Evaluation of the Effect of Pulse Shape Discrimination on Prompt Neutron Period Estimates

John-Tyler J. Iacovetta, Michael Y. Hua, and Sara A. Pozzi
Department of Nuclear Engineering and Radiological Sciences, University of Michigan, 48109
Sara Pozzi, *pozzisa@umich.edu*
Consortium for Monitoring, Technology, and Verification (MTV)

Detection for Nuclear Nonproliferation Group

Introduction and Motivation

- Assemblies exhibiting fission chains are characterized by reactivity and/or multiplication.
- Reactivity is a quantity of interest in nuclear nonproliferation, stockpile stewardship, and criticality safety.
- The Rossi-alpha method is a neutron noise technique that can be used to infer the reactivity of delayed critical or near-critical systems.
- Organic Scintillators can be used in Rossi-alpha measurements of fast, fissioning assemblies.
  - Sensitive to gamma rays (gammas) and neutrons.
  - Previous work shows gamma detections can be used in the Rossi-alpha method.
- Pulse Shape Discrimination (PSD) is typically necessary to separate neutron and gamma detections.
- **Motivation**: if PSD is not necessary:
  - Increased accuracy in measurements and shorter time needed to process data.
  - Alternative detector materials.
  - Adds another tool for use in the nuclear threat reduction mission.

Background

- Rossi-alpha Measurements

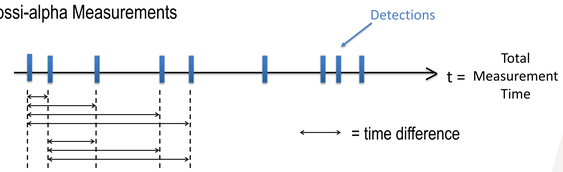

Fig 1. Sample pulse train and time-difference binning.

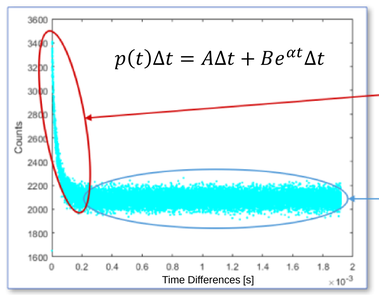

Fig 2. Typical histogram shape for prompt neutron Rossi-alpha.

- In fission-chain systems, we expect to see correlated detections in small time difference windows.
- In a subcritical system, the number of fission events in one fission chain will eventually die away.
- Pulse Shape Discrimination
  - Gammas and neutrons undergo different interactions in the scintillator.
  - Neutron pulses will have longer tail regions compared to gamma pulses

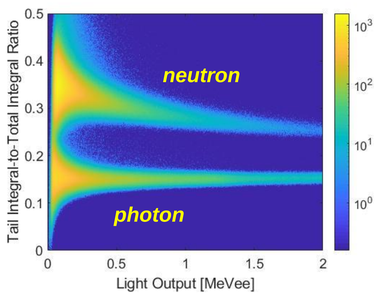

Fig 3. Sample PSD plot from nickel-reflected plutonium.

Experiment

- Detectors: twelve 5.08 cm × 5.08 cm diameter *trans*-stilbene organic scintillators.
- Source specifications:
  - Weapons-grade, alpha-phase plutonium, driven by spontaneous fission of ^{240}Pu.
  - 4.5kg reflected by 7.62cm of copper (Cu), nickel (Ni), iron (Fe), or tungsten (W).
- Each configuration was measured 20 times for 1 minute each time
- PSD plots were evaluated for each configuration to separate out neutron only data

Fig 4. (Left) Ni-reflected assembly used in measurement. (Right) Photo of the measurement system.

- Rossi-alpha histograms were generated for each configuration using composite data and neutron only data sets.
- Early features were noticeably different

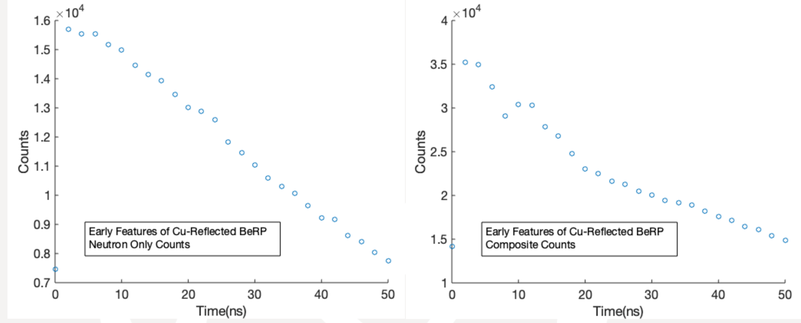

Fig. 5 Comparison of Early Features of Rossi-alpha histograms in Cu-reflected assemblies.

- Cross-correlation plots were generated to understand these differences.
- Time coincident distribution of detections shows the early effect prompt photons have on Rossi-alpha histograms.

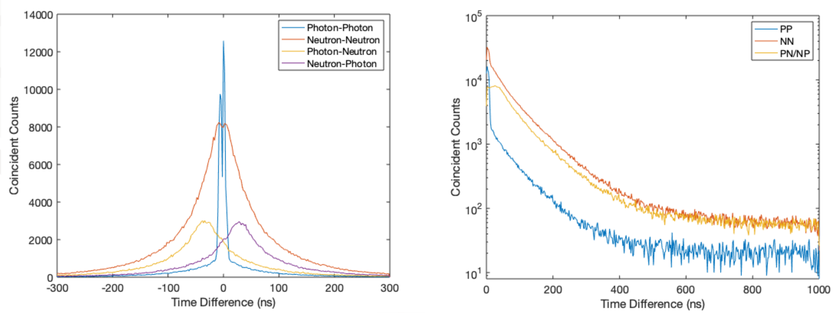

Fig. 6. (Left) Cross- correlation plot for measurements of Cu-reflected assembly . (Right) Cross-correlation plot on log scale to demonstrate and compare exponential trend.

Discussion of Results

- Composite data was cut to after the photon-neutron/neutron-photon peak.
- Rossi-alpha histograms were compared for all configurations.
- Inverse α (prompt period) values are compared to demonstrate measurement agreement.
- After cutting the first 50 ns, the composite and neutron-only estimates of the prompt period agree within two standard deviations (see Fig. 7).

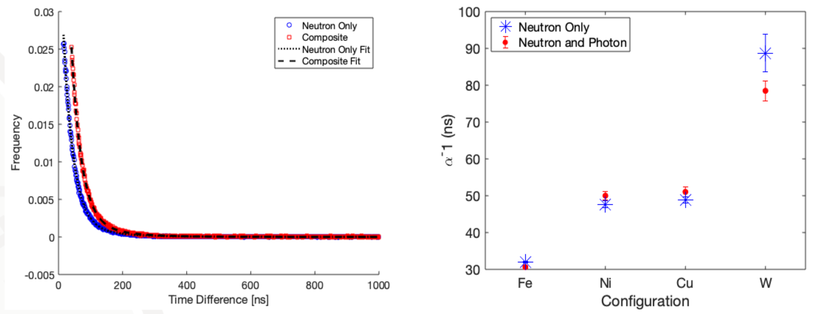

Fig 7. (left) Comparison of Rossi-alpha histograms for Fe-reflected configuration (right) Comparison of inverse α values for each configuration.

Conclusions and Future Work

- Rossi-alpha estimates from neutron-only and composite histograms exhibit agreement.
- Prior work establishes that neutron-only values are correct.
- PSD is not necessary for use in Rossi-alpha measurements using organic scintillators.
- Consider the use of cheaper detectors with greater light output (greater time and energy resolution):
  - Organic glass scintillators.
- Future work will include:
  - Evaluate Rossi-alpha estimates from cross-correlation data.
  - Evaluate cross-correlations between detectors in various geometries such as on either side of the fissile assembly.

Mission Relevance and MTV Impact

- Mission Relevance:
  - Organic scintillators augment the current Rossi-alpha toolbox by adding sensitivity to fast metal assemblies --> improved nuclear criticality safety and safeguards
  - Organic scintillators require less measurement time than He-3, thereby saving procedural and operational costs
  - Further reduce costs by using cheaper, non-PSD-capable detectors (e.g. organic glass)
- MTV Impact:
  - Funds this research (I am a fellow) and enables me to present at conferences
  - Allowed me to attend the Nuclear Safeguards course at Oak Ridge National Laboratory

References

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