CONF-810850--1

PERFORMANCE OF NEUTRON AND GAMMA PERSONNEL DOSIMETRY IN MIXED RADIATION FIELDS*

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INTRODUCTION

Routine personnel monitoring at nuclear fuel cycle facilities requires that neutron and gamma exposures be measured in fields containing both types of radiation. Health physicists responsible for personnel monitoring must know the performance characteristics of their dosimetry systems in mixed radiation fields to ensure proper interpretation of measured data. From 1974 to 1980, six personnel dosimetry intercomparison studies[1] (PDIS) were conducted at the Oak Ridge National Laboratory (ORNL) to evaluate the performance of personnel dosimeters in a variety of neutron and gamma fields produced by operating the Health Physics Research Reactor[2] (HPRR) in the steady state mode with and without spectral modifying shields. A total of 58 different organizations participated in these studies which produced approximately 2000 measurements of neutron and gamma dose equivalents on anthropomorphic phantoms for five different reactor spectra. Based on these data, the relative performance of three basic types of neutron dosimeters [nuclear emulsion film, thermoluminescent (TLD), and track-etch] and two basic types of gamma dosimeters (film and TLD) in mixed radiation fields was assessed.

*For publication in the Proceedings of the 1981 Annual Meeting of the Australian Radiation Protection Society, Sydney, Australia, August 24-27, 1981.

†Operated by Union Carbide Corporation under contract W-7405-eng-26 with the U.S. Department of Energy.

During the PDIS, participants mail dosimeters to ORNL where they are mounted on trunk sections of water-filled polyethylene phantoms and exposed to a range of low-level neutron (1-12 mSv) and gamma (0.1 - 1.2 mSv) dose equivalents using the HPRR. Following these exposures, the irradiated dosimeters are returned to the participants for evaluation. When all measured results are assembled, participating organizations can evaluate the performance of their dosimetry systems relative to calculated reference values based on reactor operating parameters and relative to other agencies who made measurements under identical experimental conditions.

MEASURED DATA

The basic measurements made during the PDIS were neutron and gamma dose equivalents. Dose is equal to dose equivalent for gamma rays, but neutron dose equivalent differs from neutron dose and has to be determined using one or more methods such as applying an effective quality factor to the measured neutron dose, using dose-equivalent factors associated with detailed knowledge of the HPRR spectrum, or performing dose-equivalent calibration of dosimeters with sources such as ^{252}Cf and assuming that direct measurements are satisfactory. Participants were free to use whatever spectral data and/or quality factors they desired to determine neutron dose equivalent and generally did not report details of their methods.

More than 96% of all PDIS measurements were made with five basic dosimeter types. Dosimeters used for neutron measurements were:

(1) Thermoluminescent Albedo Dosimeter (TLD albedo) — The TLD albedo neutron dosimeter was the most commonly used type in

the PDIS measurements. The TLD albedo dosimeters detect, via the $^{6}Li(n,\alpha)^{3}H$ reaction in lithium fluoride, thermal neutrons reflected from the body on which the dosimeter is attached. Incident thermal neutrons are differentiated from the albedo neutrons by shielding the thermoluminescent material with cadmium or boron. Corrections for gamma exposure are made by subtracting the ^{7}LiF response (gamma only) from the ^{6}LiF response. It should be noted that not all TLD neutron dosimeters are albedo dosimeters. Some use the same basic detection mechanisms as the albedo units, but do not have the elaborate shields for spectral modification designed into the dosimeter package to achieve optimum response of the various components. More than 80% of the total reported TLD neutron measurements were made with TLD albedo dosimeters. Since the detection mechanisms are the same and since no trend of measurement differences between the two is evident, data for both systems (TLD and TLD albedo) are referred to as TLD albedo in this paper. The label "TLD albedo" distinguishes these neutron dosimeters from gamma dosimeters traditionally called TLD which are described below.

(2) Neutron Emulsion Film — Film is one of the oldest types of neutron dosimeters. Neutron elastic scattering reactions with hydrogen atoms in the nuclear emulsion result in recoil proton tracks being produced in the film. When the film is developed, these tracks are visible and are counted, usually manually, with the aid of an optical microscope. Measured neutron dose is proportional to the track density.

(3) Track Etch (Track) — Neutron-induced charged particles (alphas, protons) passing through insulators such as cellulose nitrate and polycarbonate cause damage tracks in the material. The charged particles can be produced by neutron interactions in the insulator itself or in an adjacent irradiator foil. Etching of the insulator material enhances track dimensions to where they can be counted by various automated techniques or by personnel when viewed through an ordinary microscope or microfiche reader. The track density yields a quantitative estimate of the neutron dose.

Dosimeters used for gamma measurements were:

(1) Film — Gamma rays result in the darkening of photographic film. The degree of darkening is measured in terms of transmission of light and is proportional to the dose. In addition to the difference in methods of registering the dose (darkening as opposed to tracks), film used for gamma monitoring differs from that used in neutron monitoring in that gamma film emulsions are about 0.3 as thick and contain silver halide crystals about five times as large as those used for neutron monitoring.

(2) Thermoluminescent Dosimeter (TLD) — Irradiation of TLD material causes the removal of electrons from their normal positions. These electrons are trapped and form metastable centers in the material. Upon heating, the electrons return to their normal positions and, in the process, emit light proportional to the dose received by the material.

REFERENCE DOSIMETRY

Reference neutron dose equivalent values were calculated for all PDIS exposures in a uniform manner and provide a reference to which the measured data may be compared. These reference values represent the neutron dose equivalent to volume element number 57 of the cylindrical anthropomorphic phantom described by Auxier, Snyder, and Jones. Neutron dose equivalent conversion factors were derived for each shielding configuration used in the PDIS by determining the neutron dose equivalent per unit fluence due to protons and recoils as a function of energy and combining this with calculated neutron energy spectra for the HPRR.[4] Reference neutron dose equivalent values for each exposure were determined using the conversion factors along with the number of fissions during each PDIS exposure as determined by HPRR instrumentation.

Reference gamma dose-equivalent values were not calculated because residual gamma rays from the HPRR can be a significant fraction of the gamma dose equivalent for these relatively low-level exposures. This component depends on the detailed operating history of the HPRR prior to the PDIS exposure which was not well known for all reactor runs.

NEUTRON DOSIMETER PERFORMANCE

During the six intercomparison studies, about 60% of the neutron measurements were made with TLD albedo dosimeters and about 20% each with film and track. Recent trends indicate decreasing use of film, increasing use of track and relatively constant use of TLD albedo dosimeters. A comparison of results obtained using these three types of