Chapter 4 Appendix 4

# THERMOLUMINESCENCE MEASUREMENT OF GAMMA RAYS

## BY THE PRE-DOSE METHOD

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Gamma-ray dosimetry of Hiroshima atomic-bomb samples was done using the thermoluminescence (TL) pre-dose technique.[1] Samples used were wall tiles, roof tiles, and chimney tiles which were located between 1271 and 2051 m from the hypocenter. Two of these samples were parts of tiles that were analyzed by the quartz inclusion method (Chapter 4 Appendix 3). Another was collected at the same location as those used in quartz inclusion measurements. Results obtained with these three samples were compared with those obtained by the quartz inclusion method.

### Materials and Methods

**Samples.** Tile samples were collected from five buildings located at ground distances between 1271 and 2051 m. They are listed in Table 1. Samples H1 and H5-B, which were collected from the I-shaped building of Hiroshima University Faculty of Science (HUFS) and assessed by the quartz inclusion method, were also analyzed by pre-dose techniques. HP2 was collected from the same sample point on the rooftop of the E-shaped building of HUFS, from which one of the samples studied by the quartz inclusion method was collected. HP4 was a wall tile from the Red Cross Hospital and HP5 was a wall tile from the Hiroshima University Faculty of Engineering.

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**Table 1. Tile Samples Used**

| Sample | Building | Ground Distance (m) |
|---|---|---|
| H1 | I-shaped building of HUFS, rooftop railing | 1271 |
| H5-B | I-shaped building of HUFS, rooftop railing | 1298 |
| HP1 | E-shaped building of HUFS, wall | 1378 |
| HP2 | E-shaped building of HUFS, rooftop railing | 1388 |
| HP3 | E-shaped building of HUFS, wall | 1388 |
| HP4 | Red cross hospital, rooftop floor | 1451 |
| HP5 | HUFE, wall | 2051 |

**Sample Preparation.** Samples were prepared using nearly the same procedure as that for the quartz inclusion method (Chapter 4 Appendix 3). The effect of hydrofluoric (HF) acid etching was assessed using quartz grains washed in 10 % HF acid for three minutes. The reproducibility of the TL response of the 100° C peak of the HF-washed grains did not significantly differ from that of unetched grains. Practially no HF acid etching was produced during the present assessments. The grains of 74 to 149 $\mu$m were washed in diluted aqua regia for 24 hours at room temperature. Quartz grains about 3 mg in weight were attached to a silver foil 27 mg/cm$^2$ thick and 7 × 7 mm using an inorganic adhesive (Tranese 3000, Toray Co.). The inorganic adhesive and silver foil was heated to 600° C confirming that no photon emission occurred with or without $^{60}$Co gamma-ray irradiation.

**Measurements.** An improved Harshaw 2000 TL reader (600° C maximum temperature) was used for the analysis. Samples were heated at a rate of 5 or 10° C/s in an atmosphere of oxygen-free nitrogen.

A test dose was adminitstered by Gd-K x rays excited by x rays from a tungsten-target x-ray tube operated at 60 kV and 2 mA. No significant enhancement in the pre-dose peak due to the test dose was observed. An additive dose was administered using the $^{60}$Co gamma-ray irradiation facility at the Osaka Branch of the National Electro-Technical Institute.

**Characteristics of the Pre-dose Peak.** The TL glow curves of the 100° C peak for the wall tile sample HP1 of the E-shaped building of the HUFS are shown in Figure 1. In this figure, ($S_n$-$S_{ng}$) represents the quenching of the sensitivity $S_n$. Significant quenchings in $S_n$ were observed for the samples from the two buildings of HUFS.

The sensitivity increase of the peak as a function of activation temperature (activation test) was determined for each sample. It was observed that the characteristics of sensitivity enhancement differ from sample to sample. Therefore, thermal activation was done at a temperature between 500° C and 600° C appropriate for each sample.

Tests of sensitivity growth of the peak were made as a function of additional dose. Samples were exposed to $^{60}$Co gamma rays in addition to the A-bomb and background (BD) radiation doses. When each sample was irradiated only once, the linear relation between sensitivity enhancement and additional dose was observed to 300 rad additional dose.

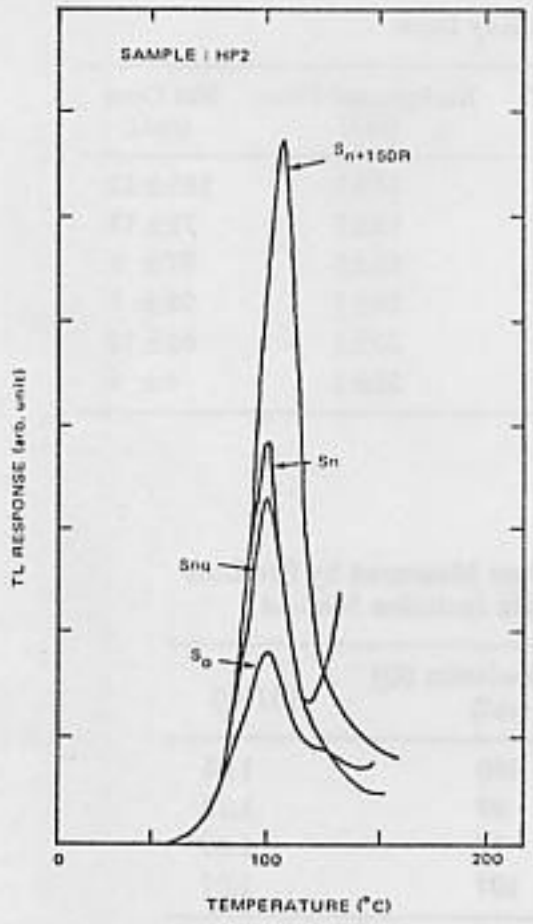


*Figure 1. TL glow curves of the pre-dose peak. $S_o$, $S_n$, and $S_{n+150R}$ represent the sensitivities for zero pre-dose, A-bomb, and background radiation doses, A-bomb and background radiation doses plus $^{60}Co$ gamma rays for calibration, respectively. $S_n - S_{nq}$ represents radiation quenching of $S_n$.*

**Analytical Procedure.** Considering the results of these prepartory experiments, analyses were made by the following two procedures.

Procedure A: (1) heat to 150° C, (2) test dose, measurement of $S_o$, (3) thermal activation in an $N_2$ atmosphere, (4) test dose, measurement of $S_n$, (5) thermal activation (in $N_2$), (6) additive dose, (7) heat to 150° C, (8) test dose, measurement of $S_{ng}$, (9) thermal activation (in $N_2$), and (10) test dose, measurement of $S_{n-150R}$.
Procedure B: (1) heat to 150° C, (2) test dose, measurement of $S_o$, (3) thermal activation (in $N_2$), (4) test dose, measurement of $S_n$, (5) additive dose, (6) thermal activation (in $N_2$), (7) test dose, measurement of $S_{n+150R}$.

In procedure A, radiation quenching in sensitivity enhancement was considered.[2] Additive dose was given with doses limited so that the 100° C peak sensitivity enhancement was proportional to the ED plus additional dose.

**Measurement of Background Dose.** Background-dose evaluations were made using TL dosimeter grains of $CaSO_4$:Tm. The procedure was the same as that of TL dosimetry using the quartz inclusion technique (Chapter 4 Appendix 2).

**Results and Discussion**

The results obtained are shown in Table 2. ED is the equivalent $^{60}Co$ gamma-ray dose including background radiation dose (BD), and GD is BD and the net dose obtained by

Table 2. Gamma Ray Dose

| Sample Number | Ground Distance (m) | Total Dose[a] (rad) | Background Dose (rad) | Net Dose (rad) |
|---|---|---|---|---|
| H1 | 1271 | 169± 9 | 14±1 | 155± 12 |
| HP1 | 1378 | 89± 10 | 18±1 | 71± 13 |
| HP2 | 1388 | 115± 8 | 18±1 | 97± 9 |
| HP3 | 1388 | 114± 5 | 18±1 | 98± 9 |
| HP4 | 1451 | 82± 11 | 20±1 | 62± 12 |
| HP5 | 2051 | 29± 5 | 23±1 | 6± 6 |

[a]Errors are standard deviations.

Table 3. Comparison of Total Dose Measured by Pre Dose Method with those by Quartz Inclusion Method

| Sample | Pre Dose (P) (rad) | Quartz Inclusion (Q) (rad) | (P)/(Q) |
|---|---|---|---|
| H1 | 169 | 160 | 1.06 |
| H5-B[a] | 115 | 97 | 1.19 |
| H5-B[b] | 104 | 97 | 1.07[b] |
| HP2 | 115 | 107 | 1.07 |
| | | average | 1.10±0.06 |

[a]Perpendicular side of tile H5.
[b]Value obtained by analytical procedure (B).

subtracting BD from ED, respectively. All values listed here were obtained by analytical procedure A.

ED obtained by the pre-dose method were compared with the dose measured by the quartz inclusion method for the same samples. Pre-dose values are about 14 % larger than the quartz inclusion values, on the average (Table 3).

## References

1. Fleming, S. J., 1970. Thermoluminescent dating: refinement of the quarta inclusion method. Archeometry 12:133-145.
2. Aitken, M. J., 1979. Pre-dose dating: prediction from the model. PACT 3:319-324.