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Third Personnel Dosimetry Intercomparison Study

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HEALTH AND SAFETY RESEARCH DIVISION
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Price: Printed Copy $4.~~50~~ 00; Microfiche $3.00

ORNL/TM-6114

Contract No. W-7405-eng-26

Health and Safety Research Division

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Date Published: January 1979

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ABSTRACT

The third Personnel Dosimetry Intercomparison Study was held at the Oak Ridge National Laboratory Dosimetry Applications Research Facility during March 15-16, 1977. The Health Physics Research Reactor (HPRR), used unshielded, with a 12-cm-thick Lucite shield or a 13-cm-thick steel shield, provided three neutron and gamma-ray spectra. The characteristics of these fields such as neutron energy spectra, intensity, and uniformity had been measured previously during nuclear accident dosimetry studies. Exposures were made to simulate total exposures likely to be encountered in personnel dosimetry. Neutron dose equivalents of the order of 500 millirem were produced by controlling the reactor power level and exposure time. Dosimeters were mounted on the trunk section of water-filled phantoms, the front edges of which were located 3 m from the reactor center. When shields were used they were placed at 2 m from the core. Sulfur pellets exposed at a standard location on the reactor during the intercomparison were used to calculate values of tissue kerma for neutrons at the 3-m position based on previous measurements. Using the fission yield and the calculated leakage of the HPRR, the neutron fluence was calculated for each reactor run. Then the dose was calculated based on the HPRR neutron spectra and the dose conversion factors, which had been calculated previously for the three spectra. The results of these personnel dosimetry intercomparison studies reveal that estimates of dose equivalent vary over a wide range. The standard deviation of the mean of participants data was in the range of 25 to 50%.

The third Personnel Dosimetry Intercomparison Study (PDIS) was conducted at the Oak Ridge National Laboratory (ORNL) Dosimetry Applications Research (DOSAR) Facility during March 15-16, 1977. Six independent organizations participated in the intercomparison study of neutron and gamma-ray dosimeters used for routine personnel dosimetry (Appendix A contains a list of participants).

The Health Physics Research Reactor (HPRR) was used as the source of gamma and neutron fields. The radiation properties of these fields have been measured[1,2] and calculated[3] in previous studies. The HPRR is a small, unshielded and unmoderated, fast reactor suitable for research in health physics, radiobiology, biomedicine, and related fields. The reactor core is a right circular cylinder (0.23 m diam, 0.20 m high) of enriched uranium (93.14 wt % ^{235}U) alloyed with 10% molybdenum. Its fuel plates are coated with nickel and held together by fuel bolts. It has one large scrammable fuel element (the safety block) and three control rods, one of which can be inserted rapidly to produce a pulse of radiation.

For these studies the reactor was operated in the steady state at a power level of 2 W for varying lengths of time to produce dose levels normally encountered in personnel dosimetry. A summary of reactor operations is given in Table 1. These operating conditions produced doses of about 500 millirem at the location of the dosimeters.

Three "standard" fields were produced by using the unshielded HPRR or by placing a steel shield or a Lucite shield between the reactor core

Table 1. Summary of reactor operations for the third PDIS

Run No.	Shield	Power (watt)	Time (sec)	Fissions
1	Unshielded	2	187	1.15×10^{13}
2	Steel	2	521	3.22×10^{13}
3	Lucite	2	990	6.11×10^{13}

and the dosimeters. The dosimeters were located on the front of the trunk section of water-filled phantoms positioned so that the dosimeters were 3 m from the center of the reactor core. The Lucite and steel shields were 12-cm- and 13-cm-thick, respectively. Figure 1 shows a typical experimental setup with the Lucite shield in place, and Fig. 2 shows a typical arrangement of dosimeters on the phantom trunk sections.

Dosimeters used in this study were generally the same type as in previous studies (mostly film and thermoluminescent dosimeters), except this is the first such study in which several participants used track etch dosimeters. Dosimeters used by participants are given in Table 2. Some participants used more than one type of dosimeter. To maintain anonymity, the participating groups have been assigned an arbitrary letter designation. In addition, each different dosimeter type used by a given participant has been designated with a letter. In Table 2, for example, the identification symbols "A-B" are used to indicate group A, dosimeter type B.

Generally, the dosimeters were mailed or shipped to the DOSAR a few days in advance of the intercomparison. They were returned in similar fashion a few days after exposure. If one or more of the dosimeter components were to be activated to the extent of 0.002 μCi/g, the participant was required to fill out and send either ERDA (now DOE) Form 375 or 391, as appropriate, in order for the activated dosimeters to be shipped from ORNL. The ERDA Form 375 applies to all federal agencies and Form 391 to all non-federal agencies. For purposes of estimating activity, one can assume a fast neutron fluence of 4×10^7 cm^{-2}, which is conservative since all exposures involved a smaller actual fluence.

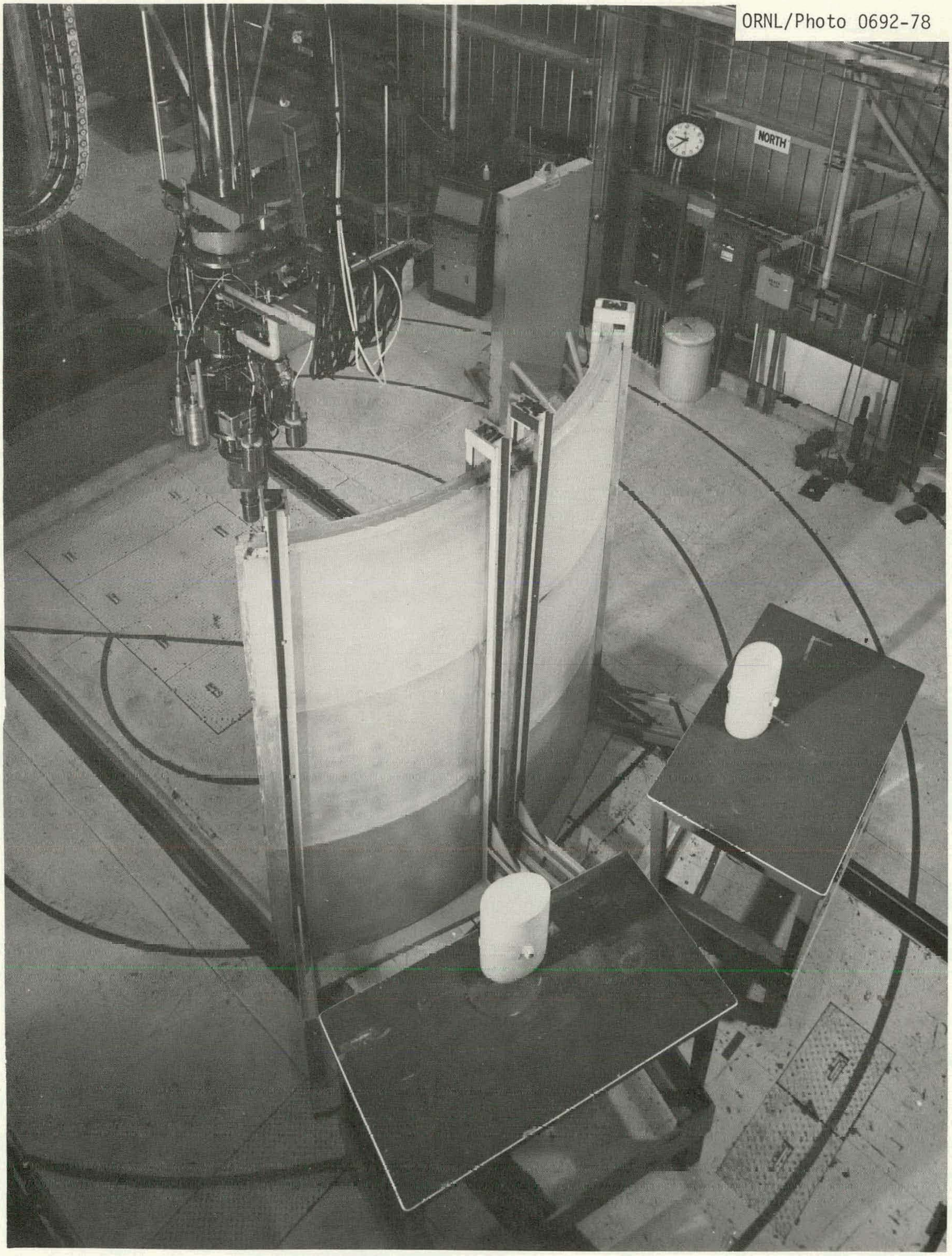

Fig. 1. A typical experimental setup with the Lucite shield in place.

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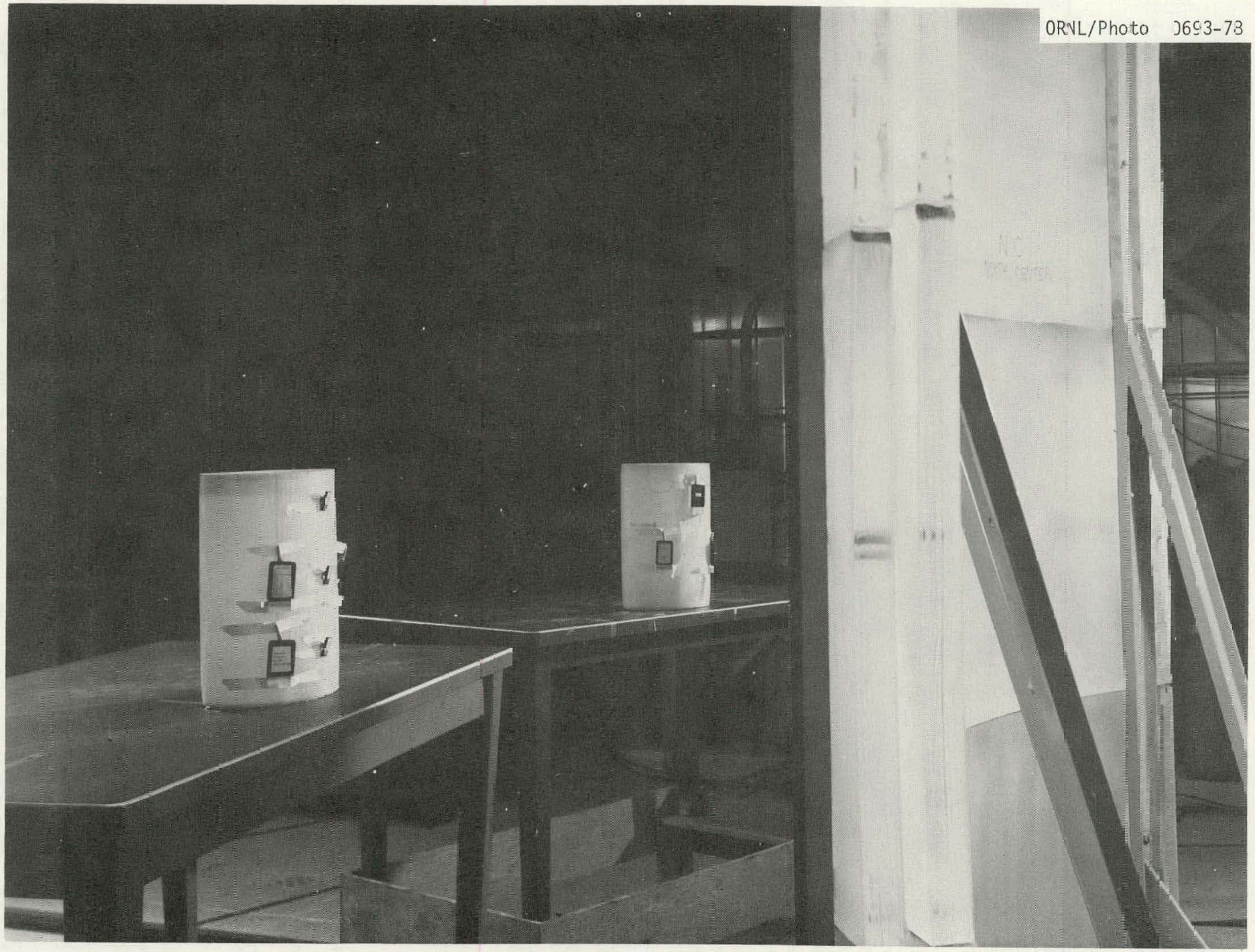

Fig. 2. A typical placement of dosimeters on phantom sections.

Table 2. Dosimeters used by participants

Identification	Dosimeter type		
(Group - Dosimeter)	Neutron	Gamma	Neutron and gamma
A-A	TLD[a] albedo		albedo + Th track etch
A-B	track etch		albedo + Th track etch
B-A	NTA film	film	
B-B	track etch		
C-A	TLD albedo	TLD	
C-B	TLD	TLD	
C-C	track etch	TLD	
D-A	NTA film	film	
D-B		TLD	
E-A	NTA film	film/TLD	
F-A	TLD albedo	TLD	

[a]Thermoluminescent dosimetry.

[b]Nuclear track emulsion film, type A.

After exposure, participants were provided with the reactor operation data shown in Table 1, the position of their dosimeters and the calculated neutron spectra at the 3-m position for the three configurations. The calculated spectra are tabulated in Table 3 and shown in Fig. 3. Calculations of the HPRR spectra were performed using a two-dimensional discrete ordinates transport (DOT) code,[3] which assumed cylindrical symmetry about the vertical axis. Cross-section data were reduced to 33 fast neutron groups and a thermal neutron group. The DOT calculations were transformed using the 34 group set.

A sulfur pellet was exposed in a standard location near the core during each reactor run to serve as a standard monitor. By using correlations of measured kerma and sulfur pellet count rate from previous nuclear accident dosimetry (NAD) studies,[4,5] estimates of kerma at 3 m could be obtained from the sulfur pellets. Using the dose conversion factors given in *Radiation Dosimetry*[6] for that section of a phantom

Table 3. Calculated HPRR spectra for intercomparison studies

Energy group	Upper energy (ev)	Mid energy (ev)	N(E)ΔE[a]		
			No shield	Lucite shield	Steel shield
1	1.49 E7	1.22 E7	9.53 E7	3.31 E7	1.35 E7
2	1.0 E7	8.19 E6	1.18 E9	3.63 E8	1.5 E7
3	6.7 E6	5.77 E6	3.43 E9	4.29 E8	3.8 E8
4	4.97 E6	3.87 E6	1.44 E10	2.58 E9	1.57 E9
5	3.01 E6	2.12 E6	3.76 E10	5.56 E9	7.94 E9
6	1.5 E6	1.16 E6	3.16 E10	3.19 E9	1.21 E10
7	9.07 E5	6.08 E5	4.61 E10	3.69 E9	3.34 E10
8	4.08 E5	2.13 E5	3.39 E10	3.08 E9	5.02 E10
9	1.11 E5	9.80 E4	2.60 E9	4.18 E8	2.13 E9
10	8.65 E4	7.64 E4	2.0 E9	3.81 E8	2.91 E9
11	6.74 E4	5.95 E4	1.5 E9	3.49 E8	1.41 E9
12	5.25 E4	4.63 E4	1.21 E9	3.24 E8	1.25 E9
13	4.09 E4	3.61 E4	9.71 E8	3.05 E8	5.61 E8
14	3.18 E4	2.81 E4	8.40 E8	2.98 E8	6.64 E8
15	2.48 E4	2.19 E4	7.35 E8	2.76 E8	2.5 E8
16	1.93 E4	1.70 E4	6.37 E8	2.66 E8	1.01 E8
17	1.50 E4	1.03 E4	1.58 E9	7.60 E8	1.14 E8
18	7.10 E3	4.88 E3	1.39 E9	7.23 E8	1.02 E8
19	3.35 E3	2.03 E3	1.62 E9	9.48 E8	1.16 E9
20	1.23 E3	8.48 E2	1.04 E9	6.97 E8	4.2 E8
21	5.83 E2	3.54 E2	1.24 E9	9.21 E8	4.47 E8
22	2.14 E2	1.47 E2	8.45 E8	6.91 E8	3.14 E8
23	1.01 E2	6.96 E1	7.76 E8	6.90 E8	2.88 E8
24	4.79 E1	3.73 E1	4.72 E8	4.59 E8	1.69 E8
25	2.90 E1	2.26 E1	4.54 E8	4.60 E8	1.67 E8
26	1.76 E1	1.37 E1	4.34 E8	4.61 E8	1.61 E8
27	1.07 E1	7.34	6.09 E8	6.93 E8	2.11 E8
28	5.04	3.93	3.82 E8	4.58 E8	1.28 E8
29	3.06	2.18	4.84 E8	6.11 E8	1.71 E8
30	1.56	1.25	3.04 E8	3.79 E8	1.12 E8
31	1.0	8.06 E-1	2.81 E8	3.41 E8	9.16 E7
32	0.65	5.41 E-1	2.42 E8	2.86 E8	7.83 E7
33	0.45	2.12 E-1	1.78 E9	2.67 E9	5.63 E8
34	0.1	2.24 E-2	3.36 E9	1.95 E10	1.09 E9

[a]This number is the area of the histogram for each energy interval.

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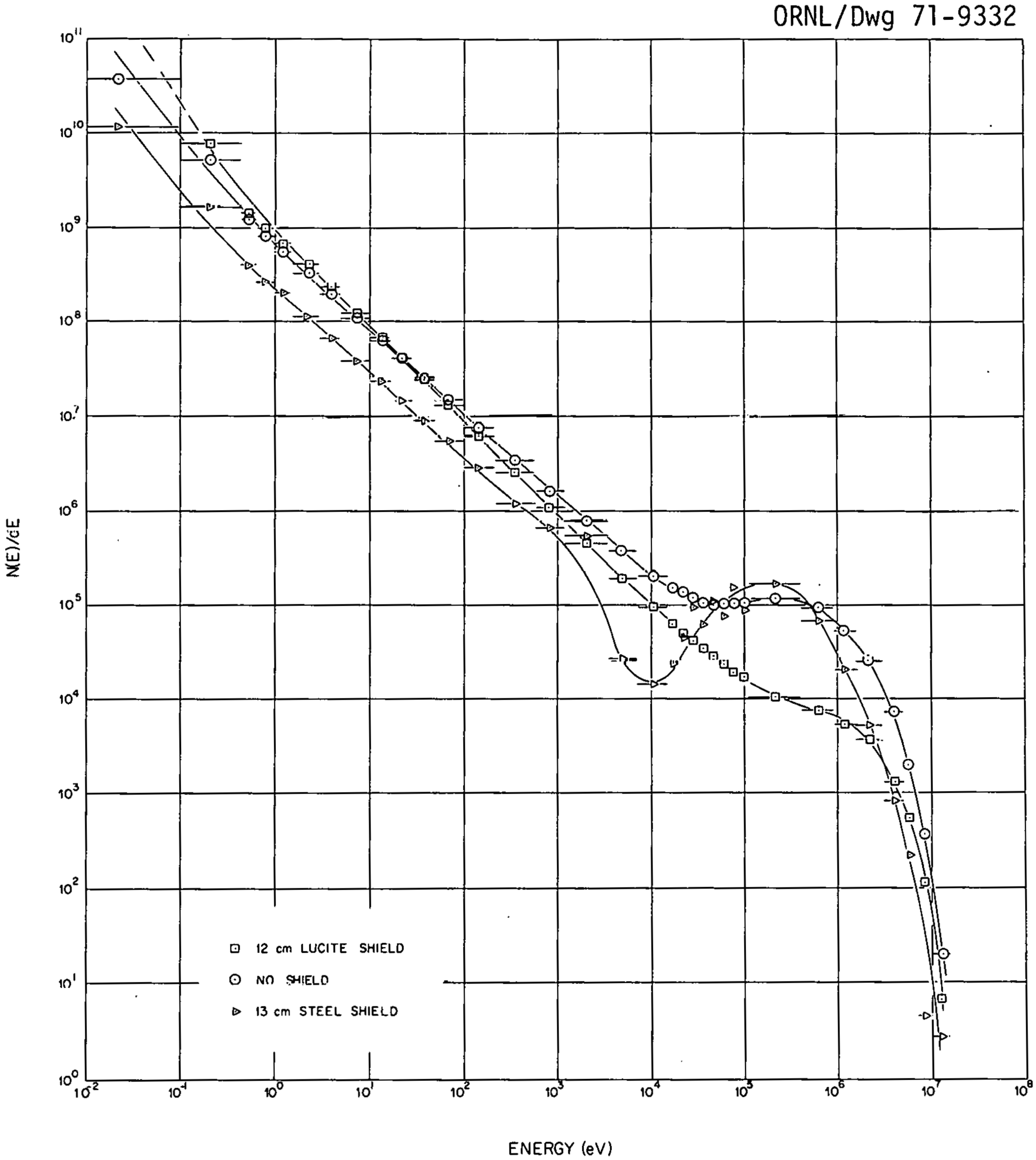

Fig. 3. Calculated HPRR leakage spectrum at 3 m from the the centerline of the core (1971).

designated element 57, the dose conversion factors for the HPRR spectra were calculated and are given in Table 4. Average quality factors determined by Murthy et al.[7] were used for calculating dose equivalent, and these values are also given in Table 4. Using the fission yield and the calculated leakage of the HPRR,[8] the neutron fluence was calculated for

Table 4. Dose conversion factors and average quality factors for HPRR spectra

Shield	Dose conversion factor (mrad cm^2 x 10^{-7})	$\overline{QF}$
Unshielded	25.5	9.4
Steel	17.9	9.5
Lucite	14.6	8.9

each reactor run. The calculated values of dose and dose equivalent were found by multiplying these fluences by the previously determined dose conversion factors and average quality factors. The fission yield, neutron fluence, dose, and dose equivalent for each reactor run are given in Table 5.

Table 6 gives reference values of neutron kerma, dose, and dose equivalent. The measured kerma is estimated from sulfur pellets exposed during each run, and the error is determined largely by evaluation of counting statistics. The calculated dose is the element 57 dose for the cylindrical phantom (Fig. 4). The element 57 is the outermost central element facing the neutron beam; therefore, element 57 dose

Table 5. Absorbed neutron dose and dose equivalent calculated from HPRR fission yield

Reactor run	Shield	Fission (10^{-13})	Fluence (cm^{-2} x 10^{-7})	Dose (mrad)	Dose equivalent (mrem)
1	Unshielded	1.15	2.26	58	545
2	Steel	3.22	3.88	70	665
3	Lucite	6.11	3.26	48	427

Table 6. Reference values of neutron kerma, dose and dose equivalent

Reactor run	Spectrum	Measured kerma (mrad)	Calculated dose (mrad)	Calculated dose equivalent (mrem)
1	Unshielded	45 ± 5	58	545
2	Steel shielded	53 ± 5	70	665
3	Lucite shielded	44 ± 5	48	427

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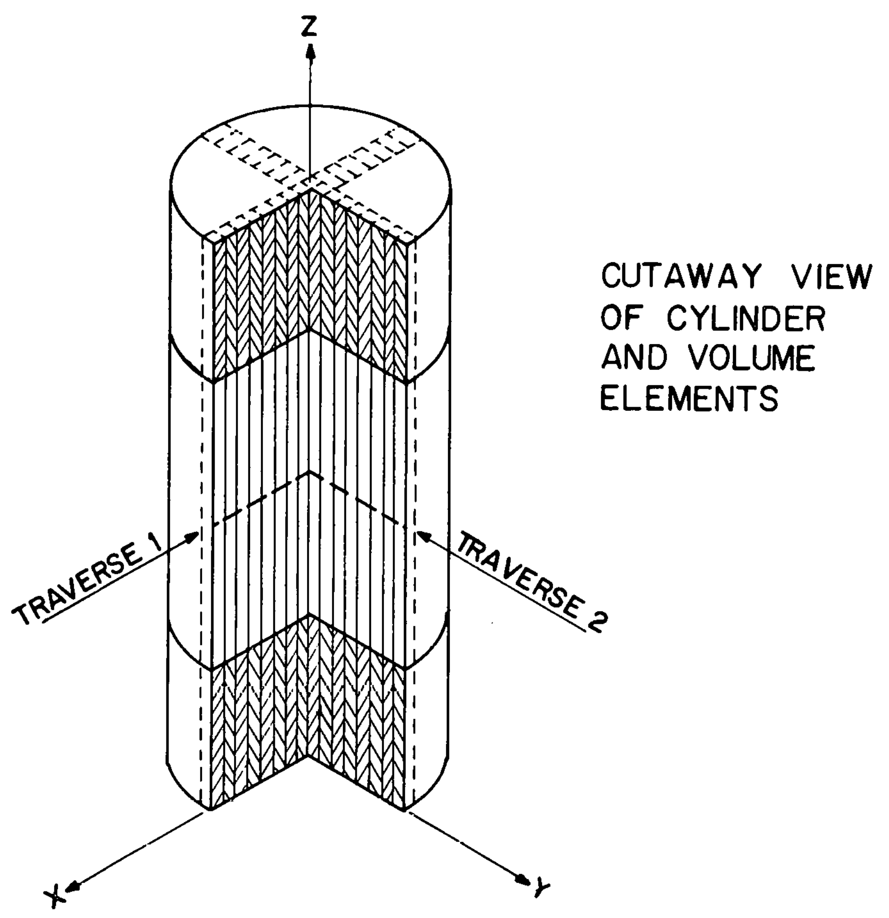

Fig. 4. Cylindrical phantom and volume elements for averaging of dose.

and kerma are not the identical. Reference values for gamma dose are unavailable due to a malfunction of the DOSAR thermoluminescent dosimetry (TLD) system. Calculated gamma doses would be misleading since a large fraction of the gamma dose is due to residual activity in the reactor core after the reactor has been operated and it has not been possible to include this in the calculation.

The results of the participant's dose measurements are given for the unshielded, Lucite-shielded, and steel-shielded configurations in Table 7, 8, and 9, respectively and are summarized in Table 10. In Table 7, 8, and 9, the dosimeters are identified by group and dosimeter

Table 7. Results of Personnel Dosimetry Intercomparison March 1977 - unshielded reactor

Dosimeter identification	Location on phantom	Phantom A				Phantom B			
		n(mrad)	n(mrem)	γ(mrem)	n + γ (mrem)	n(mrad)	n(mrem)	γ(mrem)	n + γ (mrem)
A-A1	Front						422	48	470[a]
A-B1	Front						720[b]	48[b]	768[b]
B-A1	Front	63	588	25					
B-A2	Front	70	661	25					
B-A3	Front	62	583	25					
B-B1	Front	65	607						
B-B2	Front	74	700						
B-B3	Front	52	488						
C-A1	Front		640						
C-A2	Back		110						
C-B1	Front		690	20					
C-B2	Back		150	<10					
C-C1	Front		790						
C-C2	Back		120						
D-A1	Front			14					
D-B1	Front			19					
E-A1	Front		950	50					
E-A2	Front		1050	50					
F-A1	Front		588	16					

[a]Albedo.

[b]Albedo + thorium damaged track.

type as listed in Table 2; however, there is an additional identification number which identifies individual dosimeters of a given type. For example, B-A3 identifies the third dosimeter of type A used by group B.

Table 8. Results of Personnel Dosimetry Intercomparison
March 1977 - Lucite shielded reactor

Dosimeter identification	Location on phantom	Phantom A				Phantom B			
		n(mrad)	n(mrem)	γ(mrem)	n + γ (mrem)	n(mrad)	n(mrem)	γ(mrem)	n + γ (mrem)
A-A1	Front						428[a]	83[a]	511[a]
A-B1	Front						466[a]	83[a]	549[a]
B-A1	Front	51	457	76					
B-A2	Front	44	393	63					
B-A3	Front	61	546	63					
B-B1	Front	47	417						
B-B2	Front	43	379						
B-B3	Front	55	489						
C-A1	Front						670		
C-A2	Back						180		
C-B1	Front						470	60	
C-B2	Back						80	20	
C-C1	Back						320		
C-C2	Front						670		
D-A1	Front						670	26	
D-B1	Front							61	
E-A1	Front						1350	130	
E-A2	Front		1050	140					
F-A1	Front		290	49					

[a]Albedo + thorium damaged track.

Table 9. Results of Personnel Dosimetry Intercomparison
March 1977 - steel shielded reactor

Dosimeter identification	Location on phantom	Phantom A			
		n(mrad)	n(mrem)	γ(mrem)	n + γ (mrem)
A-A1	Front		440[a]	41[a]	481[a]
A-B1	Front		476[a]	41[a]	516[a]
B-A1	Front	73	691	19	
B-A2	Front	65	617	13	
B-A3	Front	81	769	13	
B-B1	Front	101	961		
B-B2	Front	73	698		
B-B3	Front	71	670		
C-A1	Front		730		
C-A2	Back		160		
C-B1	Front		770		
C-B2	Back		250		
C-C1	Front		730		
E-A1	Front		650	40	
E-A2	Front		1200	40	
F-A1	Front		696	10	

[a]Albedo + thorium damaged track.

Table 10. Summary of results

Exposure condition	Neutron dose equivalent n(mrem)	Gamma dose equivalent γ(mrem)
Unshielded	675 ± 168	31 ± 15
Steel	721 ± 186	29 ± 14
Lucite	583 ± 280	75 ± 34

Phantoms A and B were essentially identical; two phantoms were used because all of the dosimeters could not always be placed on one. The spatial distribution of dose around the HPRR is essentially uniform over the area of the two phantoms. The data from dosimeters located on the backs of the phantoms are shown only for completeness. The averages and standard deviations given in Table 10 were obtained using all of the data from dosimeters exposed on the fronts of the phantoms. Generally, the dose equivalent data reported by participants indicated improvement over previous studies,[1,2] except for the Lucite data, which for some unknown reason, showed a deterioration. The gamma data gave a rather large standard deviation, perhaps indicating difficulty in measuring a small gamma dose in the presence of a substantial neutron dose.

These studies have been found to be useful to the participants. It is anticipated that this type of dosimetry intercomparison study will be worthwhile on an annual basis until the problems in dosimeter response and interpretation have been identified and solved.

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APPENDIX A

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March 15-16, 1977

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