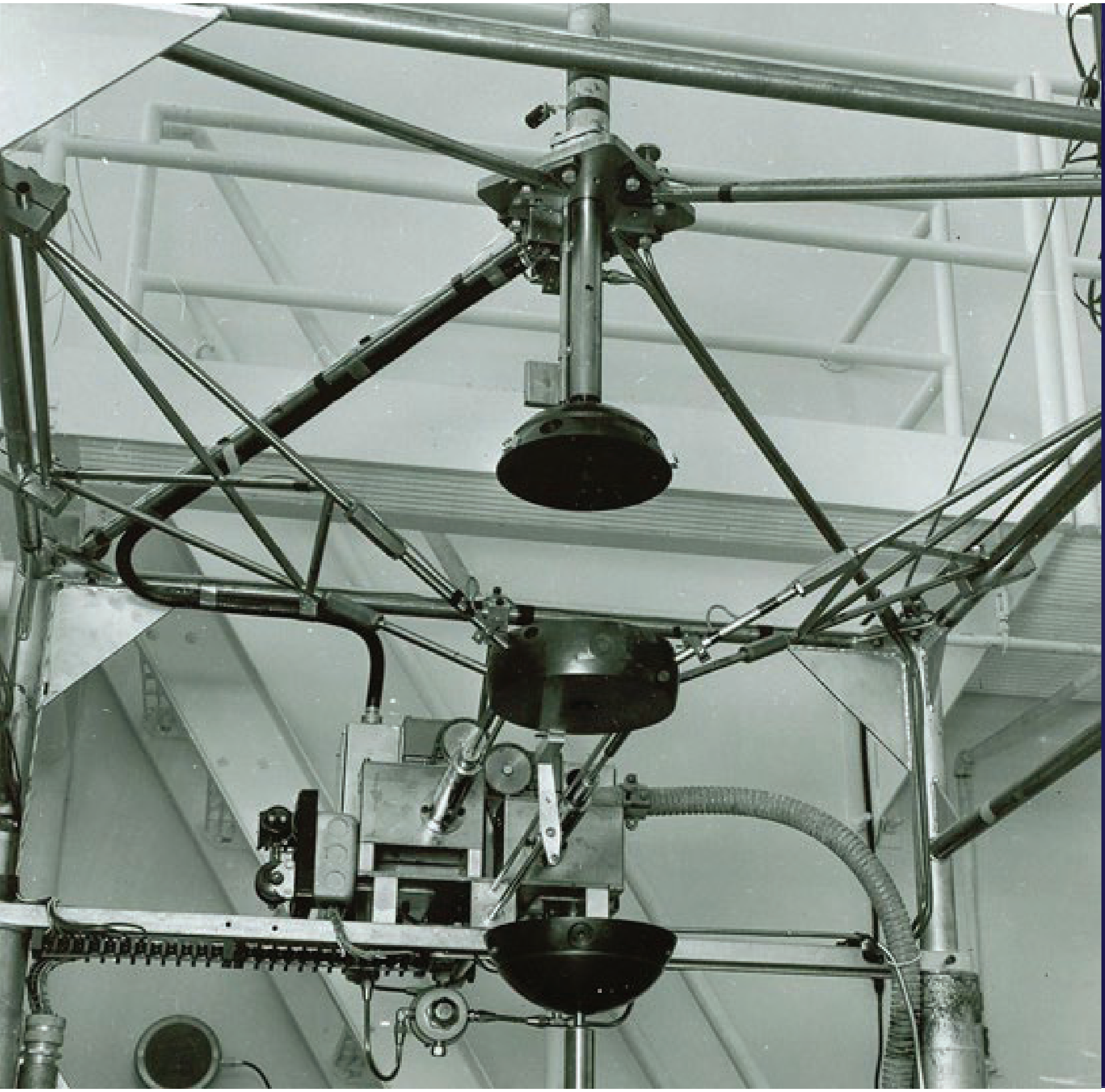

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National Nuclear Security Administration

PROMPT NEUTRON DECAY CONSTANT MEASUREMENTS ON THE KRUSTY COLD CRITICAL CONFIGURATION

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Los Alamos NATIONAL LABORATORY EST. 1943

Overview

- **What is KRUSTY?**
  - Reactor purpose
  - Phases of experimentation
- **What is Rossi-α?**
  - Method
  - Why measured?
- **Specifics for experiment**
  - Detector Placement
  - Execution
  - Results
- **Comparison to simulation**
- **Conclusions**

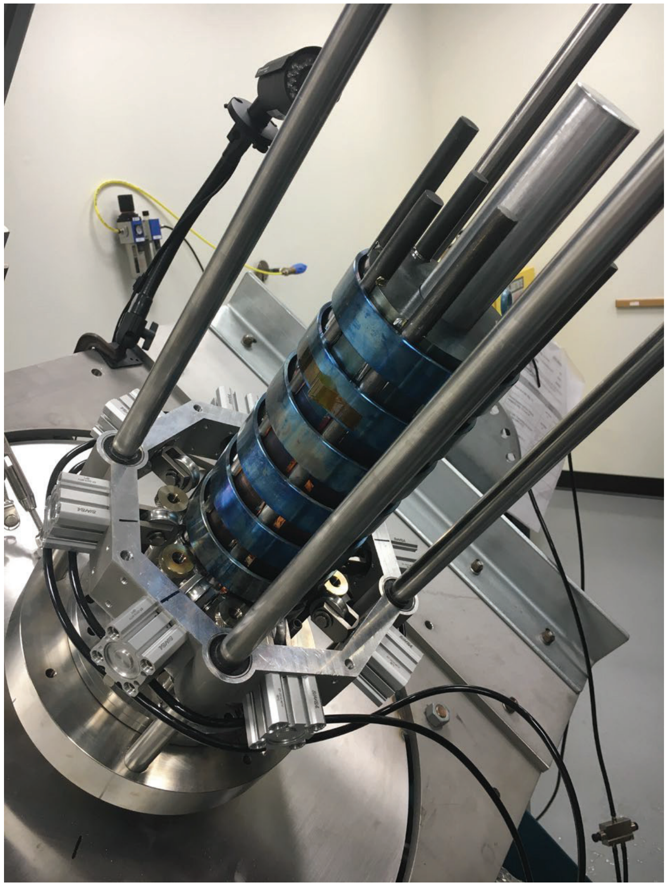
What is KRUSTY? – Reactor Purpose

- **Kilopower sized reactor intended for manned deep space missions.**
- **Concept uses heat pipes to generate electricity.**
- **Nuclear component is BeO reflected HEU.**
- **Full scale testing of nuclear component completed early 2018.**

KRUSTY Full Power Assembly

What is KRUSTY? – Phases of experimentation

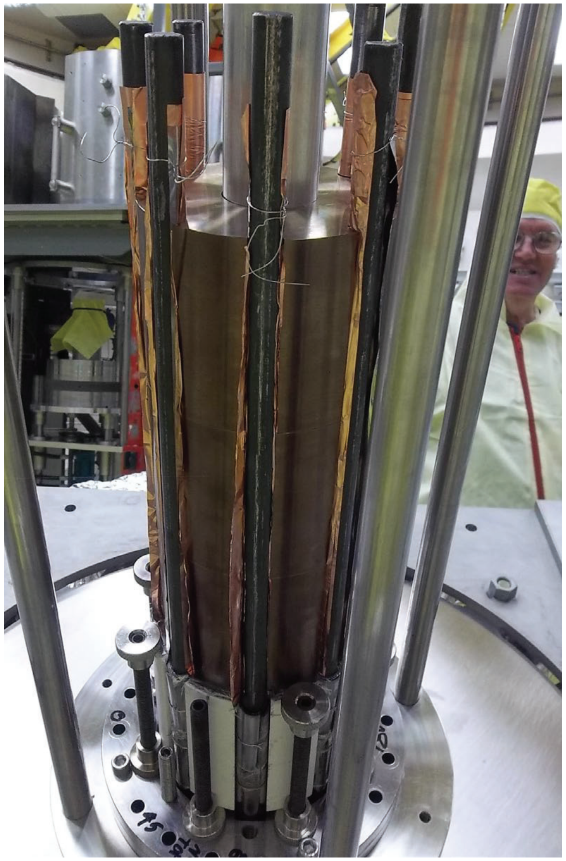
- **Phase 0**
  - Fe surrogate of the core used for systems checks and build practice.
  - DU surrogate core used for systems checks with chemically identical surrogate.
  - Electrically heated system test.
- **Phase 1**
  - Component Criticals.
  - HEU core, reflectors, and absorbers only.
  - Worth of reflector and absorber components measured.
  - Rossi-α measurements performed.



Assembly of the DU Surrogate

What is KRUSTY? – Phases of experimentation

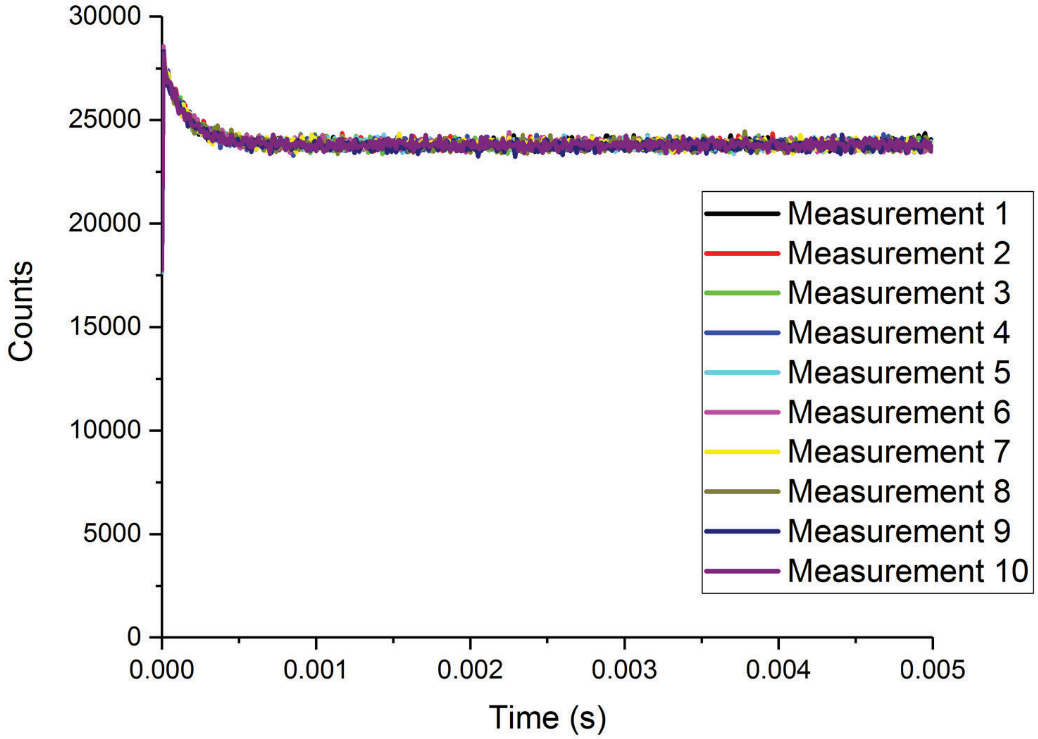
- **Phase 2**
  - Cold Critical
  - Add in heat pipes, electrical generation equipment, and vacuum chamber.
  - Worth measurements of removable components measured.
- **Phase 3**
  - Incremental increase in heat generation through three different “Free Run” scenarios.
- **Phase 4**
  - Full power test. (~800° C)
  - 28 hour continuous test.
  - Examined transient scenarios.



Transition to Cold Critical Configuration

What is Rossi-α? - Method

- The prompt neutron decay constant α is the rate at which the prompt neutron population changes as a function of time.
- $\alpha = \frac{k_p - 1}{l}$
- Measureable quantity is α, used to infer parameter of interest neutron lifetime, l.
- At delayed critical, this constant is the α-eigenvalue of the system.
- $\alpha_{DC} = \frac{-\beta}{l}$
- At prompt critical α =0.



Example Rossi-α Distribution

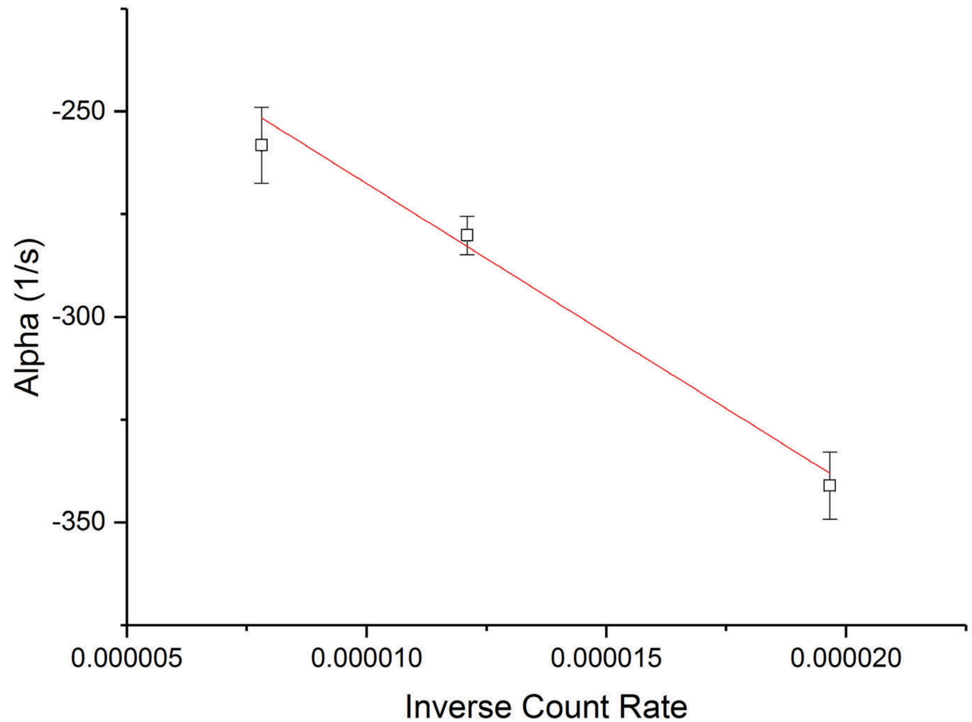
What is Rossi-α? - Method

- **The prompt neutron decay constant is calculated by measuring the correlations between neutrons emitted by a fissioning system.**
- **Rossi-α is an autocorrelation of neutron detection events.**
    - Combination of the probability of detecting a neutron from a fission chain and also detecting a second neutron from that same chain.

- $p(t) = A + Be^{\alpha t}$
    - A is related to the population of accidental neutrons.
        - Typically related to the source and multiplication of the system.
    - B is related to the population of correlated neutrons.
        - By definition correlated neutrons must be prompt.
        - The probability of detecting correlated neutrons drops exponentially with time (if the system is below prompt critical), so the exponential term is included with the correlated term.

What is Rossi-α? - Method

- **The α-eigenvalue can be determined two ways.**
  - Direct measurement at delayed critical.
  - Inference using two or more subcritical data points.
    - Plot α versus the inverse count rate.
    - The y-intercept is the α-eigenvalue.
    - Example for the polyethylene class foils experiment shown on the right.



Example for the polyethylene class foils experiment.

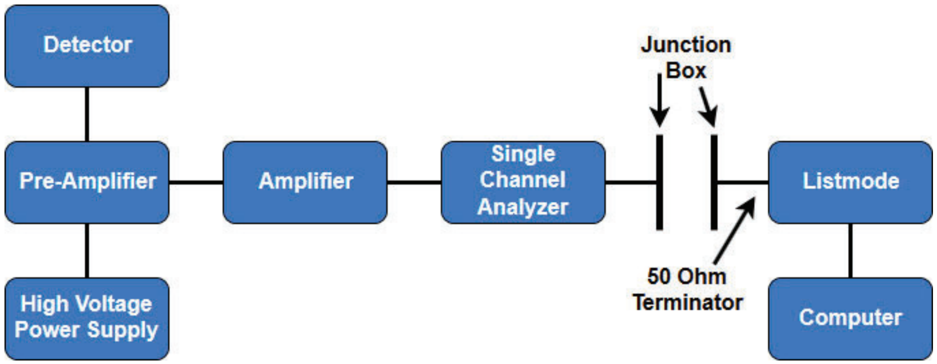
What is Rossi-α? – Why measured?

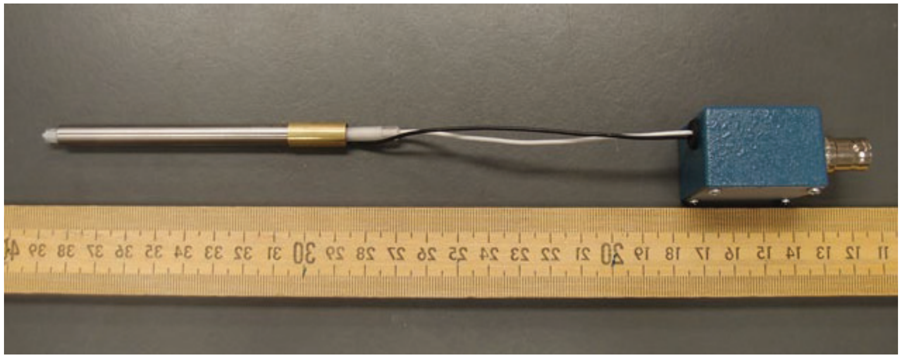
- Rate at which the prompt neutron population decays as a function of time.
- At DC comprises the fundamental α-eigenvalue.
- Useful for neutron spectrum hardness comparisons in critical experiments.
- Useful for determining neutron lifetime of a system.
- Used to measure subcritical reactivity in a system.

Assembly	α_{DC} (1/s)
Lady Godiva	-1.1×10^{6}
Godiva IV	-8.4×10^{5}
Topsy (Oy(94) w/ NU reflector)	-3.7×10^{5}
Zeus	-8.9×10^{4}
Zeus LEU Lead	-5.6×10^{4}
Zeus HEU Lead	-3.8×10^{4}
Sheba	-200
Poly Class Foils	-199.4

Specifics for experiment – Detector placement

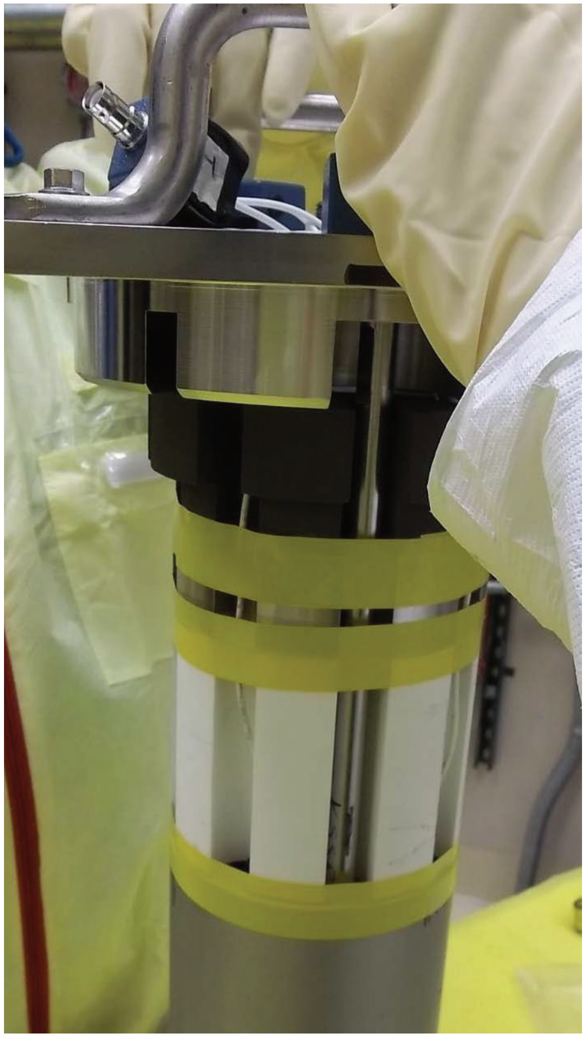
- **Consists of largely commercial off the shelf equipment.**
- **List-mode module is custom LANL designed and built module.**
  - Time tags detection events.
- **Detector is Reuter-Stokes 40 atm 0.25" diameter, 4" long ^{3}He detector.**
  - Other detectors could be used.
  - Chosen because of its fast recovery and size.





Specifics for experiment – Detector placement

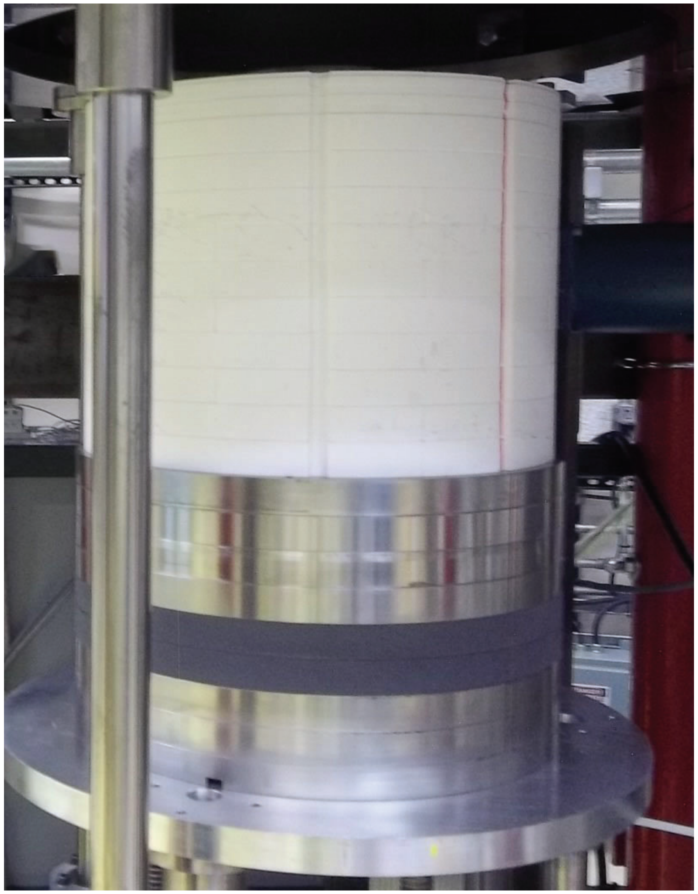
- For this system, the detectors were placed into the heat pipe channels of the core.
- Closest location feasible to the core.
- Approximately centered active region on the core.
- Radially spread out.



Detector Placement for Rossi-α experiment.

Specifics for experiment – Execution

- **Reactivity on this system adjusted in two ways.**
  - By adjusting the total height of BeO on the machine.
  - By manipulating the critical assembly machine to adjusted the “effective” height of BeO around the core.
- **Three configurations measured.**
  - Two with 10.375” BeO on Platen.
    - 25 mils below critical position.
    - 35 mils below critical position.
  - One with 10.25” BeO on Platen
    - subcritical

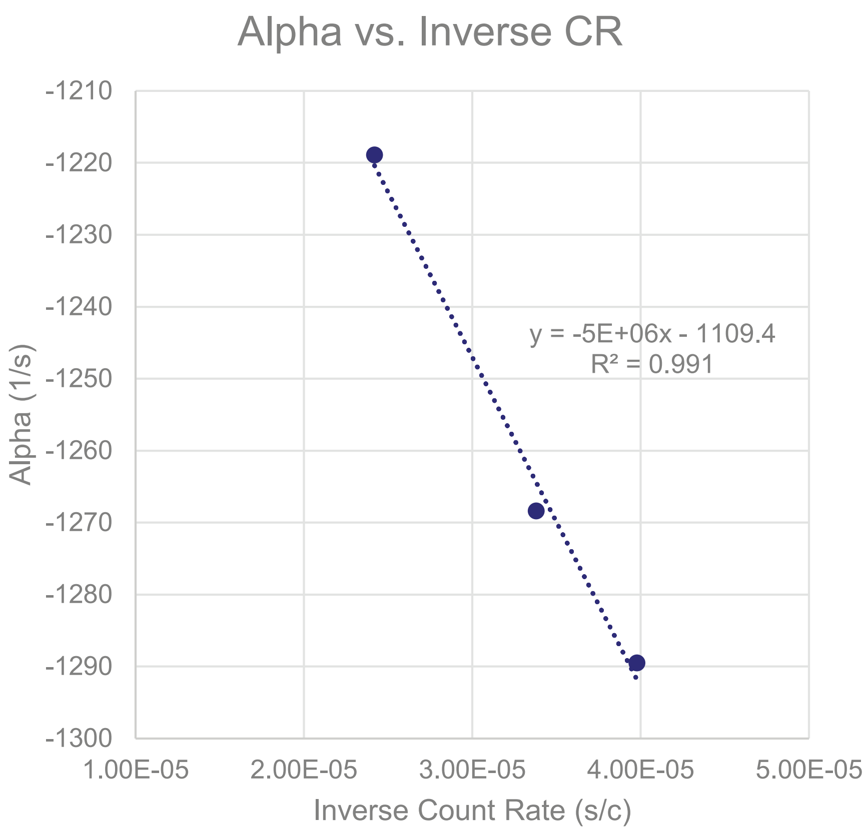


BeO reflector loaded onto the Platen.

Specifics for experiment – Results

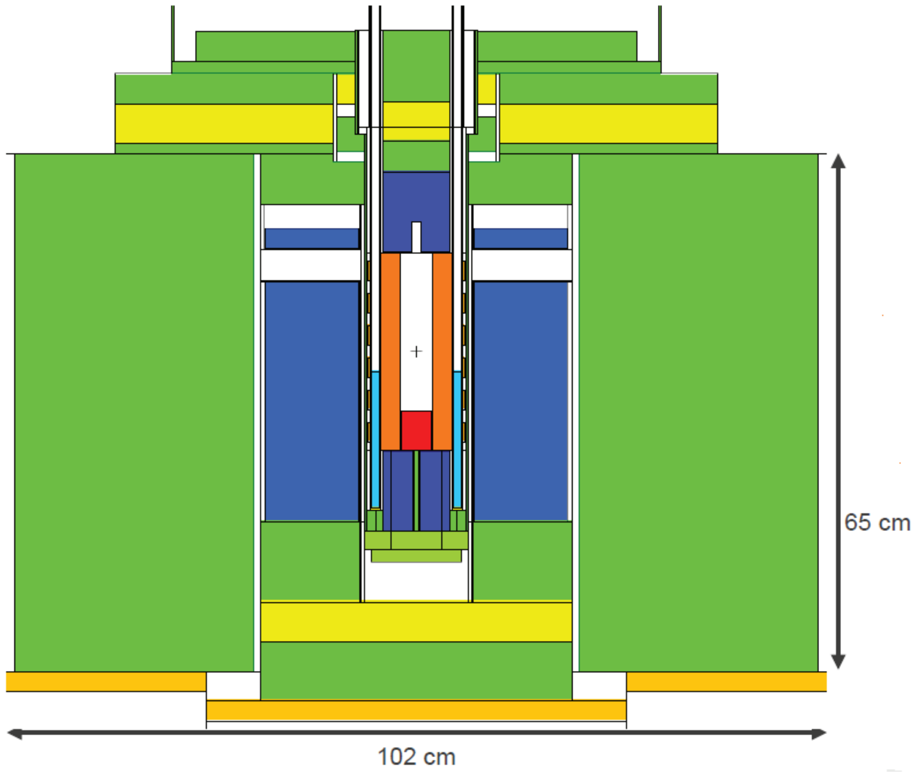
- α_{DC} = -1109.4 ± 14.5 s^{-1}
- Value determined through extrapolation of measured data.
- High count rate near critical (and thermal system) saturated detectors, so measurement was not made at DC.

	1/CR	α (s^{-1})	ρ ($)
-25 mils	2.42E-05	-1218.9	-0.10
-35 mils	3.38E-05	-1268.4	-0.14
10.25” BeO	3.98E-05	-1289.5	-0.16



Comparison to simulation

- **Measured value**
  - $\alpha_{DC} = -1109.4 \pm 14.5\ s^{-1}$
- **Calculated value**
  - $\alpha_{DC} = -1317.7 \pm 7.6\ s^{-1}$
- **About 18% difference**
  - Typically see discrepancy near 10%.
    - Simulation typically calculates high.
  - Likely caused by the value being rather small already and the exclusion of the detectors from the model.
  - Also caused by model not being exactly 1.
  - Overall adequate agreement.



Conclusions

- **Measured value**
  - $\alpha_{DC} = -1109.4 \pm 14.5\ s^{-1}$
  - Compares well to solution systems.
    - Because of thick thermalizing BeO reflection.

KRUSTY

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Poly Class Foils	-199.4

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Questions?

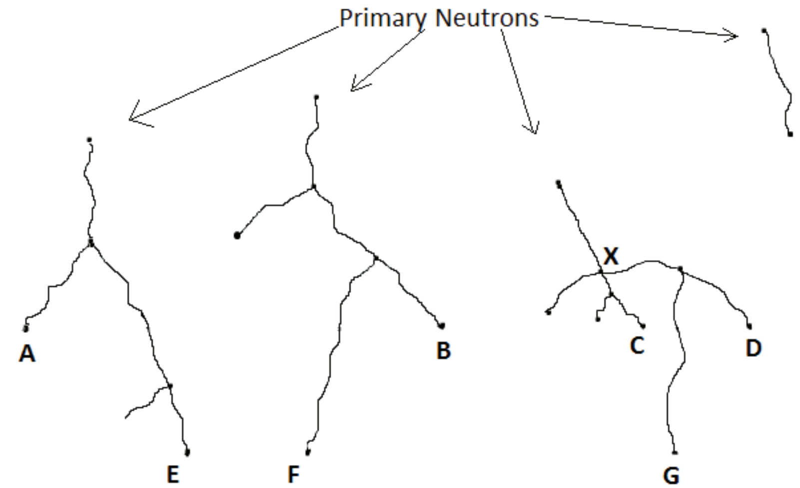
Theory – Prompt Neutron Decay Constant (cont.)

Correlated Neutrons

- Neutrons that have a common fission ancestor.
- Must all be prompt neutrons.

Accidental Neutrons

- Neutrons that do not have a common fission ancestor.
- Include delayed neutrons, source neutrons, and prompt neutrons from different fission chains.



Every branching signifies a fission.