Conf-760202--7

EXPERIENCES IN ENVIRONMENTAL MONITORING WITH BeO CERAMIC DOSIMETERS

R. B. Gammage and F. F. Haywood

EXPERIENCES IN ENVIRONMENTAL MONITORING WITH BeO CERAMIC DOSIMETERS*

R. B. Gammage and F. F. Haywood
Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Abstract

Ceramic BeO disks used as radiation detectors have been evaluated in environmental radiation fields by observing the TL and TSEE signals given off after heating the disks. Fluxes of low energy photons cause the values for the two apparent exposure rates to diverge; this provides a measure of the quality of the photon radiation field. The mean of the TL and TSEE derived exposure rates is close to the exposure rate as determined by other means.

The TL-TSEE dosimeters perform satisfactorily provided moisture is not allowed to condense onto the BeO and wet its surface when the temperature falls below the dew point. Thin impervious plastic packets or aluminum cans, containing silica gel desiccant, provide adequate protection.

Introduction

At the 1974 Midyear Symposium on Population Exposure(1) we reported on the results of a year long personnel monitoring field test of thermally stimulated exoelectron emission (TSEE) dosimeters of ceramic BeO. Since that time field testing has expanded to cover environmental radiation dosimetry. Answers were sought to the following two questions. What useful information about the intensity and quality of a radiation field can be gained by reading the thermoluminescence (TL) and TSEE from a single BeO disk which is not available from a reading of only the TL? What factors have been causing sometimes success, sometimes failure, to attend our previous attempts to make long term TSEE measurements of radiation exposure rates at low or natural background levels?

Examples of success include tests inside Oak Ridge houses(2), detectors mailed to and from, and stored inside the AEC Headquarters building in Washington(2), a 10 day intercomparison test of environmental dosimeters at ORNL in 1973(3), and the data obtained for 9 of the 12 months of the aforementioned personnel monitoring field test(1). Two examples of the failing of TSEE dosimeters are during the First International Intercomparison of Environmental Dosimeters, conducted in Houston, Texas in 1974(3), and during the three summer months of the personnel monitoring field test(1).

The studies to be reported will demonstrate vividly to the reader that evaluation of detectors under controlled, harsh laboratory conditions can be woefully lacking for predicting performance under actual field conditions.

Detectors and Associated Equipment

The gas-flow, GM counter for TSEE was the same as that reported earlier(1). The TL reading was made, prior to the TSEE reading, on a Radiation Detection Co. Mark IV TLD reader with photomultiplier tube and filter suitable for recording the U.V. emission from ceramic BeO(4). Prior to reading the TL, the exposed detectors were handled in yellow or red light to prevent bleaching. The TSEE is fairly resistant to bleaching in all except fluorescent lighting(5).

The 12.5 mm diameter, 1.5 mm thick BeO ceramic disks from Brush Beryllium Co., Elmore, Ohio, were sensitized for exoelectron emission by heating at 1320°C for 500 hours followed by a stabilizing water treatment for 100 hours, and final drying at 500°C(6). The disks, six at a time, were mounted in a Lucite rack housed in a light proof ORNL film badge. Additional protection from the elements was afforded by enclosure in either glass bottles, with or without rubber-stoppered necks, screw-capped aluminum cans (270 mg/cm^2), or heat sealed, thin plastic bags (8 mg/cm^2). In cases where a dry atmosphere was sought, a little silica gel desiccant was added to the container.

Climatic Effects

The fading of the latent TSEE and TL in exposed detectors was investigated in the laboratory under harsh temperature and humidity conditions. The data of Fig. 1 show that the TSEE signal is preserved reasonably well over a three month period provided one does not cross over the boundary between water vapor and liquid water. Immersion in liquid water produces marked fading and additional undesired changes in the intrinsic sensitivity.

*Research sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation.

The TL signal also survives a temperature of 30°C for three months without an information loss exceeding 15%(4). The TL, unlike the TSEE, is unaffected by immersion in water at 25°C(5).

Detectors left in the open unprotected from fluctuating humidity often gave poor TSEE readings. Errant behavior always followed those exposure periods which were accompanied by heavy mist or frost. On one such occasion, the detectors in their badges had been attached to the insides of two inverted glass jars. One jar was stoppered and contained silica gel to provide a dry atmosphere. The other jar was left open and on its inside frost had formed on the badge and the subsequently measured TSEE was ruined. Normal readings were obtained from the protected dosimeters. The "normal" and "ruined" TSEE glow curves that one obtains are reproduced in Fig. 2. The TL signal was not affected seriously by the wetting of the BeO. The conclusion to be drawn is that surface wetting, which occurs when the temperature of the ambient atmosphere falls below the dew point, must be prevented. This is a prerequisite for the successful working of BeO ceramic dosimeters in the TSEE mode of operation.

One can thus reflect on the results of our earlier year long personnel monitoring test with BeO TSEE dosimeters. The disks were subject to variable humidity but presumable, while worn on the body or kept in the home, were not subject to 100% relative humidity. Sensible readings were obtained for the nine months October through to June. In the remaining three months of July, August and September the detectors were ruined. Heavy evening mists are characteristic of the Oak Ridge area during this period of the year. Combining this circumstance with hightened outdoor recreational activities and removal of clothing, the likelihood of a dosimetry badge becoming separated from the owner's warm body is increased. This would allow for cooling of the BeO disks to below the dew point temperature with attendant ruination of the TSEE.

Wetting of BeO disks at dew point temperatures is also seen as the cause for failure in the International Intercomparison of Environmental Dosimeters, Houston 1974(3).

Field Testing

The BeO dosimeters inside the badge holder were calibrated, under conditions of low-scatter geometry, against an N3S calibrated ^{60}Co source positioned 20 cm from the BeO disks. Exposures were standardized at 20 mR.

The most of the field studies were conducted in an area where ^{137}Cs had been sprinkled on the ground to simulate fallout. The solid state, integrating dosimeters were all placed at position A of Fig. 3, 1.5 m above the ground. Prior to placement in the field, the disks of BeO were annealed at 400°C. The exposure rates, in parentheses in Fig. 3, were measured with a GM counter (RCL 10-60) which was shielded with tin and lead to reduce the normally enhanced response at low photon energy. This instrument exhibits a reasonably uniform energy response down to about 50 keV(7).

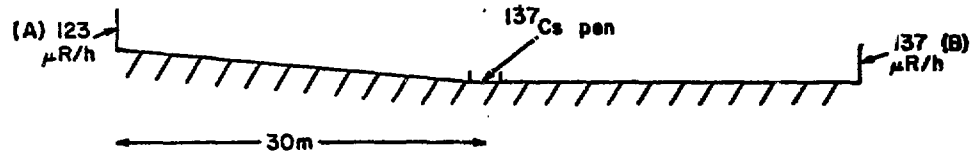

Fig. 3. Cross-sectional view of one of a series of ^{137}Cs contaminated areas.

The field exposures of phosphors were of about one week duration, the time needed to accumulate about 20 mR. In addition to multiple exposures of BeO disks, TLD phosphors of LiF 100, LiF 700 and $CaSO_4$:Dy were also exposed and read. The apparent exposure rates are listed in Table 1. Dry atmospheres were maintained with silica gel desiccant.

One anticipates that for BeO the ratio of apparent exposure rates obtained from reading the TL and TSEE should be unity. This is not so. The ratio of exposure rates, TSEE to TL, is 0.59 and 0.53 for the aluminum can and plastic bag containers, respectively. Two possible causes for the discrepancy come to mind. The residence time in the field may be long enough to permit unexpected anomalies to develop in the TSEE and/or TL response characteristics. Another possibility is that the detectors are seeing substantial collided photon flux at energies where the TSEE and TL sensitivities diverge considerably.

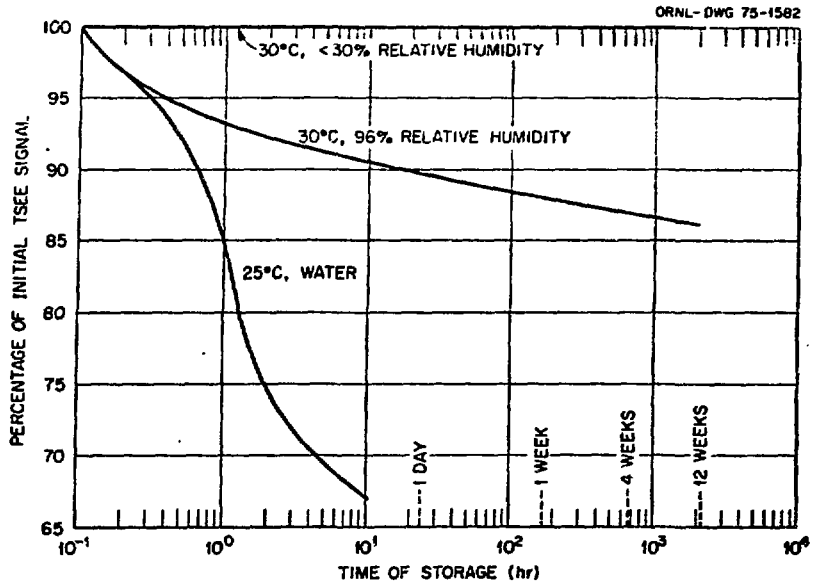

Fig. 1. Fading of the TSEE signal during storage in a laboratory climatechamber or during immersion in water.

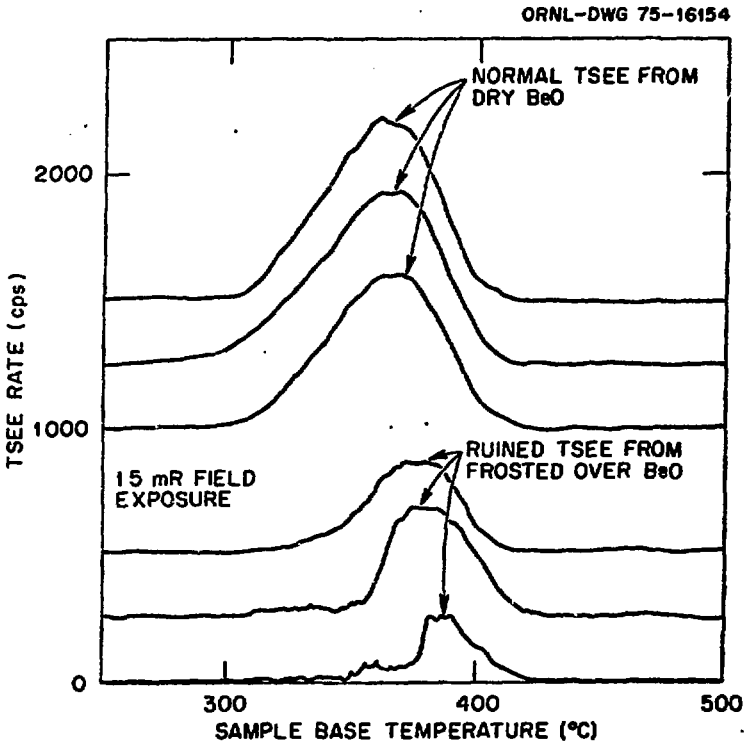

Fig. 2. Appearance of TSEE glow curves from two sets of three Thermalox 995 BeO dosimeters after field exposures of about 15 mR; one set was maintained in dry conditions, the other set suffered surface wetting.

The former possibility was tested by allowing the detectors to stand in the open for several days in low level, background radiation fields where the integral exposure was only 1 or 2 mR. The detectors received additional exposure to ^{60}Co radiation (20 mR or 50 mR) either prior to placement in, or just after retrieval from the field. The results are given in Table 2.

Table 1. Apparent Exposure Rates (μR/h) at Position A, Fig. 3.

a. Enclosed in Airtight Aluminum Cans (270 mg/cm^2)

PHOSPHOR	TSEE	TL
LiF 100	-	120
LiF 700	-	124
$CaSO_4$:Dy (540 mg/cm^2 brass)	-	199
$CaSO_4$:Dy	-	324
BeO	104	169
	94	159
	95	166

b. Enclosed in Heat Sealed Plastic Bags (8 mg/cm^2)

PHOSPHOR	TSEE	TL
BeO	121	219
	119	221
	104	211

c. BeO disk to be read tightly sandwiched between two other BeO disks.

	TSEE	TL
BeO	96	192

Table 2

	TL (mR)	TSEE (mR)
Dosimetry badge sealed in a plastic bag and left in the field for five days before exposing to 20 mR ^{60}Co	21.5	21.4
Dosimetry badge exposed to 50 mR ^{60}Co, placed in a screw-capped aluminum can and then left in the field in the direct sun for four days	44	52

It seems quite clear that the TSEE and TL response characteristics remain unchanged during the detector's sojourn in the field. The one low value of the TLD (44 mR) can be traced to thermal fading; the aluminum can was left in direct sunlight and became quite hot. Neither is there an air-BeO interface problem during the exposures since sandwiching the BeO disk between two additional BeO disks did not materially alter the TSEE/TL ratio of apparent exposure rates (Table 1 c).

Another field test with BeO was conducted in an area close to an isotope storage building, this being the site of the 1973 Intercomparison of Environmental Dosimeters(3). The results obtained in 1973 are reproduced in Table 3. At that time only the TSEE was read from the BeO. The exposure rate has since been rechecked in 1975 with readings made this time of both the TL and TSEE from the BeO. The exposure rate according to TSEE proved not to have changed. The TL exposure rate, however, was double that determined by TSEE. The situation is very much like the one prevailing at the site of the ^{137}Cs pens where the TL exposure rate was nearly double the exposure rate according to TSEE.

The mean of the exposure rates reported in Table 3 by institutes 1, 2 and 3 is 31.4 μR/h. The average of the exposure rates measured by BeO read for TL and TSEE is 29.4 μR/hr.

Table 3. Results of 1973 Oak Ridge National Laboratory Environmental Dosimeter Intercomparison

Institute	Detector	Reported Exposure Rate (μR/h)
1	CaF_2:Dy*	31.3
	LiF:Mg,Ti**	34.5
2	CaF_2:Dy*	36.7
	LiF:Mg,Ti**	33.0
3	CaF_2:Dy*	25.5
	CaF_2:Mn*	27.5
4	BeO**(TSEE)	20.5
	$CaSO_4$:Dy**	59.0
4	BeO (TL)***+	39.1
	BeO (TSEE)***+	19.7

*with photon energy compensation filter.
**without photon energy compensation filter.
+measurements made in 1975

Energy Dependence

There is a considerable low energy component to the photon flux at each of the two field testing sites. The high apparent exposure rates for high Z TLD materials such as $CaSO_4$ without energy compensation filters attest to this aspect of the radiation quality. The behavior of BeO TLD and TSEE in low energy photon radiation fields is indicated in Fig. 4. The sensitivities are shown as a function of photon energy and are normalized to unity at ^{60}Co energy. The energy response characteristics of the RCL 10-60 GM counter are also included, it being the exposure meter used to obtain the exposure rates shown in Fig. 3 at positions A and B.

The "over response" of the BeO TLD at energies below a few hundred keV seems the most likely reason for the discrepancy in the TL and TSEE readings. Why the TL should show such an over response, or even deviate from the TSEE derived exposure rate at low energies, remains unexplained at this time. It appears, nevertheless, that the higher TL over TSEE readings from BeO are providing a measure of the quality of photon radiation fields. This possibility will be investigated further by exposing the BeO dosimeters at varying distances from one of the ^{137}Cs pens shown in Fig. 3.

Beck has determined that the energy distributions of photon fluxes are strongly dependent on distance from the nuclide source(8). At 100 m more than 50% of ^{137}Cs flux is of energy <100 keV and 93% of that flux results from multiply scattered photons. Even though nearly all of the uncollided flux has disappeared at 100 m, high energy photons still contribute the bulk of the exposure. The principal difference between exposures conducted in the laboratory source and in a field situation (Fig. 3) lies in the nature of the photon flux. In the first instance one is dealing with mainly uncollided flux and in the second case most of the high energy photons have been degraded in energy via Compton scattering before they strike the BeO disk. The divergence of the TL and TSEE sensitivities is most likely associated with this property of environmental radiation fields.

Consider the exposure rate data of Table 1 a. LiF TLD is probably providing close to the correct value at 122 μR/h. The GM detector, with a flattered energy response, gives the same exposure rate of 123 μR/h (Fig. 3). The mean of the TSEE and TL readings from BeO is 130 μR/h. We propose that for monitoring photon radiation fields this mean TL, TSEE reading of the BeO dosimeters is likely to give the correct exposure rate, while at the same time providing qualitative information on radiation quality. The data of Table 3 indicates also that close to the isotope storage area, the mean of the TL and TSEE derived exposure rates (29.4 μR/h) is a "good" value.

If the dosimeter receives an exposure to weakly penetrating alpha(9) or beta radiation(10), the situation is reversed. Now the TSEE signal is the stronger of the two. The trend for beta radiation of different energy is shown in Fig. 5.

Acknowledgments

The help of J. S. Cheka is recognized in making the fading measurements, particularly those involving liquid water.

References

1. Gammage, R. B., Cheka, J. S. and Saheli, N., "Field Testing of TSEE Dosimeters for Personnel Monitoring", Proc. Symp. on Population Exposures, p. 297, CONF-741018 (1974).
2. Gammage, R. B. and Cheka, J. S., "A Practical TSEE Dosimetry System Based on BeO Ceramic", Proc. 4th Int. Conf. on Exoelectron Emission and Dosimetry, p. 247 (1973), Czech Acad. Sci. and A.E.C., Liblice, Czechoslovakia.
3. Gesell, T. F., Burke, G. de P. and Becker, K., "An International Intercomparison of Environmental Dosimeters under Field and Laboratory Conditions", ORNL-TM-4887 (1975).
4. Crase, K. W. and Gammage, R. B., "Improvements in the Use of Ceramic BeO for TLD", Health Phys. 29, 739 (1975).
5. Gammage, R. B. and Cheka, J. S., to be published.
6. Gammage, R. B. and Cheka, J. S., "Bank of Calibrated BeO Ceramic Dosimeters for TSEE and TL", in press, Health Physics.
7. Auxier, J. A., et al., Health Phys. Div. Ann. Progr. Rept. July 31, ORNL-TM-4168, p. 214 (1967).
8. Beck, H. L., "The Physics of Environmental Gamma Radiation Fields", The National Radiation Environment II, p. 101, CONF-720805-P1 (1973).
9. Gammage, R. B., Kerr, G. D. and Huskey, L., "Exploratory Study of the Use of TSEE Dosimeters in Radon Monitoring", in press, Health Physics.
10. Gammage, R. B. and Cheka, J. S., "Measuring Tritium with Exoelectron Dosimeters", Nucl. Instr. Meth. 127, 279 (1975).

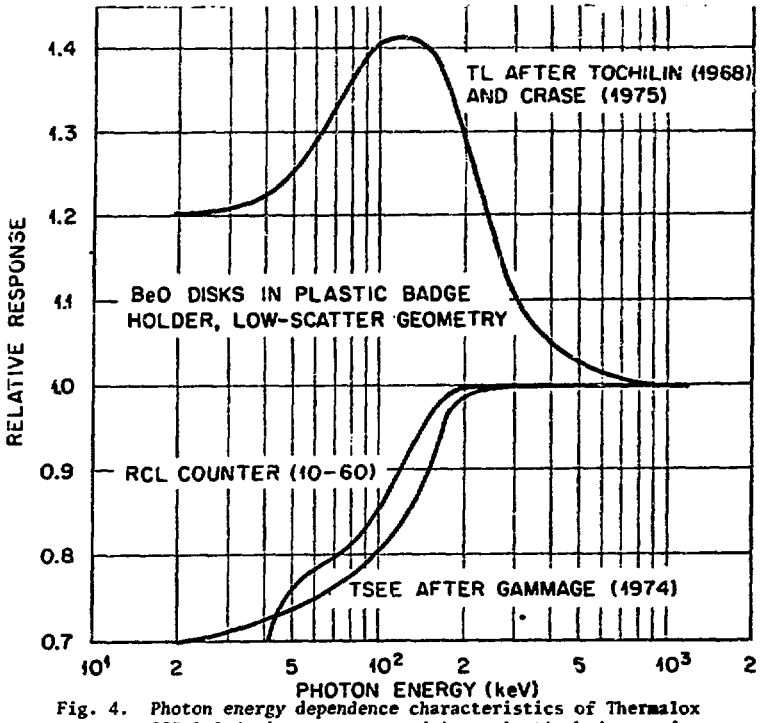

Fig. 4. Photon energy dependence characteristics of Thermalox 995 BeO dosimeters, mounted in a plastic badge, and an RCL 10-60 GM counter with tin and lead shielding for flattened energy response(7). Heavily filtered X-rays provided energies between 20 and 200 keV, the responses shown being relative to the response at ^{60}Co energy.

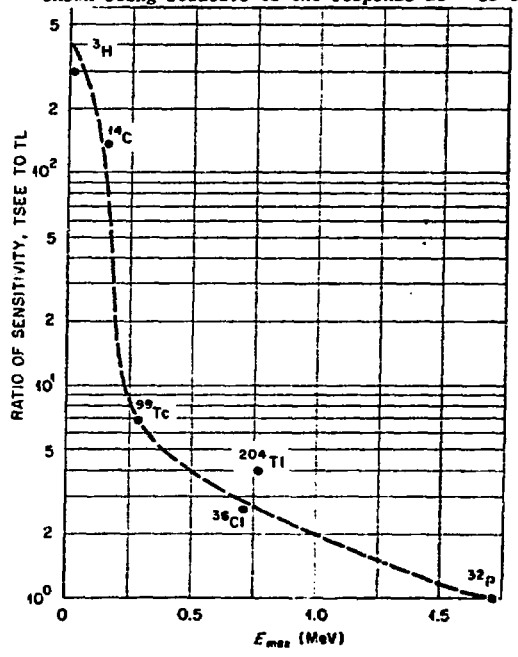

Fig. 5. Ratio of sensitivities, TSEE/TL, for radiation from different beta emitting radionuclides.