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Dale E. Hankins

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MASTER

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ENERGY DEPENDENCE MEASUREMENTS OF REMMETERS AND ALBEDO NEUTRON DOSIMETERS AT NEUTRON ENERGIES OF THERMAL AND BETWEEN 2 keV and 5.67 MeV*

Dale E. Hankins
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, California 94550

Introduction

Standard neutron fields for calibrating and developing neutron instruments and dosimeters have been established through a joint effort of ERDA' Division of Operational Safety (DOS) and the National Bureau of Standards (NBS), Center for Radiation Research. This program provides monoenergetic neutron beams in the intermediate-energy range, thermal neutron beams, monoenergetic fast neutrons, and standard neutron fields.

The intermediate-energy neutron beams are from the NBS reactor, and have predominant energies at 2.0, 25 and 144 keV. The beams are obtained by using a combination of resonant scatterers and filters. They are of high intensity, have low backgrounds of other energy neutrons and gamma rays, and are well calibrated and stable. The 2-keV beam is of particular interest since it provides a calibration point which is about one decade in energy lower than has been available previously. We also made measurements at neutron energies between 30 keV and 5.67 MeV, obtained from the Lawrence Livermore Laboratory cyclograph accelerator.

Procedure

The instruments used were the 9-in.-sphere Portable Neutron Rem Counter[1,2] Model PNR-4 manufactured by Eberline Instrument Corporation, Santa Fe, NM, and the Andersson-Braun (A-B) type Remmeter[3] built to LLL specifications. Data were obtained from the A-B remmeter exposed with the side and the end toward the source. The albedo neutron dosimeters were the Hankins-type[4] which have cadmium completely surrounding the TLDs. Additional results were obtained by placing TLDs on the bottom of the albedo dosimeter (between the dosimeter and the phantom) to simulate the simpler type albedo dosimeter.

The thermal and intermediate-energy neutron beams from the NBS reactor are small (~4.3 to 8.9 cm diam) requiring that the instruments or phantoms be placed on a scanning table. This table moves at a constant speed horizontally and in steps vertically. The table can be programmed to scan the area desired. The cyclograph results were obtained by supporting the instruments or phantoms on tripods in a low-scatter target room.

The pulse outputs of the instruments were obtained from the scaler or phone jacks and fed to a portable scaler Model PS-1 manufactured by Eberline Instrument Corporation. The albedo neutron dosimeters were placed on a chest manikin filled with water. Dose rates and fluences were determined using distances measured from the center of the source to the geometric center of the instruments or to the face of the phantom.

Discussion of Dose-Equivalent Conversion Factors

The conversion factors from fluence to dose equivalent is given in NCRP Report No. 38 for specific neutron energies.[5] For energies other than those given, it is recommended that "linear interpolation between neighboring energies" given in the report be used. The accuracy of this procedure, which gives a peculiar shape to the dose-equivalent curve when plotted on semilog or log paper, was questioned. However, calculations by Poston and Jones[6] using the same computer program that was used to calculate the values given in NCRP-38 indicate that for neutron energies of 2, 25 and 144 keV, the procedure gives values very close to the calculated conversion factors. All results in this study requiring dose equivalent were evaluated using the linear interpolation procedure (at 2, 25 and 144 keV, these are 272.9, 241 and 42.9 cm^{-2} s^{-1} respectively).

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Results

The results obtained in this study are given in Table 1. Figure 1 shows the relative response as a function of neutron energy of the 9-in. sphere and the A-B remmeter respectively. The calculated response of each instrument is also plotted, and these agree well with measured points except at energies below about 100 keV where the calculated responses are lower. The dose-equivalent curve is shown (see preceding paragraph) to illustrate the relationship between the desired and the actual response of the instruments.

Table 1. Results obtained with the instruments and dosimeters at the various neutron energies.

	[illegible]-in. sphere			9-in. sphere		Andersson-Braun remmeter							Albedo neutron dosimeters	
						Side				End				
	Dose rate Calc.	Dose rate Obs.	Counts (n/cm² s)	Counts (n/cm² s)	Ratio [illegible]	Dose rate Calc.	Dose rate Obs.	Ratio End/side	Counts (n/cm² s)	Dose rate Calc.	Dose rate Obs.	Counts (n/cm² s)	[illegible] type	[illegible]
Cyclograph														
[illegible] keV	[illegible]	[illegible]	[illegible]	[illegible]	0.264	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] keV	0.358	[illegible]	9.8[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
70 keV	1.70	[illegible]	10.7[illegible]	[illegible]	[illegible]	1.61	[illegible]	[illegible]	[illegible]	1.6[illegible]	3.20	[illegible]	[illegible]	[illegible]
100 keV	[illegible]	[illegible]	11.5[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				–					
200	[illegible]	[illegible]	[illegible]	[illegible]	0.42[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
300	[illegible]	[illegible]	[illegible]	30.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
350	[illegible]	[illegible]	15.06	26.8	0.626	[illegible]	3.70	0.7[illegible]	60.98	[illegible]	[illegible]	[illegible]	[illegible]	
400	[illegible]	[illegible]	[illegible]	29.8	[illegible]	[illegible]	[illegible]	0.78	[illegible]	[illegible]	[illegible]	[illegible]		
500	61.[illegible]	[illegible]	[illegible]	23.3	[illegible]	[illegible]	35.61	[illegible]	80.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.7[illegible]	82.[illegible]	[illegible]	[illegible]	[illegible]	–	
700	10.5	[illegible]	[illegible]	[illegible]	1.06	[illegible]	[illegible]	[illegible]	10[illegible]	10.[illegible]	[illegible]	[illegible]		
800	11.[illegible]	6.80	[illegible]	[illegible]	[illegible]	11.[illegible]	10.09	0.6[illegible]	[illegible]	11.[illegible]	[illegible]	[illegible]		
1 MeV	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.7[illegible]	12[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.[illegible]
1.2 MeV	16.4	12.76	33.05	16.3	[illegible]	[illegible]	[illegible]	0.88	133.[illegible]	[illegible]	[illegible]	[illegible]	–	
1.476	41.0	31.9	30.31	13.2	[illegible]	[illegible]	29.5	0.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
2.0	37.8	29.2	31.77	12.8	[illegible]	[illegible]	35.0	0.73	139.6	39.1	[illegible]	[illegible]	[illegible]	
3.053	17.3	12.9	30.29	13.0	[illegible]	[illegible]	14.6	0.79	135.2	17.7	[illegible]	[illegible]	0.0788	
5.[illegible]	46.7	28.1	29.85	6.51	4.59	[illegible]	38.2	0.89	132.8	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible].52					[illegible].21					–				
N.B.S.														
Thermal	3.41	3.31	1.11	0.765	1.45	[illegible]	1.22	0.36	1.61	[illegible]	[illegible]	0.580	0.281	37.0
2 keV	2.05	11.3	6.2[illegible]	[illegible]	0.133	2.06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25 keV	0.369	2.58	9.00	42.1	0.214	0.369	1.[illegible]	0.68	[illegible]	0.369	1.00	[illegible]	[illegible]	[illegible]
144 keV	38.8	66.6	12.4	32.6	0.181	39.0	[illegible]	0.68	[illegible]	38.9	[illegible]	[illegible]	[illegible]	

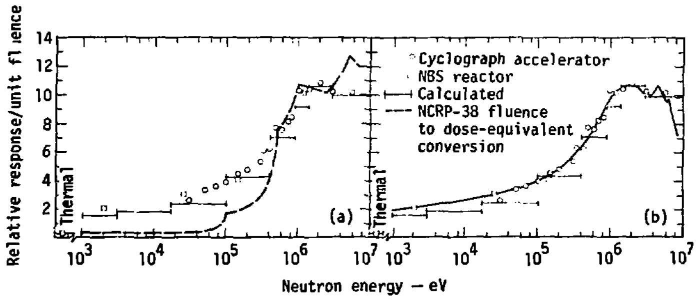

Fig. 1. Observed and calculated responses: (a) a 9-in.-sphere remmeter; (b) an type remmeter exposed with the side of the instrument toward the source.

Figure 2 shows the response curve for the 9-in. sphere and A-B remmeter which were drawn by using the results obtained in this study, and the measured response of the 8- and 12-in. spheres.[7] The irregular shape of the curve above 2 MeV is caused by the cross-section resonances of carbon.

Figure 3 shows the relative response of the two remmeters when compared to the dose curve from NCRP-38. The apparent underresponse between 400 keV and 6 MeV is probably caused by an error in our calibration procedure. The over-response of the 9-in. sphere rises to a maximum of about a factor of 7 at 25 keV compared to a factor of ~4 for the A-B remmeter. Below 10 keV the over-response becomes less, and at thermal the 9-in. sphere response is correct, but the A-B remmeter is low by a factor of 3.

Figure 4 shows the ratio of the 9-in.-sphere remmeter and the 3-in., 10-mil, Cd-covered sphere. The ratio of the 9- to 3-in. spheres is used to determine the calibration factor for albedo neutron dosimeters.[4-8] This ratio can also be used to determine the average neutron energy, but care should be used in applying average energies since they can be misleading. Figure 5 shows the results obtained with albedo neutron dosimeters. A curve is shown for the response of the Hankins-type albedo neutron dosimeters and for TLDs taped to

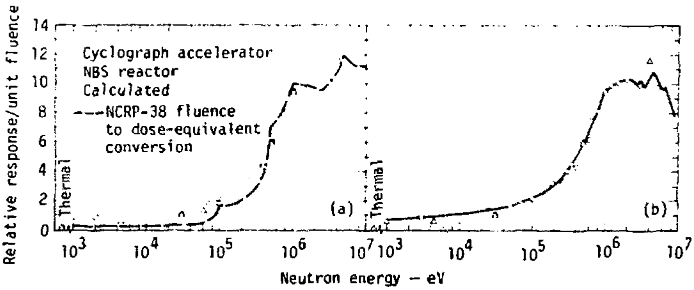

Fig. 2. Energy response curves based on results observed in this study, and measured energy response of 8- and 12-in. Bonner spheres; (a) 9-in.-sphere remmeter, and (b) an A-B remmeter.

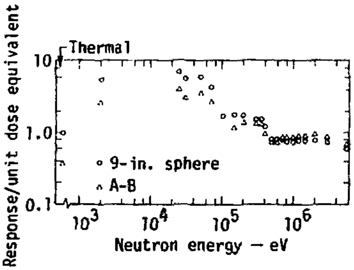

Fig. 3. Response of the 9-in.-sphere remmeter and A-B type remmeter per unit of dose.

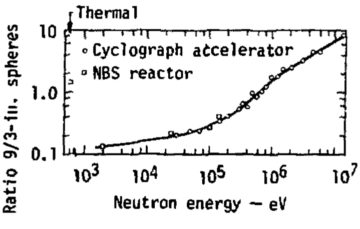

Fig. 4. Ratio of response of the 9-in.-sphere remmeter to the response of the 3-in. 10-mil Cd-covered sphere.

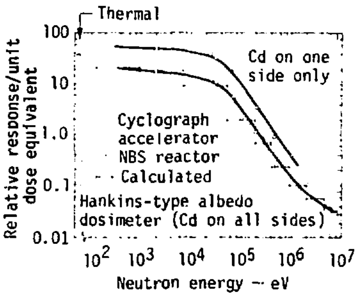

Fig. 5. Curves showing the energy dependence of the Hankins-type albedo neutron dosimeter and of TLDs taped to the bottom of the dosimeters. Also shown is calculated response by Alsmiller and Barish.

the bottom of this dosimeter. The two curves are similar, indicating that changing the TLD location does not cause a change in the energy dependence of the dosimeter. The calculated values are from Alsmiller and Barish,[9] and were made for the Hankins dosimeter. Very good agreement is found between experimental and observed results.

Discussion and Summary

The use of the NBS facilities has allowed us to extend the measured response of remmeters and albedo neutron dosimeters about 1 decade lower in energy than has been possible previously. The NBS and cyclograph exposures were made with greatly differing experimental procedures, but the results plotted in Figs. 1 and 5 at overlapping energies show good agreement. This gives us confidence in the accuracy of both experimental procedures.

The results given in Fig. 5 indicate that the 9-in. sphere would give a higher over-response to spectra containing a large component of intermediate energy neutrons. A recent study[10] comparing the readings of these two instruments indicates that no detectable difference was found except at the LPTR reactor where the 9-in.-sphere readings were higher than the A-B remmeter readings.

The directional response of the A-B remmeter is given in Table 1. The reading of the instrument when exposed to the end is consistently lower than the side reading and at thermal neutron energies, the end reading is low by a factor of ~8. This low response to thermal neutrons and the directional response to both thermal and fast neutrons encouraged us to redesign the A-B remmeter. This work has recently been completed.[10]

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