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BETA-GAMMA MONITORING OF PERSONNEL WITH THERMOLUMINESCENT DOSIMETERS

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BETA-GAMMA MONITORING OF PERSONNEL WITH THERMOLUMINESCENT DOSIMETERS

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ABSTRACT

A thermoluminescent dosimeter using two ^{7}LiF chips was developed to monitor penetrating and nonpenetrating components of personnel radiation exposures. Thermoluminescent dosimeters are more accurate, are less energy dependent, have a wider range of sensitivity, and are simpler to use than film dosimeters. The present thermoluminescent dosimeter system at Savannah River is manually operated, but it can be automated.

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INTRODUCTION

Personnel monitoring using thermoluminescent dosimetry (TLD's) has been adopted[1-3] or is being seriously considered by many nuclear facilities as a replacement for film dosimetry. Effective April 1, 1970, TLD's replaced film as the primary means of measuring external radiation exposure to personnel at the Savannah River Plant. This change was based primarily on improvements in dosimetry accuracy due to the almost tissue equivalent response of TLD's regardless of photon energy.[4] Additional consideration was given to the use of TLD's because of their wide range of sensitivity, good reproducibility, repetitive useability, and suitability for possible future automation. The TLD system described in this paper is manually operated, and is designed around commercially available detectors and electronics. Approximately 4600 employees, 1600 of whom are on a quarterly cycle for evaluating exposure, are monitored by this TLD system. The remaining badges from personnel are read monthly.

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THE TLD BADGE

Description

The TLD badge (Figure 1) consists of a pressed fiberboard insert embedded with two ^{7}LiF chips, a folded paper (5.6 mg/cm^2), and a badge cover. The badge cover is the same as that used with film because the fiberboard and film packet are the same size. The folded paper holds the ^{7}LiF chips in the two 3/16-inch-diameter recesses in the fiberboard and protects the chips from sunlight and contamination. One TLD chip is in the center of an open window, and the other is behind an aluminum shield (460 mg/cm^2) on the badge cover. These positions give a means of differentiating between skin exposures and penetrating beta and gamma radiation.

Extruded ^{7}LiF chips (available from Harshaw Chemical Co.) are used in the badge because they are insensitive to neutrons. A separate dosimeter is used to measure neutron exposure.[5] The TLD chips are selected to be within ±10% of the batch mean for personnel monitoring.

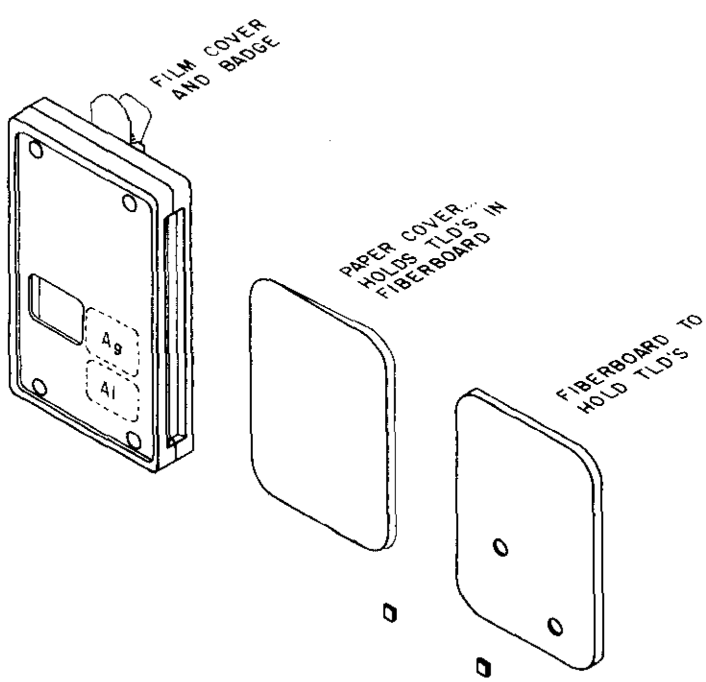


FIGURE 1. Thermoluminescent Dosimeter Badge

Annealing Procedure

The TLD chips are annealed before being inserted in the badge by heating at 425°C for 1 hour ±15 sec and then cooling reproducibly. Nickel pans containing a single layer of TLD chips are removed from the oven and placed over a screen frame, under which there is a fan circulating room air at a constant rate. The time between removal and complete cooling to room temperature is ∿2 minutes. If more than one pan of TLD chips is being annealed, they are sequentially loaded into the 425°C oven at two minute intervals. After cooling, the chips are annealed again at 100°C for 2 hours ±30 sec. The cooling following this 100°C anneal is not critical, and the pan containing the TLD chips is cooled to room temperature on a laboratory bench.

Many combinations of annealing temperatures and times may be used.[6] Some combinations enhance sensitivity,[7] some reduce fading,[8] and some recover the original sensitivity[9] after exposure to high doses. Whatever procedure is used, the chips must be annealed the same way each time and calibrated against a standard of approximately the same dose level as the exposure.

DETERMINING PERSONNEL EXPOSURE

Reading the Badge

The TLD chips are removed from the badge and the response is read with an Eberline TLR-5 reader. The reader has two ranges of sensitivity (each range having a span of 5 decades), an adjustable preheat cycle, an adjustable read cycle, and a built-in light source for checking the response of the instrument.

Reader settings are:

- Preheat Temperature, 125°C
- Preheat Time, 6 sec
- Read Temperature, 285°C
- Read Time, 12 sec
- Low Range Response, 1 count/mR (^{7}LiF chip exposed to 1 R radium gamma radiation)
- High Range Response, 1 count/R (^{7}LiF chip exposed to 100 R radium gamma radiation)
- Nitrogen Purge Rate, 2 ℓ/min
- Nominal Empty Pan Response, 1-5 counts/cycle (low range)

The response of the instrument to the light source is noted during calibration and is posted on the front of each reader. For short periods of time (up to several weeks), instrument drift can be corrected by adjusting the instrument response to the light source back to its posted value. The instrument is calibrated with each set of annealed TLD chips.

Because the TLD chips are removed from the badge, readout is rapid (a minimum mass to heat), and previous exposure history is completely removed by annealing at high temperatures. The badge and TLD chips need to be identified during readout only, and the TLD chips can be freely mixed after readout.

When the TLD chips are read, the preheat cycle (125°C for 6 sec) in the reader takes the place of annealing before reading. This preheat cycle removes low energy traps which cause fading in the TLD.

Calculating Results

^{7}LiF chips from each annealed batch are placed in badges and divided into two groups. One group of badges are exposed to various known levels of radium gamma from 50 mR to 1200 mR. The other group of badges are exposed to the emissions from a natural uranium slab.

To determine personnel exposure, the following equations are used:

$$E_P = R_{Al} \times F_{Ra} \; *$$

$$E_B = [R_{OW} - R_{Al}F_c] \; F_b$$

$$E_S = E_P + E_B$$

where

E_P = Penetrating exposure

R_{Al} = Reading from aluminum shield

F_{Ra} = Radium conversion factor (usually 1.0)

E_B = Beta exposure

R_{OW} = Open window reading

F_c = R_{OW}/R_{Al} ratio for radium exposure

F_b = Beta conversion factor from natural uranium

E_S = Total surface exposure

* For ^{7}LiF chips, $F_{Ra} \simeq 1$ because the reader is adjusted to give 1 count/mR.

CHARACTERISTICS OF THERMOLUMINESCENT DOSIMETERS

Beta Response

The beta response of the thermoluminescent dosimeter depends on beta energy, the amount of absorber in front of the dosimeter, and the self-absorption of the TLD chip itself. Skin dose from beta exposure depends on similar factors where absorbers are outer clothing and skin thickness at the point on the body where the dose is received. The dosimeter and skin response cannot be matched exactly due to differences in LiF and tissue structure and density; however, the method offers a good approximation for beta energies associated with fission products.

When the beta response is normalized to the surface dose rate from natural uranium, which consists of beta and gamma emitters, ~6% of the total exposure penetrates the aluminum shield. The response of other beta emitters relative to natural uranium for the open window and aluminum shield positions is shown in Table I.

TABLE I

Response of Dosimeter to Beta Emitters

Beta Emitter	Average Energy, Mev	Open Window Relative Response	Aluminum Shield Relative Response
Natural uranium	mixture	1.0	0.06
^{204}Tl	0.26	1.6	0
^{89}Sr	0.49	1.4	0.08
^{90}Sr (^{90}Y)	0.18 (0.76)	1.2	0.04
^{3}H	0.006	0	0

The open window position of the TLD responded satisfactorily to most beta energies encountered in personnel monitoring (^{7}LiF chips have a very low response to tritium and a very low response to neutron exposures). The aluminum shield effectively absorbs all beta energy below 1 Mev. This absorption permits satisfactory determination of skin exposure from the more penetrating radiation.

Gamma Response

The energy responses of the open window and aluminum shielded positions for photon energies from 17 kev to radium are shown in Figure 2. The responses are normalized to radium as unity. The 2-cm depth dose (testes dose) in rads is shown for an exposure to 1 R of radium gamma radiation in free air. The aluminum-shielded dosimeter was found to be approximately equal to the 2-cm depth dose for all energies within this range.

The open window response for radium (Figure 2) is 24% higher than that behind the aluminum shield. This difference and the overresponse at photon energies <100 kev will be interpreted as skin exposures. An overestimation of skin exposure is acceptable because it will attribute more exposure to the individual than was actually received. The exposure limit for skin dose is seldom restrictive.

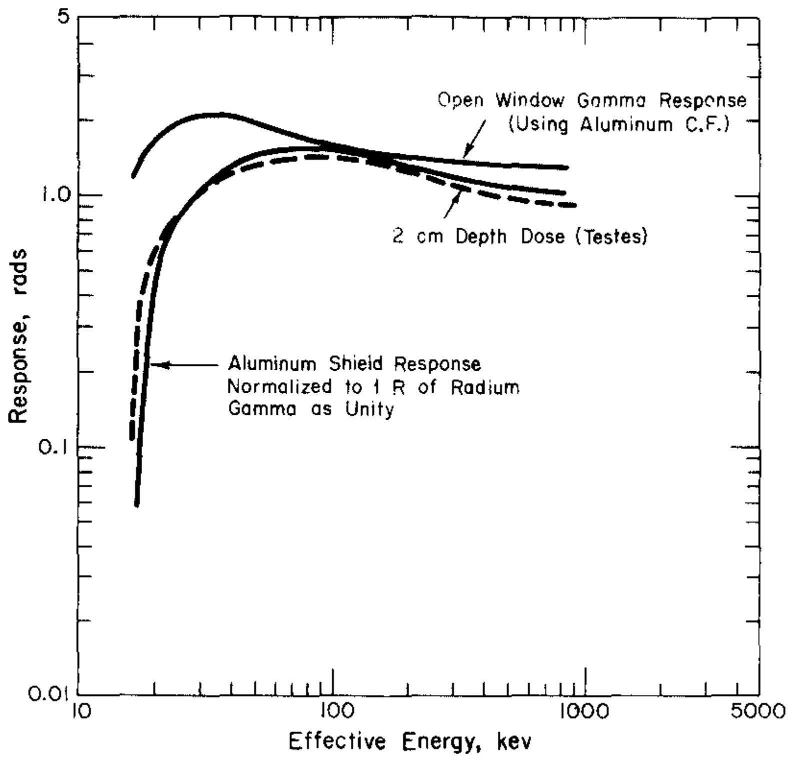


FIGURE 2. Response of Thermoluminescent Dosimeter as a Function of Energy

Effect of High Exposures

The sensitivity of thermoluminescent dosimeters decreased 10% from the batch mean when the dosimeters were exposed to 5000 R of ^{60}Co radiation. At 120,000 R, sensitivity decreased 20%. However, after the annealing process described earlier, the dosimeters recover their original background but sensitivity loss is permanent.

Cumulative exposures of LiF to high radiation fields[10] induce permanent changes in sensitivity. To maintain a sensitivity of ±10% for the dosimeters, the cumulative radiation exposure should be <5000 R.

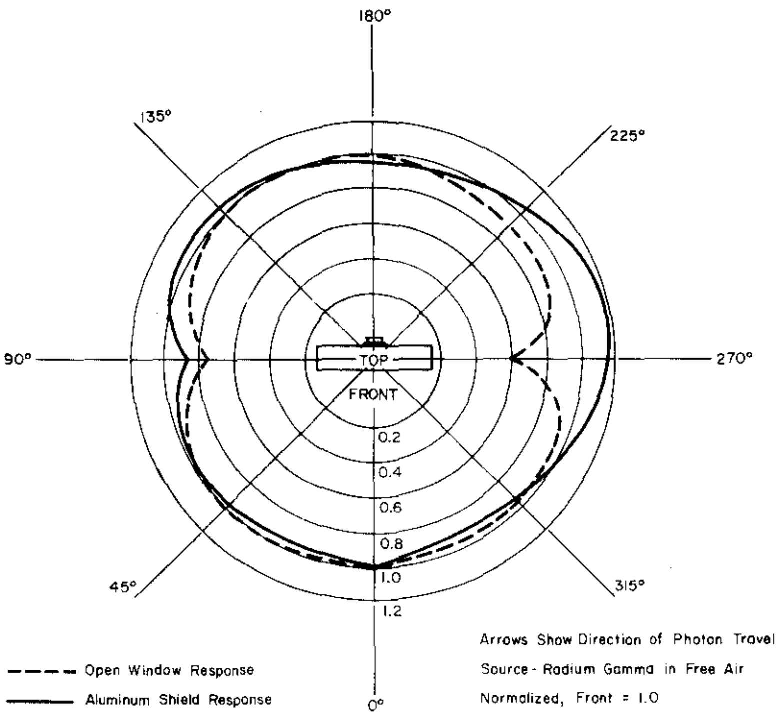
Directional Dependence

The response of thermoluminescent dosimeters is not significantly directionally dependent over a 90° cone corresponding to a frontal exposure (Figure 3). Exposures received from the opposite side of the body will vary with photon energy but for high energies will be approximately 1/2 the correct response.[11] When the badge was exposed to a radium source in air (Figures 3a and 3b), the aluminum shield was less dependent on direction than the open window.

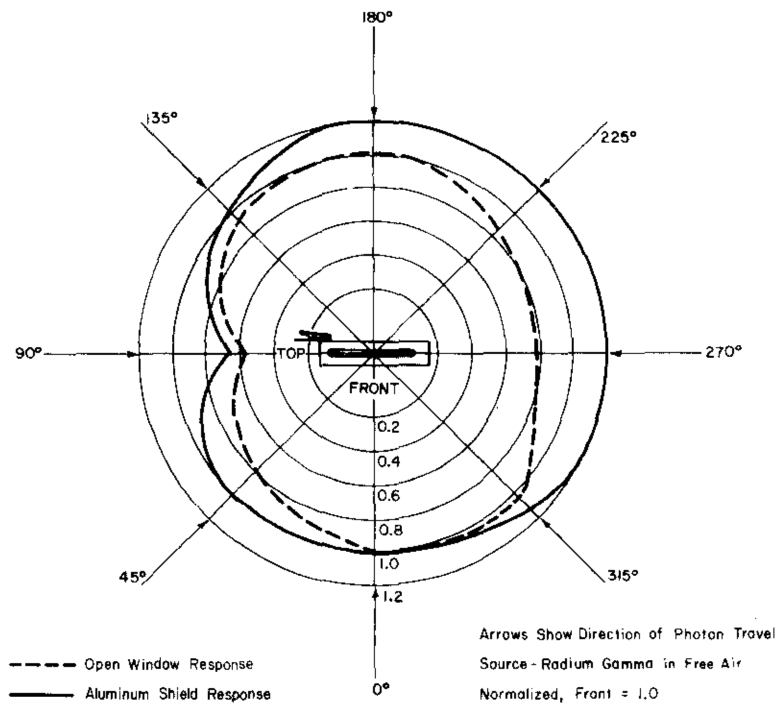
Recovering Lost Results

Routine reading of the badges usually erases the effect of the exposure to the extent that data are nonretrievable at exposures below 1 R. However, ^{7}LiF has a high-temperature trapped state between 350°C and 400°C that is not erased at normal read temperatures.

For exposures >1 R, a second reading may be made by increasing the reading temperature from 285 to 380°C. The response with this technique is about 1.9% the original response, but this second reading can be used to confirm a high reading.



a. Top View



b. Side View

FIGURE 3. Directional Response of Thermoluminescent Dosimeter

The relationship between the first and second readings with our system is

$$Y = 134X^{0.82}$$

where

X = net counts from normal reading at low temperatures

Y = net counts from high-temperature reading

The procedure for obtaining a second reading is:

- Expose a calibration set with controls to cover the range of interest
- Read all badges in normal manner, record results, and maintain the identity of each badge
- Use the same time cycles (6-sec preheat and 12-sec readout integration times), adjust the pan temperature from 125 to 200°C on the preheat cycle and from 285 to 380°C on the read cycle
- Reread the responses of controls to derive a high-temperature calibration curve

Badge Contamination

Thermoluminescent dosimeters or badge components contaminated to above 100 counts/min can be detected by checking with a G-M type survey instrument before reading. Therefore, periodic survey instrument checking is necessary to prevent a significant contribution to an individual exposure record due to external contamination.

For badge contamination at 100 counts/min over a 30-day period, the following readings were obtained:

Net G-M Survey Instrument Reading, counts/min (In contact with badge)	100 (∿3 nCi of $^{95}Zr-^{95}Nb$)
Open Window Reading, mrad (Relative to natural uranium)	1500
Aluminum Shield Reading, mrad (Relative to radium)	150

COMPARISON OF THERMOLUMINESCENT DOSIMETERS WITH FILM BADGES

Advantages of Thermoluminescent Dosimeters

Thermoluminescent dosimeters have the following advantages over film dosimeters:

- The monitoring cycle for low exposures is extended from 1 month to 3 months with the TLD.
- Immediate results can be obtained with the TLD and may become important for unusual incidents and for scheduling personnel to stay within pro-rated radiation protection guide values.
- The TLD can be used in mixed fields of beta and X-ray radiation.
- The TLD has a wide range of sensitivity that permits routine as well as emergency measurements of personnel exposures.
- TLD chips can be used repetitively after annealing.
- Experiences of lost results were fewer because TLD chips are less sensitive to many environmental factors than film.
- TLD preparation and readout equipment is simpler than that for film. Both TLD chips in a badge can be unloaded and read in two minutes and, after annealing, reloaded in the badge in 1/2 minute.
- The system can be automated. A report describing the automated system will be issued later.

Comparison of Readings from Thermoluminescent Dosimeters and Film Badges

In tests where film badges and TLD chips were worn concurrently for 5 monthly cycles, the TLD gave the most correct exposure reading in plutonium refining areas. The penetrating dose reading with film was 1.9 to 2.6 times higher than the TLD reading. The skin exposure reading with film was also high when the 17-kev interpretation of film open windows was used.[11] When the 17-kev interpretation could not be used because of beta exposure, the film results for skin exposure were as much as 10 times higher than TLD results. The overresponse of film badges was expected and the magnitude could be estimated by calibration curves; however, TLD results were more nearly correct.

Personnel radiation exposure data collected over a consecutive 24-month period, using film badges 12 months and TLD chips 12 months are shown in Table II. No significant differences in accumulated exposures were observed in any of the four work areas during changeover from film to TLD dosimetry. Any increase in exposure can be directly related to known increases in the level and amount of radiation work in that area.

TABLE II

Personnel Radiation Exposure

Period Covered	Badges/ month[a]	Monitored by	Exposure, rems Reactor	Separations	Technical	Other Groups
1969						
April, May, June	4600	Film	100	260	165	100
July, Aug., Sept.	4600	Film	195	279	210	118
Oct., Nov., Dec.	4600	Film	140	234	234	60
1970						
Jan., Feb., Mar.	4600	Film	177	247	184	78
[a]Apr., May, June	4600	TLD	155	266	140	96
[a]July, Aug., Sept.	4600	TLD	110	194	120	54
[a]Oct., Nov., Dec.	4600	TLD	232	202	82	53
1971						
[a]Jan., Feb., Mar.	4600	TLD	508	250	110	196

a. Average number of personnel badged/month. Beginning April 1, 1970, approximately 35% of badged personnel wore TLD badges for a 3-month period.

Lost Results

The change from film dosimetry to TLD resulted in a significant reduction in lost results. TLD chips are insensitive to many environmental factors and chemicals to which film responds. Data in the TLD can be lost by contamination, and, as with film dosimeters, an investigation must be made to estimate the exposure from dose rate measurements and self-reading dosimeter data. The number of investigations made for this purpose during three years with film and one year with TLD chips are listed in Table III.

TABLE III

Investigations Required Because of Lost Dosimeter Results

	Number of Investigations			
	Film			TLD
Cause	1967	1968	1969	1970
Moisture - laundry	79	90	65	6
Light - fogging	29	27	20	0
Defective Detector	6	27	11	0
Contaminated Badge	60	83	128	20[a]
TOTAL	174	227	224	26

a. Increased frequency of monitoring individual badges contributed to the lower loss of data as a result of badge contamination.

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