TECHNICAL REPORT

Experiences Gained during Twenty Field Intercomparison Studies for Self-fabricated TLD $\text{CaSO}_4:\text{Dy}$

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This paper describes a summary of results in a series of 10 international intercomparisons of environmental dosimeters held during 1974–1993 and another series of domestic intercomparison studies held in Taiwan during 1980–1984. The field conditions were harsh. Even in semitropical Taiwan where high humidity and temperature in the field is usual, the performance of our TLD could pass all the rigid tests. The ANSI N13–29 (American National Standards Institute publication N13–29) dealing with standards for environmental dosimetry and the Horlick's triangle dealing with the accuracy and the precision of TLD were used to analyze the dosimetric data.

KEY WORDS: Environmental, HORLICK's triangle, HPIC, TLD, tolerance level

I INTRODUCTION

The first batch of $\text{CaSO}_4:\text{Dy}$ was fabricated at the National Tsing Hua University (NTHU) in 1972. After a series of tests, the self fabricated thermoluminescent dosimeters (TLDs) were used extensively throughout Taiwan.¹⁾ The International Intercomparisons of Environmental Dosimeters were initiated in 1974 to assess the performance of passive integrating detectors in the measurements of environmental radiation, and to identify and investigate special problems associated with such measurements.²⁾ These intercomparisons also have provided an opportunity for scientists to compare their techniques with those of their peers worldwide. During 1974–1993 ten such intercomparison studies were held in the U.S.A. NTHU was one of the participants who took part in all 10 tests.

The Radiation Protection Department of our Atomic Energy Council (AEC) sponsored a similar

intercomparison study in Taiwan during 1980–1984 for domestic TLD users only. More than 10 tests were carried out.

In all intercomparison studies, the dosimeters were irradiated under laboratory as well as field conditions, and the distribution of participants' results were compared with the delivered exposures measured by using high-pressure ion chamber (HPIC).

These intercomparisons involved both field and laboratory irradiations. Our TLDs took part in all 20 tests internationally and domestically. The experiences gained are presented herein.

II MATERIALS AND METHOD

The production of powdered $\text{CaSO}_4:\text{Dy}$ in a laboratory for dosimetric purposes is described elsewhere.³⁾ A brief description is given below.

The TLD material was pure $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ mixed with activator material dysprosium oxide Dy_2O_3 to the extent of 0.1 mol% with regard to $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, and dissolved in 15 N conc. H_2SO_4 . The solution was then heated up to evaporate sulfuric acid with proper ventilation. Single crystals of calcium sulfate doped with dysprosium were observed to grow with the progress of evaporation of sulfuric acid. After cool-

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ing the crystals were ground to crystalline powder and were sieved to retain particle size from 0.074 to 0.175 mm. The powder thus obtained was readily activated by radiation.

Since our TLD readers were purchased from the U.S.A., the way of handling TLD powder and the annealing procedures are quite different from the Japanese products. The TLD $\text{CaSO}_4 : \text{Dy}$ powder of 40 mg was encapsulated in a black polyethylene capsule with 3 mm internal diameter, 1 mm wall thickness and 20 mm length. An annealing treatment of 1 h at 673 K was applied in an electric oven simply by placing the powder in an open pan or tray. The TL responses were recorded by two types of readers: Harshaw Model 2000 B & C and Teledyne Isotopes Models 7100 and 7300. All of them were fabricated in the U.S.A. The former uses A-P planchet which is a special material particularly for TLD powder heating during readout. The A-P is designated as a commercial name. Since this type of planchet can hold 17.25 ± 0.15 mg of $\text{CaSO}_4 : \text{Dy}$, two readings can be obtained from one polyethylene capsule. The latter (Teledyne Isotopes) uses D-20 planchet which is also a commercial name and made of special metal. It can hold 39.62 ± 0.35 mg powder. Therefore only one reading can be obtained from one irradiated polyethylene capsule. The stability of all three readers was within $\pm 1\%$ as tested by the reference light source. The total error including the powder weight, annealing treatment, counting mode, heating rate and stability was within $\pm 3\%$.

In the field portion of the intercomparison studies TLDs were suspended by plastic cable ties 1 m above the ground at a secure outdoor location. Some of them were stored in a lead container. HPICs were used to measure independently the dose at the field site.

In the laboratory portion of the intercomparison studies a relatively low exposure was given using various point sources. The factor of 8.76 mGy R^{-1} was used to convert exposure into air absorbed dose.

Domestically, in addition to the irradiations mentioned above, a monitoring post made of plastic tubing was erected in the field. The dimension of the tubing was 76.2 mm in diameter and 5.5 mm in wall thickness. Many small holes with diameter 4.8 mm were drilled. The density was 70 holes per 100 cm^2 . Bare TLDs were placed in a plastic sachet and hung at 1 m height above the ground inside the monitoring post.

Four sites in Taiwan were selected for inter-comparison studies. The first site is Chienhua where two 690 MW(e) power reactors are installed. The second site is Lungtan where a 40 MW research reactor is located. The third site is Hsinchu where a 1 MW research reactor is operated by NTHU. The fourth site is Kaohsiung where no nuclear facilities are in existence.

A TLD set consisting of three dosimeters was exposed in the field in Taiwan. For those sites with nuclear facilities, the exposure of TLDs took place inside the reactor site boundary. After exposure for one month, one dosimeter in the TLD set was replaced for a new one. After two months, another one in the TLD set was also replaced, and so on. The period for the TLD exposure was 14 months but in each month one of the three TLDs was replaced by a new one. Therefore, except the first two TLDs, all of them were exposed in the field for three months.

Fig. 1 Number of participants and dosimeter sets participated in 10 international intercomparisons.

III PERFORMANCE CRITERION

It is useful to see how dosimeters would perform for the ANSI N13-29.⁴⁾ It is the American draft standards for environmental dosimetry emphasizing the current status and future directions issued by the

American National Standards Institute. The quantity of concern is

$$|B| + S \leq L \quad (1)$$

where

Table 1 Time, sites and conditions for 10 international intercomparison studies.

No.	Time	Sponsor	Site	Conditions	
				Field	Laboratory
1	Jul-Sep, 1974 summer	ORNL	Houston	Temp 11.5–35.4°C Ave temp 23.6°C R.H. 81%, rain 258 mm HPIC 16.3±0.8 mR	Ra-226 30±1.5 mR
2	Jan-Apr, 1976 winter-spring	ORNL	New York	Temp -9 to 25.7°C Ave temp 4.8°C Snow 450 mm Rain 187 mm HPIC 17.1±0.9 mR	Cs-137 21.3±1.11 mR
3	Jul-Sep, 1977 summer	ORNL	Oak Ridge	HPIC 34.9±2.4 mR	Co-60 91.7±7.3 mR
4	Mar-May, 1979 winter-spring	DOE	Houston	HPIC 14.1±0.7 mR	Ra-226 12.2±1.2 mR and 45.8±4.6 mR
5	Aug-Nov, 1980 summer-autumn	DOE	Idaho	Altitude 2000 m HPIC 30.0±3.0 mR	Cs-137 75.2±3.8 mR and 88.4±4.4 mR
6	Jul-Oct, 1982 summer-autumn	DOE	Idaho	Temp -14 to 35°C Ave temp 13°C Altitude 1970 m Rain 670 mm HPIC 43.5±2.2 mR (old fallout) 202±10 mR (Cs-137)	Cs-137 158±8 mR
7	Apr-Jun, 1984 spring-summer	DOE	Idaho	Temp -12 to 38°C Altitude 1220 m HPIC 75.8±6.0 mR (2/3 old fallout+1/3 terrestrial)	Co-60 75.0±3.8 mR Cs-137 79.9±4.0 mR
8	Dec-Mar, 1985– 1986 winter	DOE	New York	HPIC 10.4±0.5 mR (1/4 cosmic+3/4 terrestrial) HPIC 19.7±1.5 mR (4/5 cosmic+1/5 terrestrial)	Cs-137 17.2±0.9 mR
9	May-Sep, 1987 spring-summer	DOE	New York		Co-60 Cs-137 60.9±1.0 mR 57.1±1.0 mR 59.0±1.0 mR 61.1±1.0 mR 59.9±1.0 mR 61.9±0.9 mR
10	Dec-Apr, 1993 winter-spring	DOE	Idaho	Temp -32.8 to 12.8°C Snow 760 mm Altitude 1487 m HPIC 237±14 µGy	Cs-137 227±11 µGy and 637±17 µGy

HPIC : high pressure ionization chamber.

$$B = \text{bias} = \sum_{i=1}^n \frac{P_i}{n} \quad (2)$$

with

$$P_i = \frac{\text{measured dose} - \text{delivered dose}}{\text{delivered dose}} \quad (3)$$

(of i th dosimeter)

S = standard deviation

$$= \left[\frac{\sum_{i=1}^n (P_i - B)^2}{(n-1)} \right]^{1/2} \quad (4)$$

where n is number of dosimeters (to be specified for particular testing cases) and L is tolerance level. The tolerance level (L) is assumed to be 0.5.

This type of performance criterion is easily presented by so called HORLICK's triangle⁵⁾ with the bias plotted on the x axis and the standard deviation expressed on the y axis.

VI RESULTS AND DISCUSSION

1. International intercomparisons

The number of participants and dosimeters participated in the 10 international intercomparisons is shown in **Fig. 1**. In these tests dosimeters were exposed to natural environmental radiation and laboratory sources. The field conditions were usually harsh with temperatures ranging from -32.8 to 35.4°C , snow accumulating up to 760 mm, rainfall accumulating to 670 mm, altitude up to 1979 m, and high winds as well. **Table 1** summarizes all various

Table 2 Types of TLDs used in the intercomparison studies.

Material	
Single phosphor	Multiple phosphors
Low Z	LiB/LiF, LiF/CaF ₂ : Dy
BeO, LiF: Mg, Ti,	LiF/CaF ₂ : nat/NaCl,
LiF: Mg, Cu, P,	CaF ₂ : nat/NaCl,
Li ₂ B ₄ O ₇ : Cu,	CaSO ₄ : Tm/Li ₂ B ₄ O ₇ : Cu,
Li ₂ B ₄ O ₇ : Mn, Si,	CaSO ₄ : Dy/NaCl,
Al ₂ O ₃	CaSO ₄ /LiF,
High Z	CaSO ₄ : Dy/CaF ₂ : Dy
CaF ₂ : Dy, CaF ₂ : Mn,	
CaF ₂ : nat, CaSO ₄ : Dy,	
CaSO ₄ : Tm, Mg ₂ SiO ₄ : Tb	

Remarks: Z = atomic number, nat = natural

conditions in 10 intercomparisons. Though several dosimeter types were used by various participants all over the world, more than 70% of the participants sent TLDs for field dosimeters. The types of TLDs used are shown in **Table 2**, and the TLD readers used are shown in **Table 3**.

The intercomparison results are presented graphically in HORLICK's triangle mentioned previously and are shown in **Fig. 2**. Triangle encloses those within proposed ANSI N13-29 tolerance level of 0.5. One of our results (marked with NTHU) shows unexpectedly high in the laboratory tests because the raw material of CaSO₄ used had high sodium con-

Fig. 2 The HORLICK's triangle used to analyze the dosimetric performance in one of the laboratory tests.

Table 3 The readers used in the intercomparison studies.

1. TLD readers	
Name	Model
Eberline	TLR-5, TLR-6
EG&G	TL-2A, TL-2B, TL-3A, TL-3B, "A11"
Harshaw	2000A&2000B, 2000C&2000B, 2000C&2080, 2000D, 2000P, 3000A, 3000, 4000, 2271&2000B, 2276&2000B, CP-1112/PD, 8000C
Teledyne	7100, 7300, 8300, 8310, 9100, 9150
Victoreen	2800, 2810, 2600
National (Panasonic)	UD-505A, UD-502A,B, UD-710A,B,P, UD-705A, UD-701, UD-702A,D,E, UD-703A,UD-703AG, UD-802
China	FRG-1, FRG-2, RJ-25, SR-25
Vinten Toledo	654, 802, 806, 813
Krackow	748
Conrad	5100-A,B
Atomic Energy of Canada	AEP-5256A,B
TNO	TNO Automatic
Kyokko	1200, 2500
Pitman (Toledo)	Pitman Toledo "A11"
Studsvik	Auto 1313A,B
Toshiba	FGD-6, FGD-3B
NHZ	203, 204
Alnor	1313 (Studsvik)
RDL	78
TLD	04
X-Rite	301
LDT	20
Aloka	202
RDC MKIV	1000, 1100
Self-fabricated	
2. Other readers	
Name	Model
Densitometer	"A11"
Littlemore Scientific Engineering	Type 711
R.S. Randauer	Commercial service
Therados AB Uppsala	
Self-fabricated TSEE	

tent. However, the high sodium content in TLD did not show negative results in field test as shown in **Fig. 3**. Overall, the performance of our self-made $\text{CaSO}_4 : \text{Dy}$ was good reporting within 30% of the delivered dose for the field and laboratory exposures.

2. Domestic intercomparisons

Since there were four organizations participating in the domestic intercomparison studies during 1980–1984, the sample size in these intercomparison studies was quite small. However, the bias and stan-

dard deviation were still computed for each set of dosimeters either for laboratory or field results.

The results are also presented graphically in HORLICK's triangle. **Figure 4** shows the results of the laboratory test. Two types of TLD readers were used, one with preheat cycle (Teledyne) and the other without (Harshaw). No significant difference could be detected. Similar results were obtained for the field test held at the third site as shown in **Fig. 5**. **Figure 6** indicates the difference between the field

Fig. 3 The HORLICK'S triangle used to analyze the domestic performance in one of the field tests.

Fig. 4 Domestic comparisons between dosimetric performance with and without pre-heat cycle in laboratory test.

Fig. 5 Domestic comparisons between dosimetric performance with and without pre-heat cycle in field tests.

Fig. 6 Domestic comparisons between dosimetric performance with and without using monitoring post.

Fig. 7 Domestic comparisons between dosimetric performance at sites with and without nuclear reactor operation.

tests with and without monitoring post. The performance with monitoring post is a better choice. The results of field tests with and without nuclear reactors are shown in Fig. 7. All meet the $L=0.5$ criterion.

It is noted that the results of our TLDs in the laboratory test are within $\pm 20\%$ because the photon energies of the gamma sources are known. However, in the field tests the gamma energies are unknown while our TLDs were calibrated with gamma sources with energies assumed to be higher than the average gamma energy in the field, the test results of our TLDs are within $\pm 40\text{--}50\%$ not as good as the laboratory tests.

V CONCLUSION

Our self-fabricated TLD $\text{CaSO}_4 : \text{Dy}$ has passed the performance tests internationally and domestically as a good field dosimeter. The results of intercomparison show that the laboratory tests are better than the field tests. The choice of calibration source, therefore, is essential for TLD as a field dosimeter. In addition, extra amount of sodium in TLD may cause an unexpected result and this should be avoided.

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