ORNL/TM-6357

Dosimetry with the ORNL Badge, 1978

E. D. Gupton

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DOSIMETRY WITH THE ORNL BADGE, 1978

Introduction

Thermoluminescent dosimeters (TLD's) are used in the ORNL badge (Fig. 1) for dosimetry of beta, gamma, X ray and lower energy neutrons. The filter system, dosimeter complement and dosimetry calculations now used are described in this report.

Filter System

The front filters of the badge are window (W), plastic (P), aluminum (A) and cadmium (C), plus the inherent identification insert. The absorber thicknesses (mg/cm^2) for betas are W = 60, P = 160 and A = 430. The cadmium filter is 13x15x1 mm.

Dosimetric Complement

The TLD's (Harshaw ribbons, usually called chips) are supported in a polyethylene mount, 1 mm thick. One of three configurations of TLD's may be used according to the anticipated radiation exposure of the badge user, i.e., those who will sustain little or no dose from betas or neutrons, those who are likely to sustain significant doses from betas or neutrons, those who are likely to sustain significant doses from betas and/or photons, and those likely to sustain doses from neutrons.

The TLD's used are TLD-100 (0.125x0.125x0.035 in.), TLD-600 (0.125x0.125x0.035 in.), TLD-700 (0.10x0.15x0.035 in.) and TLD-700,

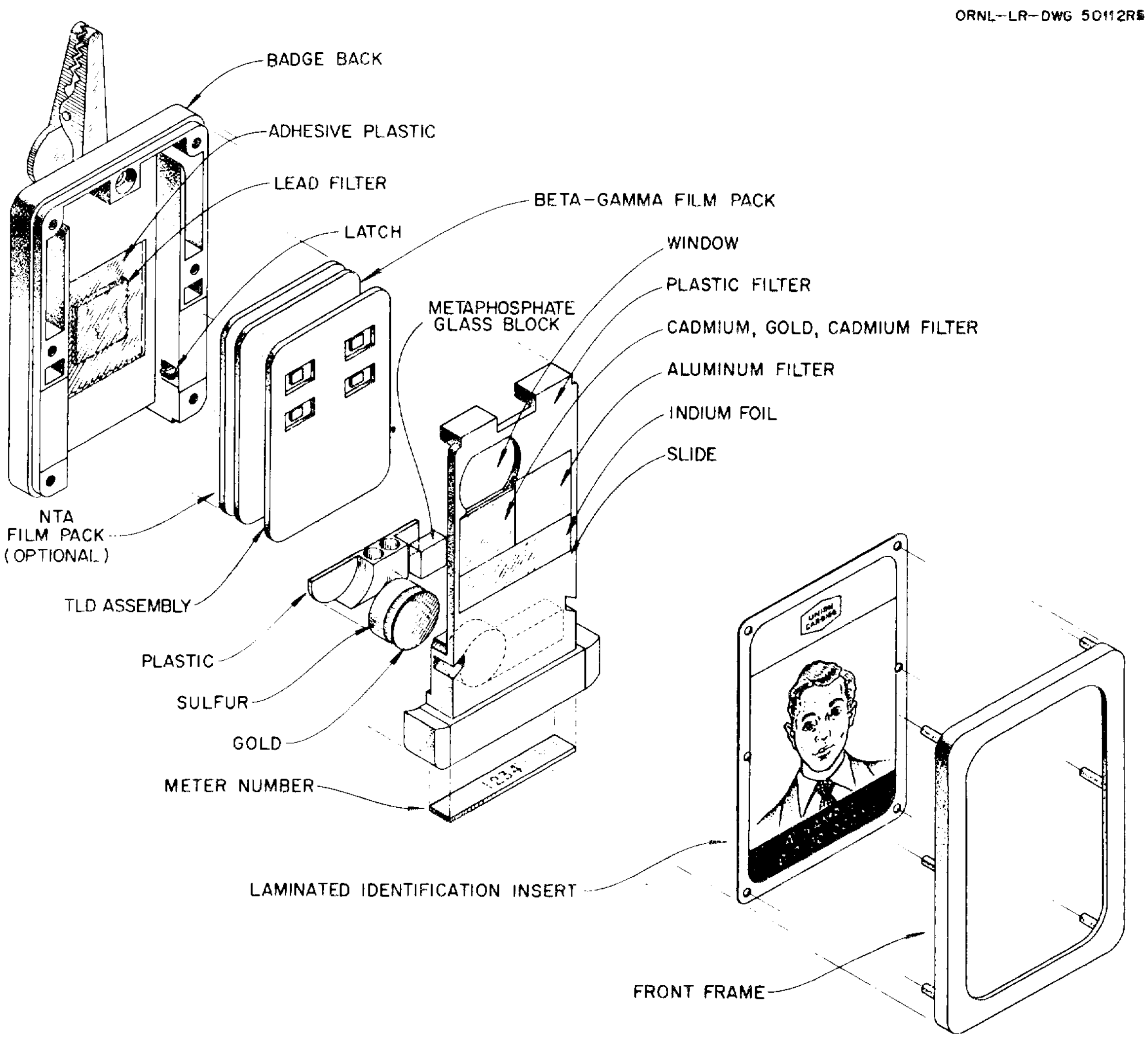

Fig. 1

ORNL Badge

thin, (0.125x0.125x0.015 in.). The TLD's used behind the filters for the three classes of users are tabulated below.

Class	W	P	A	C
1	700			100
2	700, thin	700, thin	100	
3	700, thin	700, thin	{700 600	{700 600

An Eastman Type 2 monitoring packet is installed with the TLD mount in all badges. A vapor-sealed, NTA Type A packet is installed in Class 3 badges.

Dosimetry Considerations

For Class 1 badge users it is assumed that the dose equivalent per calendar quarter will be less than the recommended maximum and that an inconsequential fraction of that dose will be from neutrons, betas or photons of energy below 30 keV. Thus, the dose to skin at 7 mg/cm^2 will not be significantly different from that at 175 mg/cm^2 - the mid-plane of the TLD-700 at the W filter.

The Classes 2 and 3 dosimeters have two thin TLD-700's, one at an absorber thickness of 107 mg/cm^2 and one at 207 mg/cm^2. The Class 2 dosimeter has a TLD-100 at a depth of 500 mg/cm^2. The readings of the two thin TLD's are used for extrapolating to a dose at 7 mg/cm^2 for skin dosimetry (q.v.). The TLD-100 in the Class 2 badge is for measuring whole body dose and for indicating neutron exposure.

The Class 3 dosimeter has, in addition to the two thin TLD's, two pairs of TLD-600 and -700 - one pair under each of the aluminum and cadmium filters. The data from these and the NTA film are used for neutron dosimetry (q.v.).

Dose Evaluation

General. The TLD's are read, calibration factors are applied and the gamma equivalent millirad doses are recorded. If there are seeming anomalies in the readings, the Type 2 film is processed. NTA films are processed and the track density is determined and recorded.

Photon Dosimetry. Unless there is indication otherwise, both TLD's in the Class 1 dosimeter, the TLD-100 in the Class 2 dosimeter and the TLD-700 under the aluminum filter in the Class 3 dosimeter are the bases for photon (>30 keV) dose. The dose determined from the TLD-700 in the Class 1 dosimeter is recorded as the superficial dose equivalent for the user and the doses from the other three TLD's are recorded as the whole body dose equivalents for the respective users.

Skin Dosimetry. The minimum dosimetric depth that is attainable with the badge and TLD is 107 mg/cm^2, the half-thickness of the TLD plus the laminated I.D. insert. As the dose to skin must be determined at a depth of 7 mg/cm^2, an artifice has been devised for estimating the skin dose by extrapolation from doses at greater depths.

Let the badge be a tissue equivalent medium into which radiation (X, β, γ) is incident parallel to a normal line 0, Z, with intermediate points X and Y, within the badge, where $0<X<Y<Z$. It is assumed that the radiation consists of two energy components; one that is attenuated

insignificantly and one that is attenuated significantly in traversing 0 to Z. Further, it is assumed that the attenuated component has the same effective attenuation coefficient (μ) over the ranges 0 to X and X to Y.

Let h represent the intensity of the "hard" component and s that of the "soft" component. Then

$$h_0 \sim h_X \sim h_Y \sim h_Z, \tag{1}$$

and

$$s_0 \sim s_X e^{\mu X} \sim s_Y e^{\mu Y}. \tag{2}$$

Within the medium the intensity of the radiation is directly proportional to the absorbed dose which, under the conditions assumed, is equal to the dose equivalent. Therefore, letting H and S represent absorbed dose from the hard and soft components and D represent dose equivalent,

$$H_0 \sim H_X \sim H_Y \sim H_Z, \tag{3}$$

$$S_0 \sim S_X e^{\mu X} \sim S_Y e^{\mu Y}, \tag{4}$$

$$D_Z = H_Z, \tag{5}$$

$$D_0 = H_0 + S_0 = H_Z + S_0 = D_Z + S_0, \tag{6}$$

$$D_X = H_X + S_X = H_Z + S_X = D_Z + S_X, \tag{7}$$

and

$$D_Y = H_Y + S_Y = H_Z + S_Y = D_Z + S_Y \tag{8}$$

If D_X, D_Y and D_Z are known, D_0 may be determined as follows:

$$S_0 = S_X e^{\mu X} = S_Y e^{\mu Y}, \quad (4)$$

$$S_X e^{\mu X} = S_Y e^{\mu Y}, \quad (9)$$

$$S_X = S_Y e^{\mu (Y-X)}, \quad (10)$$

$$\mu (Y-X) = \ln\ (S_X/S_Y), \quad (11)$$

and

$$\mu = \ln(S_X/S_Y)\ (Y-X)^{-1}. \quad (12)$$

Then,

$$S_0 = S_X e^{\ln(S_X/S_Y)\ (Y-X)^{-1}\ (X)}$$

$$= S_X \left(\frac{S_X}{S_Y}\right)^{X/(Y-X)} \quad (13)$$

If, as in the ORNL badge, Y is equal to 2X

$$S_0 = S_X \left(\frac{S_X}{S_Y}\right)^{X/(2X-X)}$$

$$= \frac{(S_X)^2}{S_Y} \quad (14)$$

Then,

$$D_0 = D_Z + \frac{(S_X)^2}{S_Y}\ , \qquad (15)$$

where

$$S_X = D_X - D_Z, \qquad (7)$$

$$S_Y = D_Y - D_Z, \qquad (8)$$

so that

$$D_0 = D_Z + \frac{(D_X - D_Z)^2}{D_Y - D_Z}\ .$$

With the ORNL badge, 0 is taken as 7 mg/cm^2, X is 107 mg/cm^2 and Y is 207 mg/cm^2. D_X is determined from the W TLD, D_Y from the P TLD and D_Z from the A TLD. The respective doses of these TLD's are recorded for W, P and A. The calculation for D_S, the superficial dose, is

$$D_S = A + \frac{(W-A)^2}{P-A}\ . \qquad (16)$$

D_S is recorded as calculated with (16) for cases in which the ratio of S_0 to W is not greater than 4 (μ<0.014 cm^2/mg). If the ratio of S_0 to W is greater than 4, then (a) μ for the radiation may be greater than 0.014 mg/cm^2 and the badge inadequate for skin dosimetry, or (b) the angle of incidence of the radiation may have been far from the normal and the relative readings of the TLD's not applicable for skin dose calculation, or (c) a TLD or its reading may have been faulty. If the ratio of S_0 to W is greater than 4 and W is greater than 100, the Type 2 film is processed to find which of these apply. If the data are insufficient for establishing the dose, an investigation of the exposure would be made.

Following is an example of the readings, calculation and doses for a Class 2 badge.

The readings of the TLD's, normalized to gamma equivalent millirads, are

$$W = 1000,$$

$$P = 750, \text{ and}$$

$$A = 500.$$

Then,

$$D_S = 500 + \frac{(1000-500)^2}{(750-500)}$$

$$= 500 + \frac{250000}{250}$$

$$= 1500.$$

The recorded doses are

Skin dose = 1500 mrem, and

Whole body dose = 500 mrem.

Neutron Dosimetry. The energies of neutrons in work areas at ORNL are in the range from thermal to a few MeV. There is no dosimeter small enough to be worn that can provide a linear response per unit dose equivalent over that range. Fission track detectors, NTA film or the TL response of ^{6}LiF may be used to estimate the dose; however, in each case it is necessary to know the neutron energy spectrum. Fission track detectors contain radioactive materials and the fission thresholds are high ($\sim$ 1.5 MeV for ^{232}Th and ^{238}U). NTA film has satisfactory response to neutrons of energy greater than 0.4 MeV; however, below 0.4 MeV there is little or no response. The TL response of TLD-600 as an albedo detector (its response is to thermal neutrons) is inversely proportional to the energy, varying from about 1 to about 200 per unit dose equivalent over the energy range 5 MeV to thermal.

For dosimetry purposes, four energy groups are treated separately: >0.5 MeV, 0.05 to 0.5 MeV, intermediate and thermal. This energy grouping corresponds to the energy ranges in which the dose equivalents per unit fluence are in the approximate ratios 30:5:1:1. The ORNL dosimeter, Class 3, has NTA film for measuring the dose equivalent for the highest energy group and TLD's for measuring the thermal neutron dose equivalent and for estimating the dose equivalent for the other two groups.

Neutron dose equivalent is calculated using the readings of the two pairs of TLD-600 and -700 and the NTA film. The empirical calculation is derived from data collected in work area measurements and concurrent exposure of badges on phantoms.

The basic calculation is

$$ND = NTA + NF + NI + NT, \quad (1)$$

where

ND = neutron dose equivalent,
NTA = dose determined with NTA film,
NF = dose from fast neutrons below NTA cutoff,
NI = dose from intermediate neutrons, and
NT = dose from thermal neutrons.

Let

C6 = gamma equivalent dose of Cd TLD-600,
C7 = that of Cd TLD-700,
A6 = that of Al TLD-600,
A7 = that of Al TLD-700,
T1 = C6-C7, the albedo response under the Cd filter,
T2 = A6-A7, the incident and albedo response under the Al filter, and
R1 = T1-NTA, the albedo response for intermediate and lower energy fast neutrons.

Then emperically:

$$NF = CF(T1/T2)R1, \qquad (2)$$

where the ratio T1/T2 is a function of the "hardness" of the spectrum;

$$NI = CI[T1-(NF+NTA)], \qquad (3)$$

where T1-(NF+NTA) is the albedo response for intermediate neutrons;

$$NT = CT(T2-T1), \qquad (4)$$

where T2-T1 is the response for incident thermal neutrons, and where CF, CI and CT are constants.

For preliminary estimates of dose, the constant values are CF = 0.1, CI = 0.035 and CT = 0.02.

Neutron dose equivalents, as calculated, are reviewed and either substantiated or modified by knowledgeable radiation survey staff prior to recording. The constant values are modified to suit special cases.

The skin dose is determined as for the Class 2 badge and the whole body photon dose is equal to the reading of the aluminum filtered TLD-700. Following is an example of the readings and calculations for neutron dose.

The NTA dose equivalent is 220 mrem and the TLD readings, normalized to gamma equivalent millirem, are:

C6 = 1320
A6 = 1750
C7 = 330
A7 = 300.

(The TLD-700 under the cadmium filter reads higher than than under the aluminum because of the n-γ reaction in cadmium.)

Then,

$$ND = NTA+NF+NI+NT, \text{ where} \tag{1}$$

$$NTA = 220 \text{ mrem},$$

$$NF = CF(T1/T2)R1 \tag{2}$$

$$= 0.1 \frac{(1320-330)}{(1750-300)} (1320-330-220)$$

$$= 53 \text{ mrem},$$

$$NI = CI[T1-(NF+NTA)] \tag{3}$$

$$= 0.035[990-(53+220)]$$

$$= 25 \text{ mrem}$$

$$NT = CT(T2-T1) \tag{4}$$

$$= 0.02\ (1450-990)$$

$$= 9 \text{ mrem, and}$$

$$ND = 220+53+25+9$$

$$= 307 \text{ mrem}.$$

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