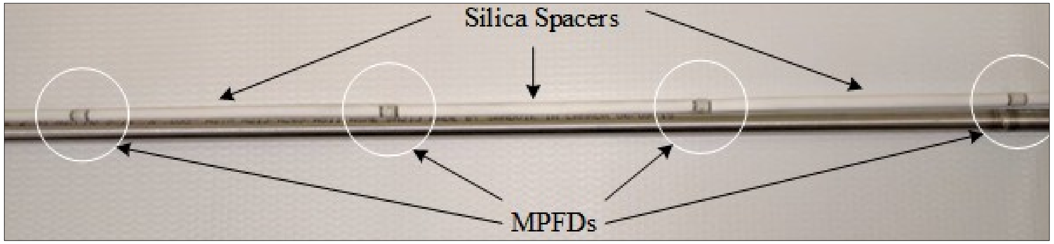
Simplified, Two-Wire Design



S.R. Stevenson, M.A. Reichenberger, D.M. Nichols, T.C. Unruh, J.A. Roberts, T.M. Swope, C.W. Hilger, and D.S. McGregor, "Micro-Pocket Fission Detector Instrumentation for Research and Test Reactors," *ANS Winter Meeting* (2016)



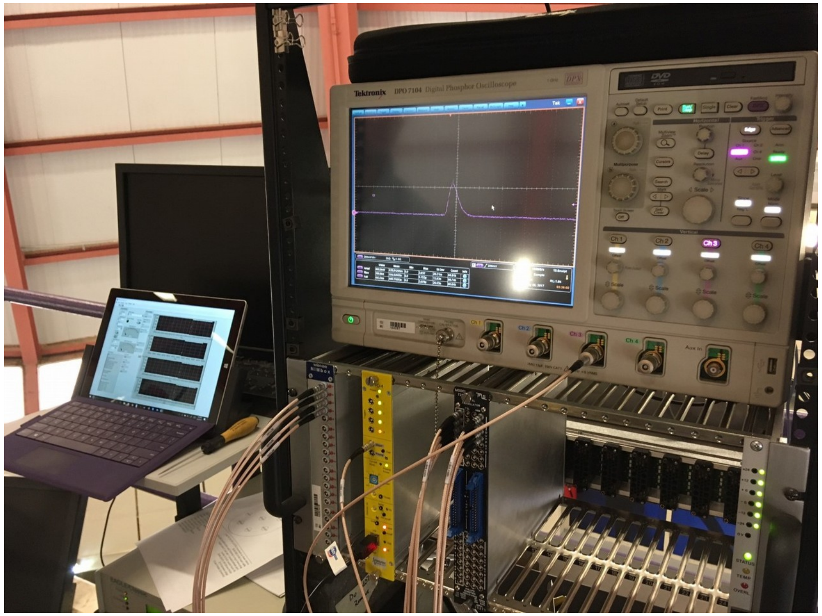




M.A. Reichenberger,, D.M. Nichols, S.R. Stevenson, T.M. Swope, Caden W. Hilger a , T.C. Unruh, Douglas S. McGregor a , J.A. Roberts, "Fabrication and testing of a 4-node micro-pocket fission detector array for the Kansas State University TRIGA Mk. II research nuclear reactor," *NIM A* **862** (2017)

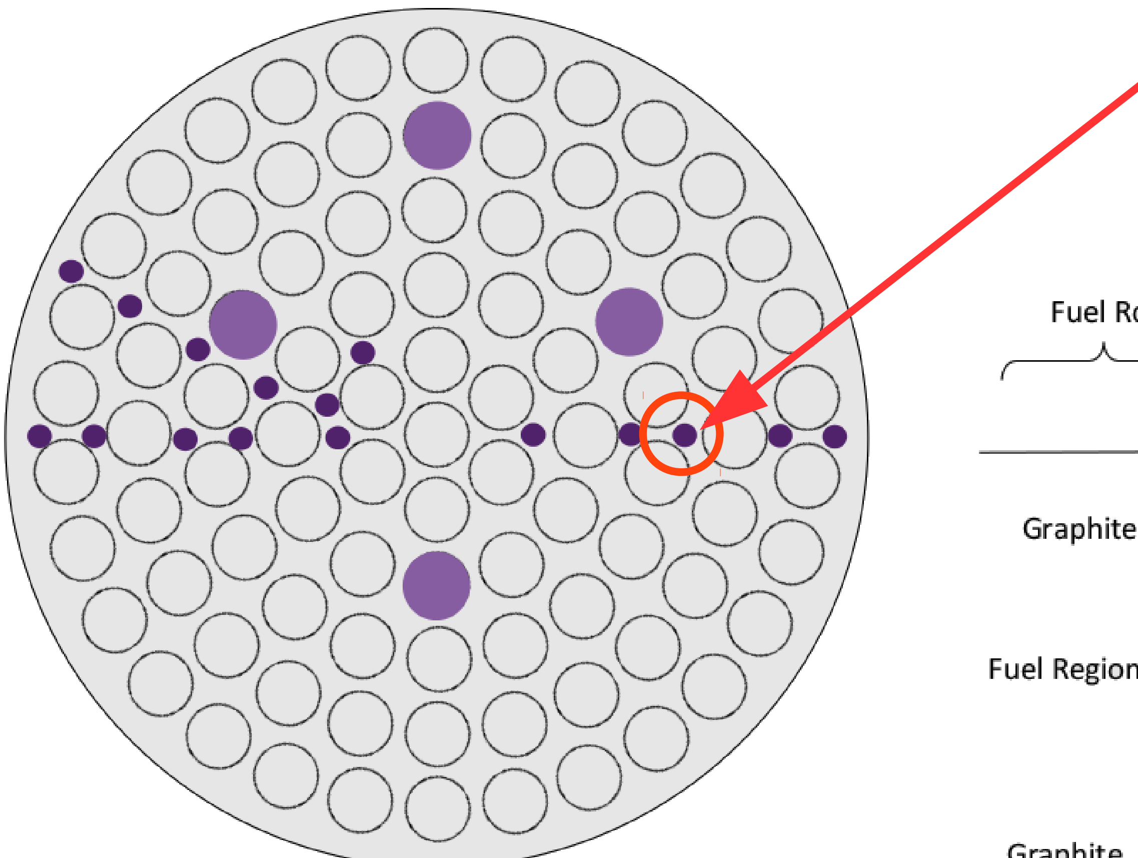
MPFD Signal Processing

- Single system to support four-node array
- Shaping amplifier with fast shaping, discrimination, and counting capability
  - Digital “count” output
  - USB interface to custom LabView counting software
- Supports both pulse- and current-mode operation (not switchable)

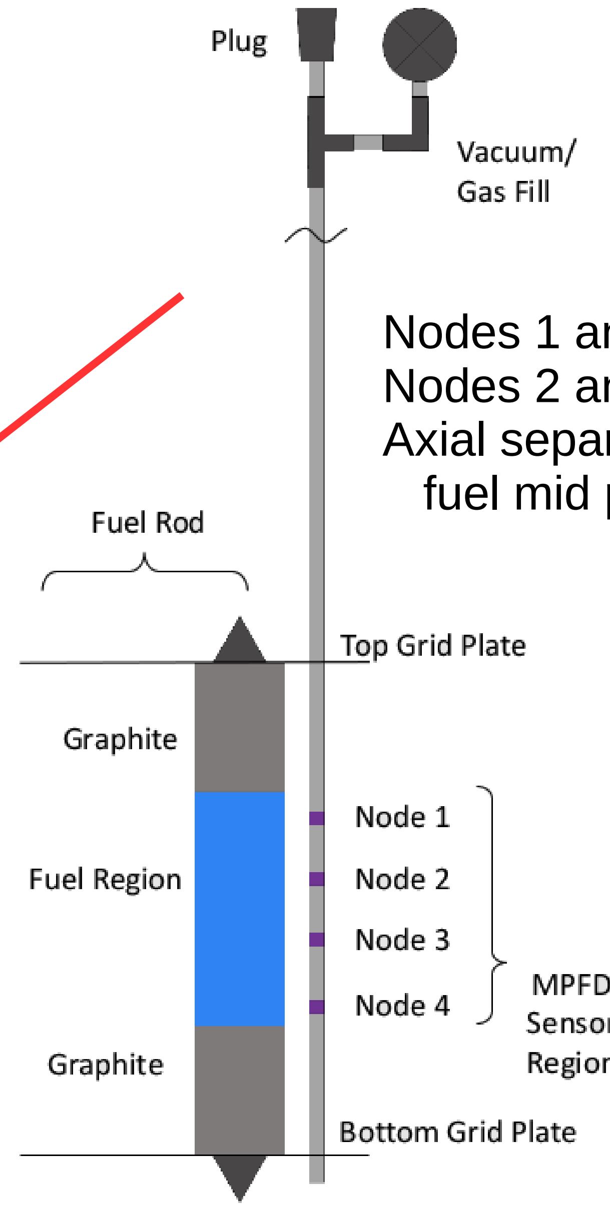


Early Mock-Up Testing at K-State

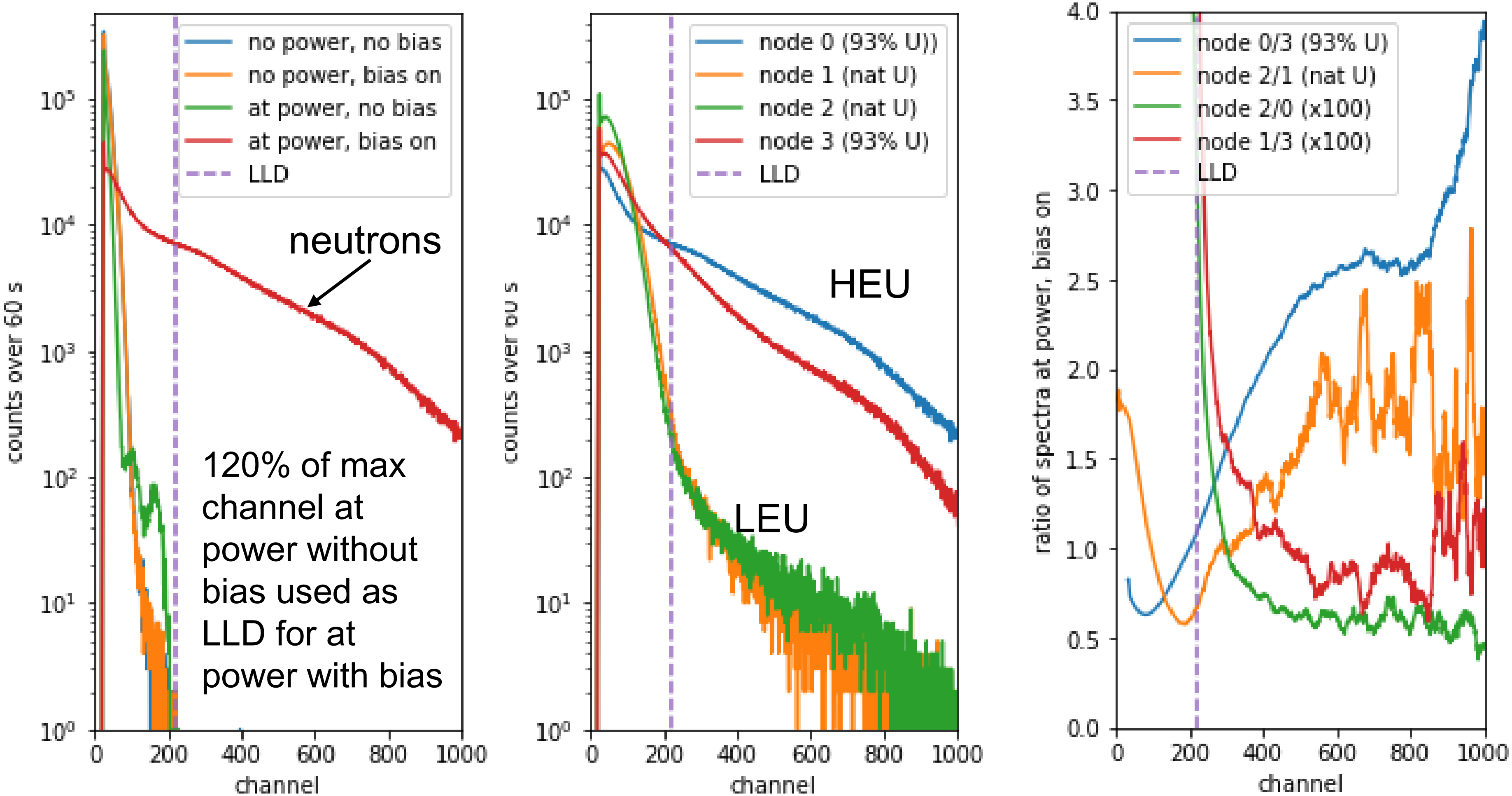
Goal: use four chambers with approximately two unique masses in small region to test new electronics and understand response.



Nodes 1 and 4 HEU
Nodes 2 and 3 nat. U
Axial separation ~1 cm at fuel mid plane



Early Mock-Up Testing at K-State



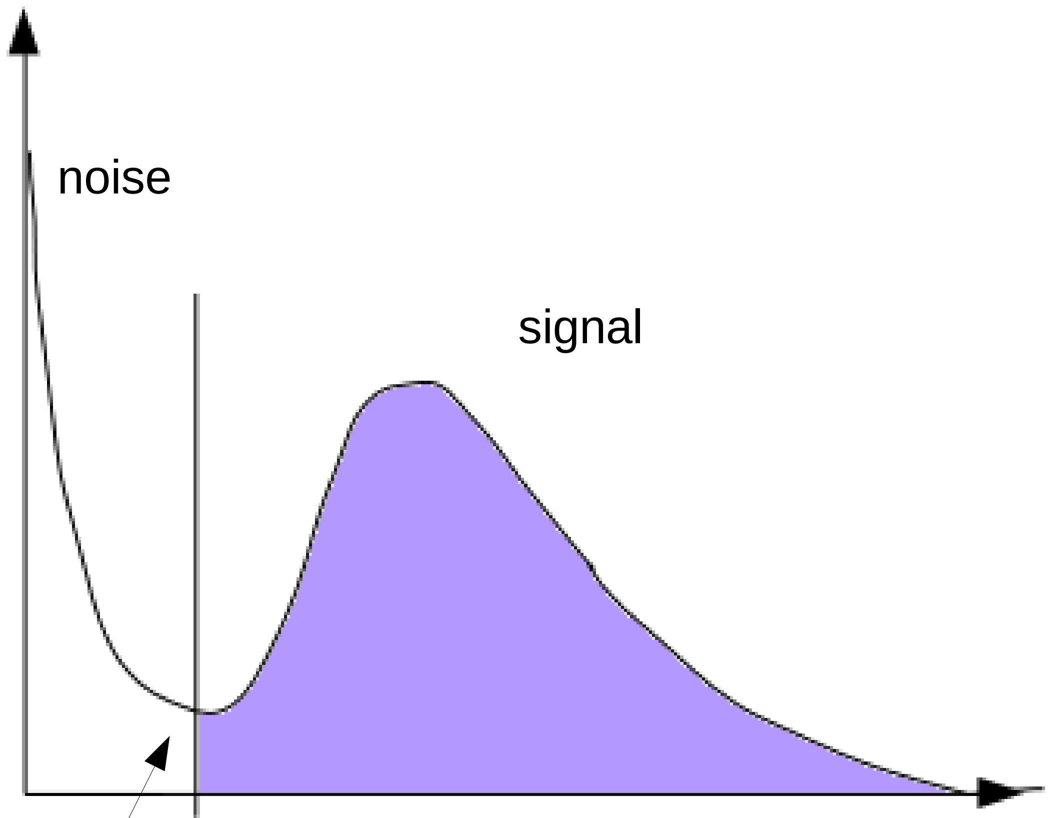
Comparison of noise and signal spectra. Only the shape is meaningful as magnitudes affected by MCA dead times.

LEU nodes same as UWNR arrays (within fabrication tolerances, etc.). HEU is more sensitive and makes testing easier.

Ratios (with smoothing) suggest somewhat consistent spectra.

Reasonably promising, but pulse-height spectrum not ideal (no “plateau”) for calibration, and linearity with power not perfect; same true for 7 wands constructed for deployment.

Pulse-Mode Operation + Calibration



Valley to the left of which noise can be eliminated with minimum lower-level discriminator (LLD) setting.

$$m_{\mathrm{eff}}(\mathrm{LLD}) = \frac{C(\mathrm{LLD})}{R}$$

C is measured count rate (s^{-1})

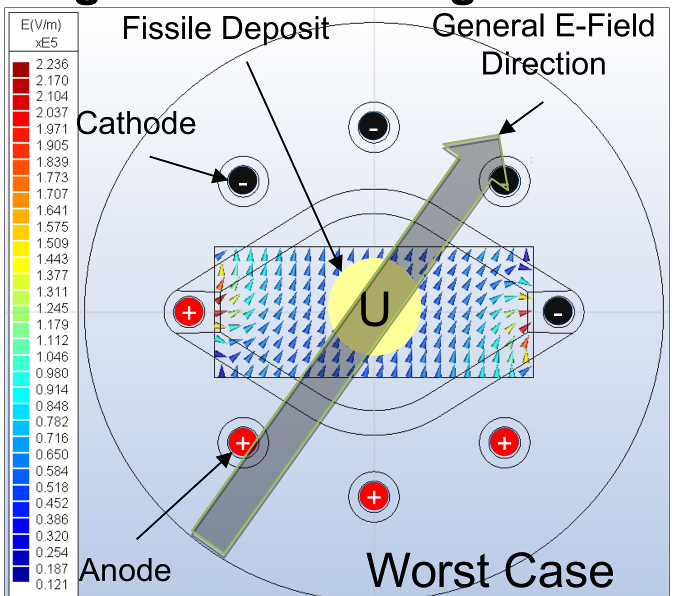
R is true fission rate ($s^{-1}\ g^{-1}$)

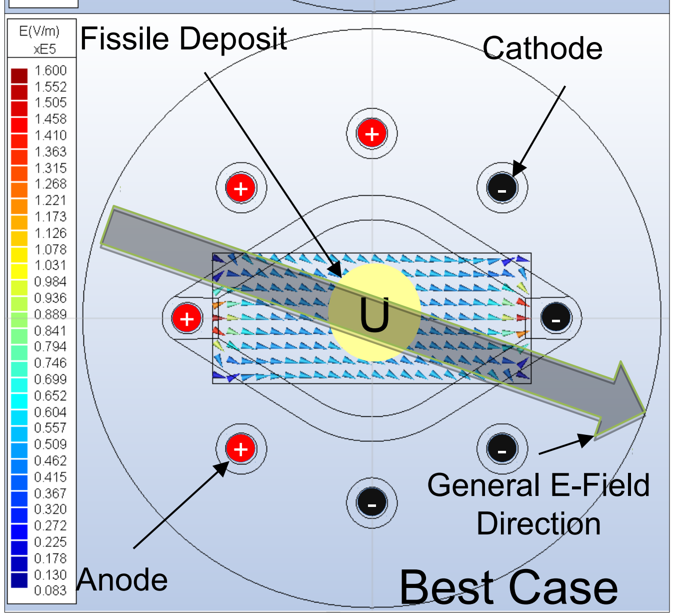
Idea* is to parameterize effective mass as a function of LLD for a known flux (or fission rate) and then <u>deduce true fission rate for any measured count rate in any other environment</u>.

* V. Lamirand, et al.Miniature Fission Chambers Calibration in Pulse Mode: Interlaboratory Comparison at the SCK-CEN BR1 and CEA CALIBAN Reactors. IEEE TNS, 61(4), 2306-2311 (2014).

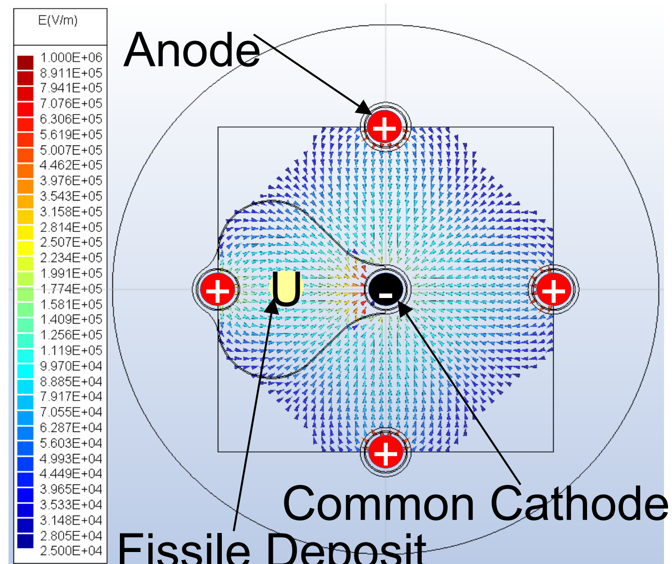
Changes, E-field, new materials

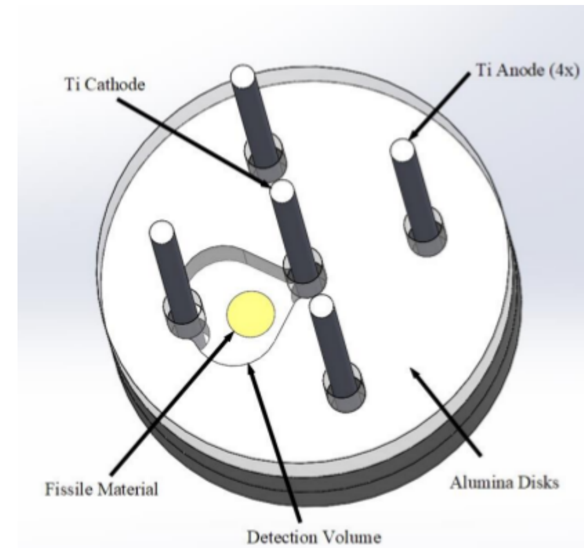
Original MPFD Design

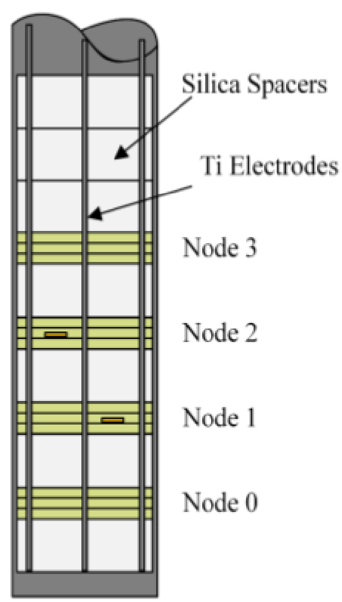




Improved E-field based on common, central cathode.

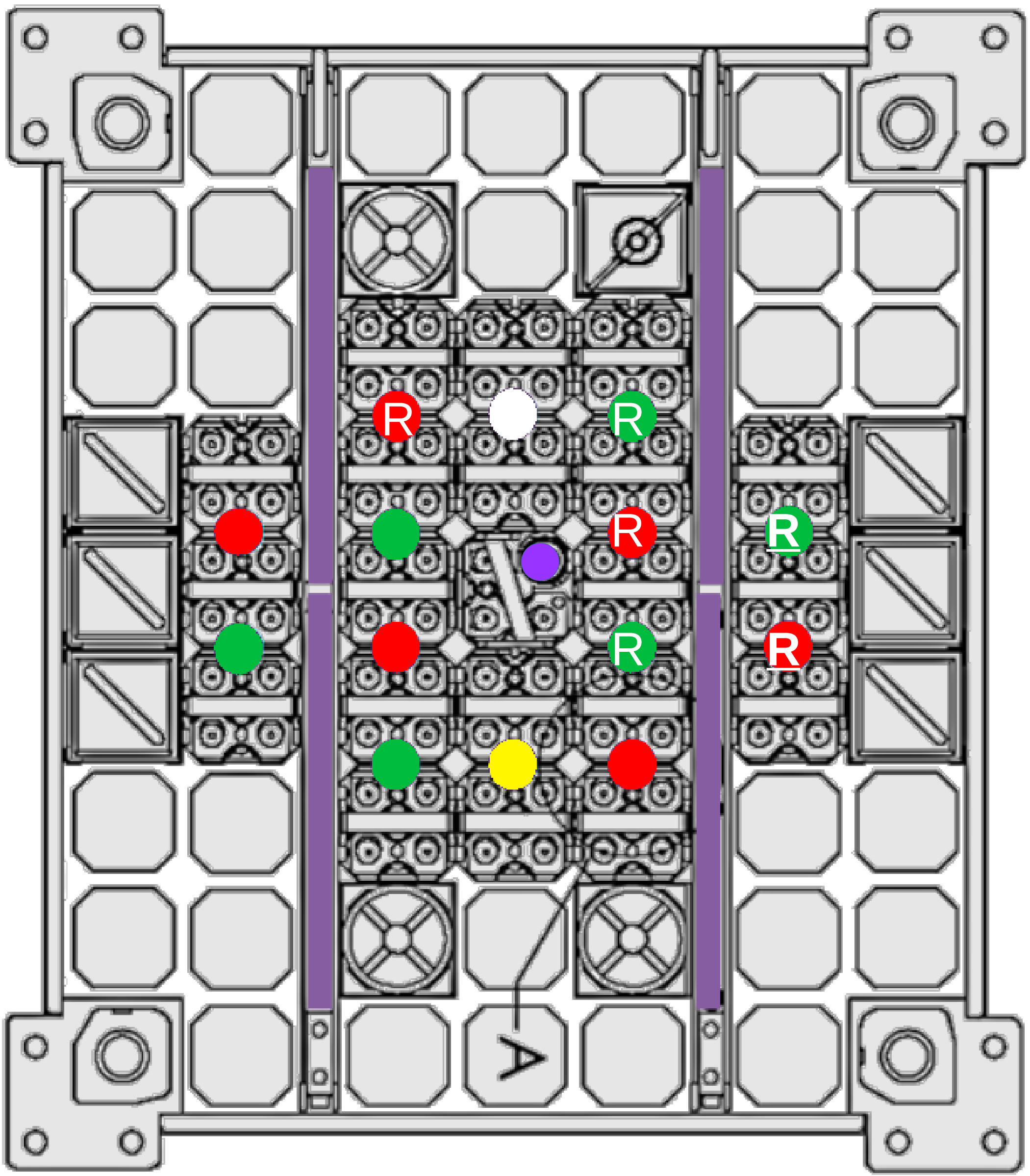






Other changes/improvements:
- titanium (in place of Fe/Ni materials)
- 20% enriched U (in place of natural)
- better feed-through fittings to eliminate gas leaks into cable
- use of shared cathode leads to some electronic coupling

Experimental Campaign



Schematic of UWNR and 13 possible probe locations.

Yellow location indicates reference position.

Red locations correspond to configuration 1 (C1).

Green locations correspond to configuration 2 (C2).

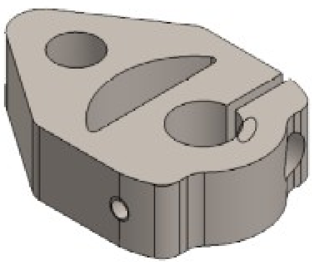
White R's indicate RTD in configurations C1* and C2*. Underline is always an RTD.

Experimental Campaign

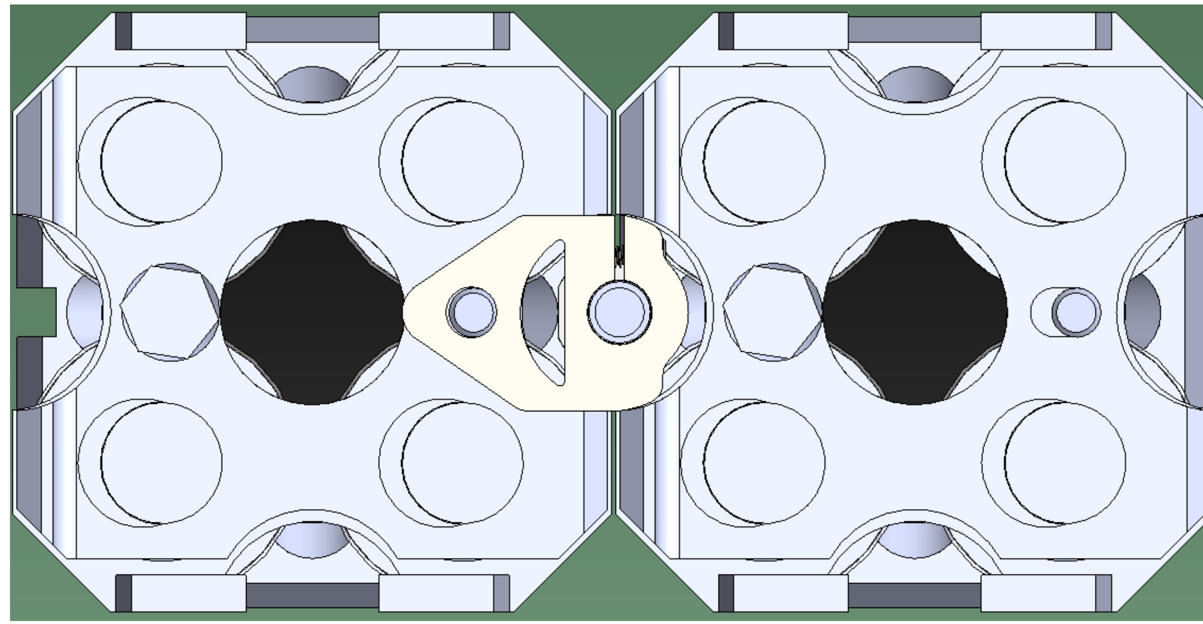
- Multiple foil activations in reference location
- Single-probe tests for calibration in reference location included pulse-height acquisition at 100 kW and measurements at 100/300/500/400/200 kW in pulse- and current-mode operation.
- Steady-state, multi-probe configurations C1/C1*/C2/C2* for multiple powers at even control banking and 100 kW for five flux-shaping control configurations
- Ramps from 300 W to 400 kW with 20-, 30-, and 50-second periods
- Square waves from 300 W to 250, 500, and 1000 kW.
- Pulses of $1.43, $1.71, and $1.97

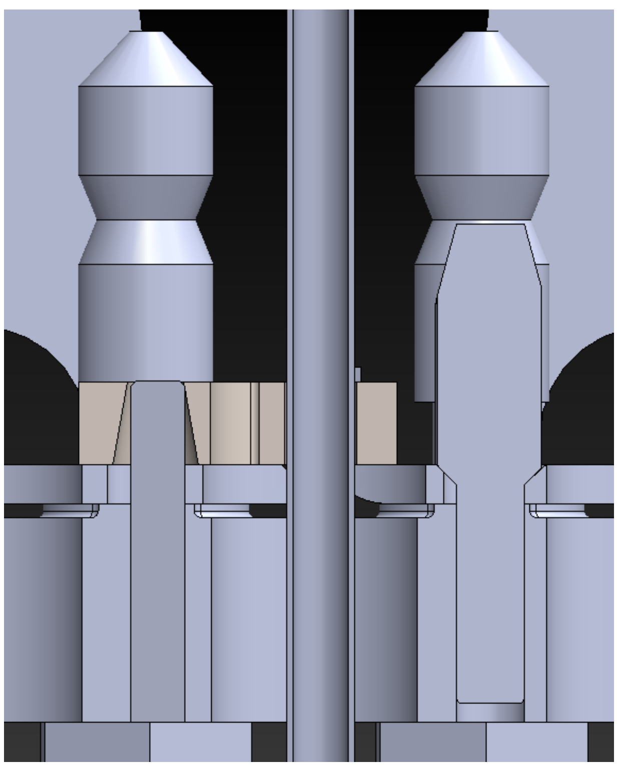
Facilitating Insertion of MPFDs

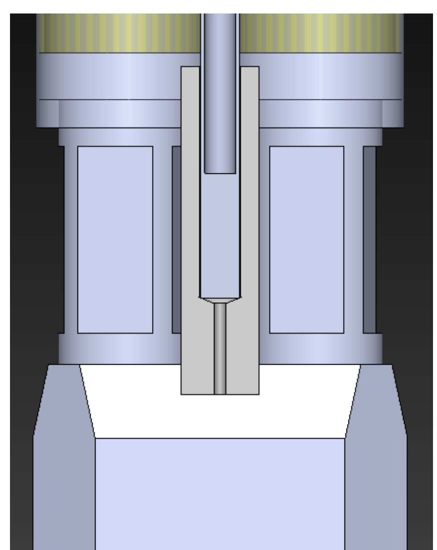
bottom stabilizer

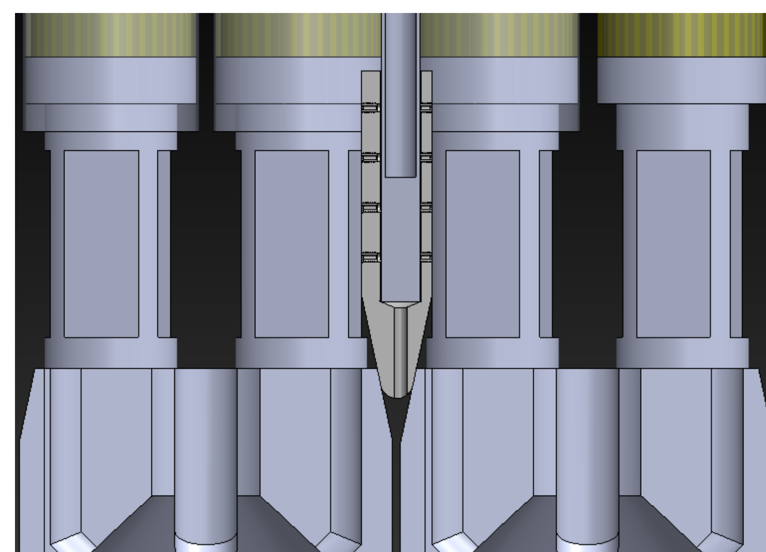


top stabilizer

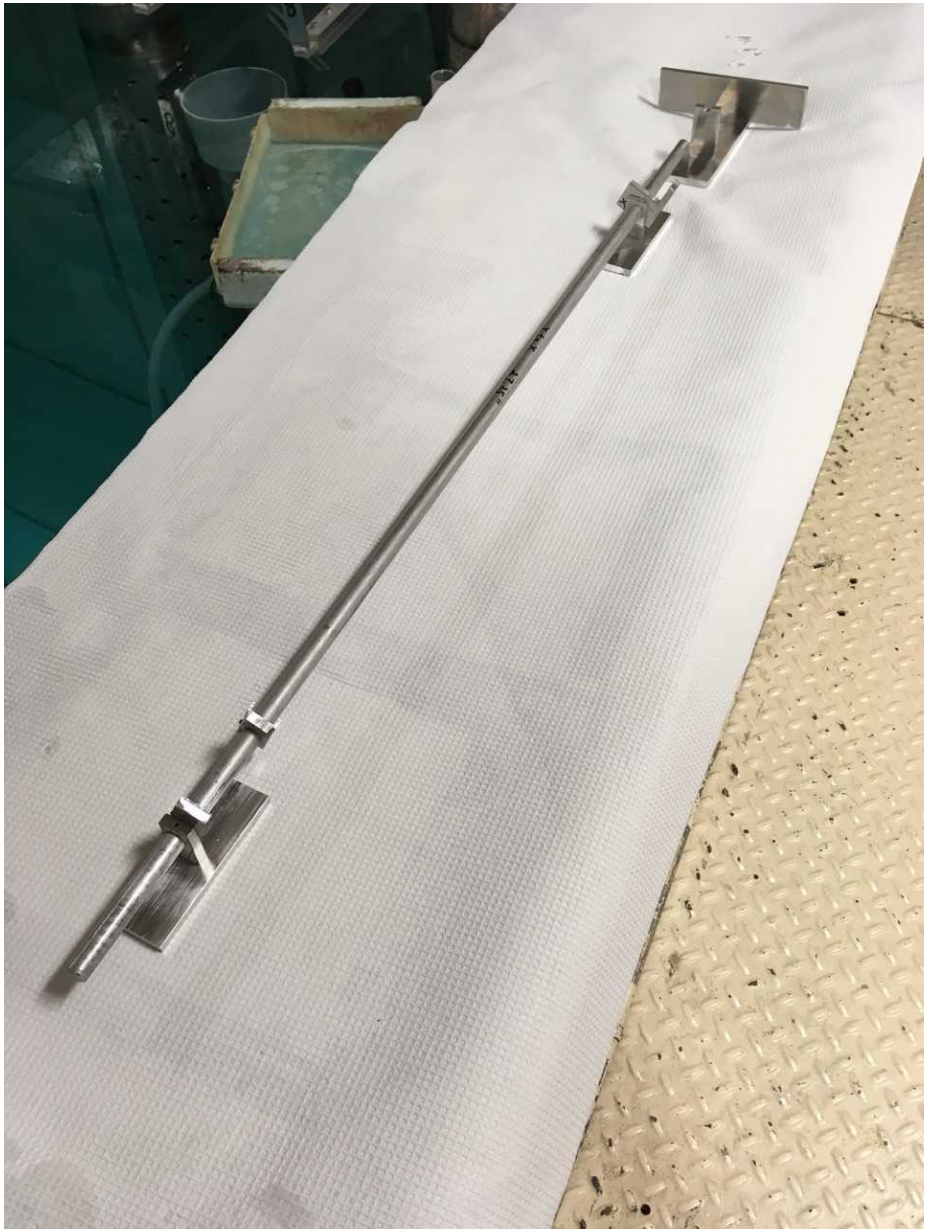


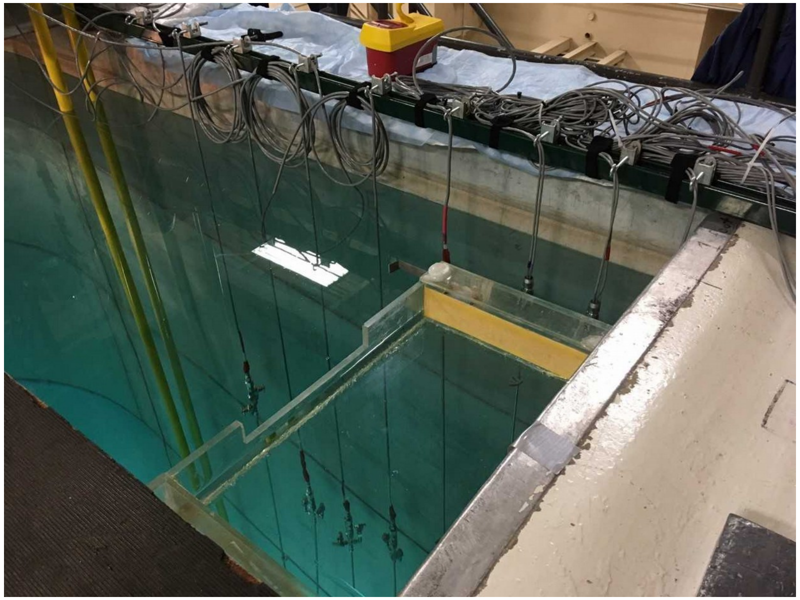


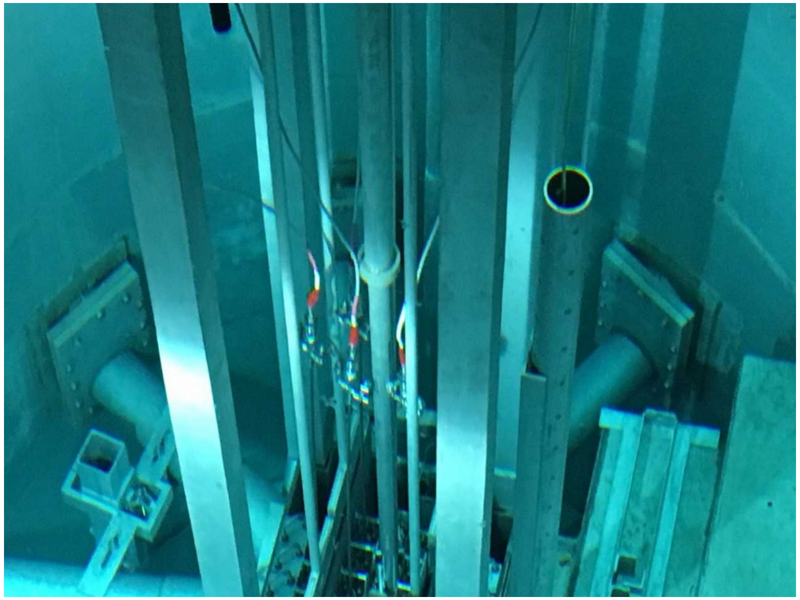




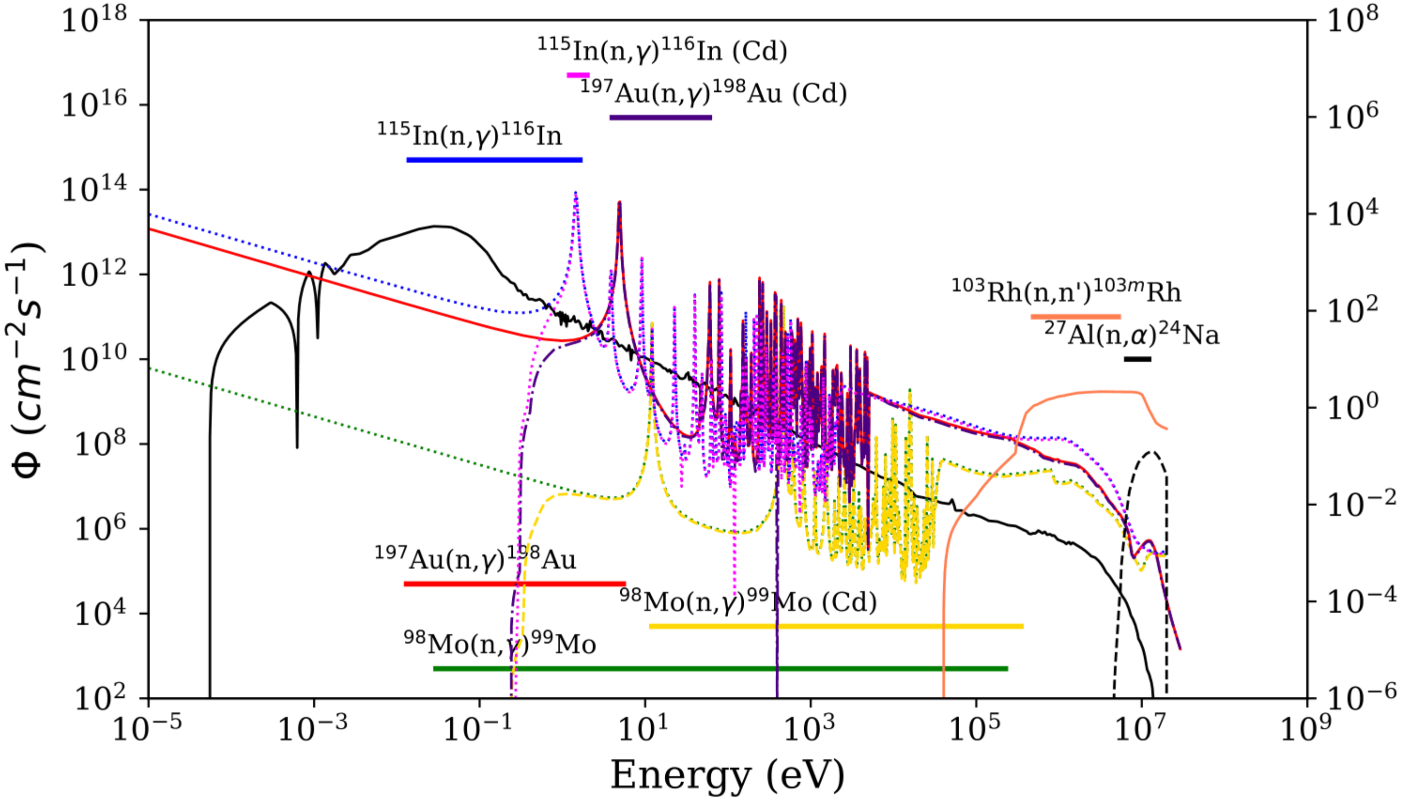
Insertion of MPFDs (and RTDs)







Activation Foil Mock-Up



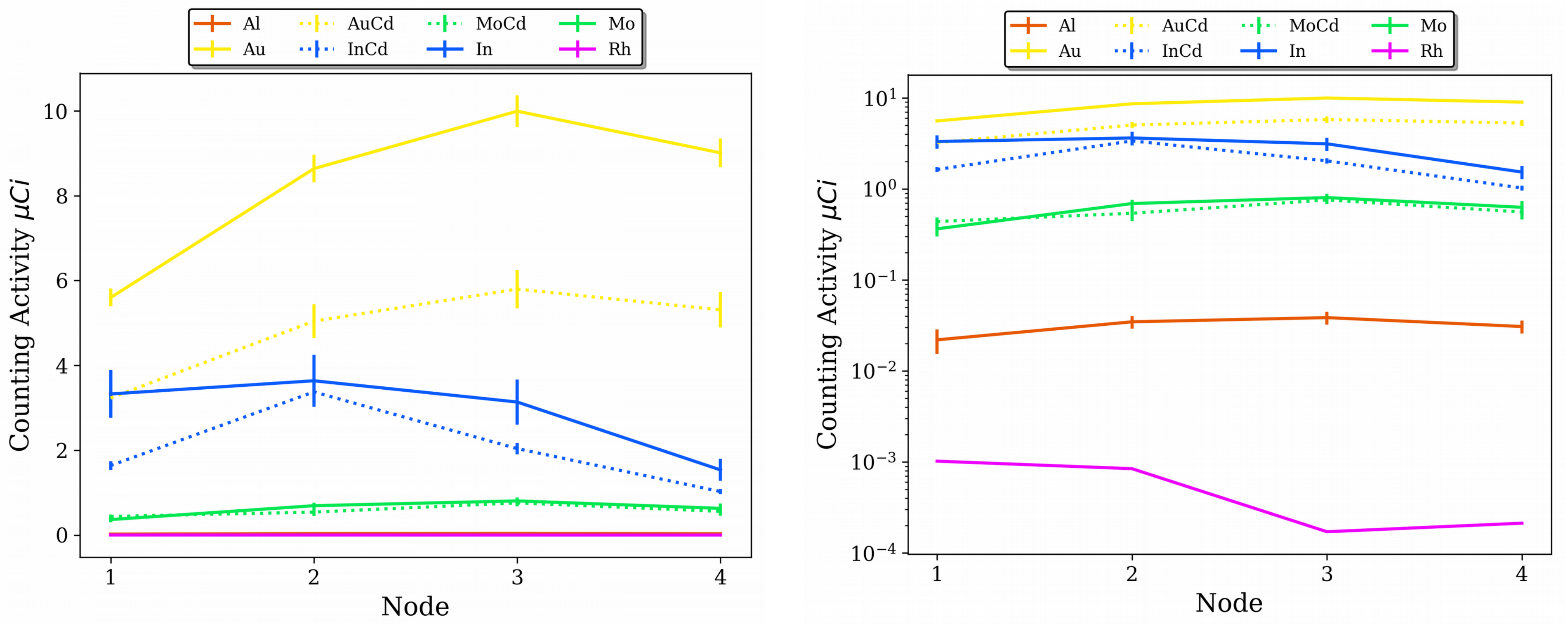
Locking of foil chambers.

pre irradiation

Mock-up wand internals.

post irradiation (from MPFD)

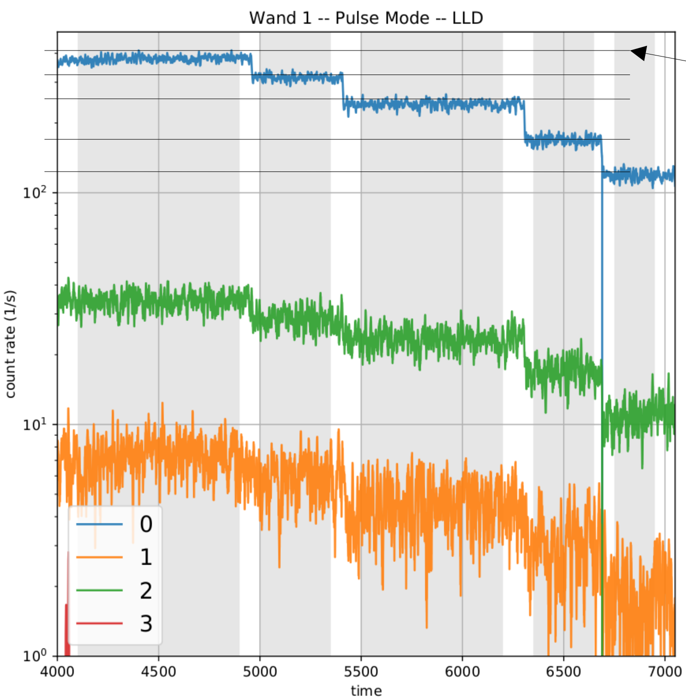
Counting Results (unprocessed)



Shown are *raw* count rates. Next steps:

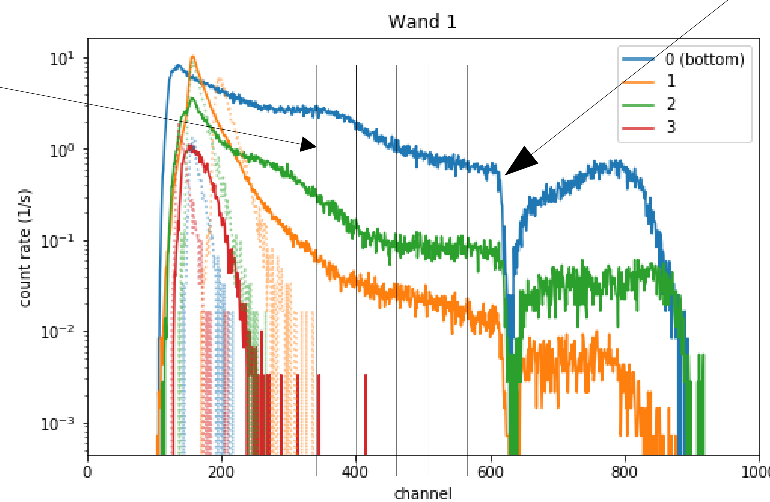
- convert to saturation activities (with uncertainties)
- apply unfolding techniques to determine flux spectrum (e.g., SAND-IV, MAXED, etc.)

Single-Probe Tests: Example Data

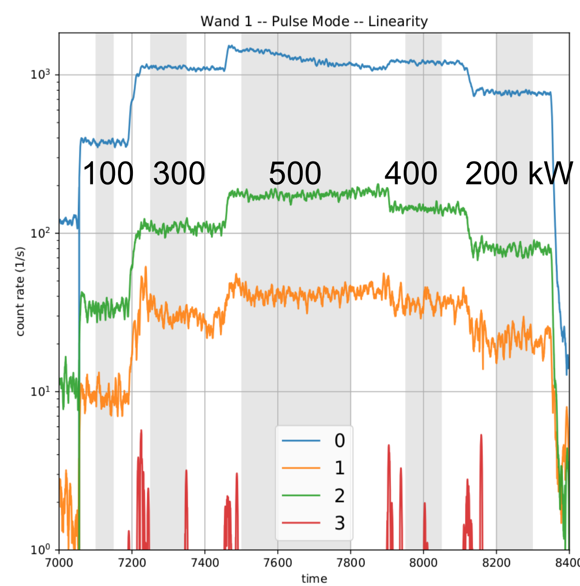


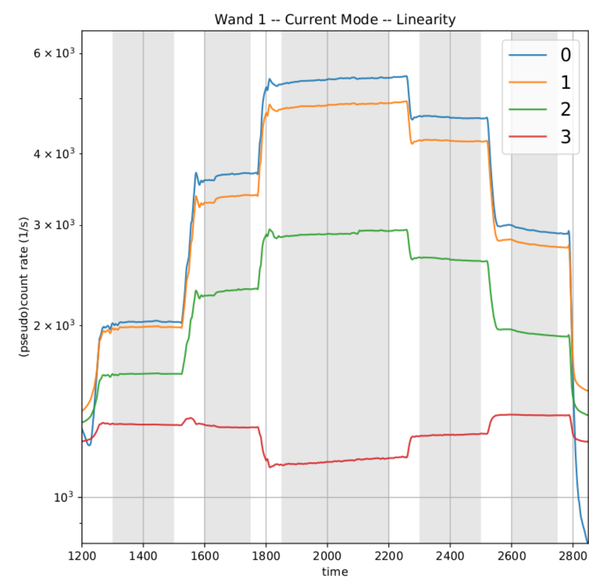
Illustrative response to reduced LLD in pulse-mode operation. May be used to validate spectrum-based calibration. Note that node 3 exhibits a negligible response, indicating, e.g., physical defect.

Potential impact from ad-hoc filter



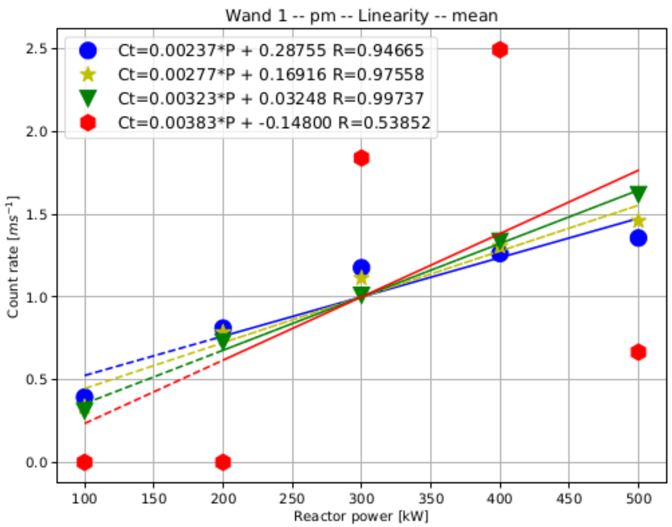
Pulse-height spectrum for Wand 1 signal (solid) and background (dotted). Again, node 3 exhibits very low sensitivity.

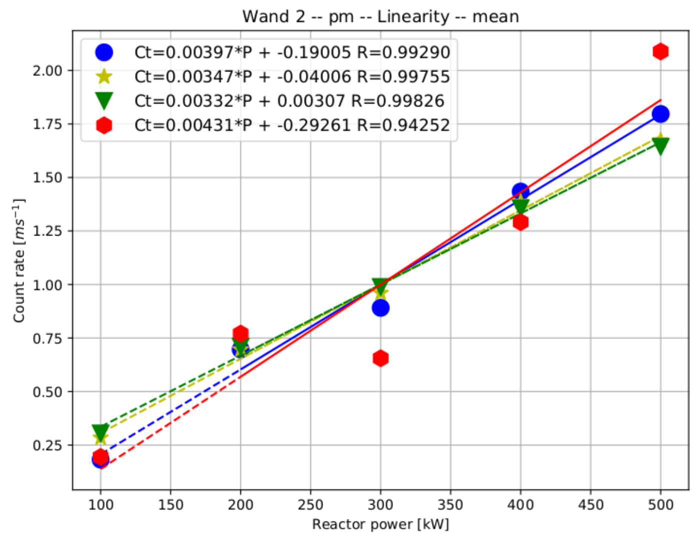


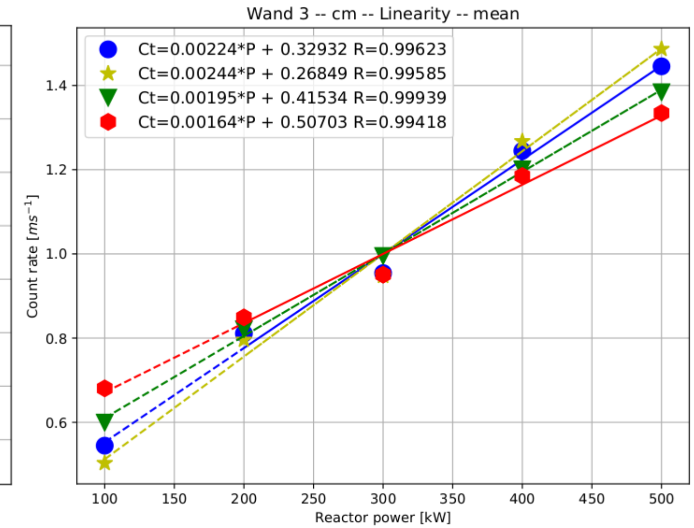


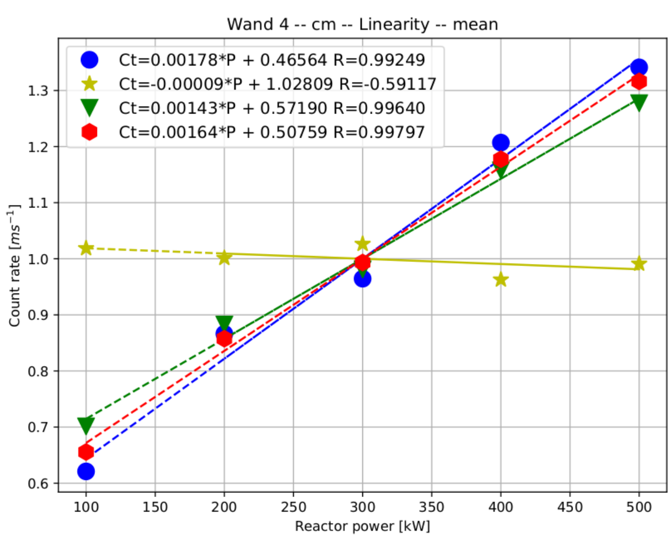
Response at several powers in both pulse- and current-mode operation. Current-mode output includes a baseline signal of ~1000 cps that must be removed

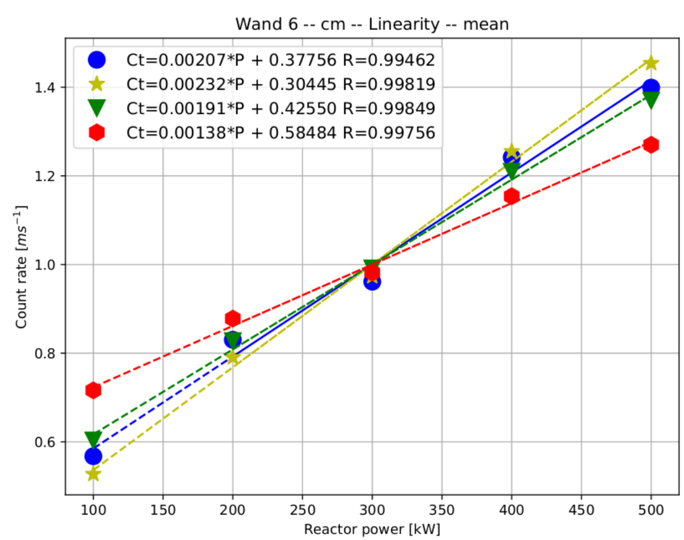
Single-Probe Tests: Linearity

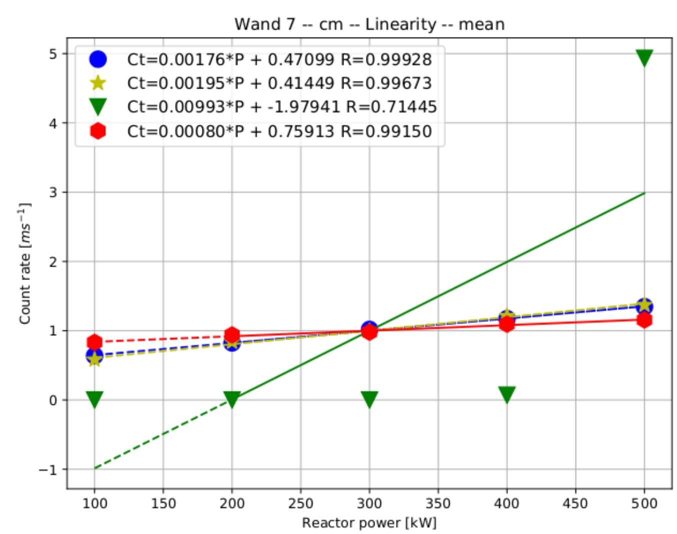












- 0 (bottom)
- 1
- 2
- 3 (top)

Ideal behavior has y-intercept of 0 for pulse-mode and ~1 for current-mode operation – no attempt made to force these values.

Summary of Single-Probe Tests

Testing showed several nodes suffered several, systematic problems.

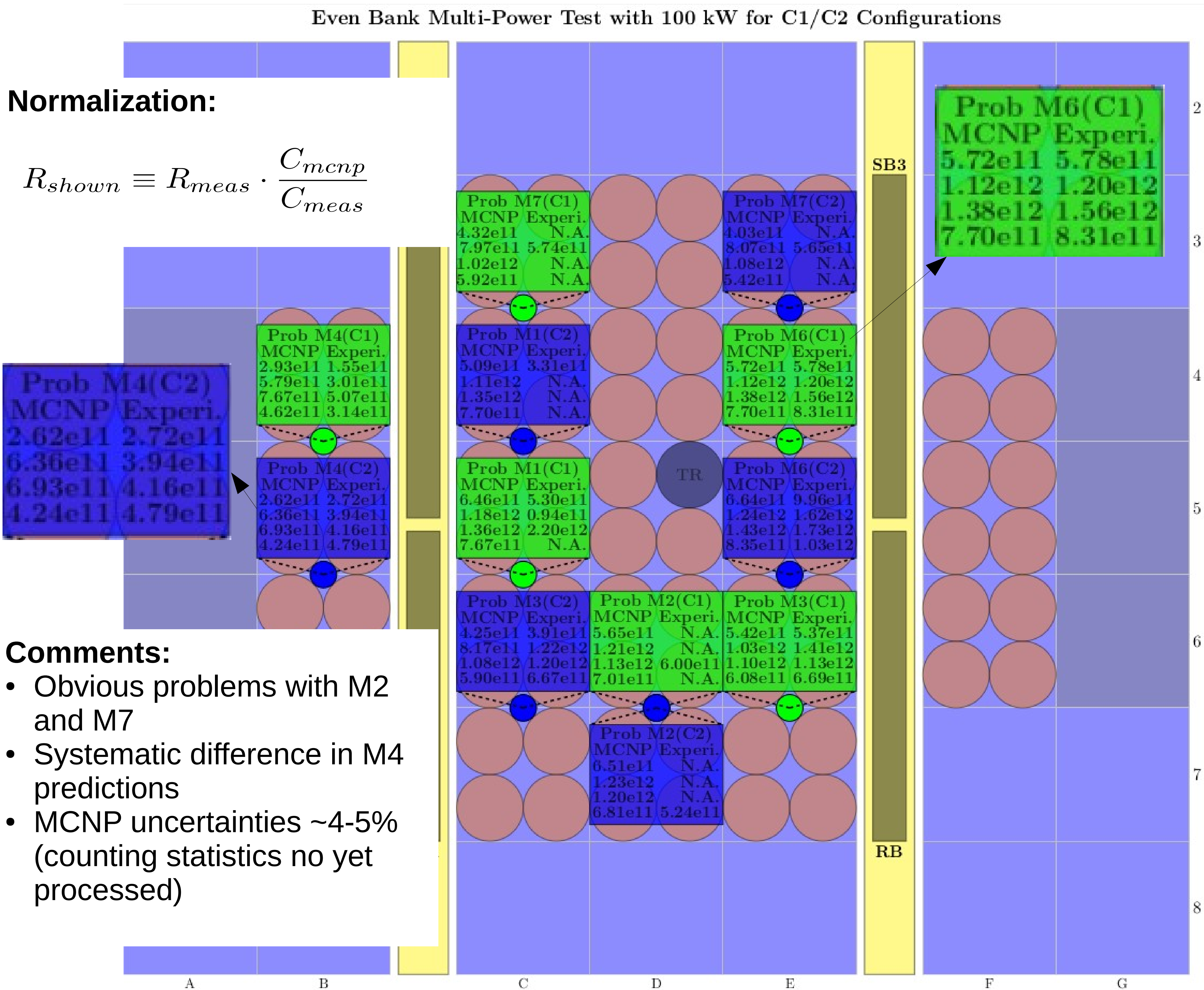
A summary of nodes in each wand that exhibited expected behavior based on initial analysis of single-wand testing is shown below. **Bolded** indicates final operation mode.

Wand	Pulse Mode	Current Mode
1	**0, 1, 2**	0, 1, 2
2	**0, 1, 2**	0, 1, 3
3	0, 1, 2	**0, 1, 2, 3**
4	0, 2	**0, 2, 3**
5	none	none
6	0, 1, 2	**0, 1, 2, 3**
7	none	**0, 1, 3**

Estimated that 20 individual detectors would provide reliable responses.

Normalization:

$$R_{shown} \equiv R_{meas} \cdot \frac{C_{mcnp}}{C_{meas}}$$

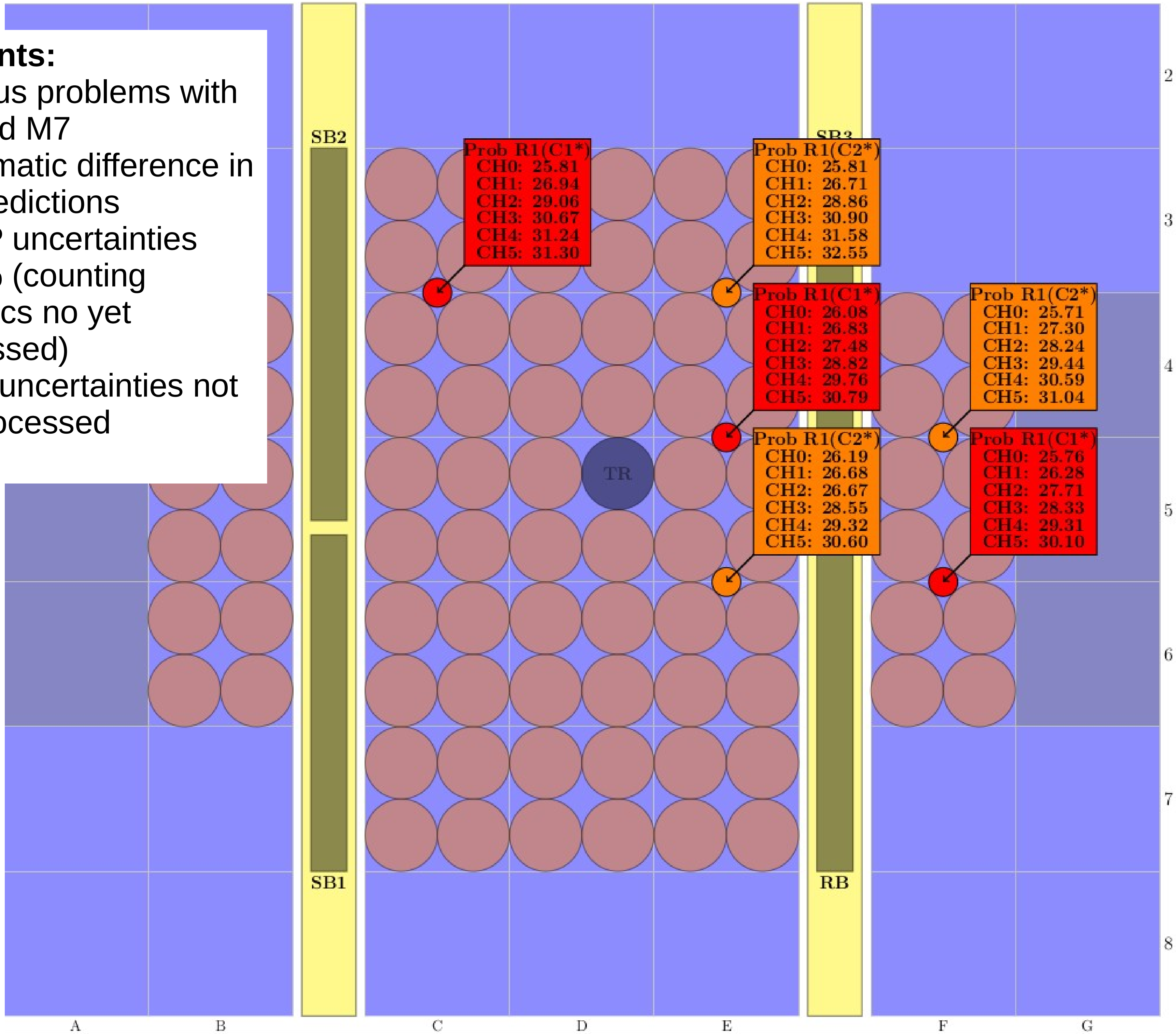


Comments:

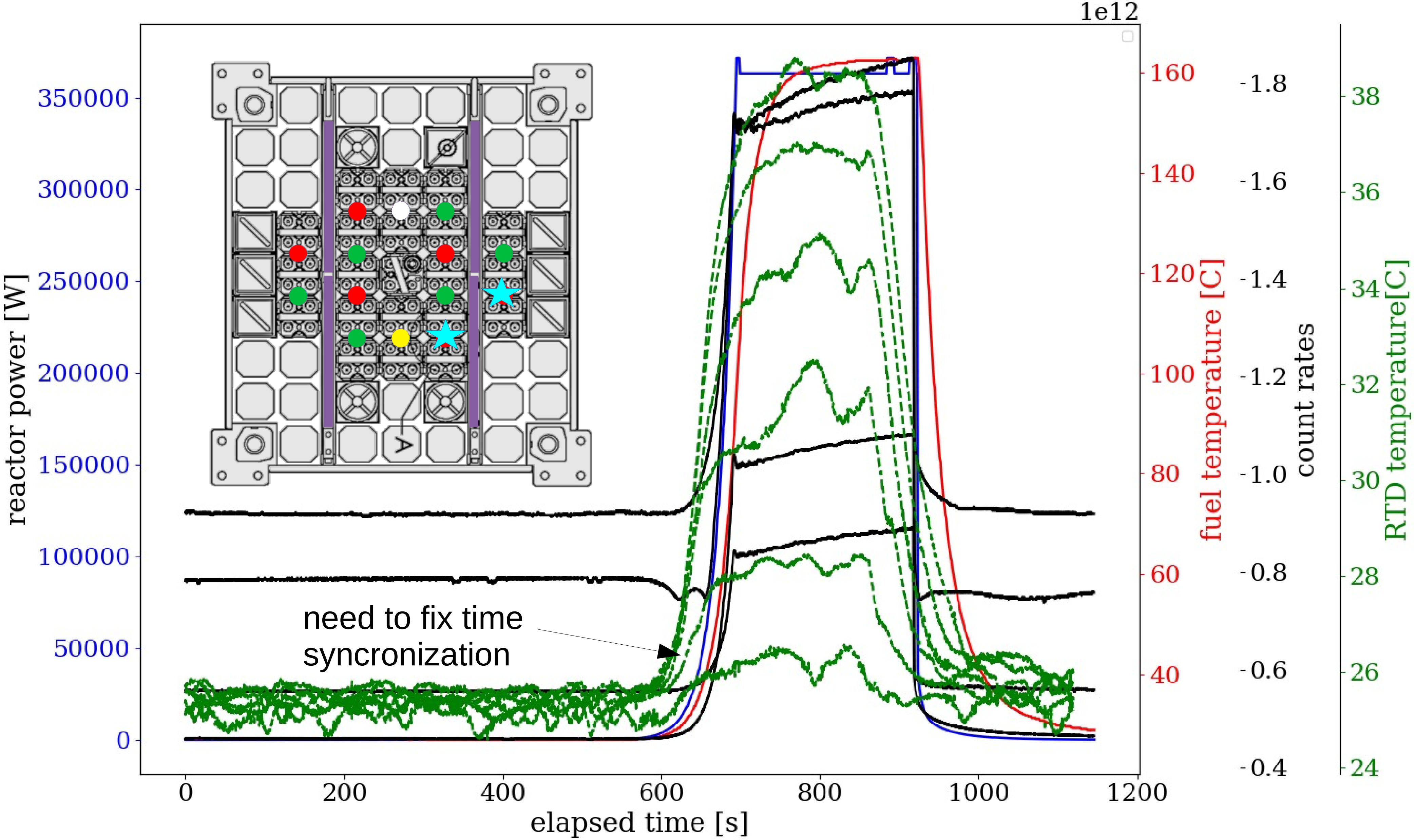
- Obvious problems with M2 and M7
- Systematic difference in M4 predictions
- MCNP uncertainties ~4-5% (counting statistics no yet processed)

RTD Results of Even Bank Multi-Power Test with 100 kW for C1*/C2* Configurations

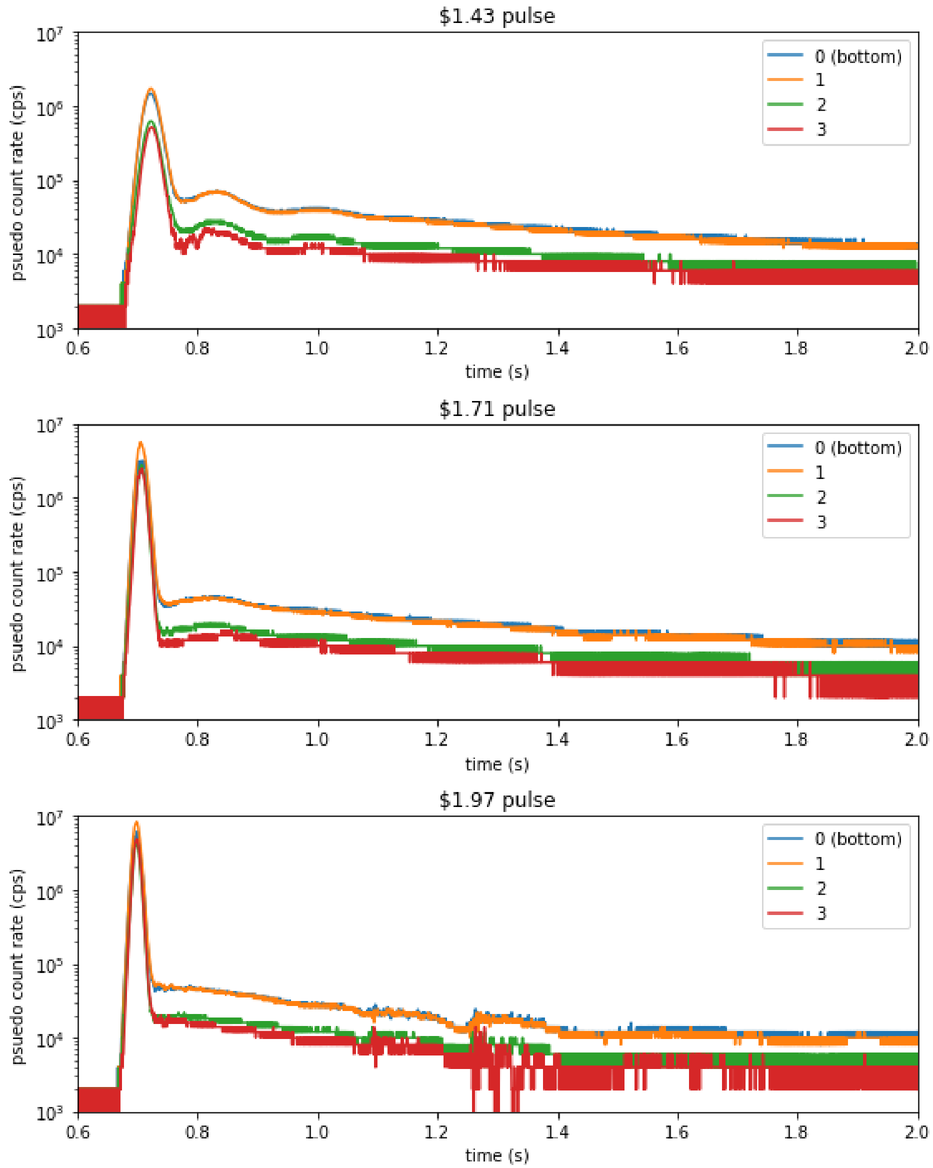
Comments:
- Obvious problems with M2 and M7
- Systematic difference in M4 predictions
- MCNP uncertainties ~4-5% (counting statistics no yet processed)
- Other uncertainties not yet processed



Example Transient: 20s ramp

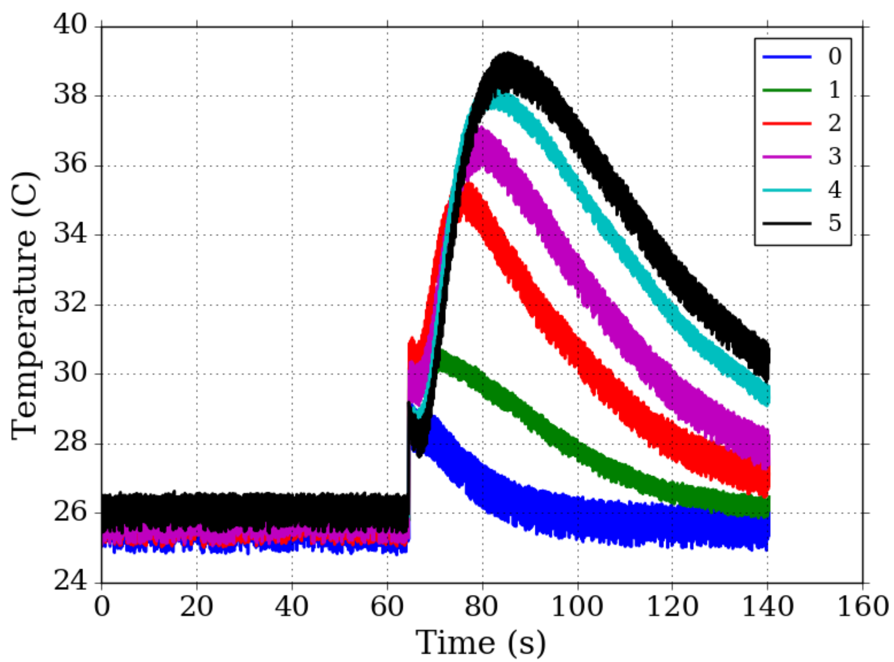


Snapshot of Pulsing Data



Pulses tracked using built-in buffer with 0.5 ms time binning in current-mode operation. Shown is the response from Wand 1 (at left).

Right: response from 6-node, platinum RTD probe. Initial peak indicates direct gamma heating followed by heat transfer from coolant.



Processing of transients still underway, but initial data suggests successful data acquisition for all six pulses performed.

Summary of Modeling Effort

- Scoping studies to understand material spatial resolution needed to capture material evolution and thermal feedback
- Systematic review of fuel-vendor information and other data formally documented
- Python-driven, input generator automates 10k+ lines of input for MCNP and Serpent
- MCNP input used as part of automated CAD model generation for 3-D meshing needed for PROTEUS, etc.

Moving Forward: Device Analysis

Several unresolved issues:

- Pulse-height spectrum inconsistent with prediction
- Sensitivities inconsistent with measured masses
- Large sensitivity to environment (gamma background, RF interference, control drives, etc.)

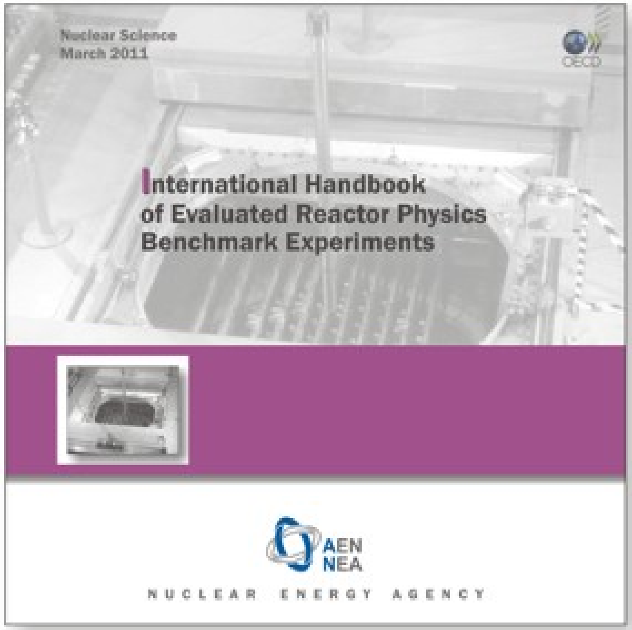
Solution: build from the ground up using a surrogate device and a software-like approach to debug and generate data for systematic model validation*.

*See poster this afternoon on initial model development.

Moving Forward: Data Analysis

Formal evaluation of data

- Experiments provide several CRIT and RRATE measurements for which ample examples exist in the IRPhEP handbook
- Transient RRATE experiments resulted in (we think) <u>first-of-a-kind measurements</u>
- Advanced models needed as part of bias evaluation effort



Conclusions

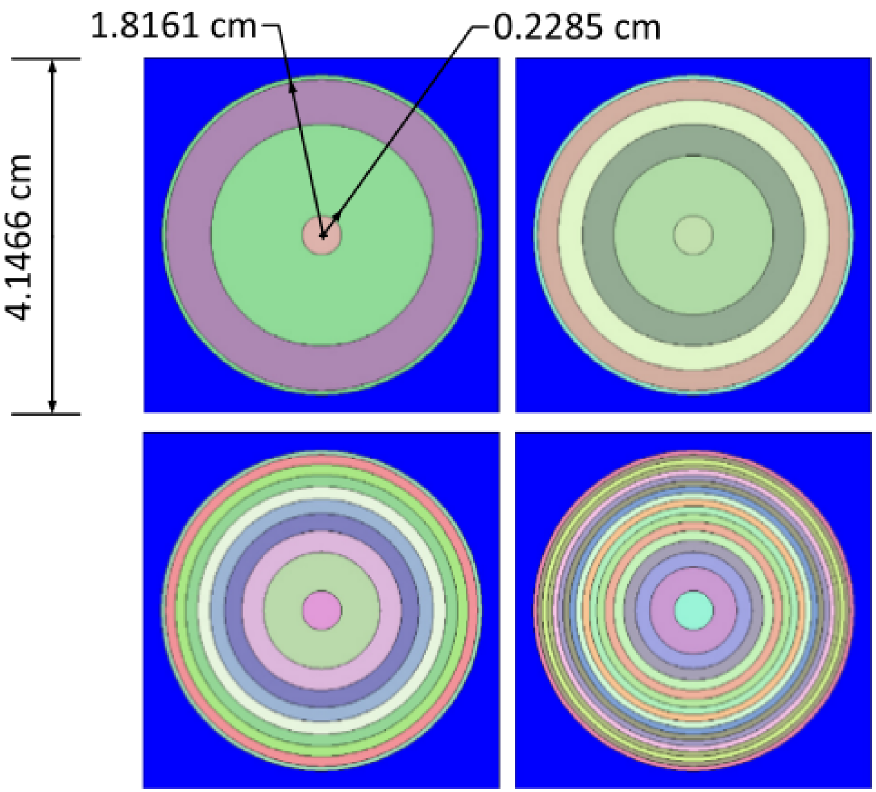
- System of novel, micro-pocket fission detectors (MPFDs) produced and deployed at UWNR
- Several steady-state and transient experiments were conducted to measure local fluxes and temperatures
- Better understanding is needed of detector response via evaluation and continued development/experiments

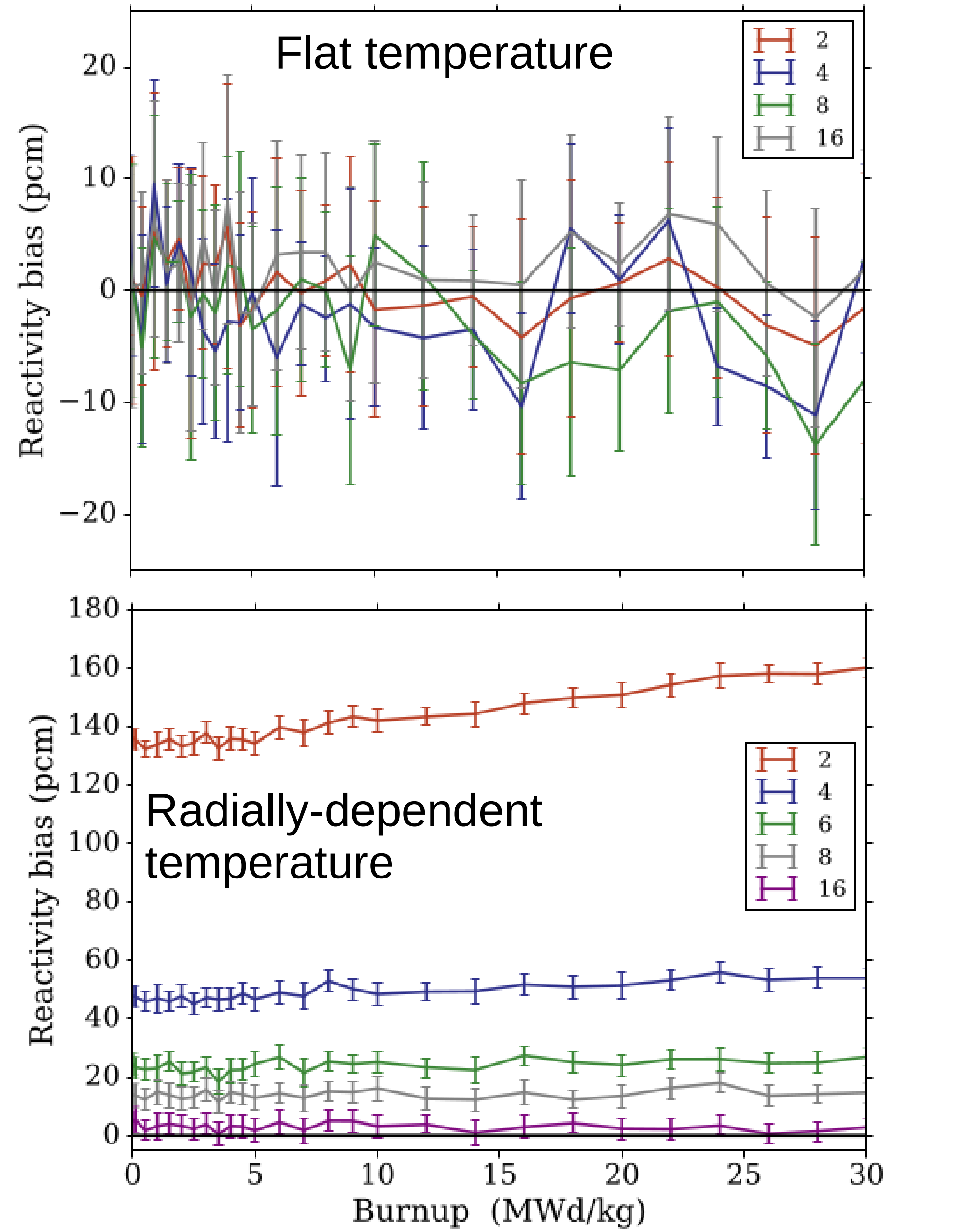
Thanks! jaroberts@ksu.edu

KANSAS STATE UNIVERSITY

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Fuel-Element Radial Discretization

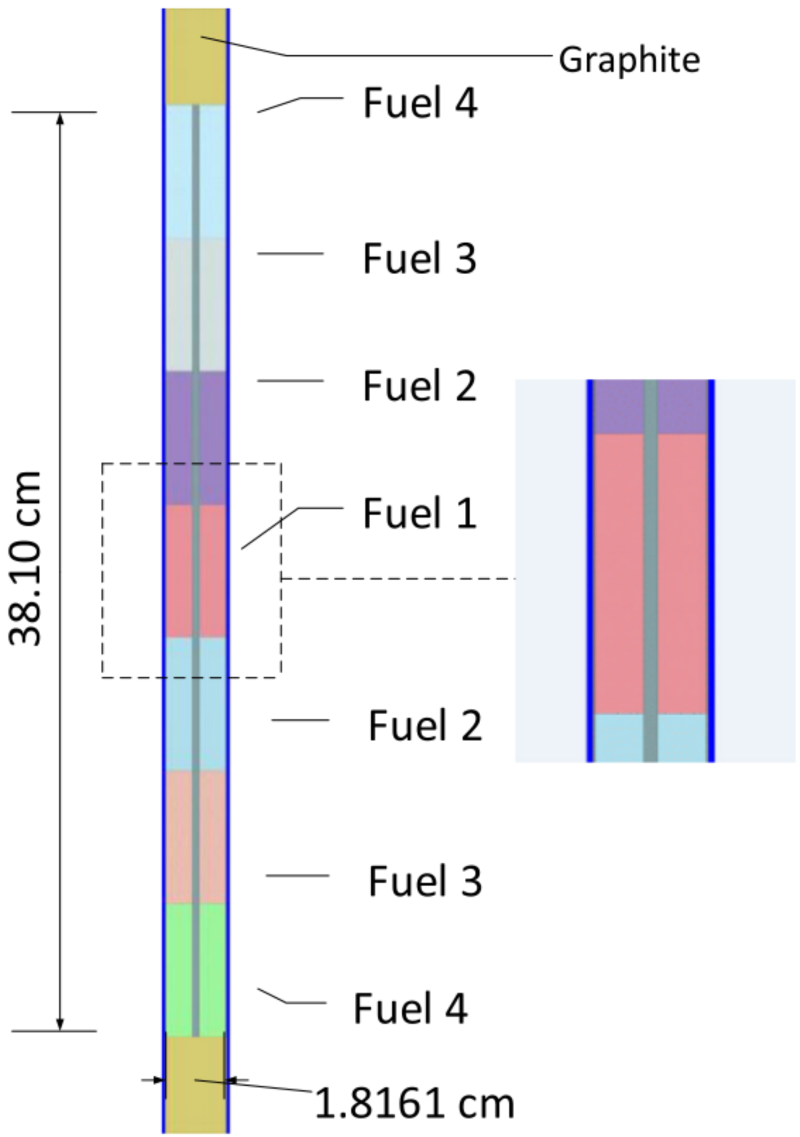


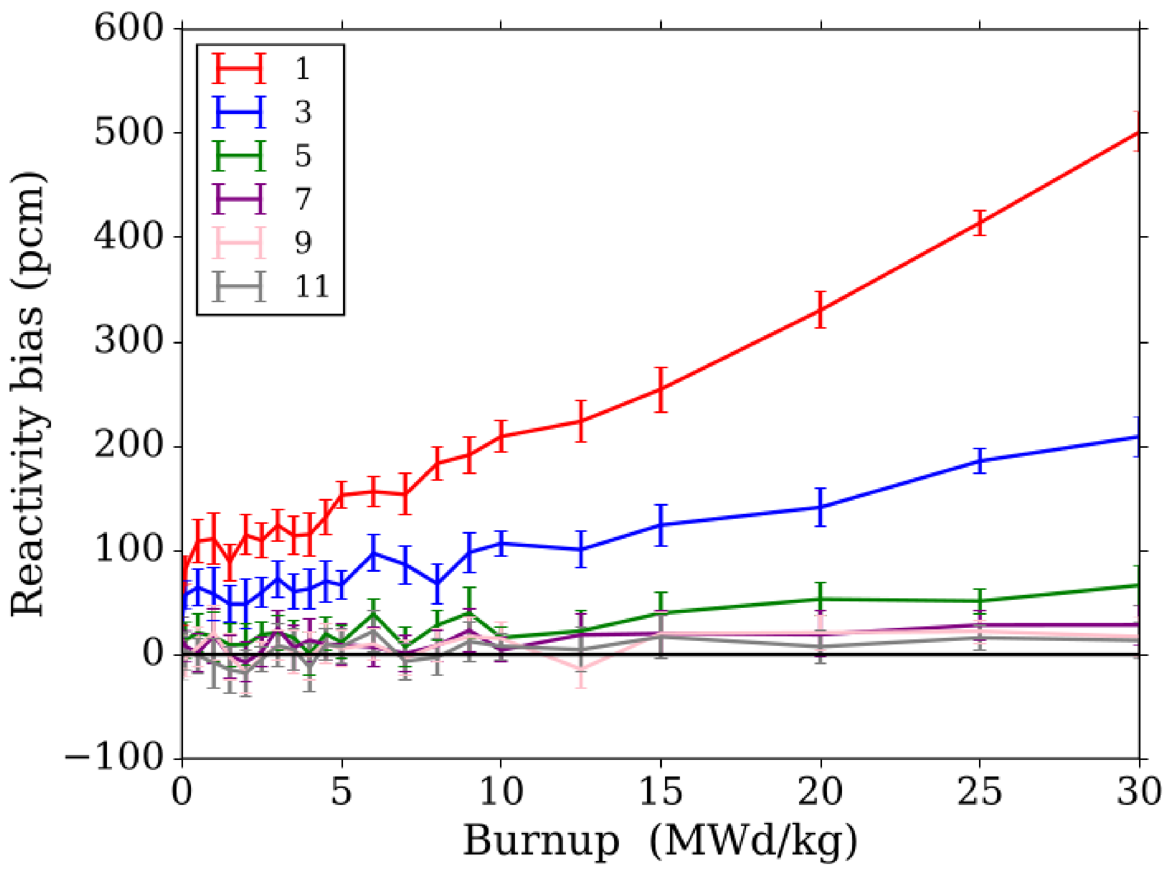


No dependence on radial discretization if temperature is independent of radius.

Strong radial dependence if temperature is function of *r* and **16 divisions** needed to produce (statistically) zero bias.

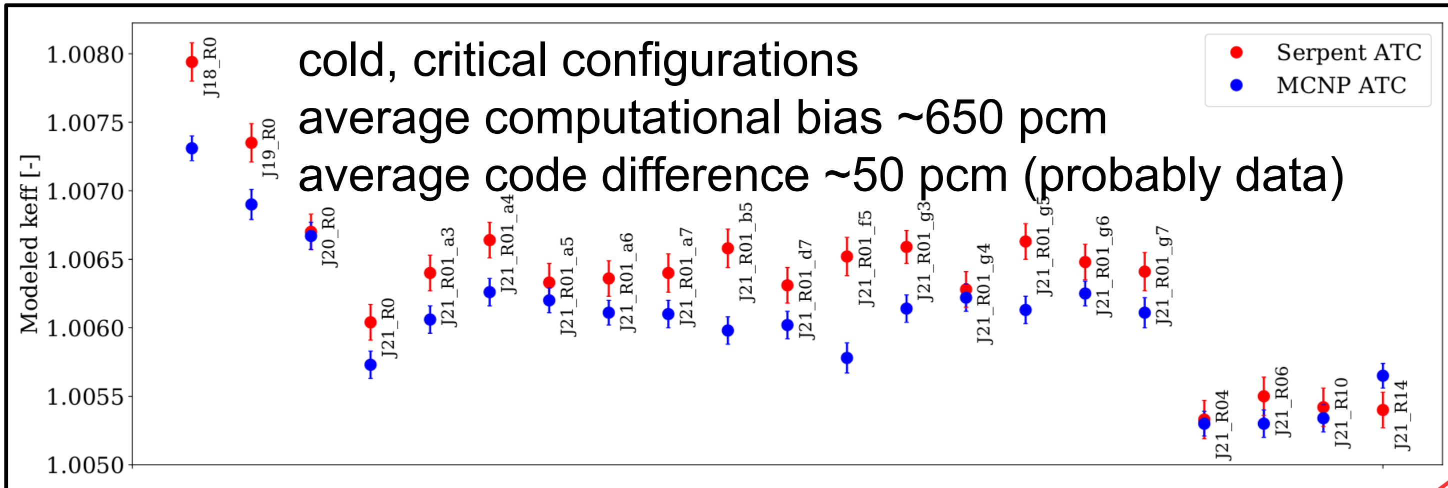
Fuel-Element Axial Discretization



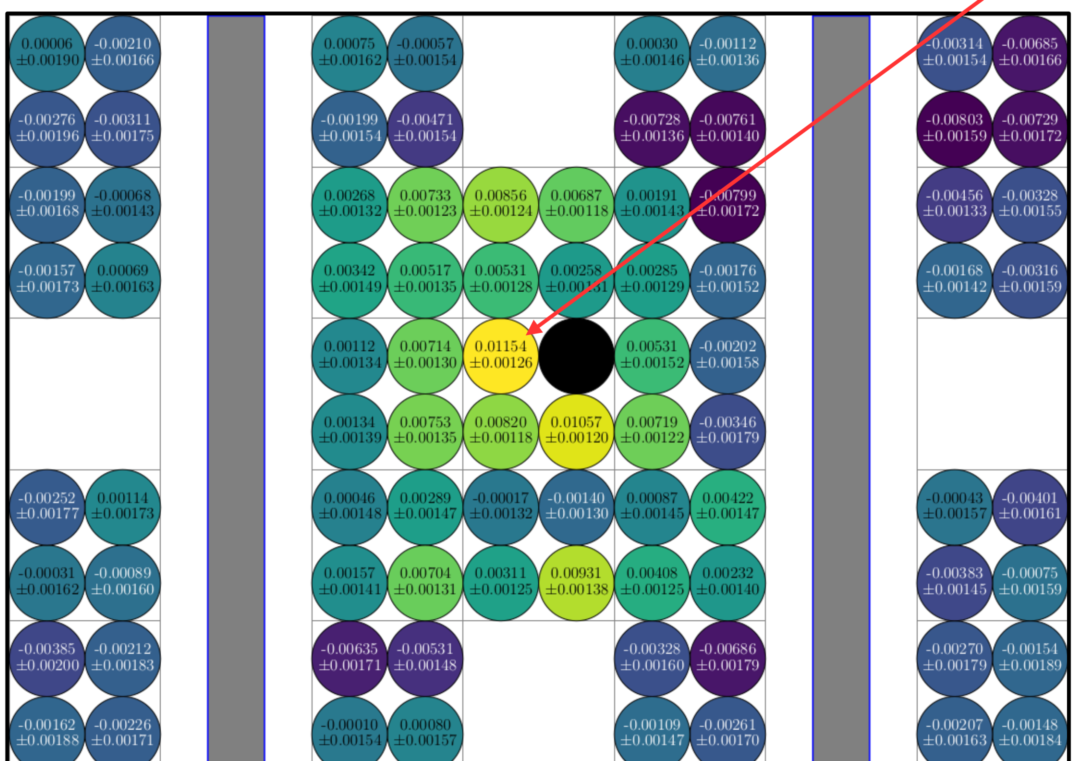


Approximately 9 axial divisions required to eliminate bias (with or without axial temperature profile)

Initial Verification of Fresh Core Model

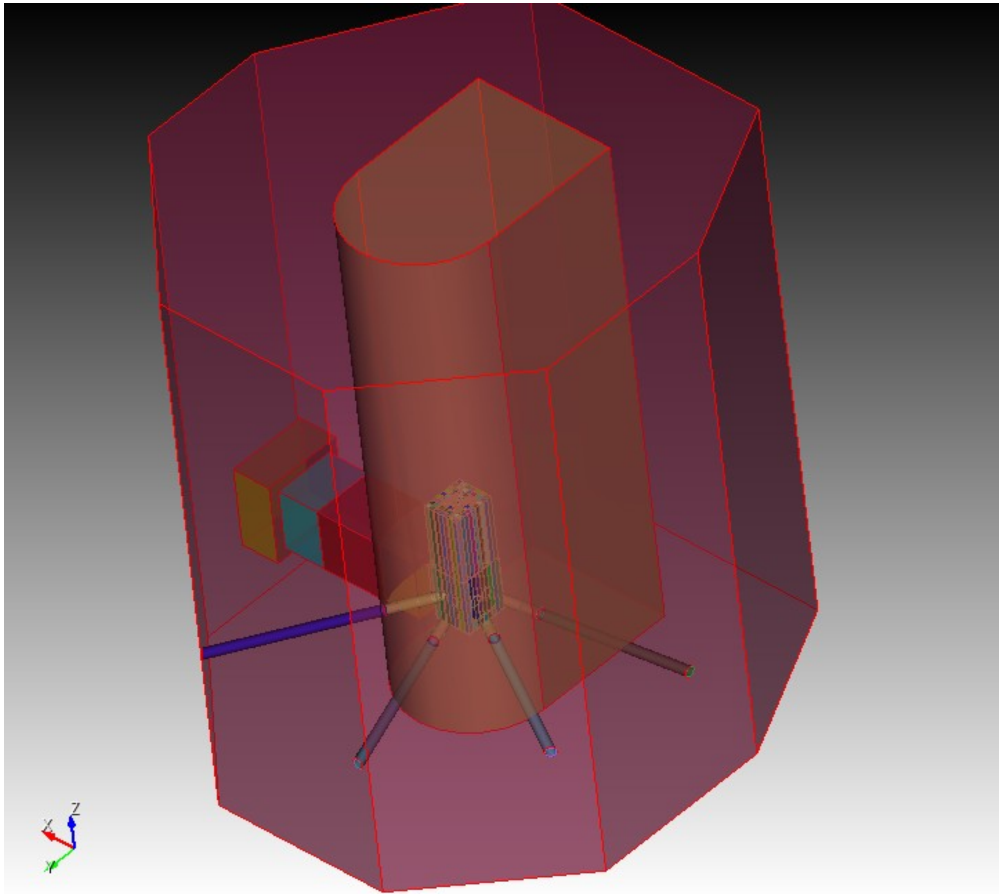


Difference between MCNP and Serpent fission densities



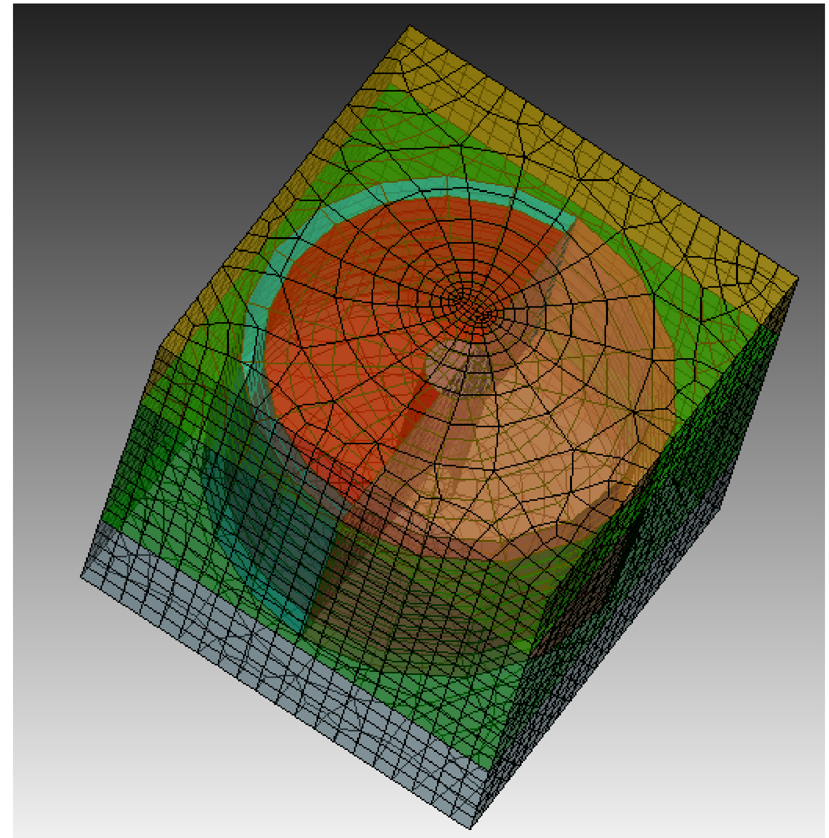
Y-H Park, A. Swenson, P.P.H. Wilson, Y. Cheng, R.L. Reed, and J.A. Roberts, "Improved Modeling of the University of Wisconsin Nuclear Reactor by Automatic Generation of Computational Models," PHYSOR 2018

Modeling of UWNR in PROTEUS



Full CAD model automatically produced from MCNP after further development of Trelis plugin.

Meshing continues, but issues remain with some material assignments and surface overlaps that may require manual adjustment.



Model	k_∞
Serpent	1.35566 ± 0.0007
MCNP	1.35536 ± 0.0019
Proteus	1.35560

PROTEUS results are deceptively close to Monte Carlo, but suggests a working flow of data.