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DOSIMETER/SPECTROMETER

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DEVELOPMENT OF A PERSONNEL NEUTRON DOSIMETER/SPECTROMETER *

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Introduction

Of the single component personnel neutron dosimeters used today, only ^{237}Np fission track detectors have an energy response that adequately matches the ICRP dose equivalent conversion curve over the range of energies encountered in personnel monitoring (1,2). Albedo detectors are severely over-sensitive to low energy neutrons, while the threshold detectors -- NTA film, ^{232}Th track etch foils, electrochemically etched polycarbonate and CR-39 -- are insensitive to the low energies that comprise a significant fraction of the neutrons present in heavily shielded fission facilities, power reactors, etc. Moreover none of the personnel dosimeters, including neptunium, can provide spectral information.

Two component dosimeters have been used to improve dose equivalent response and provide some spectral information (3,4). These feature different types of detectors that have complementary energy response characteristics (albedo + a threshold detector). At the Lawrence Livermore Laboratory, we have a wide range of neutron spectra -- highly moderated reactor neutrons, spontaneous fission neutrons with little or no moderation, alpha-neutron sources, 14 MeV neutrons and even neutrons from a 100 MeV electron linear accelerator. Under these conditions (not unusual at research laboratories), even two component systems have important limitations.

Dosimeter/Spectrometer

These considerations have led us to development of a four component dosimeter/spectrometer-(DOSPEC) - an albedo detector (5) that contains samples of polycarbonate (6), carbonate (CR-39) (7), and cellulose nitrate (Kodak Pathe LR115) (8) track etch material. The polycarbonate samples are etched electrochemically, CR-39 is pre-etched in KOH before electrochemical etching, and the LR-115 is etched conventionally in a hot caustic bath. We count all of the track etch samples optically using a microscope or a microfiche reader. The electrochemical etching enlarges tracks in the polycarbonate and CR-39 samples so that they are very visible under low magnification. A red dye has been added to the thin cellulose nitrate layer of the LR-115. Tracks which penetrate the film are visible as pinholes, particularly when illuminated with contrasting blue or green light. The ^6LiF crystals used for albedo dosimetry are read using conventional TLD techniques.

The components of the DOSPEC were selected because they have significant differences in neutron energy response characteristics (Figure 1). The albedo detector is sensitive to the intermediate range below the 100 keV threshold of the CR-39. CR-39 registers recoil protons, thereby providing needed sensitivity in the range from 100 keV to the energy threshold of polycarbonate -- 1.5 MeV. Polycarbonate responds by detecting the heavier recoils -- carbon, nitrogen and oxygen in the plastic itself. LR-115 also registers heavy recoils, but the particle range required to make a penetration

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in the 12 μm sensitive layer results in a different energy response. We have arbitrarily chosen to break the energy range above 1.5 MeV into two bands - 1.5 to 6.0 MeV and 6.0 to 18 MeV.

Figure 1. Relative responses of DOSPEC components - CR-39, polycarbonate, Kodak LR115 track etch detectors and TLD albedo. (a. Sensitivity of CR-39 and polycarbonate is the sum of tracks on both sides of the sample.)

DOSPEC Evaluation

The use of DOSPEC requires that we first assign a response for each component detector to each energy bin. We have calculated the spectrum weighted or effective responses for the four components using the responses shown in Figure 1, and a number of neutron spectra from a computer library of measurements, calculations and published data. The means of these values are presented in Table 1. This table represents a matrix that can be used as input for one of the 4 x 4 matrix operation programs now available on programmable hand calculators.

Table 1. Mean Spectrum Weighted Responses of DOSPEC Components

	Energy Bands			
	Thermal to 0.1 MeV	0.1 to 1.5 MeV	1.5 to 6.0 MeV	6.0 to 17.9 MeV
Dose Equivalent Conversion - $10^{-9}\text{rem/n} \cdot \text{cm}^{-2}$	1.6	23.	40.	41.
Relative albedo Response ^a - 10^{-8}	1.07	0.48	0.24	0.13
CR39 ^b - 10^{-6} Tracks/Neutron		130.	330.	130.
Polycarbonate ^b - 10^{-6} tracks/neutron			4.6	5.4
LR115 - 10^{-6} tracks/neutron			1.0	4.4

a. equivalent gamma rad/neutron $\cdot \text{cm}^{-2}$
b. total on both surfaces.

We have now made measurements with the DOSPEC units by exposing them, in the front of water filled phantoms to previously measured neutron fields in our calibration facility⁽¹⁰⁾ - unmoderated ^{252}Cf , $^{238}\text{PuBe}$ and D,T neutrons, as well as ^{252}Cf neutrons moderated by spheres of aluminum, D_2O and H_2O . The DOSPEC measured spectral distributions from these exposures are shown in Table 2, together with reference values from multisphere spectrum measurements⁽¹⁰⁾. (We used activation foils to determine the 14 MeV spectra from the D,T generator.) The dose equivalent values for DOSPEC were calculated from the spectra in Table 2. The dose equivalent response of an albedo dosimeter (one component of DOSPEC) has been included for comparison.

Table 2. Results of DOSPEC Measurements of Calibration Facility Neutron Fields.

		Neutron Fluence $10^6 \cdot \text{cm}^{-2}$				D.E. Rem.
		2.5 $\cdot 10^{-8}$ to 0.1 MeV	0.1 to 1.5 MeV	1.5 to 6.0 MeV	6.0 to 18 MeV	
Bare ^{252}Cf	(a)	9.1	14.2	15.	1.8	1.00
	(b)	3.3	21.0	9.5	1.4	0.92
	(c)	Albedo Component				1.00
20cm Al(d)	(a)	18.	24.	8.7	0.81	1.00
	(b)	12.	25.	6.3	-0.20	0.83
	(c)	Albedo Component				1.61
25cm D_2O (d)	(a)	250.	9.0	9.3	2.0	1.00
	(b)	330.	13.	5.9	2.4	1.15
	(c)	Albedo Component				22.6
25cm H_2O (d)	(a)	51.	12.	14.	2.1	1.00
	(b)	78.	13.	11.	2.3	0.95
	(c)	Albedo Component				5.8
Bare $^{238}\text{PuBe}$	(a)	2.2	3.0	17.	4.7	1.00
	(b)	13.	-17.	20.	4.9	0.63
	(c)	Albedo Component				0.70
D-T Neutrons	(a)	0.0	0.0	4.4	14.	0.74
	(b)	6.5	-7.6	4.2	18.	0.73
	(c)	Albedo Component				0.40

a) Measured with multisphere spectrometer

b) Measured with DOSPEC

c) Determined from albedo dosimeter, normalized to bare ^{252}Cf

d) Radius and material of sphere used to moderate ^{252}Cf neutrons.

The data in Table 2 show some differences between the DOSPEC values and the measured spectra (including some negative values). However, the important fact is that DOSPEC does detect prominent spectral features of the neutron field: large, low-energy contributions - Cf in D_2O and H_2O ; shifts due to metal scattering - Cf in Al and unmoderated; significant high energy component - PuBe and 14 MeV. The DOSPEC provides important and otherwise unavailable data information for correctly assessing the dose equivalent (D.E.). The value of this information is demonstrated by a large reduction in the D.E. error when compared with the data from the albedo component alone.

It should be understood that, in practice, we do not process every component of every dosimeter issued to our workers. The polycarbonate and LR-115 are less sensitive than the albedo or CR-39 components. If the estimated dose as determined from the automated TLD albedo detector is less than 100 mrem, only the CR-39 will be read and DOSPEC evaluated using only the albedo and CR-39 components. Moreover, many people work in areas where not all four components are required. LR-115 represents the high energy component of the spectrometer, and probably has little value when neutrons above 10 MeV are not a problem. On the other hand, if there is a facility that generates significant levels of neutrons with energies above 20 MeV, the use of the LR-115 could be extended with the high energy radiator techniques adopted at CERN(11).

Summary

We are in the process of adding a few, inexpensive plastic track etch components (CR-39, Polycarbonate, LR-115) to our albedo dosimeters. This addition will significantly extend our personnel neutron measurement capability. The resulting assembly - DOSPEC - provides information necessary to infer a four energy group spectrum. This information should significantly reduce the expected error in personnel dose assessment, and help clarify the ambiguity that results when personnel must work in more than one neutron producing facility during the monitoring period.

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