IER 501: Pulsed Neutron Die-Away Experiments at LLNL

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Why PNDA for TSL Validation?

- Does not require fissile material
  - Non-nuclear facilities, reduced costs, fewer regulations, safer

- Very simple target shapes and compositions
  - Reduced uncertainties in benchmarks
  - Reduced material costs
  - Easy to change temperature

- Only sensitive to absorption and scattering of target medium
  - Reduces uncertainties from other nuclear data and compensating effects
  - Tune target size to vary effect of absorption vs. scattering

- Well conducted experiments have uncertainties of 0.1% - 0.5%
Pulsed Neutron Die Away Experiments

1. Inject Pulse of Neutrons
2. Neutrons thermalize
3. Neutrons spatially equilibrate
4. Measure exponential decay in fundamental mode
5. Fit exponential decay for integral parameter

\[ \phi(t) = \phi_0 \exp(-\alpha t) + R \]
Sensitivity to TSLs

- Example: Historical water experiment in cylindrical geometry

![Figure: α vs. Buckling curve for experimental and simulated data](image1)

![Figure: Bias of simulations without TSLs, with ENDF/B-VII.1, and with ENDF/B-VIII.0 TSLs](image2)
FY22 PNDA Experiments

- CED-2, CED-3a, CED-3b written in FY22
- Benchmark experiments with high density polyethylene (HDPE) and Lucite
- 22 individual experiments with varying target sizes
- Conducted over one week in low-scatter facility at LLNL
HDPE Die-Away Curves

Figure: HDPE cylinders used in PNDA experiment

Experimental

MCNP6.2

Counts

Counts (a.u.)

Time (ms)

Time (ms)
First HDPE Validation

- General trend of increasing bias with smaller sampler size (larger buckling)
Lucite Results
Polymethyl Methacrylate

Figure: Lucite cylinders used in PNDA experiment

![Lucite cylinders used in PNDA experiment](image_url)

![Graph showing α₀ vs. Buckling](image_url)

![Graph showing (C-E)/E vs. Buckling](image_url)
Support to ORNL TSL Validation

- Kemal Ramic at ORNL currently evaluating Lucite and HDPE TSLs for NCSP
- Preliminary PNDA results providing validation information
- New Lucite evaluation shows improvement vis. ENDF/B-VIII.0
- HDPE shows slight poorer performance
FY23 Benchmarking Efforts

Figure: Detailed modeling of detector effects

Figure: Detailed modeling of generator and box scattering effects
Timeline

Q2 FY23
Prepare Benchmark Evaluation

Q3 FY23
Prepare Benchmark Evaluation

Q4 FY23
New Experiments in $H_2O$, $D_2O$

FY24
Prepare Benchmark Evaluation
Questions, Comments, Discussion

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Integral Parameter: $\alpha$ eigenvalue

$$\phi(t) = \phi_0 \exp(-\alpha t) + R$$

$$\alpha = \bar{\nu} \Sigma_a + \bar{\nu} D_0 B_0^2 - C B_0^4 + \cdots$$

- $\alpha$: flux decay-time eigenvalue [s$^{-1}$]
- $D_0$ [cm$^2$-s$^{-1}$] is the asymptotic diffusion coefficient
- $C$: “cooling coefficient” [cm$^2$]
- $B_0^2$: geometric Buckling [cm$^{-2}$]
- $\nu$ thermal neutron velocity ($2.2 \times 10^5$ cm/s)
- $\Sigma_a$ macroscopic absorption cross section [cm$^{-1}$]

Figure: Example of pulsed-die-away curve modeled in MCNP
Decay to Fundamental Mode
Large Cylindrical Sample

\[ \phi(r, \theta, z, t) = \sum_{l,m,n} C_{l,m,n} \sin\left(\frac{n\pi}{H} z\right) J_l(a_{l,n} r) \cos l\theta \exp\left[-\left(\nu \Sigma_a + \nu D_0 B_{n,m,l}^2\right) t\right] \]

Focusing only on modes of Bessel function:

Fundamental Mode

- \( t = 0.000 \text{ ms}, Z = H/2, \theta = 0 \)

Spatial Modes \((l,m,n)\)
Effect of Shielding Box
Measurements in Low-Scatter Facility
Sensitivity Depends on Target Size

- Small targets (large Bucklings) are more sensitive to scattering
- Large targets (small Bucklings) are more sensitive to absorption

\[ B_0^2 = \left( \frac{\pi}{H + 2\delta} \right)^2 + \left( \frac{2.405}{R + \delta} \right)^2 \]

\[ \alpha = \overline{v\Sigma a} + \overline{vD_0} B_0^2 - CB_0^4 \]

Absorption  Scattering

Figure: Buckling vs. cylinder dimensions
Figure: $\alpha$ vs. cylinder dimensions
Interpretation of Results

- Need to select data to include in the fit

- Too early data:
  - Flux is not fully thermalized or in fundamental spatial mode

- Too late data:
  - Noisy (room return) and larger uncertainty in $\alpha$

$$\phi_{fit}(t) = \phi_0 \exp(-\alpha t) + R$$

$$\chi^2 = \sum_i \left( \phi_{data}^{(i)} - \phi_{fit}^{(i)} \right)^2$$

Figure: Position of the analyzed time interval
Algorithm

- Neutron counts and generator trigger recorded as list mode data
- Few counts per pulse, but many pulses allows to reconstruct die away curve
- Trigger is initiating event, \( t_{\text{trigger}} \)
- Sum counts in bins on die away curve as \( t_{\text{tag}} - t_{\text{trigger}} \) in histogram
Algorithm: Sum pulse counts to construct curve