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Fourth Personnel Dosimetry Intercomparison Study

H. W. Dickson

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National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A03 Microfiche A01

ORNL/TM-7137

Contract No. W-7405-eng-26

Health and Safety Research Division

FOURTH PERSONNEL DOSIMETRY INTERCOMPARISON STUDY

H. W. Dickson

Date Published: February 1980

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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FOURTH PERSONNEL DOSIMETRY INTERCOMPARISON STUDY

H. W. Dickson

HIGHLIGHTS

The fourth Personnel Dosimetry Intercomparison Study was held at the Oak Ridge National Laboratory's Dosimetry Applications Research Facility during March 15-23, 1978. The Health Physics Research Reactor (HPRR) used unshielded, with a 12-cm-thick Lucite shield, a 20-cm-thick concrete shield, or a 5-cm-thick steel and 15-cm-thick concrete shield, provided four neutron and gamma-ray spectra. The characteristics of these fields such as neutron energy spectra, intensity, and uniformity have 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 millirems 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 in the case of the Lucite shield and 1 m for the concrete and steel/concrete shields. Sulfur pellets exposed at a standard location on the reactor, proportional counters, and thermoluminescent dosimeters were used to perform reference dosimetry. Using the fission yield and the calculated leakage of the HPRR, the neutron fluence at the 3-m position was calculated for each reactor run. Then the dose was calculated based on the HPRR neutron spectra and dose conversion factors which had been determined previously for the four 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 for gamma measurements was in the range of 29 to 43%; and for neutrons, it was in the range of 57 to 188%.

INTRODUCTION

For the past fourteen years the annual dosimetry intercomparisons at the Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research Facility (DOSAR) have provided an opportunity for laboratories in the United States and foreign countries to test dosimetry systems in simulated nuclear accident situations. These studies have been successful in developing guidelines in instrumentation and procedures and in establishing "standardized" radiation fields whose characteristics such as energy spectrum, intensity, and uniformity have been measured and accepted. The Health Physics Research Reactor (HPRR) has been used as the pulse radiation source. The unshielded reactor or the reactor used with one of four shields provides five different neutron and gamma-ray spectra. These shields are:

1. 12-cm-thick Lucite shield,
2. 20-cm-thick concrete shield,
3. combination 5-cm-thick steel and 15-cm-thick concrete shield, and
4. 13-cm-thick steel shield.

For the study described in this report only the first three shields were used.

Many experimenters over the years expressed interest in using the same "standardized" radiation fields for the comparison of the response of routine personnel dosimeters used at low radiation levels typically encountered in personnel monitoring. As a result, the first Personnel Dosimetry Intercomparison Study (PDIS) was conducted during the period May 14-16, 1974, with ten groups participating exclusive of the DOSAR group. Three additional intercomparison studies for personnel dosimeters have been completed at ORNL. The second PDIS was conducted February 18-19, 1976, with eleven participating groups; the third PDIS was held March 15-16, 1977, with seven participating groups; and the fourth PDIS was conducted March 15-23, 1978, with twenty-two participating groups (Appendix A contains a list of participants).

EXPERIMENTAL DETAILS

The HPRR was used as the source of gamma and neutron fields. The radiation properties of several of the possible fields around the HPRR have been measured[1-3] and calculated[4,5] 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. A more complete description of the HPRR is provided by Auxier.[6]

The HPRR was used to expose personnel dosimeters to mixed neutron and gamma fields. The reactor was operated as shown in Table 1 in a steady-state mode at a constant power level for a length of time necessary to produce dose equivalents of a few hundred millirems which is the range likely to be encountered in personnel monitoring. In order to produce this range of radiation levels, a free air tissue kerma of approximately 50 millirads was required for the neutron component; and the reactor operating time was calculated based on this kerma. Generally, the dosimeters were mailed or shipped to the DOSAR a few days in advance of the intercomparison. The dosimeters were then returned in a similar manner the day after the intercomparison exposures were completed.

All dosimeters were placed on water-filled trunk portions of phantoms, the leading edges of which were located 3 m from the reactor core. When shields were used, they were placed between the detectors and the HPRR core, at a distance of 2 m for the Lucite shield and at a distance of 1 m for the concrete and steel/concrete shields. The placement of dosimeters on the phantoms is shown in Fig. 1, and a typical experimental arrangement with reactor and shield in place is shown in Fig. 2. Several phantoms, water bottles, and other containers were used as labeled in Fig. 2 to accommodate all of the dosimeters and special requests by participants.

During the fourth PDIS, several sets of dosimeters arrived late and had to be exposed in separate but equivalent reactor operations. Dosimeters for sixteen groups were exposed March 15-16, 1978, and dosimeters from five groups were exposed March 23, 1978. The same reference dosimetry was performed for each set of dosimeters. All of the reactor parameters listed in Table 1 apply to both periods of irradiation. The runs designated 1 through 4 applied to the March 15-16 time frame and the runs designated 5 through 8 applied to the March 23 date.

REACTOR SPECTRA AND DOSIMETRY

Calculations of the HPRR spectra have been performed using a two-dimensional discrete ordinates transport (DOT) code which assumed cylindrical symmetry about the vertical axis of the HPRR core. The first set of calculations[4] was done for the unshielded reactor and the reactor with the Lucite and steel shields in place (see Fig. 3). These calculations were performed using 34 energy groups of neutrons ranging from thermal to 14 MeV. The reactor height was fixed at 150 cm above a 30-cm-thick concrete slab. The shielding configurations were a 13-cm-thick steel shield rising 213 cm above the concrete slab and a 12-cm-thick Lucite shield rising 282 cm above the slab. The fronts of these shields were placed at 200 cm from the reactor center. In addition to neutron spectra, these calculations also provided neutron dose as a function of distance from the reactor (shown in Fig. 4).

Recently, other calculations[5] have been performed to determine the neutron spectra (see Fig. 5) and dose (see Fig. 6) through two new shield configurations — a 20-cm-thick concrete shield and a combination 5-cm-thick steel and 15-cm-thick concrete shield. Each of these shields is 213 cm in height. These calculations were done using the previous calculational model except that the shields were located 100 cm from the center of the reactor and only 33 energy groups were used.

REFERENCE DOSIMETRY

In addition to the calculated neutron dose, various dosimetric devices were applied to obtain the true neutron dose delivered during the intercomparison. These devices included the routine sulfur pellet monitors on the reactor and Hurst proportional counters located at the position of the exposed dosimeters (see Fig. 2). While sulfur pellets respond only to the neutron fluence above a threshold of approximately 2.5 MeV, they may be used to monitor the reactor output since a large percentage of neutrons from the HPRR (~30%) exceed this energy. Also, because a constant fraction of the neutrons for any given shielded configuration will have an energy above the sulfur threshold, the sulfur pellets can be used to estimate neutron tissue kerma for all the experimental conditions once the calibration factor has been determined for each of the spectra. These calibration factors have been determined previously from nuclear accident dosimetry intercomparison experience[7-9] at the HPRR. Therefore, the sulfur pellets exposed at a standard location on the reactor during the intercomparisons served as a basis for estimates of tissue kerma at the experimental position. The results of the sulfur pellet dosimetry are given in Table 2.

In the case of the unshielded reactor and the Lucite-shielded reactor, average quality factors for the neutron spectra are available in the literature;[10] and these values were used as the best available data. Independent calculations by the author, performed in the manner indicated below, support the literature values. Literature values were not available for the concrete or steel/concrete shields.

For the concrete- and steel/concrete-shielded cases, the quality factors were calculated based on data from ref. 11. Using the previously calculated spectra[5] through the concrete and steel/concrete shields, it was possible to calculate spectrally weighted dose and dose equivalent conversion factors. This was accomplished by taking the product of a dose (or dose equivalent) conversion factor from ref. 11 and the fraction of the neutron fluence in a given energy interval, and then summing over the 33 energy intervals in the complete spectrum. Finally, the spectrally weighted dose equivalent conversion factor was divided by the spectrally weighted dose conversion factor to give the quality factors for the concrete and steel/concrete spectra. These calculated quality factors are given in Table 2 along with an estimated error of 5%. The error estimate is based on the fact that the use of other generally accepted dose and dose equivalent conversion factors[12,13] lead to slightly different quality factors.

A Hurst proportional counter[14] was used to measure the absorbed dose from neutrons. The absorbed dose is proportional to the size and number of pulses from this counter; therefore, the pulse height distribution was obtained with a multichannel analyzer and read into a PDP-10 computer for analysis. The pulse height distribution from the Hurst counter was due largely to neutron interactions; however, gamma radiation contributed to the low energy end of the spectrum. In order to determine only the neutron response, the computer program incorporated a stripping routine to remove the gamma response. The counter was calibrated using an Am-Be neutron source that had been standardized by the National Bureau of Standards in terms of neutron yield. The results of these measurements are given in Tables 3 and 4.

Gamma radiation levels were measured with thermoluminescent dosimeters (TLD's). Lithium fluoride dosimeters having normal isotopic components (TLD-100) and dosimeters having an enrichment of ^{7}Li (TLD-700) were used in pairs to obtain the gamma-ray exposure in the presence of neutrons. The differential neutrons response of these dosimeters had been determined previously. The TLD's were calibrated for gamma exposure using a ^{226}Ra source. The results of these measurements also are given in Tables 3 and 4. The error in these measurements is estimated not to exceed

In addition, the neutron dose equivalent for the intercomparison exposures were calculated. Using dose conversion factors for that section of a phantom[12] designated as element 57, the dose conversion factors for the HPRR spectra were calculated. Using the fission yield as determined by reactor instrumentation and the calculated leakage[15] of the HPRR, the neutron fluence was calculated for each reactor run. By applying the previously determined dose conversion factors and average quality factors (given in Table 2), the dose and dose equivalent were calculated for each experimental configuration (see Table 5). The results for the concrete and steel/concrete shields were anomalously high suggesting problems with the calculations of these spectra from the DOT code.

DOSIMETERS USED BY PARTICIPANTS

Several types of dosimeters were used by the participants in this PDIS. For measuring the neutron component, TLD albedo and nuclear track film, type A (NTA) film dosimeters were the most numerous; however, track-etch dosimeters using polycarbonate films are gaining in popularity. For measuring the gamma components, only film and TLD's were used, with TLD's being used most frequently. A breakdown of dosimeter types by participating group is given in Table 6.

INTERCOMPARISON RESULTS

The results of these personnel dosimetry intercomparison studies reveal that estimates of dose equivalent vary over a wide range. The results of all the reported measurements are given in Tables 7-10. While it was preferable to report every individual measurement, a few participants averaged measurements and reported only the average values.

Most of the dosimeters were exposed on phantoms A, B, or C (all identical for the purposes of this intercomparison); however, a few measurements were either made in air or on a water bottle by special request of the participant. The phantoms, water bottles, and air stations are marked in Fig. 2. These exceptions are pointed out in Tables 7-10. One participant used TLD-100 for gamma measurements without anticipating the effect of neutrons. The result was that the data could not be corrected for neutron response and is included in Tables 7-10 only for the sake of completeness. The data was not used for the summaries that follow.

Because similar operations were performed on two separate occassions to include all dosimeters, some effort has been made to identify measurements with the date on which they were made. One set of reactor runs was conducted March 15-16 and another set on March 23. The reactor was operated for the same length of time and at the same power level in both sets of runs. Consequently, one would not expect differences in the neutron dose between these sets of runs, and real differences were not observed. The gamma doses are a function not only of the reactor operation but how long the dosimeters stayed in the high background area around the reactor. Since this "stay" time could have varied between sets of operations, it was more important to keep track of potential differences in gamma dose. A real difference in gamma doses was observed only for the two different unshielded reactor exposures.

The participant data are summarized in Tables 11-14 for the different exposure conditions. No minimal or zero values were used in these summaries. The results would have looked worse had these values been used.

Since the median is a central tendency parameter which tends to minimize the impact of extreme data points, it was chosen as one statistic to be presented. This minimized the inclination to "sort the data" by throwing out obvious outliers. Consequently, the means and standard deviations in Tables 11-14 reflect nearly all the data (exceptions already mentioned).

For intercomparison studies, it is important to see how well the participants' measurements agree with reference values of radiation dose equivalent as well as with each others' experimental results. The neutron dose equivalents as determined for the two sets of runs (see Tables 2-4) were averaged for both the proportional counter and the sulfur pellets, independently, to serve as the reference values. These values are compared with the mean and median values of the participant's measurements in Table 15. Reference dosimetry as determined by sulfur pellets has a larger uncertainty than doses determined by the Hurst proportional counter. This is especially true for the concrete and steel/concrete shields for which the attenuation factors are not well known. A comparison of gamma reference dosimetry with participant's results is given in Table 16. While the data have been kept separate for the two sets of runs, it appears that only data from the unshielded part of the experiment needed to be separated.

CONCLUSIONS

A few tentative conclusions are suggested by this study; however, one needs to be cautious since some data points represent only a few measurements. Perhaps the data from all the PDIS studies could be combined to yield more definitive conclusions. It appears that NTA film (see Tables 11-14) consistently underestimates the dose. This would be even more dramatically portrayed if zero and minimal values had been included. Other neutron dosimeter types respond about equally well (if one considers ±50-100% acceptable).

Film has a smaller standard deviation than TLD's for gamma dosimetry. This observation is based on too little data to be conclusive, however.

Overall, standard deviations were excessively large. Few of the dosimeters in this PDIS would pass the guidelines contained in a draft American National Standard[16] and supported by the Nuclear Regulatory Commission. The few bright spots were for dosimeter types minimally represented and consequently lack the degree of confidence that is required to allow one to assert acceptable performance. For example, track-etch dosimeters generally agreed with the reference dosimetry and had a smaller standard deviation than albedo dosimeters.

This type of intercomparison activity was found to be valuable to the participants, and the results are indicative of some trouble spots in the interpretation of dosimeter responses. The participants and dosimeters have not been the same from one year's study to the next, and there is no reason to believe that the same participants will continue year after year. Thus, new groups can be helped by offering this activity on a continuing basis. It is anticipated that this type of intercomparison study will be worthwhile on an annual basis until the problems in dosimeter response and interpretation have been identified and solved.

REFERENCES

1. H. W. Dickson, W. F. Fox, and F. F. Haywood, *1974 Intercomparison of Personnel Dosimeters*, ORNL/TM-4786 (January 1976).

2. L. W. Gilley, H. W. Dickson, and D. J. Christian, *1976 Intercomparison of Personnel Dosimeters*, ORNL/TM-5672 (December 1976).

3. L. W. Gilley and H. W. Dickson, *Third Personnel Dosimetry Intercomparison Study*, ORNL/TM-6114 (January 1979).

4. J. W. Poston, J. R. Knight, and G. E. Whitesides, "Calculation of the HPRR neutron spectrum for simulated nuclear accident conditions," *Health Phys.* 26, 217 (1974).

5. H. W. Dickson and L. W. Gilley, "Personnel Dosimetry Intercomparison Studies at the ORNL Health Physics Research Reactor," *Symposium on National and International Standardization in Radiation Dosimetry, December 5-9, 1977, Atlanta, Georgia*, International Atomic Energy Agency (1977).

6. J. A. Auxier, "The Health Physics Research Reactor," *Health Phys.* 11, 89 (1965).

7. H. W. Dickson, F. F. Haywood, and K. Becker, *Tenth Dosimetry Intercomparison Study*, ORNL/TM-4566 (March 1975).

8. C. S. Sims and H. W. Dickson, "Nuclear Accident Dosimetry Intercomparison Studies at the Health Physics Research Reactor: A Summary (1965-1978)," *Health Phys.* 37, 687 (1979).

9. C. S. Sims, *Fourteenth Nuclear Accident Dosimetry Intercomparison Study: July 13-22, 1977*, ORNL/TM-6773 (June 1979).

10. M.S.S. Murthy, R. C. Bhatt, and S. S. Shinde, "Estimation of Quality Factor and RBE for Degraded Fission Neutron Spectra," *Health Phys.* 27, 9 (1974).

11. National Council on Radiation Protection and Measurement, *Protection Against Neutron Radiation,* NCRP Report No. 38 (1971).

12. F. H. Attix and W. C. Roesch (eds.), *Radiation Dosimetry,* pp. 294-298, Vol. 1, Academic Press, New York, 1968.

13. International Commission on Radiation Units and Measurements, *Neutron Fluence, Neutron Spectra and Kerma,* ICRU Report 13 (1969).

14. G. S. Hurst, "An Absolute Tissue Dosemeter for Fast Neutrons," *Br. J. Radiol.* 27, 353 (1954).

15. D. R. Johnson and J. W. Poston, *Radiation Dosimetry Studies at the Health Physics Research Reactor,* ORNL-4113 (1967).

16. American National Standards Institute, "Criteria for Testing Personnel Dosimeter Performance," Draft American National Standard, N13.11 (July 1978).

Table 1. Summary of reactor operations for the fourth PDIS

Run	Shield	Power (watt)	Time (sec)	Fissions (10^{13})
1 and 5	None	2	187	1.16
2 and 6	Lucite	2	990	6.14
3 and 7	Concrete	1.7	1285	6.77
4 and 8	Steel/Concrete	1.9	1328	7.83

Table 2. Sulfur pellet dosimetry

Run	Date	Shield	Kerma (millirad)[a]	QF	Dose equivalent (millirem)
1	3/15/78	None	45.9 ± 10%	9.4 ± 4%	431 ± 46
2	3/15/78	Lucite	49.2 ± 11%	8.9 ± 5%	438 ± 53
3	3/16/78	Concrete	67.8 ± 16%	8.6 ± 5%	583 ± 97
4	3/16/78	Steel/ Concrete	71.0 ± 19%	8.8 ± 5%	625 ± 123
5	3/23/78	None	49.4 ± 10%	9.4 ± 4%	464 ± 50
6	3/23/78	Lucite	53.3 ± 11%	8.9 ± 5%	474 ± 57
7	3/23/78	Concrete	63.3 ± 16%	8.6 ± 5%	544 ± 91
8	3/23/78	Steel/ Concrete	70.0 ± 19%	8.8 ± 5%	616 ± 121

[a]Error due to combination of counting errors, extrapolation from location of pellet to dosimeter position and uncertainty in shielding attenuation factors.

Table 3. Reference dosimetry for the fourth PDIS (March 15-16, 1978)

Exposure condition	Neutron dose[a] (millirad)	Neutron QF[b]	Dose equivalent (millirem) Neutron	Dose equivalent (millirem) Gamma[c]
Unshielded	51.2	9.4	481 ± 52	32
Lucite	46.8	8.9	416 ± 47	41
Concrete	51.7	8.6	445 ± 50	27
Steel/Concrete	53.1	8.8	467 ± 52	24

[a]Measured with a Hurst proportional counter. The error due to calibration source uncertainty and counting statistics amounts to approximately 10%.

[b]Quality factors are known to 4% for the unshielded reactor spectrum and approximately 5% for the various shielded spectra.

[c]Reference gamma dosimetry performed using TLD's.

Table 4. Reference dosimetry for the fourth PDIS (March 23, 1978)

Exposure condition	Neutron dose[a] (millirad)	Neutron QF[b]	Dose equivalent (millirem) Neutron	Dose equivalent (millirem) Gamma[c]
Unshielded	46.0	9.4	432 ± 47	15
Lucite	52.4	8.9	466 ± 52	53
Concrete	49.2	8.6	423 ± 47	33
Steel/Concrete	47.6	8.8	419 ± 47	33

[a]Measured with a Hurst proportional counter. The error due to calibration source uncertainty and counting statistics amounts to approximately 10%.

[b]Quality factors are known to 4% for the unshielded reactor spectrum and approximately 5% for the various shielded spectra.

[c]Reference gamma dosimetry performed using TLD's.

Table 5. Calculated doses and dose equivalents for PDIS operations based on reactor operating information

Shield	Fissions (10^{13})	Fluence ($cm^{-2} \times 10^{-7}$)	Dose (millirad)	Dose equivalent (millirem)
None	1.16	2.34	59.7	561
Lucite	6.14	3.26	47.5	423
Concrete	6.77	6.77	91.8	789
Steel/ Concrete	7.83	7.60	92.7	816

Table 6. Types of dosimeters used in the fourth PDIS

Group	Neutron dosimeter	Gamma dosimeter
Argonne National Laboratory	NTA film	Film
Battelle PNL	TLD albedo	TLD
Cornell University		TLD
Czechoslovak Academy of Sciences	Track etch	
Department of Navy	TLD albedo	TLD
Department of Energy/IOO	TLD albedo	TLD
Eberline Instrument Corporation	TLD	TLD
Fermi Laboratory	NTA film/Track etch	Film/TLD
Goodyear Atomic Corporation		
Kernforschungszentrum Karlsruhe	TLD albedo	TLD
Lawrence Berkeley Laboratory		
Lawrence Livermore Laboratory	TLD albedo/ Track etch	TLD
R. S. Landauer, Jr. & Company	Track etch	
Rockwell International	TLD albedo	TLD
Savannah River Plant	TLD albedo	TLD
Stanford University	TLD albedo	TLD
Teledyne Isotopes	TLD	TLD
Tennessee Valley Authority		TLD
University of California, Davis	NTA film	Film
University of San Francisco	Track etch	
Westinghouse, Bettis	TLD albedo	TLD
Yale University	NTA film	Film

Table 7. Results of participant's measurements for the unshielded HPRR exposures

Group	Neutron dosimeter	Neutron dose equivalent (millirem)	Gamma dosimeter	Gamma dose equivalent (millirem)	Phantom used	Date of exposure	Remarks
1	1 (NTA film)	280	1 (Film)	50	A	3/15/78	
	2 (NTA film)	275	2 (Film)	50	A	3/15/78	
	3 (NTA film)	250	3 (Film)	50	A	3/15/78	
2	1 (Albedo)	540	1 (TLD)	50	B	3/15/78	
3			1 (TLD-100)	188	C	3/15/78	Not corrected for neutron response
			2 (TLD-100)	200	C	3/15/78	Not corrected for neutron response
			3 (TLD-100)	225	C	3/15/78	Not corrected for neutron response
4	1 (Track etch)	600			In air	3/15/78	
5	1 (Albedo)	860	1 (TLD)	71	C	3/15/78	
	2 (Albedo)	1004	2 (TLD)	74	C	3/15/78	
	3 (Albedo)	1025	3 (TLD)	69	C	3/15/78	
6	1 (Albedo)	91	1 (TLD)	17	B	3/23/78	
	2 (Albedo)	98	2 (TLD)	14	B	3/23/78	
	3 (Albedo)	89	3 (TLD)	15	B	3/23/78	
7	1 (TLD)	508	1 (TLD)	42	A	3/15/78	
	2 (TLD)	630	2 (TLD)	32	A	3/15/78	
8	1 (NTA film)	170	1 (Film)	M[a]	A	3/23/78	
	2 (NTA film)	M[a]	2 (Film)	M[a]	A	3/23/78	
	3 (Track etch)	297	3 (TLD)	30	A	3/23/78	
	4 (Track etch)	198	4 (TLD)	30	A	3/23/78	
9					In air	3/15/78	No results reported
10	1 (Albedo)	560	1 (TLD)	15	A	3/23/78	
11					B	3/15/78	No results reported
12	1 (Albedo)	480	1 (TLD)	38	C	3/15/78	
13	1 (Track etch)	280			C	3/15/78	Combined particiation with Group 20 Reported only average of 3 measurements
14	1 (Albedo)	527	1 (TLD)	37	B	3/15/78	Reported only average of 3 measurements
15	1 (Albedo)	495	1 (TLD)	15	B	3/23/78	
	2 (Albedo)	640	2 (TLD)	15	B	3/23/78	
	3 (Albedo)	405	3 (TLD)	15	B	3/23/78	
16	1 (Albedo)	570	1 (TLD)	34	A	3/15/78	
17	1 (TLD)	595	1 (TLD)	38	H_2O bottle	3/15/78	
18			1 (TLD)	38	A	3/15/78	
19	1 (NTA film)	0	1 (Film)	40	A	3/23/78	
	2 (NTA film)	0	2 (Film)	35	A	3/23/78	
	3 (NTA film)	0	3 (Film)	20	A	3/23/78	
20	1 (Track etch)	200			C	3/15/78	Combined participation with Group 13
21	1 (Albedo)	407	1 (TLD)	20	A	3/15/78	
	2 (Albedo)	457	2 (TLD)	18	A	3/15/78	
	3 (Albedo)	452	3 (TLD)	22	A	3/15/78	
22	1 (NTA film)	34	1 (Film)	40	C	3/15/78	
	2 (NTA film)	M[a]	2 (Film)	40	C	3/15/78	

[a] M = minimum detectable or minimal but reported without specific definition.

Table 8. Results of participant's measurements for Lucite shielded HPRR exposures

Group	Neutron dosimeter	Neutron dose equivalent (millirem)	Gamma dosimeter	Gamma dose equivalent (millirem)	Phantom used	Date of exposure	Remarks
1	1 (NTA film)	205	1 (Film)	55	A	3/15/78	
	2 (NTA film)	225	2 (Film)	50	A	3/15/78	
	3 (NTA film)	230	3 (Film)	50	A	3/15/78	
2			1 (TLD)	70	B	3/15/78	
3			1 (TLD-100)	827	C	3/15/78	Not corrected for neutron response
			2 (TLD-100)	805	C	3/15/78	Not corrected for neutron response
			3 (TLD-100)	877	C	3/15/78	Not corrected for neutron response
4	1 (Track etch)	690			In air	3/15/78	
5	1 (Albedo)	1342	1 (TLD)	118	C	3/15/78	
	2 (Albedo)	1139	2 (TLD)	138	C	3/15/78	
	3 (Albedo)	1249	3 (TLD)	136	C	3/15/78	
6	1 (Albedo)	221	1 (TLD)	67	B	3/23/78	
	2 (Albedo)	193	2 (TLD)	67	B	3/23/78	
	3 (Albedo)	211	3 (TLD)	58	B	3/23/78	
7	1 (TLD)	421	1 (TLD)	0	A	3/15/78	
	2 (TLD)	447			A	3/15/78	
	3 (TLD)	447			A	3/15/78	
8	1 (NTA film)	168	1 (Film)	80	A	3/23/78	
	2 (NTA film)	M[a]	2 (Film)	80	A	3/23/78	
	3 (Track etch)	240	3 (TLD)	130	A	3/23/78	
	4 (Track etch)	192	4 (TLD)	120	A	3/23/78	
9					In air	3/15/78	No results reported
10	1 (Albedo)	420	1 (TLD)	50	A	3/23/78	
11							Did not participate in this exposure
12	1 (Albedo)	510	1 (TLD)	54	C	3/15/78	
	2 (Track etch albedo comb.)	629			C	3/15/78	
13	1 (Track etch)	460			C	3/15/78	Combined participation with Group 20 Reported only average of 3 measurements
14	1 (Albedo)	483	1 (TLD)	61	B	3/15/78	Reported only average of 3 measurements
15	1 (Albedo)	600	1 (TLD)	50	B	3/23/78	
	2 (Albedo)	625	2 (TLD)	60	B	3/23/78	
	3 (Albedo)	570	3 (TLD)	55	B	3/23/78	
16	1 (Albedo)	350	1 (TLD)	47	A	3/15/78	
17	1 (TLD)	496	1 (TLD)	67	H_2O bottle	3/15/78	
18			1 (TLD)	67	B	3/15/78	
19	1 (NTA film)	15	1 (Film)	80	A	3/23/78	
	2 (NTA film)	0	2 (Film)	85	A	3/23/78	
	3 (NTA film)	0	3 (Film)	65	A	3/23/78	
20	1 (Track etch)	460			C	3/15/78	Combined participation with Group 20
21	1 (Albedo)	273	1 (TLD)	55	A	3/15/78	
	2 (Albedo)	261	2 (TLD)	49	A	3/15/78	
	3 (Albedo)	274	3 (TLD)	67	A	3/15/78	
22	1 (NTA film)	189	1 (Film)	80	C	3/15/79	
	2 (NTA film)	M[a]	2 (Film)	80	C	3/15/79	

[a]M = minimum detectable or minimal but reported with no specific definition.

Table 9. Results of participant's measurements for concrete-shielded HPRR exposures

Group	Neutron dosimeter	Neutron dose equivalent (millirem)	Gamma dosimeter	Gamma dose equivalent (millirem)	Phantom used	Date of exposure	Remarks
1	1 (NTA film)	180	1 (Film)	35	A	3/16/78	
	2 (NTA film)	175	2 (Film)	35	A	3/16/78	
	3 (NTA film)	165	3 (Film)	35	A	3/16/78	
2	1 (Albedo)	460	1 (TLD)	50	B	3/16/78	
3			1 (TLD-100)	863	C	3/16/78	Not corrected for neutron response
			2 (TLD-100)	913	C	3/16/78	Not corrected for neutron response
			3 (TLD-100)	829	C	3/16/78	Not corrected for neutron response
4	1 (Track etch)	560			In air	3/16/78	
5	1 (Albedo)	6849	1 (TLD)	68	C	3/16/78	
	2 (Albedo)	7555	2 (TLD)	58	C	3/16/78	
	3 (Albedo)	7317	3 (TLD)	46	C	3/16/78	
6	1 (Albedo)	358	1 (TLD)	47	B	3/23/78	
	2 (Albedo)	380	2 (TLD)	64	B	3/23/78	
	3 (Albedo)	374	3 (TLD)	40	B	3/23/78	
7	1 (TLD)	493	1 (TLD)	43	A	3/16/78	
	2 (TLD)	599			A	3/16/78	
	3 (TLD)	548			A	3/16/78	
8	1 (NTA film)	468	1 (Film)	60	A	3/23/78	
	2 (Track etch)	315	2 (TLD)	90	A	3/23/78	
9							Did not participate in this exposure
10	1 (Albedo)	590	1 (TLD)	35	A	3/23/78	
11					B	3/16/78	No results reported
12	1 (Albedo)	500	1 (TLD)	39	C	3/16/78	
	2 (Track etch albedo comb.)	356			C	3/16/78	
13	1 (Track etch)	630			C	3/16/78	Combined participation with Group 20 Reported only average of 3 measurements
14	1 (Albedo)	749	1 (TLD)	39	B	3/16/78	Reported only average of 3 measurements
15	1 (Albedo)	830	1 (TLD)	40	B	3/23/78	
	2 (Albedo)	795	2 (TLD)	40	B	3/23/78	
	3 (Albedo)	735	3 (TLD)	40	B	3/23/78	
16	1 (Albedo)	710	1 (TLD)	31	A	3/16/78	
17	1 (TLD)	631	1 (TLD)	51	H_2O bottle	3/16/78	
18			1 (TLD)	38	B	3/16/78	
19	1 (NTA film)	40	1 (Film)	50	A	3/23/78	
	2 (NTA film)	50	2 (Film)	60	A	3/23/78	
	3 (NTA film)	90	3 (Film)	45	A	3/23/78	
20	1 (Track etch)	630			C	3/16/78	Combined participation with Group B
21	1 (Albedo)	335	1 (TLD)	51	A	3/16/78	
	2 (Albedo)	358	2 (TLD)	45	A	3/16/78	
	3 (Albedo)	356	3 (TLD)	41	A	3/16/78	
22	1 (NTA film)	M[a]	1 (Film)	60	C	3/16/78	
	2 (NTA film)	234	2 (Film)	70	C	3/16/78	

[a]M = minimum detectable or minimal but reported with no specific definition.

Table 10. Results of participant's measurements for steel/concrete-shielded HPRR exposures

Group	Neutron dosimeter	Neutron dose equivalent (millirem)	Gamma dosimeter	Gamma dose equivalent (millirem)	Phantom used	Date of exposure	Remarks
1	1 (NTA film)	185	1 (Film)	30	A	3/16/78	
	2 (NTA film)	170	2 (Film)	35	A	3/16/78	
	3 (NTA film)	155	3 (Film)	35	A	3/16/78	
2	1 (Albedo)	990	1 (TLD)	50	B	3/16/78	
3			1 (TLD-100)	915	C	3/16/78	Not corrected for neutron response
			2 (TLD-100)	985	C	3/16/78	Not corrected for neutron response
			3 (TLD-100)	917	C	3/16/78	Not corrected for neutron response
4	1 (Track etch)	500			In air	3/16/78	
5	1 (Albedo)	2387	1 (TLD)	128	C	3/16/78	
	2 (Albedo)	2584	2 (TLD)	127	C	3/16/78	
	3 (Albedo)	1609	3 (TLD)	143	C	3/16/78	
6	1 (Albedo)	457	1 (TLD)	36	B	3/23/78	
	2 (Albedo)	423	2 (TLD)	48	B	3/23/78	
	3 (Albedo)	453	3 (TLD)	43	B	3/23/78	
7	1 (TLD)	719	1 (TLD)	0	A	3/16/78	
	2 (TLD)	838			A	3/16/78	
8	1 (NTA film)	M[a]	1 (Film)	70	A	3/23/78	
	2 (Track etch)	306	2 (TLD)	100	A	3/23/78	
9							Did not participate in this exposure
10	1 (Albedo)	730	1 (TLD)	35	B	3/16/78	
11					B	3/16/78	No results reported
12	1 (Albedo)	420	1 (TLD)	41	C	3/16/78	
	2 (Track etch albedo comb.)	328			C	3/16/78	
13	1 (Track etch)	620			C	3/16/78	Combined participation with Group Reported only average of 3 measurements
14	1 (Albedo)	990	1 (TLD)	38	B	3/16/78	Reported only average of 3 measurements
15	1 (Albedo)	930	1 (TLD)	40	B	3/23/78	
	2 (Albedo)	965	2 (TLD)	40	B	3/23/78	
	3 (Albedo)	1130	3 (TLD)	40	B	3/23/78	
16	1 (Albedo)	1000	1 (TLD)	32	A	3/16/78	
17	1 (TLD)	741	1 (TLD)	52	H_2O bottle	3/16/78	
18			1 (TLD)	34	B	3/16/78	
19	1 (NTA film)	0	1 (Film)	50	A	3/23/78	
	2 (NTA film)	15	2 (Film)	60	A	3/23/78	
	3 (NTA film)	0	3 (Film)	50	A	3/23/78	
20	1 (Track etch)	620			C	3/16/78	Combined participation with Group 13
21	1 (Albedo)	333	1 (TLD)	39	A	3/16/78	
	2 (Albedo)	358	2 (TLD)	49	A	3/16/78	
	3 (Albedo)	372	3 (TLD)	45	A	3/16/78	
22	1 (NTA film)	M[a]	1 (Film)	70	C	3/16/78	
	2 (NTA film)	180	2 (Film)	70	C	3/16/78	

[a]M = minimum detectable or minimal but reported with no specific definition.

Table 11. Summary of unshielded measurements[a]

Dosimeter type	No. of measurements	Median	Mean	Standard deviation(σ)	% σ
Neutron					
Albedo	17	495	508	271	53
TLD	3	595	578	63	11
NTA film	5	250	202	104	51
Track etch	4	288	344	176	51
All	29	457	440	252	57
Gamma (3/15/78)					
TLD	15	38	41.2	18.2	44
Film	5	50	46.0	5.5	12
All	20	39	42.4	16.0	38
Gamma (3/23/78)					
TLD	10	15	18.1	6.3	35
Film	3	35	31.7	10.4	33
All	13	15	21.2	9.1	43

[a]No minimal or zero values were used. Gamma measurements by one participant were excluded because the data could not be corrected for neutron response.

Table 12. Summary of Lucite-shielded measurements[a]

Dosimeter type	No. of measurements	Median	Mean	Standard deviation(σ)	% σ
Neutron					
Albedo	17	420	524	374	71
TLD	4	447	453	31	7
NTA film	5	205	169	89	53
Track etch	5	460	442	224	51
All	31	420	444	314	71
Gamma (3/15/78)					
TLD	13	67	74.6	33.4	45
Film	5	55	63.0	15.6	25
All	18	64	71.4	29.6	41
Gamma (3/23/78)					
TLD	10	59	71.0	29.0	41
Film	5	80	78.0	7.6	10
All	15	67	73.3	24.0	33
All Gamma	33	67	72.3	26.8	39

[a]No minimal or zero values were used. Gamma measurements by one participant were excluded because the data could not be corrected for neutron response.

Table 13. Summary of concrete-shielded measurements[a]

Dosimeter type	No. of measurements	Median	Mean	Standard deviation(σ)	% σ
Neutron					
Albedo	17	500	1720	2642	154
TLD	4	520	568	60	11
NTA film	8	170	162	205	127
Track etch	4	458	465	153	33
All	33	493	1053	2027	192
Gamma (3/16/78)					
TLD	14	44	44.8	10.6	24
Film	5	35	47.0	16.8	36
All	19	43	45.4	12.0	26
Gamma (3/23/78)					
TLD	9	40	43.2	24.2	56
Film	4	55	53.8	7.5	14
All	13	45	49.5	15.7	32
All Gamma	32	44	47.1	13.5	29

[a]No minimal or zero values were used. Gamma measurements by one participant were excluded because the data could not be corrected for neutron response.

Table 14. Summary of steel/concrete shielded measurements[a]

Dosimeter type	No. of measurements	Median	Mean	Standard deviation(σ)	% σ
Neutron					
Albedo	17	930	948	676	71
TLD	3	741	766	63	8
NTA film	5	170	141	71	50
Track etch	4	414	438	149	34
All	29	500	720	606	84
Gamma (3/16/78)					
TLD	13	45	61.7	41.4	67
Film	5	35	48.0	20.2	42
All	18	43	57.9	36.6	63
Gamma (3/23/78)					
TLD	9	40	46.1	20.7	45
Film	4	50	55.0	10.0	18
All	13	43	48.9	18.1	37
All Gamma	31	43	54.1	30.2	56

[a]No minimal or zero values were used. Gamma measurements by one participant were excluded because the data could not be corrected for neutron response.

Table 15. Comparison of neutron measurements of the fourth PDIS with reference dosimetry

Shield	Reference dosimetry (millirem)		Participants results (millirem)	
	Proportional counter	Sulfur	Mean ± σ	Median
None	456 ± 50	448 ± 48	440 ± 252	457
Lucite	441 ± 50	456 ± 55	444 ± 314	420
Concrete	434 ± 48	563 ± 94	1053 ± 2027	493
Steel/Concrete	443 ± 50	620 ± 122	720 ± 606	500

Table 16. Comparison of gamma measurements of the fourth PDIS with reference dosimetry

Shield	Reference dosimetry[a] (millirem)		Participants results (millirem)	
	Runs on 3/15-16	Runs on 3/23	Runs on 3/15-16	Runs on 3/23
None	32	15	42.4 ± 16.0	21.2 ± 9.1
Lucite	41	53	71.4 ± 29.6	72.3 ± 26.8
Concrete	27	33	45.4 ± 12.0	49.5 ± 15.7
Steel/Concrete	24	33	57.9 ± 36.6	48.9 ± 18.1

[a]Reference dosimetry by TLD has error of ±10%.

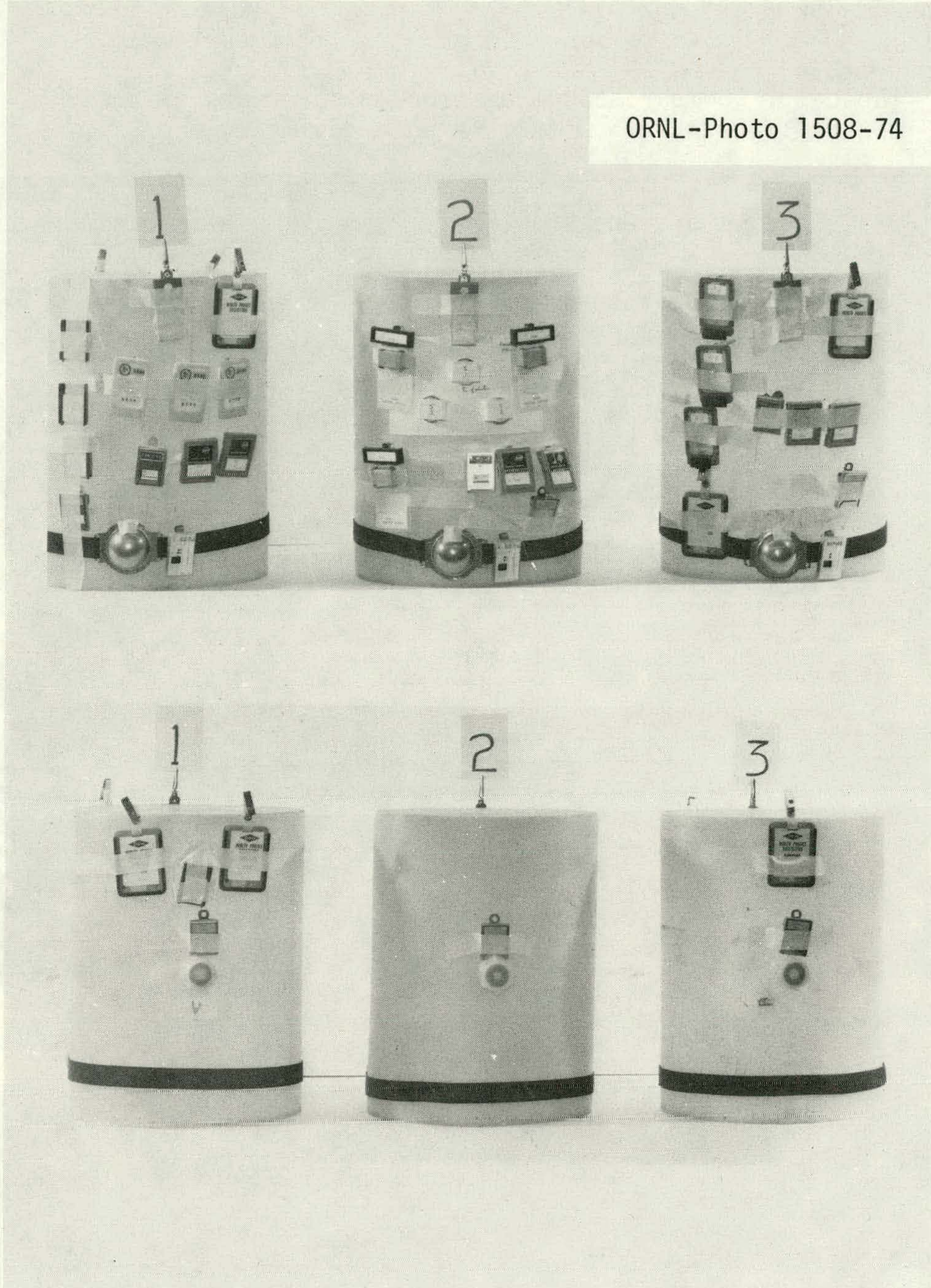

Fig. 1. Placement of dosimeters on the phantoms. Upper half of figure shows the front of the phantoms and the lower half of the figure shows the back of the phantoms.

ORNL-Photo 1202-78R

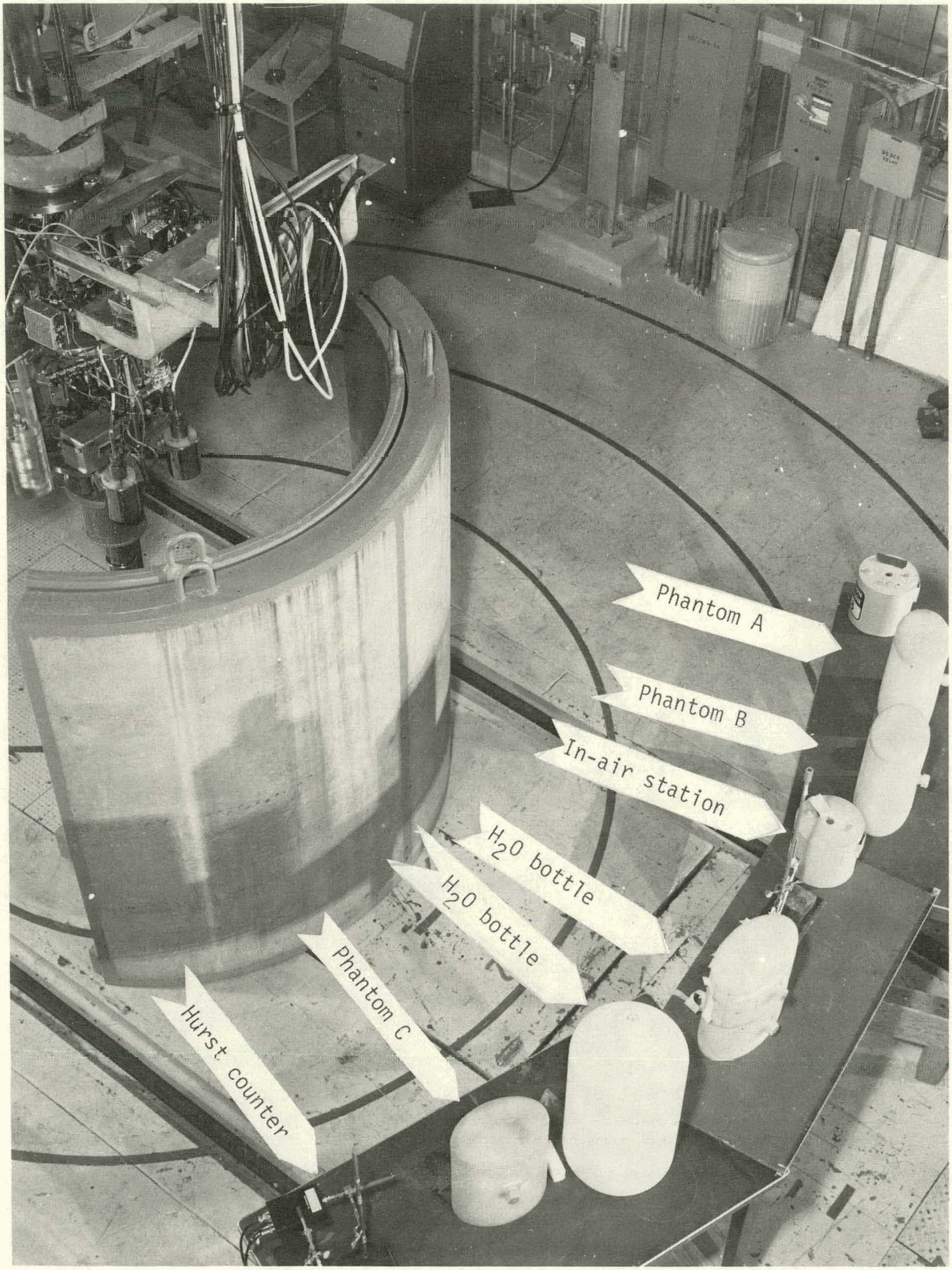

Fig. 2. Typical experimental arrangement with the steel/concrete shields in place. The Hurst proportional counter is located in the center foreground.

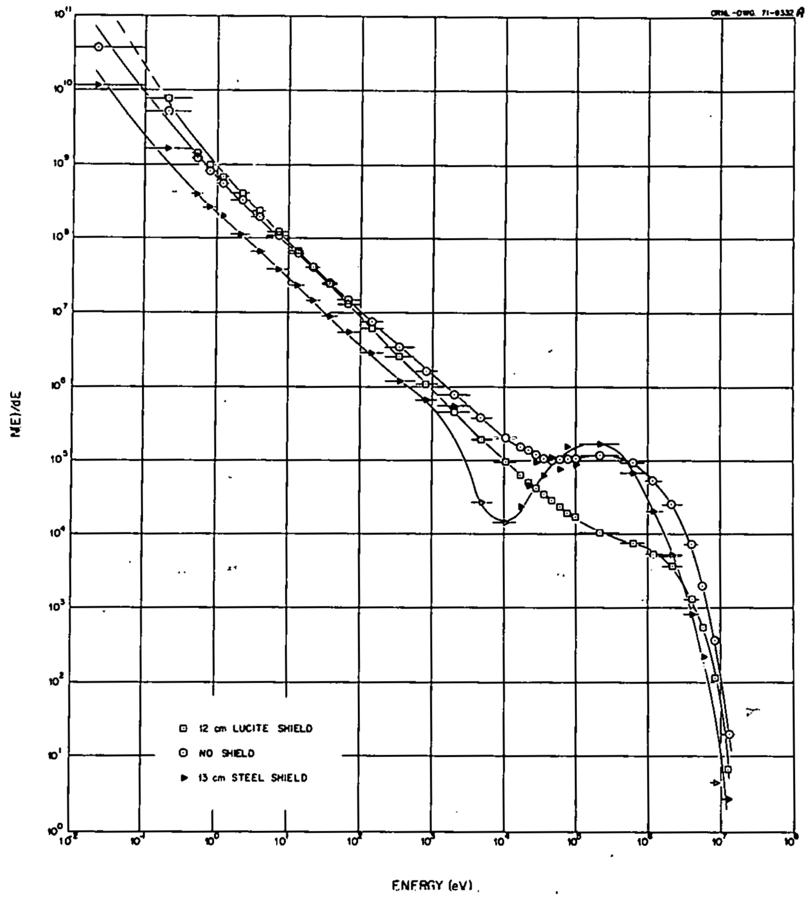

Fig. 3. Calculated HPRR leakage spectrum at 3.0 meters from the centerline of the core.

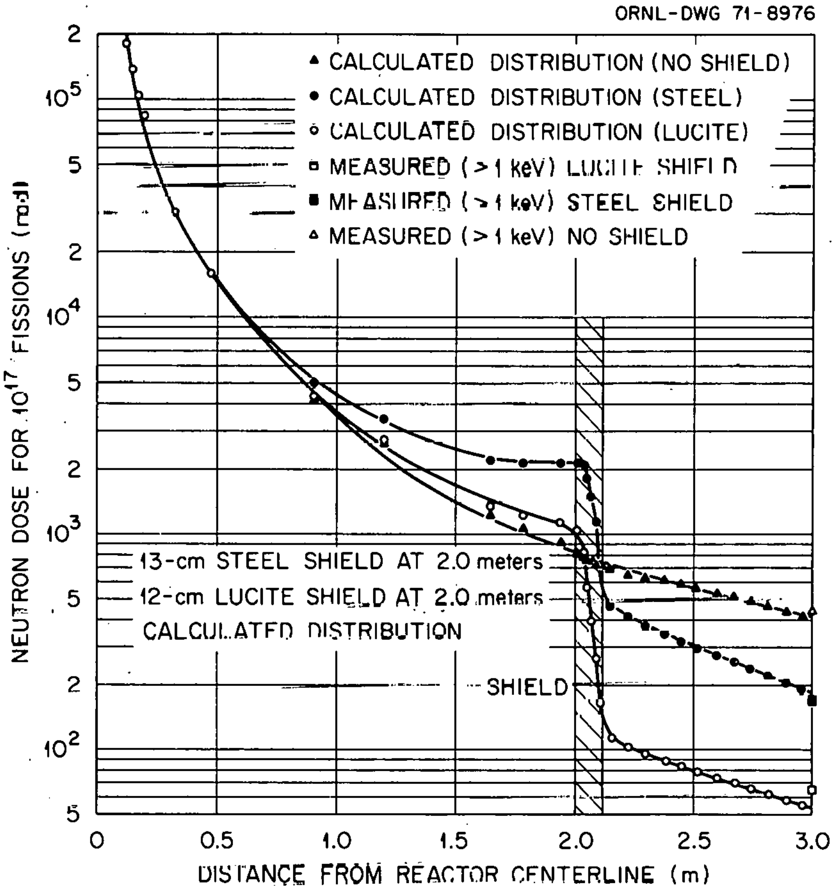

Fig. 4. Calculated neutron dose as a function of distance from the reactor centerline.

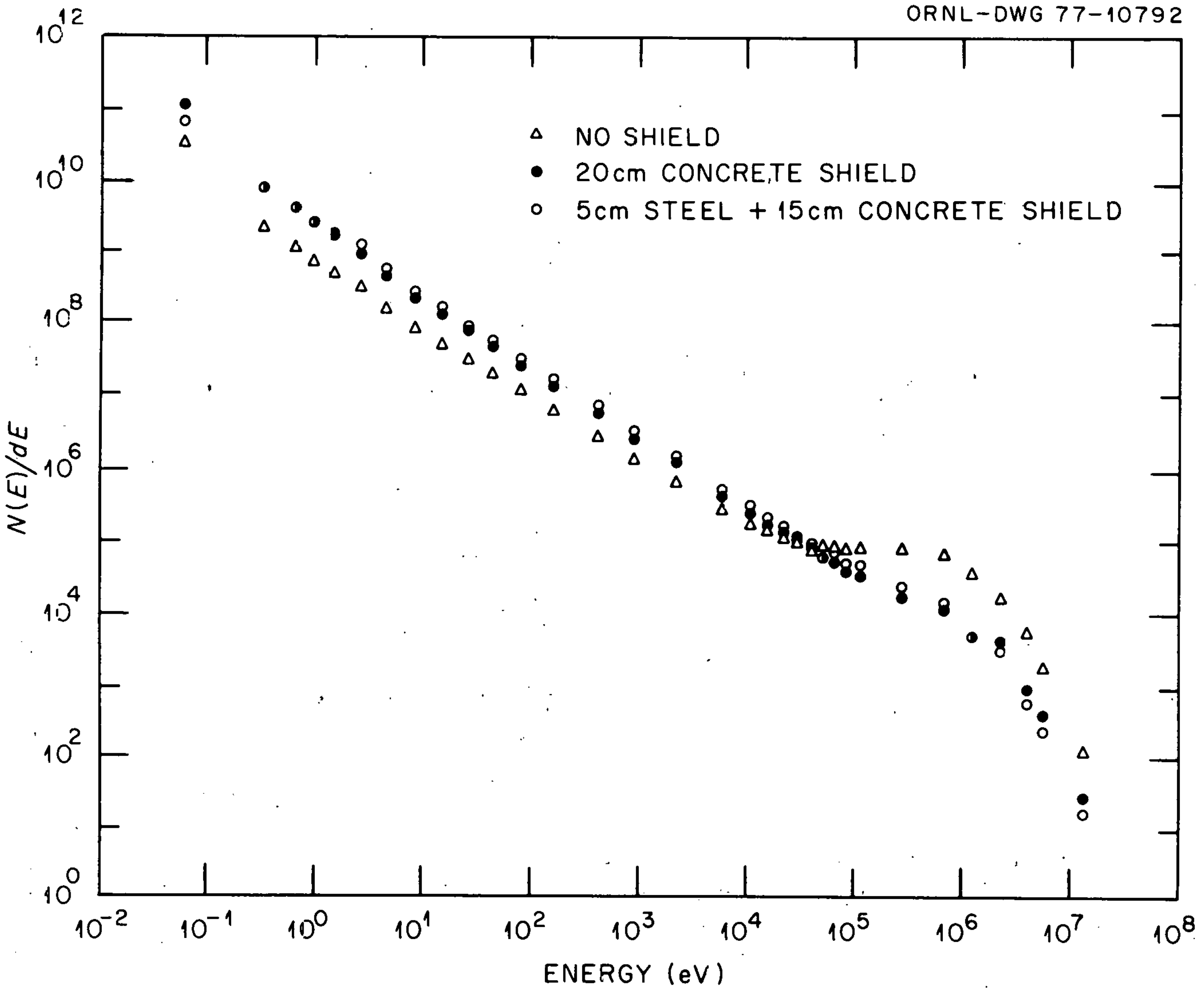

Fig. 5. Calculated HPRR leakage spectrum at 3.0 m from the centerline of the reactor.

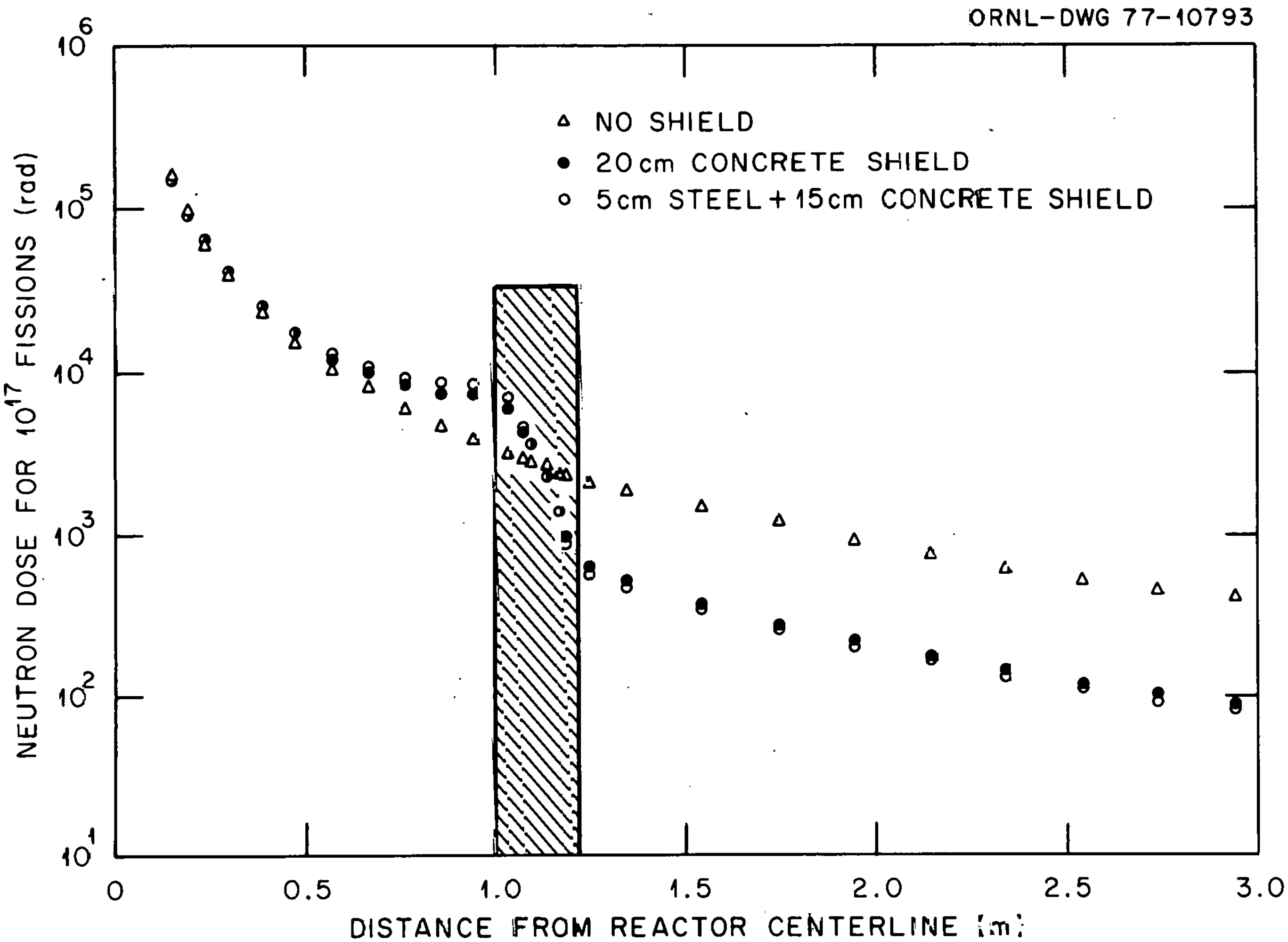

Fig. 6. Calculated neutron dose as a function of distance from the reactor centerline.

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