Directional properties of a modified Bonner spectrometer

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The study of the directional properties of a modified Bonner type spectrometer, are reported in this paper. It was established in a previous publication [1], that a small radial hole on each polyethylene sphere gives rise to a directional sensitivity when used on this apparatus. Now, the directional properties are further improved by adding a thin cylindrical cadmium shell inserted in the radial holes of each sphere. The angular response for a set of six spheres is reported using, both, a fast (non-moderated) and a moderated neutron source provided by the ^{9}Be(d,n)^{10}B reaction by bombarding a thick beryllium target with 4 MeV deuterons.

Keywords: Neutron spectrometer; Bonner spheres; angular response

En este trabajo se presenta el estudio de las propiedades de direccionalidad de un espectrómetro tipo Bonner modificado. Como ya fue establecido en una publicación previa [1], hacer pequeños hoyos radiales a las esferas de polietileno da lugar a una sensitividad direccional cuando se usa en este dispositivo. En este reporte, las propiedades direccionales son mejoradas añadiendo una cáscara cilíndrica delgada de cadmio que se inserta en los hoyos radiales de cada esfera. Se reportan las respuestas direccionales (angulares) para un conjunto de seis esferas, usando un espectro rápido (no-moderado) y un espectro moderado de neutrones generados a partir de la reacción ^{9}Be(d,n)^{10}B, al bombardear un blanco grueso de berilio con deuterones de 4 MeV.

Descriptores: Espectrómetro de neutrones; esferas de Bonner; dosimetría

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1. Introduction

It has been shown that polyethylene spheres with a minor modification consisting of a radial $^{3}\!/_{3}$ inch drilled hole, are able to detect the spatial distribution of a neutron field when they are used in a Bonner spheres spectrometer [1]. This spectrometer, proposed in late 1960 by Bramblet *et al.* [2], consisting of a thermal neutron scintillator (^{6}LiI(Eu) crystal) surrounded by moderating material (replaceable polyethylene spheres of different diameters), has a relatively low gamma sensitivity and a reasonable efficiency ($\sim$ 0.01 %) in an ample neutron energy range (0 - 15 MeV). The scintillator (4x4 mm^{2} in size), supported by a 30 cm long aluminum tube with a 3/8 inch diameter lucite light guide inside, is placed at the center of each sphere through appropriate radial holes. This geometry renders an isotropic response of the apparatus to an external neutron field, which is adequate for many applications. The minor modifications proposed adds a feature that allows to determine the relative directional intensity of a neutron field, without changing substantially the spectrometer's response.

During many years, several authors have been reporting the use of Bonner sphere spectrometer as reliable neutron monitors [3-5]. Techniques for dose rate determinations using a Bonner type spectrometer, both, as a single and as a multisphere neutron monitoring device are well established methods. However, little effort has been done in order to develop devices or techniques capable of determining the neutron angular distribution in mixed neutron fields for radiation protection purposes, when one is interested in evaluating the effective doses [6].

2. Experimental procedure

As stated previously, the detector used consists of a small ^{6}Lil(Eu) scintillator crystal set at the center of (selected) polyethylene spheres, known as a Bonner spectrometer. This spectrometer was modified by drilling a $^{3}\!/_{3}$ inch-diameter radial hole on each polyethylene sphere (perpendicular to the aluminum detector support tube). With this minor modifications, the spheres -upon rotation- were able to scan the spatial distribution of mixed neutrons fields, as was reported previously [1].

In order to improve the directional properties of this (modified) spectrometer and study the detector's angular response, we used a thermal neutron absorber made of cadmium in the form of a cylindrical shell (0.5 mm-thick and 12 cm-long), made to fit the radial holes of the spheres and cover the cylindrical surface, as shown in Fig. 1, and took a set of angular distributions using the 4, 5, 6, 8, 9 and 10 inches polyethylene sphere for a pair of neutron fields generated for the purpose.

These two neutron sources were generated from a thick ^{9}Be target bombarded with 4 MeV deuterons provided by the EN tandem accelerator of the Instituto Nacional de Investigaciones Nucleares (México).

The broad neutron energy spectra coming from the thick target ^{9}Be(d,n)^{10}B reaction can provide two different neutron fields: using it directly (without moderator material) and by using a thick 26 cm-long by 28 cm-diameter paraffin block surrounding the Be target assembly, as is shown in Fig. 2. The average neutron energy for the first neutron field (without paraffin) is larger than 4.5 MeV and the source strength

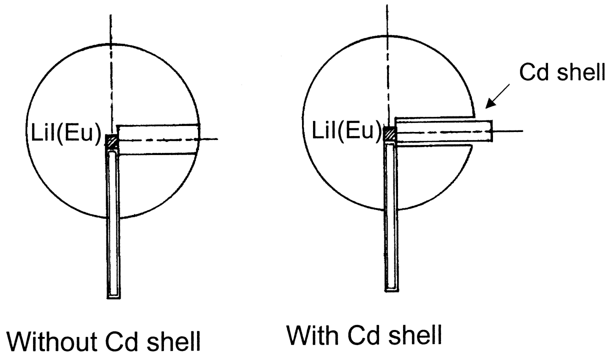

FIGURE 1. Detector geometries tested.

is about 5X10^9 neutrons/s in the forward direction. The arrangement with the paraffin block produce a neutron field whose energy is less than 1.5 MeV, rendered a source strength of approximately 5X10^6 neutrons/s in the forward direction. These estimations were obtained following the multi-sphere technique described by Hankins [4].

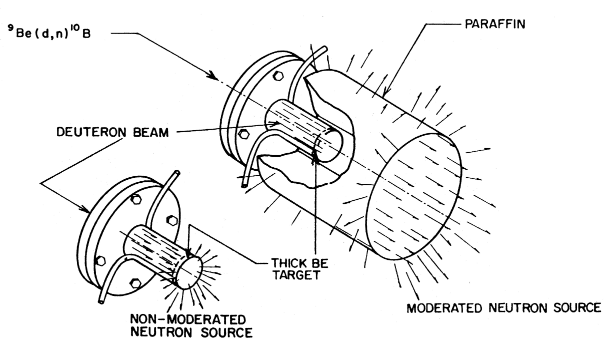

FIGURE 2. Schematic view of the target assembly used.

3. Measurements

Figure 3 shows a plan view of the scattering room, where the data was taken. The neutron detector was placed 2 m away from the sources along the zero degree line, at the same height of the target from the floor, 1.75 m. This figure indicates, as well, the main (scattering) objets near the central position, where the spheres were located in the various runs.

Fig. 4 shows a typical histogram of measurements (count rates) pertaining to a horizontal scan with the 5 inch sphere, taking (normalized) countings every 20 degrees by rotating the sphere upon its vertical axis. The zero degree reference is related to the point where the hole is oriented to the target. The filled lines are the results obtained previously with the hole drilled polyethylene sphere without the Cd shell, whereas the dashed lines are those obtained using the sphere with the Cd shell. For this later case, we have indicated a background counting rate, N_{BG} , shown by a thick dotted horizontal line (see Fig. 4). Above this counting rate, there are differential counting rates, which can be associated to contributions coming from specific directions.

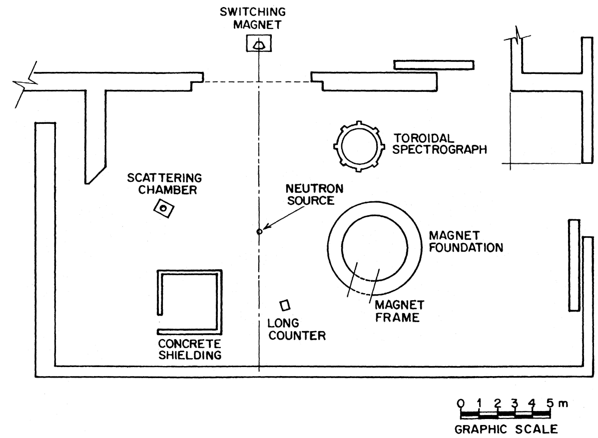

FIGURE 3. Schematic plan view of the scattering room.

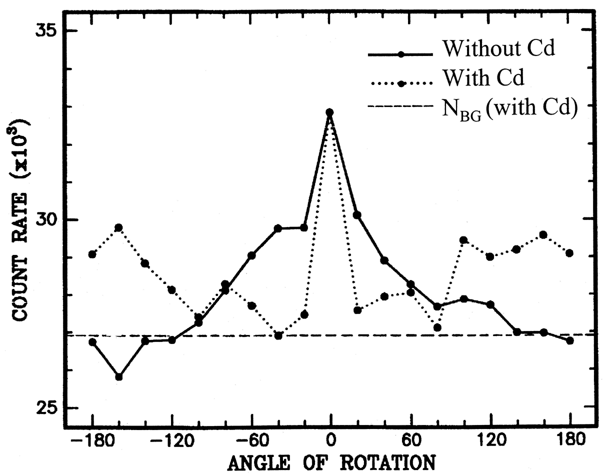

FIGURE 4. Typical angular response for 5 inch sphere with cadmium shell inserted in the radial hole.

4. Results

Figures 5 and 6 show the complete set of (differential) count rate measurements in polar coordinates obtained for the two neutron fields employed, with the spheres located at the fixed position shown in Fig. 2. The data reported here are the differential counting rates: $[(N_B - N_{BG}) / N_{LC}]$ as a function of the angle of rotation of the spheres; where, the counting rates of each sphere run, N_B, are normalized to corresponding counts (N_{LC}) of a long counter, used as a monitor, located 4 m away from the neutron sources (as shown in Fig. 2). N_{BG} is a so called "background" constant, equal to the minimum of the measured counts for each angular scan. The filled lines are the results obtained with the hole drilled polyethylene spheres without the cadmium shell, reported in a previous paper [1], whereas, the dashed lines are those obtained using the cadmium shell (for which a horizontal dashed line indicates the corresponding "background" constant). By observing these comparative figures, it is evident that the angular resolutions for detecting the main source are improved with the use of the cadmium shell, besides the fact that contributions coming from specific directions can still be associated to neutrons scattered by the objects near the place occupied by the spheres.

An outstanding point is the ability of the hole drilled spheres with the cadmium shell, to "see" the backscattered neutrons. This fact is outstanding in Figs. 5 and 6, since almost all the differential counts came from the backward hemisphere; whereas, in the case of the spheres without the cadmium shell, the differential counts came from the front hemisphere, where the main neutron source is located.

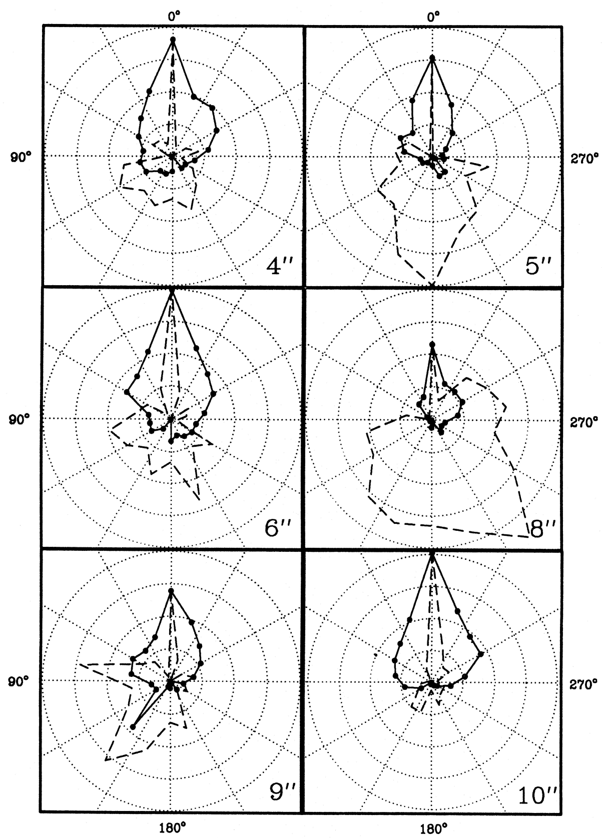

FIGURE 5. Polar coordinate graph of the differential count rate [(N_B- N_{BG}) / N_{LC}] for 4,5,6,8,9 and 10 inch spheres in the central position for the moderated neutron source. Filled lines were taken without the Cd shell, whereas, dashed lines represent the data from the spheres with the Cd inserted in the radial holes. Not in scale.

5. Applications

An essential element regarding the Bonner type spectrometer is the use of the apparatus as a neutron monitor comprising a single sphere device, which is possible, since the 10 and 12 inch spheres responses are, approximately, proportional to the Radiobiological Effectiveness (RBE) curve from thermal to 10 MeV neutron energy [2]. Several papers have been reported in the literature concerning the use of Bonner type spectrometers in the single and multisphere neutron monitoring techniques [2,3]. A useful question is if this application is still valid for the modified spheres.

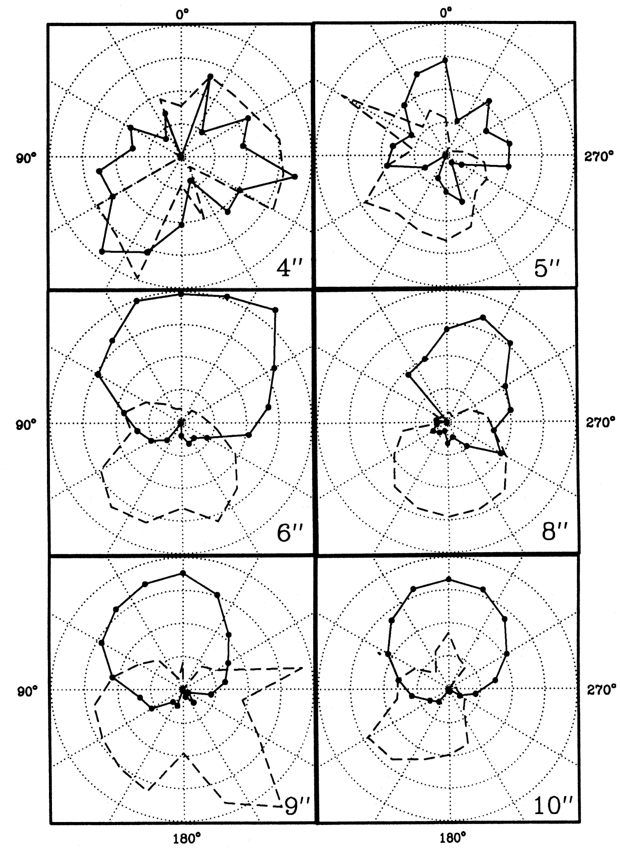

FIGURE 6. Polar coordinate graph of the differential count rate [(N_B- N_{BG}) / N_{LC}] for 4,5,6,8,9 and 10 inch spheres in the central position for the non-moderated neutron source. Filled lines were taken without the Cd shell, whereas, dashed lines represent the data from the spheres with the Cd inserted in the radial holes. Not in scale.

In order to investigate this, we took several runs using an Am-Be neutron source and the 10 inch sphere without the drilled holes and compared these measurements with the defined background count rate for the modified spheres. The results of this evaluation are summarized in Table 1, taken for a set of spheres from 4 to 10 inch-diameter. In spite of the fact that the differences between the common spheres (non-holed) and the modified ones (holed) are statistically significant (in particular, for the smaller diameters), since, in most practical situations, the dose evaluations rely on the count rates of big diameter spheres (8, 10 or 12 inch), the corresponding differences are not significant for radiation protection purposes. This was an expected result, taking into account the relative minor differences in moderator material for sphere sizes of 8 inches or more. In Table I (and Table II), the deviations of each mean value are not given, since the corresponding set of measurements (18 in total), per sphere, are all different and, each one, related to a particular scattering condition of the experimental area.

TABLE I. Relative (angular average) count rates (cps) taken from an Am-Be source, for a set of common spheres and hole-drilled spheres (without Cd).

Sphere diameter (Inches)	Average counts without hole (Common)	Average counts with hole (Modified)
4	1400	1128
5	2103	1870
6	2767	2531
8	3048	2989
9	3087	3129
10	2913	2906

Besides, in the case of the hole-drilled spheres with the cadmium shell, it turns out that the reported differences in the count rates are significant throughout the entire set, due to the additional neutron absorptions by the cadmium shell. Thus, another set of measurements taken for the moderated and non-moderated Be(d,n) sources, summarized in Table II, show up major differences in the mean count rates when the cadmium shell is used in relation to the hole drilled spheres without cadmium. On the basis of these arguments, it can be stated that the average neutron dose rates can be estimated from the average count rates of the hole-drilled spheres without using the cadmium shell.

Furthermore, using the modified Bonner sphere results (with and without cadmium), some additional information concerning the spatial neutron distribution can be extracted, and used to record the percent of deposited energy due to some particular direction. This fact can be useful for radiation protection purposes [6,7], if effective doses are of any concern.

TABLE II. Relative (angular average) count rates (cps) taken from the Be(d,n) source, for a set of hole drilled spheres with and without Cd shell.

	Moderated neutron source		Non-moderated neutron source	
Sphere diameter (Inches)	Hole drilled without Cd shell	Hole drilled with Cd shell	Hole drilled without Cd shell	Hole drilled with Cd shell
5	66098	32456	20072	15765
6	68006	31246	25811	14945
8	59952	31180	27227	17419
9	56108	28748	27819	14698
10	51568	20490	22277	11331

6. Conclusions

The main purpose of this paper was to search a better determination of the directional properties of hole-drilled spheres as a neutron monitor device. Certainly, these properties are enhanced by adding a cadmium cylindrical shell. However, the detector responses could be studied further in detail if mono-energetic neutrons are used.

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1. A. Varela, R. Policroniades, F. Jiménez, J. Calvillo, *Nucl. Instrum. Meth. Phys. Res. A* **428** (1999) 439.
2. R.I. Bramblet, T.I. Ewing and T.W. Bonner, *Nucl. Instrum. Meth*. **9** (1960) 1.
3. D.E. Hankins, Los Alamos Scientific Laboratory, *Report* **LA-2717**, Los Alamos (1962), New Mexico, USA.
4. D.E. Hankins, Los Alamos Scientific Laboratory, *Report* **LA-3700**, Los Alamos (1968), New Mexico, USA.
5. D. Nachtigall and G. Burger, *Topics in Radiation Dosimetry*, Supplement 1, Chap. VII, Edited by F.A. Attix (Accademic Press 1972).
6. M. Luszik Bhadra, H. Kluge, M. Matzke, *Radiat. Prot. Dosim.* **66** (1996) 335.
7. A. Toyokawa, A. Uritani, C. Mori, N. Takeda, K. Kudo, *Radiat. Prot. Dosim.* **70** (1997) 335.