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A COMPARISON OF CaF_2:Mn AND LiF THERMOLUMINESCENT DOSIMETERS FOR ENVIRONMENTAL RADIATION MONITORING

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PREFACE

The Eastern Environmental Radiation Facility participates in the identification of solutions to problem areas as defined by the Office of Radiation Programs. The Facility provides analytical capability for evaluation and assessment of radiation sources through environmental studies and surveillance and analysis. The EERF provides technical assistance to the State and local health departments in their radiological health programs and provides special analytical support for EPA Regional Offices and other federal government agencies as requested.

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A Comparison of Calcium Fluoride:Manganese and Lithium Fluoride Thermoluminescent Dosimeters for Environmental Radiation Monitoring

Introduction

Several chemical and physical forms of thermoluminescent dosimeters (TLD's) are commercially available, and each type has its special advantages and special applications. Two commonly used types of TLD's for environmental monitoring are calcium fluoride:manganese activated and lithium fluoride Each of the two types has several advantages and some disadvantages.

The primary advantages of lithium fluoride are negligible fading (five percent per year at twenty degrees centigrade) and energy independence from the keV to MeV energy ranges (1).

The major advantage of calcium fluoride:manganese over lithium fluoride is sensitivity. The calcium fluoride:manganese is approximately 3 times more sensitive to ^{60}Co gammas than lithium fluoride (2).

This report gives the results of a study conducted by the Eastern Environmental Radiation Facility (EERF), the University of Florida (U of F), and the Florida Division of Health (FDH). The study was designed to compare and evaluate environmental ambient radiation monitoring programs using lithium fluoride and calcium fluoride:manganese TLD's.

The study was conducted in conjunction with a preoperational radiological survey at the Crystal River Unit 3 Power Plant site, Crystal River, Florida. The pre-operational survey is being conducted by the FDH and the U of F.

As part of the Pre-Operational Radiological Survey at the Crystal River site, the University of Florida conducts an extensive TLD monitoring program using lithium fluoride TLD's. The University of Florida has sixteen TLD stations on or near the site.

The Florida Division of Health is also conducting a pre-operational survey at the Crystal River site. Their survey includes a network of five TLD stations (all off-site) to monitor the ambient gamma radiation levels. The State uses calcium fluoride:manganese, glass encapsulated TLD's.

The EERF is currently involved in ambient radiation monitoring at several nuclear plants. This ambient monitoring is in conjunction with several short-term strategic studies which are designed to meet specific objectives. The EERF uses calcium fluoride:manganese, glass-encapsulated TLD's in the ambient monitoring program.

Objectives

The objectives of this study were to answer any questions concerning the validity of reported ambient gamma radiation levels at the Crystal River site and to compare the results of TLD monitoring programs using the two types of TLD's. The second objective is especially important to the Office of Radiation Programs of EPA which routinely relies on ambient radiation levels reported by various agencies using different types of TLD's.

Study Design

A total of eight sites in the vicinity of the Crystal River plant were selected for "cross-check" purposes. Each of the sites was previously used by either the U of F or the FDH as a TLD monitoring station. Five of the sites were located inside thin aluminum storage buildings. The remaining three sites were located on wooden stakes approximately one meter above ground. A total of eight TLD's were positioned at each site -- four lithium fluoride and four calcium fluoride:manganese.

The study was continued for approximately four months, (two 1-month and one 2-month monitoring periods). At the end of each monitoring period the TLD's were read out and repositioned at their respective location.

Procedures

During the study each group performed their ambient monitoring programs using their normal operating procedures in order to obtain typical results.

A brief description of each procedure follows:

University of Florida (Lithium fluoride)

The University of Florida uses the Eberline TLR-5 integrating reader for readout of lithium fluoride ribbons. The reader is set for a 6-second pre-heat to 150 degrees centigrade with a 12-second readout to 250 degrees centigrade. A set of 200 dosimeters (TL-100) was divided into two pools of 100 for routine background measurements. The pools are alternated each month so that each pool is in the laboratory every other month where quality control measures are taken to remove ribbons which exhibit any anomalous behavior. The dosimeters used by the University for this present study were drawn from these pools and handled in the routine manner established at the University and described below.

Before being placed in the field, the dosimeters are "zeroed" by cycling them through the reader once or twice. No formal pre-irradiation batch annealing procedure is used. High temperature annealing is necessary only when the TLD is to be exposed to low levels following a high level exposure history. Four ribbons are zeroed at once, allowed to cool, and placed in a TLD shipping vial with polystyrene packing (see figure 1). The vials are wrapped in aluminum foil to make them light-tight and sealed in thick polyethylene bags along with identification tags.

After the desired exposure time, the TLD's are recovered and post-annealed for 10 minutes in boiling water to remove the low temperature components. The dosimeters are read out one at a time in a nitrogen atmosphere. The reader background is determined by recycling several TLD's just after they have been read. The recycled response is taken as background. All responses are recorded and computer analyzed for quantitative exposure.

A calibration factor is determined by exposing field packaged TLD's to one of two NBS traceable sources (^{226}Ra or ^{60}Co). The sources have been cross-checked and given the same calibration factor. Calibrations are performed at least once every three months and as often as monthly.

Eastern Environmental Radiation Facility
(Calcium fluoride:manganese)

The dosimeter used by the EERF is the EG&G model TL-15 (figure 2). This dosimeter consists of two hot- pressed calcium fluoride:manganese activated chips which are held on either side of a flat heating element. The chips and the heating element are enclosed in a glass envelope which is filled with carbon dioxide. When in use the glass envelope is placed in an energy-compensating shield which reduces the over-response of calcium fluoride:manganese to low energy radiation. The reader used was the EG&G model TL-3 equipped with a low noise photomultiplier tube.

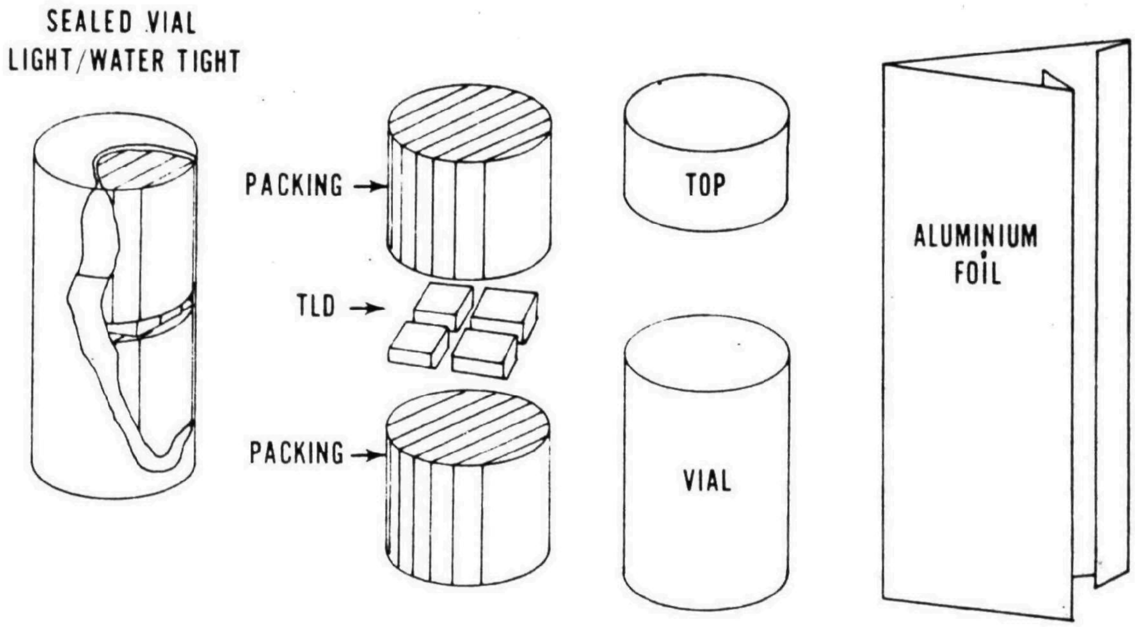

Figure 1. Details of Shipping Vial

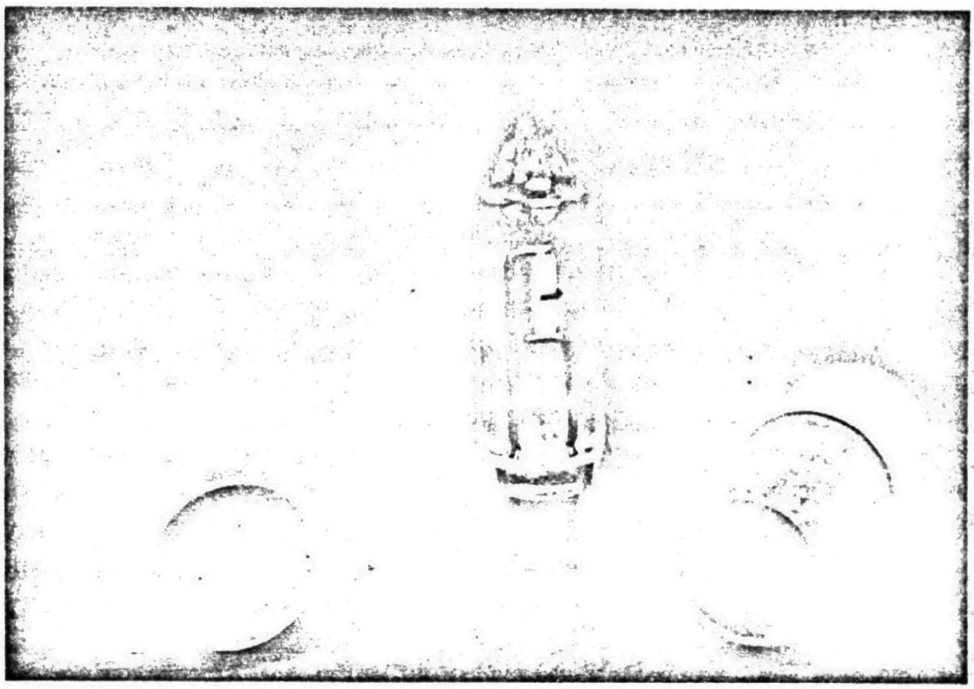

Figure 2. EG&G TL-15 Dosimeter

Prior to this study the EERF and the Tennessee Valley Authority (TVA) concluded a joint project to evaluate the suitability of this type dosimeter for environmental radiation monitoring purposes (3). The results of this project showed that each individual dosimeter should be calibrated. This calibration was performed using an NBS calibrated ^{226}Ra source. The joint EERF-TVA project also indicated the importance of knowing the self-dosing characteristics of this type dosimeter. As a result of this study, individual determinations of self-dosing characteristics for each dosimeter were performed.

The dosimeters are annealed or "zeroed" just prior to being positioned on location. This annealing process is performed using either the TL-3 reader or an EERF designed and constructed portable electronic annealer (4). This annealer duplicates the heating function of the EG&G TL-3 reader and further annealing is not required when working with environmental levels (3,4). After annealing, the dosimeters are divided into groups of three, and placed in zip-lock plastic bags for protection from moisture. The dosimeters are now ready to be positioned at the desired field locations.

Following the desired exposure period the dosimeters are collected and read out. These raw readout values are computer analyzed to calculate the average exposure rate in microroentgens/hour at each site. The computer program applies the appropriate correction factor and self-dosing correction for each dosimeter.

Florida Division of Health
(Calcium fluoride:manganese)

The Florida Division of Health uses the EG&G model TL-15 calcium fluoride:manganese activated TLD in its ambient radiation monitoring program. A Victoreen 2600B TLD reader is used for reading and annealing of the dosimeters.

A total of five FDH TLD sites surround the Crystal River Nuclear Power Facility. The TLD monitoring program at Crystal River was begun in April, 1971. These dosimeters are collected and read on a monthly schedule. One TLD is located at each site.

The Division of Health TLD program is set up to look for trends in the ambient radiation levels and has made no attempt to report the actual background values. Hence, the internal background of the TLD's arising from the ^{40}K in the glass encapsulation has not been subtracted from reported values in the past. The self-dosing values are available for some dosimeters, however.

Results

The results of the three monitoring periods are given in table 1. Only the results of the EERF and the U of F dosimeters are shown. Since the FDH looks only for trends in the ambient radiation levels and not actual background levels, their results are not shown for this comparison.

An indication of the precision or reproducibility of both (EERF and U of F) systems can be determined by calculating the mean of the one sigma error terms given in table 1. The results of this calculation show a precision of 2.6% for the calcium fluoride:manganese system and 3.3% for the lithium fluoride system.

Table 2 shows the average reading in microroentgens/hour at each site for the entire study period. Also shown in table 2 is the ratio of the calcium fluoride:manganese average to the lithium fluoride average at each site.

The dosimeters at sites 1–5 were located inside aluminum storage buildings and sites 6–8 were on wooden stakes one meter above ground. Analysis of the ratios (column 4, table 2) shows that the calcium fluoride:manganese results are 16% lower than the lithium fluoride results at sites 1–5. A similar analysis for sites 6–8 shows the calcium fluoride:manganese results 30% lower than the lithium fluoride.

Discussion and Conclusions

The precision or reproducibility of the two systems, approximately 3%, is very good.

The difference in the average microroentgens/hour values for the two systems, approximately 16% in one group and 30% in the other, is significant. This percentage is approximately 2 microroentgens/hour at these levels. At higher exposure rates the percentage difference would probably decrease. Several factors such as calibration procedures, energy response or sensitivities might account for this difference.

The differences in energy response of the two systems probably account for the variation in results between sites 1–5 and sites 6–8. Due to the energy-compensating shield the calcium fluoride:manganese dosimeter has a low energy threshold of approximately 80 keV (5). The lithium lower energies. Since the storage building acts as an effective shield against the very low energy radiation (80 keV) the lithium fluoride dosimeter would record an increased exposure rate outside the building. However, due to its low energy cut-off the calcium fluoride:manganese dosimeter would record little or no difference in the two locations. Due to this fact

Table 1. Ambient Radiation Levels - Crystal River, Florida
(microroentgens/hour ± sigma*)

Site No.	4/17-5/22 Calcium Fluoride: Manganese	4/17-5/22 Lithium Fluoride	5/22-6/26 Calcium Fluoride: Manganese	5/22-6/26 Lithium Fluoride	6/26-8/31 Calcium Fluoride: Manganese	6/26-8/31 Lithium Fluoride
1	4 4 ± .1	5.2 ± .1	4 6 ± 1	5.3 ± .5	4.4 ± .1	5.2 ± .1
2	4.9 ± .1	6.2 ± .1	4 9 ± .1	5.4 ± 2	5.1 ± .3	5.5 ± .3
3	6.2 ± .1	8.5 ± .5	6 1 ± .1	7.5 ± .1	5.9 ± .1	7.3 ± .1
4	4.4 ± .1	5.4 ± 5	4.5 ± .1	5.5 ± .2	4.3 ± .1	5.1 ± .1
5	5.0 ± .4	6.4 ± .2	5 3 ± .1	6.2 ± .1	4.9 ± .2	5.2 ± .1
6	4.3 ± .1	7.4 ± .4	4 3 ± .1	5.4 ± .1	4.1 ± .1	5.0 ± .1
7	6.3 ± .2	9.2 ± .3	5.8 ± .1	8.1 ± 2	5.0 ± .1	7.3 ± .1
8	4.4 ± .1	7.3 ±.2	4.5 ± .1	5.8 ± 1	4.2 ± .1	5.7 ± .2

* Error bounds are one standard deviation of the mean

Note: calcium fluoride manganese results are an average of three dosimeters per site and lithium fluoride results are an average of four dosimeters per site.

great care should be taken to position the TLD's at sites with similar shielding characteristics for routine monitoring.

Regardless of any errors in determining the true or actual exposure levels, the precision of either system is adequate for environmental monitoring purposes. However, even with this degree of precision it would be difficult to detect an increase of 5 mR per year in the ambient radiation levels due to the variations in natural background during the year.

Table 2 Average Exposure Rates at Each Site

Site	Calcium Fluoride: Manganese microroentgens/hour ± sigma*	Lithium Fluoride microroentgens/hour ± sigma*	Ratio ± Sigma* Calcium Fluoride: Manganese/Lithium Fluoride
1	4 5 ± 14	5 2 ± 55	85 ± .03
2	5 0 ± 26	5.7 ± 50	87 ± 09
3	6 1 ± 16	7 8 ± 76	.78 ± .08
4	4 4 ± 13	5.3 ± 58	83 ± 09
5	5 1 ± 43	5.9 ± .58	85 ± 11
6	4 2 ± .14	5 9 ± .14	.71 ± .14
7	5 7 ± 57	8.2 ± .86	.70 ± .10
8	4 4 ± .16	6 3 ± .78	.70 ± .03

* Standard Deviation of a Single Reading

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