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Sixth Personnel Dosimetry Intercomparison Study

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HEALTH AND SAFETY RESEARCH DIVISION
OAK RIDGE NATIONAL LABORATORY

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HIGHLIGHTS

The Sixth Personnel Dosimetry Intercomparison Study was conducted March 25-27, 1980, at the Oak Ridge National Laboratory. Dosimeters from 28 participating agencies were mounted on anthropomorphic phantoms and exposed to a range of low-level dose equivalents (1.8–11.5 mSv neutron, 0.1–1.1 mSv gamma) which could be encountered during routine personnel monitoring in mixed radiation fields. The Health Physics Research Reactor (HPRR) operated in the steady-state mode served as the source of radiation for six separate exposures. Lucite and concrete shields along with the unshielded reactor were used to provide three different neutron and gamma spectra. Results reported by the participating agencies showed that TLD-albedo and TLD-700 dosimeters generally provided the most accurate measurements of neutron and gamma dose equivalents, respectively. Film was found to be unsatisfactory for measuring neutron doses produced by HPRR spectra in that measured dose equivalents were much lower than reference values. The TLD-100 dosimeters yielded gamma doses which were much too high indicating that this dosimeter type is generally unsuitable for use in mixed radiation fields similar to those encountered in this study without the use of large correction factors. Although the overall reported results exhibited improvement in performance relative to previous intercomparison studies, the composite measured data showed variations of more than a factor of 2 between measurements of the same exposure made by different agencies. These results indicate that continued development and analysis of mixed field personnel dosimetry by participating agencies is required both individually by refining measurement techniques and collectively by participating in further intercomparison studies to evaluate dosimetry performance.

INTRODUCTION

The Sixth Personnel Dosimetry Intercomparison Study (PDIS) was conducted at the Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research (DOSAR) Facility during the period March 25-27, 1980. This study is the sixth in a series[1-5] which started in 1974. The PDIS is a three-day study in which personnel dosimeters previously mailed to the DOSAR Facility, are exposed to a range of low-level (typically 0.1-1.0 mSv gamma and 1-15 mSv neutron)* mixed-field radiation dose equivalents using the Health Physics Research Reactor (HPRR)[6] as the radiation source, and packaged for return to the participants for evaluation. This report is a summary and analysis of results reported by the various participants.

PARTICIPATION

A complete list of participating agencies, cognizant personnel, and abbreviations by which the agencies are identified in this report is given in Appendix A. A total of twenty-eight organizations, nineteen domestic and nine foreign, participated in the overall study with twenty-seven agencies reporting results. During March 25-27, dosimeters from twenty-six organizations were irradiated. Dosimeters from two agencies arrived subsequent to this period and were irradiated during a second set of exposures which were conducted during May 13-15, 1980.

Participation in personnel dosimetry intercomparison studies has been open to any organization legitimately interested in personnel dosimetry and willing to cooperate with the DOSAR staff in sharing results with other participants. The participant is responsible to pay dosimeter shipping costs, to provide instructions concerning handling and placement of dosimeters, and to expeditiously furnish measurement results. The DOSAR personnel set up and conduct the specified exposures, promptly return irradiated dosimeters to participants, collect and evaluate resulting data, and prepare a report describing the experiment and results.

EXPERIMENT DESCRIPTION

Six different experimental runs were performed to expose personnel dosimeters to mixed neutron and gamma fields during the Sixth PDIS. The HPRR with its horizontal centerline positioned 1.5 m above the floor was operated in the steady-state mode to serve as the radiation source.

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*Radiation dose and dose equivalent are presented in this report in the international system of units. Conversions to the more traditional units in which the results were originally reported by participants include 1 mrad = 10^{-5} Gy and 1 mrem = 10^{-5} Sv for dose and dose equivalent, respectively.

Dose equivalents and neutron-to-gamma ratios likely to be encountered in personnel monitoring were produced by controlling reactor power level and run duration and by utilizing three different shielding conditions: unshielded, a 12-cm-thick Lucite shield, and a 20-cm-thick concrete shield. Two separate runs were performed for each of the three shielding conditions.

Dosimeters were mounted on the front (i.e., surface facing the HPRR) and rear surfaces of trunk sections of six water-filled Bomab[7] phantoms. The trunk sections used in this study have elliptical cross sections with dimensions 20 cm × 30 cm and are 40 cm high. These sections were located with their front surfaces 3 m from the reactor centerline and their horizontal centerlines 1.5 m above the floor. Figure 1 shows a front view of the experimental configuration of the six phantom sections with dosimeters attached. Also shown in the figure are reference dosimeters, which are described in the next section of this report, and two spheres — a 23-cm-diameter (9 in.) polyethylene sphere and a 7.6-cm-diameter (3 in.) cadmium-covered polyethylene sphere — which are used to calibrate TLD-albedo dosimeters.[8]

Figures 2 and 3 show overhead views of the experimental arrangements for the Lucite and concrete shielded exposures, respectively. The Lucite shield, which is 2.7 m high and encompasses a 115° arc, was located 2 m from the reactor centerline. The concrete shield, which is 2.13 m high and encompasses an arc of 135°, was positioned 1 m from the HPRR centerline. Neutron energy spectra calculated using a two-dimensional discrete ordinates transport (DOT) code[9,10] are given in Appendices B and C for the HPRR with the shields used in the Sixth PDIS.

Table 1 is a summary of experimental conditions for each of the six exposures conducted during March 25-27, 1980. Table 2 summarizes experimental conditions for the second set of exposures performed on May 13-15 to accommodate late arrivals. Reactor, shield, and phantom configurations were the same for both sets of exposures. Run durations and reactor power levels were also the same for both sets of exposures, but the runs were not performed in the same sequence. The indicated reactor power levels, run times, and shields produced dose equivalents in the range 0.1-1.1 mSv (10-110 mrem) gamma and 1.8-11.5 mSv (180-1150 mrem) neutron at 3 m from the reactor centerline.

Table 3 shows measured total, neutron, and gamma doses for equivalent runs during the two sets of exposures. These data were measured by DOSAR personnel using direct measurements of integrated doses as described in the "Reference Dosimetry" section of this report. The table shows that corresponding runs (same power levels, run times, and shields) produced nearly equal total and neutron doses in every case (<11% variation). Gamma doses showed somewhat larger percentage variations (<58%) than total and neutron doses between equivalent runs which is expected at these low doses due to residual fission product and activation gamma-rays.[5] Based on these results, data from the single organization that reported results from the second set of exposures are included with data obtained during the initial exposures in the following analysis.

DOSIMETER TYPES

The types of dosimeters used in the Sixth PDIS are summarized in Table 4. Descriptions given in the table were furnished by participants with reported experimental data. Dosimeter types used for neutron measurements included thermoluminescent dosimeters (TLD), TLD-albedo, film, and track-etch. Gamma doses were measured using TLD and film dosimeters. The most popular types of dosimeters used by the participants were TLD-albedo for neutrons and TLD (primarily TLD-700) for gammas.

In the remainder of this report, the dosimeters are referred to as film, TLD (for TLD and TLD-albedo), and track (for track-etch). Descriptions of these dosimeter types are available in the literature,[8,11] and dosimetry related comments received from participants are included in Appendix D of this report.

REFERENCE DOSIMETRY

Reference gamma and neutron doses were obtained for each of the runs during the PDIS based on direct measurements of integrated doses made by DOSAR personnel. Total, neutron, and gamma doses integrated over the exposure time for each run were measured at air stations using a tissue equivalent ionization chamber (TEIC), sulfur pellet activation analysis,[12] and a Geiger-Mueller (G-M) tube,[13] respectively. The following describes each of these direct measurement techniques as used in this study.

Tissue Equivalent Ionization Chamber (TEIC)

A TEIC was installed at the DOSAR facility to perform on-line measurements of total (neutron and gamma) dose at a monitoring station in air. The sensor (a Digital Data Dosimetry Model RD-1 probe) is a 7.3-cm-diameter spherical ionization chamber which has 0.16-cm-thick walls made of Shonka A-150 plastic[14] and is filled with tissue equivalent gas. The TEIC was calibrated by the vendor using ^{137}Cs and was checked by the DOSAR staff using ^{60}Co.

Sulfur Pellet Analysis

The basis of routine neutron dosimetry at the HPRR is a standard sized (nominal 22 g) sulfur pellet[12] located at a fixed position near the reactor core. The induced ^{32}P beta activity of the pellet is measured after an operation and can be related to the unshielded tissue kerma at an area monitoring station at any distance from the HPRR via an accurately known neutron dose vs distance relationship developed at the DOSAR Facility over 16 years of operational experience. To obtain the dose at an air station when shields are used, the unshielded dose is modified by an experimentally determined shield attenuation factor.[15]

Geiger-Mueller Tube (G-M)

The integrated gamma dose at an air station was measured using a small Phillips G-M tube[13] with a lithium shield which was calibrated using ^{60}Co.

REFERENCE DOSE EQUIVALENT

Table 5 presents reference gamma dose equivalent on phantom front and rear surfaces and associated measured data and conversion factors for each run. The air station dose used as a basis for the reference values is an average of the integrated G-M gamma dose measurement and the difference of the doses obtained by TEIC and sulfur activation methods. An air-to-phantom conversion[5] developed from previous intercomparison study results[15] is applied to this average value to obtain the reference dose equivalents shown in the table. A front-to-rear conversion factor also developed from prior intercomparison study results[15] is applied to the front dose equivalent to obtain the reference gamma dose equivalent at the rear of the phantom.

Neutron dose equivalents on phantom fronts and rears and associated measured data and conversion factors are shown in Tables 6 and 7 for sulfur pellet activation analysis and the difference of TEIC and G-M measurements, respectively. Doses measured at air stations are converted to neutron dose equivalents on the front of the phantoms by applying an air-to-phantom dose conversion factor[15] and an effective quality factor[16,17] (QF) for each spectrum. Quality factors used for the unshielded and Lucite shielded spectra[3,16,17] represent the effective QF associated with volume element 57 of the Auxier phantom.[18] The QF of 9.8 for the concrete shielded HPRR is the average of measurements[17] and calculations[19] based on a Monte Carlo determined spectrum. This value is much less certain than the quality factors associated with the unshielded and Lucite shielded HPRR spectra. It is standard practice to use QF = 10 for cases where the neutron spectrum is completely unknown.[20] The dose at the rear of the phantom is estimated by applying a front-to-rear conversion factor developed from previous intercomparison study results.[15] Table 8 summarizes neutron dose equivalents on the fronts and rears of phantoms which are the average of values shown in Tables 6 and 7 for sulfur pellet activation analysis and TEIC measurements.

Dose equivalents were also calculated for each run based on the calculated HPRR spectra and energy expended (power level × time of operation) as determined from reactor instrumentation. The number of fissions during each run was determined based on an energy release conversion of 3.1×10^{10} fissions = 1 W-s. The corresponding neutron fluence at 3 m from the HPRR was computed from the number of fissions and the fluence per 10^{17} fissions from DOT code calculated spectra (Appendices B and C). Dose conversion factors (Gray per unit fluence) have been determined[1] by multiplying the fluence in each energy interval of the spectra by the element 57 dose per unit fluence in that interval[18] and summing over all intervals. The calculated fluences were multiplied by these conversion factors to give the dose in air at 3 m from the reactor for each PDIS run. Conversion to dose equivalent on the fronts and rears of the phantoms was performed using the techniques described above for measured data. These calculated results are presented in Table 9 for information only. They are not included in the reference average because they are traditionally not used[5] and because there are unresolved anomalies[4,21] between the DOT code calculated spectra and measurements made using concrete shields at the DOSAR facility.

RESULTS AND ANALYSIS

Tables 10-15 summarize reported gamma and neutron dose equivalent results for the Sixth PDIS. Appendix D is a compilation of dosimetry related comments transmitted by participants with the reported data. The DOSAR reference values are included in the tables but are not considered as part of the intercomparison results in the subsequent analysis. Six phantoms equidistant from the HPRR were required to accommodate the dosimeters exposed during each run. Dose results are not reported by phantom since variation among dosimeters on various phantoms has been shown to be insignificant.[4] Also, dose equivalents reported by KK, which were obtained during the second set of exposures, are analyzed with results obtained during the initial Sixth PDIS irradiations for reasons previously discussed.

To provide a calibration factor which accounts for energy dependence of TLD-albedo dosimeters, neutron flux measurements were made in a 23-cm-diameter (9 in.) polyethylene sphere and in a 7.6-cm-diameter (3 in.) cadium-covered polyethylene sphere using a BF_3 proportional counter during the initial set of exposures. The ratio of the responses of these spheres (9 in. to 3 in. sphere) can be used to determine an effective TLD calibration factor[8] for each run. Table 16 shows the ratios of responses in the spheres for each of the runs. These data are presented for information and are not directly related to the intercomparison study.

Neutron Dose-Phantom Front

An analysis of neutron dose equivalent results from measurements made on the front of phantoms is presented in Table 17. When all reported results are considered, the mean values of the dose equivalent are lower than the reference values in every case by an average of 13% for the unshielded runs, 12% for Lucite shielded runs, and 16% for the concrete shielded runs. Standard deviations from the mean for all reported results range from 47 to 79% with the unshielded runs indicating a lower average percent standard deviation (48%) than the shielded runs (62%). Median values are also lower than the reference dose equivalent in every case by an average of 8% for the unshielded cases, 26% for the Lucite shielded runs, and 20% for the concrete shielded runs. Tables 10-15 show that the largest differences between measurements made by different agencies for each run range from factors of approximately 11 for runs 4 and 6 to about 75 for run 2.

Table 17 also shows an analysis of a subset of all reported results which is more representative of the ability of participants to measure neutron dose. This subset omits results reported by HPL and NTHU for reasons associated with dosimetry calibration. The HPL data was omitted because at the time that the measured dose equivalents were reported, no final calibration factors were available for the particular dosimeters used in this study. Tables 10-15 show that neutron dose equivalent results reported by this agency are significantly higher than reference values and measurements reported by all other organizations in almost every case. Results reported by NTHU were also omitted from this subset because no correction was made for differences between spectra from the Pu-Be calibration source and those encountered in the PDIS.

Data from the subset of reported neutron dose equivalents have mean values which are lower than the reference values in every case by an average of about 14% for the unshielded runs, 16% for the Lucite shielded runs, and 17% for the concrete shielded runs. These results for the shielded runs represent a significant improvement over corresponding Fifth PDIS results,[5] which produced means that were an average of 38% different from reference dose equivalents. Percent standard deviations from the mean shown in Table 17 vary from an average of 32% for the unshielded runs to an average of 46% for the shielded cases. These results are significantly lower than corresponding values obtained during the Fifth PDIS,[5] which showed a variation in standard deviations of 46 to 100% of the means for all runs. Median values indicated the same trends observed for all reported neutron dose equivalent measurements. From Tables 10-15, maximum differences between individual measurements in this subset of reported results varied from a factor of approximately 2 for run 2 to a factor of about 16 for runs 3 and 5.

The composite of neutron dose equivalent measurements considered in this subset using various dosimeter types in the range 1.8-11.5 mSv (180-1150 mrem) indicates that:

(a) the overall accuracy of neutron dose equivalent measurements relative to the reference values and to agreement of results among individual agencies improved compared to the previous PDIS,

(b) the same neutron dose equivalents measured by different agencies can differ by more than a factor of 2,

(c) doses resulting from the unshielded HPRR spectrum were more accurately measured than doses from shielded spectra, and

(d) the majority of reported doses were lower than the reference values.

An analysis of neutron dose equivalents measured by three different types of dosimeters is presented in Table 18. Although the relatively small number of participants who used film (3) and track-etch (4) dosimetry precludes a detailed statistical analysis of these results, some trends are clearly evident from the data shown in the table. All agencies which used film to measure neutron dose equivalents reported results which are much lower than the reference value. The means of the reported values are less than 52% of the reference dose for all runs. These low results, which have been observed for film in prior intercomparison studies,[5] can be partly attributed to the insensitivity of film to neutrons having energies below about 0.7 MeV.[8,20] In addition, film can have a fading problem which results in low measured dose values if it is not packaged carefully and read promptly after exposure.[8]

Track-etch dosimeters yielded results closer to the reference values than doses measured using film. However, mean neutron dose equivalents were lower than the reference values in all cases by an average of 43% (28% for unshielded runs and 50% for shielded runs). Average percent standard deviations from the mean were 22 and 52% for unshielded and shielded cases, respectively. Median values show the same overall performance as the means relative to reference doses.

Neutron dose equivalent results reported by TLD (primarily TLD-albedo) users are much closer to the reference values than results obtained using film or track-etch dosimetry. The mean measured dose equivalents are within 5% of the reference values for the unshielded runs and within 11% of the reference doses for the shielded exposures. Mean measured dose equivalents are also lower than the reference values in every case except run 5. Percent standard deviations from the mean ranged from an average of 23% for the unshielded runs to an average of 34% for the shielded cases which are lower than corresponding values for film and track-etch dosimeters. Median values are within 21% of and lower than the reference dose equivalents in every case. These data represent an overall improvement in TLD-albedo dosimeter performance compared to results obtained during the Fifth PDIS,[5] which showed mean measured neutron dose equivalents within an average of 11% and 100% of the reference values for unshielded and shielded runs, respectively. Agreement between individual measurements as reflected by percent standard deviations from the means also improved for TLD-albedo dosimeters compared to results obtained during the previous PDIS, which indicated average percent standard deviations of 32% for unshielded runs and 62% for shielded runs. This improvement can be partly attributed to improved correction factors used by participants to account for energy dependence of TLD-albedo dosimeter response.[8]

Gamma Dose-Phantom Front

An analysis of gamma dose equivalent results from measurements made on the front of phantoms is presented in Table 19. When all reported results are considered, the mean values of the gamma dose equivalent for the six runs are higher than the reference values by factors of 1.4 to 3.6 and exhibit percent standard deviations from the mean of 100 to 255%. The median values vary from 0.8-1.4 times the reference values.

A subset of reported results is included in Table 19 to provide a better indication of the overall ability of participants to measure gamma dose. Results reported by RPB were omitted from this subset because this group used TLD-100 dosimeters, which are extremely sensitive to neutrons and yield very high measured gamma doses in mixed radiation fields.[5] Tables 10-15 show that the reported RPB gamma dose equivalents are significantly higher than reference doses and results from all other agencies in every case.

Mean values of the subset of reported results shown in Table 19 vary from about 1.0 to 1.6 times the reference gamma dose equivalents. This variation represents an improvement over corresponding results obtained during the Fifth PDIS,[5] which produced mean gamma doses that differed from the reference values by factors of 1.2 to 2.6 for the six runs. The percent standard deviations shown in Table 19 are between 40 and 85% of the mean with no significant differences between unshielded and shielded measurements. Median values vary from 0.8 to 1.3 times the reference doses with medians of half of the runs being less than the reference values. These data also represent improvements over Fifth PDIS results,[5] which showed variations of 39 to 172% of the mean for standard deviations and 0.9 to 1.9 times the reference dose for median measured values. Tables 10-15 show that the maximum differences between individual gamma dose measurements in each run vary from a factor of about 3 for run 2 to a factor of approximately 20 for run 5. For gamma dose equivalents in the range 0.1-1 mSv (10-100 mrem) measured in the presence of larger neutron dose equivalents, these composite reported results indicate no significant measurement bias relative to reference doses and possible differences of greater than a factor of 3 between measurements of the same dose equivalent made by different agencies.

A summary of gamma dose equivalents measured by various dosimeter types is presented in Table 20. In contrast to the film-measured neutron dose equivalent, film-measured gamma dose equivalents were generally higher than the reference values with mean values ranging from 1.2 to 1.9 times the reference dose and median values ranging from 0.8-1.8 times the reference for the six runs. These high doses could be a result of the sensitivity of most radiation monitoring films to neutrons. Tests conducted on eight commercial film types made to measure gamma dose showed that they were an average of four times more sensitive to thermal neutrons on a gray (or rad) basis than to ^{60}Co gamma-rays.[22] Some individual film types were ten times more sensitive to thermal neutrons than to ^{60}Co gamma-rays. The fast neutron response per gray (or rad) averaged about 5% of the gamma response. Depending on the type of film used in the PDIS and whether or not users corrected for the neutron response, this sensitivity could be a significant contributor to the high reported gamma doses.

Table 20 also presents gamma dose measurements made using various types of TLD's. The majority of participants measured gamma doses using TLD-700 material which contains 99.993% of the ^{7}Li isotope and 0.007% of the ^{6}Li isotope. Mean doses measured using TLD-700's are generally closer to the reference values than the film results and do not indicate a significant measurement bias. Mean measured doses vary from 0.8-1.8 times the reference values while median values range from 0.8-1.6 times the reference. In every case, the mean values are within one standard deviation of the reference dose. These results are consistant with the performance observed for the TLD-700 dosimeter during the Fifth PDIS.[5]

Since only three participants used $CaSO_4$ thermoluminescent dosimeters and only one participant used TLD-100 dosimeters to measure gamma dose, a detailed statistical analysis of these reported results is not possible. However, some trends are evident from the reported results. Mean and median gamma doses for the $CaSO_4$ TLD dosimeters are less than the reference doses for every run and range from about 0.6 to 1.0 times the reference value. Results obtained using TLD-100 dosimeters are significantly higher than all other measured data and are higher than the reference values by factors of 6 to 42 for the six runs. The TLD-100 material consists of natural lithium fluoride and contains 7.5% of the ^{6}Li isotope which responds to neutrons as well as gamma-rays. Thus, gamma dose can be grossly overestimated in mixed radiation fields unless spectrum dependent corrections are made.[5,23] The PDIS data also indicates that the amount of overestimation increases as the mean energy of the neutron spectrum decreases in that the measured doses are higher than the reference values by average factors of 10, 17, and 32 for unshielded, Lucite shielded, and concrete shielded runs, respectively. The poor performance of TLD-100 dosimeters with regard to measuring gamma doses in mixed radiation fields has been demonstrated in previous intercomparison studies[5] and has been attributed to the failure to correct for neutron response.

Neutron Dose-Phantom Rear

An analysis of neutron dose equivalent results measured on the rears of the phantoms is presented in Table 21. Results reported by NTHU are excluded because of differences between the calibration source (Pu-Be) and actual neutron spectra encountered in this study. Considering all dosimeter types the means and medians of the measured neutron dose equivalents are lower than the reference values for every run by factors of about 0.6-1.0 times the reference dose equivalent. As was the case with measurements on the phantom fronts, film dosimeters yielded significantly lower neutron dose estimates on the phantom rears than did TLD dosimeters. The relatively few neutron dose equivalent measurements made on the rears of the phantoms precludes any detailed statistical analysis of these data.

Gamma Dose-Phantom Rear

Table 22 presents an analysis of gamma dose measurements made on the rears of the phantoms. The subset of reported results for all dosimeter types (RPB measurements excluded) indicates that the mean gamma dose equivalents vary from 1.2 to 2.7 times the reference values. Median values vary between 0.6 to 2.8 times the reference dose. As with the phantom front measurements, film-measured gamma doses are significantly higher than the reference values (1.7 to 4.6 times the reference) presumably due to the neutron sensitivity of the film. Mean gamma doses measured using TLD dosimeters (primarily TLD-700) are much closer to the reference dose (0.4-2.6 times the reference) than film-measured doses and are higher than the reference in every case except for run 1. Dose equivalents based on $CaSO_4$ thermoluminescent dosimeters yield mean doses which range from 0.6-3.0 times the reference dose. The TLD-100 results were again much higher than all other reported doses (8 to 27 times the reference) for every run presumably due to failure to correct for the neutron sensitivity of the thermoluminescent material. No further analysis of these data is presented because of the relatively few gamma dose measurements made on the rears of the phantoms.

COMPARISON TO PREVIOUS INTERCOMPARISON STUDIES

Results presented in the preceeding text for the Sixth PDIS are consistent with the following statements which are based on results of th. .evious five studies:[1-5]

1. The most popular types of personnel dosimeters used by participating agencies are TLD-albedo for neutron measurements and TLD-700 for gamma measurements.
2. For measurements of neutron dose equivalents between 1-15 mSv (100-1500 mrem) in mixed radiation fields, TLD and track-etch dosimeters provide more accurate dose measurements than film dosimeters.
3. Mean and median values of neutron dose equivalents measured using film dosimeters are less than about 50% of the reference values. This indicates that film is inadequate for neutron personnel dosimetry applications when large numbers of low energy (<0.7 MeV) neutrons are present.
4. It is not unusual for neutron dose equivalents measured under the same conditions by different agencies to differ by more than a factor of 2.
5. Neutron dose equivalents are more accurately measured for unshielded relative to shielded runs.
6. The TLD-measured gamma doses are more accurate than film-measured doses in the 0.1-1 mSv (10-100 mrem) range when relatively large numbers of neutrons are present.
7. It is not unusual for measurements of the same gamma dose by different agencies to differ by more than a factor of 3.
8. Gamma dose equivalents measured using film are generally higher than the reference values.
9. The TLD-100 dosimeters yield doses which are significantly higher than reference values and are unsuitable for the measurement of gamma dose equivalents in mixed radiation fields unless suitable correction factors can be applied.

CONCLUSIONS

Although the overall performance of results reported by the participants indicates improvement relative to the previous PDIS, the composite measured data show variations of more than a factor of 2 between measurements of the same exposure made by different agencies. The accuracy of personnel dose measurements in mixed radiation fields could be improved for some participating agencies by using dosimeters more suited to the particular types of incident radiation, by applying correction factors which account for dosimeter response characteristics associated with the anticipated radiation fields, and by calibrating dosimetry with a source appropriate for the energy spectrum to be measured. Improved dose estimates for personnel monitoring will require continued efforts by individual organizations to evaluate and implement the items discussed above and by the collection of agencies to participate in future intercomparison studies of this type to test dosimetry performance and refine measurement techniques.

Since most participants had information concerning experimental geometries, neutron energy spectra, and source characteristics, results presented in this report probably reflect the most accurate dose estimates that can be made by the participating agencies. Personnel measuring mixed field doses in actual practice may not have this information so that resulting dose estimates may have greater uncertainties than those observed during this intercomparison study.

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. H. W. Dickson, *Fourth Personnel Dosimetry Intercomparison Study*, ORNL/TM-7137 (February 1980).

5. C. S. Sims, *Fifth Personnel Dosimetry Intercomparison Study*, ORNL/TM-7155 (February 1980).

6. J. A. Auxier, "The Health Physics Research Reactor," *Health Phys.* 11, 89-93 (1965).

7. F. W. Sanders and J. A. Auxier, "Neutron Activation of Sodium in Anthropomorphous Phantoms," *Health Phys.* 8, 371-379 (1962).

8. R. V. Griffith, D. E. Hankins, R. B. Gammage, L. Tommasino, and R. V. Wheeler, "Recent Developments in Personnel Neutron Dosimeters — A Review," *Health Phys.* 36, 235-260 (1979).

9. J. W. Poston, J. R. Knight, and G. E. Whitesides, "Calculation of the HPRR Neutron Spectrum for Simulated Nuclear Accident Conditions," *Health Phys.* 26, 217-211 (1974).

10. C. S. Sims, *Fifteenth Nuclear Accident Dosimetry Intercomparison Study: August 14-22, 1978*, ORNL/TM-6554 (May 1979).

11. T. P. Barton and C. E. Easterly, *Neutron Personnel Dosimetry Considerations for Fusion Reactors*, ORNL/TM-6756 (July 1979).

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

13. E. B. Wagner and G. S. Hurst, "A Geiger-Mueller γ-Ray Dosimeter with Low Neutron Sensitivity," *Health Phys.* 5, 20-26 (1961).

14. L. J. Goodman, "Density and Composition Uniformity of A-150 Tissue-Equivalent Plastic," *Phys. Med. Biol.* 23, 4 (1978).

15. 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, 687-699 (1979).

16. M.S.S. Murthy, R. C. Bhatt, and S. S. Shinde, "Estimation of Quality Factor and RBE for Degraded Fission Neutron Spectra," *Health Phys.* 37, 9-17 (1974).

17. C. S. Sims, H. W. Dickson, and L. W. Gilley, "Neutron Quality Factor Measurements at the Oak Ridge National Laboratory's Dosimetry Applications Research Facility," *Health Phys.* 38, 851-853 (1980).

18. J. A. Auxier, W. S. Snyder, and T. D. Jones, "Neutron Interactions and Penetration in Tissue," *Radiation Dosimetry*, Vol. 1, p. 275, ed. by F. H. Attix and W. C. Roesch, Academic Press, New York (1968).

19. H. W. Dickson, Unpublished hand calculations using a Monte Carlo calculated spectrum for the concrete shielded HPRR (1979).

20. International Commission on Radiation Units and Measurements, *Radiation Protection Instrumentation and Its Application*, ICRU Report 20 (1971).

21. C. S. Sims and H. W. Dickson, "Health Physics Research Reactor Spectrum Measurements with Threshold Detector Units," *Health Phys.* 37, 687-699 (1979).

22. R. J. Smith and R. F. Benck, "Thermal and Fast Neutron Effects on Dosimeter Films," *Health Phys.* 9, 473-484 (1963).

23. D. E. Hankins, "Evaluation of the Fast Neutron Dose Equivalent Using the Thermal Response of LiF TL Material," *Health Phys.* 31, 170-173 (1976).

ORNL-Photo 1983-80

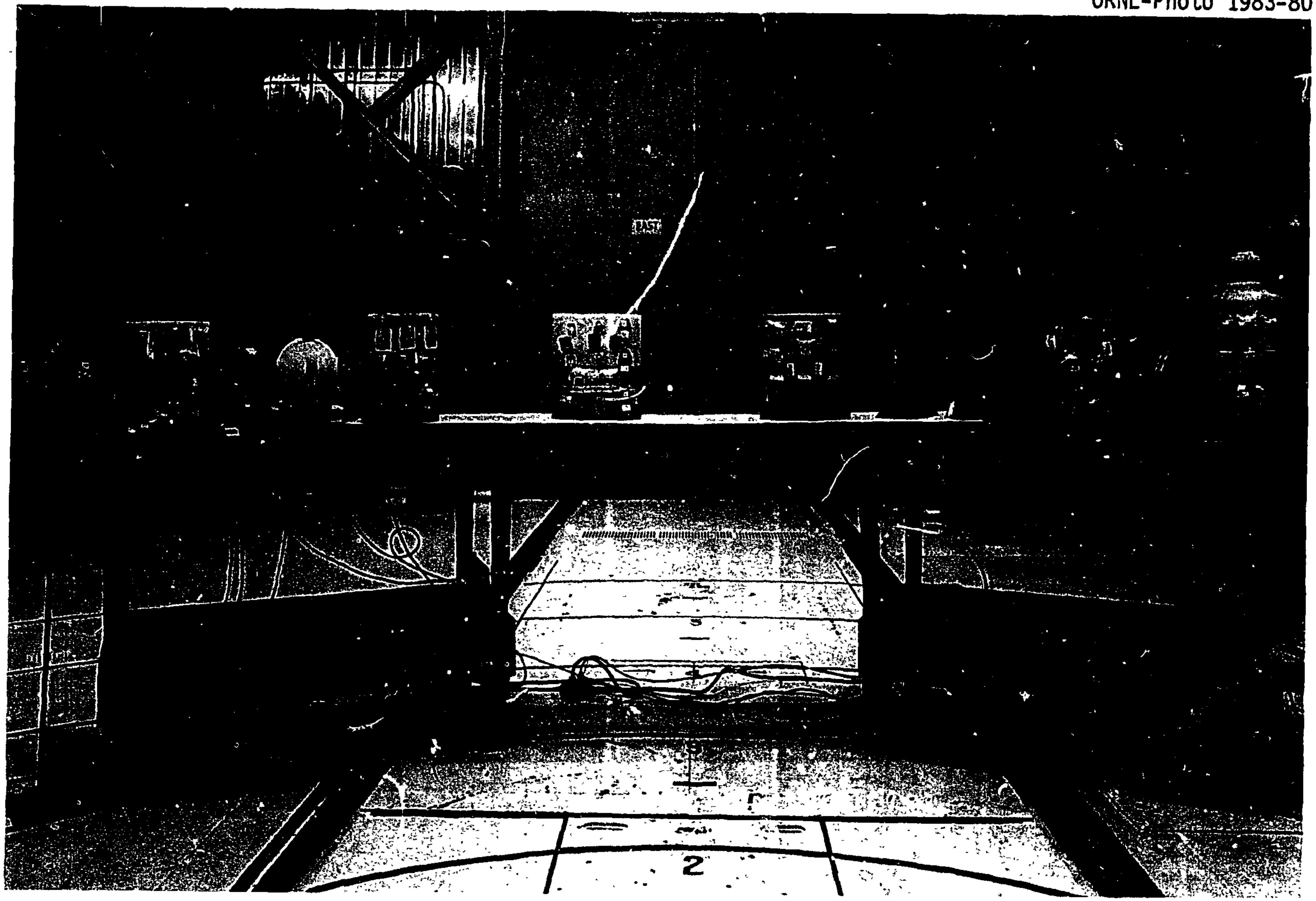

Fig. 1. Front view of typical experimental arrangement of phantoms and dosimetry.

ORNL-Photo 1980-80

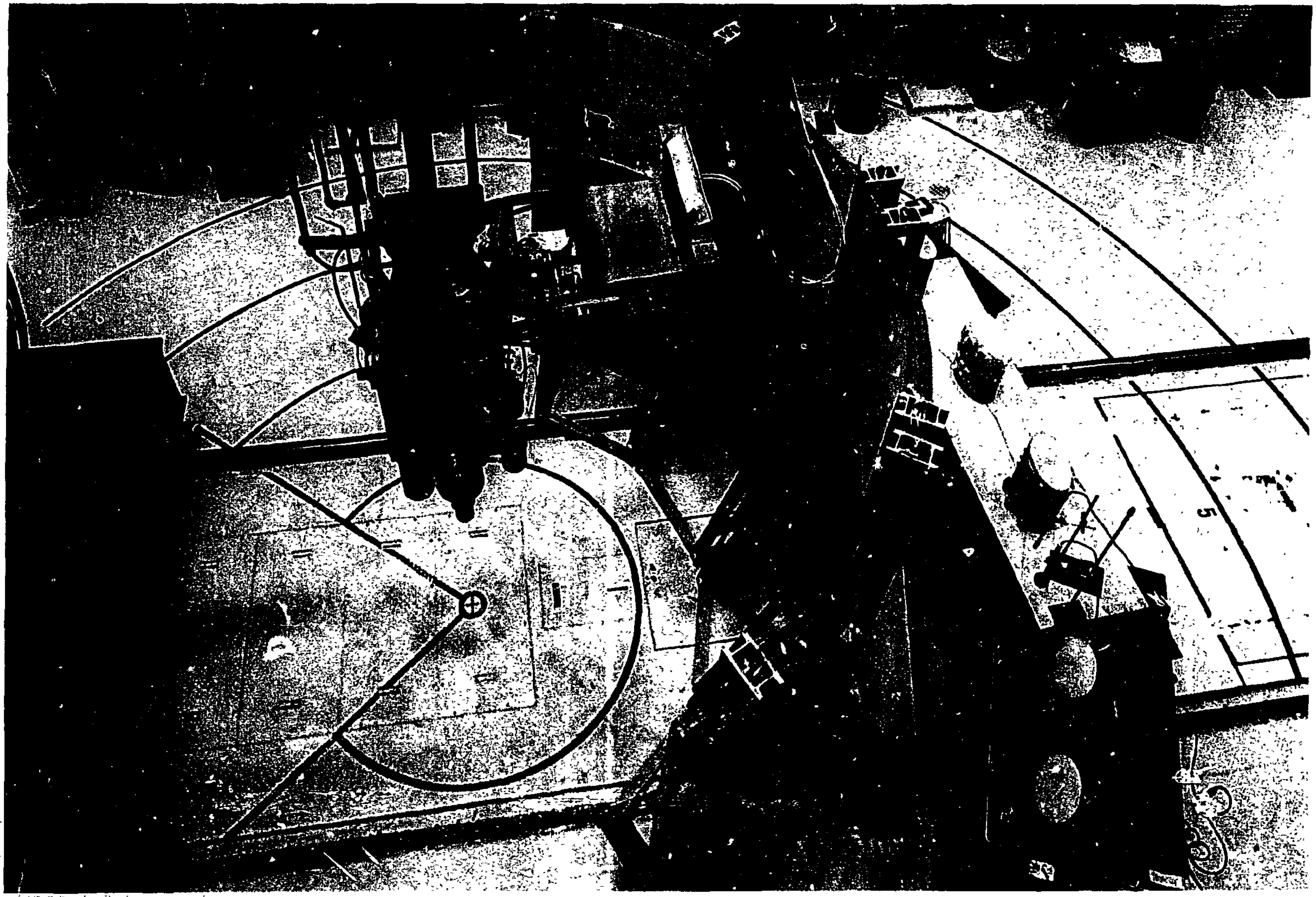

Fig. 2. Top view of experimental arrangement for Lucite shielded exposures.

ORNL-Photo 1984-80

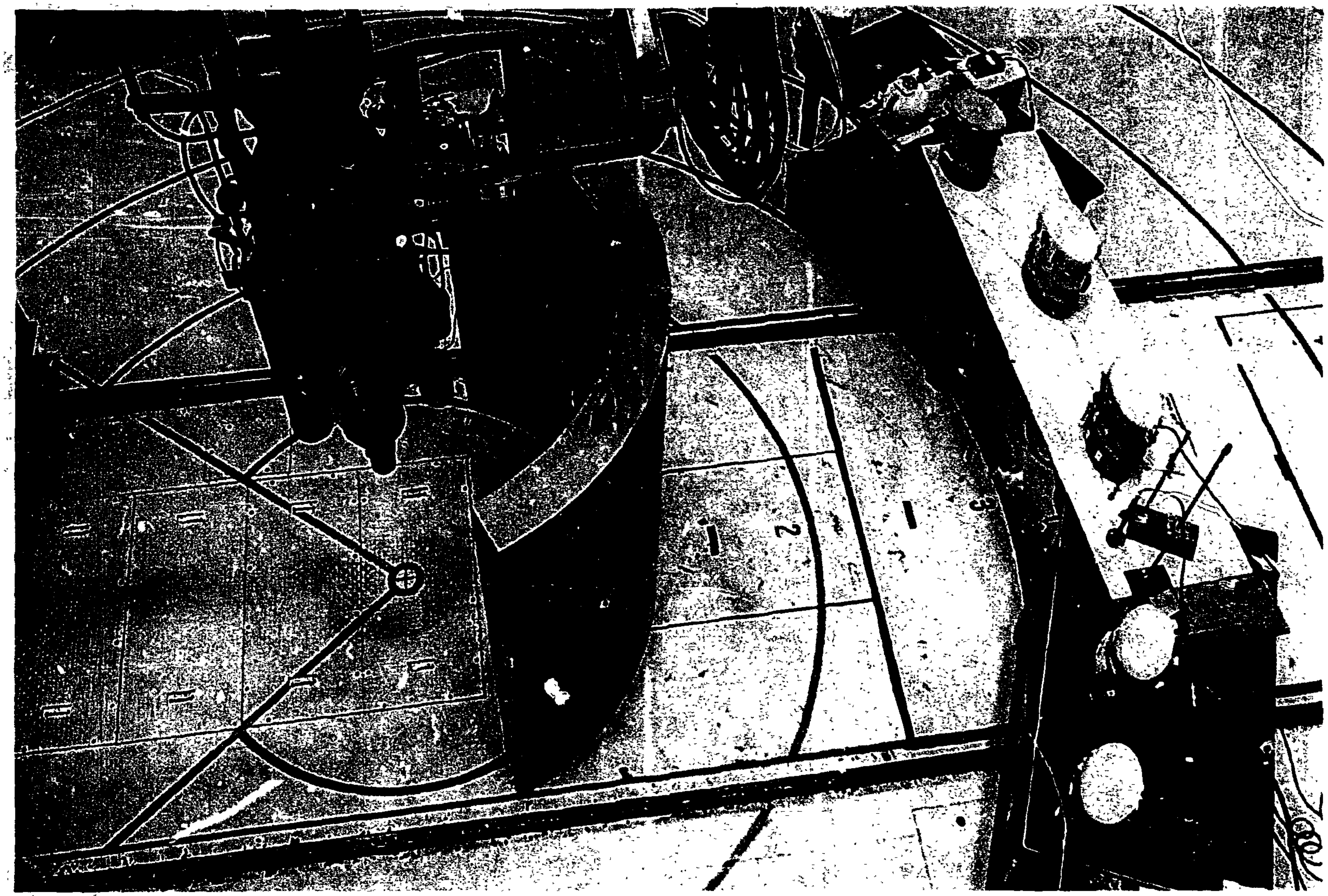

Fig. 3. Top view of experimental arrangement for concrete shielded exposures.

Table 1. Summary of experimental conditions for the initial set of exposures[a]

Run	Date of exposure	Start time[b]	Exposure duration, s	Reactor power, W	10^{-13} × number of fissions	Shield thickness and type	Shield distance from reactor, m	Distance from reactor to front of phantom,[c] m
1	3/25/80	1434	550	1.5	2.56	None		3
2	3/25/80	1603	500	0.4	0.62	None		3
3	3/26/80	1251	575	2.0	3.56	12-cm Lucite	2	3
4	3/26/80	1602	500	6.0	9.30	12-cm Lucite	2	3
5	3/27/80	1131	450	1.3	1.78	20-cm concrete	1	3
6	3/27/80	1430	525	5.1	8.30	20-cm concrete	1	3

[a]26 participating agencies.

[b]Eastern Standard Time.

[c]The horizontal centerlines of the reactor and of the phantom sections on which the dosimeters were mounted were 1.5 m above the concrete floor for all exposures.

Table 2. Summary of experimental conditions for the second set of exposures[a]

Run	Date of exposure	Start time[b]	Exposure duration, s	Reactor power, W	10^{-13} × number of fissions	Shield thickness and type	Shield distance from reactor, m	Distance from reactor to front of phantom,[c] m
1	5/13/80	836	550	1.5	2.56	None		3
2	5/13/80	1009	500	0.4	0.62	None		3
3	5/14/80	833	450	1.3	1.78	20-cm concrete	1	3
4	5/14/80	1026	525	5.1	8.30	20-cm concrete	1	3
5	5/15/80	844	575	2.0	3.56	12-cm Lucite	2	3
6	5/15/80	1221	500	6.0	9.30	12-cm Lucite	2	3

[a]Exposures performed subsequent to the initial Sixth PDIS to accommodate two late arrivals.

[b]Eastern Standard Time.

[c]The horizontal centerlines of the reactor and phantom sections on which the dosimeters were mounted were 1.5 m above the concrete floor for all exposures.

Table 3. Comparison of measured total, neutron, and gamma doses in air for initial and second exposures

Initial run	Second run	Reactor power, W	Exposure duration, s	Shield[a]	Total dose,[b] 10^{-5} Gy[c]		Neutron dose,[d] 10^{-5} Gy		Gamma dose,[e] 10^{-5} Gy	
					Initial	Second	Initial	Second	Initial	Second
1	1	1.5	550	None	138.0	133.9	116	118	19.5	22.6
2	2	0.4	500	None	38.1	37.8	28	29	6.2	9.8
3	5	2.0	575	12-cm Lucite	61.1	60.9	28	27	30.3	36.4
4	6	6.0	500	12-cm Lucite	151.3	158.5	74	73	74.7	76.9
5	3	1.3	450	20-cm concrete	23.3	21.1	14	14	7.3	10.1
6	4	5.1	525	20-cm concrete	97.2	87.4	65	63	31.2	29.4

[a]Shield locations and reactor position were identical for the indicated run numbers.

[b]Total neutron and gamma dose measured using a Digital Data Dosimetry RD-1 tissue equivalent ionization chamber at 3 m from the reactor centerline.

[c]10^{-5} Gy = 1 mrad.

[d]Neutron dose inferred from sulfur pellet activation measurements and DOSAR shield attenuation factors.

[e]Gamma dose measured using a Phillips Geiger-Mueller tube with an energy compensating shield and a lithium shield to reduce neutron sensitivity located 3 m from the reactor centerline.

Table 4. Dosimeters used by the participants

Group[a]	Neutron dosimeter	Gamma dosimeter
AECL/CR		TLD-700
AECL/W		TLD-700
ANL	TLD-albedo	TLD
BAPL	TLD-albedo	
DOSAR	See reference dosimetry section	
HPL	$Li_2B_4O_7$ TLD	$CaSO_4$ TLD
INER	Track-etch (Lexan)	
INER	TLD-albedo	TLD-700
KK[b]	TLD-600, 12-in. sphere	TLD-700
KK[b]	TLD-albedo	TLD-700
KK[b]	Track-etch	
KSU	Film	Film
LAND	Neutrak-144, CR-39	Film
LLL	TLD-albedo	TLD
LLL	DOSPEC (track-etch, albedo)	
NLC		Film (Kodak Type 2)
NTHU	$CaSO_4$:D_y TLD	$CaSO_4$:D_y TLD
NTHU		Film
OPPD	TLD-600	TLD-700
ORGDP	Activation elements	TLD
PPPL	Landauer C1 badge (track-etch)	Landauer H1 badge (film)
REECO	$^6Li/^7Li$; Cd-encased	^7LiF; Cd-encased
RFP	TLD-albedo	TLD-700
RPB	TLD-albedo	TLD-100
RPI	TLD-600, TLD-700	TLD-700
SE[b,c]		
SNL	TLD-albedo	TLD-700
SRP	TLD-albedo	TLD
TAEC		$CaSO_4$:D_y TLD
TPC		TLD (Harshaw G-7)
TVA	TLD-albedo (Harshaw 2271)	^7Li TLD (Harshaw 2271)
UCD	Film	Film
YALE	Landauer Gardray Film	Landauer Gardray Film

[a]Identifying acronyms are defined in Appendix A.

[b]Dosimetry was exposed subsequent to the initial Sixth PDIS due to late arrival.

[c]No results reported.

Table 5. Reference gamma dose equivalent

Run	Phantom front: Gamma dose equivalent in air, 10^{-5} Sv[a] G-M	TEIC-sulfur	Average	Air-to-phantom dose conversion[b]	Reference gamma dose equivalent,[c] 10^{-5} Sv	Phantom rear: Front-to-rear dose conversion	Reference gamma dose equivalent,[c] 10^{-5} Sv
1	19.5	22.0	20.8	1.66	34	0.48	16
2	6.2	10.1	8.2	1.66	14	0.48	7
3	30.8	33.1	32.0	1.38	44	0.29	13
4	74.7	77.3	76.0	1.38	105	0.29	30
5	7.3	9.3	8.3	1.28	11	0.29	[illegible]
6	31.0	32.2	31.6	1.28	40	0.29	12

[a] 1 mrem = 10^{-5} Sv.

[b] Accounts for (n,γ) reactions in the phantom.

[c] Rounded to nearest whole number.

Table 6. Neutron dose equivalent from sulfur pellet analysis

Run	Unshielded dose at area monitor, 10^{-5} Gy[a]	Shield factor[b]	Shielded dose at area monitor, 10^{-5} Gy	Area monitor to phantom dose conversion	Quality factor	Dose equivalent on phantom front, 10^{-5} Sv[c]	Phantom front to rear conversion	Dose equivalent on phantom rear, 10^{-5} Sv
1	116			1.04	9.4	1134	0.16	181
2	28			1.04	9.4	274	0.16	44
3	150	0.19	28	1.03	8.9	257	0.21	54
4	391	0.19	74	1.03	8.9	678	0.21	142
5	76	0.19	14	1.20	9.8	165	0.19	31
6	341	0.19	65	1.20	9.8	764	0.19	145

[a] 1 mrad = 10^{-5} Gy.

[b] Includes correction for shield effects on reactor power indication.

[c] 1 mrem = 10^{-5} Sv.

Table 7. Neutron dose equivalent from tissue equivalent ionization chamber measurements

Run	Measured neutron and gamma dose at area monitor, 10^{-5} Gy[a]	Measured gamma dose at area monitor, 10^{-5} Gy	Inferred neutron dose at area monitor, 10^{-5} Gy	Area monitor to phantom dose conversion	Quality factor	Dose equivalent on phantom front, 10^{-5} Sv[b]	Phantom front to rear coversion	Dose equivalent on phantom rear, 10^{-5} Sv
1	138.0	19.5	118.5	1.04	9.4	1158	0.16	185
2	38.1	6.2	31.9	1.04	9.4	312	0.16	50
3	61.1	30.8	30.3	1.03	8.9	278	0.21	58
4	151.3	74.7	76.6	1.03	8.9	702	0.21	147
5	23.3	7.3	16.0	1.20	9.8	188	0.19	36
6	97.2	31.2	66.0	1.20	9.8	776	0.19	147

[a] 1 mrad = 10^{-5} Gy.

[b] 1 mrem = 10^{-5} Sv.

Table 8. Refer ıce neutron dose equivalent

Run	Reference neutron dose equivalent,[a] 10^{-5} Sv[b] Phantom front	Phantom rear
1	1146	183
2	293	47
3	268	56
4	690	145
5	176	34
6	770	146

[a]Average of dose equivalents obtained by sulfur pellet activation analysis and TEIC measurements.

[b]1 mrem = 10^{-5} Sv.

Table 9. Neutron dose equivalent from calculations

Run	Energy expended during run as determined by HPRR instrumentation, W-min	Number of fissions[a]	Neutron fluence at phantom front, n/cm^2	Dose conversion factor[b], 10^{-5} Gy-cm^2/n	Dose, 10^{-5} Gy	Quality factor	Dose equivalent on phantom front, 10^{-5} Sv[c]	Phantom front to rear conversion	Dose equivalent on phantom rear, 10^{-5} Sv
1	13.75	2.56×10^{13}	5.02×10^{7}	25.5×10^{-7}	128.0	9.4	1203	0.16	192
2	[illegible].33	0.62×10^{13}	1.22×10^{7}	25.5×10^{-7}	31.1	9.4	292	0.16	47
3	19.[illegible]	3.56×10^{13}	1.90×10^{7}	14.6×10^{-7}	27.7	8.9	246	0.21	52
4	49.[illegible]	9.30×10^{13}	4.96×10^{7}	14.6×10^{-7}	72.4	8.9	644	0.21	135
5	9.56	1.78×10^{13}	1.78×10^{7}	13.5×10^{-7}	24.0	9.8	235	0.19	45
6	44.62	8.30×10^{13}	8.30×10^{7}	13.5×10^{-7}	112.0	9.8	1098	0.19	209

[a] 1.86×10^{12} fissions = 1 W-min.
[b] 1 mrad = 10^{-5} Gy.
[c] 1 mrem = 10^{-5} Sv.

Table 10. Tabulation of reported results PDIS 6, run 1, unshielded, 13.75 W-min

Group[a]	Neutron dosimeter	Neutron dose equivalent,[b] 10^{-5} Sv				Gamma dosimeter	Gamma dose equivalent,[b] 10^{-5} Sv			
		1[c]	2	3	Average		1	2	3	Average
AECL/CR						TLD	42	44		43
AECL/W						TLD	128	66		97
ANL	TLD	706	821	766	764	TLD	45	61	59	55
BAPL	TLD	1224	1540	1290	1351					
DOSAR	Reference				1146/183[d]	Reference				34/16[d]
HPL	TLD[e]	1870			1870	TLD[f]	33			33
INEF	Track/TLD				1050/1301[g]	TLD				26.1[g]
KK[h]	TLD, sphere	1072			1072	TLD	30.1			30.1
KK[h]	TLD/Track	1113/986			1113/986	TLD	37.8			37.8
KSU	Film	230	180	250	220	Film	45	50	50	48
LAND	Track	1095	990	725	937	Film	50	64	40	51
LLL	TLD/DOSPEC[i]				1140/1050[d]	TLD				34[g]
NLC						Film	48	51	41	47
NTHU	TLD[f]				53.32/ 14.43[d,g]	TLD[f]	24			23.98/ 11.94[d,g]
NTHU						Film	24	10[d]		24/10[d]
OPPD	TLD[k]	1031	1147	1073	1083	TLD	40	44	46	43
ORGDP	ACT[j]					TLD	51	13[d]		51/13[d]
PPPL	Track	800			800	Film	80	90	90	87
REECO	TLD	1015	1040	171[d]	1028/171[d]	TLD	19	22	1[d]	20/1[d]
RFP	TLD	1413	1261	1540	1405	TLD	18	27	28	24
RPB	TLD	877	178[d]		877/178[d]	TLD[k]	480[d]	128[d]		480/128[d]
RPI	TLD	173			173	TLD	21			21
SNL	TLD	1270	1220	910	1133	TLD	30	30	30	30
SRP	TLD	1250	1320		1285	TLD	35			35
TAEC						TLD[e]				24.53[g]
TPC						TLD	42.1	44.0	43.5	43.2
TVA	TLD	1439	1554	1528	1507	TLD	62	58	56	59
UCD	Film	550	570	570	563	Film	60	65	50	58
YALE	Film	230			230	Film	90	60[d]		90/60[d]

[a]Identifying acronyms are defined in Appendix A.

[b]Dose equivalents are background corrected. Values were reported in millirems (10^{-5} Sv). Measurements were made on the fronts of phantoms (side facing HPRR) unless otherwise indicated.

[c]Each group was allowed to expose three dosimeters per run.

[d]Dosimeter on rear of phantom (side opposite HPRR).

[e]$Li_2B_4O_7$ TLD.

[f]$CaSO_4$:Dy TLD.

[g]Reported average of measured results.

[h]Dosimeters exposed subsequent to the Sixth PDIS due to late arrival.

[i]Combination of track-etch and TLD-albedo.

[j]Activation foils were used for this neutron dose measurement. No measurable activities were obtained at the dose levels encountered in this study.

[k]TLD-100.

Table 11. Tabulation of reported results PDIS 6, run 2, unshielded, 3.33 W-min

Group[a]	Neutron dosimeter	Neutron dose equivalent,[b] 10^{-5} Sv				Gamma dosimeter	Gamma dose equivalent,[b] 10^{-5} Sv			
		1[c]	2	3	Average		1	2	3	Average
AECL/CR						TLD	12	11		12
AECL/W						TLD	53	54		53/54[d]
ANL	TLD	207	196		202	TLD	10	9		10
BAPL	TLD	329	388	288	335					
DOSAR	Refrence				293/47	Reference				14/7[d]
HPL	TLD	660			660	TLD	13			13
INER	Track/TLD				113/293	TLD				8.0
KK	TLD, sphere	272			272	TLD	11.2			11.2
KK	TLD/Track	273/195			273/195	TLD	12.6			12.6
KSU	Film	0	0	0	0	Film	0	0	0	0
LAND	Track	290	260	240	263	Film	20	10	10	13
LLL	TLD/DOSAR				290/280	TLD				9
NLC						Film	9	2	12	8
NTHU	TLD				8.70/ 2.68	TLD				7.74/ 3.50[d,g]
NTHU						Film	8	10	10	9/10[d]
OPPD	TLD	265	273	242	260	TLD	14	15	11	13
ORGDP	ACT					TLD	23	7		23/7
PPPL	Track	160			160	Film	40	40	30	37
REECO	TLD	255	270	28	262/28	TLD	5	5	1	5/1[d]
RFP	TLD	114	72	104	97	TLD	0	0	0	0
RPB	TLD	215	32		215/32	TLD	85			85
RPI	TLD	18.2			18.2	TLD	0			0
SNL	TLD	30	40	40	37	TLD	<10			<10
SRP	TLD	315	315		315	TLD	10			10
TAEC						TLD				7.42[g]
TPC						TLD	12.0	13.7	12.6	12.8
TVA	TLD	354	356	418	376	TLD	15	28	43	29
UCD	Film	10	20	10	13	Film	25	20	35	27[d]

[a]Identifying acronyms are defined in Appendix A.

[b]Dose equivalents are background corrected. Values were reported in millirems (10^{-5} Sv). Measurements were made on the fronts of phantoms (side facing HPRR) unless otherwise indicated.

[c]Each group was allowed to expose three dosimeters per run.

[d]Dosimeter on rear of phantom (side opposite HPRR).

[e]LiB_4O_7 TLD.

[f]$CaSO_4$:Dy TLD.

[g]Reported average of measured results.

[h]Dosimeters exposed subsequent to the Sixth PDIS due to late arrival.

[i]Combination of track-etch and TLD-albedo.

[j]Activation foils were used for this neutron dose measurement. No measurable activities were obtained at the dose levels encountered in this study.

[k]TLD-100.

Table 12. Tabulation of reported results — PDIS 6, *run* 3, Lucite shield, 19.17 W-min

Group[a]	Neutron dosimeter	Neutron dose equivalent,[b] 10^{-5} Sv				Gamma dosimeter	Gamma dose equivalent,[b] 10^{-5} Sv			
		1[c]	2	3	Average		1	2	3	Average
AECL/CR						TLD	53	45		49
AECL/W						TLD	82	66[d]		82/66[d]
ANL	TLD	162	205	224	197	TLD	26	39	29	31
BAPL	TLD	374	547	494	472					
DOSAR	Reference				268/56[d]	Reference				44/13[d]
HPL	TLD[e]	930			930	TLD[f]	36			36
INER	Track/TLD				175/302[g]	TLD				33.0[g]
KK[f]	TLD, sphere	138			138	TLD	10.4			10.4
KK[f]	TLD/Track	137/71			137/71	TLD	13.8			13.8
KSU	Film	70	50	50	57	Film	50	60	60	57
LAND	Track	225	220	250	232	Film	60	50	50	53
LLL	TLD/DOSPEC[i]				250/180[g]	TLD				42[g]
NLC						Film	48	54	49	50
NTHU	TLD[f]				44.88/ 5.17[d,g]	TLD[f]				30.61/ 12.90[d,g]
NTHU						Film	34	47		40
OPPD	TLD	171	181	149	167	TLD	36	37	40	38
ORGDP	ACT[j]									
PPPL	Track	30			30	Film	80	90	90	87
REECO	TLD	205	210	32[d]	208/32[d]	TLD	20	20	2[d]	20/2[d]
RFP	TLD	356	485	273	371	TLD	25	24	30	26
RBP	TLD	214	62[d]		214/62[d]	TLD[k]	750	100[d]		750/100[d]
RPI	TLD	211			211	TLD	24			24
SNL	TLD	180	190	190	187	TLD	40	40	40	40
SRP	TLD	320	250		285	TLD	35			35
TAEC						TLD[f]				29.00[g]
TPC						TLD	44.6	43.0	37.4	42
TVA	TLD	248	268	273	263	TLD	65	72	67	68
UCD	Film	140	110	110	120	Film	70	95	70	78
YALE	Film	230			230	Film	90	70	60[d]	80/60[d]

[a]Identifying acronyms are defined in Appendix A.

[b]Dose equivalents are background corrected. Values were reported in millirems (10^{-5} Sv). Measurements were made on the fronts of phantoms (side facing HPRR) unless otherwise indicated.

[c]Each group was allowed to expose three dosimeters per run.

[d]Dosimeter on rear of phantom (side opposite HPRR).

[e]$Li_2B_4O_7$ TLD.

[f]$CaSO_4$:Dy TLD.

[g]Reported average of measured results.

[h]Dosimeters exposed subsequent to the Sixth PDIS due to late arrival.

[i]Combination of track-etch and TLD-albedo.

[j]Activation foils were used for this neutron dose measurement. No measurable activities were obtained at the dose levels encountered in this study.

[k]TLD-100.

Table 13. Tabulation of reported results PDIS 6, run 4, Lucite shield, 50.00 W-min

Group[a]	Neutron dosimeter	Neutron dose equivalent,[b] 10^{-5} Sv				Gamma dosimeter	Gamma dose equivalent,[b] 10^{-5} Sv			
		1[c]	2	3	Average		1	2	3	Average
AECL/CR						TLD	117	117		117
AECL/W						TLD	180	101[d]		180/101[d]
ANL	TLD	438	413	481	444	TLD	79	98	71	83
BAPL	TLD	1229	1425	1330	1328					
DOSAR	Reference				690/145[d]	Reference				105/30[d]
HPL	TLD[e]	2040			2040	TLD[e]	77			77
INER	Track/TLD				280/749[g]	TLD				64.1[g]
KK[h]	TLD, sphere	598			598	TLD	27.5			27.5
KK[h]	TLD/Track	678/333			678/333	TLD	43.7			43.7
KSU	Film	35[d]	30[d]	35[d]	33[d]	Film	55[d]	50[d]	60[d]	55[d]
LAND	Track	410	500	325	411	Film	70	100	100	90
LLL	TLD/DOSPEC[i]				680/490[g]	TLD				100[g]
NLC						Film	134	143	147	141
NTHU	TLD[k]				187.8/15.6[d,g]	TLD[k]				74.2/27.[illegible][d,g]
NTHU						Film	80	92	80	84
OPPD	TLD[f]	437	442	450	443	TLD	117	101	106	108
ORGDP	ACT[j]									
PPPL	Track	360			360	Film	100	210	170	160
REECO	TLD	520	490	112[d]	505/112[d]	TLD	79	77	25[d]	78/25[d]
RFP	TLD	244[d]	137[d]	245[d]	209[d]	TLD[f]	61[d]	31[d]	37[d]	43[d]
RPB	TLD	527	138[d]		527/138[d]	TLD[i]	1750	360[d]		1750/360[d]
RPI	TLD	76[d]			76[d]	TLD	30[d]			30[d]
SNL	TLD	110[d]	80[d]	90[d]	93[d]	TLD	40[d]	30[d]	40[d]	37[d]
SRP	TLD	765	840		802	TLD[e]	95			95
TAEC						TLD[k]				76.63[g]
TPC						TLD	111.6	121.2	110.4	114.4
TVA	TLD	630	646	623	633	TLD	135	134	140	136
UCD	Film	60[d]	30[d]	30[d]	40[d]	Film	70[d]	65[d]	60[d]	65[d]
YALE	Film	250			250	Film	150	180		165

[a]Identifying acronyms are defined in Appendix A.

[b]Dose equivalents are background corrected. Values were reported in millirems (10^{-5} Sv). Measurements were made on the fronts of phantoms (side facing HPRR) unless otherwise indicated.

[c]*Each group was allowed to expose three dosimeters per run.*

[d]Dosimeter on rear of phantom (side opposite HPRR).

[e]$Li_2B_4O_7$ TLD.

[f]$CaSO_4$:Dy TLD.

[g]Reported average of measured results.

[h]Dosimeters exposed subsequent to the Sixth PDIS due to late arrival.

[i]Combination of track-etch and TLD-albedo.

[j]Activation foils were used for this neutron dose measurement. No measurable activities were obtained at the dose levels encountered in this study.

[k]TLD-100.

Table 14. Tabulation of reported results PDIS 6, run 5, concrete shield, 9.56 W-min

Group[a]	Neutron dosimeter	Neutron dose equivalent,[b] 10^{-5} Sv				Gamma dosimeter	Gamma dose equivalent,[b] 10^{-5} Sv			
		1[c]	2	3	Average		1	2	3	Average
AECL/CR						TLD	21	16		18
AECL/W						TLD	70	103[d]		70/10[d]
ANL	TLD	164	129		146	TLD	5	6		6
BAPL	TLD	220	223	179	207					
DOSAR	Reference				176/34[d]	Reference				11/3[d]
HPL	TLD[e]	320			320	TLD[f]	10			10
INER	Track/TLD				40/190[g]	TLD				10.3[g]
KK[h]	TLD, sphere	235			235	TLD	23.5			23.5
KK[h]	TLD/Track	205/229			205/229	TLD	36.2			36.2
KSU	Film	15	40	10	22	Film	0	10	10	7
LAND	Track	125	95	120	113	Film	0	0	10	3
LLL	TLD/DOSPEC[i]				120/130[g]	TLD				20[g]
NLC						Film	13	12	9	11
NTHU	TLD[e]				21.0/ 4.56[d,g]	TLD[f]				9.1/ 4.2[d,g]
NTHU						Film	11	10	10	10
OPPD	TLD	130	137	133	133	TLD	11	14	16	14
ORGDP	ACT[j]									
PPPL	Track	60	60		[illegible]	Film	30	50	40	40
REECO	TLD	165	170	17[d]	168/17[d]	TLD	2	3	0[d]	2/0[d]
RFP	TLD	297	373	374	348	TLD	0	7	5	4
RPB	TLD	130	34[d]		130/34[d]	TLD[k]	250	25[d]		250/25[d]
RPI	TLD	127			127	TLD	24			24
SNL	TLD	170	150	130	150	TLD	10	20	20	17
SRP	TLD	280	225		252	TLD	15			15
TAEC						TLD[f]				13.47[d,g]
TPC						TLD	11.8	15.9	13.9	13.9
TVA	TLD	183	173	190	182	TLD	39	28	32	33
UCD	Film	40	50	70	53	Film	20	25	35	27

[a]Identifying acronyms are defined in Appendix A.

[b]Dose equivalents are background corrected. Values were reported in millirems (10^{-5} Sv). Measurements were made on the fronts of phantoms (side facing HPRR) unless otherwise indicated.

[c]Each group was allowed to expose three dosimeters per run.

[d]Dosimeter on rear of phantom (side opposite HPRR).

[e]$Li_2B_4O_7$ TLD.

[f]$CaSO_4$:Dy TLD.

[g]Reported average of measured results.

[h]Dosimeters exposed subsequent to the Sixth PDIS due to late arrival.

[i]Combination of track-etch and TLD-albedo.

[j]Activation foils were used for this neutron dose measurement. No measurable activities were obtained at the dose levels encountered in this study.

[k]TLD-100.

Table 15. Tabulation of reported results — PDIS 6, run 6, concrete shield, 44.62 W-min

Group[a]	Neutron dosimeter	Neutron dose equivalent,[b] 10^{-5} Sv				Gamma dosimeter	Gamma dose equivalent,[b] 10^{-5} Sv			
		1[c]	2	3	Average		1	2	3	Average
AECL/CR						TLD	69	63		66
AECL/W						TLD	117	60[d]		117/60[d]
ANL	TLD	670	614	592	625	TLD	29	34	31	31
BAPL	TLD	889	1081	973	981					
DOSAR	Reference				770/146[d]	Reference				40/12[d]
HPL	TLD[e]	1060			1060	TLD[f]	29			29
INER	Track/TLD				367/825[g]	TLD				27.8[g]
KK[h]	TLD, sphere	568			568	TLD	51.2			51.2
KK[h]	TLD/Track	494/319			494/319	TLD	79.1			79.1
KSU	Film	10[d]	10[d]	0[d]	7[d]	Film	25[d]	25[d]	20[d]	23[d]
LAND	Track	465	500	380	448	Film	40	20	60	40
LLL	TLD/DOSPEC[i]				530/520[g]	TLD				50[g]
NLC						Film	77	104	96	92
NTHU	TLD[f]				103.3/ 18.2[d,g]	TLD[f]				39.8/ 16.3[d,g]
NTHU						Film	50	55	55	53
OPPD	TLD	614	657	633	635	TLD	50	58	51	53
ORGDP	ACT[j]					TLD	63	26[d]		63/26[d]
PPPL	Track	90	170		130	Film	130	110	130	123
REECO	TLD	760	745	99[d]	752/99[d]	TLD	34	31	3[d]	32/3[d]
RFP	TLD	229[d]	239[d]	264[d]	244[d]	TLD	9[d]	11[d]	17[d]	12[d]
RPB	TLD	642	122[d]		642/122[d]	TLD[k]	1700	320[d]		1700/320[d]
RPI	TLD	79[d]			77[d]	TLD	9[d]			9[d]
SNL	TLD	140[d]	110[d]	110[d]	120[d]	TLD	10[d]	30[d]	20[d]	20[d]
SRP	TLD	1100	1075		1088	TLD	70			70
TAEC						TLD[f]				35.84[d,g]
TPC						TLD	65.6	66.1	62.9	64.9
TVA	TLD	733	748	774	752	TLD	94	85	112	97
UCD	Film	50[d]	40[d]	30[d]	40[d]	Film	80[d]	75[d]	70[d]	75[d]
YALE	Film	0[d]	0[d]		0[d]	Film	70[d]	70[d]		70[d]

[a]Identifying acronyms are defined in Appendix A.

[b]Dose equivalents are background corrected. Values were reported in millirems (10^{-5} Sv). Measurements were made on the fronts of phantoms (side facing HPRR) unless otherwise indicated.

[c]Each group was allowed to expose three dosimeters per run.

[d]Dosimeter on rear of phantom (side opposite HPRR).

[e]$Li_2B_4O_7$ TLD.

[f]$CaSO_4$:Dy TLD.

[g]Reported average of measured results.

[h]Dosimeters exposed subsequent to the Sixth PDIS due to late arrival.

[i]Combination of track-etch and TLD-albedo.

[j]Activation foils were used for this neutron dose measurement. No measurable activities were obtained at the dose levels encountered in this study.

[k]TLD-100.

Table 16. Ratios of responses of BF_3 detector in polyethylene spheres[a]

Initial run[a]	Second run[b]	Reactor power, W	Exposure duration, s	Shield	Ratio of 9-in. to 3-in. sphere response
1	1	1.5	550	None	0.86
2	2	0.4	500	None	0.79
3	5	2.0	575	Lucite	0.47
4	6	6.0	500	Lucite	0.45
5	3	1.3	450	Concrete	0.36
6	4	5.1	525	Concrete	0.34

[a]Exposures conducted on March 25-27, 1980.

[b]Exposures conducted on May 13-15, 1980.

Table 17. Analysis of neutron dose equivalent results on fronts of phantoms

Run	Neutron dose equivalent, 10^{-5} Sv		
	Reference	All reported results[b]	Subset of reported results[b,c]
1	1146	1050, 958 ± 446 (47)	1050, 958 ± 374 (39)
2	293	267, 265 ± 130 (49)	267, 256 ± 66 (26)
3	268	202, 228 ± 181 (79)	202, 204 ± 100 (49)
4	690	505, 618 ± 429 (69)	505, 559 ± 255 (46)
5	176	146, 156 ± 87 (56)	146, 154 ± 78 (51)
6	770	596, 602 ± 281 (47)	596, 605 ± 243 (40)

[a]1 mrem = 10^{-5} Sv.

[b]Values are displayed as median, mean $\pm\sigma$ ($\%\sigma$).

[c]This subset omits results reported by HPL and NTHU.

Table 18. Neutron dose equivalent on fronts of phantoms by type of dosimeter

Run	Neutron dose equivalent, 10^{-5} Sv[a]			
	Reference	Film[b]	Track[b]	TLD[b,c]
1	1146	230, 338 ± 195 (58)	962, 943 ± 106 (11)	1113, 1085 ± 319 (29)
2	293	*d*	178, 183 ± 63 (34)	272, 281 ± 47 (17)
3	268	120, 136 ± 88 (64)	156, 127 ± 93 (73)	211, 238 ± 90 (38)
4	[illegible]	250[e]	346, 346 ± 54 (16)	616, 656 ± 242 (37)
5	[illegible]	38, 38 ± 22 (58)	86, 110 ± 85 (77)	168, 182 ± 62 (34)
6	[illegible]	*d*	343, 316 ± 135 (43)	638, 701 ± 185 (27)

[a]1 mrem = 10^{-5} Sv.

[b]Values are displayed as median, mean $\pm\sigma$ (%σ).

[c]HPL and NTHU results are not included.

[d]No neutron dose measurements made using film on fronts of phantoms for this run.

[e]One neutron dose measurement made using film on fronts of phantoms.

Table 19. Analysis of gamma dose equivalent results on fronts of phantoms

Run	Gamma dose equivalent, 10^{-5} Sv[a]		
	Reference	All reported results[b]	Subset of reported results[b,c]
1	34	43, 60 ± 86 (143)	40, 44 ± 21 (48)
2	14	12, 19 ± 19 (100)	11, 16 ± 12 (75)
3	44	41, 71 ± 140 (197)	40, 44 ± 21 (48)
4	105	95, 179 ± 362 (202)	92, 101 ± 40 (40)
5	11	15, 28 ± 50 (177)	14, 18 ± 15 (85)
6	40	58, 144 ± 367 (255)	53, 62 ± 29 (46)

[a] 1 mrem = 10^{-5} Sv.

[b] Values are displayed as median, mean $\pm\sigma$ (%σ).

[c] This subset omits results reported by RPB.

Table 20. Gamma dose equivalent on fronts of phantoms by type of dosimeter

Run	Gamma dose equivalent, 10^{-5} Sv[a]				
	Reference	Film[b]	TLD[b,c]	$CaSO_4$ TLD[b]	TLD-100[d]
1	34	51, 58 ± 23 (40)	36, 40 ± 19 (48)	28, 27 ± 5 (19)	480
2	14	11, 17 ± 14 (80)	12, 16 ± 13 (80)	8, 9 ± 3 (33)	85
3	44	57, 64 ± 18 (28)	35, 37 ± 19 (51)	31, 32 ± 4 (12)	750
4	105	141, 128 ± 38 (30)	89, 96 ± 41 (43)	76, 76 ± 2 (3)	1750
5	11	10, 16 ± 14 (89)	17, 20 ± 17 (85)	10, 11 ± 2 (18)	250
6	40	72, 77 ± 38 (49)	63, 62 ± 26 (42)	36, 35 ± 5 (14)	1700

[a]1 mrem = 10^{-5} Sv.

[b]Values are displayed as median, mean ±σ (%σ).

[c]Results do not include measurements made with $CaSO_4$ TLD or TLD-100 dosimetry.

[d]Used by only one participant.

Table 21. Analysis of neutron dose equivalent results on rears of phantoms

Run	Neutron dose equivalent, 10^{-5} Sv[a]			
	Reference	Subset of reported results[b,c]	Film[b]	TLD[b,c]
1	183	174, 174 ± 5 (3)	*d*	174, 174 ± 5 (3)
2	47	28, 32 ± 31 (97)	6, 6 ± 9 (153)	32, 42 ± 31 (74)
3	56	47, 47 ± 21 (45)	*d*	47, 47 ± 21 (45)
4	145	93, 100 ± 61 (61)	36, 36 ± 5 (4)	112, 125 ± 52 (42)
5	34	26, 26 ± 12 (46)	*d*	26, 26 ± 12 (46)
6	146	88, 89 ± 79 (88)	7, 16 ± 21 (134)	120, 132 ± 65 (49)

[a]1 mrem = 10^{-5} Sv.

[b]Values are displayed as median, mean $\pm\sigma$ (%σ).

[c]Results do not include measurements reported by NTHU.

[d]No neutron dose measurements made using film on rears of phantoms for this run.

Table 22. Analysis of gamma dose equivalent results on rears of phantoms

Run	Gamma dose equivalent, 10^{-5} Sv[a]					
	Reference	Subset of reported results[b,c]	Film[b]	TLD[b,d]	$CaSO_4$ TLD	TLD-100[g]
1	16	12, 19 ± 23 (123)	35, 35 ± 35 (100)	7, 7 ± 8 (121)	12[e]	128
2	7	4, 11 ± 18 (165)	10, 12 ± 14 (114)	1, 12 ± 23 (195)	4[e]	[f]
3	13	36, 35 ± 32 (95)	60[e]	34, 34 ± 45 (133)	13[e]	100
4	30	40, 48 ± 25 (53)	60, 60 ± 7 (12)	37, 47 ± 31 (66)	28[e]	360
5	3	7, 7 ± 6 (86)	[f]	5, 5 ± 7 (141)	9, 9 ± 6 (67)	25
6	12	23, 32 ± 25 (79)	70, 56 ± 29 (51)	16, 22 ± 20 (93)	26, 26 ± 14 (54)	320

[a] 1 mrem = 10^{-5} Sv.

[b] Values are displayed as median, mean ±σ (%σ).

[c] Results do not include measurements reported by RPB.

[d] Results do not include measurements made with $CaSO_4$ TLD or TLD-100.

[e] One gamma dose measurement made on rears of phantoms.

[f] No gamma dose measurement made on rears of phantoms for this run.

[g] Used by only one participant.

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APPENDIX B

HPRR Spectra: Unshielded and Through 12-cm Lucite

Group	Upper energy (eV)	Mid-energy (eV)	N(E)ΔE,[a] n/cm²	
			No shield	Lucite shield
1	1.49E7	1.22E7	9.53E7	3.31E7
2	1.00E7	8.19E6	1.18E9	3.63E8
3	6.70E6	5.77E6	3.43E9	4.29E8
4	4.97E6	3.87E6	1.44E10	2.58E9
5	3.01E6	2.12E6	3.76E10	5.56E9
6	1.50E6	1.16E6	3.16E10	3.19E9
7	9.07E5	6.08E5	4.61E10	3.69E9
8	4.08E5	2.13E5	3.39E10	3.08E9
9	1.11E5	9.80E4	2.60E9	4.18E8
10	8.65E4	7.64E4	2.00E9	3.81E8
11	6.74E4	5.95E4	1.50E9	3.49E8
12	5.25E4	4.63E4	1.21E9	3.24E8
13	4.09E4	3.61E4	9.71E8	3.05E8
14	3.18E4	2.81E4	8.40E8	2.98E8
15	2.48E4	2.19E4	7.35E8	2.76E8
16	1.93E4	1.70E4	6.37E8	2.66E8
17	1.50E4	1.03E4	1.58E9	7.60E8
18	7.10E3	4.88E3	1.39E9	7.23E8
19	3.35E3	2.03E3	1.62E9	9.49E8
20	1.23E3	8.48E2	1.04E9	6.97E8
21	5.83E2	3.54E2	1.24E9	9.21E8
22	2.14E2	1.47E2	8.45E8	6.91E8
23	1.01E2	6.96E1	7.76E8	6.90E8
24	4.76E1	3.73E1	4.72E8	4.59E8
25	2.90E1	2.26E1	4.54E8	4.60E8
26	1.76E1	1.37E1	4.34E8	4.61E8
27	1.07E1	7.34	6.09E8	6.93E8
28	5.04	3.93	3.82E8	4.58E8
29	3.06	2.18	4.84E8	6.11E8
30	1.56	1.25	3.04E8	3.79E8
31	1.00	8.06E-1	2.81E8	3.41E8
32	0.65	5.41E-1	2.43E8	2.86E8
33	0.45	2.12E-1	1.78E9	2.67E9
34	0.10	2.24E-2	3.36E9	1.95E10
	5.0E-3			
Total fluence at 3 m from HPRR for 10^{17} fissions, n/cm²			19.61E10	5.33E10

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

APPENDIX C

HPRR Spectra: Unshielded and Through 20-cm concrete

Group	Mid-energy (eV)	ΔE (eV)	N(E)ΔE,[a] n/cm^2	
			No shield	Concrete shield
1	1.32E7	1.36E7	2.16E9	5.15E8
2	5.62E6	1.63E6	4.08E9	9.60E8
3	3.90E6	1.80E6	1.43E10	2.36E9
4	2.25E6	1.50E6	3.77E10	9.12E9
5	1.20E6	6.00E5	3.27E10	4.57E9
6	6.50E5	5.00E5	4.73E10	9.35E9
7	2.64E5	2.72E5	3.06E10	7.54E9
8	1.07E5	4.33E4	4.85E9	2.28E9
9	7.90E4	1.20E4	1.28E9	6.96E8
10	6.25E4	2.10E4	2.36E9	1.72E9
11	4.85E4	7.00E3	8.48E8	6.84E8
12	3.75E4	1.50E4	1.81E9	1.80E9
13	2.75E4	5.00E3	6.87E8	7.80E8
14	2.10E4	8.00E3	1.24E9	1.55E9
15	1.50E4	4.00E3	7.64E8	1.06E9
16	1.05E4	4.97E3	1.21E9	1.86E9
17	5.52E3	5.03E3	1.94E9	3.41E9
18	2.08E3	1.85E3	1.76E9	3.60E9
19	8.50E2	6.00E2	1.10E9	2.46E9
20	3.80E2	3.40E2	1.35E9	3.31E9
21	1.55E2	1.10E2	9.65E8	2.60E9
22	74.2	51.7	8.22E8	2.31E9
23	39.2	18.3	5.30E8	1.57E9
24	23.5	13.0	5.97E8	1.84E9
25	13.5	7.00	5.23E8	1.67E9
26	7.50	5.00	5.96E8	1.95E9
27	4.03	1.95	4.42E8	1.50E9
28	2.32	1.46	6.47E8	2.30E9
29	1.30	0.59	4.14E8	1.68E9
30	0.825	0.35	3.51E8	1.39E9
31	0.550	0.20	3.09E8	1.24E9
32	0.275	0.35	1.02E9	4.14E9
33	0.050	0.10	4.50E9	1.63E10
Total fluence at 3 m from HPRR for 10^{17} fissions, n/cm^2			20.18E10	10.01E10

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

APPENDIX D

PARTICIPANT COMMENTS CONCERNING DOSIMETRY AND MEASUREMENTS

Some of the Sixth PDIS participants reported comments concerning their dosimetry and measurement methods along with dose results. These comments, which are presented in this appendix, provide details concerning measurement, evaluation, and calibration techniques for individual participants. A list of participants and associated dosimeter types is given in Table 4 of this report, and identifying acronyms are defined in Appendix A. Dose equivalents were reported by participants in millirems (1 mrem = 10^{-5} Sv).

AECL/CR — The DOSAR received 18 dosimeters plus three background dosimeters as suggested by the study. Each dosimeter consisted of our current personnel plaque plus a package of four TLD-100's (0.089 cm-thick) wrapped in aluminum foil. In 12 of the dosimeters were packages of two TLD-600's and two TLD-700's (also wrapped in aluminum foil). The separate TLD-100's, TLD-600's, and TLD-700's were read on our Harshaw Automatic TLD Analyzer System (Model 2000 DTL detector and a Model B Picoammeter). The plaques were read on our personnel plaque reader (AEP 5256). Each chip was calibrated to 1 rad using a ^{137}Cs source. No attempt was made to estimate the neutron dose.

As expected, the neutron fields to which the dosimeters were exposed affected the results. In particular, it is difficult to believe the TLD-100 and TLD-600 readings. Since the plaques contain two TLD-100's, their results would also be affected by the neutron fields. It is not expected that the neutron activation of the aluminum wrapping had much effect on the TLD's. Therefore, the TLD-700 results would most likely be closest to the true gamma dose absorbed and are the results given in the data report sheet (the results from the TLD-100 and TLD-600 are taken only as an indication of a neutron field being present).

AECL/W — The green styrene holder contains a plaque with a 0.9-mm-thick TLD-100 dosimeter for measuring the whole body dose and a 0.38-mm-thick TLD (100 or 700) dosimeter for measuring the skin dose. The thicker TLD is covered with 540 mg/cm^2 of aluminum and the thinner one with 7 mg/cm of mylar tape. These two dosimeters are read automatically by a reader which also identifies the plaque. In addition, there is an unmounted 0.38-mm TLD-700 adjacent to the plaque-mounted thick chip and also covered by 540 mg/cm^2 of aluminum.

For calibration, dosimeters are exposed at known levels to ^{60}Co gamma-rays when mounted in holders fitted with build-up layers over the thin windows. Each plaque mounted TLD is also individually calibrated. The unmounted TLD's are calibrated afresh after each exposure.

The normal evaluation of dose is made from the two plaque mounted TLD's and is assumed to be due to photons or electrons. However, if the dose calculated from the TLD-100 dosimeter exceeds that from the TLD-700 by a factor of 2 or more, the presence of neutrons is indicated and the whole body gamma-dose is calculated from the reading of the unmounted TLD-700 dosimeter.

HPL — We have not developed a neutron calibration factor for our $Li_2B_4O_7$ dosimeter. Therefore, the dose from neutrons is an estimate only. We are just now beginning our program and are hoping that the results of this test will help us establish our program.

INER — Two sets of dosimeters were used ir. the Sixth PDIS. One neutron dosimeter consisted of Lexan polycarbonate foil (250 μm) using electrochemical etching. The second dosimeter was an albedo type (TLD-600, 700 in pair with the design to correct the energy dependence).

KK — Two types of dosimeter systems were used — the Karlsruhe albedo dosimeter consisting of a front and rear dosimeter at the phantom and the Karlsruhe Track Etch System using electrochemical etching. In our opinion, it is not correct to average the results of one participant for completely different systems.

KSU — Films and results were supplied by a commercial vender.

LAND — Calculations were based on front, incident exposures on the phantom. No energy corrections were made for energy distribution other than our standard spectrum of AmBe.

LLL — Three types of dosimeters (in a single packet) were sent to ORNL. The dosimeters were: (1) the personnel badge containing two TLD-700's and one TLD-100; (2) the Hankins' type albedo neutron dosimeter containing four Li-6 and four Li-7 TLD's per dosimeter; and (3) recoil track-etch foils, polycarbonate and ^{39}Cr, positioned inside the albedo neutron dosimeter. The dosimeters were mounted in the modified nuclear accident dosimeter (NAD) packet and in the normal configuration of the neutron badge issued at the LLNL.

The doses for the albedo neutron dosimeters were elevated using the standard curve for the 9/3-in. sphere ratios. The ratios we used were obtained during the 1977 intercomparison of criticality accident dosimeters at ORNL and were 0.98, 0.57, and 0.41 for the bare, Lucite, and concrete and steel exposures, respectively.

The albedo results follow the response of the 9-in. sphere and for two or three exposures the 9-in. sphere would overrespond. A correction for this overresponse of the 9-in. sphere has been applied. These calculated corrections were based again on the 1977 accident intercomparison study and are for the bare, Lucite, and concrete and steel exposure 0, 1.25, and 1.82, respectively.

The track-etch results were evaluated by Dick Griffith. He uses a combination of number of tracks and TLD readings from the albedos to evaluate the exposure. Mr. Griffith calls this system DOSPEC. The gamma doses are the results obtained from the personnel TLD badges.

RPI — Control badge readings were not subtracted from the reported data. Neutron values were based on RPI neutron source data by the equation: mrem neutrons = 0.192 (TLD-600-TLD-700). The TLD readings in mrem gamma are based on ^{137}Cs gammas.

SNL — The neutron conversion factors used in the Sixth PDIS were derived from our participating in the Fifth PDIS. The control dosimeters that accompanied the test badges read 40 mrem. Those that remained here read 20 mrem.

SRP — Neutron dosimeter is described in report DP-1277, "Personnel Albedo Neutron Dosimeter with Thermoluminescent ^{6}LiF and ^{7}LiF." Gamma dosimeter is described in Report DP-1288, "Beta-Gamma Monitoring of Personnel with Thermoluminescent Dosimeters."

TAEC — In this study only $CaSO_4$:Dy is used, and we assume that the response of $CaSO_4$:Dy is all due to gamma radiation.

TPC — The gamma dosimeter was a Harshaw G-7 card which was calibrated using ^{60}Co. The TLD reader was a Harshaw 2271.

YALE — Landauer Gardray Film was used for all measurements. Seven out of ten neutron measurements on phantoms including all five measurements on the rears showed minimal dose.