Characterization of an $^{241}$AmBe neutron irradiation facility by different spectrometric techniques

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Introduction and Objectives

- An automated panoramic irradiator with a 111 GBq (3 Ci) $^{241}$Am-Be neutron source is installed in a bunker-type large room (16.25 m long, 8.90 m width, 8 m high) at UPM.
- The irradiation bench is placed at 3 m from the floor and at about 4.5 m from any lateral wall.
- A neutron spectrometry campaign was organized with four groups participating with different Bonner Sphere Spectrometers (BSS) and using different spectral unfolding codes.
- The objective is to better characterize the facility, but also the intercomparison itself.
General view of the facility. The red circle indicates the position of the source. The source operation is fully automated and remote controlled.
Ludlum-BSS: Six spheres of high-density polyethylene* with diameters: 2”, 3”, 5”, 8”, 10” and 12”.
* $d = (0.96 \text{ g/cm}^3)$ Determined from weight and volume measurements

Central Detector: Scintillator crystal of Li$^6$I(Eu) of small size 0,4 Ø x 0,4 cm.

Electronics: Data acquisition: ASA-100, HT= 800 V. Pre-amp: ORTEC, mod 109PC Preamplifier, X1
Software: Genie 2000
BUNKIUT code with the response matrix UTA 4, 25 energy bins (collapsed from 171).

Uncertainties not explicitly addressed

Response Matrix (Hertel & Davidson, 1985)

Fig. 1. The calculated 171-neutron group responses for the 4 mm LiI detector and the detector inside 5.08, 7.62, 12.7, 20, 30.48, 38.1 and 45.72 cm diameter polyethylene spheres.
SDD = 115 cm

Energy [MeV]

10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}

$E \Phi(E)$ [cm$^{-2}$·A$^{-1}$]

10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}

Experimental  Monte Carlo
**Spheres: diameters:** bare, 2”, 3”, 5”, 7”, 8”, 10”, 12”, 12”+Pb (8 cm internal diameter, 1 cm lead) 7”+Pb (4” internal diameter, 1/2” lead)

**Density:** 0.95 g.cm$^{-3}$

**Central detector:** 4x4 $^6$LiI(Eu)

**Unfolding method:** FRUIT 3.0 (NIM A 580 1301-1309)
INFN - BSS Response matrix
MC code used: MCNPX 2.4.0

Validation experiments
BSS response matrix overall uncertainty $u_{mat} \ (\pm 3\%)$

1) Determined with irradiations in continuous reference fields (Am-Be, Cf, Cf(D$_2$O), thermal) at ENEA Bologna in 2005 - 2006

2) Confirmed with monochromatic beams at JRC-Geel (2 MeV, 5 MeV, 16 MeV) in Jan 2006

3) Results of monochromatic beams at PTB, March 2009 (24 keV, 144 keV, 1.2 MeV, 8 MeV, 19 MeV) under elaboration
Installation: 1 Ci Am-Be source (INFN-LNF) calibrated at NPL in 1986 and certified with less than 1% uncertainty.

Method: Shadow-cones with cones specifically designed for this BSS
FRUIT 3.0 (Nucl. Instr. and Meth. A, 580, 1301-1309. 2007)

Uncertainty treatment  YES

Pre-information  Based in physical environment related to neutron production physics

Validation  YES
- reference sources
- GSI comparison (2006)
- counting
- anisotropy about cylindrical axis
- 0° / 90° anisotropy

- BSS response matrix overall uncertainty
- BSS calibration & time stability
- Unfolding procedures
  - Fluence
  - H*(10)

- fluence-to-H* average conversion coefficient

**Disregarded:** height of the source, measurement distance (~ 0.1%)
Spheres:
Diameters: 2.5”, 3”, 4.2”, 5”, 6”, 8”, 10”, 12”, 2.5”+Cd, 3”+Cd, 4.2”+Cd
Polyethylene density: 0.95 g·cm⁻³

Central detector characteristics:
05NH1 from Eurisys. \(^3\)He filled proportional counter at 8 kPa pressure.
cylindrical 9 mm x 10 mm.

Unfolding method and references
FRUIT 3.0 unfolding code
Nucl. Instr. and Meth. A 580, 1301-1309. 2007
• counting < 1.5%
• geometry (negligible)
• anisotropies ~ 2%
• BSS response matrix (simulation) < 1%
• BSS calibration ~ 3%
• BSS time stability 0.2% in 12 h
• unfolding < 2%
• Fitting method 2%

Resulting fluence: < 5%
MC code used: MCNPX 2.4.0 and 2.5.0

Validation experiments:

PTB (mononenergetic 250 keV, 565 keV, 1.2 MeV, 2.5 MeV, 5 MeV, 14.8 MeV)

IRSN Cadarache (AmBe, Cf, Cf+D₂O/Cd, SIGMA)

Uncertainty < 3%

BSS calibration

April-May 2006, Am-Be and Cf sources at IRSN Cadarache.

Routine check of the BSS working point

Not routinely. Sporadic checks.

AmBe Frascati March 2008
CIEMAT-BSS: 12 spheres of high density polyethylene with dimensions: 3”, 3.5”, 4”, 4.5”, 5”, 6”, 7”, 8”, 9”, 9.5”, 10” and 12”.

Central detector is a SP9 $^3$He spherical proportional counter
Pressure: 228.5±2.0 kPa
Voltage: 800V

Unfolding method: UMG 3.3 package (MAXED+GRAVEL)
- Counting uncertainty less than 1%
- Geometry uncertainty is not considered.
- Anisotropies uncertainties
- BSS response matrix uncertainty not directly considered.
- BSS calibration uncertainty not considered too.
- Unfolding uncertainty considered in determination of neutron fluence and \( H^*(10) \) less than 0.5%
Response function (RF) determined by PTB.

- MC code used: MCNP with corrections for PE density and geometry dimensions of spheres.
- Calibrated at PTB (June, 2007) with a reference $^{252}$Cf source calibrated at NPL.
- Validated using monoenergetic neutrons with energies: 144keV, 565keV, 2.5MeV and 15MeV.
• **UMG3.3** unfolding pack has been employed: **GRAVEL** and **MAXED** consecutively and **IQU** for statistical analysis.

• Input data:
  • CIEMAT-BSS RF
  • Cf spectrum as initial spectrum
  • Measurements

• Output data:
  • Output spectrum expressed in 20 energies by decade
  • Fluence rate
  • H*(10)
- Thermal component practically constant and independent of the source-detector distance.
- For epithermal and fast components the shape of the spectra and their values are quite similar.
RESULTS - SPECTRUM

Normalized spectra (per unit fluence) obtained by the four groups for 115 cm distance point
Total neutron fluence rate obtained at 100 cm, 115 cm and 150 cm from the source

\[ \dot{\phi} = \int_{E} \Phi_E (E) \, dE \]

<table>
<thead>
<tr>
<th>Distance</th>
<th>100 cm</th>
<th>115 cm</th>
<th>150 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPM-UAZ</td>
<td>62 ± 2</td>
<td>49 ± 2</td>
<td>33 ± 1</td>
</tr>
<tr>
<td>INFN</td>
<td>61 ± 3</td>
<td>49 ± 2</td>
<td>32.8 ± 1.2</td>
</tr>
<tr>
<td>UAB</td>
<td>64.1 ± 2.6</td>
<td>49.9 ± 2.0</td>
<td>34.1 ± 1.4</td>
</tr>
<tr>
<td>CIEMAT</td>
<td>64.3 ± 0.3</td>
<td>50.1 ± 0.2</td>
<td>31.8 ± 0.1</td>
</tr>
</tbody>
</table>
Ambient dose equivalent obtained at 100 cm, 115 cm and 150 cm from the source

\[ \dot{H}^* (10) = \int_{E} \Phi_E (E) h^* (10) \, dE \]

<table>
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<tr>
<th>Distance</th>
<th>100 cm</th>
<th>115 cm</th>
<th>150 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPM-UAZ</td>
<td>77.5 ± 2.3</td>
<td>59.8 ± 1.8</td>
<td>37.3 ± 1.1</td>
</tr>
<tr>
<td>INFN</td>
<td>77 ± 6</td>
<td>61 ± 5</td>
<td>37 ± 3</td>
</tr>
<tr>
<td>UAB</td>
<td>80.5 ± 5.6</td>
<td>61.8 ± 4.3</td>
<td>40.0 ± 2.8</td>
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<tr>
<td>CIEMAT</td>
<td>75.9 ± 0.3</td>
<td>57.6 ± 0.2</td>
<td>35.1 ± 0.1</td>
</tr>
<tr>
<td>LB-6411 (UPM)</td>
<td>79.5 ± 0.6</td>
<td>61.3 ± 0.5</td>
<td>38.4 ± 0.8</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- The study has offered a good opportunity to compare results from a set of different BSS, unfolding tools and experimental teams.
- The results were encouraging, showing a reasonable agreement with regard to the main quantities studied.
- However, the differences encountered should be explained, and the results consolidated.
- Relevant features to be determined are the source strength and its anisotropy.
  - Source strength determination is still work on progress.
  - Source anisotropy has been measured after this study using a device designed for this purpose.
- Monte Carlo calculations are being utilized to get a better understanding of the experimental results.
Acknowledgement

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