Los Alamos
NATIONAL LABORATORY
EST. 1943

Delivering science and technology
to protect our nation
and promote world stability

NNSA
National Nuclear Security Administration

Neutron Clustering Measurements at RPI

Nicholas Thompson, LANL
Jesson Hutchinson, LANL
Rian Bahran, LANL
Eric Dumonteil, IRSN
Wilfried Monage, IRSN

3/27/2018

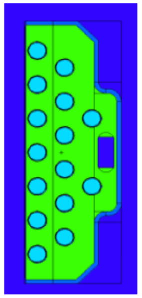
LA-UR-18-22566

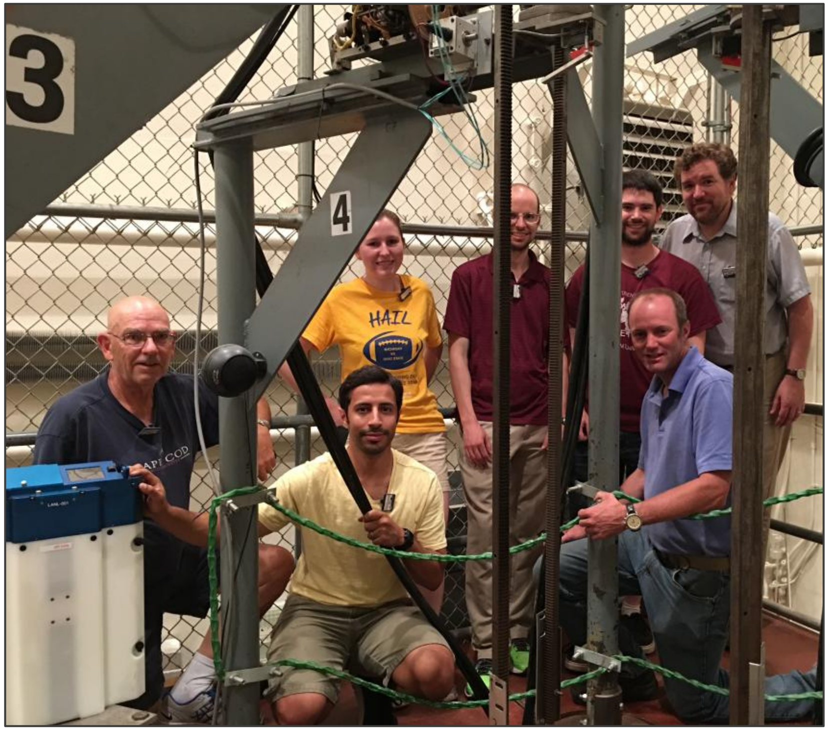
Neutron Clustering

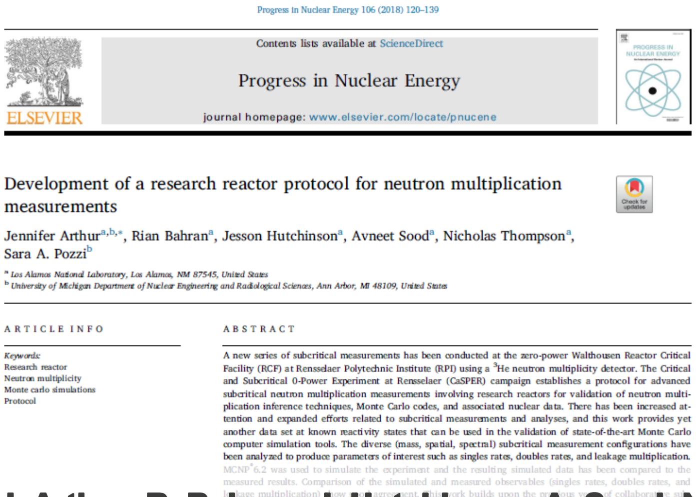
- **As mentioned earlier:**
  - At low power levels in a critical system, neutrons may start to cluster
    - Has been seen in simulations
- **Measurements at RPI were to try to measure this in a real reactor**
- **Measurements were a collaboration between LANL, IRSN, and RPI**

In 2016, LANL/UMich Performed Subcritical Measurements at the RPI-RCF with LANL Neutron Multiplicity Detectors

- **Phase 1: Established a protocol for subcritical neutron multiplication measurements at a research reactor**
  - **Did not drown <u>very expensive</u> state-of-the-art NOMAD multiplicity detectors (15 He-3 tubes encased in poly)**
- **Phase 2: Perform benchmark quality measurements at Sandia (SPRF/CX)**






Progress in Nuclear Energy 106 (2018) 120–139

Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

ELSEVIER

Development of a research reactor protocol for neutron multiplication measurements

Jennifer Arthur[a,b,*], Rian Bahran[a], Jesson Hutchinson[a], Avneet Sood[a], Nicholas Thompson[a], Sara A. Pozzi[b]

[a] Los Alamos National Laboratory, Los Alamos, NM 87545, United States
[b] University of Michigan Department of Nuclear Engineering and Radiological Sciences, Ann Arbor, MI 48109, United States

ARTICLE INFO

Keywords:
Research reactor
Neutron multiplicity
Monte carlo simulations
Protocol

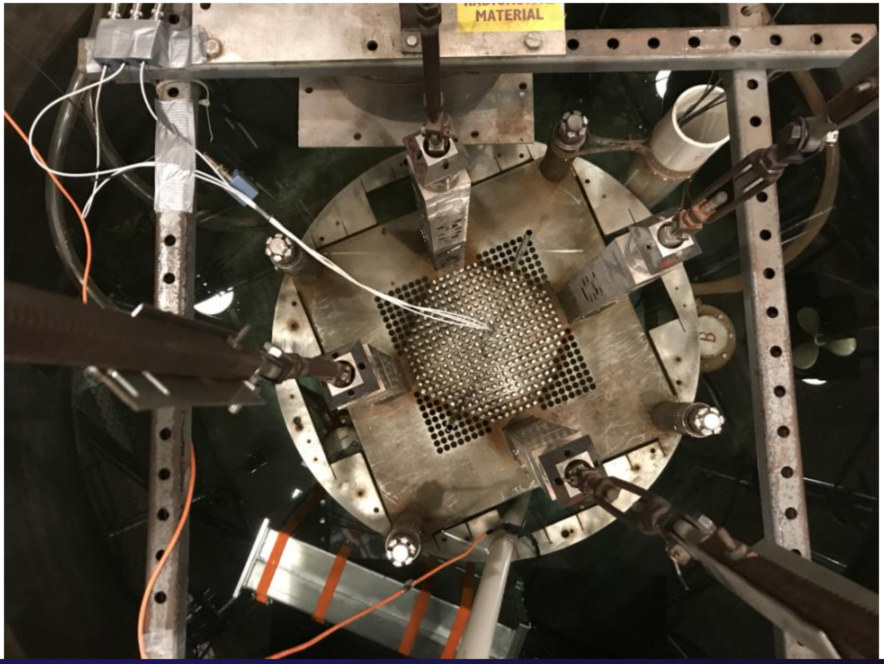
ABSTRACT

A new series of subcritical measurements has been conducted at the zero-power Walthousen Reactor Critical Facility (RCF) at Rensselaer Polytechnic Institute (RPI) using a ^{3}He neutron multiplicity detector. The Critical and Subcritical 0-Power Experiment at Rensselaer (CaSPER) campaign establishes a protocol for advanced subcritical neutron multiplication measurements involving research reactors for validation of neutron multiplication inference techniques, Monte Carlo codes, and associated nuclear data. There has been increased attention and expanded efforts related to subcritical measurements and analyses, and this work provides yet another data set at known reactivity states that can be used in the validation of state-of-the-art Monte Carlo computer simulation tools. The diverse (mass, spatial, spectral) subcritical measurement configurations have been analyzed to produce parameters of interest such as singles rates, doubles rates, and leakage multiplication. MCNP 6.2 was used to simulate the experiment and the resulting simulated data has been compared to the measured results. Comparison of the simulated and measured observables (singles rates, doubles rates, and ...

J. Arthur, R. Bahran, J. Hutchinson, A. Sood, N. Thompson, S. Pozzi "Development of a Research Reactor Protocol for Neutron Multiplication Measurements", ***Progress of Nuclear Energy* 106 (2018) 120-139**

RPI RCF

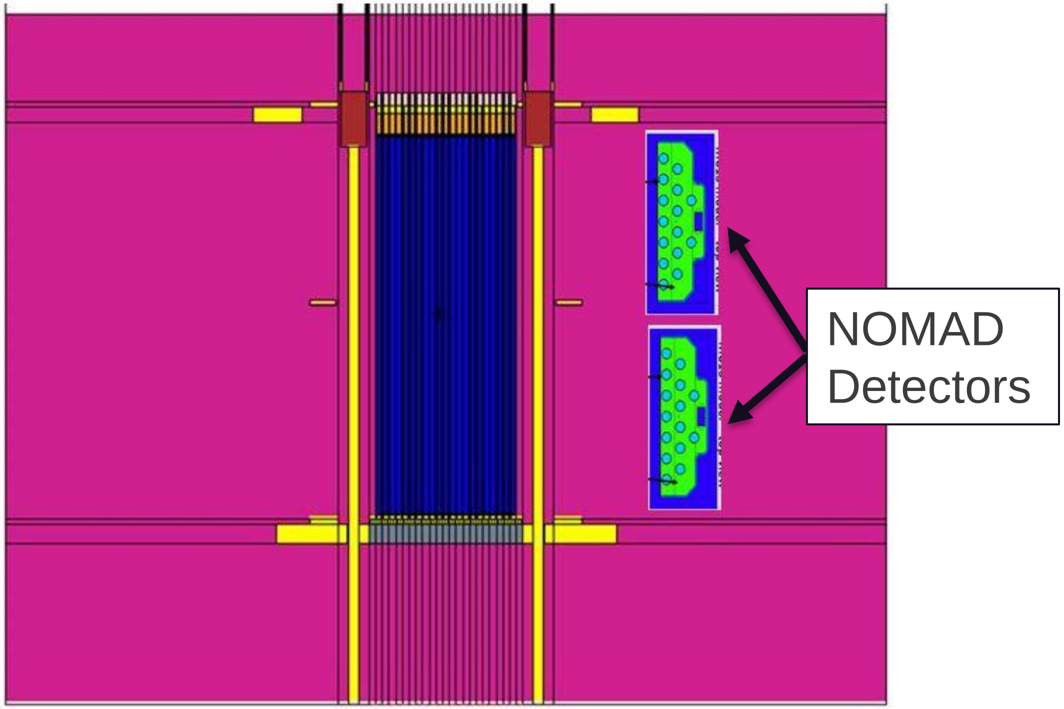
- **"Zero power" reactor (maximum operating power = 15 W)**
  - Fuel is essentially "fresh", not activated
  - Makes it very easy to set up and perform experiments
- **UO_2 ceramic fuel, 4.81 wt. % ^{235}U, 335 fuel pins for measurements**
  - Fuel is 36 inches active length
- **Water moderated**
- **Four boron control rods surrounding the core**

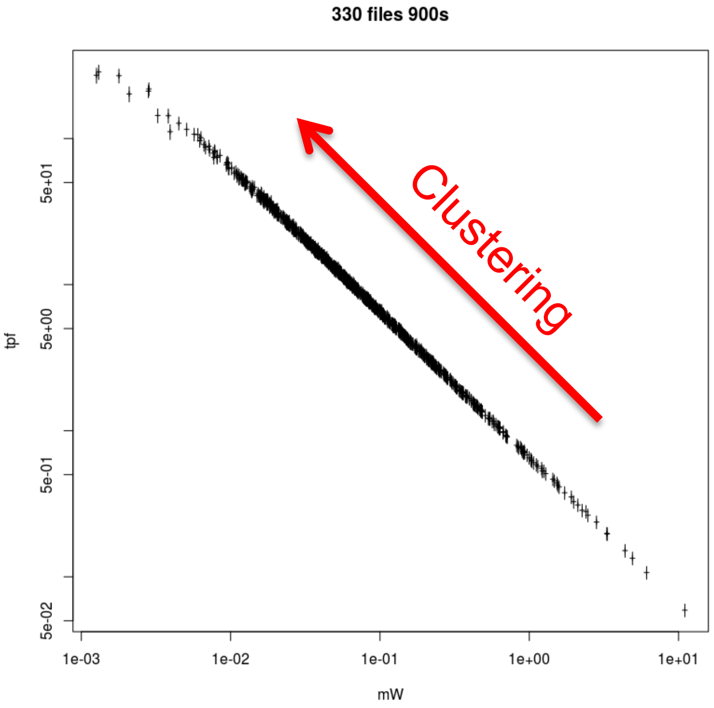


Simulations of the RCF Measurements

- Simulations of the experiment showed it might be possible to measure clustering at the RCF
- Experiments were designed with two NOMAD detectors

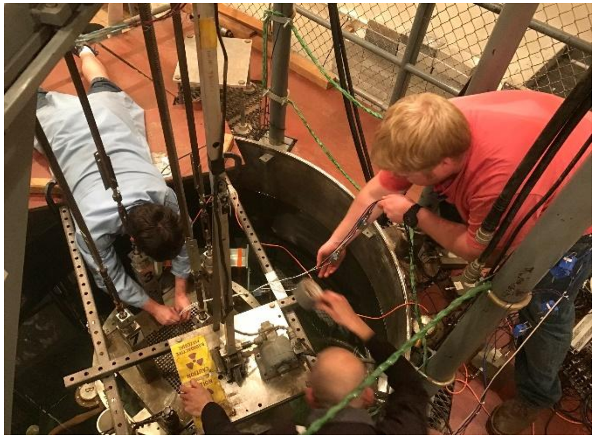
$$G_P(n,m) = \frac{\langle nm \rangle - \langle n \rangle \langle m \rangle}{\langle n \rangle \langle m \rangle}\Big|_P$$

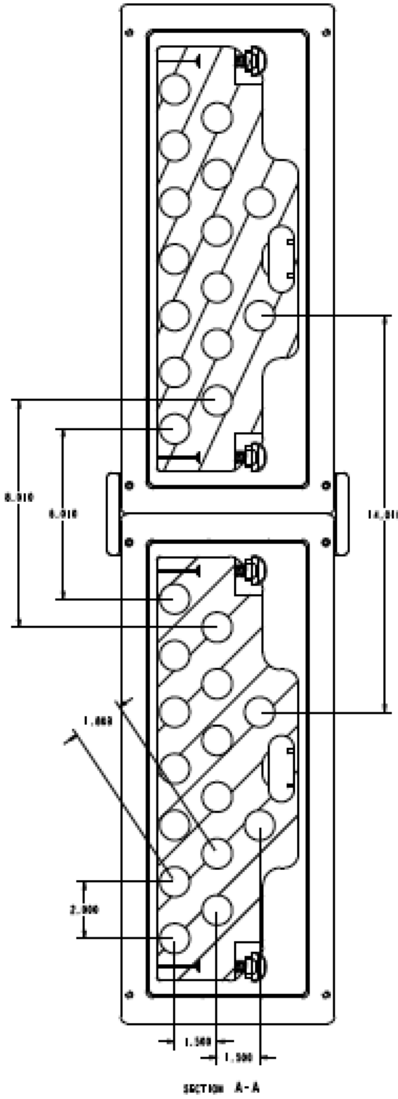




Measurements at RPI

- Were able to complete three full days of experiments
- Experiments used two NOMAD detectors
- Also used ^{3}He tubes in the core





Measurements at RPI

Measurements at RPI

- **Made over a dozen critical measurements at different reactor powers, from less than 1 mW to 0.85 W**
  – 0.93 mW, 1 mW, 1.4 mW, 1.7 mW, 4.1 mW, 4.6 mW, 7.0 mW, 43 mW, 85 mW, 90 mW, 90 mW
  – 0.47 W, 0.85 W
  – Measurement times varied from 30 seconds to 2 hours long

- **During the measurements, we did not adjust control rod positions**
  – Because of this, some measurements were slightly above or below critical
- **Measured with the in core ^{3}He detectors, NOMAD detectors, and RCF detectors (uncompensated ion chambers)**
  – In core ^{3}He detectors tended to saturate at fairly low power levels

Approach to Measurements

- Performed 1/M Approach to critical
- Critical Bank Height
- Excess Reactivity
- Measurement of reactivity of most reactive pin
- Power Calibration
- Water tests (for NOMAD detector enclosures)

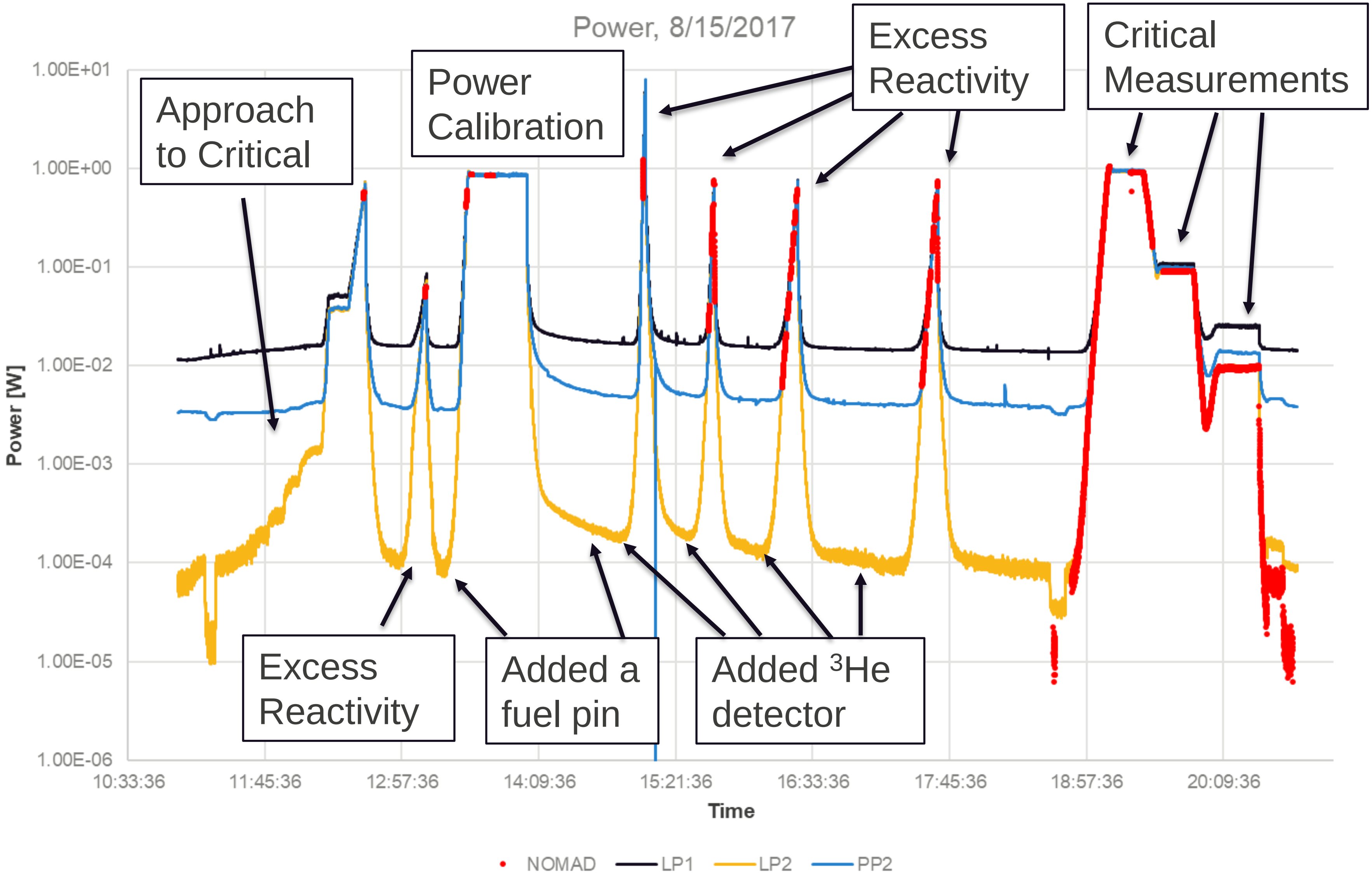
- For each change in configuration (adding more fuel pins, adding more ^{3}He detectors), needed to make sure the reactor would be operated safely and within tech specs/regulations.

Power Calibration

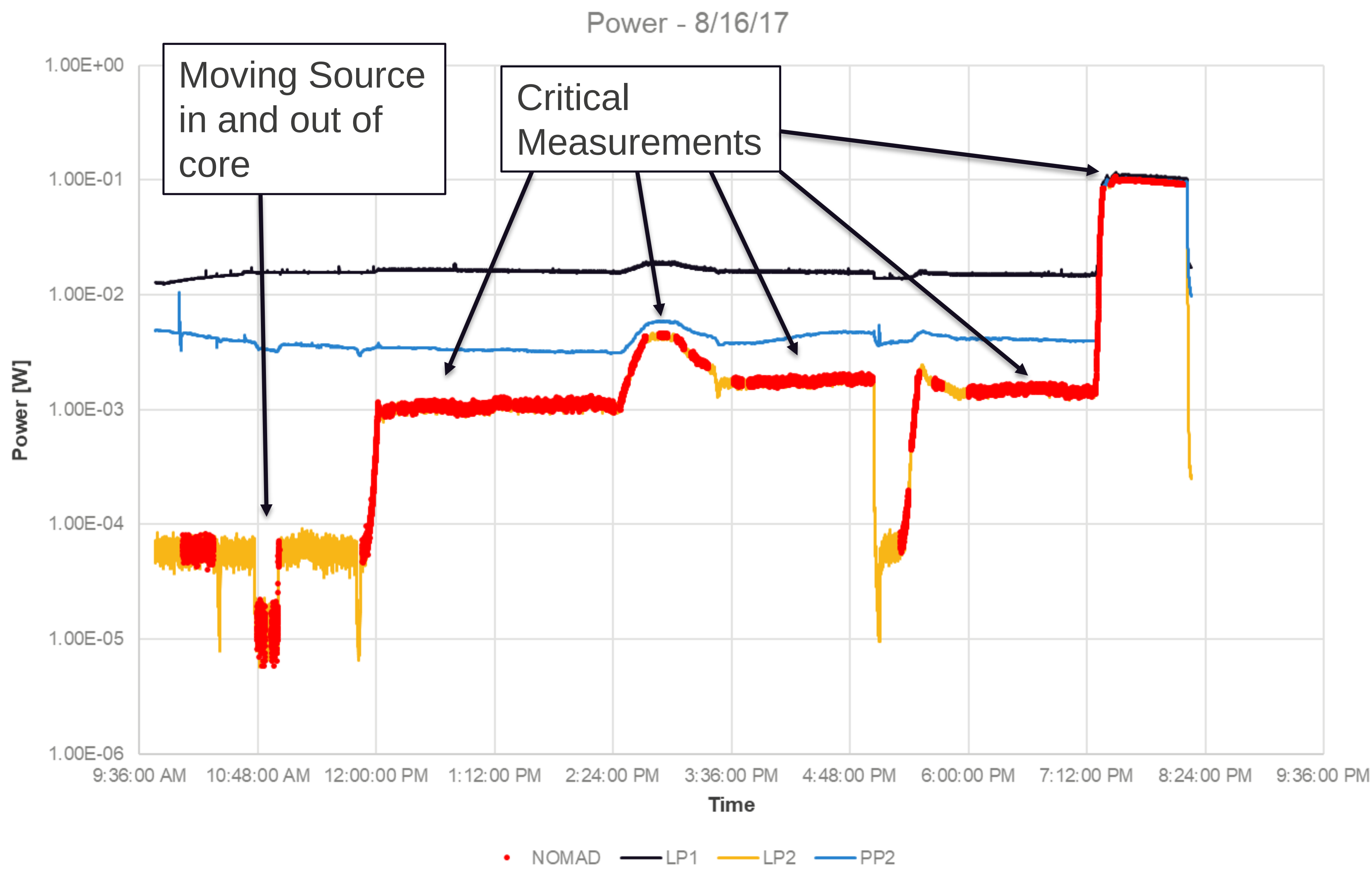
- **Power calibration was performed by irradiating gold foils**
  - Brought the reactor critical for 30 minutes at ~1 Watt
  - After, measured the gold foils, and compared activity to an MCNP simulation of the reactor
  - This was used to calibrate the RCF detectors
- **NOMAD detector data was then converted to count rate, corrected for deadtime, and scaled to power**

- **In next few plots – NOMAD detectors were not constantly counting, only when a particular measurement was being made. This helped to conserve batteries (and storage space).**

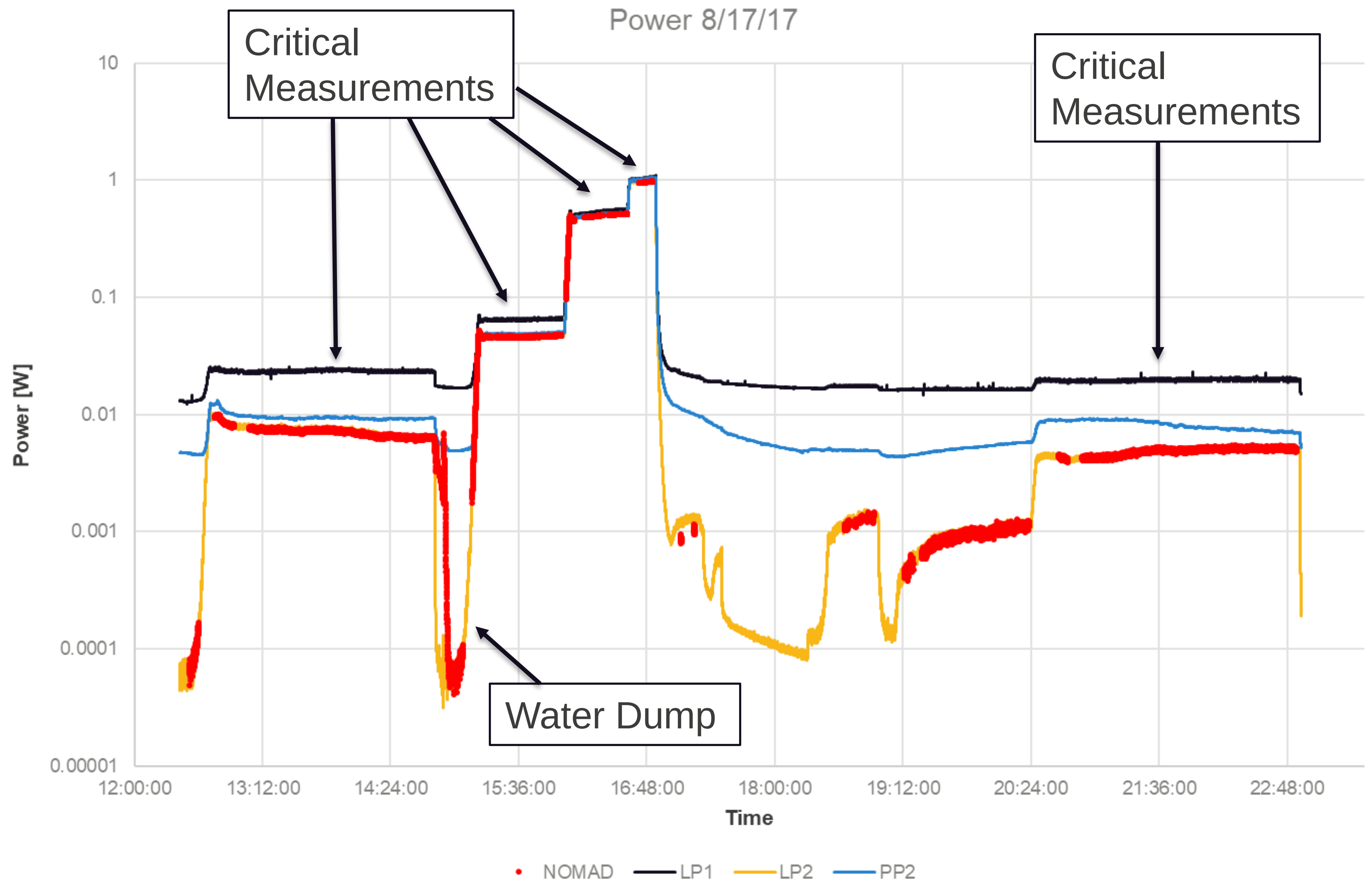
Measurements at RPI



Measurements at RPI

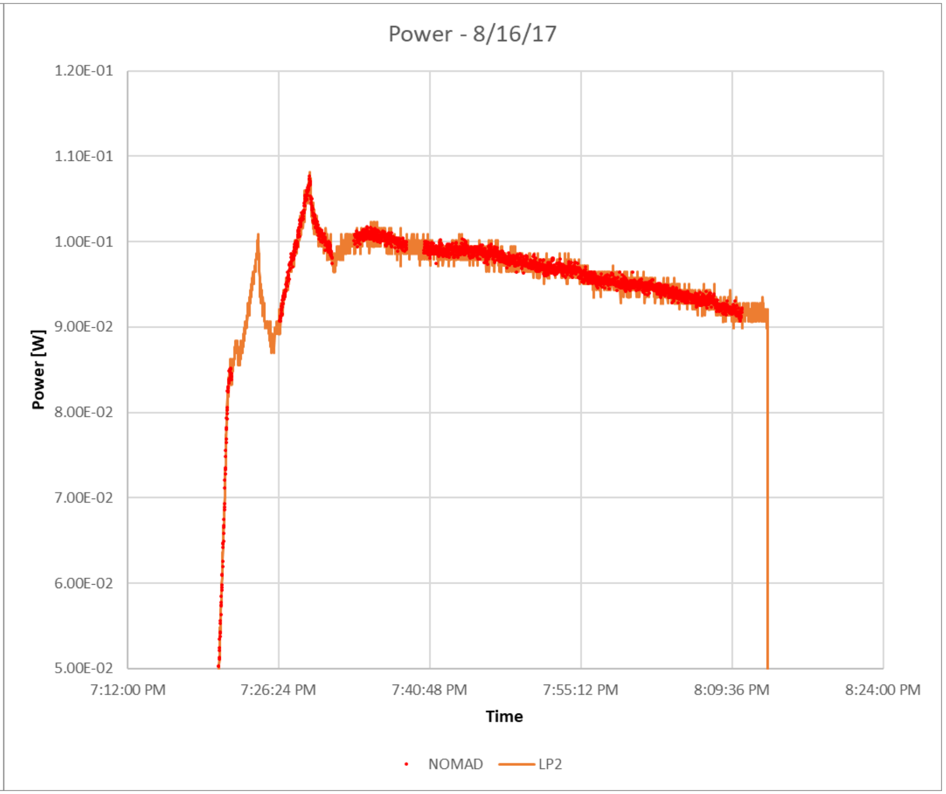


Measurements at RPI



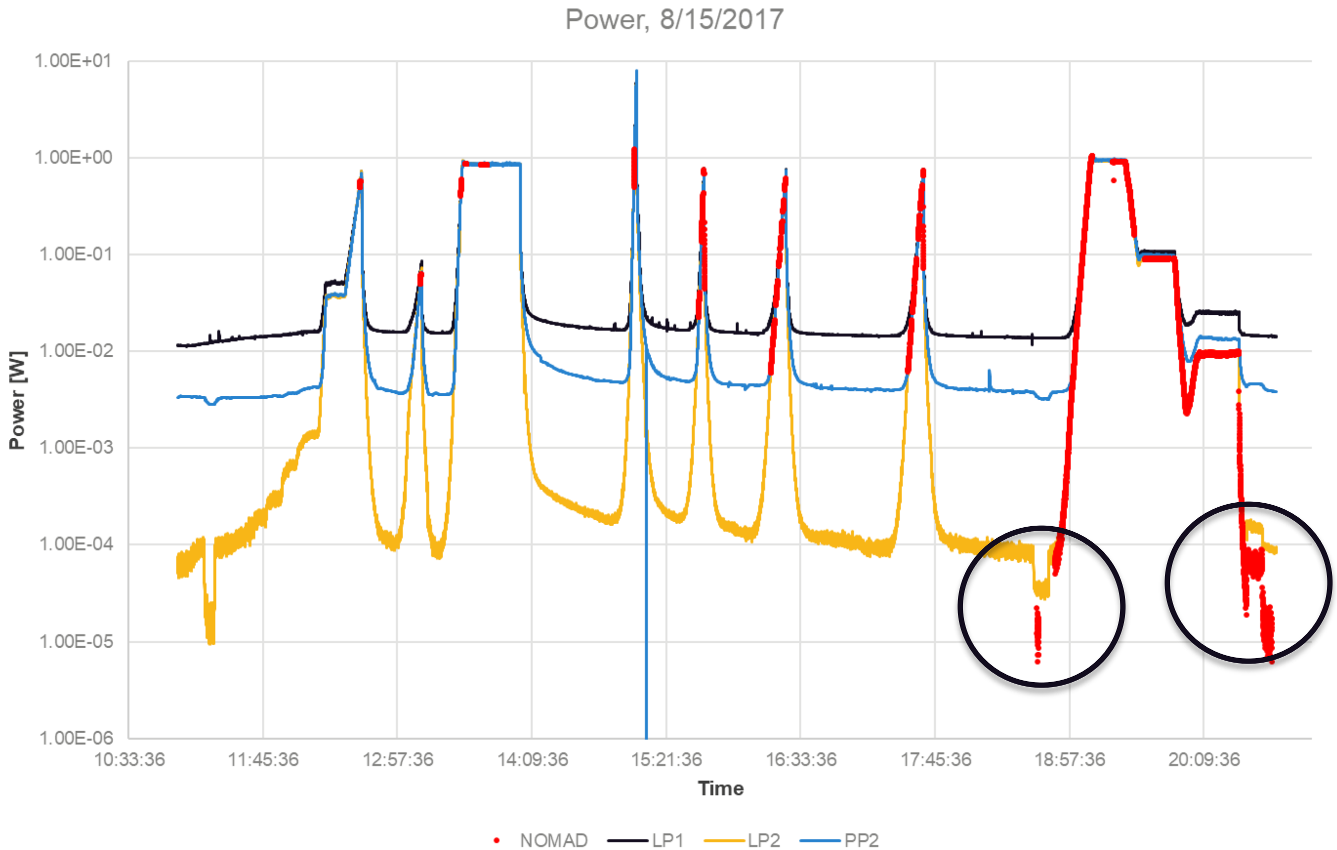
Measurements at RPI

- Very good agreement between LP2 indicated power and NOMAD detector, even at indicated reactor power of under 20 µW
- LP1 and PP2 detectors had too much background to be useful at low powers



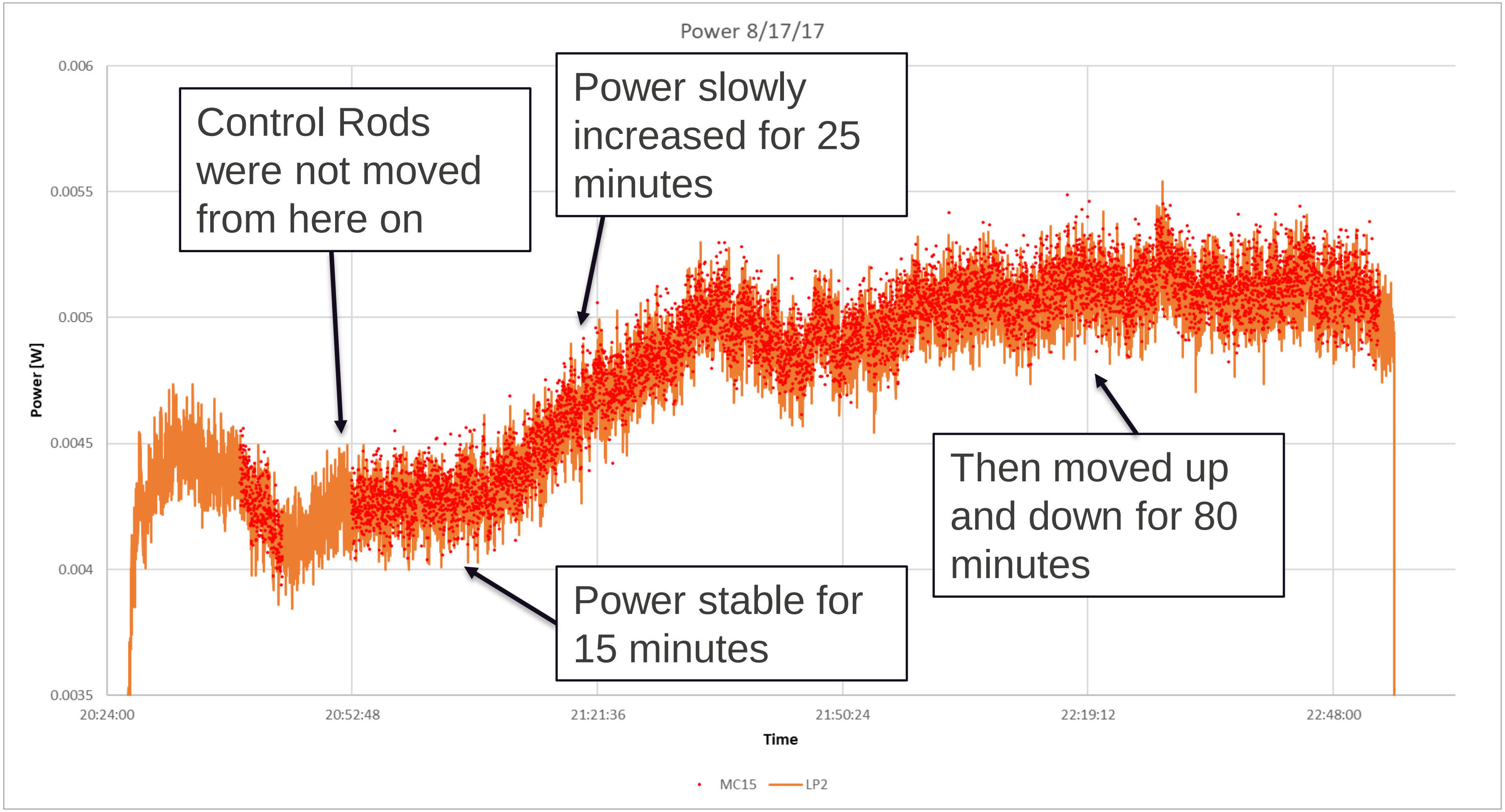
Measurements at RPI

- **Some discrepancies – mostly due to operating at a higher power and then dropping to a lower power**
- **LP2 (uncompensated ion chamber) is sensitive to gammas, NOMAD detectors are not, discrepancies are due to decay gammas**



Measurements at RPI

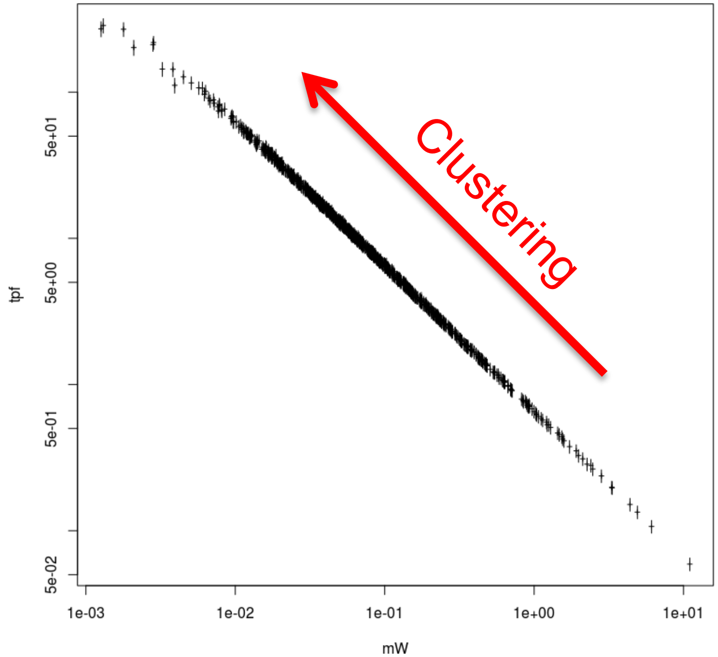
- **Example of one measurement ~5 mW**
- **Two hour measurement – 500 MB of data, ~60,000,000 counts**



Results

- **Results still preliminary**

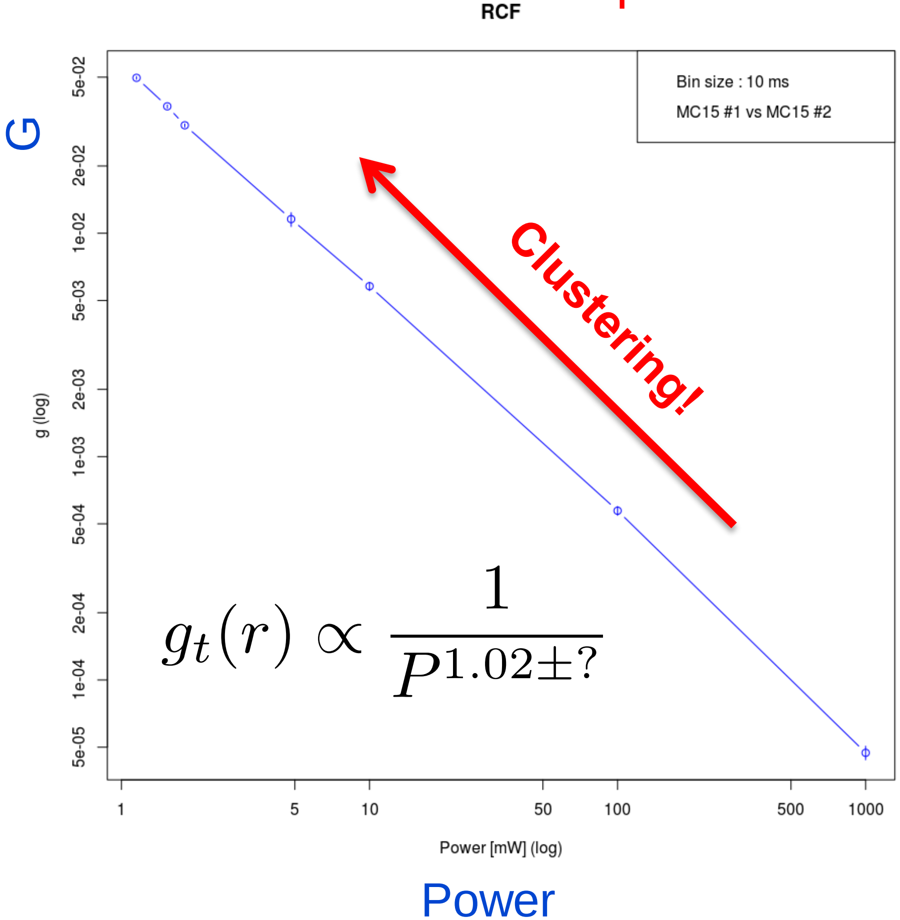
Simulation of spatial correlations vs power



$$g_t(r) = \frac{\lambda \nu_2}{8 D c_0 \pi^{3/2} r} \Gamma\left(\frac{1}{2}, \frac{r^2}{8Dt}\right)$$

$$g_t(r) \propto \frac{1}{c_0} = \frac{1}{P}$$

RCF results of spatial correlations vs power

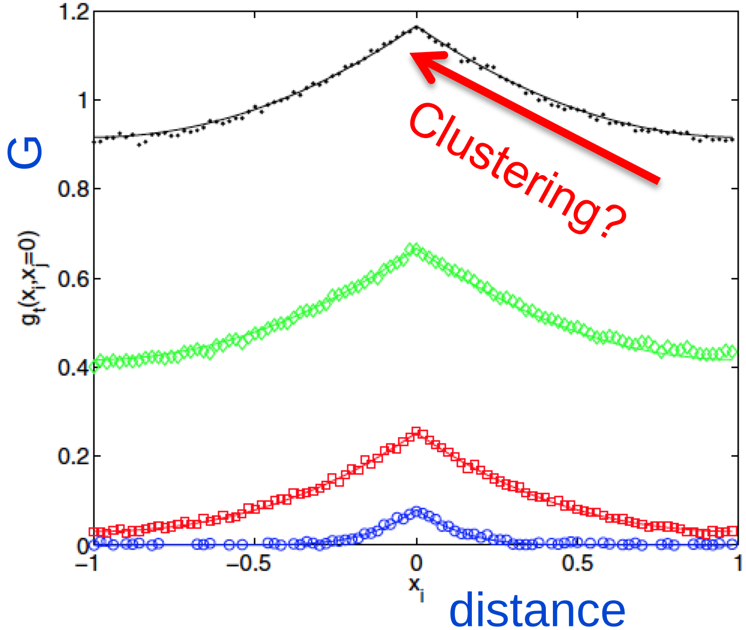


$$g_t(r) \propto \frac{1}{P^{1.02\pm?}}$$

Results

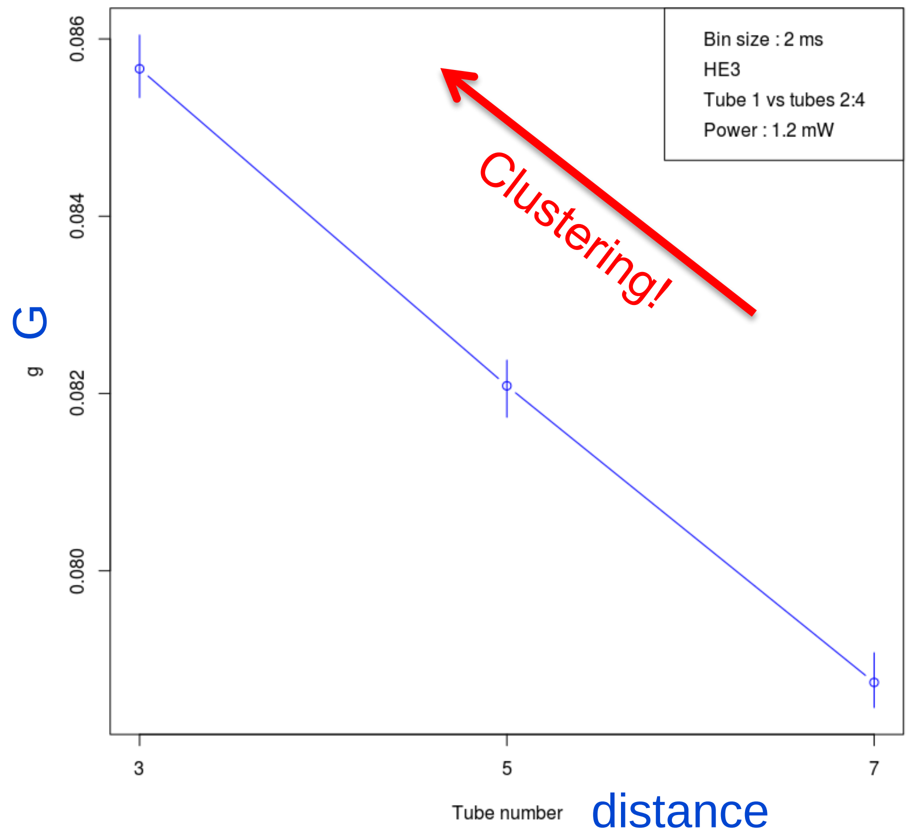
- **Results still preliminary**

Modelling of spatial correlations vs distance



$$g_t(r) = \frac{\lambda \nu_2}{8 D c_0 \pi^{3/2} r} \Gamma\left(\frac{1}{2}, \frac{r^2}{8Dt}\right) \quad g_t(r) \propto \frac{1}{r}$$

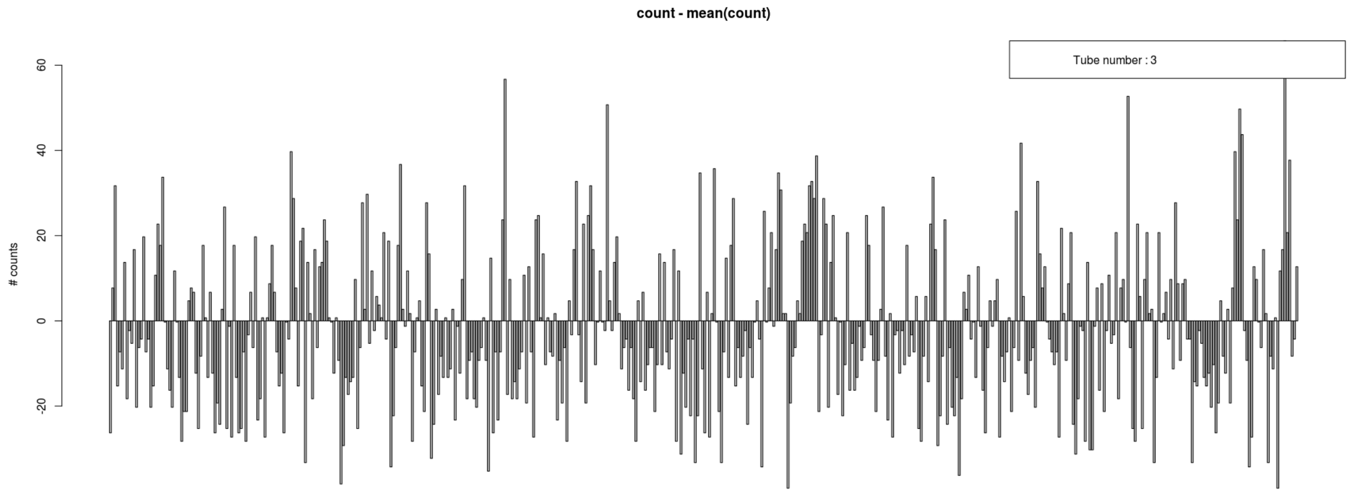
- **RCF results of spatial correlations vs distance**

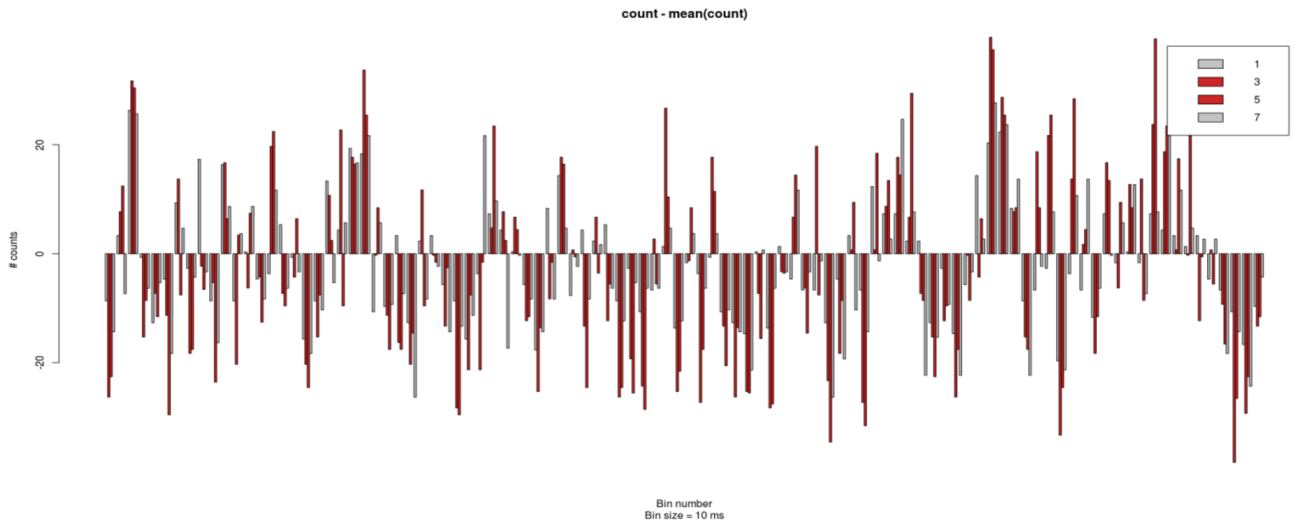


Results

- **Results still preliminary**

Temporal correlations





Results

- Still working on analyzing the data (there is a lot of data)
- Now have accurate estimates of power for all measurements
- Preliminary evidence of spatial correlations, as a function of power, distance, and time

Thanks!

This work was supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.