J. RADIAT. RES., 33, 211–217 (1992)

Comparison of the Measured Gamma Ray Dose and the DS86 Estimate at 2.05 km Ground Distance in Hiroshima

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(Received November 29, 1991)
(Revision Received June 15, 1992, Accepted June 19, 1992)

TL Dosimetry/γ Ray/Atomic Bomb/Hiroshima/DS86
The gamma ray dose at 2.05 km ground distance from the Hiroshima atomic bomb hypocenter was measured from roof tile samples by a thermoluminescence technique. Two tile samples collected at 2.45 km also were analyzed to check the reliability of the background estimates. The result for the 2.05 km distance was 129±23 mGy for five-tile sample average. This value is 2.2 times larger than the corresponding DS86 estimate. These results and those in the literature show the DS86 estimate is 50% or less of the measured value 2.05 km from the Hiroshima hypocenter.

INTRODUCTION

The dosimetry system used for the atomic bomb (A-bomb) survivors in Hiroshima and Nagasaki was reassessed, and the summarized results reported in 1987 as dosimetry system 1986 (DS86)[1]. This DS86 system has been used to re-analyze the epidemiological information gathered on A-bomb survivors registered at the Radiation Effects Research Foundation (RERF)[2,3]. DS86 provides gamma ray dose estimates that are much closer to the measured gamma doses than those obtained using the previous dose system (tentative 1965 dose [T65D]).

The discrepancies between the measured gamma ray doses and DS86 estimates in Hiroshima, however, are not negligible, especially at ground distances more than 1.3 km from the hypocenter.

In 1987, Ichikawa et al.[4] reported experimental dose estimates of the gamma rays from the Hiroshima A-bomb based on measurements of the thermoluminescence (TL) intensities of quartz grains extracted from tile samples collected from the roofs of two buildings at Hiroshima University, located between 1.27 and 1.46 km from the hypocenter. Their estimates were +15% larger on the average than estimates based on Loewe's calculations[5] (Loewe's calculations are close with the DS86). Gamma doses also were measured by Nagatomo et al.[6] and Maruyama et al.[7]. Their results also mostly exceed the corresponding DS86 estimates. More recently, the TL method has been used by Hoshi et al. for tiles collected at ground distances between 1.91 and 2.05 km[8]. They suggested that DS86 understimates gamma ray doses by about 70% in that distance range from the hypocenter.

To compensate for these discrepancies, it is necessary to make additional estimates of the radiation doses received at Hiroshima by using experimental techniques sensitive enough to detect low doses. Accurate dose assessments at ground distances of from 1 to 2 km also are needed for epidemiological studies because most A-bomb survivors registered at the RERF were exposed to radiations at these distances.

The only method that measures the Hiroshima A-bomb gamma ray dose with sufficient accuracy beyond 1.5 km ground range is the TL techinique. Although detection of low A-bomb doses at more than 1.5 km from the hypocenter may be possible through the use of sensitive techniques such as electron spin resonance (ESR) and neutron-induced activity measurements, the dose limit of detection for the ESR technique is higher by two orders than that for the TL technique. Moreover, the data obtained from neutron-induced activity measurements lie within the 1.5 km ground range (e.g., Nakanishi et al.[9]).

Extant ceramic samples beyond 1.5 km from the hypocenter are very rare because almost all structures were burned down at the time of detonation (Hoshi et al.[8]). Fortunately, roof tile samples that had been collected but not analyzed have been preserved. We analyzed these samples in order to obtain accurate data at about 2 km from the hypocenter to use in the discussion of the validity of the DS86 estimates.

MEASUREMENTS

The roof tiles were collected from two Japanese homes; Hiramoto house (2.05 km from the hypocenter) and Kirihara house (2.45 km from the hypocenter), which respectively were built 48 and 66 years before the measurements. The locations and physical characteristics of the samples are given in Table 1. Detailed information is given by Hoshi et al.[8]

Table 1. Location and characteristics of the roof tile samples

Sample	Notation	Thickness (cm)	Direction	Location[a]	Ground[b] Distance (m)	Approximate Height from the Ground (m)
Hiramoto "Oni-gawara"	A	1.5	West Southwest	742.15×1262.05	2053	4.8
Kirihara	B1	1.7	West Northwest	741.73×1262.48	2453	—[c]

[a] Coordinates were estimated from the U.S. Army Map Service map, series L902, plate number 138,449. Numbers are east-west and north-south coordinates.

[b] From the hypocenter of Hubbell et al.[10] used in the A-bomb reevaluation.

[c] Unknown.

The total exposure (A-bomb gamma exposure plus natural background exposure) of each sample was evaluated by the TL method. The TL technique used was the quartz inclusion method which assays quartz grains of about 0.1 mmϕ extracted from tile samples.

To determine the total exposure equivalent to ^{60}Co gamma ray exposure, the TL intensities of 15-mg quartz grain samples were compared with those of 15 mg samples of known exposure given by a ^{60}C source. TL glow curves are shown in Fig. 1 for a Hiramoto roof tile with and without irradiation by ^{60}Co gamma rays.

The natural background (BG) exposures of the tile samples were estimated with $CaSO_4$: Tm phosphors (Matsushita Industrial Equipment Co. Ltd.). Because the alpha component of natural BG exposure is negligible in the quartz inclusion method, the beta, gamma and cosmic ray components in BG exposure were measured. Total BG exposure was obtained by the summaiton of these values.

Details of the experimental procedures used to prepare the quartz samples and to determine the total and BG exposures are given in Ichikawa et al.[4] The artificial irradiation procedure for calibration with a ^{60}Co source is described in Hoshi et al.[11]

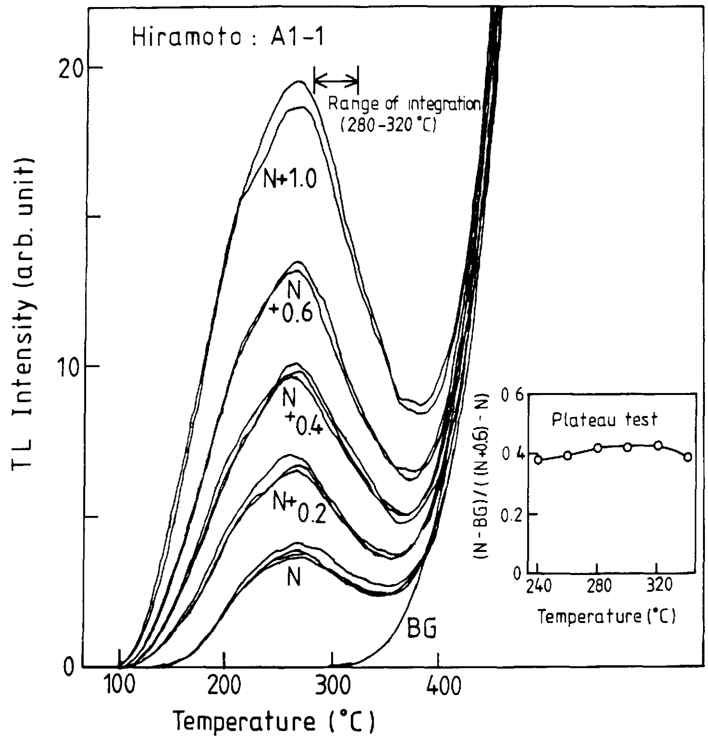

Fig. 1. Thermoluminescence glow curves and the plateau test. The sample is a Hiramoto roof tile. Notation: N, N+0.2 and N+0.4 indicates glow curves for samples given respective ^{60}Co gamma ray doses of 0, 0.2 and 0.4 Gy.

RESULTS AND DISCUSSION

Results given in units of ^{60}Co equivalent exposure (Ckg^{-1}) are shown in Table 2. Supralinear relations of the TL response vs. the induced dose occasionally are observed in the low dose region.[12] Supralinearity corrections are given in the fourth column of Table 2. In the sixth and seventh columns the net doses are given in units of exposure and tissue kerma. A factor of 36.8 $GykgC^{-1}$ was used to convert exposure into soft tissue kerma in Gy units for the ICRU muscle component[13].

Table 2. Gamma ray exposures from the Hiroshima A-bomb at ground distances of 2.05 and 2.45 km from the hypocenter

Sample[a]	Ground Distance (m)	Equivalent Exposure (mC/kg)		Supralinearity Correction (mC/kg)		Background Exposure (mC/kg)		Net Dose			
								Exposure (mC/kg)		Tissue Kerma[b] (mGy)	
A1-1	2053	6.3	±0.6	0.0	±1.0	2.9	±0.3	3.4	±1.1	126	±42
A1-2	2053	5.1	±0.7	1.0	±0.6	2.9	±0.3	3.2	±0.7	119	±26
A1-3	2053	6.2	±0.3	0.4	±1.6	2.9	±0.3	3.7	±1.7	135	±61
A2	2053	5.5	±0.4	1.0	±0.4	3.0	±0.3	3.6	±0.6	132	±22
A3	2053	5.8	±0.4	0.1	±0.6	3.3	±0.2	2.6	±0.7	95	±27
A4-1	2053	5.7	±0.7	0.2	±0.8	2.9	±0.3	2.9	±1.1	108	±40
A4-2	2053	7.4	±1.7	0.3	±0.3	2.9	±0.3	4.5	±1.8	165	±65
A5	2053	5.9	±0.7	1.1	±0.7	2.9	±0.2	4.1	±0.9	152	±34
B1-1	2453	3.5	±0.3	0.0	±0.8	3.8	±0.4	−0.3	±1.0	−10	±35
B1-2	2453	3.2	±0.3	0.1	±0.3	3.8	±0.4	−0.5	±0.6	−18	±21

[a] A1-1, A1-2 and A1-3 signify different portions of roof tile A1. A4-1, A4-2, B1-1 and B1-2 are identical.
[b] Tissue kerma values obtained by multipying the exposure by the factor 36.8 $GykgC^{-1}$.

Figure 2 compares our results for the Hiramoto tile samples with DS86 estimates. A closed circle shows the result of Hoshi et al.[8] The average kerma for out data is 129±23 mGy; of 2.2 times larger than the corresponding DS86 estimate of 59 mGy. The results indicate that the difference in the present and DS86 values is similar to that reported by Hoshi et al.[8] They estimated that the respective gamma doses 1.91 and 2.05 km from the hypocenter were 2.1 and 1.7 times the DS86 values.

Two tile samples from the Kirihara house, located 2.45 km from the hypocenter, also were analyzed. The net doses found and earllier values[8] are shown together with the corresponding DS86 values in Figure 3. Our results, −10±35 and −18±21 mGy, agree with the previous value of −7±20 mGy within acceptable experimental error. These low values suggest that the A-bomb gamma ray dose at a distance of 2.45 km or more is so low as to be indistinguishable from the natural BG dose measured by the present method. The fact that the measured net dose at 2.45 km is smaller than the corresponding DS86 value, 14.7 mGy suggests that the net doses estimated 2.05 km from the hypocenter in Hiramoto tile samples are not overstimated.

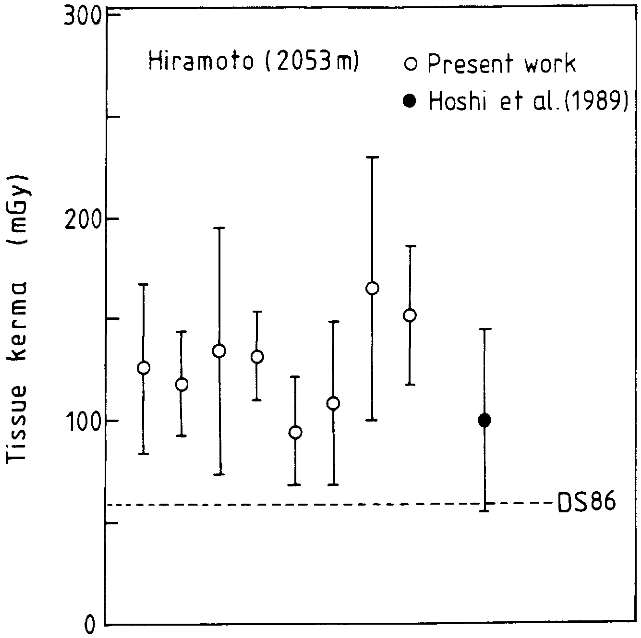

Fig. 2. Tissue kerma values at 2.05 km ground distance from the hypocenter (the Hiramoto house). Our measured values are shown by ○ and that of Hoshi et al.[8] by ●. The dashed line shows the theoretical DS86 estimate.

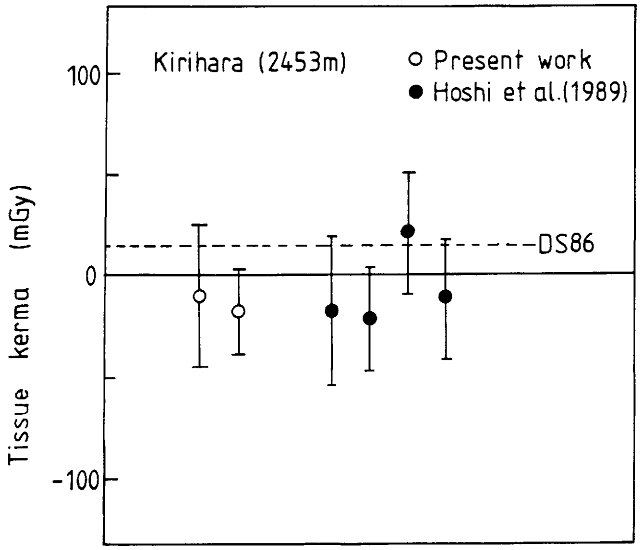

Fig. 3. Tissue kerma values at 2.45 km ground distance from the hypocenter (the Kirihara house). Our measured values are shown by ○ and those of Hoshi et al.[8] by ●. The dashed line shows the theoretical DS86 estimate.

The results of our study and those of Hoshi et al.[8] provide strong evidence that the DS86 gamma ray dose found for a ground distance 2.05 km from the Hiroshima hypocenter underestimates the actual value by 50% or more.

ACKNOWLEDGEMENTS

One of research group, Professor Yoneta Ichikawa, died during the course of this study. We deeply regret his death and are sincerely grateful for the very important contributions he made to this series of studies on A-bomb dosimetry in Hiroshima and Nagasaki. We also thank Professor S. Kondo for his continuous encouragement. Moreover, we are indebted to Mr. and Mrs. Kirihara, and to Mr. and Mrs. Hiramoto for the gifts of the roof tiles. We wish also to acknowledge the help and information concerning sample collections given by Mr. Yamada (deceased) and Mr. Watanabe at RERF. This research was supported in part by grants from the Ministry of Education, Science and Culture, Japan; the Ministry of Health and Welfare, Japan; and the Asahi Shimbun Foundation.

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