DOSE CALIBRATION OF THE ISS-RAD FAST NEUTRON DETECTOR (FND)

Cary Zeitlin on behalf of the ISS-RAD Science Team
FND REQUIREMENTS & DESIGN

- Detect neutrons with energies from 0.5 to 8 MeV.
- Report dose equivalent to within ± 10% accuracy in known AmBe field — very stringent.
- Considered designs with $^3$He tubes, or MSL-RAD with enlarged “E” detector (plastic scintillator).
- Boron-loaded plastic scintillator with PMT readout was chosen.
NEUTRON DETECTION WITH BORON-LOADED SCINTILLATOR

- Use capture-gating method, that is, 2-pulse coincidence.
- First pulse from recoil interaction(s) that thermalize the incident neutron.
- Second pulse within ~ few microseconds when thermalized neutron is captured by $^{10}\text{B}$ which then fissions into $^4\text{He} + ^7\text{Li} + \gamma$
- For H recoils, amplitude of first pulse is ~ proportional to energy of incident neutron.
In 0.5 to 10 MeV range, cross sections are comparable, ~ 1 to 3 barns, so ~ equal numbers of interactions on both nuclei. But ~ 0 light output from low-energy neutrons on carbon.

At higher energies carbon recoils become detectable.
BAD NEWS/GOOD NEWS

- The bad news: Inherent resolution is not very good — there are many ways to form the first pulse (H recoils, C recoils, inelastic reactions, variable numbers of recoils).

- Resolution gets worse above a few MeV largely due to carbon recoils.

- The good news: Even with poor resolution, dosimetry is sufficiently accurate.
**HOW TO USE AMPLITUDE DISTRIBUTION FOR DOSIMETRY?**

- Blue curve: ISO AmBe spectrum
- Black curve: AmBe spectrum with efficiency (early JSC Monte Carlo simulation).
- Simulated energy spectrum after smearing.
BASIC IDEA FROM BYRD & URBAN (LANL REPORT)

- Average amplitude of recoil pulse goes as $\sim E^{1.6}$ where $E$ is the incident neutron energy.
  - Caveat: this seems to only hold for H recoils.

- Associate a given amplitude with a neutron energy by $E \sim A^{(1/1.6)}$. This will be right on average if H recoils dominate.

- Fluence to dose equivalent is weakly dependent on $E$ in this range, so errors/poor resolution may not be critical.
RECIPE

- Measure amplitude and use rough approximation to convert to E.
- PTB calibration data gives us efficiency vs. E curve.
- ICRP 74 gives us fluence to H conversion factors as a function of neutron E.
- We can make a function that incorporates all factors and goes from amplitude to H.
BACKGROUNDS

- Two main types of background: chance coincidence & room return.
- Chance coincidence background is determined from spectrum at large $\Delta t$ between first and second pulse.
  - Neutron capture $\Delta t$ distribution is exponential, background is flat.
- Room return is determined from shadow-bar runs.
PTB RECOIL AMPLITUDE DATA

- Make reasonable cuts on capture pulse amplitude & timing, subtract backgrounds.
- Note log-log scales.
- Peaks for lowest energies are well defined but broaden with increasing neutron energy and long tails to low end develop.
FIT PEAKS

- Get expected exponent of \(~1.6\).
- Calibration with this curve yields underestimate of dose equivalent because it ignores the low-end tails in the recoil distributions.
Using means instead of peaks, the power-law exponent decreases from 1.62 to 1.44.

8 MeV data point does not fall on the curve.
EFFICIENCY CURVE

- Initially used power-law fit (red curve) for efficiency vs. energy.
- Inverse form fits better:
  \[ \varepsilon = \varepsilon_0 + \frac{k_1}{E} + \frac{k_2}{E^2} \]
Use ICRP 74, Table A.42 $H^*(10)/\Phi$ for the ICRU sphere.

~ flat over most of the FND range but consider what happens if neutron energy is underestimated.
Method 1 uses fit to peaks \((E^{1.62})\), method 2 uses means \((E^{1.44})\).

Blue curves: power-law fits for comparison, actually use polynomials shown in green.
AmBe DATA

- Distribution of time between first and second pulse ($\Delta t$) fit by exponential + constant.

- Short $\Delta t$ dominated by source neutrons, long $\Delta t$ dominated by chance coincidence.

- In offline analysis, subtract scaled background from signal.

- In onboard cyclic analysis, use the whole $\Delta t$ range $\rightarrow$ need a different conversion function.
Thanks to Martin Leitgab for calculating the expected “true” rates corresponding to the real FND energy range.

Method 1 underestimates H rate for AmBe beyond acceptable error.

Method 2 is reasonably close for both.

There is clearly a systematic issue relating to amplitude-to-energy conversion but we do not need to address it to meet the accuracy requirement.
CYCLIC ANALYSIS

- Same procedure but without subtracting the long-$\Delta t$ background. Repeat for all QMN beams.
- Get a different efficiency curve and a different counts to pSv conversion function.
- Apply to AmBe data.

<table>
<thead>
<tr>
<th>Method</th>
<th>AmBe H*(10) Rate</th>
<th>$^{252}$Cf Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>True Rate = 0.708 $\mu$Sv/min</td>
<td>True Rate = 0.495 $\mu$Sv/min</td>
</tr>
<tr>
<td>1</td>
<td>0.606 $\mu$Sv/min</td>
<td>1.047 $\mu$Sv/min</td>
</tr>
<tr>
<td>2</td>
<td>0.673 $\mu$Sv/min</td>
<td>1.091 $\mu$Sv/min</td>
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</table>
CONCLUSIONS

- Relatively simple analysis method meets accuracy requirement for AmBe dose equivalent in both analysis modes (ground and onboard).
- Accuracy of neutron spectrum obtained by this method is questionable due to complexity of the mechanisms that create the recoil pulse.
- Unfolding in some form is likely to yield improved accuracy.