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Characterization of the neutron field from the ^{241}Am-Be isotopic source of the IPHC irradiator

K. Amgarou [a,*], M. Trocmé [b], M.J. García-Fusté [a], M. Vanstalle [b], E. Baussan [b], A. Nourreddine [b], C. Domingo [a]

[a] Grup de Recerca en Radiacions Ionitzants (GRRI), Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain
[b] Groupe de Radioprotection et Mesures Environnementales (RAMSES), Institut Pluridisciplinaire Hubert-Curien (IPHC), UMR 7178 CNRS-UN2P3/ULP, 23 rue de Loess, F-67037 Strasbourg Cedex 2, France

HIGHLIGHTS

► We describe a neutron irradiation facility based on ^{241}Am-Be radioactive source.
► The neutron field was characterized with a Bonner sphere spectrometer (BSS).
► Monte Carlo simulations using the MCNPX code were in good agreement with BSS.
► The un-scattered neutron spectrum is provided and compared to that given by the ISO-8529 standard.
► The neutron intensity of the ^{241}Am-Be source is also estimated.

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ABSTRACT

A measurement campaign has been carried out recently to provide the source intensity and the reference spectra around a neutron irradiation facility based on ^{241}Am-Be radionuclide source, using the UAB Bonner Sphere Spectrometer. This facility, which consists of a bunker, a container/shielding for the source and an irradiation device that uses an automated remote-controlled system for the source positioning and rotating during the dosimeter irradiation, is intended to be routinely used to check the response of passive dosimeters, namely those based on photo-stimulated imaging plates and solid-state nuclear track detectors. The measurement results, in terms of neutron spectra and global dosimetric quantities (i.e., fluence and ambient dose equivalent rates) at different distances with respect to the ^{241}Am-Be source, were compared with Monte Carlo simulations using the MCNPX code and a good agreement was observed. An estimation of the un-scattered neutron spectrum directly emitted from the ^{241}Am-Be source is given as well.

1. Introduction

The French RAMSES (*Radioprotection et Mesures Environnementales*) group of the IPHC (*Institut Pluridisciplinaire Hubert-Curien*, Strasbourg) centre develops its research activities in the field of radiation protection and offers expertise services in the environmental radioactivity (natural or artificial) measurements (Dziri et al., 2012; Abou-Khalil et al., 2009; Ouziane et al., 2010; Ngachin et al., 2008). The group is currently accredited for external personal dosimetry of workers professionally exposed to ionizing radiation and participates in their initial formation and on-going training. To routinely check the response of the passive dosimeters, namely those based on photo-stimulated imaging plates (Mouhssine et al., 2005) and solid-state nuclear track detectors (Fernández et al., 2005), a neutron irradiation facility, using an ^{241}Am-Be radionuclide source, was set-up in 2008. An automated remote-controlled system is used for the source positioning and rotation during the dosimeter irradiation.

This work reports on the description of this irradiation facility as well as on a measurement campaign carried out recently by the Spanish GRRI (*Grup de Recerca en Radiacions Ionitzants*) group of the *Universitat Autònoma de Barcelona* (UAB), in the framework of a research collaboration. The aim of this campaign is to provide the source intensity and the neutron spectra at different locations within the bunker by means of a Bonner sphere spectrometer (BSS). This

* Corresponding author. Tel.: +34 93 581 1364; fax: +34 93 581 2155.
E-mail addresses: khalil.amgarou@uab.cat (K. Amgarou), carles.domingo@uab.cat (C. Domingo).

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measuring system, firstly introduced by Bramblett et al. in (1960), consists of a set of polyethylene moderating spheres of various sizes with a central detector mainly sensitive to thermal neutrons. The angular response of the BSS shows a very small dependence on the neutron direction of incidence (Fernández et al., 2007a). Its fluence response extends over a wide energy range (from thermal up to a few tens MeV and can be extended to several hundreds MeV by inserting shells of materials with high atomic mass). The unique drawback of a BSS is its limited energy resolution that does not allow appreciating detailed structures such as oscillations and resonances on the measured neutron spectrum. Therefore, only smooth distributions of possible neutron fluence peaks could be indicated by this system. Even with this limitation, the UAB-BSS (Bakali, 2001), which was extensively validated in reference quasi mono-energetic beams as well as in radionuclide based sources and the thermal SIGMA facility at IRSN (Cadarache, France) (Lacoste et al., 2004; Bedogni et al., 2010), has shown its convenience to characterize the neutron fields in several workplace environments (Amgarou et al., 2011; Bedogni et al., 2007a; Esposito et al., 2010; Domingo et al., 2009; Fernández et al., 2004, 2007b, 2007c; Gressier et al., 2004).

2. Material and methods

2.1. Neutron irradiation facility

The IPHC neutron irradiation facility is located in a small concrete bunker (see Fig. 1) and consists of a polyethylene (PE) cube ($84 \times 84 \times 84$ cm^3), located at the centre of the bunker floor, with a central Al tube through which the ^{241}Am-Be source, with a nominal activity of 3.7×10^{10} Bq (1 Ci), can be extracted by means of an automated system. This system consists of a motor-driven screw that can go up and down within the Al tube, and that can be also used to rotate the source during the irradiation to avoid irradiation irregularities due to the effects of possible source inhomogeneity. The vertical source irradiation position is about 44 cm above the PE cube at 128 cm from the room floor. Two Al arms on opposite sides of the PE cube are used as supports and in one of them the source-detector distance can be adjusted automatically. At the end of irradiation, the ^{241}Am-Be source is stored in the centre of the PE cube that absorbs almost all the emitted neutrons. The bunker, which is accessed by a maze entrance, has a main space of approximately $404 \times 413 \times 386$ cm^3 surrounded with lateral walls 1 m in thickness. All the irradiator controls can be done remotely, from outside the bunker, to avoid any unnecessary risk of exposure for the user.

2.2. Bonner sphere spectrometer

The UAB-BSS measuring system is based on a cylindrical (10 mm diameter and 9 mm high) ^{3}He filled (8 kPa) proportional counter (model 05NH1 from EURISYS) that is normally introduced in the centre of 8 PE (100% purity and 0.920 ± 0.003 g cm^{-3} density) spheres, whose diameters are labelled in inch units (2.5 in., 3 in., 4.2 in, 5 in., 6 in., 8 in., 10 in., 12 in.) for convenience. In addition, a 1 mm thick cadmium (Cd) cover may be used for the 3 smallest spheres to accurately derive the thermal component (below 0.5 eV) of the neutron spectra. Since this spectrometer shows an inherent upper limit at 20 MeV (above this energy the cross-section of the n-p elastic scatterings drops off significantly), two extended range spheres, with Cu and Pb inserts, were added recently (Esposito et al., 2010) to measure also neutrons with energies up to several hundreds of MeV. One of these new high-energy spheres (7 in. + Cu) consists on an internal PE sphere 3 in. in diameter, covered with a Cu shell 1 in. in thickness, adjacent to an external PE layer 1 in. in thickness. The other extended-range sphere (7 in. + Pb) is similar, hosting a lead shell 1 in. in thickness.

The response matrix of the UAB-BSS was calculated, using MCNPX (Waters, 2002), for 121 logarithmic equidistant discrete neutron energy values ranging from 7.943×10^{-4} eV up to 1.259 GeV. As already stated in Section 1, the matrix was validated in reference quasi mono-energetic beams at PTB (Braunschweig, Germany) and JRC-IRMM (Geel, Belgium) as well as in radionuclide based sources and the thermal SIGMA facility at IRSN (Cadarache, France) (Lacoste et al., 2004; Bedogni et al., 2010), providing an overall uncertainty of ±3%. The spectrometer calibration was verified in March 2008 using the INFN ^{241}Am-Be source and in February 2010 with the NPL ^{252}Cf source, and its calibration factor was confirmed within 2%.

The extended-range spheres were not used, since the neutron spectrum form an Am-Be source extends up to about 10 MeV. Because of the small dimension of the bunker, five points at distances 75, 110, 145, 180 and 215 cm from the ^{241}Am-Be source, along the diagonal direction of the bunker and at the same vertical position of the source (128 cm from the room floor) were selected for measurements. The last point was already very close to the room corner, at practically 50 cm from the two adjacent lateral walls.

2.3. Full count rates, un-scattered and scattered components and source intensity

The source neutron yield and energy distribution (spectrum) may be obtained from the readings at the measurement points, taking into account room scattering and, eventually, air attenuation. According to the ISO-8529 standard, it can be assumed that the *scattered component* is uniform in a finite irradiation room (constant scattering approximation), whereas the *direct component* follows exactly the $1/d^2$ law. As the dimensions of the room are small, air-attenuation can be neglected. Linear fits of the *full* count rates c_d^i vs. $1/d^2$ were performed for the readings obtained at the 5 measurement points with the 11 sphere configurations of our Bonner spectrometer. If there were no room scattering, the intercept

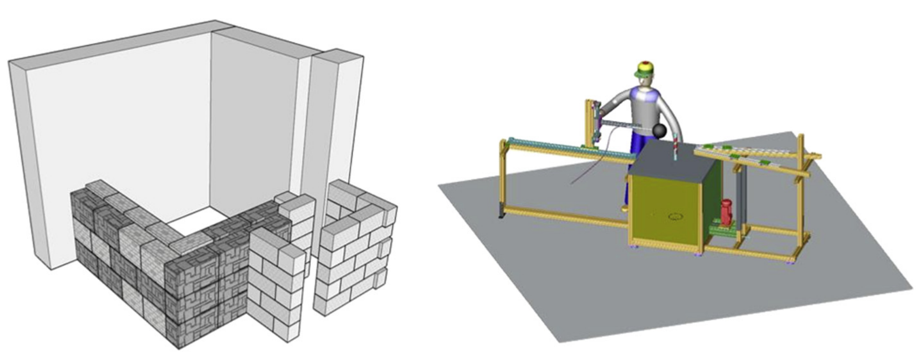

Fig. 1. A simple sketch of the IPHC neutron irradiation facility.