Fermi National Accelerator Laboratory

FERMILAB-Conf-96/334

CONF-970134--4

A Study of Neutron Room Scattering at RPCF

Andrew Kemp, David Boehnlein, Alexander Elwyn and Kamran Vaziri

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

September 1996

Submitted to *Health Physics Society 1997 Midyear Topical Meeting*, San Jose, California, January 5-8, 1997.

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

DISCLAIMER

A STUDY OF NEUTRON ROOM SCATTERING AT RPCF

Andrew Kemp[#], David Boehnlein, Alexander Elwyn, and Kamran Vaziri

Fermi National Accelerator Laboratory, P. O. Box 500, Batavia, IL 60510[*]

Introduction

High energy physics facilities must monitor the radiation doses received by their personnel. This monitoring can only be effective if the radiation detection devices can be calibrated with a good degree of accuracy. Radiation fields are usually composed of several types of radiation, including gamma rays, beta radiation, neutrons, etc. The neutron detection instruments respond not only to the neutrons coming directly from the source but also those scattered from the floor, walls, and ceiling. The amount of neutron scattering varies from site to site depending on the construction materials and layout of the building. The purpose of this study was to determine the scattered neutron fraction in the central volume of the calibration mezzanine of the Radiation Physics Calibration Facility (RPCF) at the Fermi National Accelerator Laboratory (Fermilab). At Fermilab, radiation workers dosimeters use CR39 for neutron detection, which are sent to an outside vendor for reading. As part of the quality assurance program, Fermilab routinely sends the vendor "spiked" badges, i.e. badges exposed to a known amount of neutron dosage at RPCF. This study determines a correction factor due to scattered neutron to the spiked badges. The study was conducted in a room with floor dimensions of 12 m by 9.5 m. The walls and ceiling are thin steel and insulation supported by steel I-beams. We determined the total amount of radiation at three heights above the floor, and at three distances from an AmBe neutron source at each height in the RPCF using the Bonner Sphere technique (Awschalom and Sanna 1983).

Financial support for this project was partially provided by the Teacher Research Associate (TRAC) Program, which is administered by Associated Western Universities, Inc., and sponsored by the U. S. Department of Energy.

* This work was performed at the Fermi National Accelerator Laboratory under contract DE-AC02-76CH03000 with the U. S. Department of Energy.

Equipment

Detectors were exposed to an ^{241}AmBe source with a flux of 1.98 x 10^7 neutrons per second (Krueger 1992). This is the same source used for most spiking of badges because its spectrum most resembles that found outside radiation shields at Fermilab. A 4 mm thick lead cap was used to remove the 59.6 keV gamma rays from ^{241}Am decay. Neutrons were moderated by a set of polyethylene Bonner spheres, each containing a 12.7 mm high x 12.7 mm diameter ^{6}LiI(Eu) scintillation detector. The diameters of the spheres were: 5.08 cm, 7.62 cm, 12.7 cm, 20.32 cm, 25.4 cm, 30.48 cm, and 45.72 cm. One unmoderated (bare) detector was also used in each test. Spheres were placed on an aluminum scaffold propped between two aluminum ladders.

Methods

The Bonner Spheres were placed one at a time into the neutron field of the source. (see Cossairt, et al. 1988 for operating procedures). A count rate for each run was obtained from the spectrum by marking the boundary of the peak of interest. Then, after fitting a background the area of the peak above background was extracted.

The source and detectors were placed at the same heights above the floor for any given run. The three heights used were 37.5 cm, 94.8 cm, and 239.2 cm. The spheres were also placed at three distances from the source for each height: 100 cm, 150 cm, and 200 cm. Heights and distances were measured with respect to the geometrical centers of the source and spheres. Detectors were exposed one at a time in order to avoid potential problems with nonuniformities in the radiation field, and the possibility of sphere to sphere "crosstalk." Detectors were exposed for a time sufficient to register a minimum of 10^4 counts. Thus, the 5.08 cm sphere was exposed for 45 minutes, the bare detector for 100 minutes, and the remaining spheres for 10 minutes.

The neutron fluence spectrum was unfolded from individual sphere responses using the computer program BUNKI (see Elwyn 1989 and references therein for a discussion of unfolding spectra from measured multisphere counting rates). This program calculates the total measured fluence (F_m), as well as several other quantities of interest, such as dose equivalent. There are several possible routes to determine the amount of neutron scattering, each with its advantages and disadvantages. Here, we use 3 methods, discussed below.

Method 1: Subtraction

If total measured fluence (F_m) is the sum of those neutrons detected as coming directly at the detector (F_D) and those neutrons scattered into the detector (F_S), then

$$F_S = F_m - F_D, \quad (1)$$

The scattered fraction (S_S), then, is F_S/F_m. Theoretical direct fluence can be determines by considering that the neutron radiation arises from a point-like isotropic source, and follows the inverse-square law. Thus, the ideal direct fluence (F_D) at a given point can be predicted from

$$F_D = Q/4\pi\, r_o^{\,2}, \quad (2)$$

where Q is the source neutron rate, and r_o is the source to detector distance.

Method 2: Curve-fitting

The observed total response for each sphere—on the assumption that air scattering, source anisotropy, and geometric corrections are negligible—is given by

$$C_{obs} = a/\, r_o^{\,2} + b, \quad (3)$$

where r_o is the source to detector distance, $a/\, r_o^{\,2}$ is the direct neutron contribution from the source, and b, the room scattering contribution, is assumed to be independent of distance from the source. The coefficients a and b were obtained for each detector at each height by fitting Eqn

(3) to a plot of count rate versus r_0 (Fig. 1). The direct and scattered count rates from the fit for all spheres at each height were entered into the BUNKI program to obtain fluences and dose equivalents for the direct and scattered portions. The scattered fluence portions divided by the total measured fluences (F_m), which will be different at each distance r_0 from the source, give the scattered fractions (S_C) for this method.

Method 3: Jenkins' formulae

Using a wide range of energies and source to detector configurations, Jenkins (1980) has determined an empirical formula for predicting the fluence due to neutrons scattered mainly from one surface (F_1). His formula is based on a simple geometric model and may be written as:

$$F_1 = F_D N, \qquad (4)$$

where F_D is, again, the "ideal" fluence calculated from Eqn (2), and N is the fluence scattering factor determined from

$$N = \frac{1.52\, R/r_0}{(1+0.1E)\left[1+\left(R/r_0\right)^3\right]}, \qquad (5a)$$

where r_0 is the source to detector distance, and R is the source to detector distance after one bounce off the floor, and E is the average energy (in MeV) of the neutrons from the source, which for an ^{241}AmBe source is assumed to be 4.2 MeV. Therefore, for the AmBe source Eqn (5a) reduces to

$$N = \frac{1.07\, R/r_0}{1+\left(R/r_0\right)^3}. \qquad (5b)$$

Jenkins' (1980) formula for total fluence can be written as

$$F_J = F_D + F_1. \qquad (6)$$

Therefore the scattered fluence fraction (S_J) is F_1/F_J.

Results & Discussion

The scattered fractions determined by the three methods are shown in Table 1. The largest differences are found at the lowest height. Specifically, the amount of scattering found at h = 37.5 cm by the curve-fitting method is significantly less than the scattering predicted by the other two methods at this height.

The direct neutron contribution to the measured fluence is proportional to $1/r^2$, but the scattered portion is not so constrained. Therefore, we expected the contribution of scattered neutrons to the total fluence to become proportionally larger as the source-to-detector distance increased. This hypothesis is supported by the results of all three methods used for determining scattered fractions (Table 1). We expect that the higher the detectors were above the concrete floor, the lower the number of scattered neutrons they would intercept. Except for the scattered fraction at h = 37.5 cm determined from curve-fitting, the scattered neutron fractions shown in Table 1 are inversely proportional to height, supporting this hypothesis.

In the curve-fitting method, there is a smaller percentage of scattered neutrons near the floor than there are at the larger heights, a result which contradicts expectations from geometric considerations, as well as differing from the results of the other two methods for calculating scattering. It should be recalled that the curve-fitting method assumes that the amount of scattering is independent of distance from the source. At a height of only 37.5 cm from a thick scatterer (the floor) this assumption is clearly not satisfied.

The fluence values actually measured in the RPCF agree to within 10% with those predicted by Eqn (6) (Table 2). Therefore, total fluences within 10% of those measured in the RPCF can be calculated using Eqn (6). Jenkins (1980) also derived a corresponding formula for the dose equivalent of the scattered fraction ($D.E._{scat}$) which can be written,

$$D.E._{scat} = CF_D f. \tag{7}$$

The variable "C" is the source fluence-to-dose equivalent conversion factor; for our source C has a value of 1.37 (μSv hr^{-1} n^{-1} cm^2•sec) (Krueger 1992). The variable f is the dose equivalent scattering factor. This factor may be calculated from

$$f = \frac{0.75\, R/r_0}{1 + \left(R/r_0\right)^3}. \tag{8}$$

The scattered contribution to the dose equivalent calculated from the curve fitting method is given in Table 3. At the lower height, the calculated values are not very close to those predicted by the Jenkins equation (Table 4) because of the limitations on use of Eqn (3) at these heights, as discussed earlier. However, the total dose equivalents predicted by Jenkins' formula are close to those determined in this study, as obtained from actual measured counting rates by use of BUNKI. Jenkins' formula for total dose equivalent may be written as

$$D.E._J = F_D C(1 + f). \tag{9}$$

On the average Eqn (9) gives values about 9% higher than those measured (Table 5). As an example Fig. 2 shows a typical plot of fluence (neutrons cm^{-2} min^{-1}) per unit lethargy as a function of neutron energy for the scattered and the direct neutrons as deconvoluted by BUNKI for a height of 239 cm. The scattered neutrons are more than an order of magnitude less intense than the direct neutrons, and the peak energy is about an order of magnitude lower than that of the direct neutrons, as expected.

Conclusions

There is a significant amount of neutron scattering in the RPCF, mostly arising from the concrete floor. Spiking runs are usually conducted at a height of about 2 meters and a horizontal distance of 1 meter. The data from this study suggest scattered neutrons contribute about 15% to 20% to the total fluence and 10% to the dose-equivalent at this configuration. The contribution of scattering to total fluence can now be predicted by using the Eqn (6), with F_1 given by Eqn (4). The dose equivalent can also be calculated using the Eqn (9).

Although the present study detailing the fractions and energy spectra associated with scattered neutrons at RPCF only holds rigorously for moderated spherical neutron detectors, the fact that the measurements agree with the formulae for the scattered fraction given by Jenkins (which are independent of the particular neutron detection technique) gives confidence that the results should hold for any detector used during spiking activities.

References

Awschalom, M.; Sanna, R. S. Applications of Bonner sphere detectors in neutron field dosimetry. Fermilab TM-1209, 1183.000; 1983. (Also Radiat. Prot. and Dosim. 10: 89-101; 1985.)

Awschalom, M.; Sanna, R. S. Applications of Bonner sphere detectors in neutron field dosimetry.

Cossairt, J. D.; Elwyn, A.J.; Freeman, W.S.; Salsbury, W.C.; Yurista, P. M. Measurements of neutrons in enclosures and outside of shielding at the Tevatron. Proceedings of the 22 Midyear Tropical Meeting of the Health Physics Society. San Antonio, Texas; Dec. 4 - 8, 1988.

Eisenhauer, C. M.; Schwartz, R. B.; Johnson, T. Measurement of neutrons reflected from the surfaces of a calibration room. Health Phys. 42: 489-495; 1982.

Elwyn, A. Observations on spectrum unfolding with BUNKI. Fermilab Radiation Physics Note 80; 1989.

Jenkins, T. M. Simple recipes for ground scattering in neutron detector calibration. Health Phys. 39: 41-47; 1980.

Krueger, F. Calibration of radioactive sources used by Fermilab ES&H Section for instrument calibration and characterization. Fermilab Radiation Physics Note 83; 1992.

Table 1. Comparison of scattered fractions determined by 3 methods: S_S = subtraction method, S_C = curve-fitting method, and S_J = Jenkins formula, Eqn (3).

	Height (cm)	S_S	S_C	S_J
r_0=100 (cm)	239.2	14.9 %	3.6 %	4.3 %
	94.8	21.9 %	8.5 %	17.4 %
	37.5	37.0 %	1.5 %	31.2 %
r_0=150 (cm)	239.2	18.6 %	7.7 %	8.5 %
	94.8	30.1 %	17.1 %	25.0 %
	37.5	38.3 %	3.2 %	33.3 %
r_0=200 (cm)	239.2	23.5 %	12.9 %	13.0 %
	94.8	37.4 %	27.3 %	29.1 %
	37.5	39.0 %	5.7 %	34.0 %

Table 2. Total measured fluences (F_m) compared to those predicted by the Jenkins formula (F_J) in neutrons cm^{-2} min^{-1}.

	Height (cm)	F_m	F_J
r_0=100 (cm)	239.2	11110	9875
	94.8	12100	11439
	37.5	15010	13736
r_0=150 (cm)	239.2	5164	4592
	94.8	6008	5601
	37.5	6807	6298
r_0=200 (cm)	239.2	3087	2718
	94.8	3773	3332
	37.5	3872	3581

Table 3. Scattered neutron contribution to dose equivalent as determined by the curve-fitting method. Values are from the BUNKI program.

Height (cm)	Dose equivalent (μSv hr^{-1})
239.2	6.1
94.8	16.7
37.5	5.0

Table 4. Predicted scattered neutron contribution to dose equivalent ($D.E._{scat}$) as determined by Jenkins' formula (in micro-Sv hr^{-1}).

	r=100 (cm)	r=150 (cm)	r=200 (cm)
h=239.2 (cm)	8.22	7.66	6.91
h= 94.8 (cm)	39.10	27.30	18.77
h= 37.5 (cm	83.53	40.90	23.75

Table 5. Comparison of measured dose equivalent ($D.E._m$) and dose equivalent predicted by Jenkins' formula ($D.E._J$).Units are in micro-Sv hr^{-1}.

	Height (cm)	$D.E._m$	$D.E._J$
r_0=100 (cm)	239.2	259.0	271.3
	94.8	253.3	302.2
	37.5	308.2	346.7
r_0=150 (cm)	239.2	119.4	124.6
	94.8	126.8	144.2
	37.5	140.4	157.8
r_0=200 (cm)	239.2	69.7	72.7
	94.8	76.9	84.6
	37.5	79.6	89.5

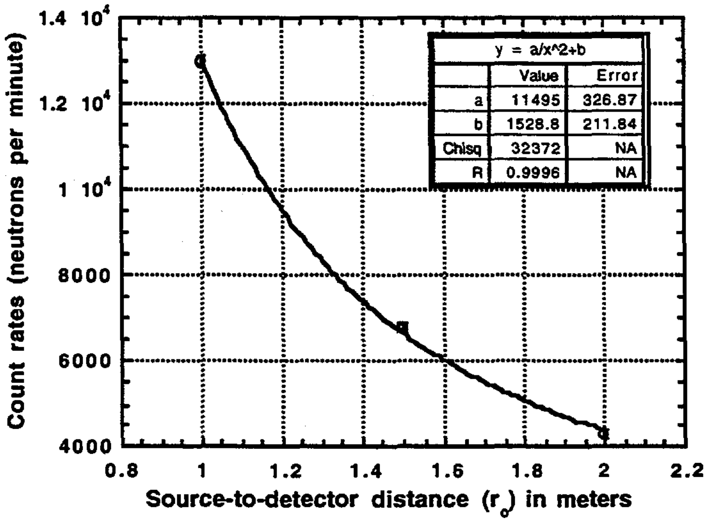

Fig. 1. An example of curve-fitting to obtain the direct and scattered neutron fluence portions. This example is for the 12.7 cm diameter sphere at a height of 94.8 cm.

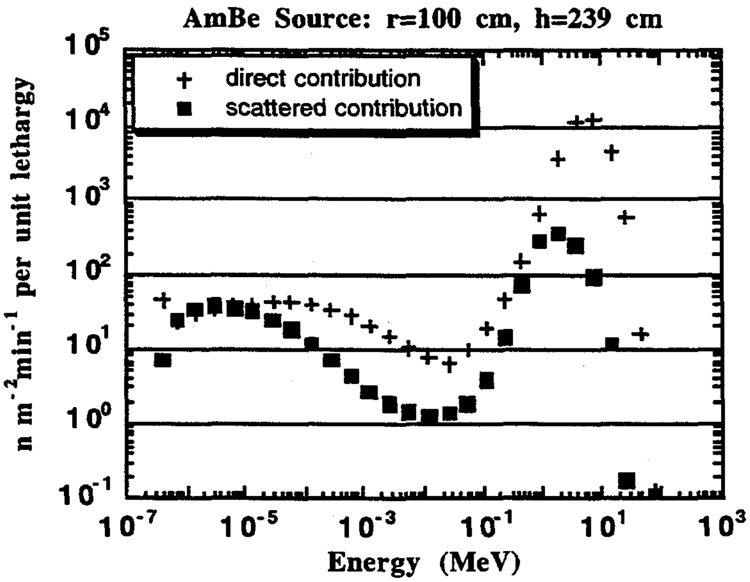

Fig. 2. A comparison of direct and scattered neutron spectrum for the AmBe source at a given point.