Determination of the Optimal Time Bin Width for the Rossi-alpha Analysis of Highly Subcritical Fast Metal Systems

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Overview

The predictive capabilities of MCNP®6 for neutron noise experiments are studied.

The effect of the choice of the time bin width for Rossi-alpha analysis for fast, subcritical systems is shown to be significant. An "optimal" time bin width was selected by minimizing the error in the fit parameters.

Criticality and the Prompt Neutron Decay Constant

Systems below a k_{eff} of 0.95 are generally considered "deeply subcritical"

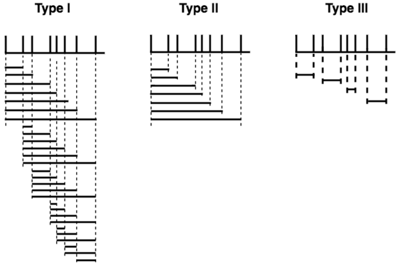
Time behavior of the prompt neutron chain depends on the critical state of the system

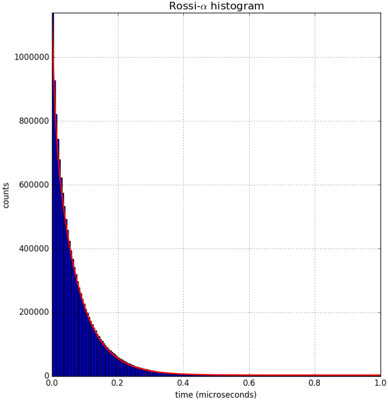
$$\frac{dn}{dt} = \alpha n(t)$$

- $\alpha > 0 \rightarrow$ supercritical
- $\alpha = 0 \rightarrow$ prompt critical
- $\alpha < 0 \rightarrow$ sub-prompt critical

Rossi-alpha Theory

Neutrons originating from the same initial fission event are correlated in time.





Historical Rossi-alpha Measurements

Historical Rossi-alpha measurements required gating hardware that necessitated selecting a fixed time bin width.

Many modern neutron noise measurements record time-stamped counts, allowing for the selection of analysis method to be chosen post-measurement.

MCNP®6 and List-Mode Data Generation

Monte Carlo N-Particle 6

`MCNP6` can simulate list-mode data:

- Simulations must be run in analog mode
- Simulations cannot be run in MPI mode
- `ptrac` file must be written in binary format

```
3     10035191690.87059
3     10035191689.20313
3     10035191684.16972
3     10035191691.67078
3     10035191689.24472
3     10035191694.43176
3     10035191692.64740
3     10035191686.76237
3     10035191685.77344
3      2860361396.20510
3      2860361409.82146
3      2860361414.89785
3      2401813372.04363
3     18722673899.28493
3     27312955763.88393
3     27989481182.50493
3     29228832099.21028
3       314421464.47605
3       314421470.23480
3       314421470.49030
3       314421458.02021
3       314421456.55176
3       314421457.66738
3     38418787101.66085
3     25426334978.87869
3     33635592966.54404
3     18793043613.40993
3     43419192793.41262
```

MPKRA

MPKRA is a Rossi-alpha analysis code developed to obtain the prompt neutron decay constants for coupled reactors from list-mode data.

User provides:

- List-mode filename
- Total measurement time in seconds
- Time window size in microseconds
- Time bin width in microseconds*
- Number of exponentials to fit to the data

MPKRA process:

1. Data are sorted in ascending time
2. Data are binned using Type I binning
3. A histogram is created from the binned data
4. A sum-of-exponentials curve is fit to the data
5. The prompt neutron decay constants are printed

Computational Hardware and Capabilities

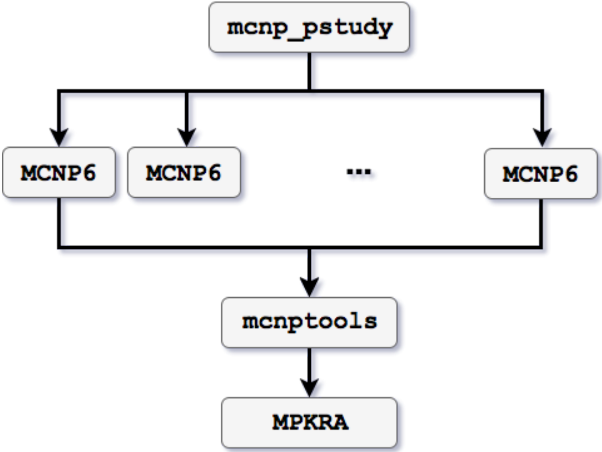
Moonlight (`MCNP6`):

- 308 nodes
- Two 2.6 GHz eight-core Intel Xeon processors/node
- 32 GB RAM/node
- Two Nvidia Tesla GPU cards/node
- 488 TFlops

Laptop (`MPKRA`):

- MacBook Air
- 2.2 GHz Intel Core i7
- 8GB RAM

Workflow



Verification of MCNP6 List-Mode Data Generation and MPKRA Processing

Ensure that:

- MCNP6/ptrac is producing list-mode data as expected
- MPKRA is sorting, binning and curve-fitting correctly

$$\alpha = \frac{k\,(1-\beta)-1}{k\Lambda}$$

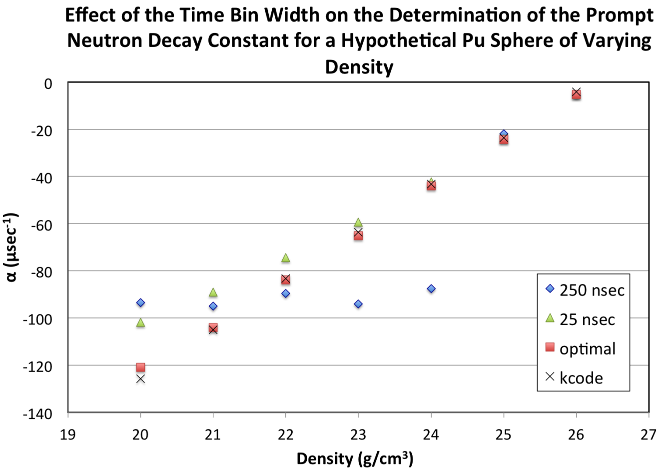
Prompt Neutron Decay Constant (10^4 inverse seconds)				
Benchmark	Measured	MCNP5 (Mosteller)	MCNP6/ kopts	MCNP6/ptrac
Jezebel-Pu	-64 ± 1	-65 ± 1	-63 ± 1	-65.082 ± 0.004
Jezebel-U233	-100 ± 1	-108 ± 1	-103 ± 2	-109.525 ± 0.009
THOR	-19 ± 1	-20 ± 1	-21.0 ± 0.4	-19.48 ± 0.02

Problem Description

- Plutonium sphere (BeRP ball as starting point)
- Increase density to bring system closer to critical level

Density (g/cc)	k_{eff}
19.604	0.77427 ± 0.00011
20.0	0.78974 ± 0.00011
21.0	0.82496 ± 0.00011
22.0	0.85992 ± 0.00012
23.0	0.89427 ± 0.00012
24.0	0.92808 ± 0.00012
25.0	0.96178 ± 0.00012
26.0	0.99476 ± 0.00014

Effect of the Time Bin Width Size on Estimating α for Fast, Bare Metal Systems



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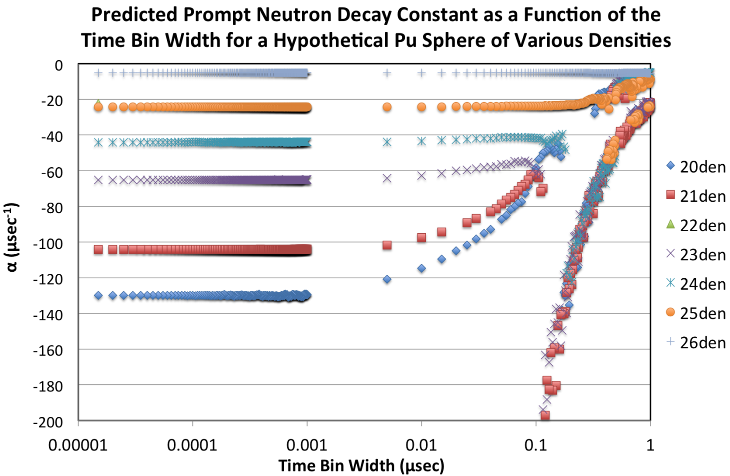
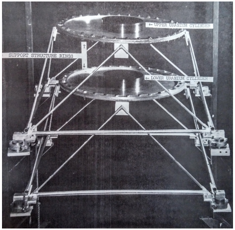


Prompt Neutron Decay Constants for a Hypothetical Pu Sphere of Varying Densities

α (μsec^{-1})			
Density (g/cc)	kcode	ptrac/Rossi-alpha	C/E
19.604	-136.550 ± 0.005	-127.90 ± 0.02	1.068
20.0	-125.714 ± 0.005	-129 ± 1	0.974
21.0	-104.956 ± 0.004	-104.06 ± 0.07	1.009
22.0	-83.371 ± 0.004	-83.90 ± 0.04	0.994
23.0	-63.591 ± 0.005	-65.1 ± 0.2	0.977
24.0	-43.289 ± 0.005	-43.95 ± 0.09	0.985
25.0	-23.511 ± 0.006	-24.30 ± 0.02	0.967
26.0	-4.15 ± 0.03	-5.170 ± 0.004	0.803

Mihalczo's HEU Cylinders Measurements

27.94cm-diameter HEU cylinders
of varying thicknesses



	α_{iso} (μsec^{-1})		
Experiment	Measured	`MCNP6/ptrac`	C/E
8.255 cm	-5.05	-5.168 ± 0.002	1.02
7.314 cm	-16.70	-17.15 ± 0.02	1.03
6.676 cm	-25.26	-25.85 ± 0.02	1.02
6.042 cm	-34.55	-36.65 ± 0.03	1.06

Summary

- MCNP6, using the ptrac capability, is a viable tool for detailed planning of neutron noise experiments.
- As a multiplying system's decay constant increases in magnitude, smaller time bin sizes are needed for appropriate application of the Rossi-alpha method.
  - Even modern measurement systems may not have the resolution to observe the prompt neutron decay constant for a deeply subcritical system.

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