Photoneutron Source Characterization and Neutron Simulations

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Low Energy Calibration Workshop
Photoneutron Sources and Simulations

- Portable
- Monochromatic
- Low-energy
- $10^5 - 10^6$ photons/neutron

FIG. 5. Simulated response of a small LXe detector to an $^{88}$Y/Be source (nuclear recoil energies in keV$_{nr}$, electron recoil energies from gamma component in keV$_{ee}$). A very similar spectral response to low-mass WIMPs like those of present interest is shown, normalized to an arbitrary cross section.
## Radioisotope / beryllium sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Half-life</th>
<th>Photons</th>
<th>Neutron Energy</th>
</tr>
</thead>
</table>
| $^{226}\text{Ra}$ | 1600 y | 1764 keV (15.3 %)  
2204 keV (4.92 %)  
others (9.69 %) | 89 keV  
479 keV |
| $^{124}\text{Sb}$ | 60.2 d | 1691 keV (47.6 %)  
2091 keV (5.49 %)  
others (0.52 %) | 23.5 keV  
379 keV |
| $^{88}\text{Y}$ | 106.6 d | 1836 keV (99.9 %)  
2734 keV (0.71 %) | 152 keV  
950 keV |
| $^{207}\text{Bi}$ | 31.6 y | 1770 keV (6.87 %) | 94 keV |
Photoneutron Calibrations

- Need
  - Well defined energy spectrum
  - Absolute recoil rate
- Measure source yield
- Minimize moderator
- Understand neutron recoil response.
The NIST calibrated neutron source is a 1 Ci $^{226}$Ra/Be photoneutron source.
Photoneutron History

- Measurements of $^9\text{Be}(\gamma,n)$ cross-section
  - 1940-60's & 1982: Radioisotopes.
  - 1960-70's: Bremstrallung photons, charged particle scattering.
A selection of existing measurements

- Fujishiro et al. (1982)
- Other radioisotope measurements
- Arnold et al. (2012)
- Burda et al. (2010)
- Barker (2000)
- Berman et al. (1967)
Reanalyzed radioisotope measurements and corrected for:

- Branching ratios
- Detector efficiencies (using modern MCNP simulations)

Fitted to Breit-Wigner resonance parameters:

\[ E_n = 1738.8 \text{ keV}, \Gamma_n = 268.7 \text{ keV}, \Gamma_\gamma = 0.7715 \text{ eV} \]
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$^9\text{Be}(\gamma,n)$ Cross-section

Gibbons et al. (1959)
John and Prosser (1962)
Snell et al. (1950)
Fujishiro et al. (1982)
Arnold et al. (2012)
Barker (2000)

Fit to radioisotope measurements

Cross-section (mb)

Photon Energy (MeV)
Source Yield

- Calculated from known cross-sections
  - 0.659 mb at 1836 keV
  - 1.397 mb at 1691 keV
  - 955 mb at 1770 keV
- Directly measured using He-3
Photoneutron emission from $^9$Be radioisotope sources is isotropic in the rest frame.

- Energy-angle dependence in the lab frame.
  - $\pm6\%$ spread in Sb/Be neutron energy.

Photoneutron yield and energy spectrum depend on the source geometry.

- Diminishing returns on yield of unmoderated neutrons for Be or BeO thickness >1cm.
Source Design

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Large yield sensitivity to BeO – $^{88}$Y distance.

Low yield uncertainty
Larger spread of neutron energies

Configuration 1
14.87 g BeO
0.92
1.327

Configuration 2
16.29 g BeO
1.02
1.327

Configuration 3
106.32 g BeO
0.92
2.30

Type-D source
0.25
0.277
1.27
0.635

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Energy degradation in BeO may be subdominant to other moderators.
Source Design

- If using a lead shield
  - Surround the source with lead on all sides so that lead is a diffuser instead of a reflector.
Libraries for both MCNP and Geant4 incorrectly describe the angular distribution from neutron scattering for most isotopes.

- Problem not applicable to oxygen and lighter.
- New libraries for F, Si, Ar, Cr, Fe, and Pb are available. PRC 89 032801 (2014).
Figure 3. Simulated neutron energy spectra from an $^{88}\text{Y}/\text{Be}$ surrounded by 20 cm of lead as used in the ongoing XCD experiment at Fermilab (see text).
Figure 2. Simulated nuclear recoil distributions from 97 keV neutrons on C$_3$F$_8$ in the PICO-0.1 bubble chamber calibration experiment. The calibration of the detector’s bubble nucleation efficiency depends critically on the number of recoils at the endpoint of the simulated nuclear recoil distribution. A factor of 2 discrepancy is found between the R-matrix calculation used in this library release and ENDF/B-VII.
Neutron Recoils

- Recoil spectrum uncertainties
  - Cross-section uncertainty
  - Resonance parameter uncertainty
  - Unresolved resonances
Extra slides
Neutron Elastic Scattering

- Resonances from compound states
- Continuum from potential scattering
Breit-Wigner Resonances

- Parameterized by
  - Resonance widths
  - Neutron Energy
  - Spins
  - Parity

- Interference handled by R-matrix formalism
Recalculating $d\sigma/d\Omega$

- Dipole term of scattering angle distribution vs. energy