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Characterization of an 241AmBe neutron irradiation facility by different spectrometric techniques

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An automated panoramic irradiator with a 3 Ci ^{241}Am-Be neutron source is installed in a bunker-type large room at the Universidad Politécnica de Madrid (UPM). It was recently modified and a neutron spectrometry campaign was organized to characterize the neutron fields in different measurement points along the irradiation bench. Four research groups working with different Bonner Sphere Spectrometers (BSS) and using different spectral unfolding codes took part to this exercise.

INFN–LNF used a BSS formed by 9 spheres plus bare detector, with cylindrical, almost point like, 6LiI(Eu) scintillator (4 mm x 4 mm, from Ludlum); UAZ-UPM employed a similar system but with only 6 spheres plus bare detector; UAB worked with a ^{3}He filled proportional counter at 8kPa filling pressure, cylindrical 9 mm x 10 mm (05NH1 from Eurisys) with 11 spheres configuration; and CIEMAT used 12 spheres with an spherical ^{3}He SP9 counter (Centronic Ltd., UK) with very high sensitivity due to the large diameter (3.2 cm) and the filling pressure of the order of 228 kPa.

Each group applied a different spectral unfolding method: INFN and UAB worked with FRUIT ver. 3.0 [1] with their own response matrixes; UAZ-UPM used the BUNKIUT unfolding code with the response matrix UTA4 [2] and CIEMAT employed the GRAVEL-MAXED-IQU package [3] with their own response matrix.

The paper shows the main results obtained in terms of neutron spectra at different distances from the source as well as H*(10) determined from the spectra. These values are compared with the readings of a common active survey-meter (LB 6411).
In addition, the intensity of the source is estimated from the spectrometric measurements. The small differences in the results of the various groups are discussed.

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

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Abstract

An automated panoramic irradiator with a 3 Ci ^{241}Am-Be neutron source is installed in a bunker-type large room at the Universidad Politécnica de Madrid (UPM). It was recently modified and a neutron spectrometry campaign was organized to characterize the neutron fields in different measurement points along the irradiation bench. Four research groups working with different Bonner Sphere Spectrometers (BSS) and using different spectral unfolding codes took part to this exercise.

INFN–LNF used a BSS formed by 9 spheres plus bare detector, with cylindrical, almost point like, ^{6}LiI(Eu) scintillator (4 mm x 4 mm, from Ludlum); UAZ-UPM employed a similar system but with only 6 spheres plus bare detector; UAB worked with a ^{3}He filled proportional counter at 8kPa filling pressure, cylindrical 9 mm x 10 mm (05NH1 from Eurisys) with 11 spheres configuration; and CIEMAT used 12 spheres with an spherical ^{3}He SP9 counter (Centronic Ltd., UK) with very high sensitivity due to the large diameter (3.2 cm) and the filling pressure of the order of 228 kPa.

Each group applied a different spectral unfolding method: INFN and UAB worked with FRUIT ver. 3.0 with their own response matrixes; UAZ-UPM used the BUNKIUT unfolding code with the response matrix UTA4 and CIEMAT employed the GRAVEL-MAXED-IQU package with their own response matrix.

The paper shows the main results obtained in terms of neutron spectra at fixed distances from the source as well as total neutron fluence rate and ambient dose equivalent rate H*(10) determined from the spectra. The latter are compared with the readings of a common active survey-meter (LB 6411). The small differences in the results of the various groups are discussed.

Keywords: Neutron spectrometry; neutron dosimetry.

1. Introduction

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 the Universidad Politécnica de Madrid (UPM). It was recently modified to install a metrology bench with automated distance control (0.5 m – 1.5 m) and irradiation time with a pneumatic source transfer system. The irradiation bench is placed at 3 m from the floor and at about 4.5 m from any lateral wall (Fig. 1).

The ^{241}Am-Be source, had a nominal strength of $6.64\cdot10^{6}$ s^{-1} on February 5, 1969 (with no available data on the uncertainty and the determination method).

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To better characterize the neutron fields in different measurement points along the irradiation bench a neutron spectrometry campaign was organized in which four research groups working with different Bonner Sphere Spectrometers (BSS) and using different spectral unfolding codes participated. These groups were from CIEMAT (Ionizing Radiation Standard Laboratory LMRI), INFN-LFN (U.F. Fisica Sanitaria), Universitat Autonoma de Barcelona (UAB, Grup de Física de les Radiacions, Departament de Física) and the own Laboratory of UPM in cooperation with the Academic Unit of Nuclear Studies, Universidad Autónoma de Zacatecas (UAZ).

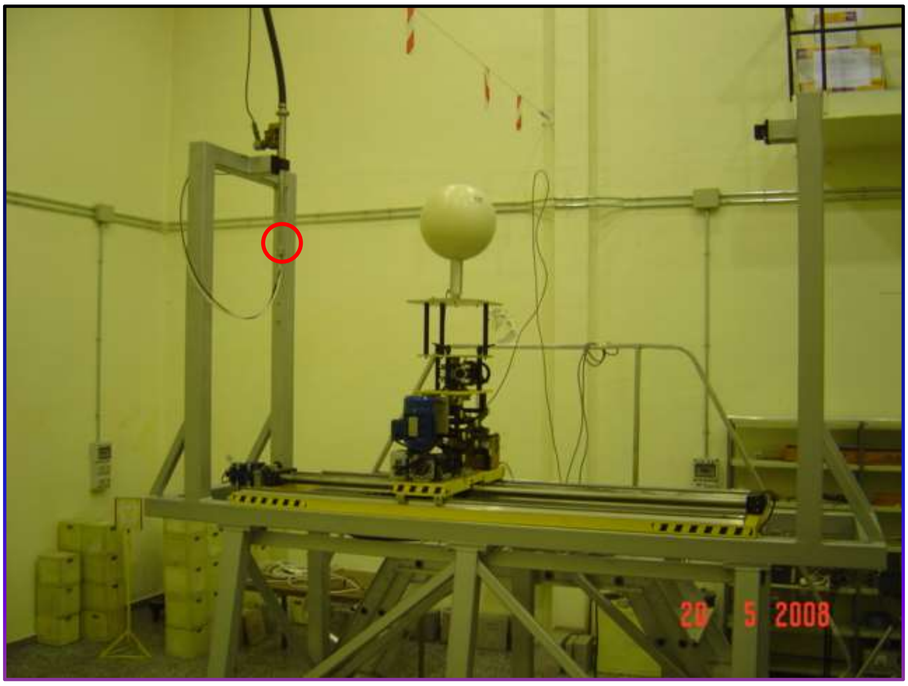

Figure 1. General view of the irradiation facility. The red circle indicates the position of the source. The source operation is fully automated and remote controlled.

2. Materials and methods

Each group used a different Bonner Sphere Spectrometer (BSS) and applied a different spectral unfolding method, as described in the following paragraphs. Counting uncertainties were kept below 1% for all the groups. Geometry uncertainty on measurement distance and height of the source above ground was not considered, becasue of its high reproducibility. Other uncertainties were taken into account, like in the response matrix or in the calibration of instruments. However, the main one was the anisotropy of the source which was unknown at the moment of performing the experiments.

2.1. UPM-UAZ

UPM-UAZ group used a Ludlum Measurements BSS with 6 spheres (2”, 3”, 5”, 7”, 8”, 10”, 12” diameter) and the bare detector (4 mm x 4 mm ^{6}LiI(Eu) scintillator) (Fig. 2). The polyethylene spheres have a density of 0.96 ± 0.01 g·cm^{-3}, which was determined by weight and volume measurements. The unfolding method utilized was an iterative procedure with the SPUNIT algorithm [1] in the BUNKIUT code [2] with the response matrix UTA-4, with 31 energy bins (collapsed from 171) [3]. Uncertainties in the response matrix were not explicitly addressed.

Figure 2. The UPM BSS and the ^{6}LiI(Eu) detector unmounted (left).

2.2. INFN

The BSS of the INFN-LNF Frascati National Labs. (Fig. 3) has a central detector of 4 mm x 4 mm ^{6}LiI(Eu) scintillator from Ludlum Measurements. It uses polyethylene spheres with a density 0.950 g·cm^{-3} of the sizes 2”, 3”, 5”, 7”, 8”, 10”, 12”, plus the bare detector and two additional spheres with 7” polyethylene + 1.27 cm Pb and 12” polyethylene + 1 cm Pb, respectively. The BSS response matrix was calculated with MCNPX 2.4.0. It was validated experimentally to have an overall uncertainty of ± 3% determined with irradiations in continuous reference fields (Am-Be, Cf, Cf(D_2O), thermal) at ENEA, Bologna, and confirmed with monochromatic beams at JRC-Geel (2, 5 and 16 MeV) and at PTB (24 keV, 144 keV, 1.2 MeV, 8 MeV, 19 MeV). As far as the metrological traceability of the INFN measurements is concerned, the BSS spectrometer was calibrated and its calibration is traceable, within 2%, to a ^{241}Am-Be source calibrated at NPL with state-of-art techniques. The calibration factor value (May 2007), is routinely verified by means of a reproducibility check device allowing exposing the scintillator to the neutron field produced by a moderated 0.1 Ci ^{241}Am-Be source in fixed geometry (geometric repeatability 0.1%) (Fig. 3, right). For the UPM campaign this value was checked before and after the trip to Madrid.

Figure 3. The INFN BSS: bare, 2”, 3”, 5”, 7”, 7”+Pb (4” int. diameter, 1/2” lead), 8”, 10”, 12”, 12”+Pb (8cm int. diameter, 1cm lead). Polyethylene density 0.95 g·cm^{-3}. At the right, the reproducibility check device.

The unfolding code used by INFN was FRUIT (Frascati Unfolding Interactive Tool) ver. 3.0 [4] in “parametric mode”. It is an unfolding code that models a generic neutron spectrum as the superposition of up to four components (thermal, epithermal, fast and high energy), fully defined by up to seven positive parameters. Different physical models are available to unfold the sphere counts, covering the majority of the neutron spectra encountered in workplaces. The iterative algorithm uses Monte Carlo methods to vary the parameters and derive the final spectrum as limit of a succession of spectra fulfilling the established convergence criteria. Uncertainties on the final results are evaluated taking into consideration the different sources of uncertainty affecting the input data.

2.3. UAB

UAB worked with a ^{3}He filled proportional counter at 8kPa filling pressure, cylindrical 9 mm x 10 mm (05NH1 from Eurisys) with 11 spheres configuration: bare, 2.5”, 3”, 4.2”, 5”, 6”, 8”, 10” and 12” + Cd shell for covering the three smallest spheres (total of 11 configurations, Fig. 4). The polyethylene density is 0.95 g·cm^{-3}.

Figure 4. The UAB BSS. At the right, the 4.2” sphere with cadmium shell during measurement.

The unfolding method was also FRUIT (as INFN). The response matrix was calculated with MCNPX 2.4.0 and 2.5.0 and validated with experiments at PTB (mononergetic 250 keV, 565 keV, 1.2 MeV, 2.5 MeV, 5 MeV, 14.8 MeV) and IRSN Cadarache (Am-Be, Cf, Cf+D_2O/Cd and SIGMA facility). Its overall uncertainty is lower than 3%. The BSS was calibrated with ^{241}Am-Be and ^{252}Cf sources at IRSN Cadarache.

2.4. CIEMAT

The LMRI from CIEMAT used 12 spheres with a spherical ^{3}He SP9 counter (Centronic Ltd., UK) with very high sensitivity due to the large diameter (3.2 cm) and the filling pressure of 228±2.0 kPa. The CIEMAT-BSS response matrix was determined at PTB. The MCNP5/MCNPX codes were used applying corrections to take into account the polyethylene density (0.955 g·cm^{3}) and geometric dimensions of the spheres. Validation experiments were performed at PTB using monoenergetic neutrons with energies 144keV, 565keV, 2.5MeV and 15MeV. Also, the system was calibrated at PTB with a reference ^{252}Cf source, calibrated at NPL by the Mn bath technique.

The unfolding method used was the UMG 3.3 package (MAXED+GRAVEL) [5], which explicit treatment of uncertainty. The method needs a physical model as pre-information, and ^{252}Cf spectrum was selected.

Figure 5. The CIEMAT BSS: bare, 3", 3.5", 4", 4.5", 5", 6", 7", 8", 9", 9.5", 10" and 12". Polyethylene density, determined by PTB: average 0.955 g·cm^{-3}.

3. RESULTS

The results obtained included neutron spectra as well as neutron fluence rate $\dot{\Phi}$ and ambient dose equivalent rate $\dot{H}*(10)$ at one reference point on the irradiation bench. Some "blind results" are showed below. Uncertainties presented by INFN and UAB include all relevant causes of uncertainty: counting, overall response matrix uncertainty, source anisotropy, detector response variability with time, calibration factor and unfolding procedure. UPM-UAZ and CIEMAT only considered uncertainty of counting and of the unfolding procedure.

Figure 6 illustrates the kind of obtained neutron spectra. Only the 115 cm distance results are shown, comparing the four groups' estimations. The spectra are expressed per unit lethargy. In all cases it can be observed a dominance of the fast region components, as it corresponds to the uncollided ^{241}Am-Be source spectrum. The thermal region component is also quite similar for all the groups, responding to the neutron scattering in the material elements of the facility, mainly in walls and ground of the hall. However, the CIEMAT thermal region shows a distribution slightly displaced to higher energies, which may deserve some analysis, since it must be probably due to the deconvolution method used.

To better study the experimental results, UPM-UAZ also performed Monte Carlo calculations with MCNP5 code [6], after developing a very detailed model of the irradiation facility. The comparison between the experimental-unfolded and the calculated spectrum for the 115 cm reference point is displayed in Figure 7. Both spectra look reasonably close, although there are some differences in the intermediate energy region, which the spectrometry and deconvolution method used is not able to adjust.

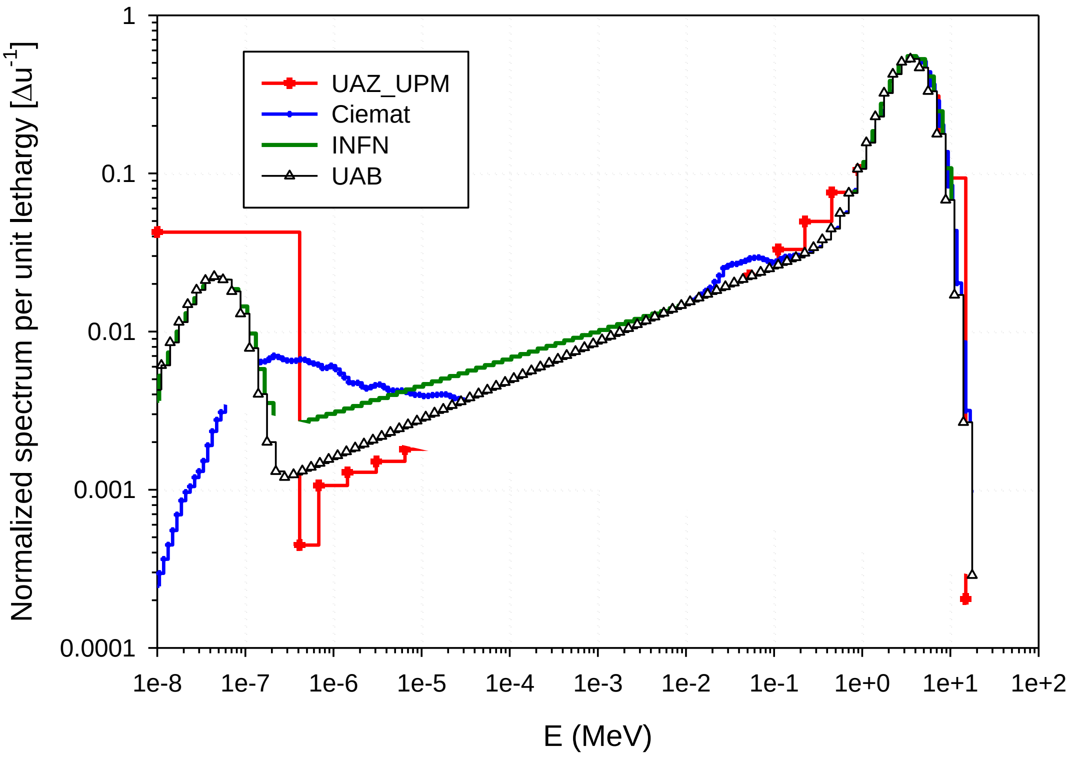

Figure 6. Graphical comparison of the normalized spectra obtained by the four groups for 115 cm distance point.

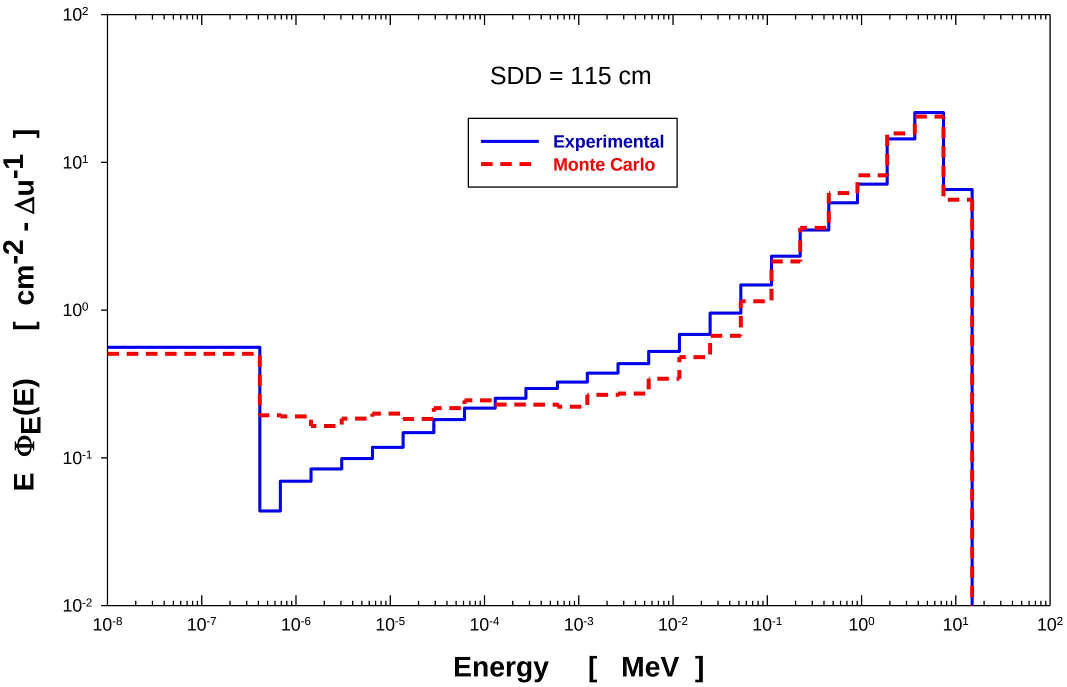

Figure 7. Comparison between experimental (UPM-UAZ) and calculated (MCNP5) spectra at the 115 distance point.

3.1. Neutron fluence rate

From the spectral distribution of the neutron fluence rate, one can obtain the total neutron fluence rate as the energy integral of the neutron fluence rate: $\dot{\phi} = \int_E \dot{\Phi}_E(E)\, dE$. Table 1 summarizes the results obtained by each group. As main comment it can be said that they look very consistent.

Table 1. Total neutron fluence rate obtained at 100 cm, 115 cm and 150 cm from the source.

Distance	100 cm	115 cm	150 cm
	Total neutron fluence rate, Φ ($cm^{-2}\cdot s^{-1}$)		
UPM-UAZ	62 ± 2	49 ± 2	33 ± 1
INFN	61 ± 3	49 ± 2	32.8 ± 1.2
UAB	64.1 ± 2.6	49.9 ± 2.0	34.1 ± 1.4
CIEMAT	64.3 ± 0.3	50.1 ± 0.2	31.8 ± 0.1

3.2. Ambient dose equivalent

Ambient dose equivalent can also be obtained from the spectral distribution of the neutron fluence rate, as $\dot{H}^*(10) = \int_E \dot{\Phi}_E(E)\; h^*(10)\; dE$, where *h*(10)* are the fluence to ambient dose equivalent conversion coefficients recommended in ICRP74 [7]. The obtained values are indicated in table 2. They are compared with the values obtained with the reference instrument of the Laboratory, a Berthold monitor model LB-6411, calibrated at PTB. As it can be concluded, the results are consistent in general.

Table 2. Ambient dose equivalent rate obtained at 100 cm, 115 cm and 150 cm from the source.

Distance	100 cm	115 cm	150 cm
	Ambient dose equivalent rate $\dot{H}^*(10)$ ($\mu Sv\cdot h^{-1}$)		
UPM-UAZ	77.5 ± 2.3	59.8 ± 1.8	37.3 ± 1.1
INFN	77 ± 6	61 ± 5	37 ± 3
UAB	80.5 ± 5.6	61.8 ± 4.3	40.0 ± 2.8
CIEMAT	75.9 ± 0.3	57.6 ± 0.2	35.1 ± 0.1
LB-6411 (UPM)	79.5 ± 0.6	61.3 ± 0.5	38.4 ± 0.8

4. CONCLUSIONS

The study 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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