MTV Student Virtual Research Symposium

Validating Organic Scintillator Rossi-alpha Measurements of Fast Metal Assemblies using Simulations

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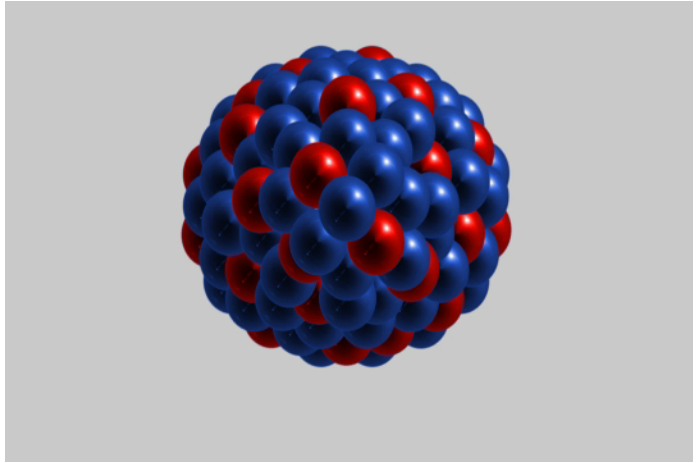
Introduction and Motivation

- k_{eff} describes the neutron multiplication within a system; inter-generational ratio.
- Rossi-alpha measurements estimate the prompt neutron decay constant, α, to infer k_{eff}, which cannot be measured directly.
- Previous work has shown that ^{3}He-gas proportional counter-based detection systems (tens of microseconds) are insensitive to α^{-1} of fast assemblies (tens of nanoseconds).
- Faster detection systems based on organic scintillators are of interest to augment the current Rossi-alpha toolbox.



Nuclear fission chain; neutron multiplying system

We validate organic scintillator-based Rossi-alpha measurements of fast assemblies by comparing measurement to two different, independent simulations.

Mission Relevance

- Measurements of reactivity, ρ, or the k-effective multiplication factor, k_{eff}, of SNM assemblies are crucial to nuclear nonproliferation, safeguards, and criticality safety.

- Criticality safety monitoring uses k_{eff} to prevent accidents.
  - Louis Slotin criticality accident

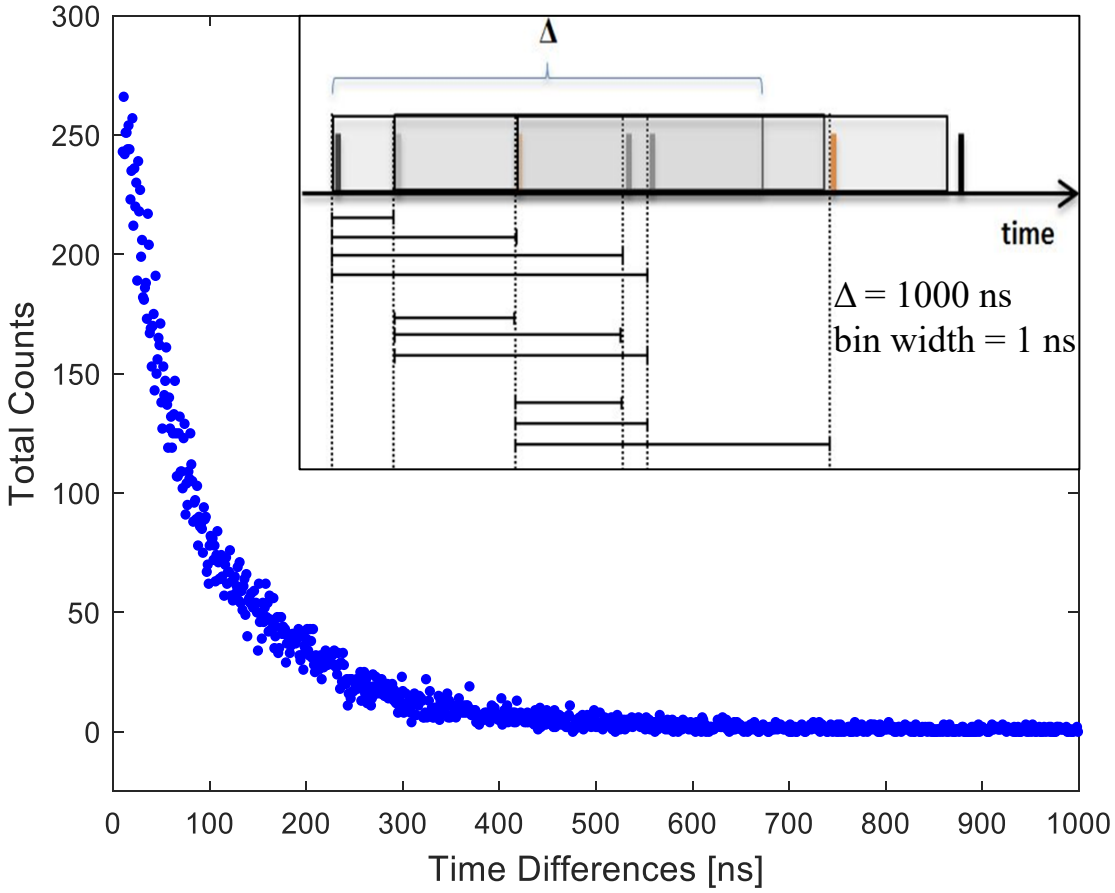
Louis Slotin separating plutonium hemispheres with a screwdriver

Rossi-alpha

- Obtain and histogram time differences between all neutron detections.
- Prompt neutron decay constant, α, determined from fit of time-difference histogram.

$$\rho = \frac{k_{\text{eff}} - 1}{k_{\text{eff}}} = \beta_{\text{eff}} - \alpha\Lambda$$

- Effective delayed neutron fraction, β_{eff}, and mean neutron lifetime, Λ, are typically determined through simulation.



Type-I binning time difference (inner) becomes a Rossi-alpha histogram (outer)

Organic Scintillators

- Organic scintillators capable of detecting both fast neutron and gamma rays have become popularized.
- They are scatter-based recoil detectors sensitive to fast neutrons **without moderation** and have:
  - Observable neutron energy range from 0.5 MeV to 5.5 MeV
  - Nanosecond timing capabilities
  - Pulse-shape discrimination (PSD) implemented to separate neutron events

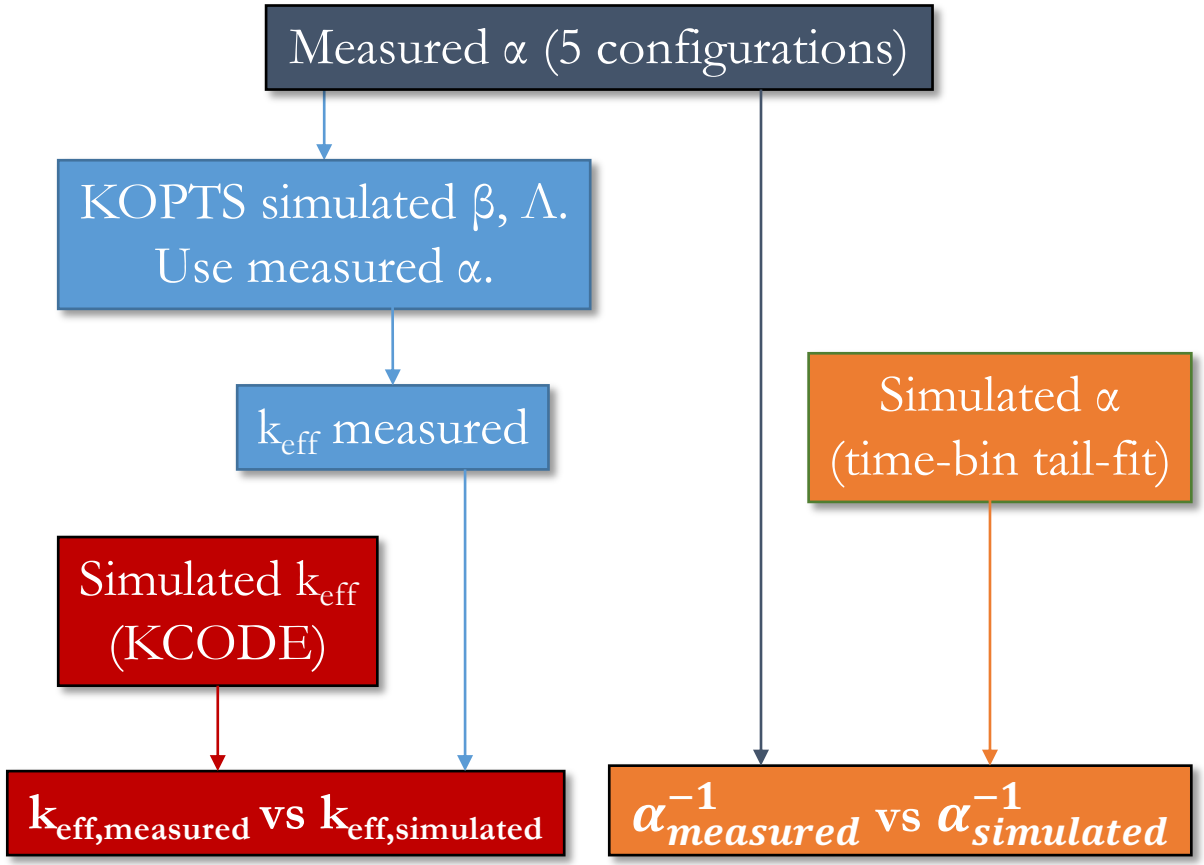
Trans-stilbene crystal and ET 9214B PMT couple.

Measurement and Analysis

- 4.5 kg of alpha-phase, beryllium reflected weapons-grade plutonium (BeRP ball) in five different reflector configurations:
  - Bare
  - 7.62 cm Iron
  - 7.62 cm Copper
  - 7.62 cm Tungsten
  - 7.62 cm Nickel

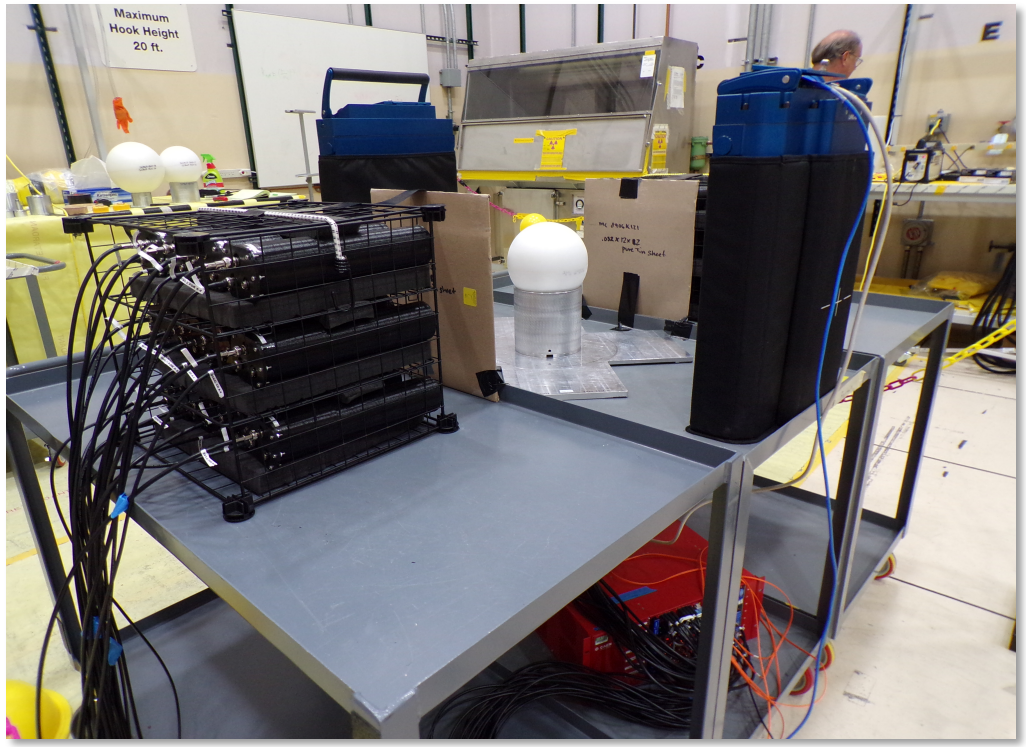
- Measurements performed at National Criticality Experiments Research Center at the Device Assembly Facility.

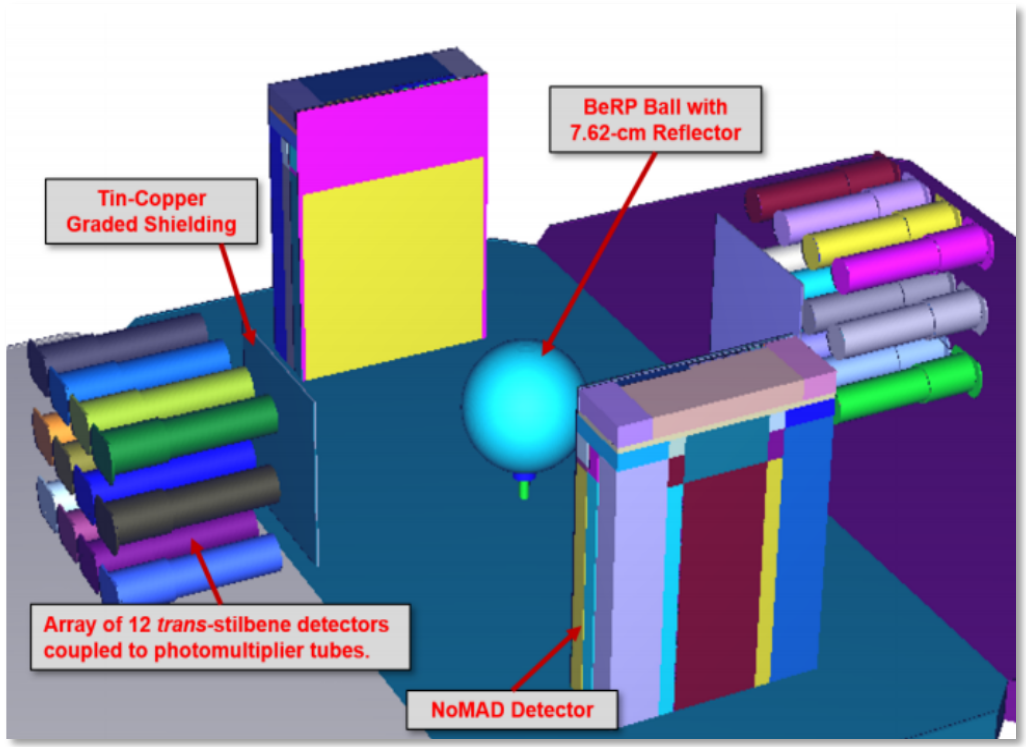
- Two 12 trans-stilbene scintillator arrays and two NoMAD detectors.



Process of independently simulating and comparing time-bin tail-fit and KCODE

Experimental and Simulation Setups

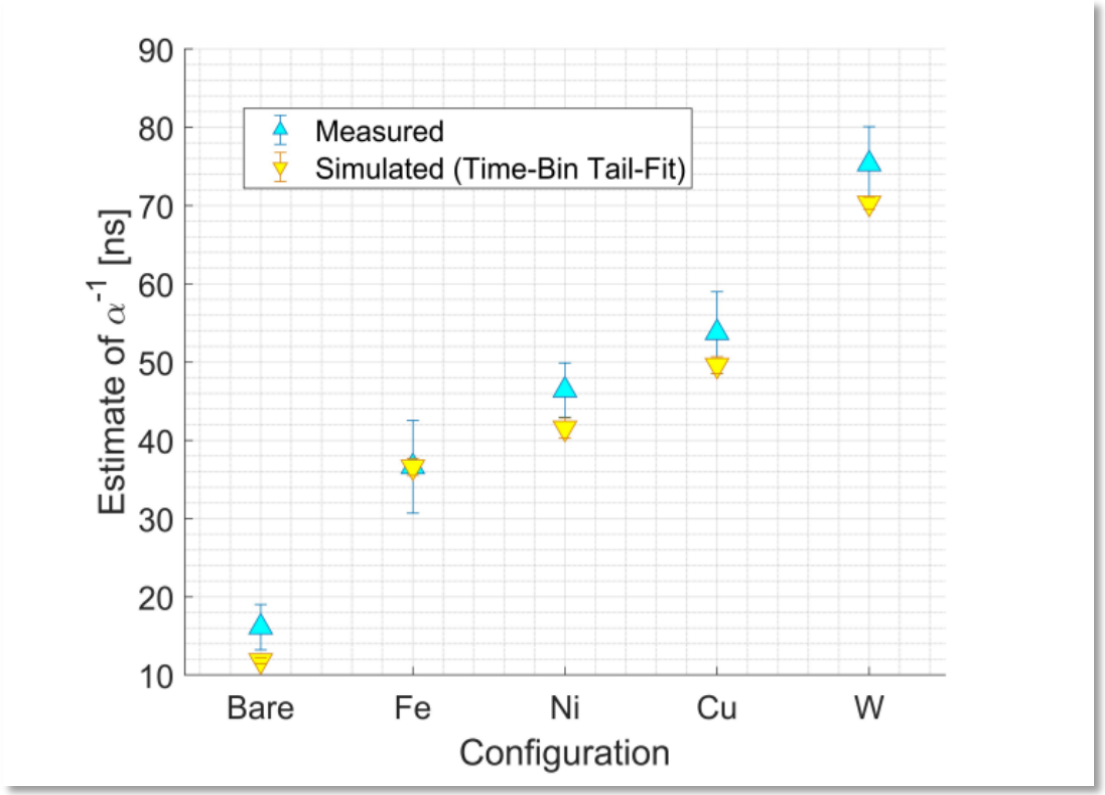




(Left) Experimental setup of 12 *trans*-stilbene detectors measuring the BeRP ball in five different reflectors for 30 minutes and (Right) MCNP model representative of all scenarios used to obtain two true/known values: an α value and a k_{eff} value.

Results

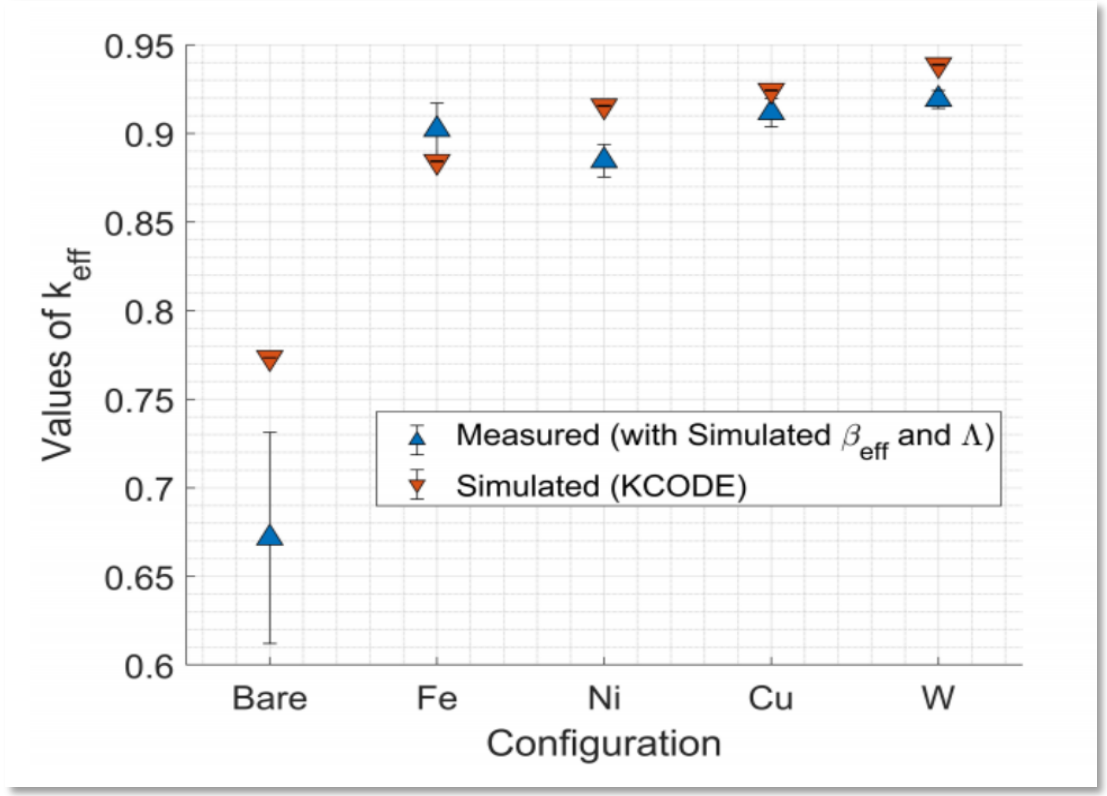
- Given as inverse alpha, α^{-1}, to compare units of time.
- Measured and simulated confidence intervals overlap as:
  - 1 σ: iron, copper, and tungsten cases
  - 1.02 σ: nickel case
  - 1.31 σ: bare case
- Overall, good agreement between α_{meas}^{-1} and α_{sim}^{-1}
- The measured value of α, KOPTS simulated values of β_{eff} and Λ are then used to estimate a measured value of $k_{eff,meas}$.



Comparison of time-bin tail-fit α_{meas}^{-1} and α_{sim}^{-1}

Results

- MCNP's KCODE criticality source card option was used to calculate $k_{eff,sim}$ and obtain uncertainty.
- The $k_{eff,meas}$ and the $k_{eff,sim}$ from KCODE simulations are compared.
- Measured estimates of k_{eff} are less than simulation calculated k_{eff} except for iron.
- Error and uncertainty in $k_{eff,meas}$ increases as $k_{eff,sim}$ decreases.
  - As expected, since the point kinetics model assumes $k_{eff} \approx 1$, and thus performs worse for more subcritical systems.



Comparison of KCODE $k_{eff,sim}$ and α with KOPTS $k_{eff,meas}$

Expected Impact

- If successful, this work will contribute to the phasing out of slower detections systems in favor for fast systems such as organic scintillators.
- Validation of the two exponential model opens the door to explore:
  - Various shielded and reflected assembly configurations.
  - Increasingly smaller masses to counter smuggling of SNM

Conclusion

- Performed analysis with the two-exponential Rossi-alpha model and found good agreement between measured and simulated values of α
- This work shows that organic scintillator-based systems are sensitive to fast assemblies.
- Organic scintillators should replace ^{3}He in fast metal applications.
- The two-exponential model adequately describes physical phenomenon using two region point kinetics.

Next Steps

- Validating the model for both ^{3}He-based and organic scintillator-based systems for general reflectors.
- Comparison of ^{3}He-based and organic scintillator-based detection systems in time-correlated, microscopic neutron noise methods.

MTV Impact

- Funded my work across several projects
- Provided the opportunity to be a summer fellow
- Connected me with LANL for an internship
- Allowed me to follow the development of organic scintillator capabilities at NCERC

Acknowledgements

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