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

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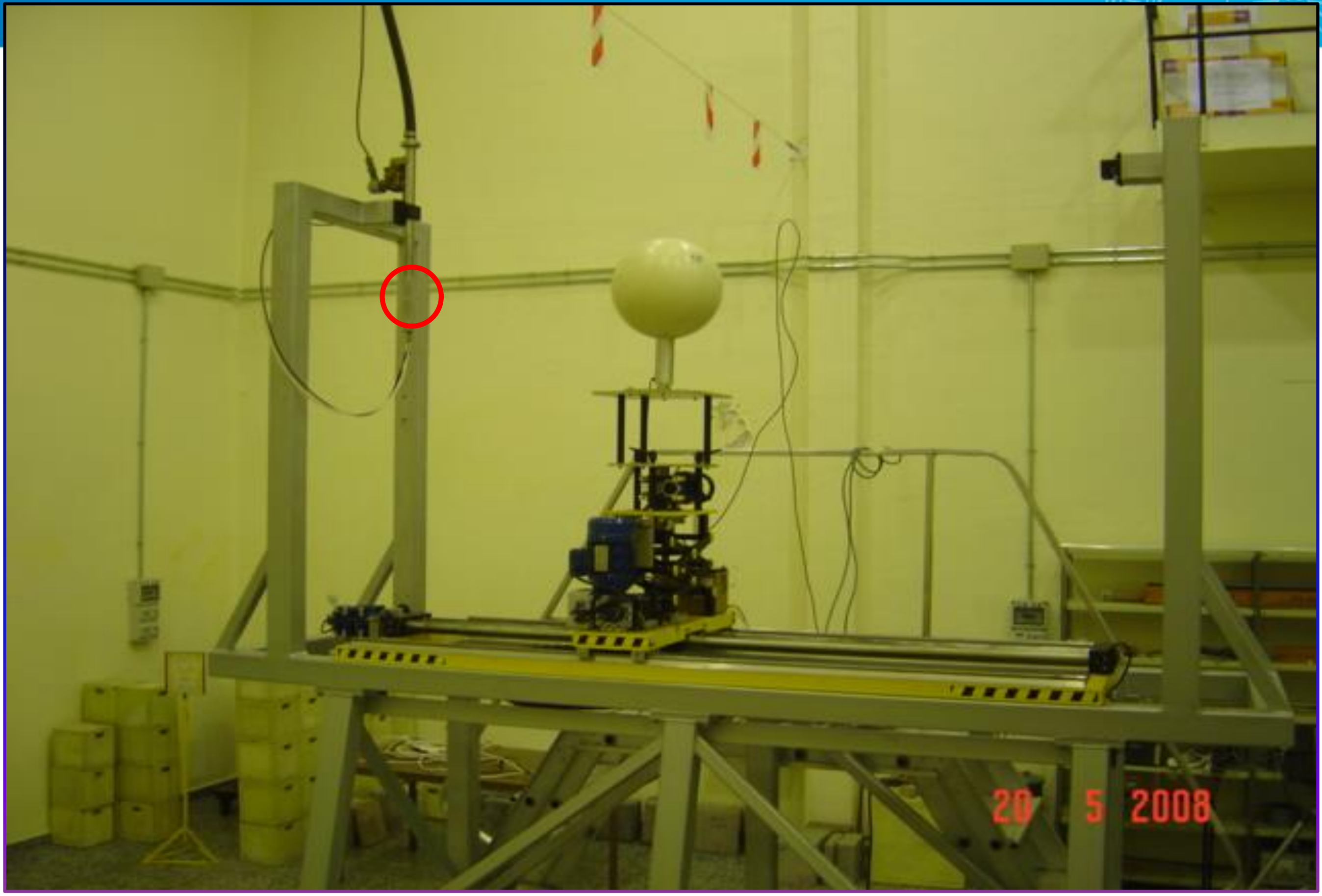
IRPA13 Glasgow
13th International Congress of the International Radiation Protection Association
13 - 18 May 2012

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.

The facility



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

UPM-UAZ BSS (LiI)

Ludlum-BSS: Six spheres of high-density polyethylene* with diameters: 2”, 3”, 5”, 8”, 10” and 12”.

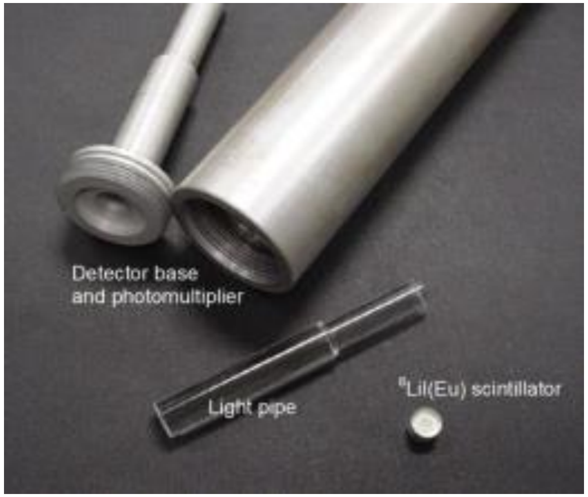
* d= (0.96 g/cm^3) Determined from weight and volume measurements

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



UPM-UAZ Unfolding method

BUNKIUT code with the response matrix UTA 4, 25 energy bins (collapsed from 171).

Uncertainties not explicitly addressed

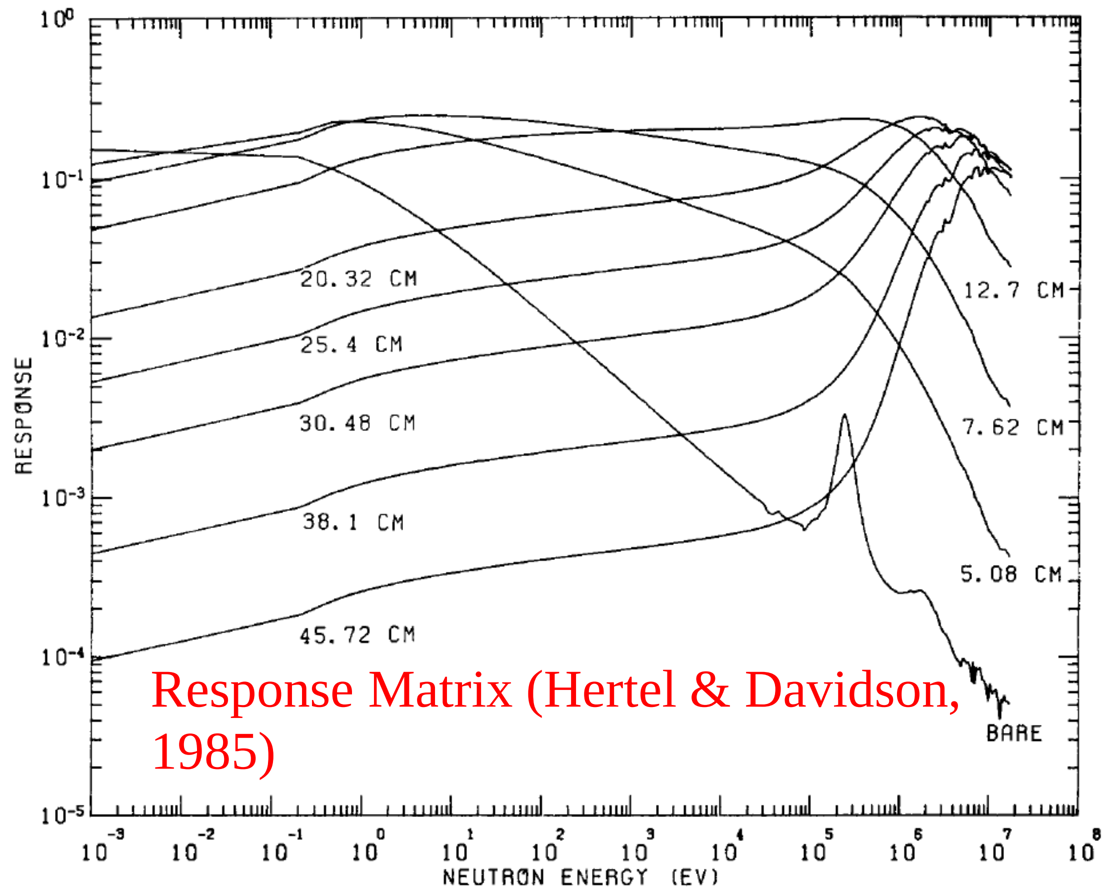
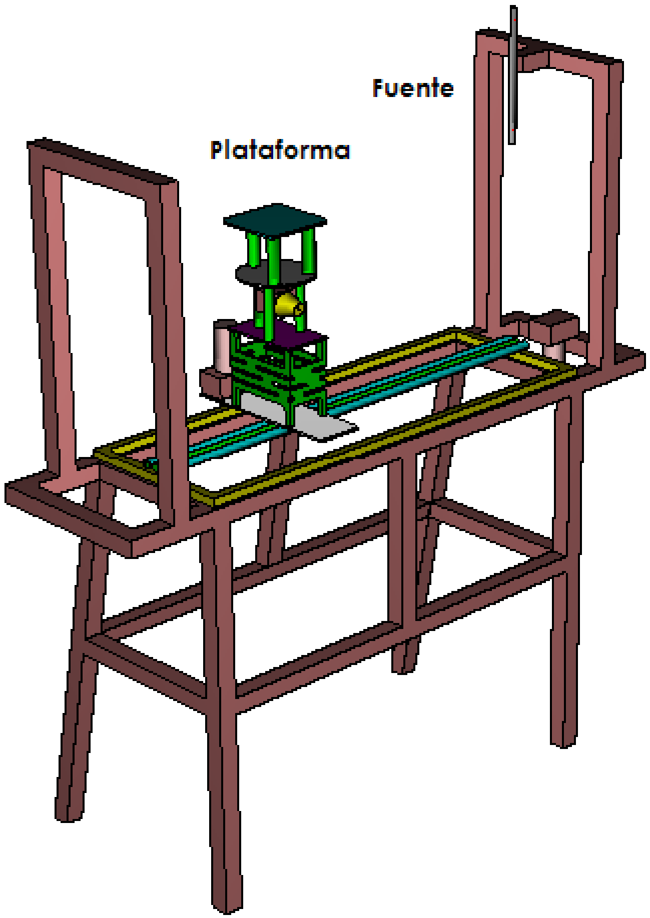
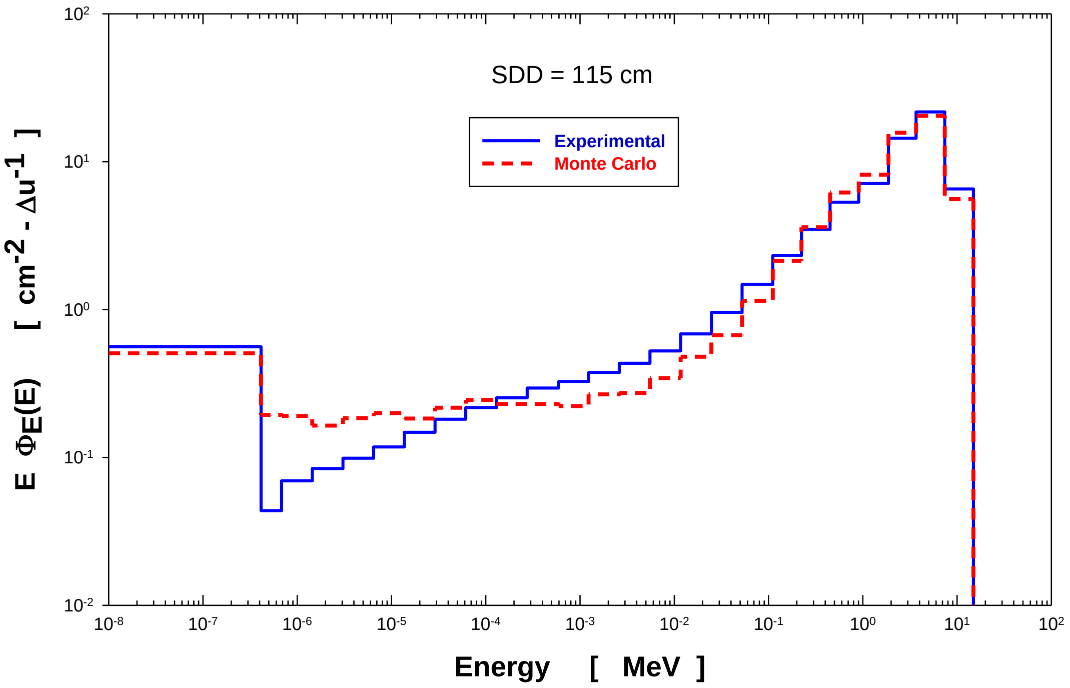


Fig. 1. The calculated 171-neutron group responses for the 4 mm LiI detector and the detector inside 5.08, 7.62, 12.7, 20 30.48, 38.1 and 45.72 cm diameter polyethylene spheres.

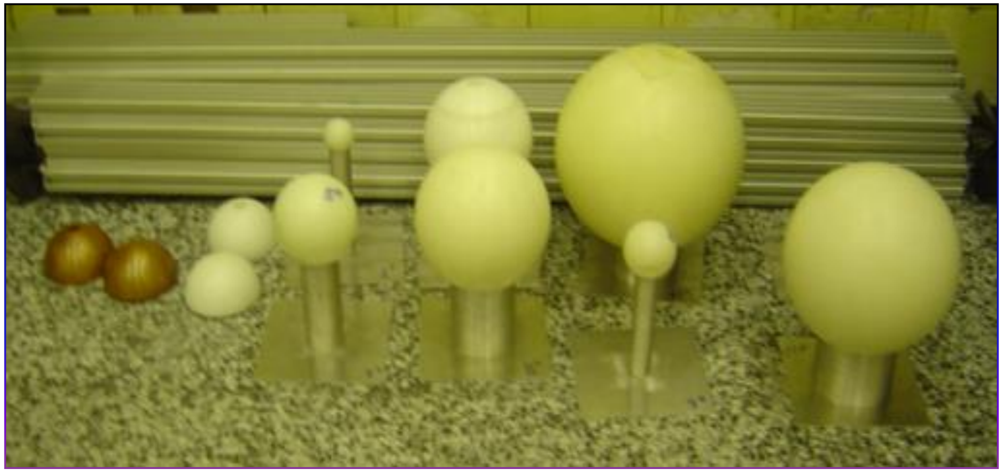
UPM-UAZ MCNP5 CALCULATIONS





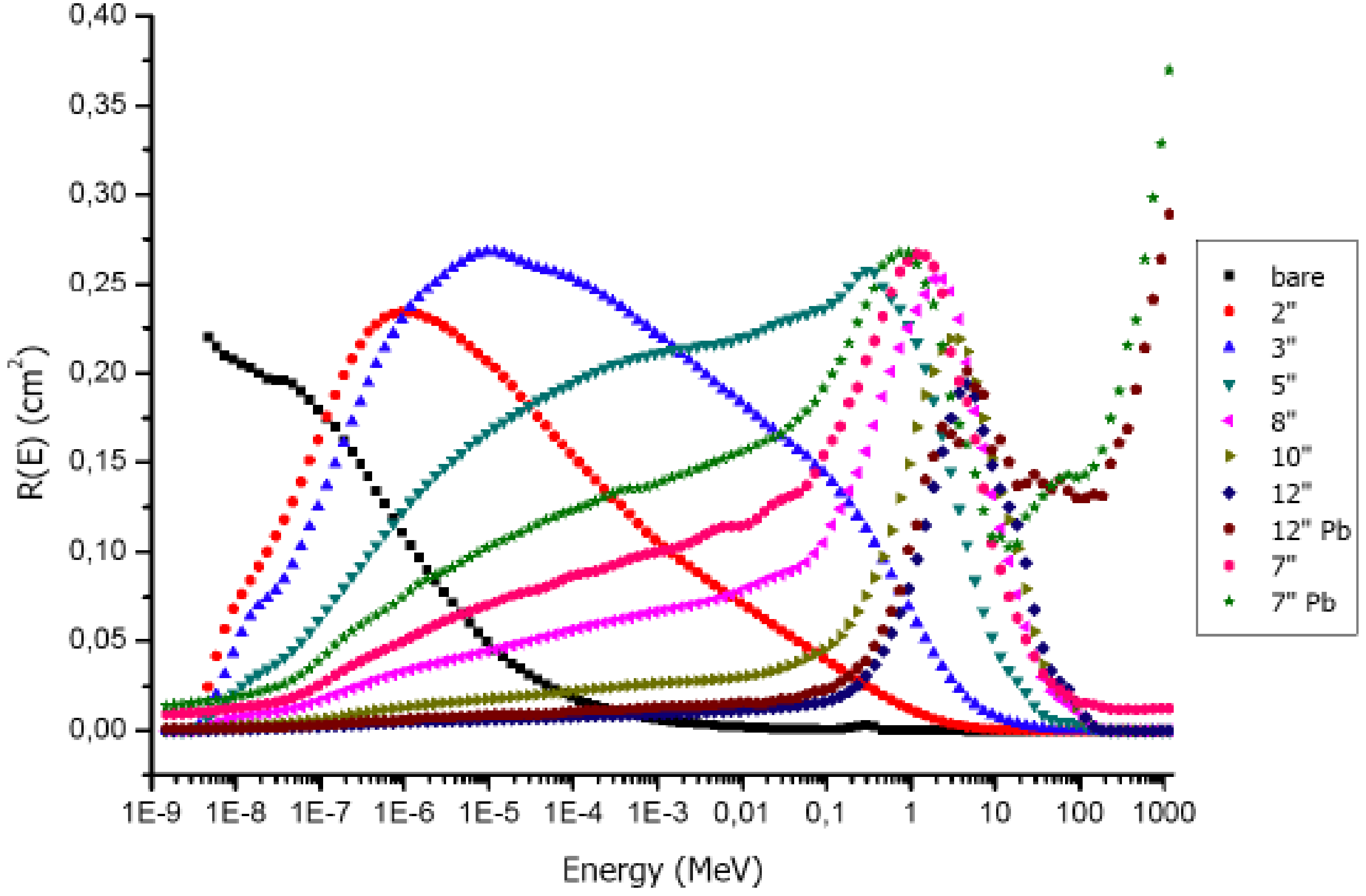
INFN BSS

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)



Reproducibility check device

INFN - BSS Response matrix



INFN - BSS Response matrix

MC code used: MCNPX 2.4.0

Validation experiments

BSS response matrix overall uncertainty u_{mat} **(± 3%)**

1) Determined with irradiations in continuous reference fields (Am-Be, Cf, Cf(D_2O), 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

INFN - BSS Calibration

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

INFN – Unfolding method

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)

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INFN- Uncertainties considered

- ☑ counting — u_c (1%-2%)
- ☑ anisotropy about cylindrical axis — u_{anis} (3%) determined from UPM report
- ☑ 0° / 90° anisotropy — $u_{90°}$ (1%) determined from NPL report CIRM 24 for same encapsulation
- ☑ BSS response matrix overall uncertainty — u_{mat} (3%)
- ☑ BSS calibration & time stability — u_f (2%)
- ☑ Unfolding procedures
  - Fluence — 1% - 2%
  - H*(10) — 4% - 7%
- ☑ fluence-to-H* average conversion coefficient — 4% ISO 8529-2

Disregarded: height of the source, measurement distance (~ 0.1%)

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UAB BSS

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:

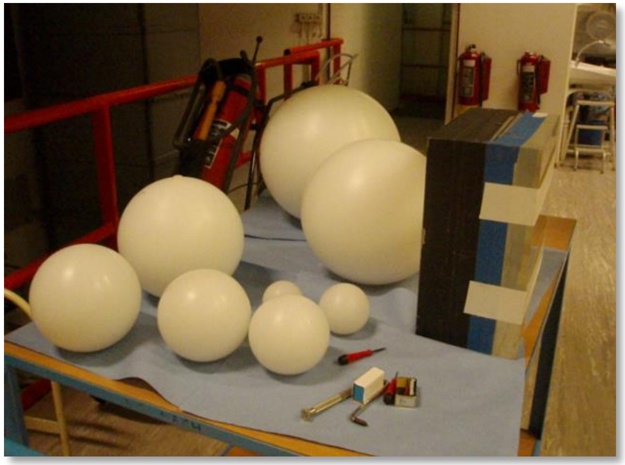
05NH1 from Eurisys. ^{3}He filled proportional counter at 8 kPa pressure.

cylindrical 9 mm x 10 mm.

Unfolding method and references

FRUIT 3.0 unfolding code

Nucl. Instr. and Meth. A 580, 1301-1309. 2007



UAB- Uncertainties considered

- 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%

UAB - BSS Response matrix

MC code used: MCNPX 2.4.0 and 2.5.0

Validation experiments:

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

IRSN Cadarache (AmBe, Cf, Cf+D_2O/Cd, SIGMA)

Uncertainty < 3%

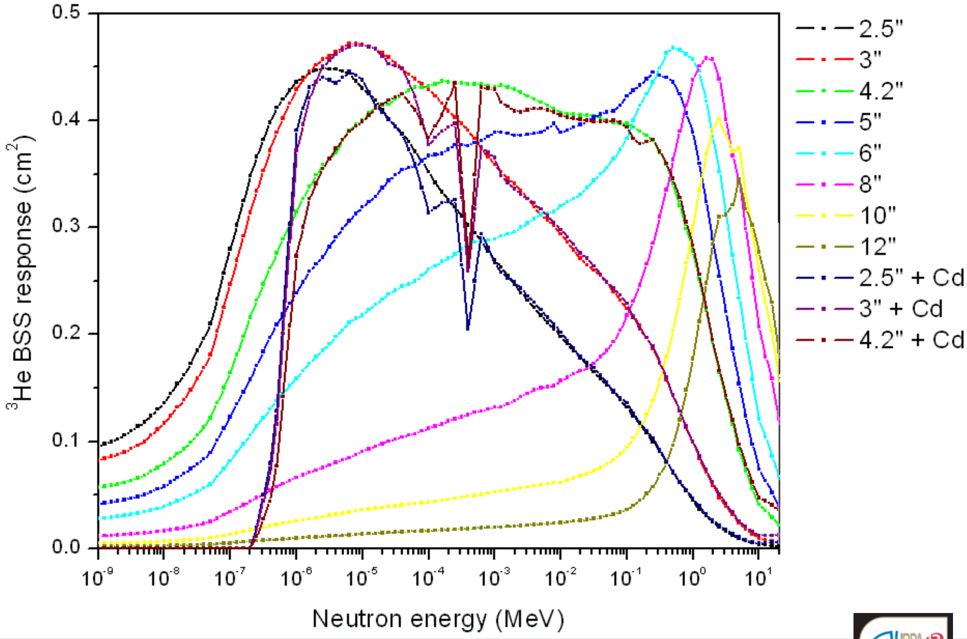
BSS calibration

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

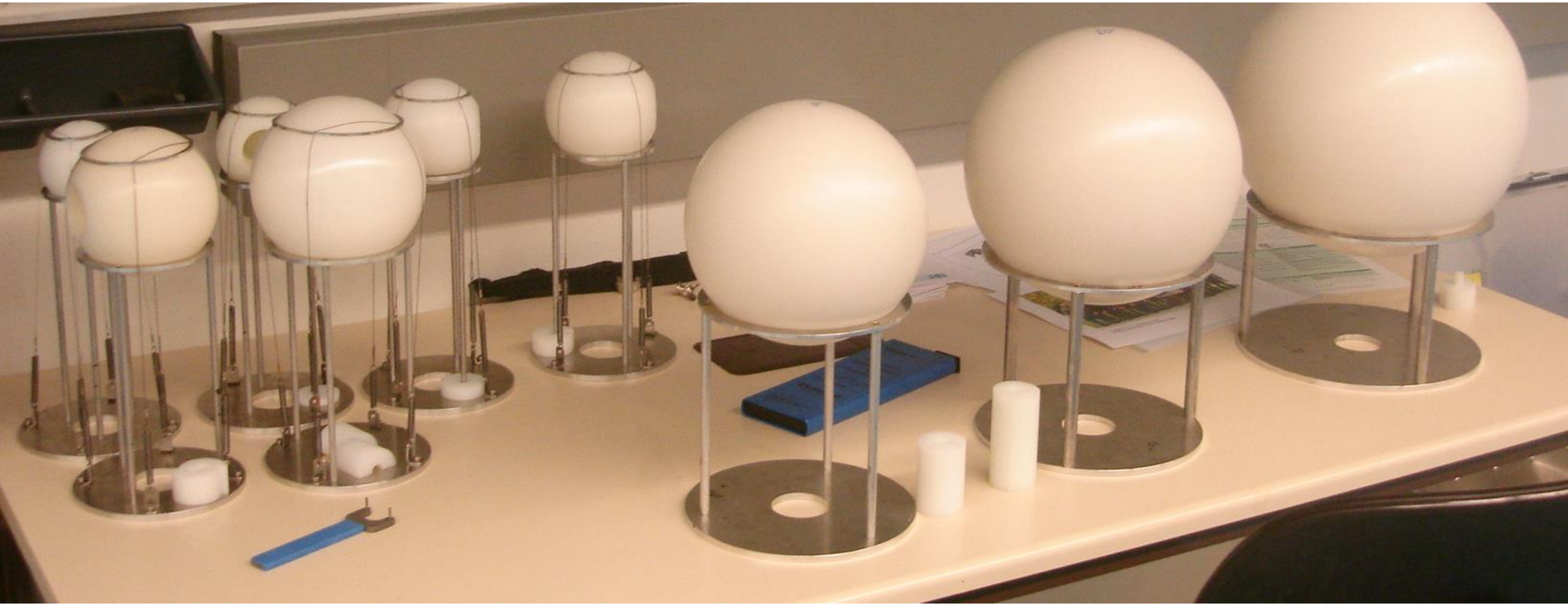
Routine check of the BSS working point

Not routinely. Sporadic checks.

AmBe Frascati March 2008



CIEMAT BSS



CIEMAT BSS

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)

CIEMAT - Uncertainties considered

- 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%

CIEMAT - BSS Response matrix

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.

CIEMAT – Unfolding technique

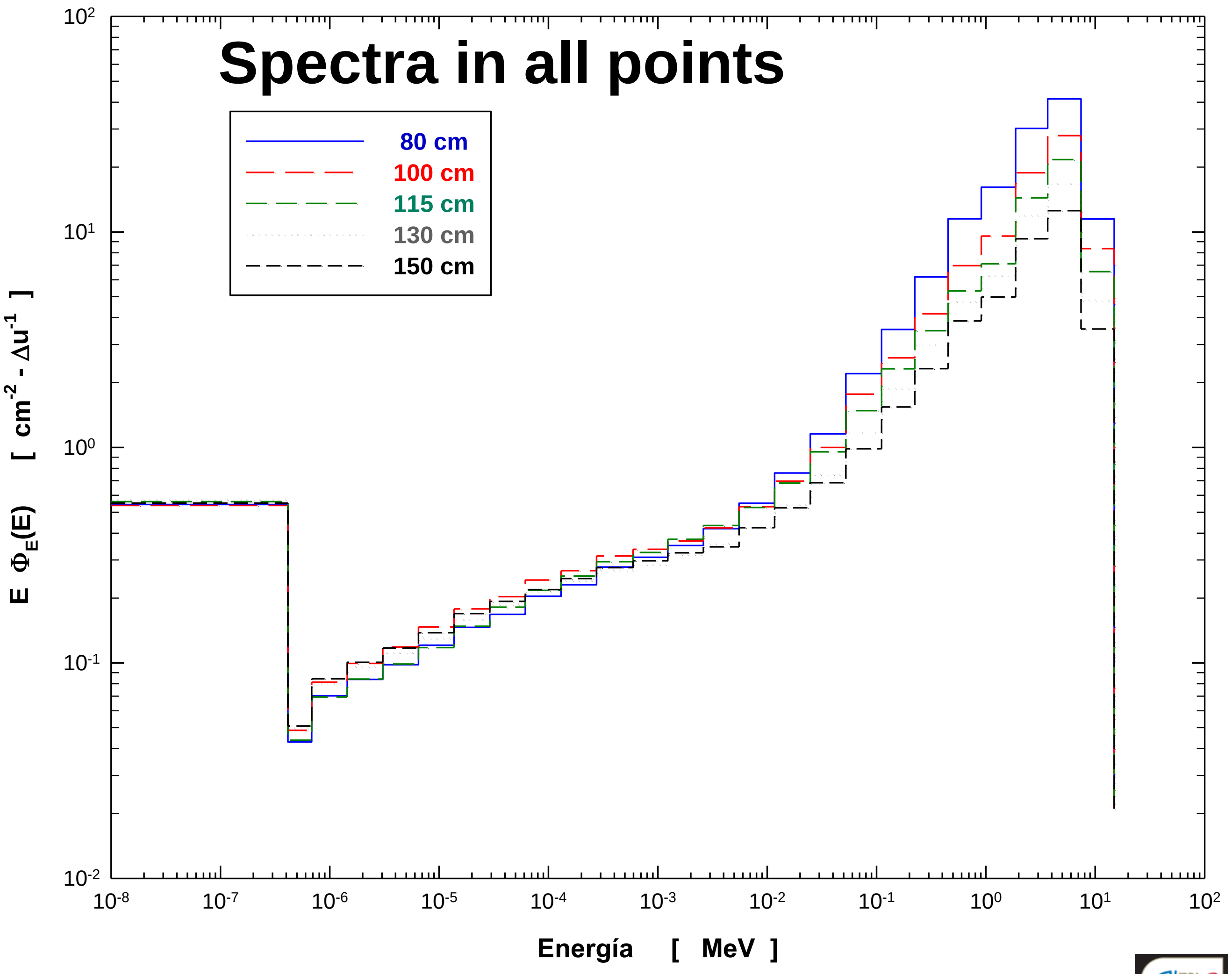
- **UMG3.3** unfolding pack has been employed: **GRAVEL and MAXED** consecutively and **IQU** for statistical analysis.

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

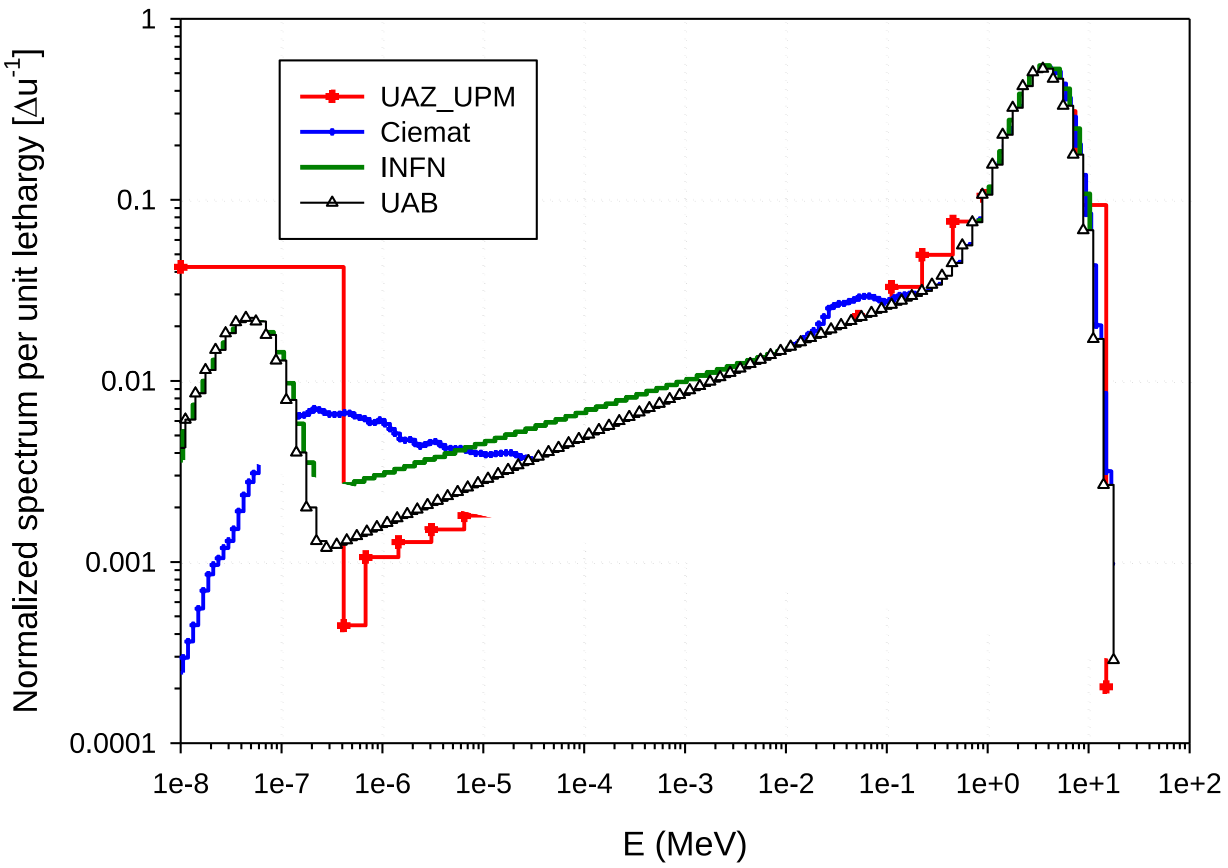
- Output data:
    - Output spectrum expressed in 20 energies by decade
    - Fluence rate
    - H*(10)

UPM-UAZ RESULTS

- 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

$$\dot{\phi} = \int_E \dot{\Phi}_E(E)\, dE$$

Distance	100 cm	115 cm	150 cm
	Total neutron fluence rate, Φ (cm^{-2}·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

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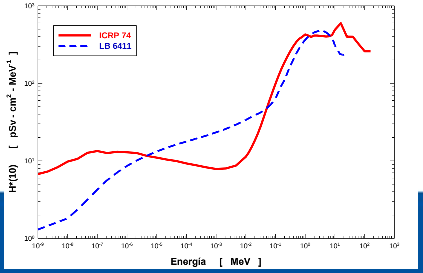
Ambient dose equivalent obtained at 100 cm, 115 cm and 150 cm from the source

$$\dot{H}^*(10) = \int_E \dot{\Phi}_E(E)\; h^*(10)\; dE$$

Distance	100 cm			115 cm			150 cm		
	Ambient dose equivalent rate (µSv·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



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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.

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Acnowledgement

This work was developed within the framework of the agreement between CIEMAT and UPM, with the sponsoring of the Nuclear Safety Council of Spain (CSN) with the objective of development of a neutron metrology system for Spain.