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Different spectra with the same neutron source

H.R. Vega-Carrillo[a,*], J.M. Ortíz-Rodríguez[a,b], V.M. Hernández-Dávila[a,b],
Ma. del R. Martínez-Blanco[a], B. Hernández-Almaraz[a], and A.A. Ortíz-Hernández[a]
[a]*Unidad Académica de Estudios Nucleares Universidad Autónoma de Zacatecas,*
Apartado Postal 336, Zacatecas, 98000, Zac. Mexico,
Telephone: (492) 922 7043, Ext.118 and 119,
[*]*e-mail: fermineutron@yahoo.com*
[b]*Departamento de Electrotécnia y Electrónica, Escuela Politécnica Superior,*
Avda. Menéndez Pidal s/n Córdoba, Spain.

G.A. Mercado
Unidad Académica de Matemáticas, Universidad Autónoma de Zacatecas,
Jardín Juárez 147, 98000 Zacatecas, Zac. Mexico.

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Using as source term the spectrum of a ^{239}Pu-Be source several neutron spectra have been calculated using Monte Carlo methods. The source term was located in the centre of spherical moderators made of light water, heavy water and polyethylene of different diameters. Also a ^{239}Pu-Be source was used to measure its neutron spectrum, bare and moderated by water. The neutron spectra were measured at 100 cm with a Bonner spheres spectrometer. Monte Carlo calculations were used to calculate the neutron spectra of bare and water-moderated spectra that were compared with those measured with the spectrometer. Resulting spectra are similar to those found in power plants with PWR, BWR and CANDU nuclear reactors. Beside the spectra the dosimetric features were determined. Using moderators and a single neutron source can be produced neutron spectra alike those found in workplaces, this neutron fields can be utilized to calibrate neutron dosimeters and area monitors.

Keywords: Neutron sources; neutron transport; Monte Carlo applications.

Mediante el espectro de una fuente de ^{239}Pu-Be varios espectros de neutrones han sido calculados mediante métodos Monte Carlo donde el término fuente se colocó en el centro de moderadores esféricos de agua ligera, agua pesada y polietileno de diferentes diámetros. Una fuente real de ^{239}Pu-Be se utilizó para medir el espectro de neutrones mediante un espectrómetro de Esferas Bonner. El espectro se midio a 100 cm de distancia de la fuente desnuda y de la fuente dentro de un moderador cilíndrico de agua. Con la información de los espectros se obtuvieron las características dosiméticas de la fuente desnuda y de la moderada con agua. Mediante cálculos Monte Carlo se calcularon los espectros y se compararon con los espectros medidos. Los espectros resultantes son similares a los reportados en plantas nucleares con reactores BWR, PWR y tipo CANDU. Mediante el uso de moderadores se pueden producir espectros que se asemejan a situaciones reales y se pueden usar para calibrar dosímetros y monitores de área.

Descriptores: Fuente de neutrones; transporte de neutrones; aplicaciones Monte Carlo.

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1. Introduction

Neutron energy spectra found in workplaces are often complex, the range of neutron energies involved can extend over nine or ten orders of magnitude. To improve the assessment of personal equivalent dose (H_p) and ambient dose equivalent [H*(10)] in workplace requires the proper characterization of neutron spectra. Dosimeters used to survey either the personal equivalent or the ambient equivalent doses have responses that strongly vary with neutron energy [1,2].

During calibration of dosimetric devices utilized in neutron fields the use of calibrating sources with spectra alike to those meet in practice is strongly recommended [3-5].

To calibrate dosimetric devices the International Organization for Standardization (ISO) recommends ^{252}Cf and ^{252}Cf/D_2O, ^{241}AmBe, and ^{241}AmB as calibration sources [6]. However, these source have spectra that are different from those found in actual situations [7,8].

To produce realistic neutron spectra whose spectrum look alike to those found in workplaces different approaches have been made in several facilities [1,2,8-10].

The neutron spectrum of a primary neutron source is modified using different materials, some of which are moderators, this practice is commonly used to obtain a desired neutron spectra, where beside to produce a realistic neutron spectra, the dosimetric features must be determined [11].

In aim to this work was to produce different neutron spectra using the same neutron source. To achieve this objective the neutron spectra of a ^{239}Pu-Be neutron source was modified by inserting the neutron source in the centre of moderating materials, this part was done using Monte Carlo calculations. Also, the neutron spectrum of a ^{239}Pu-Be source, bare and water-moderated, was measured and calculated; with the spectra information the dosimetric features were calculated. In this case the source and the moderator are cylindrical.

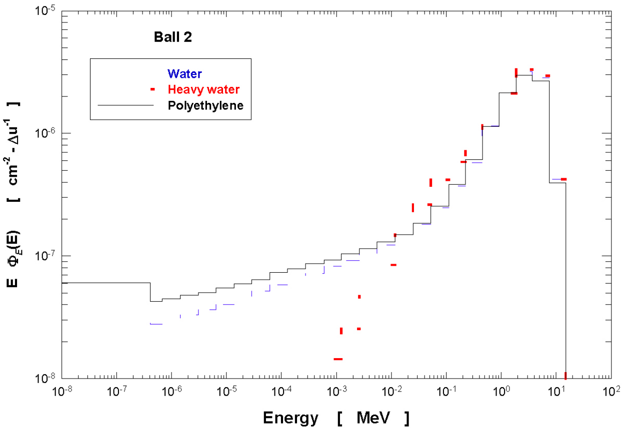

FIGURE 1. Ball 2-moderated ^{239}Pu-Be spectra.

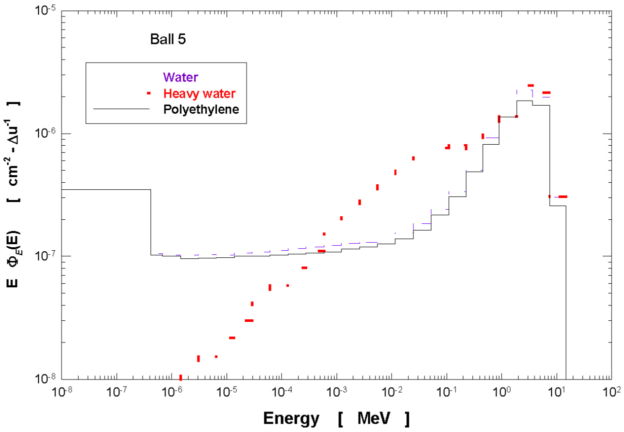

FIGURE 2. Ball 5-moderated ^{239}Pu-Be spectra.

2. Materials and methods

2.1. Spherical moderators

The neutron spectra produced by point-like ^{239}Pu-Be isotopic neutron source located inside spherical moderators were calculated using the MCNP code [12]. Moderating spheres were 5.08, 7.62, 12.7, 25.4, and 30.8 cm in diameter and were modelled as water, heavy water and polyethylene were used as moderating materials. Neutron spectra were calculated at 100 cm from the centre of the spheres, were the point-like source term was located. The amount of histories utilized for each moderator was large enough to have a Monte Carlo uncertainty of 5%.

2.2. Cylindrical moderator

The neutron spectrum produced by a ^{239}Pu-Be at 100 cm in an open space at 200 cm above floor level was measured using the Bonner spheres spectrometer with 0.4 Ø × 0.4 mm ^{6}LiI(Eu) scintillator. The source is 1.85×10^{11} Bq, is distributed in three cylindrical pellets 2.54 Ø×14 cm. Then the source was inserted in a 28 Ø×40 cylindrical container with water, and the neutron spectrum was measured with the Bonner spheres spectrometer. Height of water moderator was 30 cm. The bare and water-moderated spectra of ^{239}Pu-Be source were unfolded using the BUNKIUT code and the UTA4 response matrix [13]. Resulting spectra, $\Phi_E(E)$, were utilized to estimate the total fluence, ϕ, and the ambient dose equivalent, H*(10), using the ICRP 74 fluence-to-dose conversion coefficients, h*(10) [14]; these magnitudes were calculated using Eqs. (1) and (2).

$$\phi = \int_E \Phi_E(E)dE \tag{1}$$

$$H*(10) = \int_E \Phi_E(E)\, h^*(10)dE \tag{2}$$

Nowadays the area neutron monitor Berthold LB 6411 is widely utilized to survey the H*(10); the response of this device is not exactly the same of ICRP 74. Thus the bare and the water-moderated ^{239}Pu-Be spectra were utilized to calculate the H*(10) using the response function of Berthold LB 6411 [15].

3. Results and discussion

3.1. Spherical moderators

A neutron source spectrum can be modified with the use of moderating materials; modified spectrum depend upon the size and type of moderator. In Fig. 1 are shown the spectra of a ^{239}Pu-Be point-like neutron source located in the centre of a 5.08 cm-diameter sphere (Ball 2) made of water, heavy water and polyethylene. Resulting spectra from water and polyethylene moderators are alike, having epithermal and thermal neutrons. It can be noticed that moderating features of polyethylene are better than those for water, probably due to differences in their absorption features. The spectrum produced by the heavy water moderator is quite similar to the bare ^{239}Pu-Be source because the amount of heavy water in the Ball 2 container is small to produce strong effect in the spectrum.

In Fig. 2 the resulting spectra of a point-like ^{239}PuBe located in the centre of 12.7 cm-diameter moderator (Ball 5) of water, heavy water and polyethylene are shown. As in the case of Ball 2 moderators, water and polyethylene moderators have similar spectra; the peak in the 1 to 10 MeV tend to decrease while the thermal peak tend to increase as the moderator size is increased. The spectrum produced in the heavy water moderator has a large contribution of epithermal neutrons in the region from 10^{-3} to 0.4 MeV in comparison with the amount of neutrons with energy less than 1 keV.

In Fig. 3 moderated ^{239}Pu-Be spectra are shown for 25.4 cm-diameter moderators (Ball 10). Here, the spectrum produced by the polyethylene moderator is smaller than the spectrum produced by the water moderator, but the shapes are very alike. On the other hand the spectrum produced by the heavy water moderator is quite similar to the spectrum produced by the heavy water moderated ^{252}Cf source [6], even when the unperturbed spectrum of ^{239}Pu-Be is quite different of the unperturbed ^{252}Cf. From this figure is evident that heavy water moderator absorbs less neutrons that other two moderators.

In Fig. 4 is shown the neutron spectra of a point-like ^{239}Pu-Be source located inside a 30.48 cm-diameter moderators (Ball 12). The tendency observed for the ball 10 is kept for the ball 12. Spectrum produced in the water moderator is alike to spectrum produced by the polyethylene moderator, where this last produces less neutrons.

Using Eq. (1) the total neutron fluence produced by the different spherical moderators were calculated. In Fig. 5 is shown the total neutron fluence produced by the moderators. The total fluence produced by the heavy water moderators is almost constant regardless the moderator diameter, meaning that neutron capture in heavy water is negligible in comparison to water and polyethylene moderators. For water and polyethylene spherical moderators, with diameters larger than 12.7 cm, the total fluence produced by polyethylene moderators is smaller than total fluence produced in water moderators, this is due to differences in the neutron capture and scattering features of both moderators. This is an important fact that must to be taken into account for safety reasons, because neutron capture can produce prompt gamma-rays that could affect the response of instrumentation and safety of personal.

In Figs. 1 to 4 all spectra show a peak between 1 and 10 MeV. As the moderator diameter increases epithermal and thermal neutrons increases and fast neutrons tend to decrease. Resulting spectra for Ball 5, 10 and 12, either polyethylene or water moderators are alike to those produced at some locations in PWR and BWR nuclear reactors [16], therefore a ^{239}Pu-Be inside spherical water moderators can be used to calibrate dosimetric instruments used in this facilities.

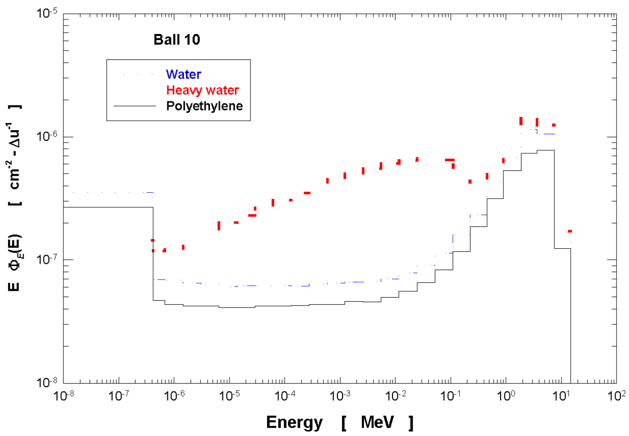

FIGURE 3. Ball 10-moderated ^{239}Pu-Be spectra.

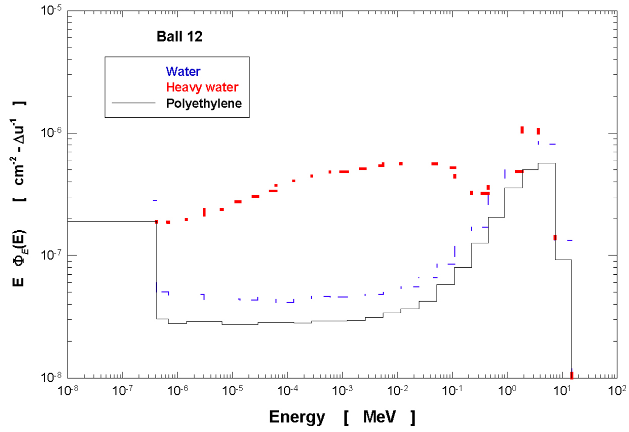

FIGURE 4. Ball 12-moderated ^{239}Pu-Be spectra.

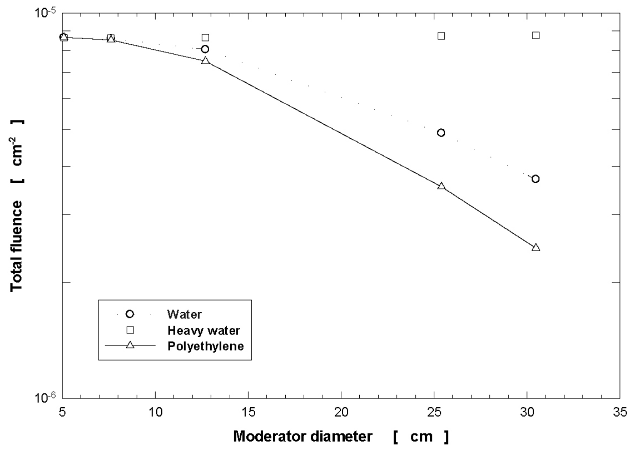

FIGURE 5. Total fluence a 100 cm produced by the moderated ^{239}Pu-Be spectra in function of moderator diameter.

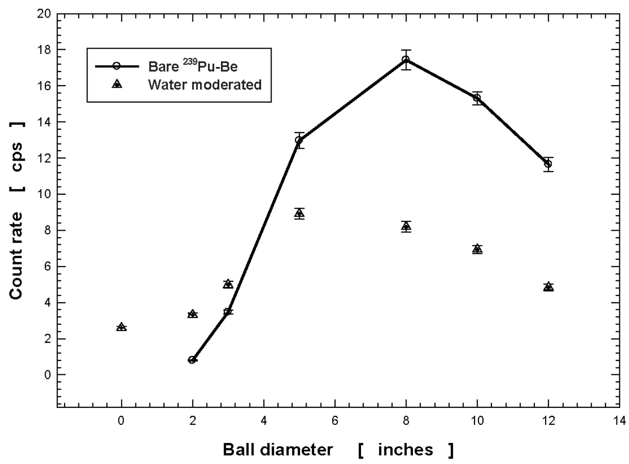

FIGURE 6. Bonner spheres count rates produced by bare and water-moderated ^{239}Pu-Be source.

Heavy water contains deuterium whose capture cross section is lower than hydrogen, therefore less neutrons are lost by capture. The spectra produced by a ^{239}Pu-Be neutron source inside the spherical heavy water moderators, Ball 10 and 12, is similar to neutron spectra produced by D_2O-

moderated ^{252}Cf source, therefore this source can be used in all those facilities where the ^{252}Cf/D_2O source is recommended for calibration. Some of the spectra produced by the ^{239}Pu-Be inside the heavy water moderator are alike to spectra reported in literature [17] for CANDU-like workplace neutron fields.

3.2. Cylindrical moderator

The count rates measured with Bonner spheres at 100 cm form the bare and water-moderated ^{239}PuBe source is shown in Fig. 6, here can be noticed that for 2 and 3 inches-diameter spheres the count rates produced by the water-moderated source are larger than count rates produced by the bare ^{239}Pu-Be source, this is because bare source do not produce epithermal or thermal neutrons, and the response of those spheres are large for low energy neutrons; this is also the reason why no count rate is shown for bare detector, 0 inches-diameter sphere. For 5 to 12 inches-diameter sphere the count rates are larger for bare source in comparison to water-moderated source, this is because the neutron capture, mainly in hydrogen, is increased as the neutron energy is decreased.

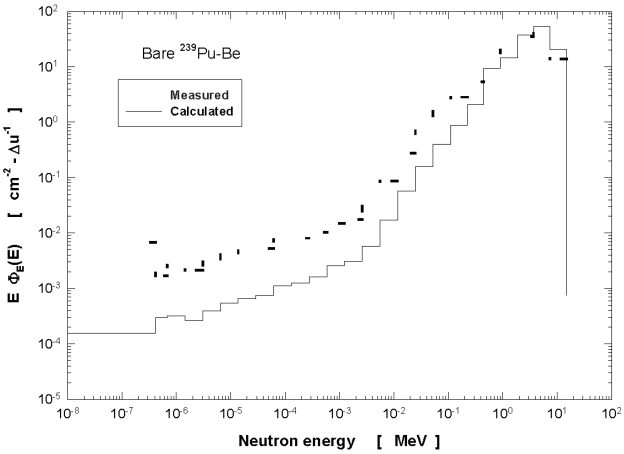

FIGURE 7. Bare ^{239}Pu-Be source neutron spectrum.

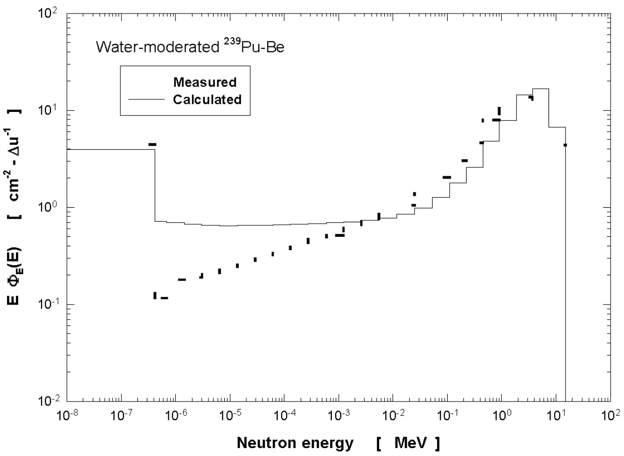

FIGURE 8. Water-moderated ^{239}Pu-Be source neutron spectrum.

TABLE I. The dosimetric features of bare and water-moderated ^{239}Pu-Be source at 100 cm.

Magnitude	Bare ^{239}Pu-Be	Water-moderated ^{239}Pu-Be
ϕ[$cm^{-2} - s^{-1}$]	97 ± 8	64 ± 5
$\langle E \rangle$ [MeV]	5.0± 0.4	2.6± 0.2
H*(10)$_{ICRP74}$ [μSv – h^{-1}]	141 ± 11	59 ± 5
H*(10)$_{LB6411}$ [μSv – h^{-1}]	132 ± 11	55 ± 4

With the count rates the neutron spectra were unfolded, in Fig. 7 the bare ^{239}Pu-Be neutron spectra measured with the Bonner sphere spectrometer is shown, here is also included the neutron spectra that was calculated with Monte Carlo methods. It can be notice that both spectra are similar.

The calculated and unfolded spectra produced by ^{239}Pu-Be source moderated by water is shown in Fig. 8. The differences between calculated and measured spectra are due to the limitations of the model of the source utilized during calculations. Uncertainties due to Monte Carlo calculations are as large as 5% while the experimental uncertainties that are around 10%; doing the quadratic sum of these uncertainties gives out a overall uncertainty of 11.2%.

The dosimetric features of bare and water-moderated ^{239}Pu-Be source at 100 cm are shown in Table I. The neutron mean energy of bare ^{239}Pu-Be is 5 MeV, this is in agreement to value reported for this type of sources [4]. The mean energy is reduced to 2.6 MeV when the source is inserted in the moderator of water. Moderated spectrum can be utilized to represent the neutron spectra in power plants. If a larger moderator is utilized the resulting spectrum could be similar to neutron field found in medical use linear accelerators [18] and PET cyclotrons [13,19].

4. Conclusions

With the use of moderating materials different neutron spectra can be produced using the same neutron source.

A precise knowledge of neutron spectral distributions of calibrating sources is essential to have a neutron field useful for calibration of radiation protection devices. Is no doubt that more neutron reference sources, beside to those recommended by the ISO, are needed for the calibration of personal neutron dosimeters and survey meters. Is highly desirable that the spectra of those sources must be realistic to emulate the neutron fields found in workplaces.

The feasibility of producing a neutron fields in a laboratory facility was investigated by Monte Carlo simulation. It was found that such neutron fields could be produced by a ^{239}Pu-Be neutron source located inside light water, heavy water and polyethylene moderators.

A single isotopic neutron source in combination with water, heavy water and polyethylene moderators produce a wide range of neutron spectra that allow to have a set of relatively inexpensive calibrating neutron sources some of which are alike to neutron fields found in power plants and neutron producing medical devices.

Resulting neutron spectra depend upon the size and type of moderator; thus a bare ^{239}Pu-Be source looks different when is located inside a water moderator. The mean neutron energy varies from 5 to 2.6 MeV and the H*(10) is reduced from 141 to 59 mSv-h^{-1}. Using a single neutron source the use of different moderators will lead to have neutron sources with different dosimetric features some of which are similar to those found in workplaces.

The spectra here calculated will be modified by the calibrating room features mainly due to "room return" [20], this factor must be estimated depending of room's size.

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