A NEUTRON DOSEMETER WITH SPHERICAL MODERATOR CONTAINING ABSORBERS AND A BF_3 COUNTER

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Abstract—The Bonner moderating sphere, 25–30 cm in diameter, is widely used because of its isotropic and dose equivalent response for neutrons over an energy range from near thermal to about 10 MeV. However, two properties of the instrument limit its convenience: (1) the LiI scintillation counter in its center tends to make it difficult to use the instrument in high γ-fluxes, also response changes of the scintillation counter make frequent recalibrations necessary. (2) The moderating sphere is rather large and heavy for a portable instrument. The use of a BF_3 thermal neutron counter of 5 cm sensitive length and 2.5 cm diameter eliminated all difficulties mentioned under (1). Insertion of cadmium discs at appropriate locations in the polyethylene sphere near the counter ends made the response isotropic for all neutron energies. To improve on (2), neutron absorption studies were made in a slab geometry containing cadmium and polyethylene sheets, so as to obtain the best rem dose response for neutrons from an Am-Be source (E_{av} = 4.4 MeV) and from a Sb-Be source (E_{av} = 40 keV). On this basis, a compact neutron dosemeter 20 cm in diameter containing an inner cadmium shell of 10 cm diameter was constructed and tested.

INTRODUCTION

To obtain the dose equivalent (DE) at some location of a neutron radiation field, knowledge of the fluence and the neutron energy spectrum is normally required. The measurements are laborious and during the last years use is being made of neutron monitors the response of which is essentially proportional to the DE. Such instruments can then be calibrated in "rem" units. The response, as recommended by the National Committee on Radiation Protection and Measurements[1] is shown in Fig. 1. An approximation to a DE response can for instance be achieved by surrounding a thermal neutron detector with a moderator of appropriate thickness.

Two approaches have been used: the first, consisting of a BF_3 counter surrounded by a cylindrical moderator, was originally realized by De Pangher.[2] The second is a Bonner sphere[3] with a small LiI scintillation detector in the center. Many variations of these basic systems have been reported in the literature.[4-8] Both systems have certain limitations: a cylindrical geometry will not ensure a true isotropic response at all energies and will not respond as a point detector. On the other hand, for the spherical geometry, the γ-rejection rate of a LiI scintillation detector is much less than that of a BF_3 counter which tends to make it difficult to use the spherical dosemeter in high γ-fluxes. Also the smallness of the LiI detector results in reduced neutron sensitivity. For both geometries the moderator has to be rather large and heavy for a truly portable instrument.

It seemed therefore desirable to try to design an instrument which combines the advantages of the two basic systems, by using spherical geometry and a BF_3 counter as detector. To reduce the size of the instrument, neutron absorbing material can be incorporated into the moderator as shown by Andersson and Braun[5] for cylindrical geometry.

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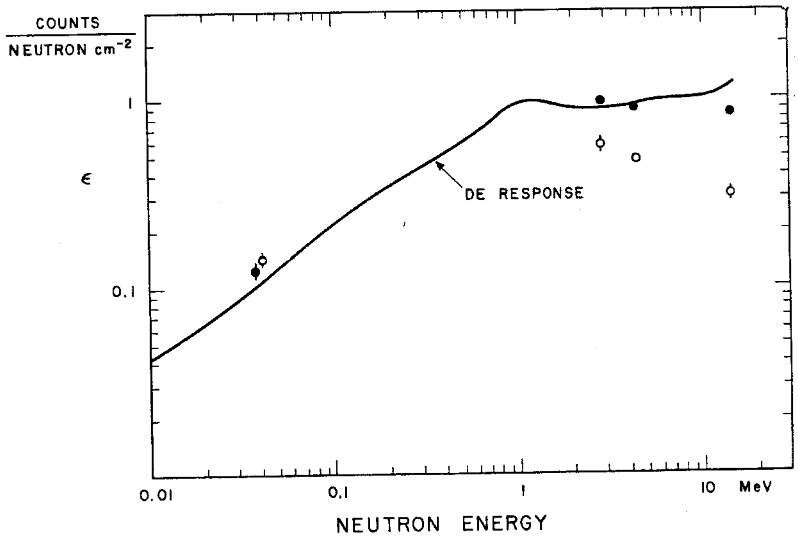

FIG. 1. Closed circles: response of the 30 cm sphere with BF_3 counter in center. Open circles: response of compact dosemeter.

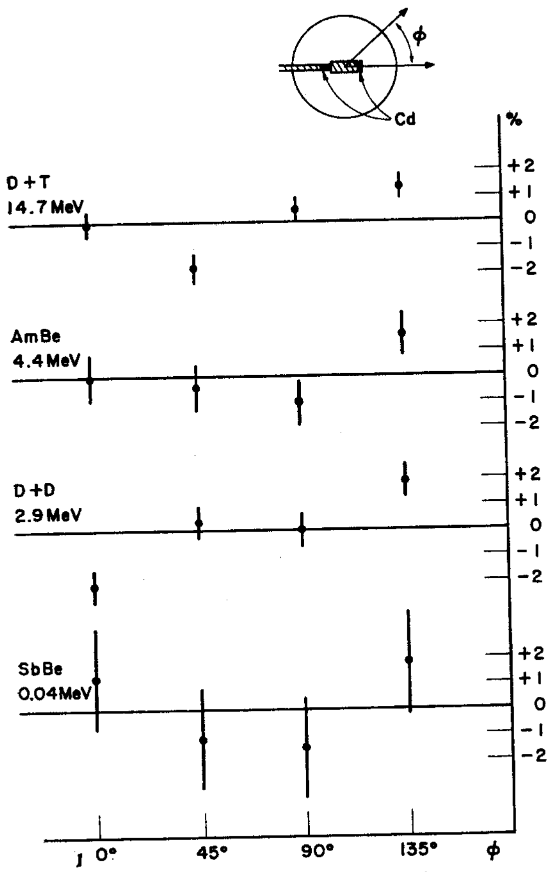

FIG. 2. Angular response of 30 cm dosemeter.

NEUTRON SOURCES

To test the response of the instruments, neutrons from the D + D (2.9 MeV) and D + T (14.7 MeV) reaction were used, as well as from ^{124}Sb-Be(γ,n) and ^{241}Am-Be(α,n) sources. An Sb-Be source emits two neutron groups, one centred around 24 keV, the other around 380 keV with an intensity ratio of 1 : 0.046 respectively,[7] resulting in an average energy of 40 keV. For the Am-Be source a mean energy of 4.4 MeV has been assumed, as derived by Geiger and Hargrove[8] from the measurement of the neutron spectrum.

Neutron emission rates have been determined absolutely with a precision long counter[9] taking into account the change of the effective center with neutron energy. The calibration of the counter was carried out with an Am-Be source, the neutron emission rate of which was measured absolutely in a manganese sulphate bath.[10] The ratio for the emission rate of the Sb-Be source to the emission rate of the Am-Be source as determined with the long counter agreed with the ratio measured in a manganese sulphate bath to within 3%.

POLYETHYLENE SPHERE DOSEMETER, 30 CM DIAMETER

A regular size Bonner sphere, 30 cm in diameter,[3] was equipped with a BF_3 counter of 2.5 cm diameter with its sensitive volume of 5 cm length in the center of the sphere.* The energy response to neutrons conformed to the DE curve of Fig. 1 only when irradiated from a direction at right angles to the BF_3 counter; i.e. the angular response was not uniform. Insertion of a cadmium sleeve at the connector end of the counter and of a cadmium disc at the other end, as indicated on the top of Fig. 2, made the response isotropic for the neutron energies available. The lower part of Fig. 2 shows that the deviations from the mean are less than 2%. The counting efficiency versus energy is shown in Fig. 1 by the closed circles and follows well the dose equivalent curve.

The response of this instrument has also been compared to that of a regular 30 cm polyethylene sphere dosemeter with a 4 × 4 mm ^{6}LiI (Eu) scintillation detector in its center. Within the error of the measurement (±2%) the response agreed with that of the sphere dosemeter containing the BF_3 counter, but the one containing the LiI detector showed its sensitivity reduced by a factor 5.2. Because the high γ-field of the Sb-Be source caused pulse pile-up in the scintillation detector, an Am-Be source, embedded into a 20 cm polyethylene sphere, was used to check the low energy neutron response.

COMPACT NEUTRON DOSEMETER

The 30 cm spherical dosemeter is rather large and heavy for a portable monitor. An attempt was therefore made to reduce its size and still retain approximate DE response by incorporating a cadmium absorber within the moderator. Neutron absorption studies in slab geometry using polyethylene and cadmium sheets were carried out; these measurements led to the design of a 20 cm diameter sphere, containing an inner 0.5 mm cadmium shell, 10 cm in diameter, as shown in Fig. 3. When a cadmium sleeve was added around the connector of the BF_3 counter, an optimized angular response as shown in Fig. 4 was found. The deviations from the mean now reach 6% at low energies which is still acceptable for neutron monitoring. The energy response is shown in Fig. 1 by the open circles. The new design has changed the sensitivity very little but

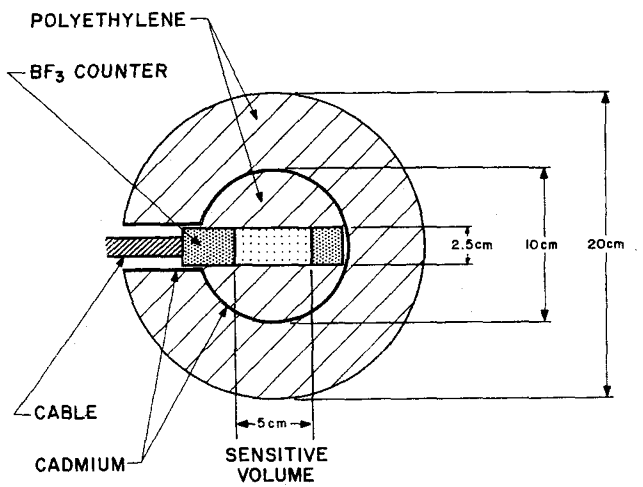

FIG. 3. Compact neutron dosemeter.

* BF_3 counter supplied by Reuter Stokes Inc., Skokie, Ill., filling pressure 70 cm Hg of $^{10}BF_3$, Model No. RSN-40A-M2.

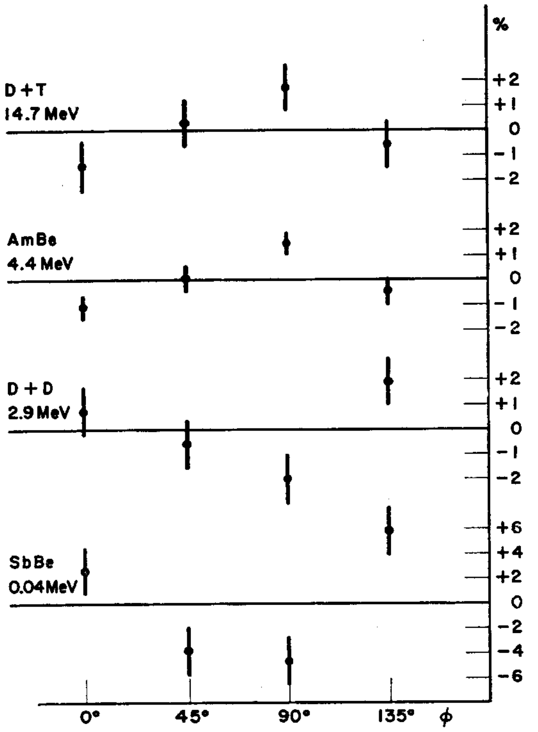

FIG. 4. Angular response of compact neutron dosemeter.

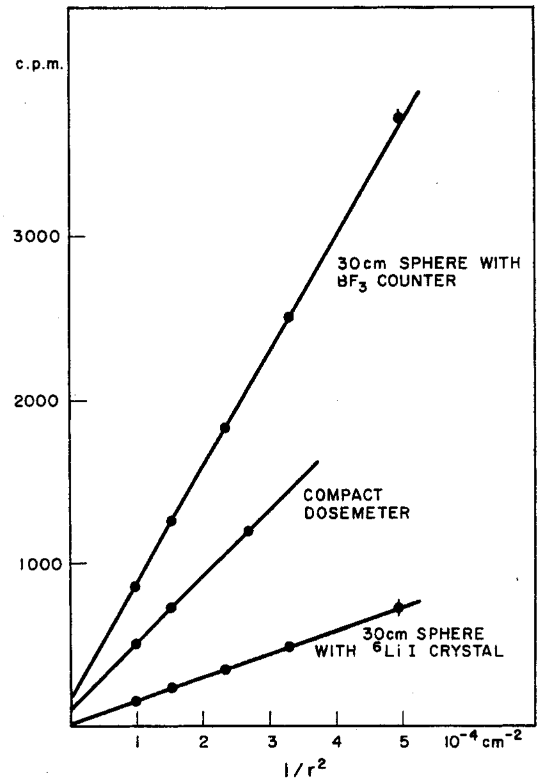

FIG. 5. Counting rate versus inverse square of distance between Am-Be source and center of dosemeter.

deviations from the dose equivalent curve are somewhat larger.

CONCLUSIONS

The use of a BF_3 counter with appropriately located cadmium absorbers instead of a small LiI detector in spherical dosemeters results in a simple to operate and more sensitive instrument with the stable operation inherent to BF_3 counters. By embedding further cadmium into the moderator a truly portable instrument evolved where the weight is reduced from 13.4 kg for the 30 cm sphere to 4.1 kg for the compact dosemeter. The shape of the dose equivalent curve from 0.040 to 5 MeV is still followed to within $\pm$ 30% which can be considered adequate for a radiation protection monitor. Even at higher energies its response follows more closely the DE curve than that of a regular 25 cm diameter polyethylene sphere with a LiI detector,[4] an instrument frequently used at present where weight is a disadvantage. All dosemeters investigated show the properties of a point detector. This is borne out by Fig. 5 showing the dependence of the counting rate on the inverse square of the distance between the center of the sphere and the Am-Be source, resulting in straight lines. The same behaviour is found for the other neutron energies. Room scattered neutrons add a background which is essentially independent of distance. This background is given in Fig. 5 by the intersection of the straight line with the counting rate axis.

The high sensitivity of the instruments containing a BF_3 counter is particularly advantageous for the investigation of radiation shielding effects and protection measurements around accelerator installations. For the 30 cm sphere dosemeter or the compact dosemeter both containing the BF_3 counter of 5 cm sensitive length, the sensitivity is approximately 20,000 counts per millirem.

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