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

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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.
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
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.
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
- \texttt{ptrac} file must be written in binary format
**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

```
mcnp_pstudy

| MCNP6 | ... | MCNP6 |

mcnptools

MPKRA
```
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)

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Measured</th>
<th>MCNP5 (Mosteller)</th>
<th>MCNP6/kopts</th>
<th>MCNP6/ptrac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jezebel-Pu</td>
<td>−64 ± 1</td>
<td>−65 ± 1</td>
<td>−63 ± 1</td>
<td>−65.082 ± 0.004</td>
</tr>
<tr>
<td>Jezebel-U233</td>
<td>−100 ± 1</td>
<td>−108 ± 1</td>
<td>−103 ± 2</td>
<td>−109.525 ± 0.009</td>
</tr>
<tr>
<td>THOR</td>
<td>−19 ± 1</td>
<td>−20 ± 1</td>
<td>−21.0 ± 0.4</td>
<td>−19.48 ± 0.02</td>
</tr>
</tbody>
</table>
Problem Description

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

<table>
<thead>
<tr>
<th>Density (g/cc)</th>
<th>$k_{\text{eff}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.604</td>
<td>0.77427 ± 0.00011</td>
</tr>
<tr>
<td>20.0</td>
<td>0.78974 ± 0.00011</td>
</tr>
<tr>
<td>21.0</td>
<td>0.82496 ± 0.00011</td>
</tr>
<tr>
<td>22.0</td>
<td>0.85992 ± 0.00012</td>
</tr>
<tr>
<td>23.0</td>
<td>0.89427 ± 0.00012</td>
</tr>
<tr>
<td>24.0</td>
<td>0.92808 ± 0.00012</td>
</tr>
<tr>
<td>25.0</td>
<td>0.96178 ± 0.00012</td>
</tr>
<tr>
<td>26.0</td>
<td>0.99476 ± 0.00014</td>
</tr>
</tbody>
</table>
Effect of the Time Bin Width Size on Estimating $\alpha$ for Fast, Bare Metal Systems

Effect of the Time Bin Width on the Determination of the Prompt Neutron Decay Constant for a Hypothetical Pu Sphere of Varying Density

$\alpha$ (µsec$^{-1}$)

Density (g/cm$^3$)

-140 -120 -100 -80 -60 -40 -20 0

250 nsec
25 nsec
optimal
kcode
Effect of the Time Bin Width Size on Estimating $\alpha$ for Fast, Bare Metal Systems
Prompt Neutron Decay Constants for a Hypothetical Pu Sphere of Varying Densities

<table>
<thead>
<tr>
<th>Density (g/cc)</th>
<th>$\alpha$ ($\mu$sec$^{-1}$)</th>
<th>$\text{kcode}$</th>
<th>ptrac/Rossi-alpha</th>
<th>C/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.604</td>
<td>$-136.550 \pm 0.005$</td>
<td></td>
<td>$-127.90 \pm 0.02$</td>
<td>1.068</td>
</tr>
<tr>
<td>20.0</td>
<td>$-125.714 \pm 0.005$</td>
<td></td>
<td>$-129 \pm 1$</td>
<td>0.974</td>
</tr>
<tr>
<td>21.0</td>
<td>$-104.956 \pm 0.004$</td>
<td></td>
<td>$-104.06 \pm 0.07$</td>
<td>1.009</td>
</tr>
<tr>
<td>22.0</td>
<td>$-83.371 \pm 0.004$</td>
<td></td>
<td>$-83.90 \pm 0.04$</td>
<td>0.994</td>
</tr>
<tr>
<td>23.0</td>
<td>$-63.591 \pm 0.005$</td>
<td></td>
<td>$-65.1 \pm 0.2$</td>
<td>0.977</td>
</tr>
<tr>
<td>24.0</td>
<td>$-43.289 \pm 0.005$</td>
<td></td>
<td>$-43.95 \pm 0.09$</td>
<td>0.985</td>
</tr>
<tr>
<td>25.0</td>
<td>$-23.511 \pm 0.006$</td>
<td></td>
<td>$-24.30 \pm 0.02$</td>
<td>0.967</td>
</tr>
<tr>
<td>26.0</td>
<td>$-4.15 \pm 0.03$</td>
<td></td>
<td>$-5.170 \pm 0.004$</td>
<td>0.803</td>
</tr>
</tbody>
</table>
27.94cm-diameter HEU cylinders of varying thicknesses

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Measured</th>
<th>α_{iso} (µsec⁻¹)</th>
<th>MCNP6/ptrac</th>
<th>C/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.255 cm</td>
<td>−5.05</td>
<td>−5.168 ± 0.002</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td>7.314 cm</td>
<td>−16.70</td>
<td>−17.15 ± 0.02</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>6.676 cm</td>
<td>−25.26</td>
<td>−25.85 ± 0.02</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td>6.042 cm</td>
<td>−34.55</td>
<td>−36.65 ± 0.03</td>
<td>1.06</td>
<td></td>
</tr>
</tbody>
</table>
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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