Prompt Neutron Decay Constants in a Highly Enriched Uranium-Lead Copper Reflected System

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Background

- **Bruno Rossi proposes these measurements (1944).**
- **Theory of “Chain reactor neutron population” is developed by R. Feynman, F. de Hoffmann, and R. Serber. “Intensity Fluctuations of a Neutron Chain Reactor,” LADC-256 (June 1944).**
- **J. Orndoff extended and applied the theory. “Prompt Neutron Periods of Metal Critical Assemblies” Nucl. Sci. and Eng. 2, 450 (1957).**

Purpose

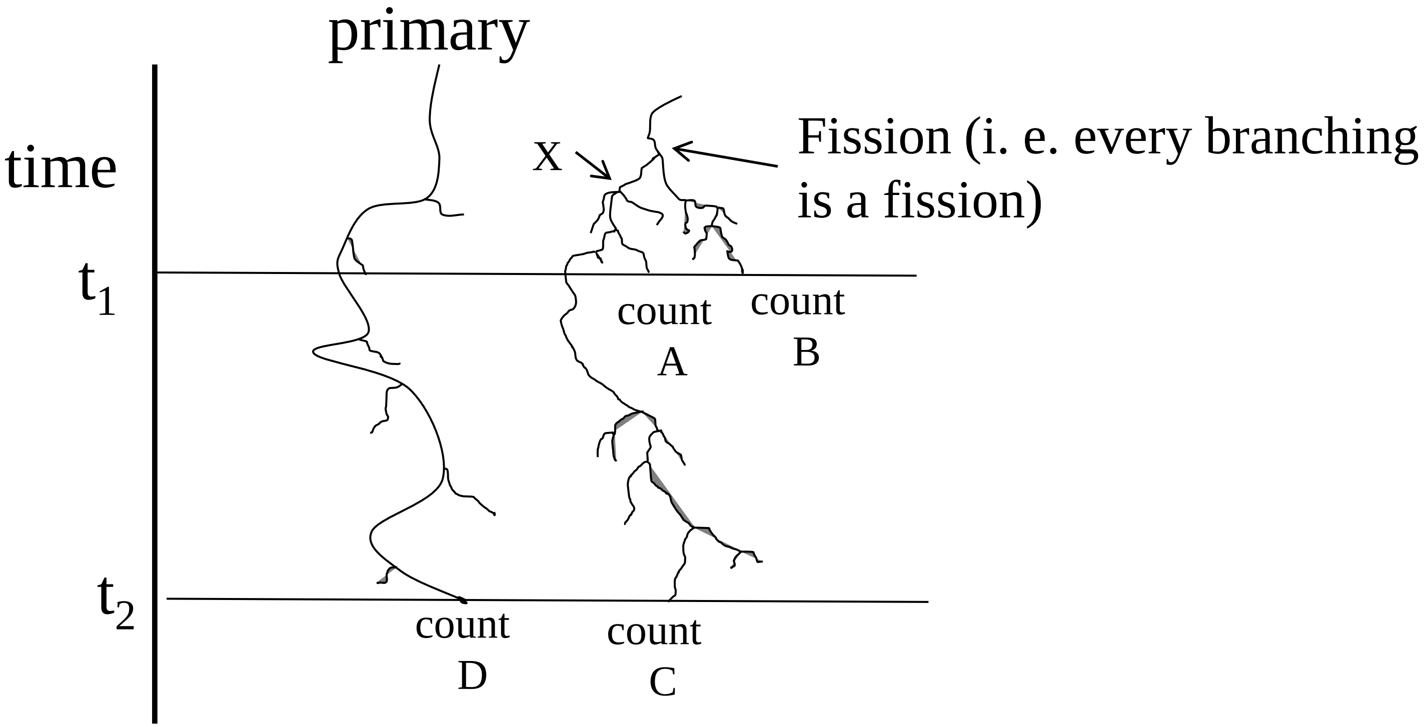
- **Prompt Neutron Decay Constants**

  Purpose:

  - To provide information regarding the neutron lifetime, β_{eff} of the system, and $k_{eff.}$
  - Indicators of the neutron energy spectrum
  - Benchmarks

Reference
Intensity Fluctuations of Neutron Chain Reactor
R. Feynman, F. de Hoffmann, R. Seber

Primary Neutrons



Theory

$$\dot{N} \,\alpha\, N \qquad \frac{\partial N}{\partial t} = \alpha N \qquad N(t) = N_0 e^{\alpha t}$$

$\varepsilon \frac{dt}{\tau_f}$ Probability of any neutron present being detected and producing a count in ^{3}He detector at t_1 or t_2

$F dt_0$ Probability that a fission occurs at t_0 in dt_0

Theory (cont.)

$\nu e^{-\alpha(t_1 - t_0)}$ Expected number of neutrons at t_1 due to neutrons created at t_0

$(\nu - 1) e^{-\alpha(t_2 - t_0)}$ Expected number of neutrons at t_2 due to neutrons created at t_0

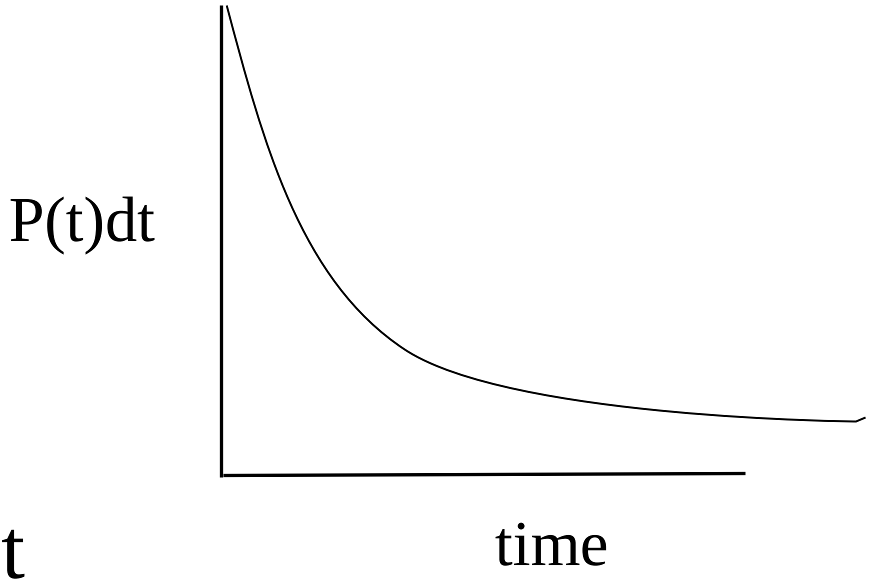
$\int_{-\infty}^{t_1} (\nu - 1) e^{-\alpha(t_2 - t_0)} \varepsilon \frac{dt_2}{\tau_f} \nu e^{-\alpha(t_1 - t_0)} \varepsilon \frac{dt_1}{\tau_f} F dt_0$ Probability of correlated counts

$F\varepsilon dt_1 F\varepsilon dt_2$ Probability of uncorrelated counts

Theory (cont.)

$$\alpha = \frac{k_p - 1}{l}$$

$$\alpha_{dc} = \frac{1 - \beta_{eff} - 1}{l} = \frac{-\beta_{eff}}{l}$$

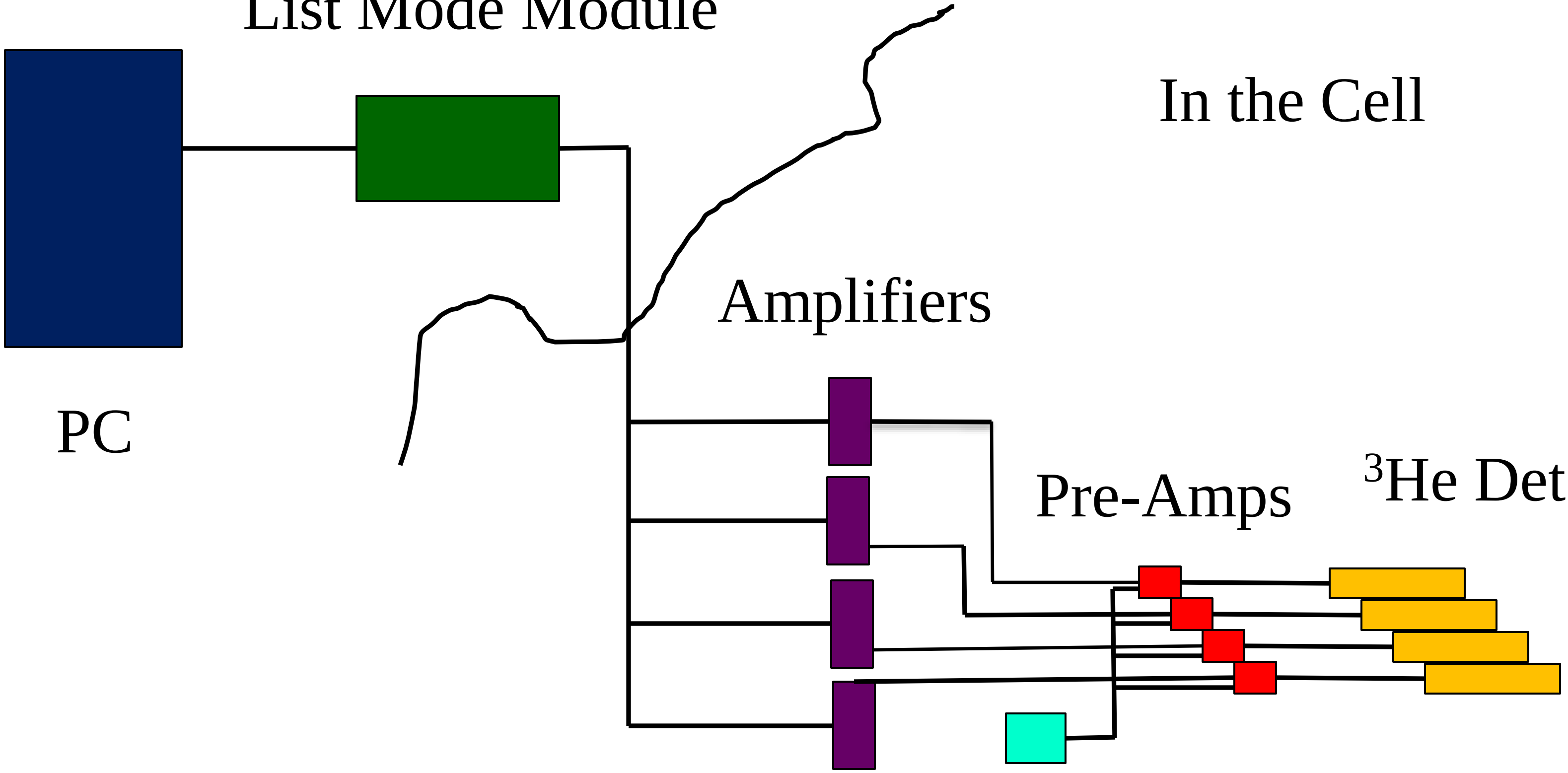


$$P(t)dt = Cdt + Qe^{\alpha t}dt$$

$$C = F\varepsilon F\varepsilon$$

$$Q = F\varepsilon^2\left(\frac{\overline{\nu^2} - \overline{\nu}}{2\alpha\tau_f^2}\right)$$

Detection System



In the Control Room

List Mode Module

In the Cell

Amplifiers

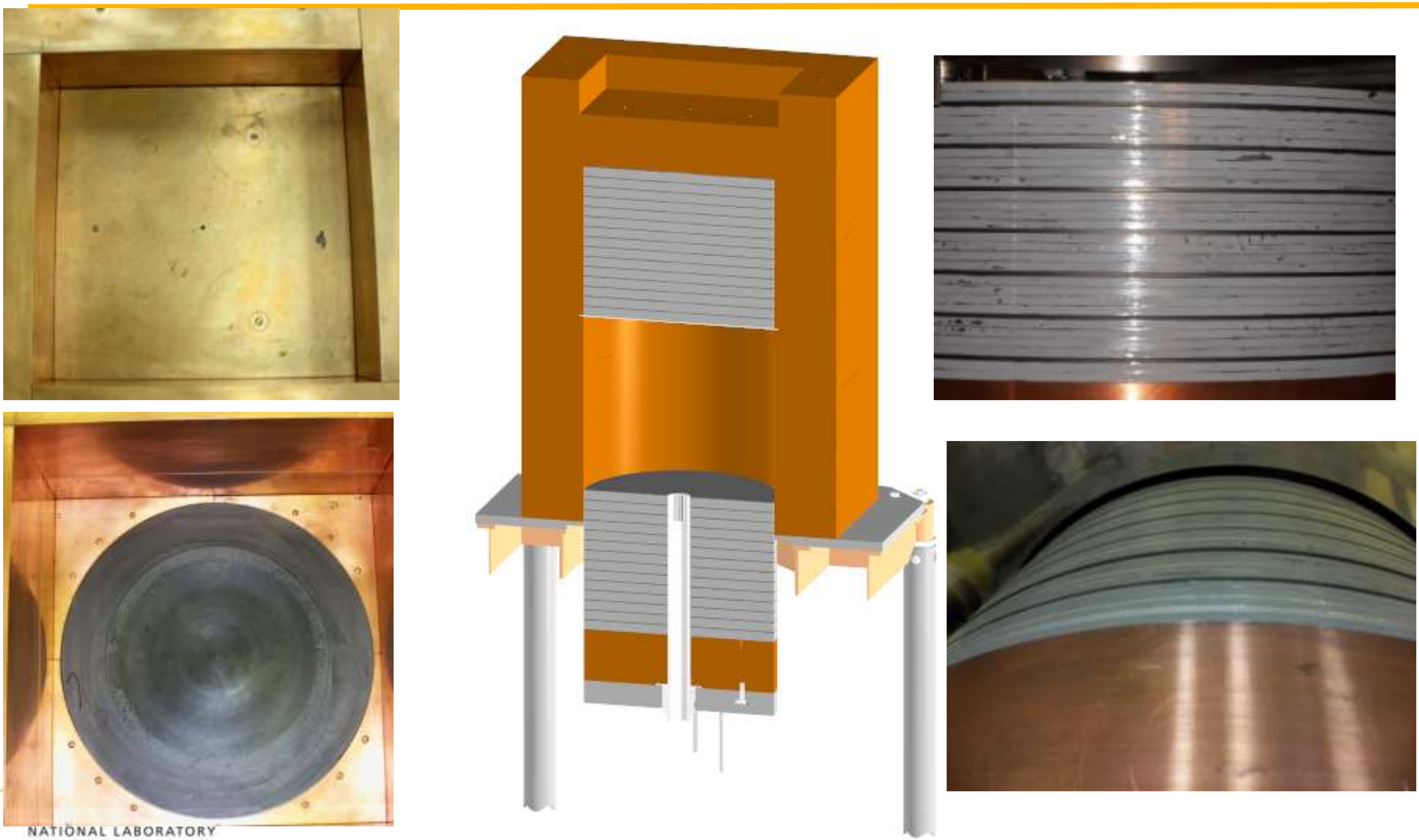
PC

Pre-Amps

^{3}He Detectors

High Voltage

The HEU-Lead core surrounded with copper



^{3}He Detectors

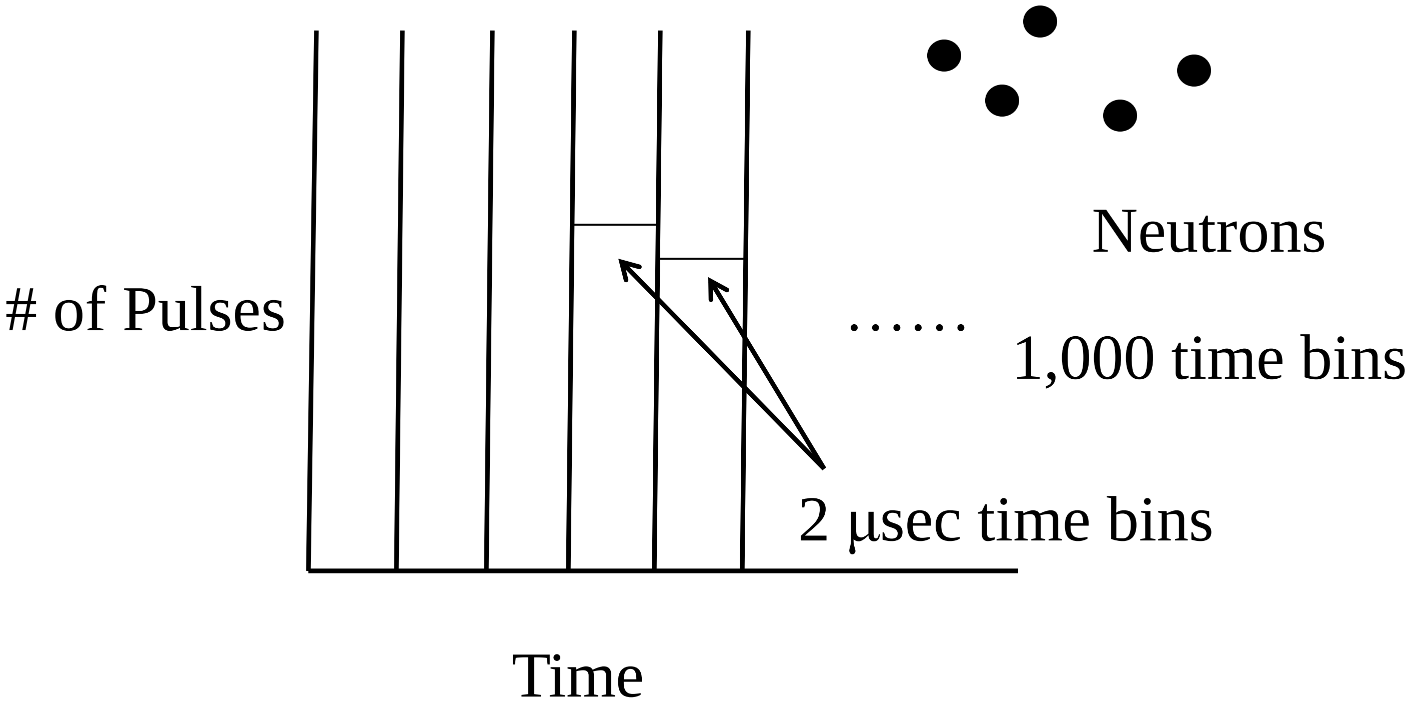
Detector diameter 0.25 inches

Detector length 3.75 inches

Sensitive length 3.0 inches

Fill pressure of 40 atmospheres of ^{3}He

Recording of Neutron Pulses



Neutrons

\# of Pulses

……

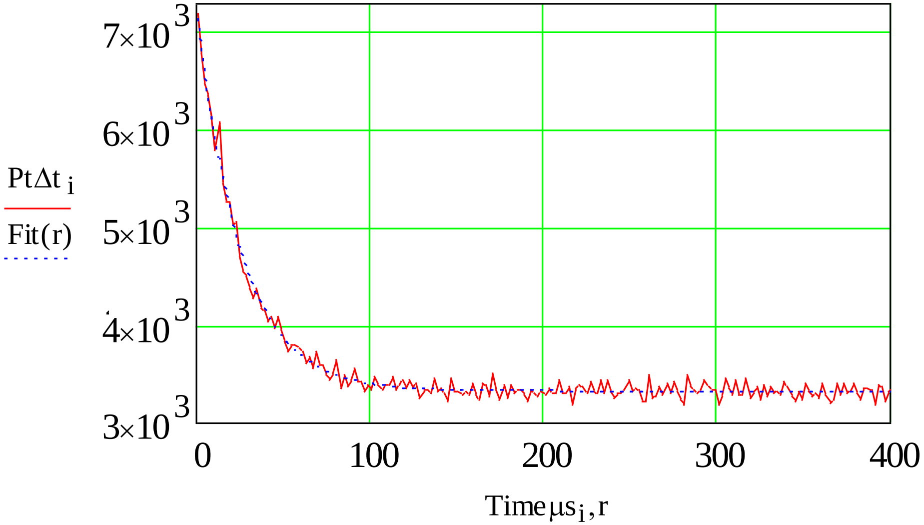
1,000 time bins

2 μsec time bins

Time

Analysis of the Data (Mathcad)

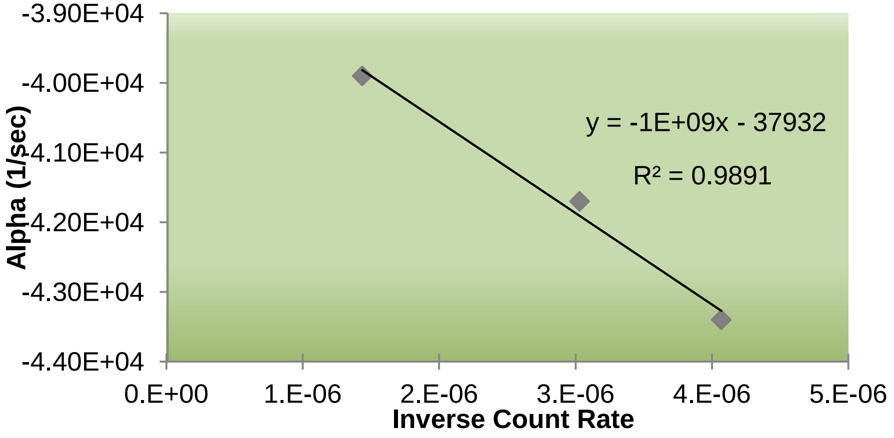
$$F(t,u) := \begin{bmatrix} u_0 + u_1 \cdot \exp(-u_2 \cdot t) \\ 1 \\ \exp(-u_2 \cdot t) \\ -t \cdot (u_1) \cdot \exp(-u_2 \cdot t) \end{bmatrix}$$



$$P1 := \text{genfit}(Time\mu s, Pt\Delta t, vg1, F)$$

$$alpha1 = 3.977 \times 10^4$$

α (delayed critical)



Prompt Neutron Decay Constants vs Inverse Count Rate (No Glue)

$$\alpha = \frac{k_p - 1}{l}$$

$$\alpha(dc) = \frac{1-\beta_{eff} - 1}{l} = -\frac{\beta_{eff}}{l}$$

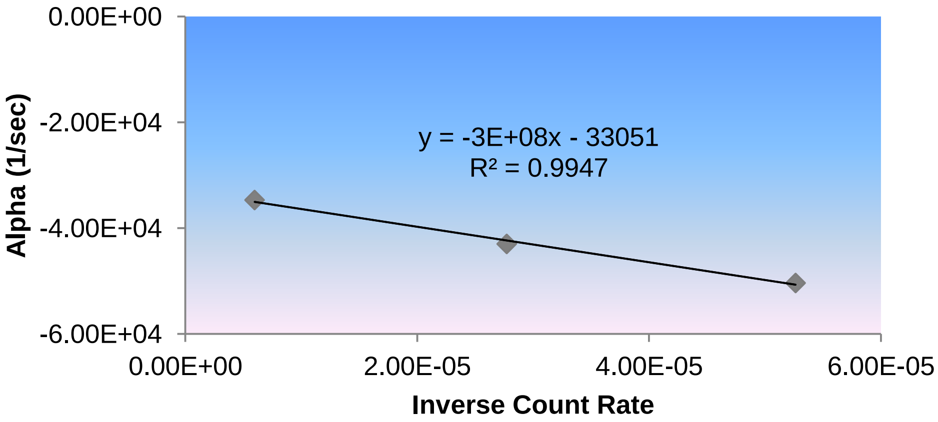
$$\beta = 0.00687$$

$\alpha(dc)$ = -37, 932 s^{-1} (No Glue)

$\alpha(dc)$ = -33,951 s^{-1} (Glue)

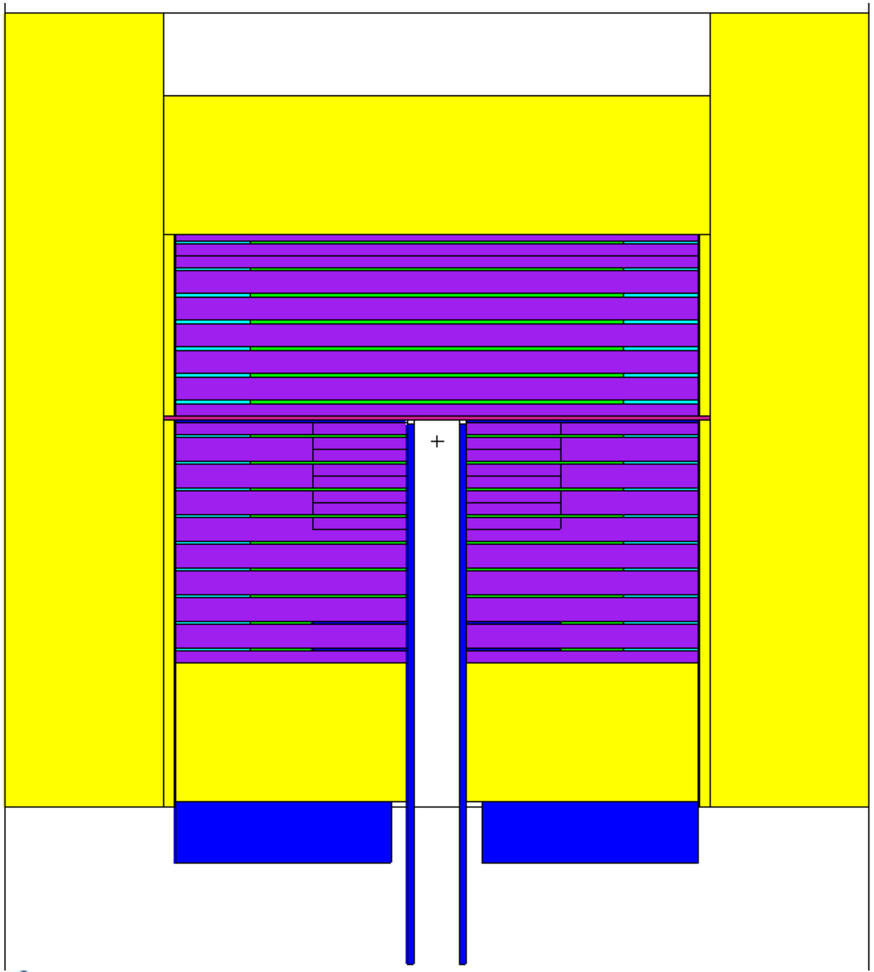
l = 1.82 x 10^{-7} sec (No Glue)

l = 2.02 x 10^{-7} sec (Glue)



Prompt Neutron Decay Constants vs Inverse Count Rate (Glue)

MCNP Model



🟥 Stainless Steel Diaphragm

🟨 Copper Reflector

🟪 Lead plates

🟩 HEU Plates

🟦 Aluminum plates

KOPTS card

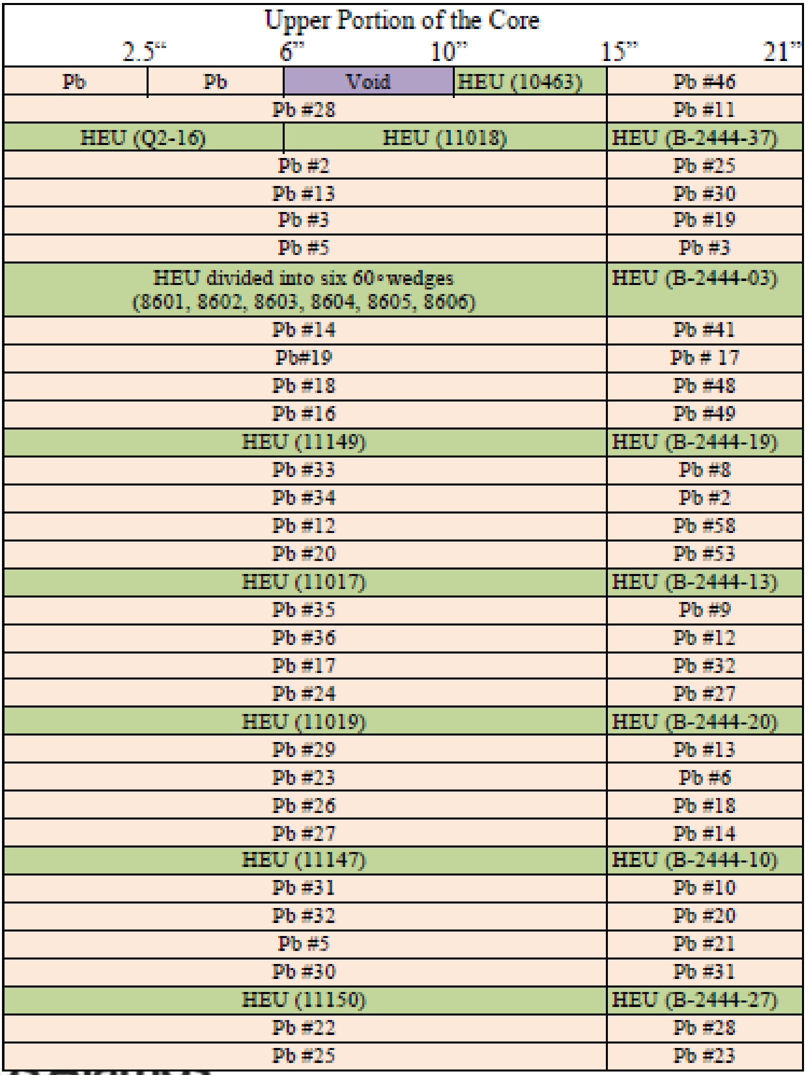
Computes the point kinetics Parameters: Λ, β_{eff}, Rossi-α

Hybond:

98.6 wt% polychloroprene

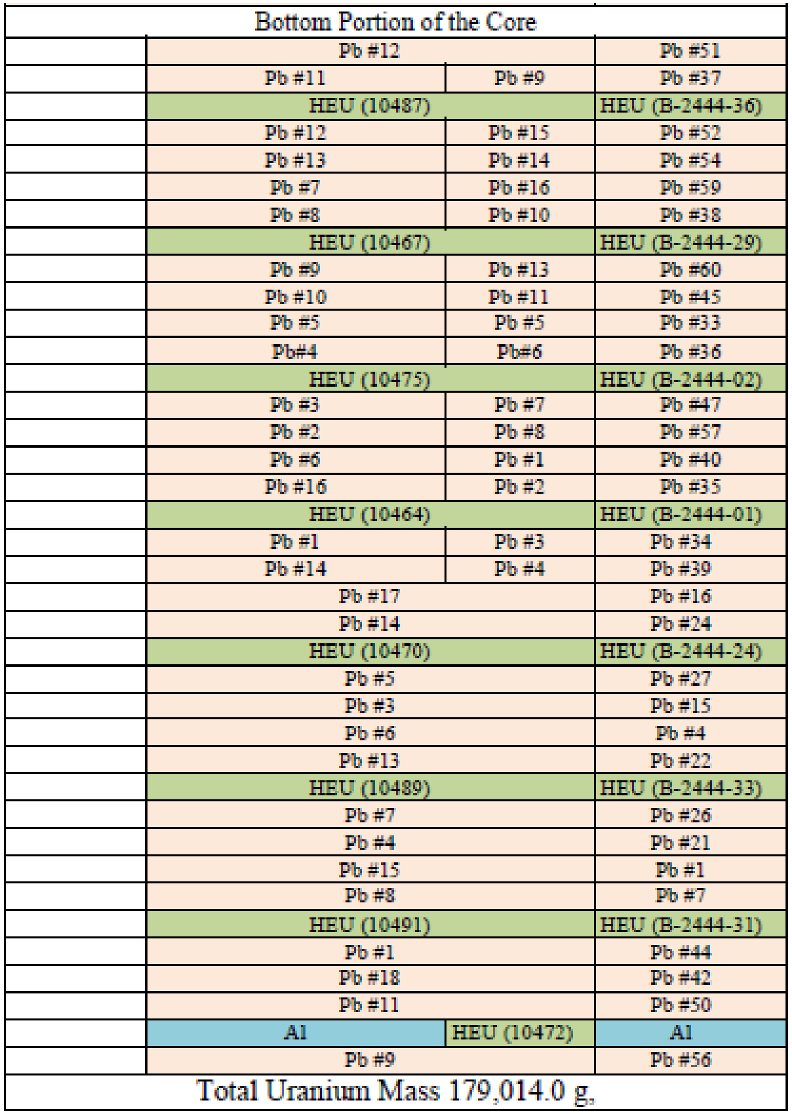
0.35 wt% moisture

Configuration (with glue)



Upper Portion of the Core

2.5"	6"	10"	15"	21"
Pb	Pb	Void	HEU (10463)	Pb #46
Pb #28				Pb #11
HEU (Q2-16)		HEU (11018)		HEU (B-2444-37)
Pb #2				Pb #25
Pb #13				Pb #30
Pb #3				Pb #19
Pb #5				Pb #3
HEU divided into six 60∘wedges (8601, 8602, 8603, 8604, 8605, 8606)				HEU (B-2444-03)
Pb #14				Pb #41
Pb#19				Pb # 17
Pb #18				Pb #48
Pb #16				Pb #49
HEU (11149)				HEU (B-2444-19)
Pb #33				Pb #8
Pb #34				Pb #2
Pb #12				Pb #58
Pb #20				Pb #53
HEU (11017)				HEU (B-2444-13)
Pb #35				Pb #9
Pb #36				Pb #12
Pb #17				Pb #32
Pb #24				Pb #27
HEU (11019)				HEU (B-2444-20)
Pb #29				Pb #13
Pb #23				Pb #6
Pb #26				Pb #18
Pb #27				Pb #14
HEU (11147)				HEU (B-2444-10)
Pb #31				Pb #10
Pb #32				Pb #20
Pb #5				Pb #21
Pb #30				Pb #31
HEU (11150)				HEU (B-2444-27)
Pb #22				Pb #28
Pb #25				Pb #23



Bottom Portion of the Core

	Pb #12		Pb #51
	Pb #11	Pb #9	Pb #37
	HEU (10487)		HEU (B-2444-36)
	Pb #12	Pb #15	Pb #52
	Pb #13	Pb #14	Pb #54
	Pb #7	Pb #16	Pb #59
	Pb #8	Pb #10	Pb #38
	HEU (10467)		HEU (B-2444-29)
	Pb #9	Pb #13	Pb #60
	Pb #10	Pb #11	Pb #45
	Pb #5	Pb #5	Pb #33
	Pb#4	Pb#6	Pb #36
	HEU (10475)		HEU (B-2444-02)
	Pb #3	Pb #7	Pb #47
	Pb #2	Pb #8	Pb #57
	Pb #6	Pb #1	Pb #40
	Pb #16	Pb #2	Pb #35
	HEU (10464)		HEU (B-2444-01)
	Pb #1	Pb #3	Pb #34
	Pb #14	Pb #4	Pb #39
	Pb #17		Pb #16
	Pb #14		Pb #24
	HEU (10470)		HEU (B-2444-24)
	Pb #5		Pb #27
	Pb #3		Pb #15
	Pb #6		Pb #4
	Pb #13		Pb #22
	HEU (10489)		HEU (B-2444-33)
	Pb #7		Pb #26
	Pb #4		Pb #21
	Pb #15		Pb #1
	Pb #8		Pb #7
	HEU (10491)		HEU (B-2444-31)
	Pb #1		Pb #44
	Pb #18		Pb #42
	Pb #11		Pb #50
	Al	HEU (10472)	Al
	Pb #9		Pb #56

Total Uranium Mass 179,014.0 g.

Results (Computational vs Experimental)

Experimental Results

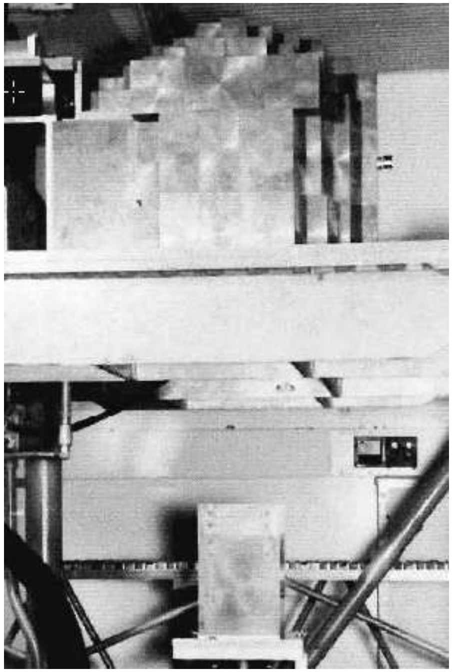
$\alpha(dc) = -37{,}932\ s^{-1}$ (No glue)
$\alpha(dc) = -33{,}951\ s^{-1}$ (Glue)

MCNP
$\alpha(dc) = -43{,}667\ s^{-1}$ (No glue)
Thermal: 0.00% Intermediate: 23.27% Fast: 76.73%

$\alpha(dc) = -37{,}934\ s^{-1}$ (Glue)
Thermal: 0.00% Intermediate: 26.56% Fast: 73.44%

Results and Comparisons

Assemblies	α (dc)	*l* (neutron lifetime)
Lady Godiva (bare Oy-94)	$-1.1 \times 10^{6}\ s^{-1}$	5.9×10^{-9} s
Godiva IV (bare Oy-93 and 1.5 wt% Mo)	$-8.4 \times 10^{5}\ s^{-1}$	7.7×10^{-9} s
Topsy (Oy-94 in thick NU)	$-3.7 \times 10^{5}\ s^{-1}$	1.75×10^{-8} s
Zeus (all-oralloy reflected with copper	$-8.3 \times 10^{4}\ s^{-1}$	7.86×10^{-8} s
HEU-Lead (no Hybond)	$-37{,}932\ s^{-1}$	1.82×10^{-7} s
HEU-Lead (Hybond)	$-33{,}951\ s^{-1}$	2.02×10^{-7} s
SHEBA (Solution High Energy Burst Assembly	$-200\ s^{-1}$	4.0×10^{-5} s



Topsy

Conclusions

- The Rossi-α at delayed critical for this experiment compares quite well with other α's from other assemblies.

- Neutron lifetime compares quite well with those from other assemblies.

- There is a significant difference between the computational and experimental Rossi-α at delayed critical values.

Acknowledgments

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