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Health and Safety Research Division

**SUMMARY AND ANALYSIS OF THE
1986 ORNL PERSONNEL DOSIMETRY INTERCOMPARISON STUDY**

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**SUMMARY AND ANALYSIS OF THE
1986 ORNL PERSONNEL DOSIMETRY INTERCOMPARISON STUDY**

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S. H. Yeh

Abstract

The Twelfth Personnel Dosimetry Intercomparison Study was conducted at the Oak Ridge National Laboratory (ORNL) during April 14-17, 1986. Objectives of this study were to determine neutron dosimeter performance characteristics at neutron dose equivalent levels near the minimum specified for accreditation testing programs and to provide several radiation fields different from those that have been considered in prior ORNL intercomparisons. Dosimeter badges from 49 participating organizations were mounted on Lucite block phantoms and exposed to six mixed-radiation fields (five using the Health Physics Research Reactor and one using a PuBe source) with neutron dose equivalents of about 1.5 mSv and gamma dose equivalents between 0.04 and 5.37 mSv. Results of this study indicated that participants had no difficulty obtaining measurable indication of neutron exposure at dose equivalent levels of about 1.5 mSv. Average neutron results for all dosimeter types were within approximately 60% of reference values with hard spectra being more accurately measured than soft spectra. Considering all irradiations, albedo and direct interaction TLD systems provided about the same performance characteristics. With regard to precision, about 58% of the reported neutron results had single standard deviations within 10% at the means which indicates that precision was not a problem relative to accuracy for over half of the participants. Average gamma results varied from 0.98 to 2.22 times reference values for all exposures with TLD systems being more accurate than film. Some participants, especially those using film, had difficulty obtaining measurable indication of gamma exposures at dose equivalent levels lower than 0.09 mSv. About 69% of all neutron results and 77% of all gamma results met regulatory standards for measurement accuracy and approximately 65% of all neutron data satisfied national dosimetry accreditation criteria for accuracy plus precision.

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INTRODUCTION

The twelfth in a series of annual mixed-field personnel dosimetry intercomparison studies (PDIS)¹⁻⁷ was conducted at the Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research (DOSAR) Facility during April 14-17, 1986. In this study, personnel neutron and gamma dosimeters were mailed to ORNL, exposed to a range of low-level (1.47 to 1.70 mSv neutron and 0.04 to 5.37 mSv gamma) dose equivalents using the Health Physics Research Reactor (HPRR)⁸ and isotopic sources, and then returned to participants for evaluation. This document is a summary and analysis of results reported by the intercomparison participants.

Primary objectives of this study were to evaluate neutron dosimeter performance characteristics at dose equivalent levels near the minimum specified for accreditation testing programs and to provide a wide variety of radiation fields with different neutron energy spectra and neutron-to-gamma dose equivalent ratios. To satisfy the first objective, reference neutron dose equivalents for all irradiations were approximately 1.50 mSv which is the lower limit specified for neutron dosimeter testing in dosimetry accreditation programs⁹. With regard to the second objective, two new radiation fields were used in this study--the HPRR shielded with a combination of 5-cm steel, 15-cm concrete and 12-cm Lucite (SCL), and an unmoderated ²³⁸PuBe source. The SCL irradiation provided a softer neutron energy spectrum and the PuBe source provided a harder spectrum than any used in previous ORNL intercomparisons. As an additional test of participants' capabilities, irradiation conditions for these two runs and for a ¹³⁷Cs gamma-enhanced Lucite-shielded HPRR irradiation were unknown to participants prior to dosimeter

evaluation. This study was similar to the Eleventh PDIS⁷ in that the HPRR was operated over Storage Pit 1 and was attached to a hydraulic vertical positioning device. Reference dosimetry for this study was based on data developed explicitly for this reactor configuration¹⁰.

PARTICIPATION

A total of 49 different organizations, 33 from the United States and 16 from abroad, participated in the Twelfth PDIS. Measured results were reported by a total of 44 organizations which consisted of 12 laboratories (national laboratories or industrial research laboratories), 23 utilities, 3 vendor services, 4 government agencies (military or regulatory), and 2 universities. To ensure anonymity, participating organizations are designated by numbers in the data summary tables.

DOSIMETER TYPES

The 49 participating agencies provided a total of 52 groups of badges since some of the agencies submitted more than one badge type. A total of 957 dosimeters were mounted on phantoms and exposed during the intercomparison. Adding the 160 control badges which accompanied the irradiated dosimeters, a total of 1117 badges were processed by the DOSAR staff. Measured results were reported for 673 of the exposed neutron dosimeters and for 739 of the exposed gamma dosimeters.

Figure 1 shows the collection of badge designs submitted by participants in the Twelfth PDIS. Although few of the badge designs are the same, the basic detection mechanisms can be classified into six categories: direct interaction thermoluminescent (TLD), TLD -albedo,

recoil track (CR-39), converter track (thorium or B_4C converters), NTA film, and combination albedo and CR-39 track¹¹. The TLD-based albedo and direct interaction systems, which were the most popular neutron dosimeters in this study, were used by 61% and 24%, respectively, of the organizations reporting results. Recoil track dosimeters based on CR-39 material were used by 5% of the reporting organizations. Film, fission track, LR-115 (B_4C converter) and combination systems were used by about 2% (one organization each) of the responding agencies.

Considering the reported gamma results, a total of 88% of the reporting organizations used TLD systems with the remaining 12% using film. About 41% of the TLD badges used TLD-700 (7LiF) material, approximately 57% used $CaSO_4$ alone or in combination with another phosphor (usually $Li_2B_4O_7$), and about 2% (one agency) used TLD-100 (natural LiF) material.

EXPERIMENT DESCRIPTION

The Twelfth PDIS consisted of five exposures using the HPRR as the source of radiation and one exposure using a PuBe neutron source. Table 1 lists the run numbers, dates, radiation sources, reactor operating parameters, exposure times, and albedo ratios (ratios of BF_3 detector responses inside 23-cm and 7.6-cm diameter polyethylene spheres) for the six irradiations. Runs 4-6, which were unknown to participants prior to evaluation, consisted of a repeat of run 3 (Lucite-shielded HPRR) plus about 5.0 mSv gamma enhancement using a ^{137}Cs source, a combination of the steel/concrete/Lucite shields with the HPRR, and a PuBe source (no HPRR), respectively. For all exposures, badges from each organization were mounted side-by-side on 40x40x15 cm Lucite blocks¹² with their

front edges located 3 m from the HPRR centerline for runs 1 through 4, 4 m from the HPRR for run 5, and 50 cm from the PuBe source for run 6.

REFERENCE DOSIMETRY

The following text gives details of reference neutron and gamma dose equivalents determined for this study.

Neutron Dose Equivalent

Reference neutron dose equivalents were obtained using fission yields measured by sulfur pellet activation analysis and dose-equivalent-per-fission conversion factors for the various HPRR spectra. The number of fissions produced during an irradiation was determined by measuring the ^{32}P beta activity induced in a 22 g sulfur pellet located at a fixed position near the reactor core. The dose-equivalent-per-fission values were based on multisphere measurements and fluence-to-dose-equivalent conversion factors for several conventions.¹⁰

In this report, reference neutron dose equivalents used for comparison to measured results are based on specifications given in ICRP 21.¹³ This convention consists of log-log interpolation of maximum dose-equivalent-per-fluence values calculated at discrete energies for a tissue-equivalent cylindrical phantom. The ICRP convention was used by 49% of the organizations who reported neutron dose equivalents in this study. Twenty-seven percent of the responding organizations reported neutron results in terms of the NCRP 38 convention.¹⁴ This method is based on linear interpolation of the maximum dose-equivalent-per-fluence values calculated at discrete energies for a cylindrical phantom. The element 57 convention¹⁵ was used by 16% of the organizations reporting

results. Element 57 dose equivalent refers to the value calculated for the central volume of a cylindrical phantom exposed to an external radiation field (log-log interpolation between discrete energies). The remaining 8% of the reported results was either associated with some other convention (2%) or the convention was not known (6%). Table 2 summarizes reference neutron dose equivalents for this study in the ICRP, NCRP and element 57 conventions.

Gamma Dose Equivalent

Table 3 shows reference gamma dose equivalents and neutron-to-gamma dose equivalent ratios determined for the Twelfth PDIS. Reference gamma values were measured with a Philips Geiger-Mueller (G-M) detector¹⁶ mounted directly on a phantom. The G-M detector was covered with a lithium shield and calibrated with a ^{137}Cs source. Gamma dose equivalents ranged from 0.04 to 5.37 mSv for the six exposures. Neutron-to-gamma dose equivalent ratios on a phantom varied from 0.28 to 39.25 with the lowest value obtained for the Lucite-shielded HPRR enhanced with ^{137}Cs and the highest value obtained for the steel-shielded HPRR.

RESULTS AND ANALYSIS OF NEUTRON MEASUREMENTS

Reported neutron results for the six irradiations conducted during the Twelfth PDIS are summarized in Tables 4-9. Data given in these tables for each participant include identifying organization number, basic dosimeter type, reported neutron dose equivalents, the average of reported results, and the percent of the mean of one standard deviation

of the reported data. Reference neutron dose equivalents in the ICRP 21 convention are included for each exposure. In the following text, neutron dosimeter performance characteristics are described based on results presented in these tables.

Tables 10-17 present analyses of reported neutron dose equivalents for the composite of all results and for each of the six basic dosimeter types considered in this study. Data given for each irradiation include the total number of reported results, the range of normalized (measured divided by reference) reported results, the mean and one standard deviation about the mean of all normalized results, and the average and range of standard deviations about the mean of the reported results for each participating organization. Only one of the measured neutron results (run 2, participant 14, NTA film) was reported as below the minimum detectable value which indicates that monitoring systems used in this intercomparison had no problems providing indication of neutron exposure at dose equivalent levels of about 1.5 mSv.

An analysis of results for the composite of all neutron measurements (all dosimeter types) is presented in Table 10. Although performance characteristics of individual dosimeter types cannot be determined from the data, the following observations are noted concerning the ability of the collection of participants to measure neutron dose equivalents under identical conditions:

1. Means of normalized results varied from 1.13 to 1.56 times reference values with standard deviations of about 60% of the means. On the average, harder neutron energy spectra (unshielded, steel-shielded, and PuBe) were measured more accurately than the softer spectra (Lucite and SCL-shielded).
2. Results reported by different organizations for the same irradiation differed by factors between 15 and 97 for each run. It was not unusual for neutron dose equivalent estimates made under identical conditions by different organizations to differ by a factor of two. Ranges of reported results for the "unknown" spectra (runs 4-6) were higher than those observed for the "known" spectra (runs 1-3).
3. Single standard deviations about the mean (precision) for results reported by individual organizations averaged about 11% of the mean for all six irradiations. About 31% of the reporting organizations showed standard deviations of 5% or less of the mean values while about 58% indicated standard deviations of 10% or less of the means. Precisions for individual organizations ranged from less than 2% to approximately 50% of the means for all runs. In most cases, the individual standard deviations were based on measured results for three badges placed side-by-side on the same phantom. These data indicate that measurement precision is not a problem compared to accuracy for more than half of the participating organizations.

Table 11 presents a summary of results for TLD-albedo dosimeters, the most popular type (61% of the reporting organizations) used by intercomparison participants. The following observations concerning albedo dosimeter performance are based on data shown in this table:

1. Albedo dosimeter accuracy as reflected by the mean normalized results varied from 0.95 to 1.56 times reference values. Standard deviations associated with these values were about 57% of the means. Harder neutron spectra (runs 1, 2, 6) were more accurately measured than softer spectra (runs 3-5).
2. Ranges of reported normalized results varied from a minimum of about 0.07 to a maximum of about 3.39 times reference values for all runs. Typically, neutron dose equivalent measurements made under identical conditions by different organizations using albedo systems differed by factors of approximately 4 to 9 for this study.
3. With regard to measurement precision for the individual participants, single standard deviations ranged from less than 2% to about 36% of the means for the six irradiations. The average standard deviation was about 8.4% of the mean, and approximately 58% of the participants using albedo systems exhibited standard deviations of 10% or less. No obvious correlations between albedo measurement precision and incident spectrum are evident from these data.

A summary of results for direct interaction TL dosimeters, the second most popular type (24% of the reporting organizations) used by Twelfth PDIS participants, is presented in Table 12. These systems use differences between responses of neutron plus gamma and gamma-only sensitive phosphors to obtain an estimate of the neutron dose equivalent in a mixed radiation field.¹¹ The following observations concerning direct interaction TL performance are based on data shown in Table 12:

1. Mean normalized results for the direct interaction TL dosimeters varied from 1.05 to 1.75 times reference values for the six exposures. Results for the harder HPRR energy spectra (unshielded and steel-shielded) were more accurate on the average (within 7% of reference values) than results obtained for softer spectra (runs 3-5) which were 72% to 75% higher than references. Average results for the PuBe source were 41% higher than reference values. Standard deviations associated with these results were about 79% for unshielded and steel-shielded HPRR, 94% for the PuBe source, and over 100% for Lucite- and SCL-shielded HPRR. Although average results for the hard spectra are slightly more accurate than those obtained for albedo dosimeters, average direct interaction TLD system data are much less accurate for the soft spectra.
2. Measurement precision as indicated by one standard deviation of results reported by the individual participants averaged about 10% of the mean which is comparable to results obtained for TLD-albedo dosimeters. Standard deviations ranged from 1.4% to 53.8% of the means for the six irradiations. Approximately 70% of the

participants using direct interaction TL dosimeters exhibited standard deviations of 10% or less of the mean reported dose equivalents. No obvious correlations between measurement precision and incident spectrum are evident from the data shown in Table 12. An analysis of results obtained using CR-39 recoil track dosimeters is presented in Table 13. This type of system was used by only two (5%) of the reporting organizations. Both agencies calibrated their badges with unmoderated ^{252}Cf and made no corrections to measured data. The following observations concerning CR-39 dosimeter performance are based on data shown in Table 12:

1. Average measured dose equivalents were within 41% of reference values for all spectra. Dose equivalents were overestimated by 41% for the unshielded HPRR spectrum and underestimated by 28% for the PuBe spectrum. Standard deviations associated with these results averaged about 22% of the means.
2. Ranges of measured results reported by two organizations varied between factors of about 0.5 to 1.8 times reference values for all runs. These variations are smaller than those observed for TL-based systems in this study.
3. With regard to measurement precision, standard deviations for individual organizations ranged from 3% to 44% of the mean values with an average precision of 16% of the means for all irradiations. The average of reported standard deviations is greater than that observed for TL systems.

Tables 14-17 summarize results of LR-115 (B_4C converter), NTA film, thorium fission track, and combination albedo-track neutron dosimeters, respectively. Since each of these dosimeter types was used by only one organization, no detailed analysis of performance characteristics is possible. However, the following observations are evident from data shown in these tables:

1. The LR-115 material with a B_4C converter significantly overestimated reference neutron dose equivalents by factors of about 1.7 to 6.8 for the six exposures. Poorest results were obtained for the PuBe source which was used to calibrate this system. Best results were obtained for the "known" spectra.
2. The NTA film underestimated neutron dose equivalents for the HPRR irradiations by 12 to 48%. Results for the PuBe source overestimated reference values by about 77%. Largest underestimates were obtained for the moderated HPRR spectra while highest overestimates were obtained for the hardest spectrum (PuBe).
3. The fission track dosimeter with a ^{232}Th converter provided results within 9% of reference values for the hardest neutron spectra but were more than 30% different from reference values for the softer spectra.
4. Combination albedo-track dosimeters provided results within 85% of reference values for all six exposures. Neutron dose equivalents for the softest spectrum (SCL) were underestimated by about 37%

while values for all other spectra were overestimated by 10 to 85% relative to reference data.

In addition to the performance observed for individual dosimeter types, average neutron measurement accuracies exhibited for Lucite-shielded runs 3 and 4 were within 6% for the composite of results which indicates that most participants had no problems measuring neutron dose equivalents of about 1.5 mSv in radiation fields with significantly different gamma components. Average neutron dose equivalents determined using albedo and direct interaction TLD systems were within 3% for these irradiations. Ranges of reported results and associated standard deviations were slightly higher for the gamma-enhanced run compared to the Lucite-shielded irradiation. Also, the fact that the irradiation conditions for run 4 were unknown to participants prior to evaluation had no significant effect on neutron measurement accuracy and precision.

The "unknown" steel-concrete-Lucite shield combination used in run 5 had not been used in any previous PDIS and provided the softest neutron energy spectrum considered in this study. Based on dosimeter energy sensitivities and incident spectrum characteristics, this irradiation would be expected to produce the highest dose equivalent overestimates for TLD systems and the largest underestimates for NTA film dosimeters. Measurement precision should not be significantly different from results obtained for other soft spectra. This performance is exactly what was observed in this study which indicates that the fact that this radiation field was "unknown" to participants had almost no effect on neutron measurement accuracy or precision.

The PuBe spectrum, which is significantly harder than any HPRR spectrum and well outside the range of albedo ratios considered in previous intercomparisons, caused relatively few problems for albedo systems which provided average neutron dose equivalents within 5% of the reference values with a standard deviation of about 45% of the mean. These results are expected based on the fact that 60% of all albedo users had calibrations to multiple sources including PuBe, AmBe, or unmoderated Cf. Direct interaction TL dosimeters yielded an average overestimate of 41% relative to reference values for this case with a standard deviation of about 67% of the mean. The CR-39 systems underestimated dose equivalents by an average of about 28% for this case while NTA film badges produced 77% overestimates relative to reference values.

RESULTS AND ANALYSIS OF GAMMA MEASUREMENTS

Tables 18-23 summarize gamma results as reported by 41 different organizations who made gamma measurements. Data given in these tables for each participant include organization number, gamma dosimeter type, reported gamma dose equivalents, and the average of reported results. Reference gamma dose equivalents are also included for each run. Dosimeter performance characteristics described in the following text are based on results presented in these tables.

Analyses of reported gamma measurements are given in Tables 24-29 for the composite of all dosimeter types, all TLDs, TLD-700 (^7LiF) material, CaSO_4 phosphors alone or in combination with another material (usually $\text{Li}_2\text{B}_4\text{O}_7$), TLD-100 (LiF) phosphors, and film dosimeters, respectively. Data given for each irradiation include the reference gamma dose equivalent, the total number of reported results, the number of

reported results greater than zero or the minimum detectable value, the range of normalized reported results, and the mean and one standard deviation about the mean of the normalized results. Data reported as zero or below the minimum detectable value were included in the calculation of the means and standard deviations shown in the analysis tables.

Table 24 represents an analysis of gamma results for all dosimeter types. The following observations concerning the ability of all participants to estimate gamma dose equivalents in mixed radiation fields under identical conditions are based on data shown in this table:

1. Some participants had difficulty obtaining measurable indication of gamma exposure at dose equivalent levels lower than 0.09 mSv. About 17% of all measurements below this level were reported as zero or below minimum detectable. Only 2% of the measurements above 0.09 mSv gamma dose equivalent was reported as zero. These results are consistent with observations made in previous FDIS^{6,7}.
2. Average normalized results were greater than reference values for all runs except run 4 (¹³⁷Cs gamma enhanced) which had the highest reference gamma dose equivalent. Mean results varied from 0.98 to 1.74 times references with the most accurate results obtained from the spectrum with the lowest neutron-to-gamma dose equivalent ratio and highest reference value (run 4) and the least accurate results obtained for the highest dose equivalent ratio with the lowest gamma dose equivalent (run 2). The observed overestimates are primarily due to neutron interactions with badge materials and phosphors¹⁷. The good accuracy observed for the gamma-enhanced

irradiation is consistent with results obtained in previous studies.⁶ Standard deviations associated with these results were about 141% of the means for all runs.

3. Ranges of normalized results reported by individual organizations for the same irradiation varied from factors of about 1.84 to 22.50 for the six runs. The smallest differences were obtained for run 4 which had the highest reference gamma dose equivalent (5.37 mSv). The largest differences were observed for runs 2 and 3 which had reference gamma dose equivalents of 0.04 and 0.22 mSv, respectively. Maximum variations among results reported by different individual organizations for the same irradiations were much greater than those obtained for corresponding neutron measurements in this study. Part of the reason for this large variation is that two agencies used TLD-100 (LiF) phosphor which is very sensitive to neutrons for mixed-field gamma measurements.

An analysis of data reported for all gamma TL dosimeters, which were used for 88% of the gamma measurements, is presented in Table 25. The following observations concerning gamma TL dosimeter performance are based on data shown in this table:

1. Some participants who used TL gamma dosimeters had difficulty obtaining measurable indication of gamma exposure at dose equivalent levels less than 0.09 mSv. About 11% of the results below this level were reported as zero or below minimum detectable. Above 0.09 mSv, none of the results were reported as zero for TLD systems.

2. Ranges, means, and standard deviations of the indicated data show the same qualitative trends observed for the composite of all results. Mean values are greater than reference dose equivalents for all irradiations and vary from 1.01 to 1.88 times references. Best accuracy and smallest differences among individual organizations were obtained for run 4 which had the highest reference gamma value and lowest neutron-to-gamma dose equivalent ratio. Poorest results were obtained for run 2 (steel-shielded HPRR) which had the lowest reference gamma dose equivalent and highest neutron component.

Among participants who used TL systems for gamma measurements, 39% used TLD-700 material, 55% used CaSO_4 alone or in combination with another phosphor, and 6% used TLD-100 material. Tables 26-28 summarize results for participants who used TLD-700, CaSO_4 , and TLD-100, respectively. At reference gamma dose equivalents lower than 0.09 mSv, 14% of the TLD-700 measurements were reported as zero and 9% of the CaSO_4 results were reported as zero. Above this value, none of the results for these phosphors were reported as zero. None of the results for TLD-100 dosimeters were reported as zero at any dose equivalent level. The CaSO_4 dosimeters were the most accurate providing results within 16% of reference values for all runs and the most precise indicating the smallest variations in results of all phosphors. The TLD-700 data showed good accuracy for spectra with low neutron-to-gamma ratios (within 17% of references) and poorest accuracy (75% higher than references) for spectra with the highest neutron components. Results obtained for TLD-100 phosphors showed much larger variations in individual results and significant overestimates of gamma dose equivalents (factors of about 2 to 12 times reference values) due to the higher neutron sensitivity of

natural LiF. Best results with this phosphor were obtained for the gamma-enhanced run which had a very low neutron component and poorest results were obtained for the steel-shielded HPRR irradiation which had the highest neutron component.

Table 29 presents an analysis of results obtained using film gamma dosimeters which were used for 12% of all reported results. The following observations are based on data presented in this table:

1. Participants had significant difficulty obtaining measurable indication of gamma exposure at dose equivalent levels below 0.09 mSv. Below this level, 74% of all film-measured results were reported as zero or below minimum detectable. Above 0.09 mSv, 21% of the results were reported as zero. This performance is much poorer than that observed for TL systems.
2. Mean normalized dose equivalents were less than reference values for all irradiations except run 3 (Lucite-shielded) which had one participant who reported very high results. Due to the large number of reported zero dose equivalents, average film results are difficult to interpret relative to accuracy and precision performance. Previous intercomparisons have shown that gamma film significantly overestimates gamma dose equivalents in mixed-radiation fields.³⁻⁷

DOSIMETER PERFORMANCE RELATIVE TO REGULATORY CRITERIA

Guidelines specified by the U. S. Nuclear Regulatory Commission (NRC)¹⁸ and the American National Standards Institute (ANSI)⁹ suggest that personnel neutron and gamma dosimeters used in the dose equivalent

range considered in this study should be accurate to within $\pm 50\%$ of reference values. Table 30 shows the percent of reported neutron and gamma dose equivalents which satisfy this criterion for each irradiation and the total of all exposures. Neutron results are presented for all dosimeters, albedo systems, and TLD's. Gamma data are shown for all dosimeters, TLD's, and film systems.

About 69% of all reported neutron results satisfied the NRC and ANSI standards. Percentages of results within $\pm 50\%$ of reference values varied from 58% to 78% for all dosimeter types with the highest percentages produced for the hardest spectra (unshielded and steel-shielded HPRR). Lowest percentages were obtained for the softest (SCL-shielded) spectrum. About 75% of all albedo-measured results satisfied the subject standards while 55% of the direct interaction TL data were within $\pm 50\%$ of references. For both dosimeter types, the hardest HPRR spectra (runs 1 and 2) provided the most accurate results while the softest spectrum (run 5) provided the least accurate. These results are less accurate than measurements reported for the Eleventh PDIS⁷ which indicated about 80% of all neutron results within $\pm 50\%$ of reference values at neutron dose equivalents around 5.0 mSv.

With regard to gamma measurements, about 77% of all reported results were within suggested limits for all spectra. Poorest results were obtained for runs 1, 2, and 6 which had the lowest reference dose equivalents and the highest neutron components. Best results were obtained for run 4 (gamma-enhanced Lucite) which had the highest reference gamma value and lowest neutron component. About 96% of all gamma results were within $\pm 50\%$ of the reference dose equivalent for this case. Approximately 82% of all TLD-measured results and 46% of all film results satisfied the accuracy standard. For both dosimeter types,

poorest performance occurred for runs 1, 2, and 6 (highest neutron components, lowest reference values) and best results were obtained for run 4 (lowest neutron component, highest reference dose equivalent). These results are consistent with those obtained in previous intercomparisons^{6,7}.

Development of the National Voluntary Laboratory Accreditation Program (NVLAP) has provided standards for neutron personnel dosimetry based on ANSI criteria.⁹ For mixed-field monitoring, NVLAP requirements specify that the sum of the accuracy (mean result minus reference) and precision (one standard deviation about the mean) must be equal to or less than 50%. Considering those organizations which submitted three dosimeters per run, 65% of all neutron measurements satisfied this criterion. Percent of results meeting this standard varied from 50% to 76% for all spectra with the bare and steel-shielded runs providing the best results.

CONCLUSIONS

The following conclusions are based on observations presented in the preceding text:

1. For neutron monitoring, TLD-based systems were the most popular in this study with 61% and 24% of the organizations reporting results using albedo and direct interaction TLD's, respectively. Recoil-track systems were used by 5% of the PDIS participants while film, fission-track, LR-115, and combination albedo-track dosimeters were used by about 2% of the participants.

2. Most (49%) participating organizations reported neutron dose equivalents in terms of the ICRP 21 convention. Twenty-seven percent of the participants used the NCRP 38 convention while 16% reported dose equivalents in terms of element 57.
3. None of the neutron monitoring systems used in this study had any problems providing measurable indication of neutron exposure at dose equivalent levels of about 1.5 mSv.
4. It was not unusual for neutron dose equivalents determined by different organizations under the same irradiation conditions to differ by a factor of two. Variations of more than a factor of 50 were observed for some runs.
5. On the average, normalized results for all neutron measurements were within 56% of reference values with hard spectra being measured more accurately than soft spectra. Considering all irradiations, albedo and direct interaction TLD systems provided about the same performance characteristics for hard spectra with albedo dosimeters being more accurate for soft spectra.
6. Neutron measurement precisions as reflected by one standard deviation about the mean of results were within 10% of the mean for 58% of the reporting organizations. These results indicate that for over half of the participants, precision is not a problem relative to accuracy.

7. Performance characteristics observed for the HPRR-only and gamma-enhanced irradiations indicate that most participants had no problems measuring neutron dose equivalents of about 1.5 mSv in radiation fields with significantly different gamma components.
8. The steel/concrete/Lucite-shielded HPRR and the PuBe source produced expected neutron dosimeter performance characteristics based on dosimeter energy sensitivity and neutron energy distributions. The fact that these fields plus the gamma-enhanced Lucite were "unknown" to participants prior to evaluation had almost no effect on neutron measurement accuracy or precision.
9. With regard to gamma dosimetry, most participants (88%) used TLD systems with the remainder using film. About 39% of the TLD's were TLD-700 (^7LiF), 55% were CaSO_4 alone or in combination with another phosphor, and 6% were TLD-100 (LiF).
10. Some participants had difficulty obtaining measurable indication of gamma exposure at dose equivalents less than 0.09 mSv. About 11% and 74% of results obtained in this range using TLD's and film, respectively, were reported as zero or below minimum detectable. Only 2% of the gamma measurements above this value were reported as zero.
11. Average gamma results varied from 0.98 to 2.22 times reference values for all exposure conditions. Mean TLD-measured dose equivalents were slightly more accurate for CaSO_4 dosimeters than for TLD-700 systems. The TLD-measured results were more accurate

than average film results for each irradiation. The most accurate results were obtained for the highest reference gamma dose equivalent with the lowest neutron component, and the poorest accuracies were exhibited for spectra with low dose equivalents and high neutron components.

12. Maximum variations among gamma results reported by different organizations for the same irradiations were greater than those obtained for corresponding neutron measurements.
13. About 69% of all neutron and 77% of all gamma results reported for all dosimeter types were within $\pm 50\%$ at reference values which is the accuracy standard suggested by the NRC and ANSI for personnel dosimeters. In addition, approximately 65% of all neutron results satisfied NVLAP standards for personnel neutron dosimetry which specify that measurement accuracy plus precision must be equal to or less than 50% relative to reference values. Best performance was exhibited for the unshielded and steel-shielded HPRR spectra while poorest performance was obtained for the unmoderated PuBe spectrum. Albedo neutron systems and TL gamma dosimeters were the most accurate for their respective measurements.

RECOMMENDATIONS

The large number of participants in the past several ORNL Personnel Dosimetry Intercomparison Studies indicates that dosimetrists are concerned with testing and evaluating performance characteristics of their personnel neutron and gamma monitoring systems. To facilitate these efforts, the DOSAR staff plans to continue annual ORNL intercomparisons

and to increase the scope of the radiation fields and exposure conditions. The construction of a comprehensive radiation calibration facility at ORNL which will greatly expand DOSAR irradiation capabilities is now underway. In addition, the DOSAR staff assisted with an international radiation dosimetry symposium which was held in Taipei, Taiwan, Republic of China, during March 2-4, 1987. This conference was be aimed at combining information on research advances and practical needs and experience and provided a valuable forum for information exchange and discussion among international dosimetrists.

Figure 1. Collection of dosimeter badges for one exposure during the Twelfth PDIS.

Table 1. Summary of experimental conditions for the Twelfth PDIS^a

Run	Date	Radiation source	Reactor power, w ^b	Run duration, s	Number of fissions, $\times 10^{13}$ ^c	Albedo ratio ^d
1	4/14/86	HPRR-unshielded	0.375	318	0.40	0.90
2	4/16/86	HPRR-shielded with 13-cm steel	0.75	355	0.84	0.62
3	4/15/86	HPRR-shielded with 12-cm Lucite	1.5	472	2.14	0.50
4 ^e	4/15/86	HPRR-shielded with 12-cm Lucite plus ¹³⁷ Cs gamma enhanced ^f	1.5	472	2.14	0.50
5 ^e	4/17/86	HPRR-shielded with 5-cm steel, 15-cm concrete, and 12-cm Lucite ^g	7.5	607	13.81	0.38
6 ^e	4/14/86	Unmoderated PuBe source ^h		5400		3.33

^aThe horizontal centerlines of the reactor and the Lucite blocks on which the badges were mounted were 1.4 m above the floor level for all exposures. The HPRR was operated over Storage Pit 1 and was attached to a hydraulic positioning device.

^bBased on reactor instrumentation.

^cBased on sulfur pellet activation analysis.

^dRatio of BF³ detector responses inside 23-cm and 7.6-cm diameter polyethylene spheres.

^eIrradiation conditions unknown to participants prior to evaluation.

^fHPRR exposure gamma enhanced with 18.5 minute irradiation using a ¹³⁷Cs source.

^gLucite shield located 3 m from the HPRR with phantoms and polyethylene spheres located 4 m from the reactor centerline.

^hPhantoms and spheres located 0.5 m from the source centerline.

Table 2. Reference neutron dose equivalents for the Twelfth PDIS

Exposure number	Radiation sources	Reference neutron dose equivalent, mSv		
		ICRP21 ^a	NCRP38 ^b	Element 57 ^c
1	HPRR-unshielded	1.70	1.76	1.58
2	HPRR-steel shield	1.57	1.70	1.45
3	HPRR-Lucite shield	1.48	1.52	1.38
4	HPRR-Lucite shield- gamma enhanced	1.48	1.52	1.38
5	HPRR-SCL shield	1.53	1.57	1.41
6	PuBe source	1.47	1.52	1.37

^aUsed for comparison to measured results in this report. Consists of ICRP 21 data with log-log interpolation between energy points.

^bNCRP 38 data with linear interpolation.

^cElement 57 data (capture gamma component excluded) with log-log interpolation.

Table 3. Reference gamma dose equivalents for the Twelfth PDIS.

Run	Radiation source	Reference gamma d.e., mSv ^a	Neutron-to-gamma d.e. ratio ^b
1	HPRR - unshielded	0.09	18.89
2	HPRR - steel shield	0.04	39.25
3	HPRR - Lucite shield	0.22	6.73
4	HPRR - Lucite shield plus ¹³⁷ Cs	5.37	0.28
5	HPRR - SCL shield	0.30	5.10
6	PuBe - unmoderated	0.08	18.38

^aReference gamma dose equivalent based on measurements made with a Philips Geiger-Mueller detector mounted on a phantom.

^bNeutron-to-gamma dose equivalent ratio on a phantom based on reference dosimetry for this study.

Table 4. Summary of reported neutron results - FDIS 12, run 1, unshielded

Group ^a	Neutron dosimeter type	Neutron dose equivalent, mSv ^b				Percent standard deviation ^d
		1 ^c	2	3	Average	
DOSAR	Reference ^c	1.70				
1	Albedo	2.60	2.30	2.70	2.53	8
2	Albedo	1.77	1.96	2.04	1.92	7
3	Albedo	1.97	1.97	1.65	1.86	10
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	Albedo	1.18	1.47	1.41	1.35	9
7	Albedo	2.23	2.57	2.37	2.39	6
	Albedo	1.80	1.64	1.73	1.72	4
8	Albedo	2.52	2.36	-	2.44	3
9	TLD	0.64	0.53	0.57	0.58	8
10	Albedo	0.88	0.92	0.87	0.89	3
11	Albedo	1.38	1.47	1.49	1.45	3
12	Albedo	1.84	1.61	1.63	1.69	6
13	Albedo	1.31	1.44	1.43	1.39	4
14	Albedo	1.70	-	-	1.70	0
	Film	1.60	1.40	-	1.50	9
15	Albedo	3.45	2.33	3.38	3.05	21
16	Albedo	4.26	5.51	4.86	4.88	13
17	Combination ^f	1.80	2.00	1.80	1.87	6
18	TLD	0.22	0.16	0.09	0.16	41
19	Albedo	2.60	2.60	2.39	2.53	5
20	Albedo	1.81	-	-	1.81	0
	Albedo	1.98	-	-	1.98	0
21	Albedo	1.77	1.69	1.96	1.81	8
22	Albedo	1.39	1.66	1.66	1.57	10
23	Albedo	1.49	1.60	1.72	1.60	7
24	Albedo	1.62	1.66	1.49	1.59	6
25	-	-	-	-	-	-
26	TLD	1.97	1.71	1.96	1.88	8
27	Albedo	1.33	1.45	1.45	1.41	7
28	CR-39	2.20	2.00	2.00	2.07	8
29	TLD	1.41	1.26	1.74	1.47	17
30	TLD	4.26	4.78	5.02	4.09	8
31	TLD	1.87	1.64	1.92	1.75	9
32	TLD	3.20	2.96	2.73	2.96	11
33	-	-	-	-	-	-
34	TLD	1.71	1.79	1.60	1.70	6
35	LR-115	5.00	-	-	5.00	40
36	Fission track	1.86	-	-	1.86	0
	Albedo	-	1.86	1.74	1.80	5
37	Albedo	1.88	1.62	1.53	1.68	11
38	-	-	-	-	-	-
39	TLD	1.08	1.40	1.16	1.21	14
40	Albedo	2.23	2.18	2.24	2.22	1
41	-	-	-	-	-	-
42	TLD	2.03	2.21	1.89	2.04	8
43	Albedo	1.78	1.60	1.72	1.70	5
44	CR-39	2.40	2.60	3.15	2.72	14

^aParticipants designated by numbers to preserve anonymity.^bBackground corrected values as reported by participants.^cParticipants were permitted to submit three badges per exposure.^dPercent of the mean of one standard deviation of reported results^eReference values given in the ICRP 21 convention.^fTLD-albedo and CR-39 recoil track.

Table 5. Summary of reported neutron results - PD1S 12, run 2, 13-cm steel shield

Group ^a	Neutron dosimeter type	Neutron dose equivalent, mSv ^b				Percent standard deviation ^d
		1 ^c	2	3	Average	
DOSAR	Reference ^e	1.57				
1	Albedo	1.90	1.80	1.10	1.60	28
2	Albedo	1.68	2.13	1.60	1.80	16
3	Albedo	1.94	2.19	1.97	2.03	7
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	Albedo	1.48	1.43	1.19	1.37	9
7	Albedo	2.11	1.47	1.48	1.69	18
	Albedo	1.80	1.62	1.77	1.73	5
8	Albedo	2.53	2.59	2.47	2.53	2
9	TLD	0.55	0.64	0.58	0.59	6
10	Albedo	1.17	1.11	1.51	1.26	14
11	Albedo	1.34	1.91	1.24	1.20	12
12	Albedo	2.05	2.30	1.97	2.11	7
13	Albedo	1.47	1.54	1.41	1.47	4
14	Albedo	1.30	-	-	1.30	0
	Film	0	0	-	0	0
15	Albedo	4.47	4.75	3.83	4.35	11
16	Albedo	3.41	4.05	3.91	3.79	9
17	Combination ^f	2.70	2.70	2.70	2.70	0
18	TLD	0.18	0.14	0.17	0.16	13
19	Albedo	2.40	2.40	2.40	2.40	0
20	Albedo	2.23	-	-	2.23	0
	Albedo	2.26	-	-	2.26	0
21	Albedo	1.33	1.11	1.46	1.30	14
22	Albedo	1.42	1.47	1.34	1.41	3
23	Albedo	1.20	1.09	1.22	1.17	6
24	Albedo	1.36	1.34	1.52	1.41	7
25	-	-	-	-	-	-
26	TLD	1.75	1.78	1.68	1.74	3
27	Albedo	0.88	0.94	0.90	0.91	3
28	CR-39	1.30	3.00	1.70	2.00	44
29	TLD	1.24	1.42	1.34	1.33	7
30	TLD	4.01	4.35	5.19	4.52	13
31	TLD	1.28	1.55	1.56	1.46	11
32	TLD	1.90	1.96	1.87	1.91	2
33	-	-	-	-	-	-
34	TLD	2.17	1.83	2.08	2.03	9
35	LR-115	2.70	-	-	2.70	89
36	Fission track	1.60	-	-	1.60	0
	Albedo	-	1.56	1.55	1.56	1
37	Albedo	1.56	1.58	1.30	1.48	14
38	-	-	-	-	-	-
39	TLD	1.00	1.05	1.27	1.11	13
40	Albedo	1.62	1.70	1.68	1.67	2
41	-	-	-	-	-	-
42	TLD	1.10	1.19	1.08	1.12	5
43	Albedo	1.35	1.51	1.62	1.49	9
44	CR-39	2.00	2.55	1.50	2.02	26

^a Participants designated by numbers to preserve anonymity.^b Background corrected values as reported by participants.^c Participants were permitted to submit three badges per exposure.^d Percent of the mean of one standard deviation of reported results.^e Reference values given in the ICRP 21 convention.^f TLD-albedo and CR-39 recoil track.

Table 6. Summary of reported neutron results - FDIS 12, run 3,
12-cm Lucite shield

Group ^a	Neutron dosimeter type	Neutron dose equivalent, mSv ^b				Percent standard deviation ^d
		1 ^c	2	3	Average	
DOSAR	Reference ^c	1.48				
1	Albedo	3.00	2.80	2.50	2.77	9
2	Albedo	1.34	1.31	1.30	1.32	2
3	Albedo	4.19	4.65	4.45	4.43	5
4	-	-	-	-	0	
5	-	-	-	-	0	
6	Albedo	1.56	1.58	1.55	1.56	1
7	Albedo	1.87	1.90	1.65	1.81	6
	Albedo	1.38	1.42	1.23	1.34	6
8	Albedo	1.06	1.49	1.70	1.42	11
9	TLD	2.88	2.94	2.98	2.93	1
10	Albedo	2.00	1.91	2.13	2.01	5
11	Albedo	1.43	1.55	1.55	1.51	4
12	Albedo	1.38	1.33	1.28	1.33	3
13	Albedo	1.21	1.28	1.27	1.25	3
14	Albedo	0.10	-	-	0.10	-
	Film	1.00	1.20	-	1.10	9
15	Albedo	4.03	2.53	2.91	3.16	25
16	Albedo	1.82	1.35	2.22	1.80	24
17	Combination ^f	2.00	2.40	1.80	2.07	15
18	TLD	0.36	0.39	0.39	0.38	5
19	Albedo	3.27	3.27	2.08	2.87	24
20	Albedo	2.00	-	-	2.00	0
	Albedo	1.89	-	-	1.89	0
21	Albedo	1.48	1.72	1.34	1.51	13
22	Albedo	1.47	1.43	1.40	1.43	2
23	Albedo	1.04	1.02	1.09	1.05	3
24	Albedo	3.59	3.71	3.87	3.72	4
25	-	-	-	-	-	-
26	TLD	1.75	1.70	1.74	1.73	2
27	Albedo	1.66	1.80	1.57	1.68	2
28	CR-39	1.80	2.20	2.40	2.13	14
29	TLD	1.77	1.63	1.79	1.73	5
30	TLD	5.76	5.96	5.65	5.79	2
31	TLD	1.29	1.37	1.34	1.33	3
32	TLD	5.60	5.86	5.58	5.68	3
33	-	-	-	-	-	-
34	TLD	2.26	1.52	1.80	1.86	20
35	LR-115	3.50	-	-	3.50	40
36	Fission track	1.00	-	-	1.00	0
	Albedo	-	1.55	1.49	1.52	3
37	Albedo	1.10	1.19	1.24	1.18	6
38	-	-	-	-	-	-
39	TLD	1.39	1.40	1.44	1.41	2
40	Albedo	2.18	2.11	2.22	2.17	3
41	-	-	-	-	-	-
42	TLD	1.55	1.45	1.55	1.52	4
43	Albedo	-	1.17	1.10	1.14	4
44	CR-39	1.30	1.75	1.60	1.55	15

^aParticipants designated by numbers to preserve anonymity.

^bBackground corrected values as reported by participants.

^cParticipants were permitted to submit three badges per exposure.

^dPercent of the mean of one standard deviation of reported results.

^eReference values given in the ICRP 21 convention.

^fTLD-albedo and CR-39 recoil track.

Table 7. Summary of reported neutron results - PDIS 12, run 4,
12-cm Lucite shield, gamma enhanced

Group ^a	Neutron dosimeter type	Neutron dose equivalent, mSv ^b				Percent standard deviation ^d
		1 ^c	2	3	Average	
DOSAR	Reference ^e	1.48				
1	Albedo	1.10	1.30	1.40	1.27	12
2	Albedo	1.33	1.36	1.30	1.33	2
3	Albedo	5.06	3.97	4.45	4.49	12
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	Albedo	1.72	1.61	1.64	1.66	3
7	Albedo	3.20	3.29	3.21	3.23	1
	Albedo	-	-	-	-	-
8	Albedo	1.01	1.84	2.63	1.83	36
9	TLD	3.19	3.17	2.51	2.96	11
10	Albedo	2.77	2.15	2.88	2.60	12
11	Albedo	1.41	1.32	1.40	1.38	3
12	Albedo	1.17	1.34	1.21	1.24	6
13	Albedo	1.35	1.42	1.24	1.34	6
14	Albedo	0.50	-	-	0.50	-
	Film	1.00	1.20	-	1.10	13
15	Albedo	4.03	2.78	3.12	3.31	15
16	Albedo	1.63	2.09	1.78	1.83	13
17	Combination ^f	2.00	3.30	2.90	2.73	24
18	TLD	0.41	0.39	0.60	0.47	25
19	Albedo	2.62	2.62	2.11	2.45	12
20	Albedo	1.62	-	-	1.62	0
	Albedo	2.13	-	-	2.13	0
21	Albedo	1.35	1.57	1.45	1.46	8
22	Albedo	1.15	0.95	0.97	1.02	11
23	Albedo	2.14	1.74	1.83	1.90	11
24	Albedo	5.10	4.69	4.35	4.71	8
25	-	-	-	-	-	-
26	TLD	1.38	1.38	1.56	1.44	7
27	Albedo	1.51	1.23	1.52	1.42	11
28	CR-39	2.40	2.90	2.70	2.67	9
29	TLD	0.98	1.03	0.93	0.98	5
30	TLD	5.55	5.88	5.37	5.60	5
31	TLD	1.40	1.73	1.21	1.44	18
32	TLD	7.60	7.95	7.70	7.55	4
33	-	-	-	-	-	-
34	TLD	0.58	1.31	1.58	1.16	45
35	LR-115	4.70	-	-	4.70	19
36	Fission Track	1.00	-	-	1.00	0
	Albedo	-	1.52	1.70	1.61	13
37	Albedo	0.88	1.18	1.64	1.23	31
38	-	-	-	-	-	-
39	TLD	1.41	1.24	1.08	1.24	13
40	Albedo	1.22	1.61	1.57	1.47	15
41	-	-	-	-	-	-
42	TLD	1.24	1.13	1.31	1.23	7
43	Albedo	1.11	1.20	1.32	1.21	9
44	CR-39	1.50	1.45	1.25	1.40	9

^aParticipants designated by numbers to preserve anonymity.

^bBackground corrected values as reported by participants.

^cParticipants were permitted to submit three badges per exposure.

^dPercent of the mean of one standard deviation of reported results.

^eReference values given in the ICRP 21 convention.

^fTLD-albedo and CR-39 recoil track.

Table 8. Summary of reported neutron results - PDIS 12, run 5,
5-cm steel/15-cm concrete/12-cm Lucite shields

Group ^a	Neutron dosimeter type	Neutron dose equivalent, mSv ^b				Percent standard deviation ^d
		1 ^c	2	3	Average	
DOSAR	Reference ^e	1.53				
1	Albedo	2.30	2.50	2.50	2.43	5
2	Albedo	1.70	1.77	1.75	1.74	2
3	Albedo	5.77	4.81	4.97	5.18	10
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	Albedo	1.81	1.67	1.41	1.63	10
7	Albedo	2.57	2.82	2.86	2.75	5
	Albedo	1.05	1.23	1.56	1.28	16
8	Albedo	3.36	3.14	-	3.25	3
9	TLD	2.87	2.83	2.76	2.82	2
10	Albedo	1.79	1.66	1.44	1.63	9
11	Albedo	1.71	1.25	1.47	1.48	13
12	Albedo	2.05	2.14	1.94	2.04	4
13	Albedo	1.99	1.97	2.09	2.02	3
14	Albedo	1.80	-	-	1.80	0
	Film	0.80	0.80	-	0.80	0
15	Albedo	3.42	4.23	3.62	3.76	5
16	Albedo	4.13	4.23	4.16	4.17	1
17	Combination ^f	1.10	0.90	0.90	0.97	6
18	TLD	0.47	0.47	0.45	0.46	3
19	Albedo	4.30	4.30	4.47	4.36	2
20	Albedo	-	-	-	-	-
	Albedo	-	-	-	-	-
21	Albedo	2.61	2.90	2.58	2.70	7
22	Albedo	2.50	2.60	2.46	2.52	3
23	Albedo	1.66	1.73	1.75	1.71	3
24	Albedo	2.23	2.21	2.27	2.24	1
25	-	-	-	-	-	-
26	TLD	2.28	2.24	2.40	2.31	4
27	Albedo	1.17	1.23	1.20	1.20	1
28	CR-39	1.60	2.00	-	1.80	16
29	TLD	2.24	2.43	2.62	2.43	7
30	TLD	6.74	7.23	6.91	6.96	4
31	TLD	2.59	2.39	2.44	2.47	4
32	TLD	2.96	3.21	3.11	3.09	4
33	-	-	-	-	-	-
34	TLD	2.09	2.11	1.86	2.02	7
35	LR-115	5.00	-	-	5.00	10
36	Fission Track	2.08	-	-	2.08	0
	Albedo	-	2.00	1.76	1.88	9
37	Albedo	1.41	1.30	1.67	1.46	13
38	-	-	-	-	-	-
39	TLD	1.48	1.56	1.47	1.50	3
40	Albedo	2.44	2.73	2.51	2.23	19
41	-	-	-	-	-	-
42	TLD	2.25	1.94	1.98	2.06	8
43	Albedo	1.66	1.62	1.73	1.67	3
44	CR-39	1.90	1.75	1.45	1.70	14

^aParticipants designated by numbers to preserve anonymity.

^bBackground corrected values as reported by participants.

^cParticipants were permitted to submit three badges per exposure.

^dPercent of the mean of one standard deviation of reported results.

^eReference values given in the ICRP 21 convention.

^fTLD-albedo and CR-39 recoil track.

Table 9. Summary of reported neutron results - FDIS 12, run 6.

PuBe source						
Group ^a	Neutron dosimeter type	Neutron dose equivalent, mSv ^b				Percent standard deviation ^d
		1 ^c	2	3	Average	
DOSAR	Reference ^e	1.47				
1	Albedo	1.40	1.50	1.00	1.30	20
2	Albedo	1.08	1.13	1.12	1.11	2
3	Albedo	0.55	0.55	0.52	0.54	3
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	Albedo	1.67	1.16	1.40	1.41	15
7	Albedo	1.98	1.88	1.99	1.92	2
	Albedo	2.90	-	0.62	1.17	107
8	Albedo	1.22	0.94	1.17	1.11	11
9	TLD	0.13	0.10	0.08	0.10	20
10	Albedo	1.61	1.75	1.56	1.64	5
11	Albedo	0.72	0.96	0.88	0.85	12
12	Albedo	3.05	2.61	2.57	2.74	8
13	Albedo	0.56	0.66	0.59	0.60	7
14	Albedo	0.40	-	-	0.40	-
	Film	2.50	2.70	-	2.60	5
15	Albedo	0.48	0.97	0.83	0.76	33
16	Albedo	0.78	0.73	0.86	0.73	14
17	Combination ^f	2.30	2.10	1.90	2.10	10
18	TLD	0.10	0.21	0.08	0.13	54
19	Albedo	2.77	2.77	1.08	2.21	41
20	Albedo	1.67	-	-	1.67	0
	Albedo	1.38	-	-	1.38	0
21	Albedo	0.56	0.54	0.56	0.55	2
22	Albedo	1.03	1.04	0.88	0.98	9
23	Albedo	2.25	2.25	2.42	2.31	4
24	Albedo	2.00	2.17	2.42	2.20	10
25	-	-	-	-	-	-
26	TLD	3.30	3.81	3.39	3.50	8
27	Albedo	1.55	1.58	1.64	1.59	3
28	CR-39	0.90	0.60	-	0.75	28
29	TLD	0.98	1.16	1.17	1.10	10
30	TLD	2.70	2.73	2.43	2.62	6
31	TLD	1.45	1.31	1.20	1.32	9
32	TLD	3.64	3.27	3.82	3.58	8
33	-	-	-	-	-	-
34	TLD	0.40	0.38	0.43	0.40	6
35	LR-115	10.00	-	-	10.00	50
36	Fission Track	1.40	-	-	1.40	0
	Albedo	-	1.92	1.65	1.79	11
37	Albedo	1.33	0.91	1.01	1.08	20
38	-	-	-	-	-	-
39	TLD	0.61	1.57	1.24	1.14	43
40	Albedo	1.94	2.08	1.31	1.78	23
41	-	-	-	-	-	-
42	TLD	1.31	1.60	1.31	1.41	12
43	Albedo	2.55	2.59	2.69	2.61	3
44	CR-39	1.35	1.15	1.55	1.35	15

^aParticipants designated by numbers to preserve anonymity.^bBackground corrected values as reported by participants.^cParticipants were permitted to submit three badges per exposure.^dPercent of the mean of one standard deviation of reported results.^eReference values given in the ICRP 21 convention.^fTLD-albedo and CR-39 recoil track.

Table 10. Analysis of reported neutron results for all dosimeter types

Run	Radiation source	N ^a	<u>Normalized dose equivalent^b</u>		<u>Standard deviation^c</u>	
			Range	Mean $\pm$ σ^d	Range	Mean
1	HPRR - Unshielded	113	0.04-2.87	1.18 $\pm$ 0.57	1.5-40.7	9.83
2	HPRR - Steel	113	0.00-2.88	1.13 $\pm$ 0.57	0.0-88.0	11.62
3	HPRR - Lucite	114	0.07-3.91	1.36 $\pm$ 0.80	0.8-24.7	8.04
4	HPRR - Lucite (gamma enhanced)	111	0.32-5.24	1.42 $\pm$ 1.00	1.2-44.6	12.60
5	HPRR - Steel/Concrete/Lucite	110	0.30-4.55	1.56 $\pm$ 0.84	0.0-19.4	6.43
6	PuBe - Unmoderated	112	0.07-6.80	1.21 $\pm$ 1.06	2.2-50.0	17.10

^aNumber of reported results.

^bMeasured divided by reference values (ICRP convention).

^cPercent of the mean of one standard deviation about the mean of results reported for each organization.

^dMean of normalized results $\pm$ one standard deviation about the mean.

Table 11. Analysis of reported neutron results for TLD-albedo dosimeters

Run	Radiation source	N ^a	Normalized dose equivalent ^b		Standard deviation ^c	
			Range	Mean $\pm \sigma$ ^d	Range	Mean
1	HPRR - Unshielded	70	0.52-2.87	1.15 $\pm$ 0.44	2.6-25.6	7.24
2	HPRR - Steel	71	0.58-2.77	1.16 $\pm$ 0.50	0.0-28.0	9.22
3	HPRR - Lucite	70	0.07-3.00	1.27 $\pm$ 0.61	0.8-24.7	7.23
4	HPRR - Lucite (gamma enhanced)	68	0.34-3.18	1.30 $\pm$ 0.69	2.3-36.0	11.37
5	HPRR - Steel/Concrete/Lucite	68	0.78-3.39	1.56 $\pm$ 0.69	0.5-19.4	6.60
6	PuBe - Unmoderated	71	0.27-1.86	0.95 $\pm$ 0.45	2.2-10.7	8.91

^aNumber of reported results.

^bMeasured divided by reference values (ICRP convention).

^cPercent of the mean of one standard deviation about the mean of results reported for each organization.

^dMean of normalized results $\pm$ one standard deviation about the mean.

Table 12. Analysis of reported neutron results for direct interaction TL dosimeters

Run	Radiation source	N ^a	Normalized dose equivalent ^b		Standard deviation ^c	
			Range	Mean $\pm \sigma^d$	Range	Mean
1	HPRR - Unshielded	30	0.09-2.76	1.07 $\pm$ 0.79	5.6-40.7	13.47
2	HPRR - Steel	30	0.10-2.88	1.05 $\pm$ 0.79	2.4-13.3	6.39
3	HPRR - Lucite	30	0.26-3.91	1.72 $\pm$ 1.30	1.4-20.0	4.71
4	HPRR - Lucite (gamma enhanced)	30	0.32-5.24	1.73 $\pm$ 1.68	3.9-44.6	14.72
5	HPRR - Steel/Concrete/Lucite	30	0.30-4.55	1.75 $\pm$ 1.17	1.6- 6.9	4.09
6	PuBe - Unmoderated	30	0.07-2.72	1.41 $\pm$ 0.94	6.3-53.8	18.22

^aNumber of reported results.

^bMeasured divided by reference values (ICRP convention).

^cPercent of the mean of one standard deviation about the mean of results reported for each organization.

^dMean of normalized results $\pm$ one standard deviation about the mean.

Table 13. Analysis of reported neutron results for CR-39 recoil track dosimeters

Run	Radiation source	N ^a	Normalized dose equivalent ^b		Standard deviation ^c	
			Range	Mean $\pm \sigma$ ^d	Range	Mean
1	HPRR - Unshielded	6	1.22-1.60	1.41 $\pm$ 0.27	8-14	11
2	HPRR - Steel	6	1.27-1.29	1.28 $\pm$ 0.01	26-44	35
3	HPRR - Lucite	6	1.05-1.44	1.25 $\pm$ 0.28	14-15	15
4	HPRR - Lucite (gamma enhanced)	6	0.95-1.80	1.38 $\pm$ 0.60	9-9	9
5	HPRR - Steel/Concrete/Lucite	5	1.11-1.18	1.15 $\pm$ 0.05	14-16	15
6	PuBe - Unmoderated	5	0.51-0.92	0.72 $\pm$ 0.29	3-15	9

^aNumber of reported results.

^bMeasured divided by reference values (ICRP convention).

^cPercent of the mean of one standard deviation about the mean of results reported for each organization.

^dMean of normalized results $\pm$ one standard deviation about the mean.

Table 14. Analysis of reported neutron results for LR-115 (B_4C converter) dosimeters

Run	Radiation source	N ^a	Normalized dose equivalent ^b	Standard deviation ^c
1	HPRR - Unshielded	1	2.94	40
2	HPRR - Steel	1	1.72	89
3	HPRR - Lucite	1	2.36	40
4	HPRR - Lucite (gamma enhanced)	1	3.18	19
5	HPRR - Steel/Concrete/Lucite	1	3.27	10
6	PuBe - Unmoderated	1	6.80	50

^aNumber of reported results. Only average values and associated standard deviations reported by this agency.

^bMeasured divided by reference values (ICRP convention).

^cPercent of the mean of one standard deviation about the mean of results.

Table 15. Analysis of reported neutron results for NTA film dosimeters

Run	Radiation source	N ^a	Normalized dose equivalent ^b		Standard deviation ^c
			Range	Mean $\pm \sigma$	
1	HPRR - Unshielded	3	0.82-0.94	0.88 $\pm$ 0.08	9.4
2	HPRR - Steel	2	0	0	0.0
3	HPRR - Lucite	2	0.81-0.83	0.82 $\pm$ 0.01	9.1
4	HPRR - Lucite (gamma enhanced)	2	0.68-0.81	0.75 $\pm$ 0.09	12.9
5	HPRR - Steel/Concrete/Lucite	2	0.52-0.52	0.52 $\pm$ 0.00	0.0
6	PuBe - Unmoderated	2	1.70-1.84	1.77 $\pm$ 0.99	5.4

^a Number of reported results for one organization.

^b Measured divided by reference values (ICRP convention).

^c Percent of the mean of one standard deviation about the mean of results reported for this organization.

^d Mean of normalized results $\pm$ one standard deviation about the mean.

Table 16. Analysis of reported neutron results for fission track
(Nakrofol plus ^{232}Th converter) dosimeters.

Run	Radiation source	N ^a	Normalized dose equivalent ^b
1	HPRR - Unshielded	1	1.09
2	HPRR - Steel	1	1.02
3	HPRR - Lucite	1	0.68
4	HPRR - Lucite (gamma enhanced)	1	0.68
5	HPRR - Steel/Concrete/Lucite	1	1.36
6	PuBe - Unshielded	1	0.95

^aNumber of reported results. Only one result reported by one organization.

^bMeasured divided by reference values (ICRP convention).

Table 17. Analysis of reported neutron results for combination albedo-track dosimeters.

Run	Radiation source	N ^a	Normalized dose equivalent ^b		Standard deviation ^c
			Range	Mean $\pm$ s ^d	
1	HPRR - Unshielded	3	1.06-1.18	1.10 $\pm$ 0.07	6.2
2	HPRR - Steel	3	1.72-1.72	1.72 $\pm$ 0.00	0
3	HPRR - Lucite	3	1.22-1.62	1.40 $\pm$ 0.20	14.8
4	HPRR - Lucite (gamma enhanced)	3	1.35-2.23	1.85 $\pm$ 0.43	24.4
5	HPRR - Steel/Concrete/ Lucite	3	0.59-0.72	0.63 $\pm$ 0.08	6.0
6	PuBe - Unmoderated	3	1.29-1.56	1.43 $\pm$ 0.14	9.5

^aNumber of reported results. Dosimeter type used by only one organization.

^bMeasured divided by reference values (ICRP convention).

^cAverage percent of the mean of one standard deviation about the mean of results reported for this organization.

^dMean of normalized results $\pm$ one standard deviation about the mean.

Table 18. Summary of reported gamma results - FDIS 12, run 1, unshielded

Group ^a	Gamma dosimeter type	Gamma dose equivalent, mSv ^b			
		1 ^c	2	3	Average
DOSAR	Reference	0.09			
1	TLD-700	0	0	0	0
2	TLD-CaSO ₄	0.09	0.08	0.09	0.09
3	TLD-700 ⁴	0.43	0.34	0.31	0.36
4	TLD-700	0.10	0.10	0.10	0.10
5	TLD-CaSO ₄	0.14	0.16	0.16	0.15
6	TLD-700 ⁴	-	-	0.07	0.07
7	TLD-CaSO ₄	0.08	0.07	0.08	0.08
	TLD-CaSO ₄	0.07	0.11	0.08	0.09
8	TLD-CaSO ₄	0.05	0.05	0.05	0.05
9	TLD-CaSO ₄	0.07	0.10	0.09	0.09
10	TLD-700 ⁴	0.08	0.10	0.08	0.09
11	TLD-700	0.08	0.08	0.08	0.08
12	TLD-700	0.10	0.10	0.10	0.10
13	TLD-CaSO ₄	0.10	0.11	0.10	0.10
14	TLD-700 ⁴	-	-	0	0
	Film	0.20	0.20	-	0.20
15	TLD-700	0.09	0.10	0.10	0.10
16	TLD-700	0.08	0.08	0.08	0.08
17	Film	0	0	0	0
18	TLD-CaSO ₄	0.06	0.07	0.07	0.07
19	TLD-700 ⁴	0.04	0.04	0.04	0.04
20	TLD-700	-	-	0.12	0.12
	TLD-700	-	-	0.11	0.11
21	TLD-700	0.08	0.03	0.04	0.05
22	TLD-CaSO ₄	0.06	0.07	0.07	0.07
23	TLD-700 ⁴	0.18	0.18	0.15	0.17
24	TLD-CaSO ₄	0.08	0.07	0.09	0.08
25	Film	0.05	0.05	0.10	0.07
26	TLD-CaSO ₄	0.09	0.09	0.08	0.09
27	TLD-700 ⁴	0.07	0.06	0.06	0.06
28	TLD-100	0.70	0.80	0.80	0.77
29	TLD-CaSO ₄	0.07	0.11	0.08	0.09
30	TLD-100	0.15	0.16	0.17	0.16
31	TLD-CaSO ₄	0	0	0	0
32	TLD-CaSO ₄	0.07	0.08	0.07	0.07
33	Film	0	0	0	0
34	TLD-700	0.11	0.09	0.10	0.10
35	-	-	-	-	-
36	-	-	-	-	-
37	TLD-CaSO ₄	0.10	0.10	0.08	0.09
38	TLD-CaSO ₄	0.11	0.11	0.10	0.11
39	TLD-CaSO ₄	0.05	0.07	0.07	0.06
40	TLD-CaSO ₄	0.13	0.11	0.07	0.10
41	Film	0	0	0	0
42	TLD-CaSO ₄	0.08	0.09	0.07	0.08
43	TLD-CaSO ₄	0.09	0.10	0.09	0.09
44	-	-	-	-	-

^a Participants designated by numbers to preserve anonymity.^b Background-corrected values as reported by participants.^c Participants were permitted to submit three badges per exposure.

Table 19. Summary of reported gamma results - FDIS 12, run 2, steel shield

Group ^a	Gamma dosimeter type	Gamma dose equivalent, mSv ^b			
		1 ^c	2	3	Average
DOSAR	Reference	0.04			
1	TLD-700	0	0	0	0
2	TLD-CaSO ₄	0.04	0.04	0.04	0.04
3	TLD-700 ⁴	0.24	0.22	0.17	0.21
4	TLD-700	0	0	0.10	0.03
5	TLD-CaSO ₄	0.11	0	0	0.04
6	TLD-700 ⁴	0.23	0.26	0.38	0.29
7	TLD-CaSO ₄	0.03	0.03	0.03	0.03
	TLD-CaSO ₄	0.05	0.04	0.03	0.04
8	TLD-CaSO ₄	0	0.05	0	0.02
9	TLD-CaSO ₄	0.04	0.05	0.02	0.04
10	TLD-700 ⁴	0.03	0	0.02	0.02
11	TLD-700	0.05	0.05	0.05	0.05
12	TLD-700	0	0.15	0.10	0.08
13	TLD-CaSO ₄	0.03	0.04	0.03	0.03
14	TLD-700 ⁴	-	-	0	0
	Film	0.10	0.10	-	0.10
15	TLD-700	0.05	0.05	0.04	0.05
16	TLD-700	0.04	0.04	0.05	0.04
17	Film	0	0	0	0
18	TLD-CaSO ₄	0.03	0.03	0.03	0.03
19	TLD-700 ⁴	0.10	0.10	0.10	0.10
20	TLD-700	-	-	0.05	0.05
	TLD-700	-	-	0.03	0.03
21	TLD-700	0	0.01	0.07	0.03
22	TLD-CaSO ₄	0.03	0.03	0.03	0.03
23	TLD-700 ⁴	0.16	0.13	0.12	0.14
24	TLD-CaSO ₄	0.05	0.10	0.05	0.07
25	Film	0.05	0	0	0.02
26	TLD-CaSO ₄	0.03	0.04	0.03	0.3
27	TLD-700 ⁴	0.02	0.02	0.03	0.02
28	TLD-100	0.90	0.90	0.90	0.90
29	TLD-CaSO ₄	0.04	0.03	0.05	0.04
30	TLD-100 ⁴	0.11	0.10	0.06	0.09
31	TLD-CaSO ₄	0	0	0	0
32	TLD-CaSO ₄	0.04	0.04	0.04	0.04
33	Film	0	0	0	0
34	TLD-700	0.04	0.04	0.03	0.04
35	-	-	-	-	-
36	-	-	-	-	-
37	TLD-CaSO ₄	0.04	0.04	0.05	0.04
38	TLD-CaSO ₄	0.06	0.06	0.06	0.06
39	TLD-CaSO ₄	0.03	0.02	0.02	0.02
40	TLD-CaSO ₄	0.09	0.05	0.05	0.06
41	Film	0	0	0	0
42	TLD-CaSO ₄	0.05	0.04	0.04	0.04
43	TLD-CaSO ₄	0.05	0.11	0.06	0.07
44	-	-	-	-	-

^a Participants designated by numbers to preserve anonymity.^b Background-corrected values as reported by participants.^c Participants were permitted to submit three badges per exposure.

Table 20. Summary of reported gamma results - FDIS 12, run 3, 12-cm Lucite shield

Group ^a	Gamma dosimeter type	Gamma dose equivalent, mSv ^b			
		1 ^c	2	3	Average
DOSAR	Reference	0.22			
1	TLD-700	0.20	0.30	0.30	0.27
2	TLD-CaSO ₄	0.23	0.23	0.21	0.22
3	TLD-700 ⁴	0.42	0.39	0.35	0.39
4	TLD-700	0.20	0.20	0.20	0.20
5	TLD-CaSO ₄	0.41	0.42	0.39	0.41
6	TLD-700 ⁴	0.22	0.50	0.21	0.31
7	TLD-CaSO ₄	0.18	0.18	0.17	0.18
	TLD-CaSO ₄	0.21	0.10	0.20	0.20
8	TLD-CaSO ₄	0.30	0.30	0.35	0.32
9	TLD-CaSO ₄	0.19	0.21	0.19	0.20
10	TLD-700 ⁴	0.25	0.26	0.23	0.25
11	TLD-700	0.21	0.20	0.22	0.21
12	TLD-700	0.52	0.50	0.34	0.45
13	TLD-CaSO ₄	0.20	0.20	0.20	0.20
14	TLD-700 ⁴	-	-	0.10	0.10
	Film	0.30	0.30	-	0.30
15	TLD-700	0.24	0.30	0.21	0.25
16	TLD-700	0.27	0.23	0.25	0.25
17	Film	0.30	0.20	0.20	0.23
18	TLD-CaSO ₄	0.17	0.19	0.18	0.18
19	TLD-700 ⁴	0.23	0.23	0.23	0.23
20	TLD-700	-	-	0.21	0.21
	TLD-700	-	-	0.22	0.22
21	TLD-700	0.16	0.17	0.15	0.16
22	TLD-CaSO ₄	0.17	0.16	0.15	0.15
23	TLD-700 ⁴	0.39	0.42	0.38	0.39
24	TLD-CaSO ₄	0.26	0.24	0.23	0.24
25	Film	0.25	0.25	0.25	0.25
26	TLD-CaSO ₄	0.21	0.24	0.18	0.21
27	TLD-700 ⁴	0.18	0.20	0.18	0.19
28	TLD-100	4.00	3.70	3.80	3.83
29	TLD-CaSO ₄	0.20	0.17	0.20	0.30
30	TLD-100 ⁴	0.12	0.45	0.52	0.36
31	TLD-CaSO ₄	0.17	0.17	0.17	0.17
32	TLD-CaSO ₄	0.17	0.16	0.17	0.17
33	Film	0.78	0.78	0.78	0.78
34	TLD-700	0.21	0.20	0.20	0.21
35	-	-	-	-	-
36	-	-	-	-	-
37	TLD-CaSO ₄	0.21	0.23	0.22	0.22
38	TLD-CaSO ₄	0.28	0.23	0.22	0.24
39	TLD-CaSO ₄	0.15	0.15	0.15	0.15
40	TLD-CaSO ₄	0.35	0.34	0.29	0.33
41	Film	0	0	-	0
42	TLD-CaSO ₄	0.19	0.20	0.20	0.20
43	TLD-CaSO ₄	-	0.28	0.19	0.24
44	-	-	-	-	-

^aParticipants designated by numbers to preserve anonymity.^bBackground-corrected values as reported by participants.^cParticipants were permitted to submit three badges per exposure.

Table 21. Summary of reported gamma results - FDIS 12, run 4,
Lucite shield, ^{137}Cs gamma enhanced

Group ^a	Gamma dosimeter	Gamma dose equivalent, μSv ^b			
		1 ^c	2	3	Average
DOSAR	Reference				
1	TLD-700	5.37			
2	TLD- CaSO_4	5.70	5.00	5.60	5.43
3	TLD-700 ⁴	5.30	5.10	5.07	5.16
4	TLD-700	5.43	5.97	5.66	5.69
5	TLD-700	6.00	5.70	6.00	5.90
6	TLD- CaSO_4	6.89	5.66	6.97	6.51
7	TLD-700 ⁴	4.70	4.76	4.33	4.60
	TLD- CaSO_4	4.84	4.85	4.73	4.81
	TLD- CaSO_4	5.11	5.04	4.81	4.99
8	TLD- CaSO_4	4.65	4.45	4.95	4.68
9	TLD- CaSO_4	4.92	4.85	5.61	5.13
10	TLD-700 ⁴	7.67	7.00	7.68	7.45
11	TLD-700	5.34	5.55	4.98	5.29
12	TLD-700	3.85	4.35	4.20	4.13
13	TLD- CaSO_4	6.43	6.42	6.34	6.40
14	TLD-700 ⁴	-	-	4.80	4.80
	Film	4.80	5.00	-	4.90
15	TLD-700	5.67	6.31	5.06	5.68
16	TLD-700	4.88	5.33	4.51	4.91
17	Film	4.60	4.60	4.60	4.60
18	TLD- CaSO_4	4.25	4.50	4.47	4.41
19	TLD-700 ⁴	5.50	5.50	5.50	5.50
20	TLD-700	-	-	9.86	9.86
	TLD-700	-	-	5.63	5.63
21	TLD-700	4.63	4.68	4.65	4.65
22	TLD- CaSO_4	4.48	4.72	4.68	4.63
23	TLD-700 ⁴	4.57	4.77	5.07	4.80
24	TLD- CaSO_4	4.87	5.20	5.02	5.03
25	Film	5.50	5.20	5.40	5.37
26	TLD- CaSO_4	5.90	5.74	5.60	5.75
27	TLD-700 ⁴	5.04	5.44	5.09	5.19
28	TLD-100	7.80	8.20	7.80	7.93
29	TLD- CaSO_4	5.42	6.46	5.88	5.92
30	TLD-100 ⁴	4.96	4.24	4.01	4.40
31	TLD- CaSO_4	5.34	5.61	5.24	5.39
32	TLD- CaSO_4	5.42	5.19	5.69	5.43
33	Film	0	0	0	0
34	TLD-700	6.61	6.50	6.31	6.47
35	-	-	-	-	-
36	-	-	-	-	-
37	TLD- CaSO_4	5.08	4.58	5.34	5.00
38	TLD- CaSO_4	4.37	4.30	3.97	4.21
39	TLD- CaSO_4	4.19	4.74	4.21	4.38
40	TLD- CaSO_4	4.87	4.99	5.44	5.10
41	Film	4.70	4.70	4.70	4.70
42	TLD- CaSO_4	5.43	5.66	5.74	5.61
43	TLD- CaSO_4	4.90	5.43	5.35	5.23

^aParticipants designated by numbers to preserve anonymity.

^bBackground-corrected values as reported by participants.

^cParticipants were permitted to submit three badges per exposure.

Table 22. Summary of reported gamma results - PDIS 12, run 5, steel/concrete/Lucite shield

Group ^a	Gamma dosimeter type	Gamma dose equivalent, mSv ^b			
		1 ^c	2	3	Average
DOSAR	Reference	0.30			
1	TLD-700	0.40	0.30	0.20	0.30
2	TLD-CaSO ₄	0.26	0.26	0.26	0.26
3	TLD-700 ⁴	0.33	0.33	0.29	0.32
4	TLD-700	0.20	0.20	0.20	0.20
5	TLD-CaSO ₄	0.40	0.50	0.45	0.45
6	TLD-700 ⁴	0.16	0.35	0.42	0.31
7	TLD-CaSO ₄	0.21	0.20	0.20	0.20
	TLD-CaSO ₄	0.23	0.25	0.23	0.24
8	TLD-CaSO ₄	0.25	0.30	0.30	0.28
9	TLD-CaSO ₄	0.23	0.23	0.22	0.23
10	TLD-700 ⁴	0.30	0.30	0.43	0.34
11	TLD-700	0.25	0.24	0.23	0.24
12	TLD-700	0.10	0	0.10	0.07
13	TLD-CaSO ₄	0.26	0.26	0.26	0.26
14	TLD-700 ⁴	-	-	-	0.20
	Film	0.40	0.30	-	0.35
15	TLD-700	0.29	0.29	0.29	0.29
16	TLD-700	0.31	0.29	0.28	0.29
17	Film	0.40	0.30	0.20	0.30
18	TLD-CaSO ₄	0.22	0.22	0.22	0.22
19	TLD-700 ⁴	0.26	0.26	0.26	0.26
20	TLD-700	-	-	-	-
	TLD-700	-	-	-	-
21	TLD-700	0.17	0.17	0.17	0.17
22	TLD-CaSO ₄	0.20	0.22	0.20	0.21
23	TLD-700 ⁴	0.49	0.47	0.46	0.47
24	TLD-CaSO ₄	0.27	0.24	0.25	0.25
25	Film	0.35	0.30	0.35	0.33
26	TLD-CaSO ₄	0.24	0.23	0.23	0.23
27	TLD-700 ⁴	0.24	0.25	0.26	0.25
28	TLD-100	3.80	3.80	-	3.80
29	TLD-CaSO ₄	0.23	0.25	0.23	0.24
30	TLD-100 ⁴	0.48	0.43	0.62	0.51
31	TLD-CaSO ₄	0.20	0.22	0.21	0.21
32	TLD-CaSO ₄	0.19	0.19	0.20	0.19
33	Film ⁴	0.00	0.00	0.00	0.00
34	TLD-700	0.25	0.24	0.24	0.24
35	-	-	-	-	-
36	-	-	-	-	-
37	TLD-CaSO ₄	0.25	0.24	0.24	0.24
38	TLD-CaSO ₄	0.30	0.27	0.25	0.27
39	TLD-CaSO ₄	0.19	0.17	0.17	0.18
40	TLD-CaSO ₄	0.41	0.43	0.46	0.43
41	Film	-	-	-	-
42	TLD-CaSO ₄	0.24	0.25	0.24	0.24
43	TLD-CaSO ₄	0.24	0.28	0.24	0.25
44	-	-	-	-	-

^aParticipants designated by numbers to preserve anonymity.

^bBackground-corrected values as reported by participants.

^cParticipants were permitted to submit three badges per exposure.

Table 23. Summary of reported gamma results - FDIS 12, run 6. PuBe source

Group ^a	Gamma dosimeter type	Gamma dose equivalent, μSv ^b			
		1 ^c	2	3	Average
DOSAR	Reference	0.08			
1	TLD-700	0	0	0.10	0.03
2	TLD-CaSO ₄	0.08	0.08	0.08	0.08
3	TLD-700	0.07	0.10	0.07	0.08
4	TLD-700	0.10	0.10	0.20	0.13
5	TLD-CaSO ₄	0	0	0	0
6	TLD-700	0.63	0.36	0.17	0.39
7	TLD-CaSO ₄	0.08	0.10	0.10	0.09
	TLD-CaSO ₄	0.08	0.08	0.09	0.08
8	TLD-CaSO ₄	0	0.10	0.15	0.08
9	TLD-CaSO ₄	0.11	0.13	0.12	0.12
10	TLD-700	0.07	0.06	0.06	0.06
11	TLD-700	0.08	0.09	0.09	0.09
12	TLD-700	0.10	0	0.10	0.07
13	TLD-CaSO ₄	0.13	0.12	0.12	0.12
14	TLD-700	-	-	0	0
	Film	0	0.20	-	0.10
15	TLD-700	0.08	0.07	0.08	0.08
16	TLD-700	0.07	0.07	0.08	0.07
17	Film	0	0	0	0
18	TLD-CaSO ₄	0.08	0.08	0.09	0.08
19	TLD-700	0.17	0.17	0.17	0.17
20	TLD-700	-	-	0.12	0.12
	TLD-700	-	-	0.08	0.08
21	TLD-700	0.02	0.01	0.01	0.01
22	TLD-CaSO ₄	0.08	0.08	0.08	0.08
23	TLD-700	0.05	0.06	0.07	0.06
24	TLD-CaSO ₄	0.06	0.06	0.05	0.06
25	Film	0	0.05	0.10	0.05
26	TLD-CaSO ₄	0.10	0.09	0.10	0.10
27	TLD-700	0.05	0.05	0.05	0.05
28	TLD-100	0.30	0.40	-	0.35
29	TLD-CaSO ₄	0.10	0.10	0.13	0.11
30	TLD-100	0.08	0.07	0.07	0.07
31	TLD-CaSO ₄	0.10	0	0.11	0.07
32	TLD-CaSO ₄	0.09	0.09	0.10	0.09
33	Film	0	0	0	0
34	TLD-700	0.05	0.06	0.06	0.06
35	-	-	-	-	-
36	-	-	-	-	-
37	TLD-CaSO ₄	0.06	0.07	0.08	0.07
38	TLD-CaSO ₄	0.11	0.15	0.09	0.12
39	TLD-CaSO ₄	0.09	0.10	0.12	0.10
40	TLD-CaSO ₄	0.07	0.08	0.08	0.08
41	Film	0	0	0	0
42	TLD-CaSO ₄	0.08	0.08	0.09	0.08
43	TLD-CaSO ₄	0.10	0.11	0.16	0.12

^a Participants designated by numbers to preserve anonymity.^b Background-corrected values as reported by participants.^c Participants were permitted to submit three badges per exposure.

Table 24. Analysis of reported gamma results for all dosimeter types.

Run	Radiation source	Reference d.e., mSy ^a	N ^b	N>0 ^c	Normalized dose equivalents ^d	
					Range	Mean $\pm$ SD
1	HPRR - Unshielded	0.09	123	107	0-8.56	1.12 $\pm$ 1.34
2	HPRR - Steel	0.04	125	97	0-22.50	1.74 $\pm$ 3.47
3	HPRR - Lucite	0.22	123	121	0-18.20	1.44 $\pm$ 1.71
4	HPRR - Lucite (gamma enhanced)	5.37	125	123	0-1.84	0.98 $\pm$ 0.25
5	HPRR - Steel/Concrete/ Lucite	0.30	119	116	0-12.70	1.17 $\pm$ 1.87
6	PuBe - Unmoderated	0.08	123	103	0-4.88	1.10 $\pm$ 0.92

^aReference gamma dose equivalent from Table 3.

^bNumber of reported results.

^cNumber of reported results greater than 0 or the minimum detectable value.

^dMeasured divided by reference values.

^eMean of normalized results $\pm$ one standard deviation about the mean.

Table 23. Analysis of reported gamma results for all TL dosimeters

Run	Radiation source	Reference d.e., mSv ^a	N ^b	N>0 ^c	Normalized dose equivalents ^d	
					Range	Mean $\pm$ σ
1	HPRR - Unshielded	0.09	109	102	0-8.56	1.19 $\pm$ 1.37
2	HPRR - Steel	0.04	111	94	0-22.50	1.88 $\pm$ 3.65
3	HPRR - Lucite	0.22	110	110	0.45-18.2	1.50 $\pm$ 2.64
4	HPRR - Lucite (gamma enhanced)	5.37	111	111	0.77-1.48	1.01 $\pm$ 0.20
5	HPRR - Steel/Concrete/Lucite	0.30	108	108	0.23-12.7	1.20 $\pm$ 1.96
6	PuBe - Unmoderated	0.08	109	100	0-4.88	1.19 $\pm$ 0.92

^aReference gamma dose equivalent from Table 3.

^bNumber of reported results.

^cNumber of reported results greater than 0 or the minimum detectable value.

^dMeasured divided by reference values.

^eMean of normalized results $\pm$ one standard deviation about the mean.

Table 26. Analysis of reported gamma results for TLD-700 dosimeters

Run	Radiation source	Reference d.e., mSv ^a	N ^b	N>0 ^c	Normalized dose equivalents ^d	
					Range	Mean $\pm$ σ
1	HPRR - Unshielded	0.09	43	39	0-4.00	0.99 $\pm$ 0.97
2	HPRR - Steel	0.04	45	35	0-7.25	1.75 $\pm$ 2.06
3	HPRR - Lucite	0.22	45	45	0.45-2.05	1.14 $\pm$ 0.40
4	HPRR - Lucite (gamma enhanced)	5.37	45	45	0.77-1.84	1.06 $\pm$ 0.27
5	HPRR - Steel/Concrete/Lucite	0.30	43	43	0.23-1.50	0.83 $\pm$ 0.26
6	PuBe - Unmoderated	0.08	44	40	0-4.88	1.24 $\pm$ 1.19

^aReference gamma dose equivalent from Table 3.

^bNumber of reported results.

^cNumber of reported results greater than 0 or the minimum detectable value

^dMeasured divided by reference values.

^eMean of normalized results $\pm$ one standard deviation about the mean.

Table 27. Analysis of reported gamma results for CaSO_4 dosimeters^{*}

Run	Radiation source	Reference d.e., mSv ^a	N ^b	N>0 ^c	Normalized dose equivalents ^d	
					Range	Mean $\pm \sigma$
1	HPRR - Unshielded	0.09	60	57	0.0-1.67	0.92 $\pm$ 0.30
2	HPRR - Steel	0.04	60	53	0.50-1.50	0.96 $\pm$ 0.44
3	HPRR - Lucite	0.22	59	59	0.68-1.86	1.01 $\pm$ 0.20
4	HPRR - Lucite (gamma enhanced)	5.37	60	60	0.78-1.21	0.97 $\pm$ 0.10
5	HPRR - Steel/Concrete/Lucite	0.30	60	60	0.60-1.50	0.84 $\pm$ 0.19
6	PuBe - Unmoderated	0.08	60	55	0.0-1.50	1.08 $\pm$ 0.25

^aReference gamma dose equivalent from Table 3

^bNumber of reported results.

^cNumber of reported results greater than 0 or the minimum detectable value.

^dMeasured divided by reference values.

^eMean of normalized results $\pm$ one standard deviation about the mean.

^{*}Includes CaSO_4 alone or in combination with another phosphor such as $\text{Li}_2\text{B}_4\text{O}_7$.

Table 28. Analysis of reported gamma results for TLD-100 dosimeters

Run	Radiation source	Reference d.e., mSv ^a	N ^b	N>0 ^c	Normalized dose equivalents ^d	
					Range	Mean $\pm$ σ
1	HPRR - Unshielded	0.09	6	6	1.67-8.9	5.15 $\pm$ 1.93
2	HPRR - Steel	0.04	6	6	1.5-22.5	12.38 $\pm$ 4.25
3	HPRR - Lucite	0.22	6	6	0.5-18.2	9.53 $\pm$ 7.21
4	HPRR - Lucite (gamma enhanced)	5.37	6	6	0.7-1.5	1.15 $\pm$ 0.47
5	HPRR - Steel/Concrete/Lucite	0.30	5	5	1.4-12.7	6.09 $\pm$ 5.14
6	PuBe - Unmoderated	0.08	5	5	0.9-5.0	2.30 $\pm$ 1.62

^aReference gamma dose equivalent from Table 3.

^bNumber of reported results.

^cNumber of reported results greater than 0 or the minimum detectable value.

^dMeasured divided by reference values.

^eMean of normalized results $\pm$ one standard deviation about the mean.

Table 29. Analysis of reported gamma results for film dosimeters

Run	Radiation source	Reference d.e., mSv ^a	N ^b	N>0 ^c	Normalized dose equivalents ^d	
					Range	Mean $\pm \sigma$
1	HPRR - Unshielded	0.09	14	5	0-2.22	0.60 $\pm$ 0.97
2	HPRR - Steel	0.04	14	3	0-2.50	0.60 $\pm$ 1.08
3	HPRR - Lucite	0.22	13	11	0-3.50	1.53 $\pm$ 1.55
4	HPRR - Lucite (gamma enhanced)	5.37	13	12	0-0.91	0.75 $\pm$ 0.43
5	HPRR - Steel/Concrete/Lucite	0.30	11	8	0-1.17	0.82 $\pm$ 0.55
6	PuBe - Unmoderated	0.08	14	3	0-1.25	0.38 $\pm$ 0.56

^aReference gamma dose equivalent from Table 3.

^bNumber of reported results.

^cNumber of reported results greater than 0 or the minimum detectable value.

^dMeasured divided by reference values.

^eMean of normalized results $\pm$ one standard deviation about the mean.

Table 30. Percent of reported neutron and gamma results within $\pm 50\%$ of reference values

Run	Radiation source	Percent of results within $\pm 50\%$ of reference values ^a					
		Neutron dosimeters			Gamma dosimeters		
		All ^b	Albedo	TLD	All ^b	TLD	Film
1	HPRR - Unshielded	78	85	60	56	52	7
2	HPRR - Steel	77	87	70	73	80	22
3	HPRR - Lucite	71	77	60	80	83	77
4	HPRR - Lucite (gamma enhanced)	71	72	60	96	98	80
5	HPRR - Steel/Concrete/Lucite	58	65	30	87	89	73
6	PuBe ₃ - Unmoderated	60	66	47	69	78	15
Total		69	75	55	77	82	46

^aPercent of results reported for each dosimeter type and irradiation.

^bComposite results for all dosimeter types.

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