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TWELVE YEARS OF NEUTRON PERSONNEL DOSIMETRY INTERCOMPARISON STUDIES AT OAK RIDGE NATIONAL LABORATORY: WHAT HAVE WE LEARNED?

Richard E. Swaja
Oak Ridge National Laboratory

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INTRODUCTION

To provide an opportunity for dosimetrists to test and calibrate their personnel neutron monitoring systems in a variety of incident radiation fields, the staff of the Dosimetry Applications Research (DOSAR) Facility at the Oak Ridge National Laboratory (ORNL) has conducted personnel dosimetry intercomparison studies (PDIS) periodically since 1974 and annually since 1976 (Si82, Sw87). During these studies, personnel dosimeters are mailed to ORNL, mounted on phantoms and exposed to low-level (less than 15 mSv) dose equivalents in mixed-radiation fields mainly produced using the Health Physics Research Reactor (HPRR) at ORNL (Au65), and then returned to the participants for evaluation. Reported dose equivalents are compared to reference values provided by the DOSAR staff and to results reported by individual organizations which made measurements under identical conditions. These intercomparisons, which require no fee and are open to any organization interested in external personnel dosimetry, have provided more data concerning neutron dosimeter performance characteristics in mixed-radiation fields than any other periodic open test program conducted to date. The following text presents a summary and analysis of neutron dose equivalent measurements reported for the Seventh through Twelfth intercomparisons (1981-1986) using the HPRR as the source of radiation. Particular factors examined include low dose equivalent sensitivity and measurement accuracy for the basic types of neutron personnel dosimeters.

INTERCOMPARISON DATA

A total of 116 different organizations (78 from the United States and 38 from other countries) has participated in the ORNL intercomparisons. These organizations include industrial and government laboratories (40%), nuclear utilities (20%), universities (14%), vendor services (13%), military and regulatory agencies (12%), and hospitals (1%). Participants submitted a total of 5750 personnel dosimetry badges - 4700 were exposed and 1050 were controls - for PDIS 7-12, and 3451 measured neutron dose equivalents were reported for HPRR-only irradiations. Most (about 85%) of the PDIS exposures have used the HPRR with and without spectrum-modifying shields as the source of radiation. About 90% of the HPRR irradiations have been conducted for four different shield conditions: unshielded (bare reactor) and the reactor shielded with 13-cm of steel, 20-cm of concrete, and 12-cm of Lucite. These fields range from a hard, almost U-235 fission neutron spectrum with relatively low thermal fluence and a small gamma component (unshielded HPRR) to a soft, hydrogen-moderated neutron spectrum with a high thermal fluence and

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strong gamma component (Lucite-shielded spectrum). The steel- and concrete-shielded spectra in that order are between the unshielded and Lucite-shielded HPRR spectra in terms of increasing thermal component. The analysis presented in the following text is based on data obtained for these four radiation fields since they provided the most measured results and should give the best indication of dosimeter performance.

Although few of the badge designs submitted by different organizations are the same, the basic neutron detection mechanisms can be classified into six categories: direct-interaction thermoluminescent (TLD), TLD-albedo, film, recoil track, fission track, and combination albedo plus recoil track. Direct-interaction TLD's differ from albedos in that direct systems are affected by all incident neutrons including thermals while albedo systems either discriminate against incident thermals by using a thermal neutron absorber or by measuring the incident thermal component separately. Recoil track dosimeters considered in this study consisted of allyl diglycol carbonate (CR-39) plastic and were electrochemically etched to enhance track sizes. Results presented in this report are for those CR-39 systems that were commercially available between 1981 and 1986 and do not include any data for recently developed dosimetry-grade CR-39 and improved etching techniques (Ha87).

LOW DOSE EQUIVALENT SENSITIVITY

To determine the sensitivity of the basic neutron personnel dosimetry systems at low dose equivalents, irradiations were conducted for the four primary HPRR spectra at neutron dose equivalents of about 0.5 mSv (50 mrem). Results of these studies showed that participants who used TLD-based systems had fewer problems obtaining measurable indication (results above zero or the minimum detectable) of neutron exposure than did those who used track-based systems. Only approximately 4% of all results for albedo systems were reported as zero or below minimum detectable for dose equivalents of about 0.5 mSv. Combination albedo-track and direct-interaction dosimeters exhibited slightly greater difficulty providing measurable indication of neutron exposure at this level with about 9% and 17%, respectively, of the results reported as zero. Track-based systems had much more difficulty providing indication of neutron exposure in that approximately 25% of all fission track results, 29% of all reported film results, and 47% of all CR-39 results were reported as zero or below minimum detectable. The next lowest neutron dose equivalent level considered in the ORNL intercomparisons was about 1.5 mSv (150 mrem) which is the lowest limit specified for neutron dosimetry accreditation testing (AN83). None of the basic dosimeter types exhibited any difficulty providing measurable indication of neutron exposure at dose equivalent levels above this value.

MEASUREMENT ACCURACY

The quantity of most concern to those involved in applied dosimetry or accreditation program testing is measurement accuracy. In this analysis, accuracy is indicated by the mean normalized dose equivalent which is the average of all measured-divided-by-reference dose equivalents for a particular incident spectrum reported for PDIS 7-12. Measurement accuracy for albedo, direct-interaction TLD, film, and recoil track neutron dosimeters as a function of the four most used HPRR spectra (unshielded, steel-shielded, concrete-shielded, and Lucite-shielded) are shown in the figure below for neutron dose equivalents above 1.5 mSv. The spectra shown on the horizontal axis are ordered such that the neutron energies get increasingly softer (e.g., higher thermal neutron component) going from left to right. Points shown in the figure are accuracy values and represent the average normalized results reported for PDIS 7-12 by all participants who used a particular dosimeter type. Fission track systems are not included in the figure since only a few measurements were reported for this dosimeter type. Combination albedo-track dosimeters are also not included because the variation in accuracy as a function of incident spectrum is almost identical with that observed for recoil track systems.

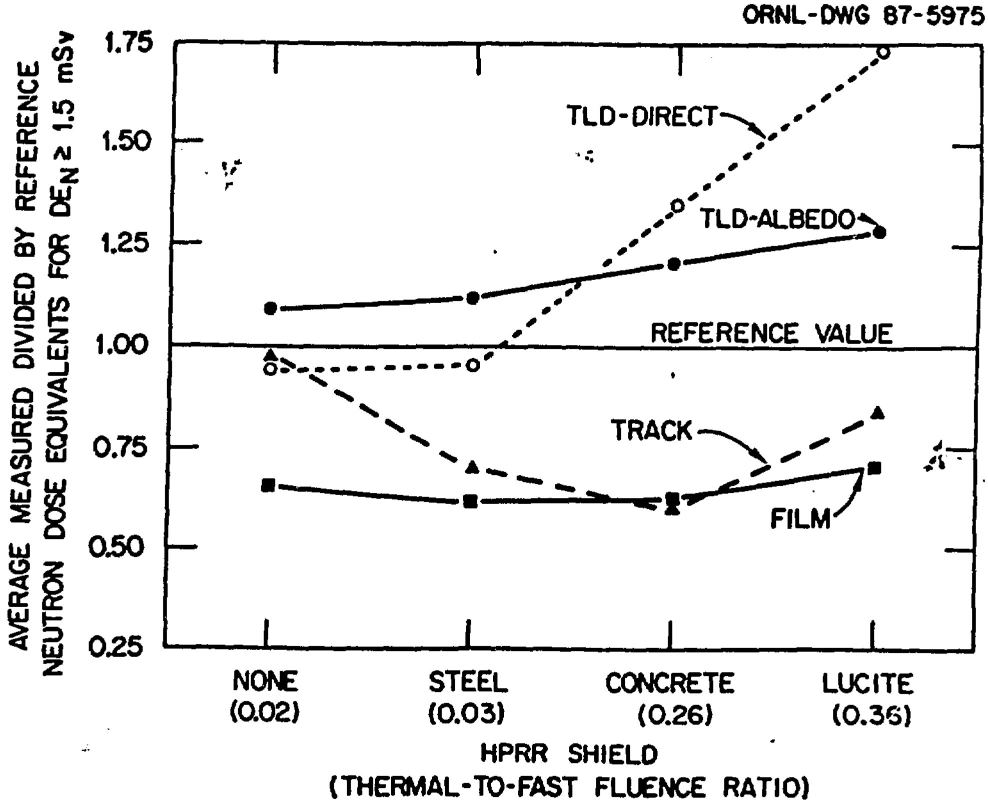

Figure 1. Neutron dosimeter accuracy as a function of incident spectrum for dose equivalents greater than 1.5 mSv.

The figure shows that direct-interaction TLD's, albedo systems, and recoil track dosimeters provide average results within about 10% of reference values for the hardest (unshielded) HPRR spectrum. Since most of these dosimeters were calibrated with hard energy spectra (e.g., unmoderated californium or PuBe), this performance is expected. As the spectra become softer, TLD-based systems tend to overestimate reference dose equivalents with direct-interaction systems overresponding more than albedos with increasing spectrum softness. Dosimeter types with threshold detection energies such as recoil track and film underestimate reference dose equivalents for moderated spectra by more than 20%. Film neutron dosimeters, which were generally calibrated in spectra much harder than the unshielded HPRR, also underestimate reference values for the unmoderated reactor spectrum. These observed variations are qualitatively the same as would be expected if the dosimeters were calibrated to hard energy spectra on the order of the unshielded HPRR and no corrections were made to dosimeter responses to account for energy response characteristics and differences between incident and calibration spectra. This suggests that many PDIS participants are not making corrections to dosimeter responses or that they are using inadequate corrections. Despite this inferred problem, average reported results for all basic dosimeter types shown in the figure are within 40% of reference values with the exception of the direct-interaction TLD data for the softest incident spectrum.

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