Fermilab
ES&H Section

RADIATION PHYSICS NOTE 126

Calibration Factors for Bonner Spheres

Alex Elwyn and Kamran Vaziri

October 1996

Written by: ______________________ Date 11/4/96
Alex Elwyn

Written by: ______________________ Date 11/4/96
Kamran Vaziri

Reviewed by: ______________________ Date 11/4/96
Don Cossairt, RP Associate Head

Reviewed by: ______________________ Date 11/4/96
Bill Griffing, ES&H Section Head

Distribution via QuickMail
Radiation Protection Group

1. Introduction

Calibration factors for a 4- x 4-mm diameter ^{6}LiI Bonner sphere system have been determined by Hertel, et al (1987) by use of a ^{252}Cf neutron source. These factors are used to correct individual sphere counting rates prior to unfolding spectra from them. Most sets of response matrices used in the unfolding procedures are from calculations (based on a variety of techniques) to simulate the actual detector rather than from measurements. Calibration factors tend to correct for deficiencies in these sphere response matrices when the system is used in an unknown field, provided that the spectrum from the calibration source is at least somewhat representative of the unknown spectrum, or that the response matrices really represent the true energy dependence of the spherical detectors.

In this note, we describe the method used to determine individual sphere calibration factors for the 12.7- mm high x 12.7-mm diameter cylindrical ^{6}LiI scintillators in use with the Fermilab Bonner sphere system. An AmBe neutron source was used in these studies which took place on the mezzanine at RPCF. The results are based on the measurements described by Kemp, et al (1996).

2. Procedure and Results

The calibration factor for each moderated spherical detector is determined by dividing the measured free-field count rate from a given source by the count rate predicted for the source using a specific response matrix. These factors are then used to correct sphere counting rates from measurements in an unknown field before unfolding the spectrum.

Kemp, et al (1996) measured Bonner sphere count rates at three distances (1, 1.5, and 2 m) from an AmBe source placed near the center of the room. Measurements were done at three heights - 0.375, 0.948, and 2.392 m - above the floor. The calibration factors discussed in this report are based on the measurements at the largest height, 2.392 m. At this height Eqn. (1) discussed below represents an appropriate method for determining the room scattering contribution to the total measured individual sphere response (Kemp, et al, 1996).

The generalized equation given by Hunt (1984) for spherical detector count rates was used by Hertel, et al (1987) to determine the free-field count rate from the observed total count rate. Under the reasonable assumptions that correction for source anisotropy, geometric correction for non uniform illumination, and air scattering correction are, at the most, a few percent, and so can be neglected, the observed sphere count rate can be written as

$$C_{obs} = (B\varepsilon/4\pi r^2)\,(1 + Sr^2). \qquad (1)$$

Here, B is the source strength in neutrons per unit time, S is the room return correction factor, r is the distance of source from the spherical detector, and ε is the spectrum-averaged detector response to unit AmBe fluence in count rate per unit fluence. This is the quantity necessary to determine the calibration factor for each sphere.

Kemp, et al (1996) wrote the above equation as

$$C_{obs} = a/r^2 + b. \qquad (2)$$

From a least-squares fit to observed counting rates at the three source-to-detector distances, values of a and b were obtained for each sphere at each of the measurement heights above the floor. Then, from equations (1) and (2), the spectrum-averaged response for each sphere from the measurement is

$$\varepsilon = a\,(4\pi/B). \qquad (3)$$

Values of ε, called ε', based on what is generally accepted in the literature as the known AmBe spectrum weighted by an appropriate set of responses matrices, are also needed in order to determine sphere calibration factors, as mentioned above. The measured AmBe spectrum of Kluge and Weise (1982), given in Table 4-VIII in the IAEA Report 318 (Griffith, et al, 1990) in the form of fluence per unit log energy (lethargy), is such a spectrum. It is set up so that the integral over energy of the spectrum in lethargy ùnits is equal to one. Based on this known spectrum and by use of known (i.e., calculated) sphere response matrices the predicted spectrum weighted response ε' (in counts per unit fluence) for each sphere can be determined as

$$\varepsilon' = \int [dN/d(\log E)]R(E)dE, \qquad (4)$$

where $dN/d(\log E)$ is the spectrum (fluence as a function of energy) in lethargy units and $R(E)$ are the sphere response matrices. (In the present case, these are given by Sanna, as discussed below). The calibration factor for each sphere is then defined by taking the ratio of the measured fluence response to an AmBe source to the predicted fluence response based on the known AmBe spectrum and a given set of sphere response matrices,

$$CF = \varepsilon / \varepsilon'. \qquad (5)$$

Thus, sphere counting rates from measurements in an unknown spectrum should be modified by these factors. It is noted, however, that if the unknown spectrum is very different from that of the calibration source (in this case, AmBe), the use of these factors presupposes that the response matrices really represent the true energy dependence of the spherical detectors. This is not known a priori.

In the present work, we have used the response matrices for 12.7-mm high x 12.7-mm diameter LiI scintillators given by Sanna (see, e.g., Awschalom and Sanna, 1985). However, the AmBe spectrum in IAEA 318 is not given in that publication at the same energies at which the Sanna response functions are presented. In order to calculate spectrum-weighted sphere responses for use in the determination of ε', therefore, the values of the response functions at the appropriate energies were obtained by interpolation from those given by Sanna. Then the numerical integration, Eqn. (4), was carried out by use of the integration macro in the KaleidaGraph (1994) computer program.

Values of ε for each sphere, obtained from the study of Kemp, et al at a height of 2.392 m, by use of Eqn. (3), and ε', from use of Eqn. (4), are shown in Table 1 and plotted as a function of sphere diameter in Fig. 1. Calibration factors, CF (Eqn. 5), are also given in the Table, and plotted for each sphere in Fig. 2.

3. Discussion

The neutron energy spectrum of Kluge and Weise (1982) was not measured below 0.1 MeV. As presented in IAEA 318 (Griffith, et al, 1990) the fluence is taken to be zero at all energies below this value. The very large uncertainty in the results for the bare detector reflects this situation. The calibration factor is essentially indeterminant for any neutron source for which the fluence at low energies is very small. For all spheres of 2 inch diameter and greater the calibration factor is seen in Table 1 to have values close to unity. It seems reasonable, therefore, that, at least when the sphere response matrices of Sanna (Awschalom and Sanna, 1985) are used for spectral unfolding, calibration factors of unity are a good approximation and their use should lead to an adequate determination of the fluence spectrum from a 12.7-mm high x 12.7-mm diameter ^{6}LiI multisphere spectrometer.

4. References

Awschalom, M.. Sanna, R.S. Applications of Bonner sphere detectors in neutron field dosimetry. Radiat. Prot. and Dosim. 10, 89 (1985).

Griffith, R.V., Palfalvi, J., Madhranath, U. Compendium of neutron spectra and detector responses for radiation protection purposes, IAEA Tech. Rep. # 318, IAEA, Vienna (1990).

Hertel, N.E., Hartley, R.S., Gaines, A.D. Determining calibration factors for Bonner spheres. Trans. of Amer. Nucl. Soc. 55, 220 (1987).

Hunt, J.B. The calibration of neutron sensitive spherical devices. Radiat. Prot. Dosim. 8, 239 (1984).

KaleidaGraph Version 3.0.5, Adelbeck Software (1994).

Kemp, A., Boehnlein, D., Elwyn, A.J., Vaziri, K. A study of neutron room scattering at RPCF. Rad. Phys. Note 125, Fermilab (1996).

Kluge, H., Weise, K. The neutron energy spectrum of a ^{241}AmBe(α,n) source and resulting mean fluence to dose equivalent conversion factors. Radiat. Prot. Dosim. 2, 85 (1981).

Table 1

Values of ε, from Eqn. (3), and ε', from Eqn. (4), and calibration factors, CF, from Eqn. (5), from measurements based on the single peak data analysis of Kemp, et al (1996) at a height of 2.392 m. above the floor at RPCF.

Sphere Diam (inch)	a at h=2.39 m	error in a (%)	ε	$\Delta\varepsilon$	ε' †	CF	error CF
0	1.935E+05	123.00	2.048E-03	2.519E-03	5.022E-03	4.08E-01	5.02E-01
2	5.643E+06	26.000	5.971E-02	1.553E-02	5.017E-02	1.19E+00	3.09E-01
3	2.748E+07	2.120	2.908E-01	6.165E-03	2.449E-01	1.19E+00	2.52E-02
5	1.035E+08	0.880	1.095E+00	9.640E-03	1.007E+00	1.09E+00	9.57E-03
8	1.454E+08	0.170	1.539E+00	2.616E-03	1.638E+00	9.40E-01	1.60E-03
10	1.437E+08	0.660	1.520E+00	1.003E-02	1.548E+00	9.82E-01	6.48E-03
12	1.112E+08	0.520	1.177E+00	6.119E-03	1.288E+00	9.14E-01	4.75E-03
18	5.213E+07	0.100	5.516E-01	5.516E-04	5.223E-01	1.06E+00	1.06E-03

† from integration of IAEA spectrum folded with Sanna response functions

Figure 1

Values of ε and ε' plotted as a function of sphere diameter.

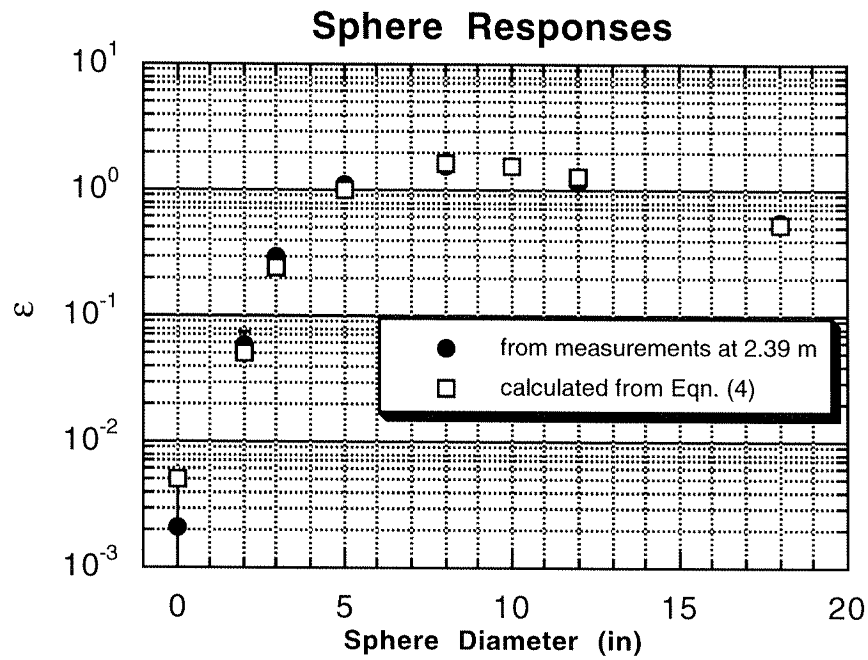

Figure 2

Calibration factors, CF, plotted as a function of sphere diameter.