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PERSONNEL-DOSIMETRY INTERCOMPARISON STUDIES AT THE OAK RIDGE NATIONAL LABORATORY*

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ABSTRACT

Since 1974, seven annual personnel dosimetry intercomparison studies have been conducted at the Oak Ridge National Laboratory using the Health Physics Research Reactor. These studies have produced more than 2,000 measurements by 72 participating organizations of neutron and gamma dose equivalents between 0.1-15.0 mSv in six mixed radiation fields. The relative performance of three basic types of personnel neutron dosimeters (nuclear emulsion film, thermoluminescent, and track-etch) and two basic types of gamma dosimeters (film and thermoluminescent) was assessed based on experimental results obtained during the seven intercomparisons.

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1. INTRODUCTION

Seven annual personnel dosimetry intercomparison studies (PDIS)[1,2] have been conducted at the Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research (DOSAR) Facility since 1974. During these studies, personnel dosimeters were mailed to the DOSAR Facility, exposed to a range of low-level (0.1-2.8 mSv gamma and 1.0-15.0 mSv neutron) mixed-field dose equivalents using the Health Physics Research Reactor (HPRR)[3] as the radiation source, and then returned to the participants for evaluation. Reported dose equivalents are compared among participating agencies and with reference values provided by the DOSAR staff. A total of 72 organizations — including vendors, laboratories, universities, nuclear facilities, and hospitals — have participated in these studies which afford an opportunity for agencies to evaluate the performance of their personnel dosimetry systems in a variety of known mixed-field conditions. This paper summarizes neutron and gamma personnel dosimeter performance characteristics based on experimental data obtained during the seven intercomparison studies.

2. DOSIMETER PERFORMANCE CHARACTERISTICS

2.1 DOSIMETER TYPES

Participants in the personnel dosimetry intercomparison studies generally used one of three basic types of neutron dosimeters [nuclear emulsion film, thermoluminescent (TLD and TLD-albedo), and track-etch] and one of two basic types of gamma dosimeters (film and TLD). The most popular types of dosimeters used by participants are TLD-albedo for neutron measurements and TLD-700 (^{7}LiF) for gamma measurements. During the most recent intercomparison,[2] about 60% of the participating organizations used TLD (24%) or TLD-albedo (36%) systems, about 18% used track-etch, about 15% used film, and the remainder generally used some combination of these basic types for neutron monitoring. Trends indicate increasing use of track dosimeters, decreasing use of film, and relatively constant use of TLD systems. About 70% of the participants in the latest PDIS used TLD systems (primarily TLD-700) to measure gamma doses with the remainder using film. No trend regarding increasing or decreasing use of film or TLD gamma dosimeters is evident.

2.2 NEUTRON DOSIMETER PERFORMANCE

To combine results from the seven intercomparison studies, average measured doses and associated standard deviations from the mean for each dosimeter type were divided by reference values and weighted by the number of measurements in each study. Table 1 shows measured normalized dose equivalents and percent standard deviations averaged over the seven PDIS for each basic neutron dosimeter type and for each shield used in these

Table 1. Average normalized dose equivalents and percent standard deviations for the basic neutron dosimeter types used in the personnel dosimetry intercomparison studies

Shield	Neutron spectrum median energy	Neutron dosimeter type			
		Film	TLD[a]	TLD-albedo	Track
None	0.78 MeV	0.41 (61)[b]	0.75 (26)	0.91 (35)	0.82 (45)
13-cm steel	0.34 MeV	0.77 (50)	--	1.41 (36)	0.97 (11)
Steel/concrete	6.9 keV	0.15 (88)	--	1.42 (67)	0.75 (30)
20-cm concrete	3.3 keV	0.18 (89)	1.47 (78)	1.51 (45)	0.60 (44)
12-cm Lucite	68 eV	0.65 (69)	2.35 (90)	1.54 (63)	0.87 (34)
Lucite/concrete	10 eV	0.28 (36)	3.42 (87)	1.94 (38)	0.70 (44)

[a]Includes data from the Seventh PDIS only.

[b]Results presented as neutron dose equivalent divided by reference value (percent standard deviation from the mean) averaged over all seven intercomparison studies.

studies. The normalized dose equivalents provide a measure of accuracy of the reported results relative to the reference values which are based on the number of fissions per exposure.[4] Average percent standard deviations from the mean indicate measurement precision which reflects agreement among reported results. Data for TLD monitors is available only for the Seventh PDIS because results for this dosimeter type were combined with TLD-albedo results for earlier intercomparisons. Conclusions derived from these data will not be affected since about 80% of the TLD-based measurements made in the first six intercomparisons were performed with albedo dosimeters and the qualitative performance of these dosimeter types is similar for spectra encountered in the PDIS.[1]

Table 1 shows that film measurements of neutron dose equivalents were significantly lower than reference values for all spectra considered in these studies. Means of the reported film results were less than 77% of the reference doses in all cases with some individual measurements indicating zero dose. These low results can be partly attributed to the insensitivity of film to neutrons having energies below about 0.5 MeV and the low sensitivity of film to neutrons with energies between 0.5 and 1.2 MeV. Film can also have a fading problem which results in low measured dose values if it is not packaged carefully and read promptly after exposure. Table 1 also shows that film measurements were generally the least precise of any of the basic dosimeter types.

The TLD and TLD-albedo dosimeters yield similar qualitative performance characteristics for the various neutron spectra. For both types of dosimeters, the ratio of measured-to-reference dose equivalents increases monotonically as the neutron spectra become softer (i.e., the median energies decrease). This behavior is due to the high sensitivity

of TLD-based dosimeters to low energy neutrons. Albedo dosimeters were generally more accurate than TLD monitors for the spectra shown in Table 1. Least accurate results were obtained for the softest neutron energy spectrum (Lucite-concrete shield) which produced average dose equivalents that were 3.42 and 1.94 times greater than reference values using TLD and TLC-albedo dosimeters, respectively.

Average measurement accuracies exhibited by track-etch dosimeters were within 0.60 to 0.97 times the reference values for all spectra encountered in the PDIS. Table 1 also shows much less variation in normalized dose as a function of spectral median energy for track-etch dosimeters compared to TLD systems. By applying a constant correction factor to track-measured dose equivalents, average measured results between 0.73 and 1.18 times reference values could be obtained for the listed spectra. In general, measurements made with track-etch dosimeters were the most precise of any of the basic dosimeter types.

2.3 GAMMA DOSIMETER PERFORMANCE

Table 2 shows measured dose equivalents normalized to the TLD-measured values and associated standard deviations from the mean for TLD and film dosimeters averaged over the seven PDIS. The TLD-measured results were used for normalization because intercomparison results have shown very little spectral variation in dose equivalents measured using these systems[2] and reference gamma doses based on the number of fissions per exposure are difficult to obtain due to the potentially significant contribution of residual gamma rays to the total dose. Also, in the

Table 2. Average normalized dose equivalents and percent standard deviations for the basic gamma dosimeter types used in the personnel dosimetry intercomparison studies

Shield	Neutron-to-gamma dose ratio[a]	Gamma dosimeter type	
		TLD	Film
None	6.2	1.00 (56)[b]	1.31 (59)
13-cm steel	7.8	1.00 (57)	1.00 (43)
Steel/concrete	2.4	1.00 (57)	0.94 (33)
20-cm concrete	2.7	1.00 (50)	1.32 (39)
12-cm Lucite	1.2	1.00 (47)	1.41 (30)
Lucite/concrete	0.6	1.00 (18)	1.46 (29)

[a]Dose ratio measured behind shield at 3 m from the reactor.

[b]Results presented as gamma dose equivalent divided by TLD-measured value (percent standard deviation from the mean) averaged over all seven intercomparison studies.

most recent PDIS, TLD-based monitors yielded average results which were between 0.84 and 1.16 times reference doses measured using Geiger-Mueller tubes mounted on the phantoms. These TLD-measured results were much more accurate than those obtained using film dosimeters.[2]

The presence of neutrons in the radiation fields considered in the PDIS results in potentially large errors in measurements of gamma dose equivalent. For instance, Table 2 shows that, on the average, film dosimeters can yield dose equivalents as much as 1.46 times those measured using TLD systems. This can be attributed to the sensitivity of most radiation monitoring films to neutrons. Also, results of individual measurements using TLD-100 (92.5% ^{7}LiF and 7.5% ^{6}LiF) monitors, which are extremely sensitive to neutrons, indicate that this dosimeter type can yield gamma doses which are more than a factor of 100 higher than reference values unless adequate correction factors can be applied.[1]

3. CONCLUSIONS

Results of the seven personnel dosimetry intercomparison studies considered in this paper indicate that significant inaccuracies can occur in neutron and gamma dose measurements in mixed radiation fields unless dosimeter performance and characteristics of the monitoring environment are considered in measured data evaluation. With regard to neutron monitoring, intercomparison results show that no single type of basic neutron dosimeter exhibits significantly better measurement accuracy than all other types for all radiation spectra encountered in these studies. Gamma dose measurements show that the selection of a basic dosimeter type which is relatively insensitive to neutrons is important with regard to measurement accuracy in mixed fields.

The accuracy of personnel dose measurements can significantly affect personnel safety and the implementation of ALARA (as-low-as-reasonably-achievable) radiation protection programs. Evaluation of individual reported results indicates that dose measurement accuracies for some participating agencies could be improved by using dosimeters more suited to the particular spectral characteristics encountered at specific facilities, by applying correction factors to account for dosimeter performance associated with anticipated radiation fields, by calibrating dosimeters with sources appropriate for the energy spectra to be measured, and by standardizing the basis of reported dose equivalents.

4. REFERENCES

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