Chapter 4 Appendix 11

CALCULATION OF DOSE IN QUARTZ FOR COMPARISON WITH THERMOLUMINESCENCE DOSIMETRY MEASUREMENTS

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Gamma radiation from the atomic bombs detonated over Hiroshima and Nagasaki left a record in the quartz grains constituent to the tile and brick in city structures. That record has been read to determine the gamma-ray dose deposited in these grains, using thermoluminescence (TL) dosimetry techniques (see Chapter 4).

Because the quartz grains are imbedded in dense tile and brick material located on structures of complex geometry, the dose in quartz is not an exact measure of the free-field kerma (see Chapter 3 for a discussion of "free field" quantities). Therefore, calculations of dose deposition in the quartz grains were performed, using the same free-field fluence data and shielding computation methods as those incorporated in the dosimetry system delivered to the Radiation Effects Research Foundation (RERF) in 1986 (Chapters 7 and 9). This report presents a summary description of the experimental results, including total dose and background dose, as well as the salient features of the tiles and brick, including their locations on the various structures. The report provides a description of the approach used to calculate the dose to the quartz in the tile and brick samples, as well as a detailed tabulation of the calculated dose, including the contribution from each component of A-bomb radiation. Finally, the report provides a comparison of DS86 and T65D dose values with measured results and a discussion of issues raised in the process of that comparison.

Thermoluminescence Measurements

TL measurements were performed by the following organizations as part of the project to reassess Japanese A-bomb survivor doses:

Nara University of Education (NUE) (Chapter 4 Appendixes 2 to 5)
National Institute of Radiological Sciences (NIRS) (Chapter 4 Appendix 1)

University of Utah (UU) (Chapter 4 Appendix 6)
Oxford University (Chapter 4 Appendix 8)
Durham University (Chapter 4 Appendix 7)

The parameters for these measurements, including distance from the hypocenter, sample description, thickness, density, and depth from which the quartz grains were taken are given in Tables 1 to 3 for Hiroshima and Table 4 for Nagasaki. Table 4 also includes the ground

Table 1. Nara University of Education Thermoluminescent Dosimetry Sample Specifications for Hiroshima

Sample	Distance(m) Army Map	Distance(m) New City Map	Description	Thickness (cm)	Density (g/cm^3)	Depth (cm)
1-04	526.3	523.4	Naka Telephone Building, Railing Tile	1.15	2.1	0.2-1.05
2-03	695.0	691.8	Chugoku Electric Company, Wall Tile	1.3	2.0	0.2-1.2
145	1135.7	1131.2	House Roof Oni-Gawara Tile	21.0	2.0	0.1-1.5
4-08	1265.0	1271.3	Hiroshima University Primary School, Railing Tile	2.6	1.87	0.2-2.5
4-07	1276.0	1282.1	Hiroshima University Primary School, Facia Tile	2.6	1.87	0.2-2.5
4-09	1291.1	1297.7	Hiroshima University Primary School, Railing Tile	2.6	1.87	0.2-2.5
4-01	1309.7	1316.5	Hiroshima University Primary School, Facia Tile	2.6	1.87	0.2-2.5
4-03	1331.1	1338.1	Hiroshima University Primary School, Railing Tile	2.6	1.87	0.2-2.5
3-08	1373.5	1378.4	Hiroshima University Fac. of Sci., Wall Tile	2.0	2.00	0.2-1.9
3-11	1383.8	1388.5	Hiroshima University Fac. of Sci., Wall Tile	2.0	2.00	0.2-1.9
3-20	1384.0	1387.9	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.10	0.2-1.9
3-36	1392.0	1393.1	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.10	0.2-1.9
3-18	1415.6	1422.0	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.10	0.2-1.9
3-17	1422.2	1427.9	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.10	0.2-1.9
3-15	1444.2	1450.5	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.10	0.2-1.9
3-35	1444.8	1449.1	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.10	0.2-1.9
5-01	1449.7	1451.8	Red Cross Hospital, Wall Tile	1.5	2.00	0.2-1.4
3-16	1456.2	1460.9	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.10	0.2-1.9
6-04	1571.6	1602.9	Chokin Kyoku, Wall Tile	0.8	2.05	0.2-0.7
8-01	2046.1	2050.5	Hiroshima University Fac. of Technology, Wall Tile	1.75	2.00	0.2-1.65

Table 2. National Institute of Radiological Sciences Thermo- luminescent Dosimetry Sample Specifications for Hiroshima

Sample	Distance(m) Army Map	Distance(m) New City Map	Description	Thickness (cm)	Density (g/cm^3)	Depth (cm)
1-01	508.5	506.8	Naka Telephone Building, Railing Tile	1.2	2.1	0.4-0.9
1-19	529.1	523.1	Naka Telephone Building, Wall Tile	1.5	2.0	0.6-1.3
12-02	618.5	621.0	San In Bank, Wall Tile	1.35	2.1	0.4-1.05
2-01	673.0	665.4	Chugoku Electric Company, Step Tread Tile	1.32	2.0	0.4-1.00
2-03	695.0	691.8	Chugoku Electric Company, Wall Tile	1.22	2.0	0.4-0.8
3-07	1372.1	1377.0	Hiroshima University Fac. of Sci., Wall Tile	2.0	2.0	0.5-1.5
3-10	1382.8	1387.4	Hiroshima University Fac. of Sci., Wall tile	2.0	2.0	0.5-1.5
3-29	1419.1	1424.9	Hiroshima University Fac. of Sci., Wall Tile	2.0	2.0	0.5-1.5
3-31	1420.2	1426.1	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.1	0.5-1.5
3-35	1444.8	1449.1	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.1	0.5-1.5
5-01	1449.7	1451.8	Red Cross Hospital, Wall Tile	1.85	2.0	0.5-1.5
5-00	1607.0	1605.7	Chokin Kyoku, Roof Tile	2.20	2.1	0.5-1.5

Table 3. University of Utah, Oxford University, and Durham University Thermoluminescent Dosimetry Sample Specifications for Hiroshima

Sample	Distance(m) Army Map	Distance(m) New City Map	Description	Thickness (cm)	Density (g/cm^3)	Depth (cm)
3-23	1388.7	1392.8	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.1	0.25-1.75
3-22	1392.0	1397.0	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.1	0.25-1.75
3-21	1421.8	1427.9	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.1	0.25-17.5
3-25	1427.7	1433.2	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.1	0.25-1.75
3-35[a]	1444.8	1449.1	Hiroshima University Fac. of Sci., Floor Tile	2.0	2.1	0.25-1.75
3-24	1452.1	1456.9	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.1	0.25-1.75
3-27	1452.5	1457.2	Hiroshima University Fac. of Sci., Kick Tile	2.0	2.1	0.25-1.75
3-26	1455.7	1460.4	Hiroshima University Fac. of Sci., Railing Tile	2.0	2.1	0.25-1.75

a. Measurements performed by all three universities, remaining samples measured by University of Utah only.

Table 4. Thermoluminescent Dosimetry Sample Specifications for Nagasaki

Sample	Distance(m) Army Map	Distance(m) New City Map	Elevation[a]	Description	Thickness (cm)	Density (g/cm³)	Depth (cm)
NUE							
N-2-1a	1437.0	1431.9	9.7	Ieno Wall Brick	10.5	1.7	0.2-3.6
b						1.7	3.6-7.0
c						1.7	7.0-10.4
NIRS							
N-4	505.8	521.5	21.0	Urakami Church Wall Brick	-	1.7	0.5-1.5
N-6	1069.8	1066.4	27.4	Sakamoto Grave Wall Brick	-	1.7	0.5-1.5
N-7	1432.4	1426.4	8.0	Zenza Grave Wall Brick	10.8	1.7	0.5-1.5
N-2-1a	1437.0	1431.9	9.7	Ieno Wall Brick	10.5	1.7	0.5-1.5
b							1.0-3.0
c							3.0-5.0
d							5.0-7.0
e							7.0-9.0
f							9.0-10.2
g							0.5-2.0
h							3.5-5.0
i							6.5-8.0
j							9.5-10.2
N-2-2a	1438.8	1434.0	9.7	Ieno Wall Brick, behind house	22 (including 1 cm grout)	1.7	0.5-1.5
b							0.8-2.3
c							6.8-8.3
d							14.3-15.8
e							20.3-21.8
N-3-1	2045.1	2049.8	-2.4	Inasa Warehouse Wall Brick	-	1.7	0.5-1.5
-2	2047.0	2050.9	-2.4				0.5-1.5
-3	2047.0	2050.9	-2.4				0.5-1.5
-4	2058.4	2061.7	-2.4				0.5-1.5
N-8	2344.4	2327.5	21.0	Chikugo Grave Wall Brick	10.8	1.7	0.5-1.5
University of Utah							
N-2-1a	1437.0	1431.9	9.7	Ieno Wall Brick	10.5	1.7	0.4-3.6
b							3.7-6.9
c							7.0-10.2
Oxford University and Durham University							
N-2-1a	1437.0	1431.9	9.7	Ieno Wall Brick	10.5	1.7	0.3-3.2
b							3.4-6.4
c							6.6-10.3

Table 5. National Institute of Radiological Sciences (1967) Thermoluminescent Dosimetry Sample Specifications for Hiroshima and Nagasaki

Sample	Distance(m) Army Map	Distance(m) New City Map	Description	Thickness (cm)	Density (g/cm³)	Depth (cm)
Hiroshima						
1	130.2	146.2	Building Wall Tile	2.1	2.0	1.0-2.0
2	130.3	118.6	Building Roof Tile	2.1	2.1	1.0-2.0
3	168.9	175.4	Building Wall Tile	2.1	2.0	1.0-2.0
4	415.1	406.4	Building Wall Tile	2.1	2.0	1.0-2.0
5	610.2	617.5	Building Wall Tile	2.1	2.0	1.0-2.0
6	707.5	710.0	Building Wall Tile	2.1	2.0	1.0-2.0
7	957.0	985.5	Building Wall Tile	2.1	2.0	1.0-2.0
Nagasaki						
1	89	88	Building Roof Tile	2.1	2.1	1.0-2.0
2	496	508	Building Wall Tile	2.1	2.0	1.0-2.0
3	719	713	Building Wall Tile	2.1	2.0	1.0-2.0
4	873	866	Building Wall Tile	2.1	2.0	1.0-2.0
5	899	891	Building Wall Tile	2.1	2.0	1.0-2.0
6	937	935	Building Wall Tile	2.1	2.0	1.0-2.0
7	975	973	Building Wall Tile	2.1	2.0	1.0-2.0

elevation relative to that at the hypocenter for each Nagasaki sample location. The ground elevation is required to preserve the proper separation between epicenter and sample in the calculation. Table 5 provides similar data for TL measurement results published in 1967 by NIRS[1] for locations at both cities. Contemporary data published by NUE[2] have not been matched with calculations due to large uncertainties in sample location, configuration, and orientation relative to the hypocenter.

Distances from sample locations to the hypocenter at each city were determined for two map systems, US Army Maps, circa 1945, and new city maps produced in the 1970s.[3] The hypocenter for each city for the two map systems are as follows:

Hiroshima		
Army Map:	44.298 ×	61.707
New Map:	26.7350 ×	−178.3995
Nagasaki		
Army Map:	93.624 ×	65.936
New Map:	34.2475 ×	−25.3945

Distances reported in Table 1 for Hiroshima University Attached Primary School sample locations according to the Army Map have changed due to an apparent error in the Army Map representation of the length of that building. As changed, all samples are located in terms of Army Map coordinates according to actual building dimensions, relative to the sample from that building closest to the hypocenter (Sample 4-08).

The density of the tiles and bricks are generally twice that of water. The quartz grain samples were taken from depths of 2 cm or more. Therefore, the amount of radiation that reaches these quartz grains is sensitive to the angle between the normal to the surface of incidence and a line from that surface to the epicenter. That angle depends on the distance from the hypocenter, orientation of the building, and orientation of the tile on the building. As referred to in Tables 1 to 5, railing, roof, and step tread tiles were parallel to the ground plane, although there are two exceptions to this convention, as will be described later. Wall and fascia tiles were oriented perpendicular to the ground plane.

The measurement results are presented in summary form in Tables 6 to 10. Results are given in the units originally presented by each group and as converted to dose in quartz [denoted rad(SiO_2)]. Dose in quartz was chosen as the quantity to measure that was most nearly proportional to the TL signal from the quartz, and, therefore, as most appropriate to calculate. However, the laboratories monitored their measurements with detectors calibrated for other quantities, usually the exposure (in roentgens).

The conversion from roentgens to rad(SiO_2) was determined by modeling the experimental configurations of the calibration facility of each laboratory, including the source, facing material, sample, and backing material. All of the laboratories except UU used ^{60}Co sources. UU used ^{137}Cs. Calculations were performed to determine the exposure in roentgens and the dose in rad(SiO_2) at the monitor/sample site. The results of the calculations indicate the conversion factor to be 0.87 ± 0.02 rad(SiO_2) per roentgen for all laboratories. This value is essentially that determined directly from the mass-energy absorption coefficients for air and quartz for gamma rays of the energy emitted by the sources. Therefore, the value 0.87 rad/R was used with no attempt made to propagate the calculational error. In the case of NIRS, the published results had been converted to dose in tissue by multiplying the exposure in roentgens by 0.95 rad/R. Therefore, the conversion factor used to obtain the NIRS data in rad(SiO_2) is 0.916. Some of the NUE results had also been converted from exposure to dose in tissue prior to being reported using a conversion factor of 0.96 rad(tissue)/R; therefore, the conversion factor the authors used to obtain the dose in quartz from these values was 0.906.

Table 6. Nara University of Education TLD Measurements at Hiroshima

Sample	Distance Army Map (m)	Reported Dose			Quartz Dose [rad(SiO₂)]	
		Gross	Background	Net	Net	Adj. Net[a]
1-04 (3-3)	526.3	3088±276[b]	20±3[c]	3068±276	2780	2724
(4-2)		2945±352[b]	20±3	2925±352	2651	2597
(4-3)		2898±418[b]	20±3	2878±418	2608	2556
2-03 (1-3)	695.0	1281±150[b]	21±3	1260±150	1142	1119
(1-3)		1089±85[b]	21±3	1068±85	968	948
(2-2)		1104±72[b]	22±3	1082±72	981	961
(2-2)		1137±77[b]	22±3	1115±77	1010	990
(2-3)		1068±100[b]	22±3	1046±100	948	929
145	1136.7	192±11[b]	20±10[c]	172±15	156	152
4-08	1265.0	167±8[d]	15±2	152±8	132	129
		169±9[b,e]	14±1	155±11	140	137
4-07	1276.0	172±15[d]	15±2	157±15	137	134
4-09	1291.1	168±22[d]	15±2	153±22	133	130
4-01	1309.7	134±25[d]	15±2	119±25	104	101
4-03	1331.1	122±16[d]	15±2	107±16	93	91
		97±unk[b,f]	14±1	83±unk	75	73
		115±unk[b,e,f]	14±1	101±unk	92	89
		104±unk[b,e,f]	14±1	90±unk	82	80
3-08	1373.5	89±10[b,e]	19±2	70±10	63	62
3-11	1383.8	115±8[b,e]	19±2	96±8	87	85
3-20	1384.0	109±17[d]	18±2	91±17	79	77
		107±5[d]	18±2	89±5	77	76
		117±6[d]	18±2	99±6	86	84
		114±5[b,e]	17±2	97±5	88	86
3-36	1392.0	102±12[d]	21±2	81±12	70	69
3-18	1415.6	94±6[d]	18±2	76±6	66	64
3-17	1422.2	85±6[d]	18±2	67±6	58	57
3-15	1444.2	101±13[d]	18±2	83±13	72	70
		96±7[d]	18±2	78±7	68	66
		89±11[d]	18±2	71±11	62	60
		96±7[d]	18±2	78±7	68	66
3-35	1444.8	75±15[b]	18±2	57±15	52	51
5-01	1449.7	82±11[b,e]	20±1	62±11	56	55
3-16	1456.2	70±6[d]	18±2	52±6	45	44
6-04	1571.6	55±6[b]	14±2	41±6	37	36
8-01	2046.1	29±5[b,e]	23±1	6±5	5.4	4.9

a. Calibration Adjustment: Gross*0.98-Background.
b. Reported as tissue dose(rad), conversion to quartz dose: rad*.87/.96.
c. Estimated.
d. Reported as roentgens, conversion to quartz dose: roentgens*.87.
e. Predose Method, other measurements performed by high temperature method.
f. Sample taken from vertical portion of tile.

Table 7. National Institute of Radiological Sciences TLD Measurements at Hiroshima

Sample	Distance Army Map (m)	Reported Dose (tissue dose)[a]			Quartz Dose [rad(SiO₂)]	
		Gross	Background	Net	Net	Adj. Net[b]
1-01	508.5	3030±270	19±10[c]	3011±270	2757	2757
1-19	529.1	3330±170	19±10[c]	3311±170	3032	3032
12-02	618.5	1960±170	19±10[c]	1941±170	1778	1778
2-01	673.0	800±110	19±10[c]	781±110	714	714
2-03	695.0	1050±170	20±2	1030±170	943	943
3-07	1372.1	115±7	17±2	98±7	90	90
3-10	1382.8	127±20	17±2	110±20	101	101
3-29	1419.1	120±13	17±2	103±13	94	94
3-31	1420.2	97±5	20±2	77±5	70	70
3-35	1444.8	123±17	17±2	106±7	97	97
5-01	1449.7	75±10	17±2	58±10	53	53
6-00	1607.0	52±7	20±2	32±7	30	30

a. Reported as tissue dose(rad), conversion to quartz dose: rad*.87/.95.
b. Calibration Adjustment: Gross*1.0-Background (no effective adjustment).
c. Estimated.

The quartz in each tile or brick sample has been accruing dose from natural sources, including alpha particle, beta particle, and gamma-ray sources within the tile and surrounding media, and cosmic radiation. That background dose was reset to zero when the ceramic material was fired and has been accruing ever since, over periods of 50 years or more.

Background dose rates were measured for most sample locations by one or more laboratories. The uncertainties associated with the total background dose are generally dominated by uncertainty in the age of the building or, more specifically, the date when the ceramic

Table 8. University of Utah, Oxford University, and Durham University TLD Measurements at Hiroshima

Sample	Distance Army Map (m)	Reported Dose (quartz dose) Gross	Background	Net	Quartz Dose [rad(SiO$_2$)] Net	Adj. Net[a]
3-23	1388.7	106±3	19±2	87±4	87	99
3-22	1392.0	110±7	19±2	91±7	91	103
3-21	1421.8	Not reported				
3-25	1427.7	14±1	19±2	-5±2	-5	-3.5
3-35	1444.8	78±5	16±2	62±5	62	71
		74±8	16±2	58±8	58	66
		84±10[b]	16±2	68±10	68	73
		87±9[b]	16±2	71±9	71	76
		87±7[b]	16±2	71±7	71	76
		77±9[c]	16±2	61±9	61	68
		78±9[c]	16±2	62±9	62	69
3-24	1452.1	83±4	19±2	64±5	64	73
3-27	1452.5	67±7	19±2	48±7	48	55
3-26	1455.7	25±1	19±2	6±2	6	8.8

a. Calibration adjustment:
University of Utah: Gross*1.11-Background
Oxford University: Gross*1.06-Background
Durham University: Gross*1.09-Background
b. Oxford University Measurements.
c. Durham University Measurements.

Table 9. Thermoluminescence Dose Measurements at Nagasaki

Sample	Distance Army Map (m)	Reported Dose Gross	Background	Net	Quartz Dose [rad(SiO$_2$)] Net	Adj. Net
NUE[a]						
N-2-1a	1437.0	125±1	16±3	109±3	99	97
b	1437.0	112±1	16±3	96±3	87	86
c	1437.0	107±1	16±3	91±3	82	81
NIRS[b]						
N-4	505.8	4430±480	19±10[c]	4411±480	4040	4040
N-6	1069.8	775±96	19±10[c]	756±96	692	692
N-7	1432.4	116±24	17±3	99±24	91	91
N-2-1a	1437.0	132±21	16±3	116±21	106	106
a		130±22	16±3	114±22	104	104
b		131±22	16±3	115±22	105	105
c		121±17	16±3	105±17	96	96
d		101±9	16±3	85±9	78	78
e		85±12	16±3	69±12	63	63
f		72±15	16±3	56±15	51	51
g		132±21	16±3	116±21	106	106
h		118±19	16±3	102±19	93	93
i		96±10	16±3	80±10	73	73
j		90±5	16±3	74±6	68	68
N-2-2a	1438.8	71±7	16±3	55±8	50	50
b		71±7	16±3	55±8	50	50
c		65±18	16±3	49±18	45	45
d		31±10	16±3	15±10	14	14
e		35±7	16±3	19±8	17	17
N-3-1	2045.1	45±7	32±7	13±10	12	12
-2	2047.0	33±4	32±7	1±8	0.9	0.9
-3	2047.0	27±5	32±7	-5±9	-4.6	-4.6
-4	2058.4	32±13	32±7	0±15	0	0
N-8	2344.4	21±15	22±5	-1±16	-0.9	-0.9
University of Utah[d]						
N-2-1a	1437.0	97±4	15±3	82±5	82	93
b	1437.0	79±2	15±3	64±4	64	73
c	1437.0	66±1	15±3	51±3	51	58
Oxford University[e]						
N-2-1a	1437.0	95±10	15±3	80±10	80	85
b	1437.0	80±9	15±3	65±9	65	70
c	1437.0	73±8	15±3	58±8	58	62
Durham University[f]						
N-2-1a	1437.0	95±10	15±3	80±10	80	89
a	1437.0	110±6	15±3	95±6	95	105
b	1437.0	85±9	15±3	70±9	70	78
b	1437.0	78±4	15±3	63±5	63	70
c	1437.0	70±9	15±3	55±9	55	61
c	1437.0	82±4	15±3	67±5	67	74

a. Dose reported in units of tissue dose, conversion to quartz dose: tis. dose*.87/.96; adjustment factor 0.98.
b. Dose reported in units of tissue dose, conversion to quartz dose: tis. dose*.87/.95, adjustment factor 1.00.
c. Estimated.
d. Dose reported in units of quartz dose; adjustment factor 1.11.
e. Dose reported in units of quartz dose; adjustment factor 1.06.
f. Dose reported in units of quartz dose; adjustment factor 1.09.

Table 10. National Institute of Radiological Sciences (1967) TLD Measurements for Hiroshima and Nagasaki

Sample	Distance Army Map (m)	Reported Dose[a]			Quartz Dose [rad(SiO_2)]	
		Gross	Background[b]	Net	Net	Adj. Net[c]
Hiroshima						
1	130.2	7723+505	19+10	7704+505	7055	7055
2	130.3	9166±349	19±10	9147±349	8377	8377
3	168.9	6863±370	19±10	6844±370	6268	6268
4	415.1	3534±168	19±10	3515±168	3219	3219
5	610.2	1426±71	19±10	1407±71	1289	1289
6	707.5	948±78	19±10	929±78	851	851
7	957.0	310±18	19±10	291±18	266	266
Nagasaki						
1	89	22304+558	19+10	22285+558	20408	20408
2	496	5794±163	19±10	5775±163	5289	5289
3	719	3856±19	19±10	3837±19	3514	3514
4	873	1503±140	19±10	1484±140	1359	1359
5	899	1349±80	19±10	1330±80	1218	1218
6	937	859±72	19±10	840±72	769	769
7	975	756±15	19±10	737±15	675	675

a. Reported as tissue dose(rad), conversion to quartz dose: rad*.87/.95.
b. Estimated.
c. No adjustment.

was fired. In those cases for which no background estimate is available from any laboratory, an estimate of 20 ± 10 R [17 rad(SiO_2) or 19 rad(tissue)] was used. This value is representative of many measured background values, and its use is thought to be preferable to a zero estimate.

All of the laboratories measured doses in samples from the Hiroshima University Faculty of Science. Therefore, it is of interest to obtain consistent background dose estimates to apply to all such measurements. The background dose rates (in quartz, rad per year) reported by all the laboratories and their given or assumed locations are as follows:

Laboratory	Location	Beta	Gamma
NUE	floor	0.236 ± 0.006	0.077 ± 0.004
NIRS	wall	0.243 ± 0.029	0.115 ± 0.037
University of Utah	railing	0.262 ± 0.006	
	floor	0.170 ± 0.017	
Oxford University	floor	0.210 ± 0.021	
Durham University	floor	0.193 ± 0.019	

It is expected that tiles of different origins should have different beta-particle backgrounds but that the gamma-ray backgrounds should be relatively uniform from tiles from a given building. Therefore, for the purpose of comparing measurements with calculations at the Faculty of Science site the following representative background dose rates were adopted:

Sample Location	Dose rate (rad(SiO_2) per year)		
	Beta	Gamma	Total
Wall	0.243 ± 0.029	0.096 ± 0.027	0.339 ± 0.040
Railing	0.262 ± 0.015	0.096 ± 0.027	0.358 ± 0.031
Floor	0.202 ± 0.028	0.096 ± 0.027	0.298 ± 0.039

The gamma-ray dose rates and the beta-particle dose rates to the floor are mean values. The age of the building was 52 ± 2 years. Thus, the representative background doses reflected in Tables 6 to 8 are as follows:

	Background Dose		
Sample Location	rad(SiO_2)	rad(tissue)	Roentgens
Wall	18	19	20
Railing	19	20	21
Floor	16	17	18

All values have an associated uncertainty of approximately ± 2 rad (or R), standard error.

In the case of the Ieno-cho wall location at Nagasaki, only NIRS has reported background measurements. Thus, those background values are assigned to all Ieno-cho wall measurements.

Experimental precision values are presented for completeness. However, since these values represent only a portion of the true uncertainty of the measurement, no attempt was made to carry them through the measurement-calculation process.

Measurement results for each laboratory are presented as reported (net) and as adjusted using correction to the gross dose measurement as determined by a laboratory intercalibration experiment using Mg_2SiO_4:Tb TLDs irradiated at the the National Bureau of Standards (Chapter 4 Appendix 10). The adjustment factors thus determined are as follows:

NUE	0.98
NIRS	1.00
University of Utah	1.11
Oxford University	1.06
Durham University	1.09

The adjustments apply only to the gross measured quantities and not to the background. Therefore, the adjusted net is obtained by subtracting the background from the product of the gross measurement and the adjustment factor. Note that no adjustment factor is available for the NIRS 1967 data; however, the more recent NIRS data required no adjustment.

The inclusion of the NIRS 1967 values in this study may seem controversial, since there is no way to perform intercalibration or other verification/validation studies using the same techniques or instruments. However, their data were used to provide justification for the T65D system; and, therefore, are of legitimate interest in the present study. Further, modern measurements by Oxford University, using undifferentiated tile samples, not unlike those used in the NIRS 1967 approach, provide results that are quite consistent with those obtained using more modern techniques.

Calculation of Depth Dose in Brick and Tile. Calculation of dose to the quartz grains in tiles and bricks was performed using the fluences of prompt neutrons and gamma rays, secondary gamma rays, delayed gamma rays, and delayed-neutron secondary gamma rays whose calculation is described in Chapter 3. The yields of the Hiroshima and Nagasaki A-bombs were assumed to be 15 and 21 kt, respectively (Chapter 1).

Transport of radiation into the tile was performed by the Monte Carlo method, using the technique of forward-adjoint coupling. That technique allows the transport of externally incident radiation to a detector location in a complex geometry, such as that of a structure to which a tile is attached, to be correlated with a free-field fluence, thereby obtaining a result in the combined system. The quantity that facilitates that correlation is called the adjoint fluence. It may be convoluted with the forward, free-field fluence to obtain the fluence at the detector site, according to the expression:

$$\phi(E') = \int_S \int_E \int_\Omega \phi(S, E, \Omega)\phi^*(S, E \rightarrow E', \Omega) n \cdot \Omega d\Omega dE dS \qquad (1)$$

where $\phi(E')$ is the mean energy-differential fluence in the detector volume, $\phi(S, E, \Omega)$ is the energy- and angle-differential fluence over some surface S surrounding the complex geometry shielding system, and $\phi(S, E \rightarrow E', \Omega)$ is the adjoint fluence tallied on that same surface, relating energy- and angle-differential fluence on that surface to energy-differential fluence in the detector volume. The same method was used to calculate structure (Chapter 7) and survivor self-shielding (Chapter 8) in the DS86 system.

Calculations were carried out using the DLC-31 cross section and kerma library,[4] which has an energy group structure as presented in Table 11. The kerma in quartz is presented in Table 12. The quartz and the surrounding medium were assumed to have the same composition and electronic equilibrium was assumed in the two. The Monte Carlo transport

Table 11. Neutron and Gamma-ray Energy Boundaries for the 37-21 Coupled Neutron-gamma Library

Group #	Neutron Group (eV) Energy	Neutron Group (eV) Lethargy	Gamma Group (eV) Energy	Gamma Group (eV) Eff. Avg.
1	1.96+7	-0.675	1.40+7	1.20+7
2	1.69+7	-0.525	1.00+7	9.00+6
3	1.49+7	-0.400	8.00+6	7.50+6
4	1.42+7	-0.350	7.00+6	6.50+6
5	1.38+7	-0.325	6.00+6	5.50+6
6	1.28+7	-0.250	5.00+6	4.50+6
7	1.22+7	-0.200	4.00+6	3.50+6
8	1.11+7	-0.100	3.00+6	2.75+6
9	1.00+7	0.000	2.50+6	2.25+6
10	9.05+6	0.100	2.00+6	1.75+6
11	8.19+6	0.200	1.50+6	1.25+6
12	7.41+6	0.300	1.00+6	8.50+5
13	6.38+6	0.450	7.00+5	5.75+5
14	4.97+6	0.700	4.50+5	3.75+5
15	4.72+6	0.750	3.00+5	2.25+5
16	4.07+6	0.900	1.50+5	1.25+5
17	3.01+6	1.200	1.00+5	8.50+4
18	2.39+6	1.433	7.00+4	5.57+4
19	2.31+6	1.467	4.50+4	3.75+4
20	1.83+6	1.700	3.00+4	2.50+4
21	1.11+6	2.200	2.00+4	1.50+4
22	5.50+5	2.900	1.00+4	
23	1.50+5	4.150		
24	1.11+5	4.500		
25	5.25+4	5.250		
26	2.48+4	6.000		
27	2.19+4	6.125		
28	1.03+4	6.875		
29	3.35+3	8.000		
30	1.23+3	9.000		
31	5.83+2	9.750		
32	1.01+2	11.500		
33	2.90+1	12.750		
34	1.07+1	13.750		
35	3.05+0	15.000		
36	1.13+0	16.000		
37	4.14-1	17.000		
Lower Bound	1.00-5	27.631		

*Read as 1.96×10^7.

Table 12. Gamma-ray Kerma in Quartz (SiO_2)

Group	Upper Energy (MeV)	KERMA [Rad(SiO_2) per unit fluence]
1	14.0	3.224-9*
2	10.0	2.448-9
3	8.0	2.065-9
4	7.0	1.828-9
5	6.0	1.600-9
6	5.0	1.369-9
7	4.0	1.131-9
8	3.0	9.488-10
9	2.5	8.219-10
10	2.0	6.862-10
11	1.5	5.330-10
12	1.0	3.892-10
13	0.7	2.724-10
14	0.45	1.773-10
15	0.30	1.021-10
16	0.15	5.835-11
17	0.10	5.440-11
18	0.07	8.142-11
19	0.045	1.895-10
20	0.030	4.483-10
21	0.020	1.447-09
	0.010	

*read as 3.224×10^{-9}.

code MORSE[5] was used to perform the neutron and gamma-ray adjoint transport calculations in the sample systems. The forward-adjoint coupling was performed using the VCS Code System,[6] which is also the basis of the DS86 shielding calculations.

The geometry systems describing the location of the tile and brick samples were modeled after the structures on which the tiles were located, in those cases where such information was available. Structure modeling was limited to those features which were thought to have an effect on TL measurements. Computer-generated pictures of the structures and structure detail as modeled in the calculations are presented in Figure 1 to 19, as follows:

Hiroshima

Naka Telephone Office	Hiroshima University Attached Primary School
San-In Bank	Hiroshima University Faculty of Science
Chugoku Electric Company	Hiroshima University Faculty of Technology
Postal Savings Bureau	House (Oni-gawara Tile)
Red Cross Hospital	

Nagasaki

Ieno-cho Wall

The perspective views are from the direction of the epicenter.

Figure 1 shows dimensions of and sample location on the Naka Telephone Office. Samples 1-01 and 1-04 are horizontal tiles on the railing; sample 1-19 is a vertical wall tile. Figure 2 shows dimensions of and sample location on the San-In Bank. Sample 12-02 is a vertical wall tile.

Figure 3 shows the dimensions of and sample location on the Chugoku Electric Company.

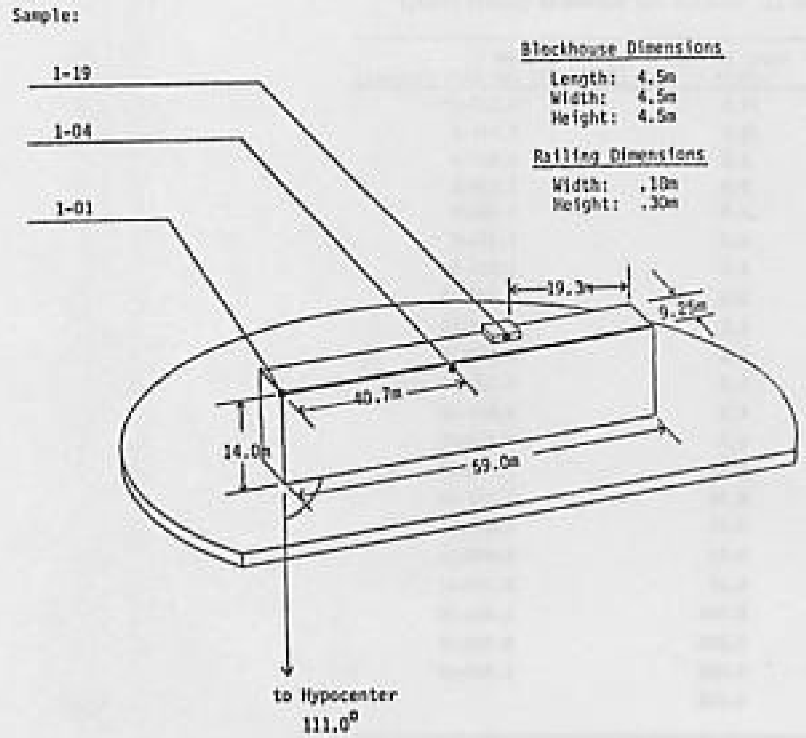

Figure 1. Naka Telephone Office

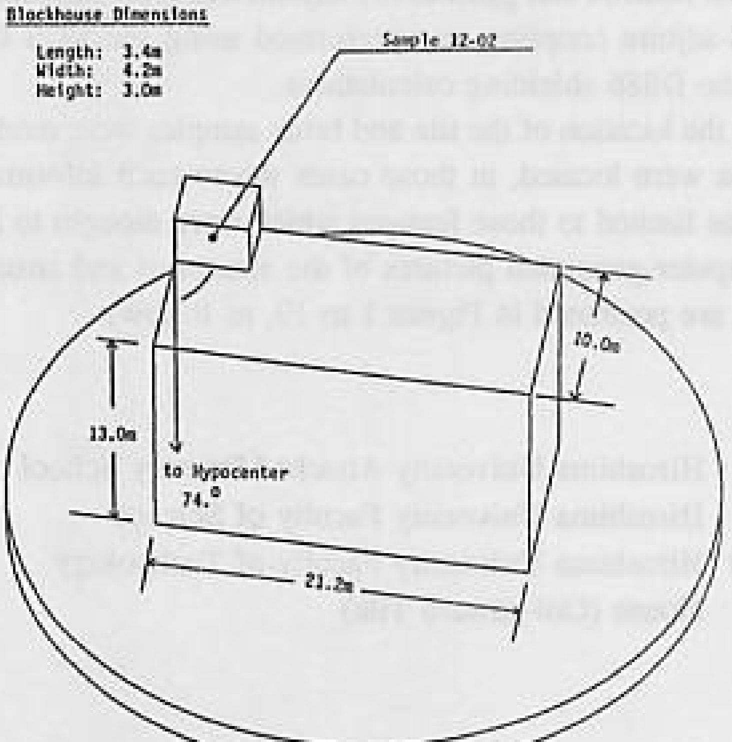

Figure 2. San In Bank

Sample 2-01 is on the horizontal surface of the second step of the stairwell, indicated in the Figure 4 detail as 2-4. Sample 2-03 is actually several vertical tiles located at the far end of the window-well as shown in Figure 5 detail. The tile measured by NIRS is 1-2. Those measured by NUE are 1-3, 2-2, and 2-3. The calculation was performed for tile 1-2.

Figure 6 shows the dimensions of and sample location on a Japanese house. The location of the Oni-gawara decorative roof ridge-end tile is approximated by sampling from a region

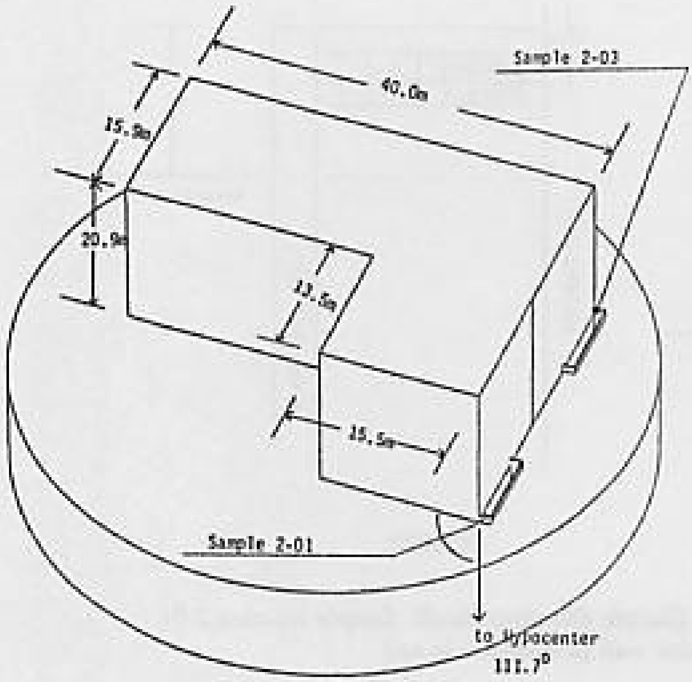

Figure 3. Chugoku Electric Company

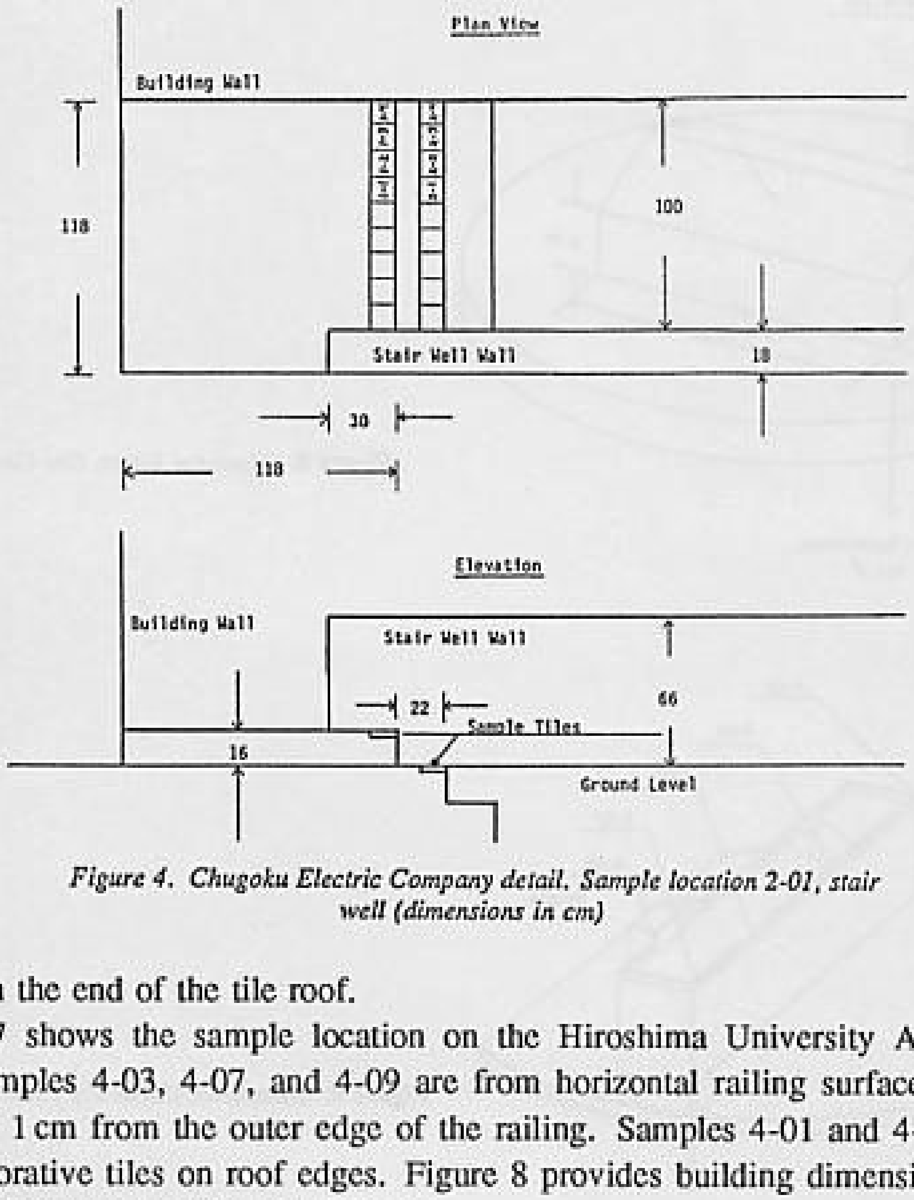

Figure 4. Chugoku Electric Company detail. Sample location 2-01, stair well (dimensions in cm)

1.0 cm from the end of the tile roof.

Figure 7 shows the sample location on the Hiroshima University Attached Primary School. Samples 4-03, 4-07, and 4-09 are from horizontal railing surfaces beginning approximately 1 cm from the outer edge of the railing. Samples 4-01 and 4-08 are fascia or vertical decorative tiles on roof edges. Figure 8 provides building dimensions as modeled. Figure 9 provides the location of samples.

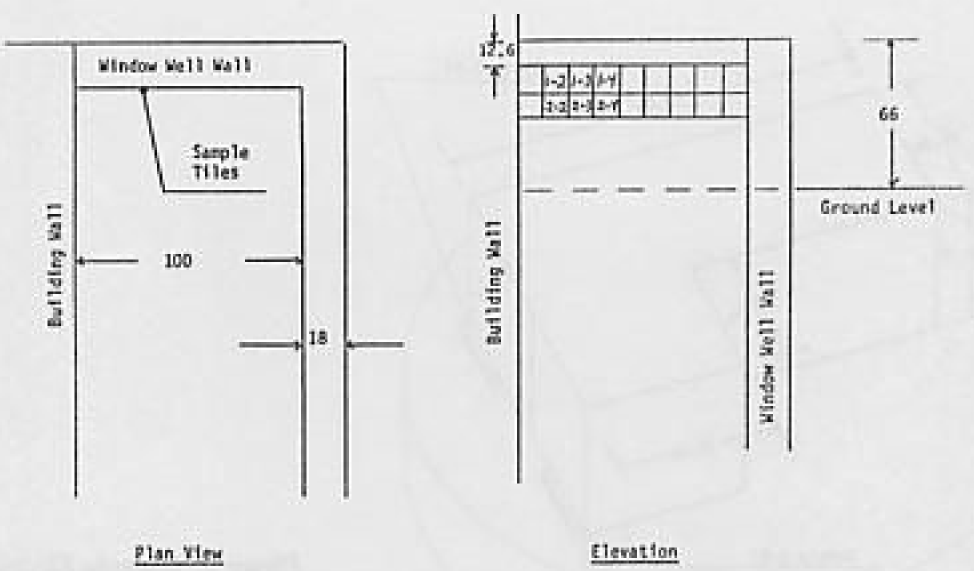

Figure 5. Chugoku Electric Company detail. Sample location 2-01, window well (dimensions in cm)

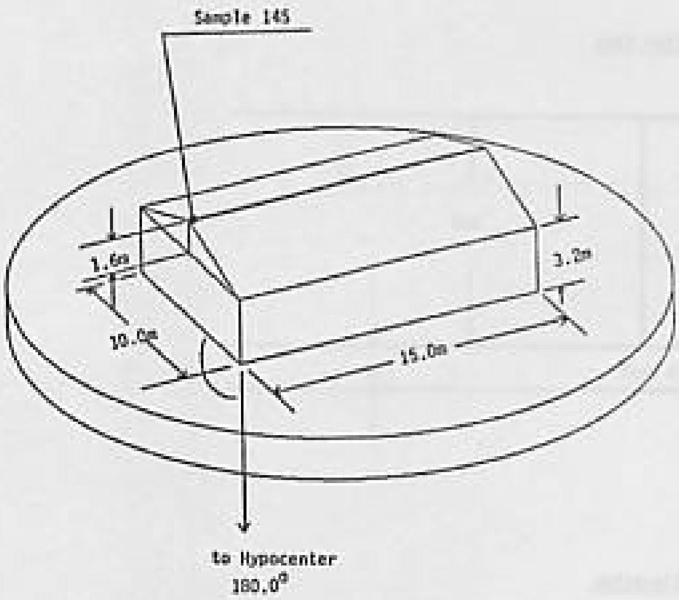

Figure 6. Japanese house, Oni-Gawara tile

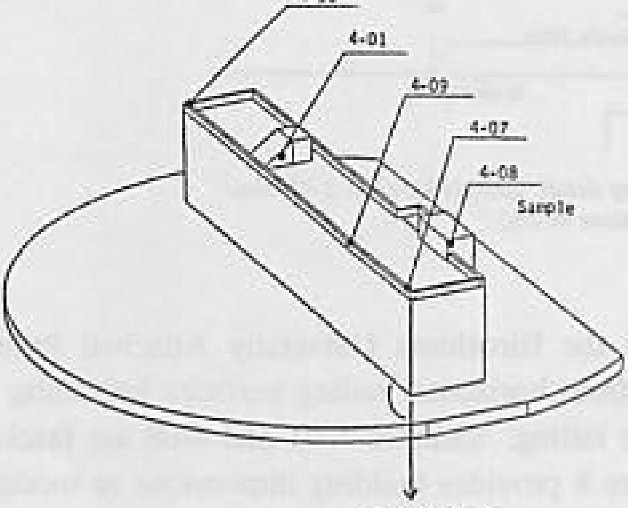

Figure 7. Hiroshima University Primary School

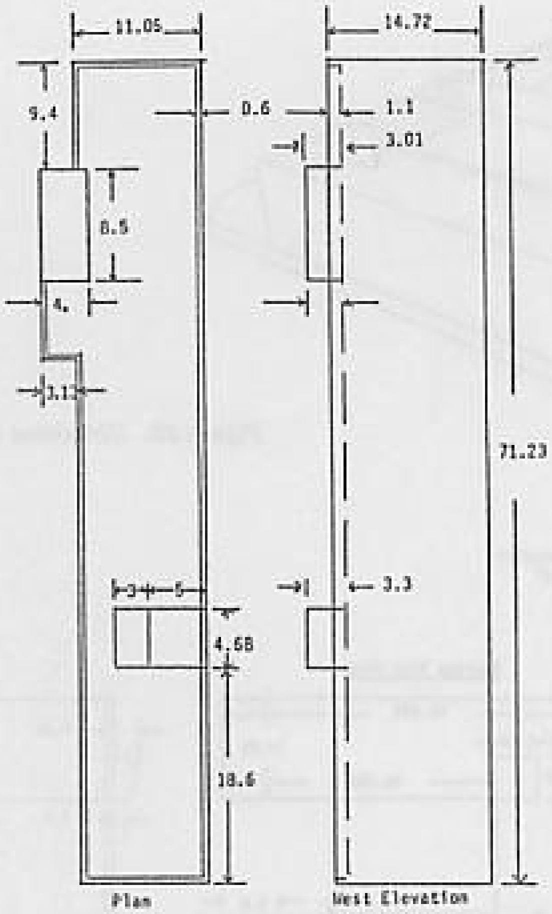

Figure 8. Hiroshima University Primary School, (in m)

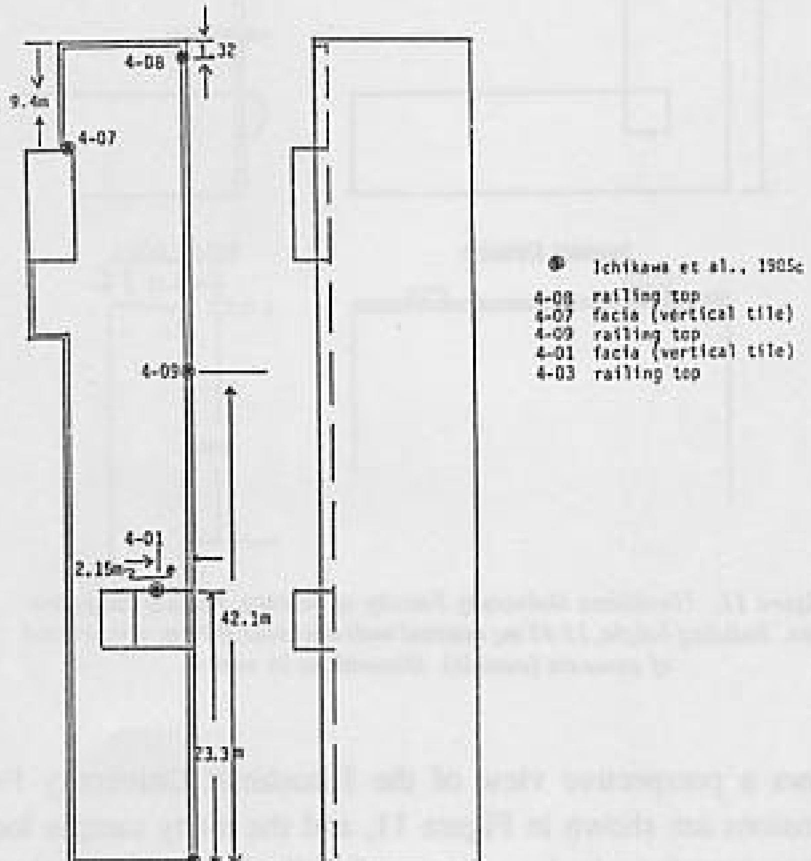

Figure 9. Hiroshima University Primary School showing TLD sample locations

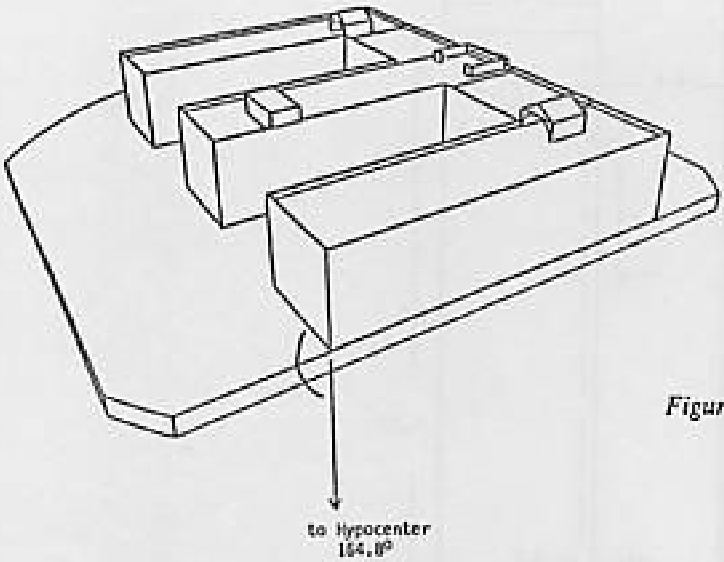

Figure 10. Hiroshima University Faculty of Science

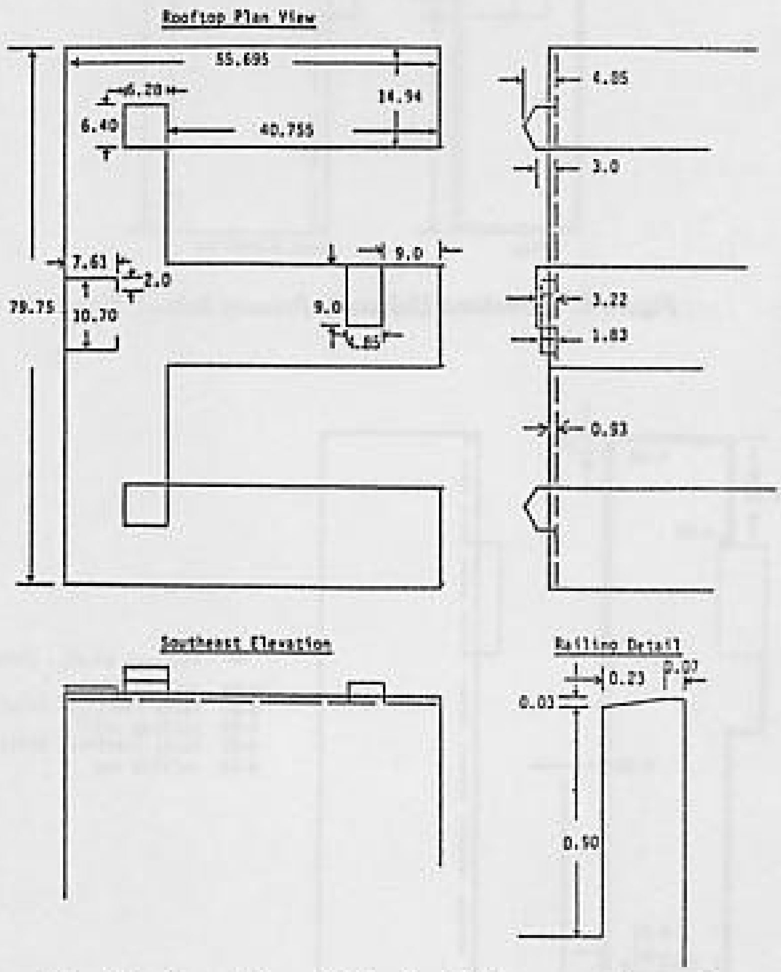

Figure 11. Hiroshima University Faculty of Science, rooftop configuration. Building height, 13.43 m; internal wall thickness, 60 cm; constructed of concrete (outside). Dimensions in meters

Figure 10 shows a perspective view of the Hiroshima University Faculty of Science building. Its dimensions are shown in Figure 11, and the many sample locations are shown in Figure 12. Railing samples take into account the tile tilt toward the inside of the railing. Samples 3-25 and 3-26 are from heavily shielded locations; 3-25, behind a wall; and 3-26, behind a pillar. Sample 3-27 is a vertical trim or "kick tile" at the base of another pillar.

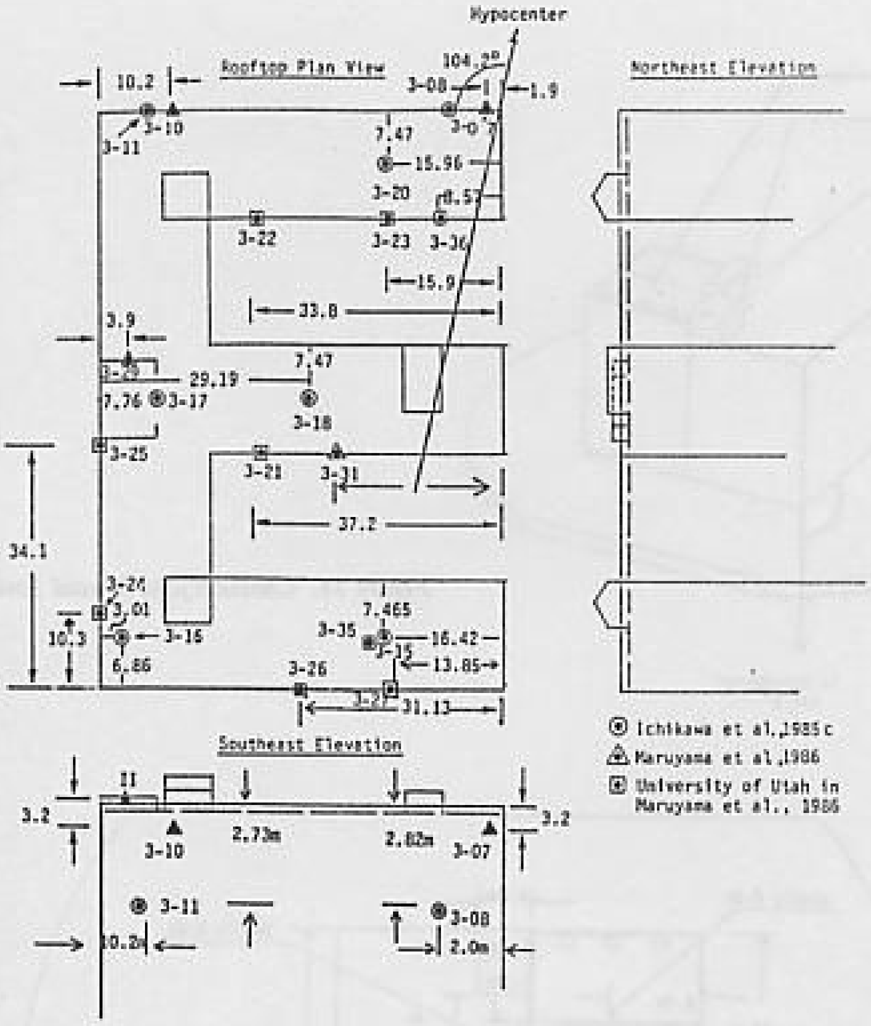

Figure 12. Hiroshima University Faculty of Science, TLD sample locations (dimensions in m)

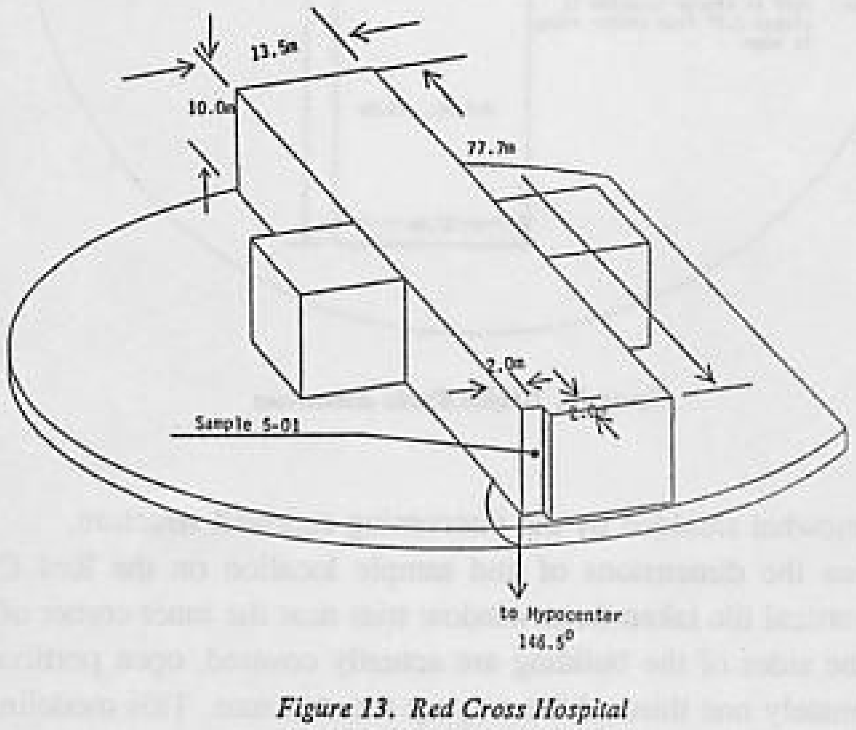

Figure 13. Red Cross Hospital

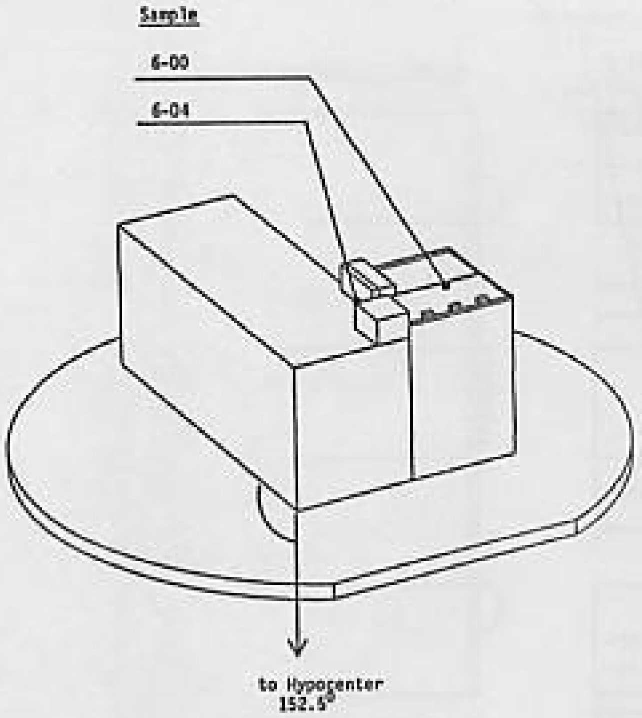

Figure 14. Chokin Kyoku (Postal Savings Bureau)

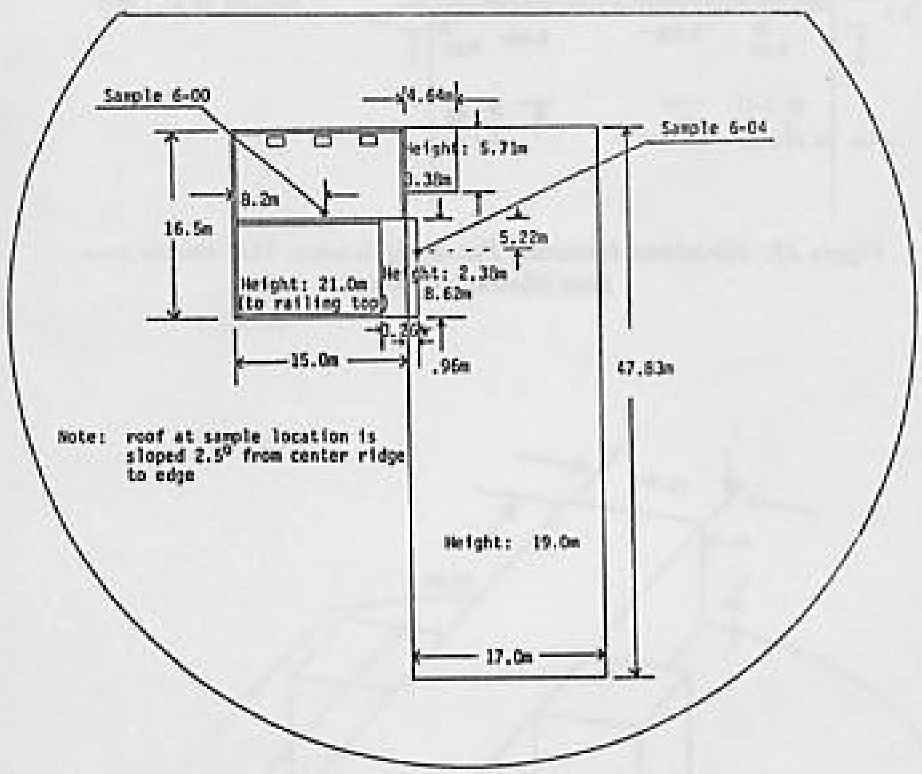

Figure 15. Chokin Kyoku dimensions

Sample 3-16 is somewhat shielded by the intervening stairwell structure.

Figure 13 shows the dimensions of and sample location on the Red Cross Hospital. Sample 5-01 is a vertical tile taken from window trim near the inner corner of the wall. The protrusions from the sides of the building are actually covered, open porticoes with a roof beginning approximately one third of the way up the structure. This modeling error should not affect the sample calculation, given its location.

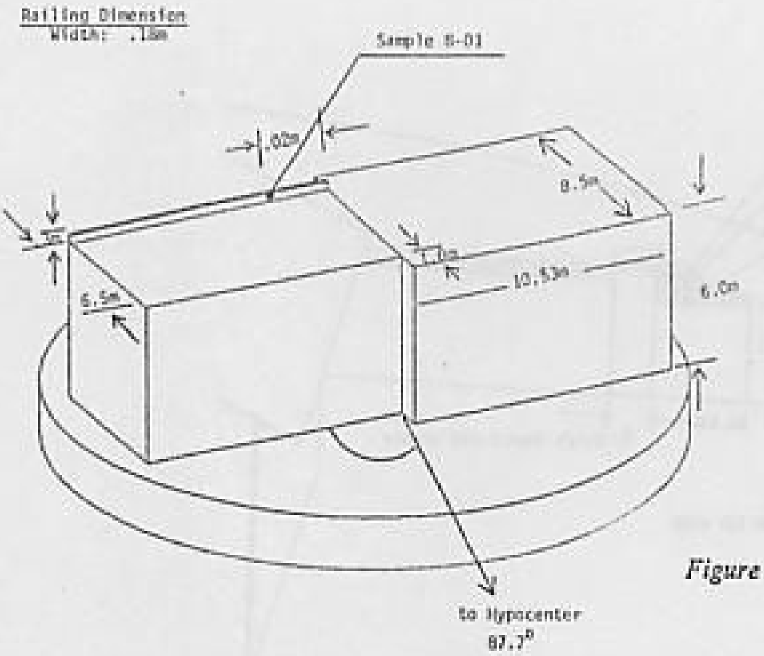

Figure 16. Hiroshima University Faculty of Technology

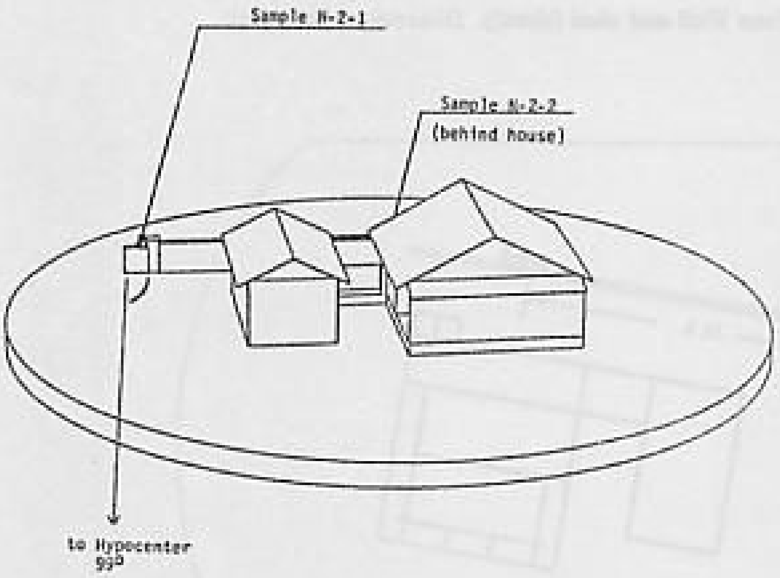

Figure 17. Ieno Wall, house, and shed

Figures 14 and 15 show perspective and plan views of the Postal Saving Bureau (Chokin Kyoku). Sample 6-00 is located near the peak of a slightly slanted roof surface. Sample 6-04 is located at the base of a blockhouse on a corner molding to the left of an entry door. It is shielded by the second blockhouse.

Figure 16 shows dimensions of and sample location on the Hiroshima University Faculty of Technology. Sample 8-01 is located on the inside vertical surface of the railing around the roof.

Figures 17 to 19 provide a perspective view, detail, and plan view, respectively, of the Ieno-cho Wall, house, and shed. As shown in Figure 18, calculations were performed for three individual bricks, modeled together with their grout, corresponding to samples used by various laboratories. Figure 19 shows the location of the shielded sample N-2-2, which is located in that portion of the wall that is two bricks thick, plus 1.0 cm of grout.

Other locations in which shielding geometry is less well known have been modeled more simply. The tile samples of Hashizume et al[1] were assumed to be located on buildings

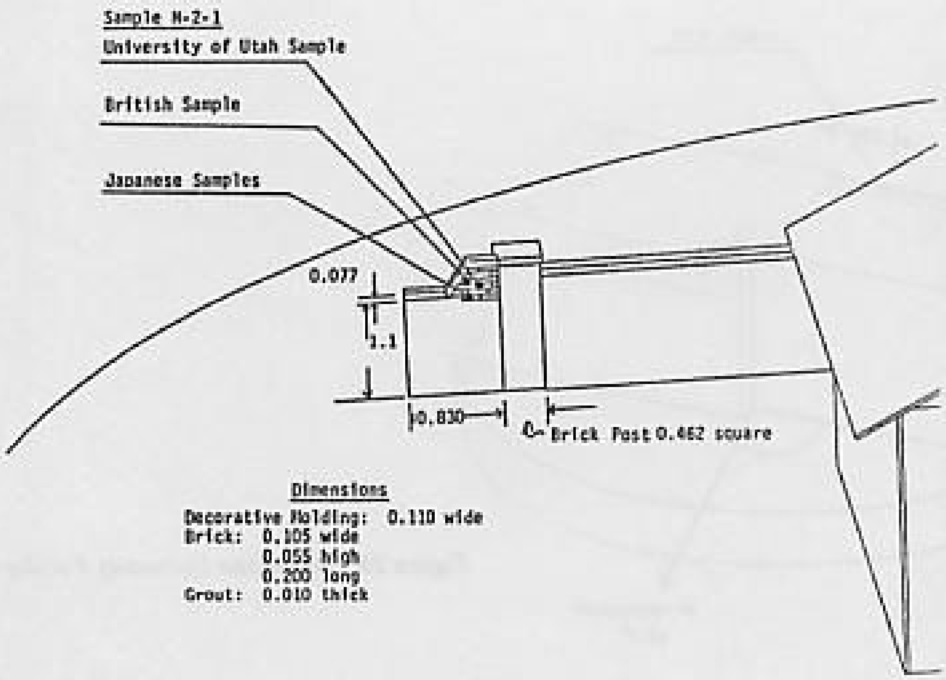

Figure 18. Ieno Wall and shed (detail). Dimensions in meters

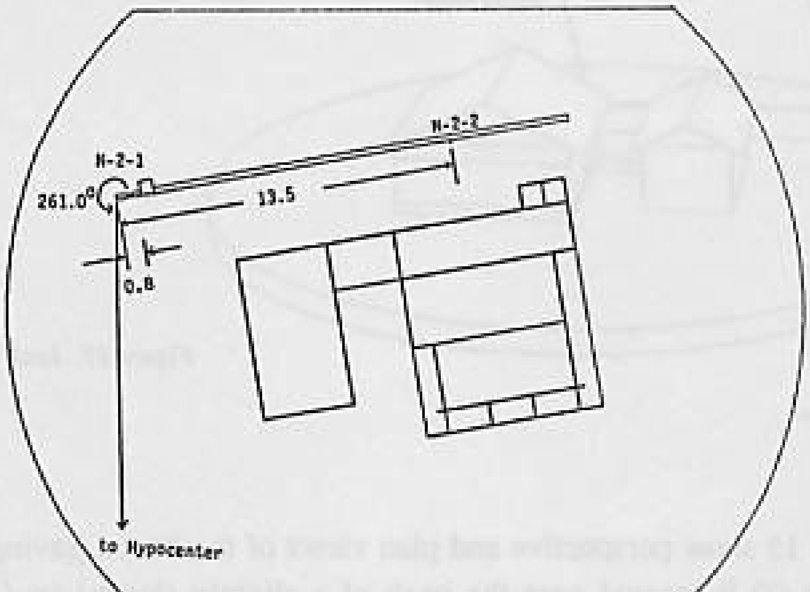

Figure 19. Plan view of Ieno Wall, house, and shed. Dimensions in meters

represented by concrete blocks 2 m wide, 20 m long, and 4 m high. The horizontal samples are located in the center of the upper surface of that structure. The vertical samples are located in the middle of the long wall, 1 m down from the top. The Urakami church was modeled as a brick block 10 m wide, 20 m long, and 10 m high. The sample (N-4) was located on a corner, 3 m above the base, the azimuth angle between the short wall and a line from the sample to the hypocenter was 46.9°. The Sakamoto grave wall was modeled as a brick block 1 m wide, 2 m long, and 1.5 m high. The sample (N-6) was taken to be located in the center of the long wall. The orientation of that surface was taken to be normal to a line from sample to hypocenter. The Zenza and Chikugo grave walls were modeled as brick walls 0.108 m wide, 2 m long, and 1.3 m high. The samples (N-7 and N-8) were taken to be located in the middle of the long walls, 1 m above the base. These surfaces were taken to be normal to a line from sample to hypocenter. The Inasa warehouse was modeled as a brick block 14 m wide, 19 m long, and 9 m high. Samples N-3-1 to N-3-3 were located on the long wall most nearly facing the hypocenter. Sample N-3-1 was located on the near corner, 3 m above the base. Samples N-3-2 and N-3-3 were located approximately 4.5 m horizontal distance from sample N-3-1, 3 m and 1.5 m above the base, respectively. The angle between the long wall and a line from sample N-3-1 to the hypocenter was 112.6°. Sample N-3-1 was located in the middle of the short wall most nearly facing away from the hypocenter, approximately 3 m from the base.

Separate calculations were performed for the dose to quartz in tiles corresponding to the measurements of each laboratory, according to the location of the sample tile and the depth for the sample region in that tile. Calculations were made using mean, ground-level air and ground constituents adapted from those in Chapter 3. All structures except the Ieno-cho Wall and its environs and other brick structures were assumed to be constructed of concrete with tile placed on external surfaces. The Ieno-cho Wall was constructed of brick, grout, and concrete with surrounding structures composed of materials typical of Japanese residential dwellings as described in Chapter 7. Other brick structures were assumed to be solid brick blocks. The materials used in the transport calculations, along with their constituent elements, are provided in Table 13. The constituents of dry brick and tile were considered

Table 13. Elemental Constituent Weight Percents Used in Modeling Air, Ground, Tiles, Bricks, and Structures at Hiroshima and Nagasaki

Material Type / Element	Air	Ground	Tile	Brick	Hiroshima Concrete	Nagasaki Concrete
Hydrogen	1.88-1*	3.04+0	9.86-2	6.55-2	5.87-1	4.57-1
Boron					8.26-3	
Carbon		8.30-1	2.35-1	1.47-1	7.98-1	
Nitrogen	7.42+1					
Oxygen	2.43+1	5.87+1	5.04+1	5.35+1	5.32+1	4.57+1
Sodium		1.22+0	1.78-1	2.77-1	1.83+0	8.74-1
Magnesium			2.11-1	3.16-1	8.18-1	
Aluminum		5.43+0	1.12+1	1.00+1	5.25+0	3.52+0
Silicon		2.56+1	3.40+1	3.04+1	2.46+1	2.02+1
Phosphorous					6.61-2	
Sulfur					1.03+0	
Chlorine		1.00-2				
Argon	1.28+0					
Potassium		2.75+0	1.49+0	1.47+0	1.32+0	1.91+0
Calcium		6.20-1	5.29-1	5.61-1	8.56+0	2.56+1
Titanium		1.20-1	5.27-1	5.16-1		7.20-2
Manganese		4.00-2	4.64-2	2.90-1	6.20-2	4.43-2
Iron		1.35+0	1.11+0	1.56+0	2.57+0	1.31+0
density (g/cc)	1.11-3	1.70+0	variable	1.70+0	2.30+0	2.30+0

*Read as 1.88×10^{-1}.

to be nominally the same. However, measurements performed by Haskell[7] indicate that the density of brick ranges between 1.55 g/cm^3 for dry brick and 1.82 g/cm^3 for saturated brick. An intermediate density value of 1.7 g/cm^3 was chosen for the calculation. The tiles were assumed to be glazed and, therefore, not subject to significant variations in moisture content. Calculations were performed using appropriate densities for individual tiles based on the location of each. These densities were developed based on measurements by several laboratories.

The results of the calculations for all sample locations are presented in Tables 14 to 23. Results for sample distances corresponding to those from the Army maps and the new city maps are presented separately. It should be noted that the distances provided in the table of calculation results for Nagasaki samples have been adjusted, using local ground elevation values relative to that of the hypocenter, to give the slant distance from epicenter to sample correctly.

Dose calculation results for each sample include the contributions from prompt and air-secondary gamma rays (P+S), delayed gamma rays (DG), and building-secondary gamma rays from prompt neutrons (BG_P) and delayed neutrons (BG_D). Typical statistical precision

Table 14. Calculated Dose to Quartz in Hiroshima Tile Corresponding to Nara University of Education TLD Measurements, Army Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S[a]	DG[b]	BG_P[c]	BG_D[d]	
1-04	526.3	918.8	1984.3	237.5	15.5	3156.1
2-03	695.0	298.6	531.7	71.8	6.1	908.3
145	1135.7	84.9	125.4	2.7	0.3	213.3
4-08	1265.0	49.2	66.6	1.2	0.1	117.1
4-07	1276.0	49.4	63.0	1.1	0.1	113.6
4-09	1291.1	44.3	60.5	1.0	0.1	105.9
4-01	1309.7	42.2	45.7	0.9	0.1	99.1
4-03	1331.1	36.6	49.8	0.8	0.1	87.3
4-03[e]		33.9	43.5	0.8	0.1	78.3
3-08	1373.5	32.2	38.9	0.6	-	71.7
3-11	1383.8	31.5	38.0	0.5	-	70.0
3-20	1384.0	28.7	35.9	0.5	-	65.1
3-36	1392.0	29.4	38.1	0.5	-	68.0
3-18	1415.6	24.8	31.6	0.4	-	56.8
3-17	1422.2	23.4	29.9	0.4	-	53.7
3-15	1444.2	22.6	28.8	0.4	-	51.8
3-35	1444.8	22.5	28.5	0.4	-	51.4
5-01	1449.7	24.6	28.5	0.4	-	53.5
3-16	1456.2	19.6	24.9	0.3	-	44.0
6-04	1571.6	10.4	12.4	0.2	-	23.0
8-01	2046.1	2.9	2.5	-	-	5.4

a. Prompt plus secondary gamma ray.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.
e. Sample from vertical portion of tile.

Table 15. Calculated Dose to Quartz in Hiroshima Tile Corresponding to Nara University of Education TLD Measurements, New City Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S[a]	DG[b]	BG_P[c]	BG_D[d]	
1-04	523.4	918.3	2053.3	242.7	16.3	3230.6
2-03	691.8	294.7	524.5	70.1	6.0	895.3
145	1131.2	86.4	128.0	2.8	0.3	217.5
4-08	1271.3	48.0	64.8	1.1	0.1	114.0
4-07	1282.1	48.2	61.5	1.1	0.1	110.9
4-09	1297.7	43.2	58.9	1.0	0.1	103.2
4-01	1316.5	41.1	54.2	0.8	0.1	96.2
4-03	1338.1	35.7	48.3	0.7	0.1	84.8
4-03[e]		33.1	42.2	0.7	0.1	76.1
3-08	1378.4	32.8	39.4	0.6	0.1	72.9
3-11	1388.5	30.9	37.2	0.5	-	68.6
3-20	1387.9	28.2	35.2	0.5	-	63.9
3-36	1393.1	29.2	37.9	0.5	-	67.6
3-18	1422.0	24.2	30.9	0.4	-	55.5
3-17	1427.9	22.9	29.4	0.4	-	52.7
3-15	1450.5	22.0	27.8	0.4	-	50.2
3-35	1449.1	22.1	27.9	0.4	-	50.4
5-01	1451.8	24.4	28.2	0.4	-	53.0
3-16	1460.9	19.3	24.4	0.3	-	44.0
6-04	1602.9	9.3	10.7	0.1	-	20.1
8-01	2050.5	2.9	2.4	-	-	5.3

a. Prompt plus secondary gamma ray.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.
e. Sample from vertical portion of tile.

Table 16. Calculated Dose to Quartz in Hiroshima Tile Corresponding to National Institute of Radiological Sciences TLD Measurements, Army Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S [a]	DG [b]	BG_p [c]	BG_D [d]	
1-01	508.5	1075.5	2273.6	226.3	16.1	3591.4
1-19	529.1	805.4	1536.9	262.7	18.7	2623.6
12-02	618.5	626.1	1164.8	131.5	10.6	1933.0
2-01	673.0	260.3	532.9	74.5	6.4	874.1
2-03	695.0	305.6	526.6	76.9	6.6	915.8
3-07	1372.1	33.6	41.3	0.6	0.1	75.6
3-10	1382.8	31.5	38.1	0.5	-	70.1
3-29	1419.1	28.3	32.3	0.4	-	61.0
3-31	1420.2	26.3	32.6	0.4	-	59.3
3-35	1444.8	22.3	27.8	0.4	-	50.5
5-01	1449.7	24.1	26.7	0.4	-	51.2
6-00	1607.0	12.2	13.7	0.1	-	26.0

a. Prompt plus secondary gamma ray.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.

Table 17. Calculated Dose to Quartz in Hiroshima Tile Corresponding to National Institute of Radiological Sciences TLD Measurements, New City Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S [a]	DG [b]	BG_p [c]	BG_D [d]	
1-01	506.8	1084.3	2229.1	220.0	16.3	3619.7
1-19	523.1	806.0	1580.4	274.1	20.2	2688.7
12-02	621.0	619.3	1152.1	128.9	10.4	1910.7
2-01	665.4	268.8	549.7	79.1	6.7	904.4
2-03	691.8	309.8	534.1	78.9	6.8	929.7
3-07	1377.0	33.0	40.6	0.6	0.1	74.3
3-10	1387.4	31.0	37.3	0.5	-	68.8
3-29	1424.9	27.7	31.5	0.4	-	59.6
3-31	1426.1	25.7	32.0	0.4	-	58.1
3-35	1449.1	21.9	27.3	0.4	-	49.6
5-01	1451.8	24.0	26.5	0.4	-	50.9
6-00	1605.7	12.3	13.7	0.1	-	26.1

a. Prompt plus secondary gamma.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.

Table 18. Calculated Dose to Quartz in Hiroshima Tile Corresponding to University of Utah, Oxford University, and Durham University TLD Measurements, Army Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S [a]	DG [b]	BG_p [c]	BG_D [d]	
3-23[e]	1388.7	30.6	39.4	0.5	-	70.5
3-22[e]	1392.0	30.2	37.3	0.5	-	68.0
3-21[e]	1421.8	26.2	34.0	0.4	-	60.6
3-25[e]	1427.7	3.9	6.2	0.4	-	10.5
3-35[e]	1444.8	22.4	27.8	0.4	-	50.6
3-35[f]	1444.8	22.4	27.8	0.4	-	50.6
3-35[g]	1444.8	22.4	27.8	0.4	-	50.6
3-24[e]	1452.1	24.1	28.6	0.4	-	53.1
3-27[e]	1452.5	23.9	27.8	0.3	-	52.0
3-26[e]	1455.7	3.7	4.6	0.3	-	8.6

a. Prompt plus secondary gamma.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.
e. University of Utah.
f. Oxford University
g. Durham University.

Table 19. Calculated Dose to Quartz in Hiroshima Tile Corresponding to University of Utah, Oxford University, and Durham University TLD Measurements, New City Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S [a]	DG [b]	BG_P [c]	BG_D [d]	
3-23[e]	1392.8	30.2	38.7	0.5	-	69.4
3-22[e]	1397.0	29.6	36.5	0.5	-	66.6
3-21[e]	1427.9	25.6	33.4	0.4	-	59.4
3-25[e]	1433.2	3.9	6.0	0.4	-	10.3
3-35[e]	1449.1	22.1	27.3	0.4	-	49.8
3-35[f]	1449.1	22.1	27.3	0.4	-	49.8
3-35[g]	1449.1	22.1	27.3	0.4	-	49.8
3-24[e]	1456.9	23.7	28.0	0.3	-	52.0
3.27[e]	1457.2	23.5	27.4	0.3	-	51.2
3-26[e]	1460.4	3.7	4.5	0.3	-	8.5

a. Prompt plus secondary gamma.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.
e. University of Utah.
f. Oxford University
g. Durham University

Table 20. Calculated Dose to Quartz in Nagasaki Brick, Army Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S [a]	DG [b]	BG_P [c]	BG_D [d]	
NUE						
B-2-1a	1433.6	56.2	47.1	0.1	-	103.4
b		49.3	38.8	0.1	-	88.2
c		41.4	32.1	0.1	-	73.6
NIRS						
N-4	484.9	2759.8	3833.7	33.3	43.3	6670.1
N-6	1057.2	269.5	313.6	0.9	0.6	584.6
N-7	1429.6	61.4	54.5	0.1	-	116.0
N-2-1a	1433.6	56.6	47.0	0.1	-	103.7
b		56.1	47.1	0.1	-	103.3
c		51.2	41.5	0.1	-	92.8
d		48.8	37.7	0.1	-	86.6
e		44.6	34.2	0.1	-	78.9
f		37.8	29.2	0.1	-	67.1
g		57.2	46.0	0.1	-	103.3
h		50.3	41.1	0.1	-	91.5
i		45.4	35.1	0.1	-	80.6
j		37.1	29.0	0.1	-	66.2
N-2-2a	1435.4	29.0	24.4	0.1	-	53.5
b		29.3	24.6	0.1	-	54.0
c		20.5	17.0	0.1	-	37.6
d		15.2	11.4	0.1	-	26.7
e		13.8	12.3	0.1	-	26.2
N-3-1	2045.7	6.2	3.9	-	-	10.1
-2	2047.6	6.3	3.8	-	-	10.1
-3	2047.6	6.4	3.6	-	-	10.0
-4	2059.0	0.77	0.71	-	-	1.5
N-8	2340.0	2.53	1.37	-	-	3.9
University of Utah						
4-2-1a	1433.6	54.4	48.5	0.1	-	103.0
b		47.5	38.1	0.1	-	85.7
c		42.9	34.4	0.1	-	77.4
Oxford University of Durham University						
4-2-1a	1433.6	57.0	49.8	0.1	-	106.9
b		46.4	37.2	0.1	-	83.7
c		42.1	31.9	0.1	-	74.1

a. Prompt plus secondary gamma ray.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.

associated with each component is 3 % for prompt and air-secondary gamma rays and delayed gamma rays and 6 % for the gamma rays from the building. At Hiroshima the delayed gamma rays constitute the largest single contributor to TL dose at all distances. At Nagasaki, however, the prompt and air-secondary component exceeds that from delayed gamma rays beyond approximately 1000 m.

Table 21. Calculated Dose to Quartz in Nagasaki Brick, New City Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S[a]	DG[b]	BG_P[c]	BG_D[d]	
NUE						
N-2-1a	1428.5	57.3	48.2	0.1	-	105.6
b		50.2	39.7	0.1	-	90.0
c		42.2	32.8	0.1	-	75.1
NIRS						
N-4	501.3	2614.9	3584.0	29.4	39.7	6268.0
N-6	1053.8	273.4	319.0	0.9	0.6	593.9
N-7	1423.6	63.3	55.7	0.1	-	119.1
N-2-1a	1428.5	57.7	48.0	0.1	-	105.8
b		57.2	48.1	0.1	-	105.4
c		52.2	42.5	0.1	-	94.8
d		49.7	38.6	0.1	-	88.4
e		45.5	34.9	0.1	-	80.5
f		38.6	29.8	0.1	-	68.5
g		58.3	47.1	0.1	-	105.5
h		51.3	42.0	0.1	-	93.4
i		46.2	35.9	0.1	-	82.2
j		37.8	29.6	0.1	-	67.5
N-2-2a	1430.6	29.6	24.9	0.1	-	54.6
b		29.8	25.1	0.1	-	55.0
c		20.9	17.3	0.1	-	38.4
d		15.5	11.6	0.1	-	27.2
e		14.0	12.5	0.1	-	26.6
N-3-1	2049.5	6.1	3.8	-	-	9.9
2	2051.5	6.2	3.8	-	-	10.0
3	2051.5	6.3	3.6	-	-	9.9
4	2062.3	.76	.7	-	-	1.5
N-8	2323.1	2.32	1.28	-	-	3.6
University of Utah						
N-1-1a	1428.5	55.5	49.5	0.1	-	105.2
b		48.4	38.9	0.1	-	87.4
c		43.8	35.2	0.1	-	79.1
Oxford University						
N-2-1a	1428.5	58.2	50.9	0.1	-	109.2
b		47.3	38.0	0.1	-	85.4
c		43.0	32.7	0.1	-	75.8

a. Prompt plus secondary gamma ray.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.

Table 22. Calculated Dose to Quartz in Hiroshima and Nagasaki Tile Corresponding to National Institute of Radiological Sciences (1967) TLD Measurements, Army Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S[a]	DG[b]	BG_P[c]	BG_D[d]	
Hiroshima						
1	130.2	1412.5	2670.4	2566.2	114.5	6763.7
2	130.3	2456.5	5920.9	1556.3	64.3	9997.9
3	168.9	1361.5	2666.3	2273.0	113.4	6414.2
4	415.1	948.7	2198.5	682.6	45.3	3875.1
5	610.2	533.9	1054.9	174.3	14.2	1777.3
6	707.5	380.6	695.1	81.7	7.2	1164.6
7	957.0	147.7	231.2	11.0	1.0	391.0
Nagasaki						
1	89	11485.6	16862.1	692.5	140.7	29180.9
2	496	2681.0	3760.9	48.9	70.4	6561.2
3	719	1082.4	1369.9	10.9	15.6	2478.8
4	873	572.4	669.8	4.1	4.7	1251.0
5	899	513.7	597.6	3.5	3.7	1118.5
6	937	440.8	507.1	2.8	2.7	953.4
7	975	376.0	420.3	2.2	2.0	800.5

a. Prompt plus secondary gamma ray.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.

At both cities the contribution from building-secondary gamma rays is small beyond a distance of approximately 500 m. However, inside that distance the building-secondary gamma ray contribution can be quite large, particularly at Hiroshima. The Hiroshima building-secondary component is itself dominated by that from prompt neutrons. However, Nagasaki

Table 23. Calculated Dose to Quartz in Hiroshima and Nagasaki Tile Corresponding to National Institute of Radiological Sciences (1967) TLD Measurements, New City Map

Sample	Distance (m)	Dose Components [Rad(SiO_2)]				Total
		P+S [a]	DG [b]	BG_P [c]	BG_D [d]	
Hiroshima						
1	146.2	1366.9	2592.7	2451.5	112.0	6523.1
2	118.6	2509.7	5886.1	1620.9	65.8	10082.5
3	175.4	1405.8	2899.4	2220.4	108.0	6633.6
4	406.4	981.4	2260.5	720.8	47.4	4010.0
5	617.5	517.4	1022.6	165.0	13.5	1718.4
6	710.0	376.6	687.6	80.1	7.1	1151.2
7	985.5	132.7	204.7	8.8	0.8	347.0
Nagasaki						
1	68	11509.2	16880.9	695.3	140.8	29226.2
2	508	2570.5	3577.7	44.4	66.5	6259.1
3	713	1110.6	1406.9	11.3	16.3	2545.1
4	866	589.6	692.9	4.3	4.9	1291.7
5	891	531.4	621.5	3.7	4.0	1160.6
6	935	444.5	512.1	2.8	2.8	962.2
7	973	379.1	424.3	2.2	2.0	807.6

a. Prompt plus secondary gamma ray.
b. Delayed gamma ray.
c. Building gamma rays from prompt neutrons.
d. Building gamma rays from delayed neutrons.

results show a much different relationship between building-secondaries from prompt and delayed neutrons. The neutron output from the Nagasaki bomb is dominated by neutrons having energies below approximately 3 keV. These neutrons can barely reach the ground and are thus important only within 100 or 200 m from the hypocenter. Beyond that distance, delayed neutrons are more numerous though somewhat less energetic than the remaining prompt neutrons and provide the bulk of the building-secondary gamma rays at Nagasaki through nearly 1000 m distance.

Few of the tiles are shielded by intervening structures. The self-shielding of the quartz by the tile or brick and the building to which it is attached varies with sample depth and angle of incidence of the radiation. At a distance of approximately 1400 m a sample taken from a depth of 0.5 to 1.5 cm on a horizontal surface has a dose that is approximately 0.8 of the free-field values, while on a vertical surface, facing the hypocenter, it is approximately 0.9. Samples deeper in the brick or tile, such as the 1.0 to 2.0 cm depth of the NIRS 1967 measurements, are reduced another 10 % or more, depending on sample orientation. These reductions are consistent with those determined by Hashizume et al.[1]

Comparison of Calculations and Measurements

Comparisons between calculated and measured doses in quartz were made for 49 locations at Hiroshima and 42 at Nagasaki, counting all the various sample depths at the Ieno-cho Wall. Each location is associated with two distances, one from the Army map and one from the new city map. Also, for all laboratories except NIRS, each measurement has an unadjusted and an adjusted value based on calibration factors provided by the measurers. Thus, there are many comparisons that can be made. These comparisons are presented in tabular form in Tables 24 to 28. Comparisons are made in terms of the ratio, (calculated value − measured value) ÷ (calculated value). Thus, the value given indicates the fraction by which the calculation would have to change to match the measurement. The sign indicates whether the calculation is low (−) or high (+ understood) relative to the measurement. The following four conventions were adopted governing the comparison process: (1) the mean

Table 24. Comparison of Calculated and Measured Doses to Quartz in Hiroshima Tile Samples, Nara University Measurements

Sample	Distance Army Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.	Distance New City Map (m)	(Calc.-Meas.)/Calc unadj.	(Calc.-Meas.)/Calc adj.
High Temperature Method						
1-04	526.3	.151	.168	523.4	.170	.187
2-03	695.0	-.112	-.089	691.8	-.128	-.105
145	1135.7	.269	.287	1131.2	.283	.301
4-08	1265.0	-.127	-.102	1271.3	-.158	-.132
4-07	1276.0	-.206	-.180	1282.1	-.235	-.208
4-09	1291.1	-.256	-.228	1297.1	-.289	-.260
4-01	1309.7	-.049	-.019	1316.5	-.081	-.050
4-03 Hor.	1331.1	-.065	-.042	1338.1	-.097	-.073
Vert.		.042	.068		.014	.041
3-20	1384.0	-.244	-.214	1387.9	-.262	-.236
3-36	1392.0	-.029	-.015	1393.1	-.036	-.021
3-18	1415.6	-.162	-.127	1422.0	-.189	-.153
3-17	1422.2	-.080	-.061	1427.9	-.101	-.082
3-15	1444.2	-.293	-.274	1450.5	-.335	-.315
3-35	1444.8	-.012	.008	1449.1	-.032	-.012
3-16	1456.2	.004	.018	1460.9	-.023	.000
6-04	1571.6	-.609	-.565	1602.9	-.840	-.791
Mean		-.105±.194	-.080±.189		-.138±.240	-.112±.234
Mean w/o 6-04 & 145		-.097±.122	-.073±.119		-.119±.132	-.095±.130
Predose Method						
4-08	1265.0	-.196	-.170	1271.3	-.228	-.202
4-03 Vert.	1331.1	-.111	-.086	1338.1	-.143	-.117
3-08	1373.5	.121	.135	1378.4	.136	.150
3-11	1383.8	-.243	-.214	1388.5	-.268	-.239
3-20	1384.0	-.352	-.321	1387.9	-.377	-.346
5-01	1449.7	-.047	-.028	1451.8	-.057	-.038
8-01	2046.1	.000	.093	2050.5	-.019	.075
Mean		-.118±.162	-.084±.167		-.137±.175	-.102±.179
Mean (all locations)		-.134±.195	-.104±.192		-.157±.236	-.132±.231
w/o 6-04 & 145		-.103±.131	-.076±.131		-.125±.142	-.097±.142
Mean: -Distance less than 1000m		.019±.186	.040±.182		.021±.211	.041±.206
Mean -Distance greater than 1000m (w/o 6-04 & 145)		-.116±.125	-.088±.126		-.139±.132	-.111±.133
Mean: -Distance Greater than 1000m predose		-.118±.162	-.084±.167		-.137±.175	-.102±.179
Mean: -Distance greater than 1000m High Temperature (w/o 6-04 & 145)		-.114±.109	-.090±.107		-.141±.114	-.115±.112

comparison between calculations and the measurements was determined on the basis of sample location, (2) thus, if more than one measured value is given for a specific location, the mean comparison for that location was determined before determining the overall mean for the laboratory, (3) similarly, if results are given at a specific location for more than one measurement technique, the mean for a technique was taken before obtaining the mean for the location, and (4) finally, all laboratories were given equal weight in determining the overall calculation-measurement comparison mean.

Nara University of Education. Comparisons of calculations with NUE Hiroshima measurements (Table 24) are uniformly good as a whole and in various groupings based on measurement method and distance from the hypocenter. Samples 6-04 and 145 should be omitted from the comparisons because they are outliers and have complex geometries not adequately modeled in the calculations.

NUE has obtained the majority of its dose data using the high temperature method with

Table 25. Comparison of Calculated and Measured Doses to Quartz in Hiroshima Tile Samples, National Institute of Radiological Sciences Measurements

Sample	Distance Army Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.	Distance New City Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.
High Temperature Method						
1-01	508.5	0.232	0.232	506.8	0.238	0.238
1-19	529.1	-0.156	-0.156	523.1	-0.128	-0.128
12-02	618.5	0.080	0.080	621.0	0.069	0.069
2-01	673.0	0.183	0.183	665.4	0.211	0.211
2-03	695.0	-0.030	-0.030	691.8	-0.014	-0.014
Predose Method						
3-07	1372.1	-0.190	-0.190	1377.0	-0.211	-0.211
3-10	1382.8	-0.441	-0.441	1387.5	-0.468	-0.468
3-29	1419.1	-0.541	-0.541	1424.9	-0.577	-0.577
3-31	1420.2	-0.180	-0.180	1426.1	-0.205	-0.205
3-35	1444.8	-0.921	-0.921	1449.1	-0.956	-0.956
5-01	1449.7	-0.035	-0.035	1451.8	-0.041	-0.041
6-00	1607.0	-0.154	-0.154	1605.7	-0.149	-0.149
Mean		-0.179±.325	-0.179±.325		-0.186±.342	-0.186±.342
Mean w/o 3-35		-0.112±.237	-0.112±.237		-0.116±.252	-0.116±.252
Mean Distance less than 1000m		0.062±.158	0.062±158		0.075±.153	0.075±.153
Mean Distance greater than 1000m w/o 3-35		-0.257±.192	-0.257±.192		-0.275±.204	-0.275±.204

Table 26. Comparison of Calculated and Measured Doses to Quartz in Hiroshima Tile Samples, University of Utah, Oxford University, and Durham University Measurements

Sample	Distance Army Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.	Distance New City Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.
3-23[a]	1388.7	-0.234	-0.404	1392.8	-0.254	-0.427
3-22[a]	1392.0	-0.338	-0.515	1397.0	-0.366	-0.547
3-21[a]	1421.8	-	-	1427.9	-	-
3-25[a]	1427.7	1.048	1.033	1433.2	1.485	1.340
3-35[a]	1444.8	-0.186	-0.354	1449.1	-0.205	-0.376
3-35[b]	1444.8	-0.374	0.472	1449.1	-0.396	-0.496
3-35[c]	1444.8	-0.215	-0.354	1449.1	-0.235	-0.376
3-24[a]	1452.1	-0.205	-0.375	1456.9	-0.231	-0.404
3-27[a]	1452.5	0.077	-0.058	1457.2	0.063	-0.074
3-26[a]	1455.7	0.300	0.023	1460.4	0.294	-0.035
University of Utah mean w/O 3-21, 3-25, 3-26		-.177±.154	-0.341±.170		-0.199±.159	-0.366+.176

a. University of Utah.
b. Oxford University
c. Durham University.

some additional data from the pre-dose method. A comparison of the results of the two methods at three coincident locations indicated that the pre-dose technique gives results which are 10% higher than those obtained by the high temperature method. However, that difference is not considered significant, being of the same order as the precision of the measurements. Further, differences between the calculated results and those obtained by NUE using the two methods at all of their respective locations are very similar. What does differ substantially between the comparisons, as grouped by measurement method, is the standard error of the mean comparison value. The pre-dose method results show a larger spread in comparison with the calculations than do those obtained by the high temperature method.

The NUE mean measurement-calculation comparisons do differ with range, being less than the calculations at distances less than 1000 m and greater at distances more than 1000 m. The differences are not significant within the stated uncertainties. However, a similar trend is demonstrated by comparison of NIRS data with the calculations, as discussed later.

Comparisons of calculations with NUE Nagasaki measurements (Table 27) generally show better than 10 % agreement between the two, though there is a consistant gradient in the comparison with sample depth. At the front surface, however, the calculations were between 4 and 8 % high, which is consistent with the degree of calculation precision and probably within the range of a realistic assessment of measurement uncertainty.

National Institute of Radiological Sciences. Comparison of calculations with NIRS Hiroshima measurements (Table 25) yields very different results within and without a distance of 1000 m. Inside 1000 m the calculations exceed the measurements by approximately 7 %, compared to 3 % for a similar comparison with NUE data. In both cases the spread in the data is large, providing standard errors of the distribution of about 0.15 to 0.20. Beyond 1000 m the measurements exceed the calculations by approximately 28 %, provided that Sample 3-35 is omitted as an outlier. There is no apparent reason why the NIRS value at Sample 3-35 should be so high. However, as will be discussed later it is well outside the envelope of the four other measurements; therefore, its omission is considered justifiable.

It should be noted that NIRS switches measurement techniques at 1000 m, from quartz inclusion at shorter distance to pre-dose at larger distances. The NIRS and NUE pre-dose results differ in comparison with the calculations, with the NIRS data being higher than either. However, the variances of the comparison ratios for pre-dose data from both laboratories are similarly large.

Comparison of calculations with NIRS measurements at Nagasaki (Table 27) indicates that for shallow samples (depth less than 5 cm) overall agreement is better than 10 % (much better if the comparison is limited to distances greater than 1000 m). Inclusion of all measurements in the comparison, including all sample depths, yields a somewhat greater discrepancy between calculation and measurement; the calculations would have to be lower by approximately 13% to match the measurements overall. However, in all of these comparisons the spread is very large, yielding a large standard error of the population (0.2).

At Ieno-cho Wall (Sample N-2) the comparison between calculation and measurement is very good and consistent for depths less than 5 cm. At larger depths most, but not all, of the measurements drop below the corresponding calculations. The comparison between shielded and unshielded Ieno-cho Wall samples is of particular interest because it serves as an indication of the quality of DS86 house shielding calculations. Using measurements and calculations at like depths (0.5 to 1.5 cm), the measured and calculated transmission factors (see Chapter 7 for a discussion of "transmission factors") are:

Measured 0.48 Calculated 0.52

which are in good agreement with each other.

University of Utah. Comparisons of calculations with the UU Hiroshima measurements (Table 26) are very different with and without the calibration adjustment. The measurements

Table 27. Comparison of Calculated and Measured Doses to Quartz in Nagasaki Brick Samples

Sample	Distance Army Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.	Distance New City Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.
NUE						
N-2-1a	1437.0	0.043	0.062	1431.9	0.063	0.081
b		0.014	0.025		0.033	0.044
c		-0.114	-0.101		-0.092	-0.079
Mean		-0.019±0.084	-0.005±0.085		0.001±0.082	0.015±.084
NIRS						
N-4	505.8	0.394	0.394	521.5	0.356	0.356
N-6	1069.8	-0.182	-0.182	1066.4	-0.163	-0.163
N-7	1432.4	0.216	0.216	1426.4	0.236	0.236
N-2-1a	1437.0	-0.013	-0.013	1431.9	0.008	0.0098
b		-0.016	-0.016		0.004	0.004
c		-0.034	-0.034		-0.013	-0.013
d		0.099	0.099		0.118	0.118
e		0.202	0.202		0.217	0.217
f		0.240	0.240		0.255	0.255
g		-0.026	-0.026		-0.005	-0.005
h		-0.016	-0.016		0.004	0.004
i		0.094	0.094		0.112	0.112
j		-0.027	-0.027		-0.007	-0.007
N-2-2a	1438.8	0.065	0.065	1434.0	0.084	0.084
b		0.074	0.074		0.091	0.091
c		-0.197	-0.197		-0.172	-0.172
d		0.476	0.476		0.485	0.485
e		0.351	0.351		0.361	0.361
N-3-1	2045.1	-0.188	-0.188	2048.9	-0.212	-0.212
-2	2047.0	0.911	0.911	2050.9	0.910	0.910
-3	2047.0	1.46	1.46	2050.9	1.46	1.46
-4	2058.4	1.00	1.00	2061.7	1.000	1.000
N-8	2344.4	1.23	1.23	2327.5	1.25	1.25
Mean: -except N-3, N-8		0.126±0.213	0.126±0.213		0.134±0.196	0.134±0.196
Mean: -sample depth less than 5.0 cm -except N-3, N-8		0.095±0.220	0.095±0.220		0.103±0.202	0.103±0.202
Mean: -sample depth less than 5.0 cm -except N-3, N-8 -distance greater than 1000m		0.021±0.167	0.021±0.167		0.040.167	0.040±0.167
Mean: -Ieno Wall -Unshielded		0.050±0.103	0.050±0.103		0.069±0.100	0.069±0.100
Mean: -Ieno Wall -Unshielded -Sample depth less than 5.0 cm		-0.021±0.009	-0.021±0.009		0.000±0.009	0.000±0.009
Mean: -Ieno Wall -Shielded		0.154±0.265	0.154±0.265		0.170±0.258	0.170±0.258
Mean: -Ieno Wall -Shielded -Sample depth less than 5.0 cm		0.070±0.006	0.070±0.006		0.088±0.005	0.088±0.005
University of Utah						
4-2-1a	1437.0	0.204	0.097	1431.9	0.221	0.116
b		0.253	0.149		0.268	0.165
c		0.341	0.251		0.355	0.267
Mean:		0.266±0.069	0.166±0.078		0.281±0.068	0.183±0.077
Oxford University						
4-2-1a	1437.0	0.252	0.167	1431.9	0.267	0.222
b		0.223	0.164		0.239	0.180
c		0.217	0.163		0.235	0.182
Mean		0.231±0.019	0.165±0.002		0.247±.0017	0.195±0.024
Durham University						
4-2-1a	1437.0	0.181	0.093	1431.9	0.199	0.112
b		0.205	0.116		0.221	0.133
c		0.177	0.089		0.195	0.109
Mean		0.188±0.015	0.099±0.015		0.205±0.014	0.118±0.013

are approximately 35 and 16% higher than the calculations with and without the calibration adjustment, respectively. Three samples were omitted to obtain this level of agreement. They are 3-21, which was withdrawn by UU, and 3-25 and 3-26, which were substantially shielded and are therefore subject to large errors in measurement by being close to background. Even without these samples the spread in the comparisons is still quite large, resulting in a large standard error of the distribution. It should be noted that the mean comparisons of the other laboratories using the pre-dose technique, including those from Japan, are within the range of that standard error.

The Nagasaki samples show a distinct improvement with the inclusion of the adjustment to the measurements. Even so, the calculations would have to be reduced by 17% to match the adjusted mean for all thicknesses or by 10 % to match the adjusted front-face value.

Oxford and Durham Universities. At Hiroshima (Table 26) the comparisons between Oxford and Durham Universities data and the calculations suffer substantially with the inclusion of the calibration adjustment, though the Durham results are reasonably consistent with those of UU. The Oxford results are very high compared with all the other laboratories as well as compared with the calculations.

At Nagasaki (Table 27) the results for the two British laboratories are both quite consistent over the entire brick thickness, unlike the results of other laboratories. In the case of Nagasaki calculation-measurement comparisons, the calibration adjustments produce an improvement. According to the adjusted values, the Oxford results for all thicknesses at the Ieno-cho Wall are consistent with those of UU, while the Durham results are closer to those of the Japanese laboratories. For front surface comparisons the results of UU and Durham are both consistent with the Japanese results, while Oxford remains low.

NIRS 1967. The NIRS 1967 calculation-measurement comparison (Table 28) provides results that are remarkably consistent with those from comparisons with more recent measurements, considering the limitations in technique that existed at that time. The comparisons for NUE, NIRS, and NIRS 1967 are all essentially the same, within uncertainties, for distances less than 1000 m.

Comparison Summary and Conclusions

A summary of measurement-calculation comparisons for all laboratories is presented in Table 29 for Hiroshima and in Table 30 for Nagasaki. These tables have been prepared under the assumption that data at new city map distances, subject to calibration adjustment, are the best that can currently be produced. The data in Tables 29 and 30 provide several points of view pertaining to the comparison of measurements and calculations. First, the mean comparison for all data at each city, less outliers as discussed previously, are presented for each laboratory. Next, for Hiroshima (Table 29) comparisons are provided for distances less than and greater than 1000 m, and for location 3-35, the only location at Hiroshima treated by all five laboratories. For Nagasaki (Table 30) mean comparisons are provided for shallow sample depths at all ranges and for locations at distances greater than 1000 m. Comparisons are also provided for the Ieno-cho wall for samples throughout the thickness of the wall and for shallow depths only. Finally, mean results for the laboratories as a whole

Table 28. Comparison of Calculated and Measured Doses to Quartz in Hiroshima and Nagasaki Tile Samples, National Institute of Radiological Sciences (1967) Measurements

Sample	Distance Army Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.	Distance New City Map (m)	(Calc.-Meas.)/Calc. unadj.	(Calc.-Meas.)/Calc. adj.
Hiroshima						
1	130.2	-0.043	-0.043	146.2	-0.082	-0.082
2	130.3	0.162	0.162	118.6	0.169	0.169
3	168.9	0.023	0.023	175.4	0.055	0.055
4	415.1	0.169	0.169	406.4	0.197	0.197
5	610.2	0.275	0.275	617.5	0.250	0.250
6	707.5	0.269	0.269	710.0	0.261	0.261
7	957.0	0.320	0.320	985.5	0.233	0.233
Mean		0.168±.136	0.168±.136		0.155±.125	0.155±.125
Nagasaki						
1	89	0.301	0.301	88	0.302	0.302
2	496	0.194	0.194	508	0.155	0.155
3	719	-.417	-.417	713	-0.300	-0.300
4	873	-.086	-.086	866	-0.051	-0.051
5	899	-.088	-.088	891	-0.049	-0.049
6	937	.194	.194	935	0.202	0.202
7	975	.158	.158	973	0.165	0.165
Mean		0.037±.248	0.037±.248		0.049±.229	0.049±.229

Table 29. Summary Comparison of Calculated and Measured Doses to Quartz (Adjusted) in Hiroshima Tile Samples, New City Map

Sample Locations	NUE	NIRS	NIRS 1967	Japan Mean	University of Utah	Oxford University	Durham University	Anglo-American Mean	Overall Mean
All	-0.097	-0.116	0.155	-0.019±0.151	-0.366	-0.496	-0.376	-0.413±0.072	-0.216±0.240
w/o NIRS 1967			-	-0.107±0.053					-0.290±0.175
Distance less than 1000m	0.041	0.075	0.155	0.091±0.058	-	-	-	-	0.091±0.058
w/o NIRS 1967			-	0.059±0.025					0.059±0.025
Distance greater than 1000m	-0.111	-0.275	-	-0.193±0.116	-0.366	-0.496	-0.376	-0.413±0.072	-0.325±0.143
Hiroshima University 3-35	-0.246	-0.956	-	-0.601±0.502	-0.376	-0.496	-0.376	-0.416±0.069	-0.490±0.275
w/o NIRS				-0.246± ---					-0.374±0.102

Table 30. Summary Comparison of Calculated and Measured Doses to Quartz (Adjusted) in Nagasaki Brick and Tile Samples, New City Map

Sample Locations	NUE	NIRS	NIRS 1967	Japan Mean	University of Utah	Oxford University	Durham University	Anglo-American Mean	Overall Mean
All	0.015	0.134	0.049	0.066±0.061	0.183	0.195	0.118	0.165±0.041	0.116±0.072
w/o NIRS 1967			-	0.075±0.084					0.129±0.071
All, depth less than 5.0 cm	0.081	0.103	0.049	0.078±0.027	0.116	0.222	0.112	0.150±0.062	0.114±0.058
w/o NIRS 1967			-	0.092±0.016					0.127±0.055
All, depth less than 5.0 cm, distance greater than 1000m	0.081	0.040	-	0.061±0.029	0.116	0.222	0.112	0.150±0.062	0.114±0.068
Sena Wall all unshielded	0.015	0.069	-	0.042±0.038	0.183	0.195	0.118	0.165±0.041	0.116±0.076
Sena Wall unshielded, depth less than 5.0 cm	0.081	0.000	-	0.041±0.057	0.116	0.222	0.112	0.150±0.062	0.106±0.080

are presented with and without the contribution of the NIRS 1967 data.

One important conclusion that may be drawn from the tables is that there is general agreement between calculations and measurements at Nagasaki at least within the experimental uncertainty limits, which are estimated to be 10 to 15%. This is not surprising since similar levels of agreement have been achieved between calculations and measurements of gamma radiation dose at tests of weapons having the same design as that of the Nagasaki weapon. Not all locations were subject to measurement at other than shallow depths. Thus, comparisons are provided for such depths alone. Those comparisons demonstrate very good and consistent agreement between calculations and measurements. At the Ieno-cho wall, measurements were made throughout the 10 cm thick brick. Comparisons with the calculations for all depths (Table 27) indicate that, while results for some laboratories show trends with depth, on the whole the agreement throughout the brick thickness is also good, as suggested by the mean values provided in Table 30. That indicates that the characterizations of the brick sample and the incident gamma-ray spectra are quite good.

The measurements made at distances less than 1000 m at Nagasaki consist almost wholly of the NIRS 1967 data. Only one other measurement was made in that region, a modern NIRS measurement for which the comparison value is 0.356. However, the NIRS 1967 measurements are quite consistent with the modern results at ranges greater than 1000 m, when compared to the calculations. At Hiroshima, the modern and 1967 measurements are very consistent with respect to the calculations at distances less than 1000 m. The consistency of the old with the new measured data is remarkable, given the 20-year lapse between the two measurements.

The comparisons of measurements and calculations at Hiroshima for distances beyond 1000 m are not consistent from laboratory to laboratory and provide a real dilemma for the assessment of the quality of DS86. It was intended that interlaboratory differences were to have been resolved based on measurements at a common location. The location chosen was the roof of the University of Hiroshima, Faculty of Science Building (location 3-35). As can be seen from Table 29, such resolution has not been entirely achieved. However, without the NIRS value, the comparisons of the four remaining laboratories are relatively consistent. The NUE value is actually the mean of results for five tiles, one at location 3-35 and four at location 3-15, an adjacent location with identical tile types. The comparisons for the five tiles range from −0.012 to −0.394 and are, therefore, inclusive of the UU and Durham data.

Even if the NIRS value is discounted as an outlier, the mean dose to quartz measured at the 3-35 (and 3-15) location is 68.7 ± 5.1 rad, where 5.1 is the standard error of the distribution. That level of precision is well within the 10 to 15% uncertainty claimed for the measurements. However, the mean measured dose is considerably higher than the calculated value of 50 rad; it is even larger than the calculated free field at the same height and location, which is approximately 57 rad.

The mean comparison of measurement and calculation for all five laboratories for all locations beyond 1000 m at Hiroshima shows a large disagreement between the calculated and measured values similar to that at location 3-35. However, comparisons made for individual laboratories differ as to the degree of the disagreement. Three laboratories, NUE, NIRS, and UU, have made measurements at Hiroshima locations other than 3-35. The mean comparisons for those laboratories range from −0.111 to −0.366, a large range.

The data from NUE stand out as being in consistently good agreement with the calculations. That consistency is exemplified in the comparison made for horizontal floor/roof tiles on top of the Hiroshima University Faculty of Sciences Building. Both the calculations and measurements decrease monotonically with increasing distance from the hypocenter as should be expected for similarly oriented, largely unshielded tiles. The only exception to this is the measurement at location 3-15, which is sigificantly higher than other nearby measured points, both on an absolute scale and relative to the calculations.

The mean comparison for all NUE data and matching calculations beyond 1000 m at Hiroshima is −0.111 with a standard error of the distribuion of 0.133. Given the large number of sample locations represented (17), the standard error of the mean is very small indeed, 0.032. Thus, the NUE measurement-calculation comparison has been reliably determined to be within the 10 to 15% accuracy which is estimated to be that of the measurements and which is also attributable to the DS86 free field gamma-ray fluence.

The NIRS measurement locations beyond 1000 m at Hiroshima are many fewer in number (7) than those of NUE. Further, one of these locations, 3-35, must be regarded as an outlier and is, in fact, not included in the mean measurement-calculation comparison value (−0.275) given in Table 29. The standard error of the distribution associated with that comparison value is 0.204, which is much larger than that associated with the NUE data as a whole. However, it is consistent with the standard error associated with the NUE data obtained by the pre-dose method alone (0.18), which is also the method used by NIRS.

The cause of the large variation in the NIRS data-calculation comparison is apparent if the measured values at each location are viewed independently (Table 17). Three locations on the Faculty of Sciences Building (3-07, 3-10, 3-29) are similarly oriented toward the burst and are unshielded. However, the measured dose values generally increase rather than decrease with increasing distance. It should be noted that NUE has a similar problem with its measurements at adjacent locations (3-08, 3-11), also made using the pre-dose technique.

The UU mean measurement-calculation comparison for Hiroshima exhibits a standard error (0.18) which is consistent with those of other laboratories using the pre-dose technique. A possible reason for the relatively large standard error for pre-dose measurement values compared to those obtained using the high temperature technique is the difference in sample quantity used in the two methods. The pre-dose technique required as little as 10 mg per location, where the high temperature measurements of NUE require as much as 200 mg per location. The large sample is not nearly as susceptible to sample-sample differences as the small sample.

The good agreement between calculation and measurement at Nagasaki and the variable, if not poor, agreement at Hiroshima make difficult any overall assessment of the quality of DS86 gamma radiation dose based on such comparisons. It is, therefore, of interest to examine the measurements for possible irregularities and to look for independent evidence which either supports or refutes the calculations.

The comparisons of results obtained by high temperature and pre-dose measurements as performed by NUE, Oxford, and Durham seem to rule out differences in the basic TL approach as a source of the interlaboratory discrepancies, excepting sample-sample variation. However, other issues involving source calibration and sample irradiation techniques remain in question. The Anglo-American laboratories require source calibration corrections of 6 to 11%, a correction which improves calculation-measurement agreement at Nagasaki at the expense of that at Hiroshima. The need for such corrections to what are supposedly well-calibrated sources is disturbing and raises questions concerning the differences between source calibration and sample irradiation practices among the laboratories. The Anglo-American laboratories all irradiate their samples using beta radiation sources, calibrated to gamma rays from Cs^{137} sources which have been calibrated to a standard. The Japanese laboratories irradiate their samples using standard-calibrated Co^{60} sources. The method used by the Anglo-American laboratories is more complex and, therefore, more subject to uncertainty that is that of the Japanese laboratories.

The good agreement between calculations and measurements at Nagasaki and at tests of similar weapons and the reasonable limits on values of parameters, which might be varied independently at the two cities, provide bounds on uncertainties which can be associated with the calculated gamma-ray fluence distribution at Hiroshima. Comparisons of calculated gamma-ray dose with test results for weapons very similar to the Nagasaki weapon indicate that current radiation models are in good agreement with the measured data, generally underestimating the measurements by 5 to 15%. Thus, it appears that the good agreement between calculated and measured dose at Nagasaki might reasonably be expected. However, there are few aspects of the calculation model which can be varied independently between the two cities in order to selectively improve the comparison at Hiroshima. For example, the delayed gamma-ray component accounts for approximately 50% of the kerma beyond 1000 m at each city. It is also the component which is associated with the greatest uncertainty. However, any reasonable modification of the delayed gamma-ray model would affect Hiroshima and Nagasaki nearly equally. Thus, it is unlikely that the reason for the measurement-calculation discrepancy at Hiroshima can be found in the delayed gamma rays. Similarly, radiation transport uncertainties would affect the two cities to approximately the same degree. That leaves weapon yield and radiation output as possible sources of a selective increase in the Hiroshima gamma rays. A yield increase of as much as 10% is possible, given the findings of Kennedy et al.[8] However, other yield estimates militate equally strongly for a value lower than 15 kt. A change in the output spectrum of the Hiroshima weapon to produce more energetic neutrons would result in the same or somewhat lower gamma-ray kerma inside 1000 m and higher kerma outside 1000 m. The most that could reasonably be expected from such a change would be a 20% increase in air secondary gamma rays and, hence, a 10% increase in total gamma rays beyond 1000 m. While cross section error could account for the neutron output spectra variation, the increase in yield could lead by itself to a more energetic neutron leakage. Thus, a plausible upper bound for an increase in Hiroshima kerma beyond 1000 m based on a combination of yield and neutron leakage energy perturbations, is approximately 20%, much less than that required by the Anglo-American laboratory measurement results.

In summary, the TL data provide generally uniform support for the DS86 gamma-ray fluence data at Nagasaki and for those less than 1000 m from the hypocenter at Hiroshima. Beyond 1000 m at Hiroshima, major discrepancies exist between measurements and calculations and among the measurements themselves. However, the majority of the TL data from that region, as produced by NUE, support the DS86 gamma-ray fluence data within the estimated experimental uncertainties of 10 to 15% standard error. For reasons given above, this level of measurement-calculation agreement is deemed sufficient to support DS86 gamma-ray

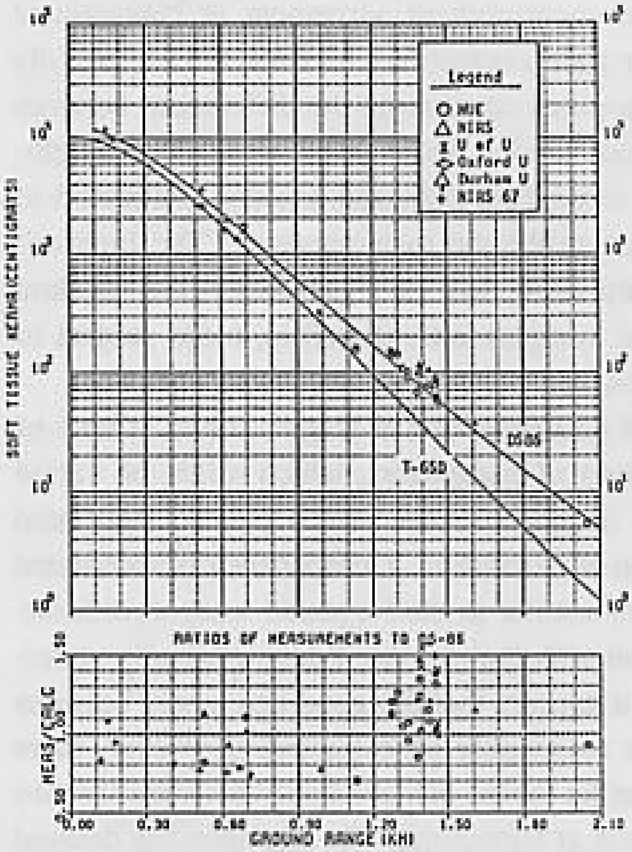

Figure 20. Free field kerma in soft tissue vs ground range at Hiroshima: new map. All measurements (adjusted)

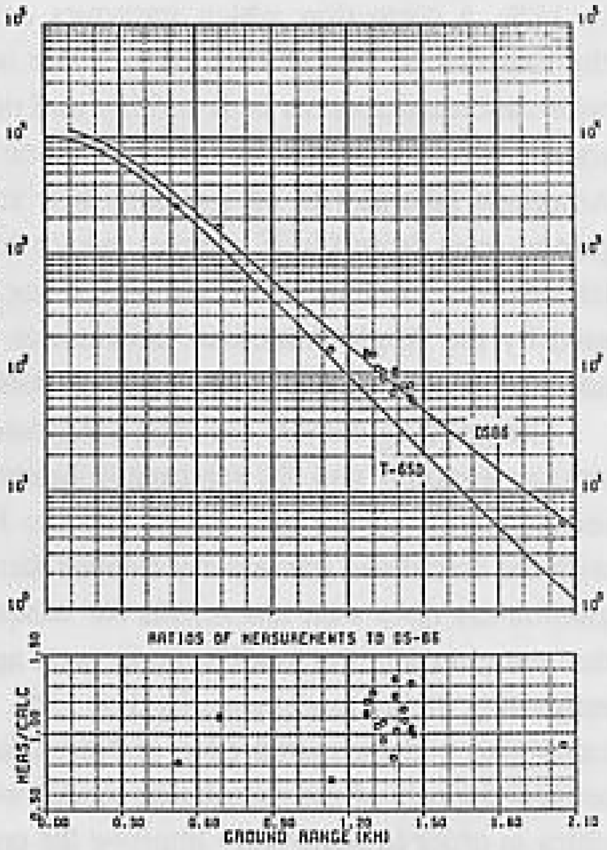

Figure 21. Free field kerma in soft tissue vs ground range at Hiroshima; new map. NUE measurements (adjusted)

data and its associated uncertainty of 10 to 15% at the present time. However, dependence on the results of a single laboratory to confirm DS86 in the important Hiroshima region beyond 1000 m is not very satisfactory particularly considering the existence of contradictory data from other laboratories. It is hoped, therefore, that further measurement-calculation efforts, particularly those for samples from the Postal Savings Building, approximately 1500 m from the Hiroshima hypocenter, will resolve the existing discrepancies.

It is also of interest to examine the measured TL dose in relationship both to DS86 and T65D, the system it replaces. Figures 20 to 29 depict DS86 and T65D free-field kerma in tissue versus distance from the hypocenter for Hiroshima and Nagasaki, superimposed on free-field kerma in tissue determined from the measured values of the dose in quartz. The conversion from measured dose in quartz to free-field kerma in tissue was accomplished using the calculations described above. Figure 20 shows all measurements as well as kerma from the two systems for Hiroshima. The measurement to calculation ratios are shown in the box below the main portion of the figure. Subsequent figures show the results for individual laboratories. It can be seen from these figures that the majority of the TL data strongly support DS86 over T65D. That is particularly true of the recent measurements, whereas the 1967 NIRS measurements tend to support the data from the T65D system. Further, any modification of DS86 to bring it more into line with the measured data would cause the discrepancy between DS86 and T65D to become larger, particularly beyond 1000 m from the hypocenter.

Figure 25 shows all measurements as well as kerma from DS86 and T65D, together with

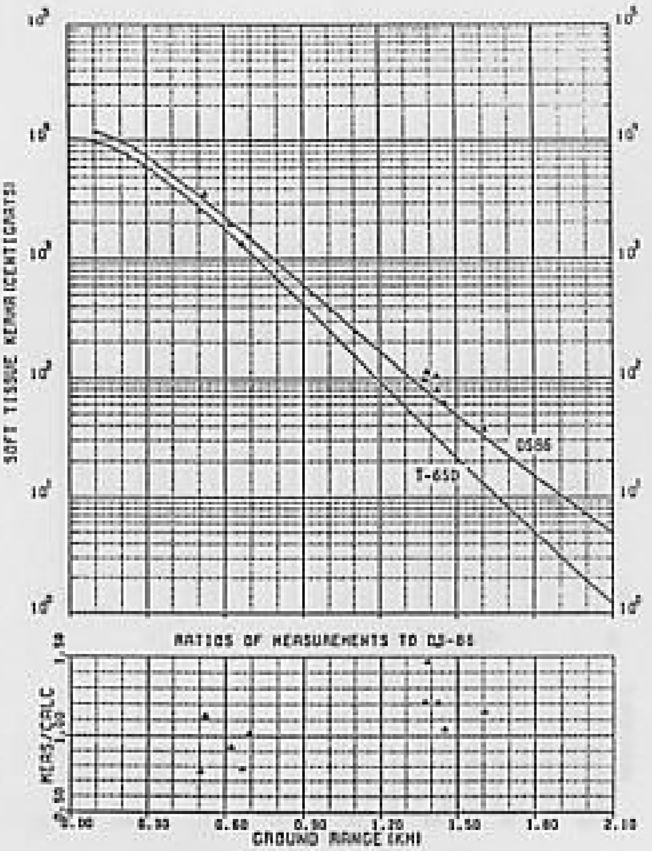

Figure 22. Free field kerma in soft tissue vs ground range at Hiroshima; new map. NIRS measurements (adjusted)

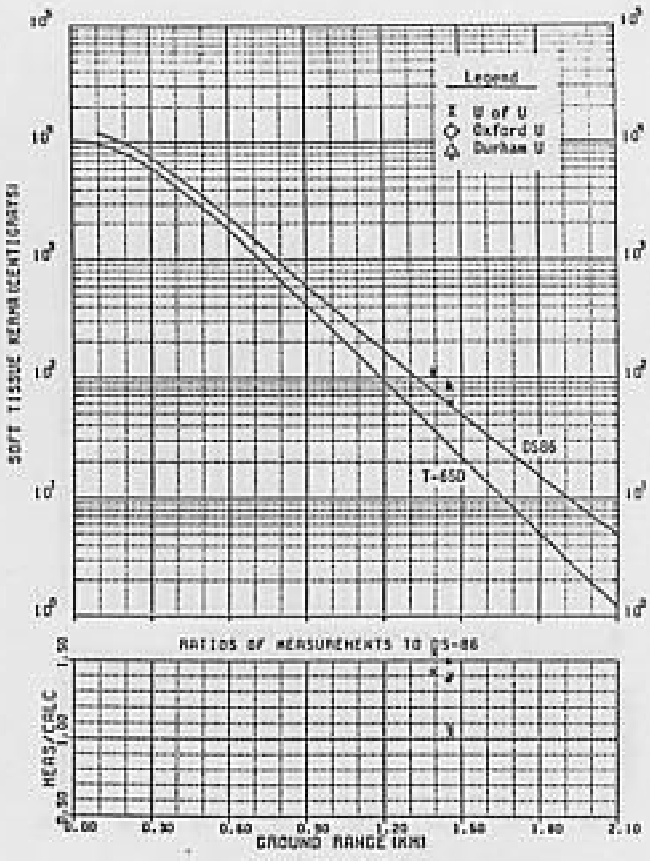

Figure 23. Free field kerma in soft tissue vs ground range at Hiroshima; new map. Anglo-American measurements (adjusted)

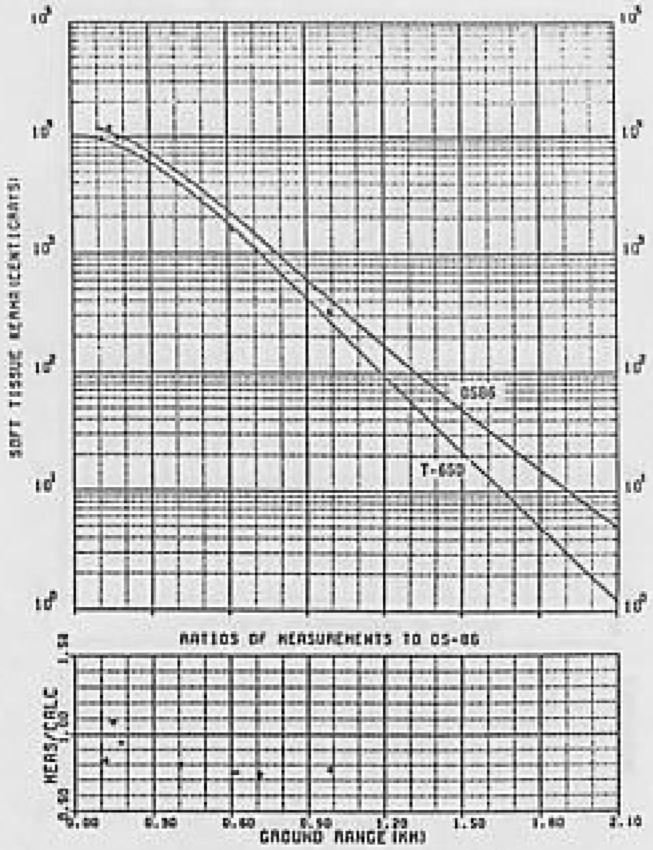

Figure 24. Free field kerma in soft tissue vs ground range at Hiroshima; new map. NIRS-67 measurements (adjusted)

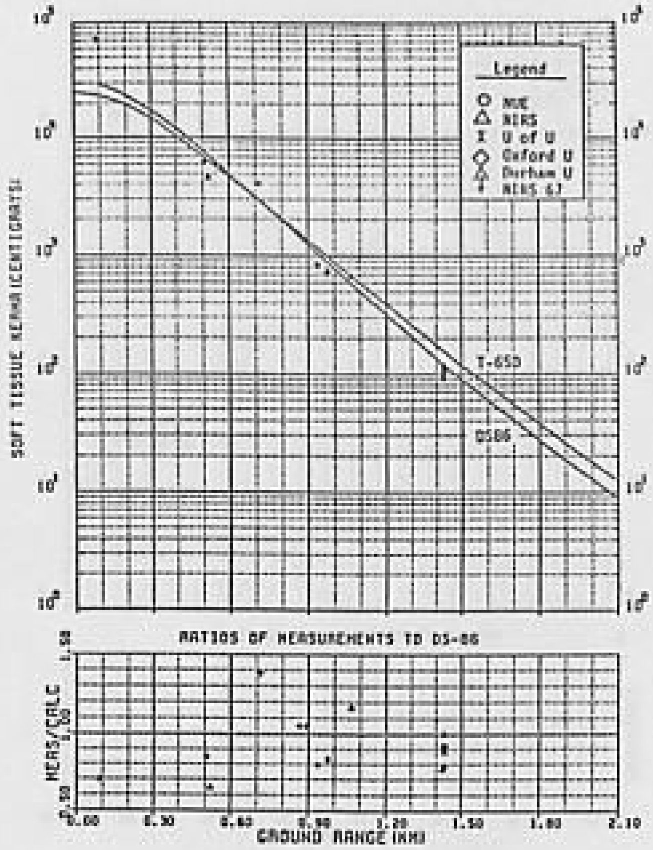

Figure 25. Free field kerma in soft tissue vs ground range at Nagasaki; new map. All measurements (adjusted)

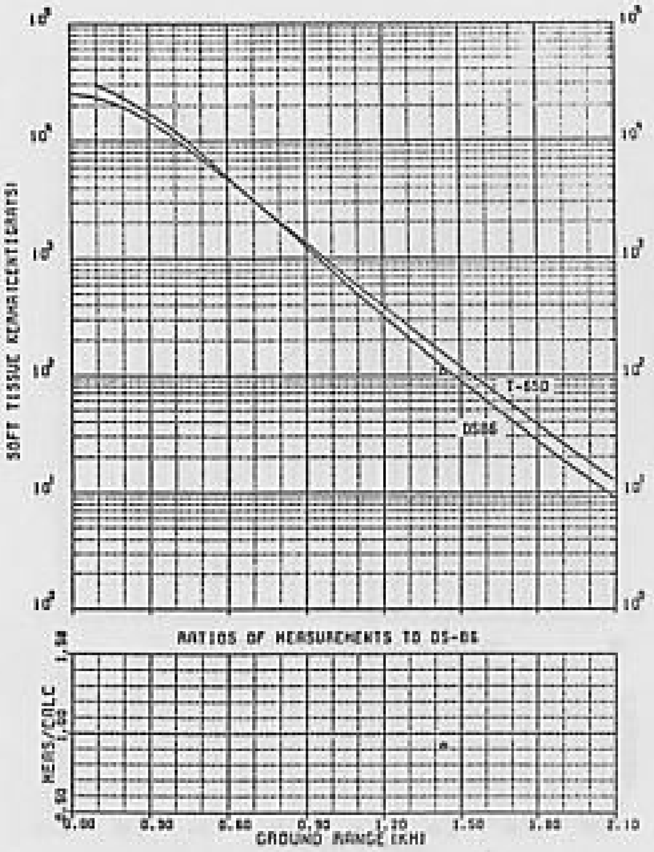

Figure 26. Free field kerma in soft tissue vs ground range at Nagasaki; new map. NUE measurements (adjusted)

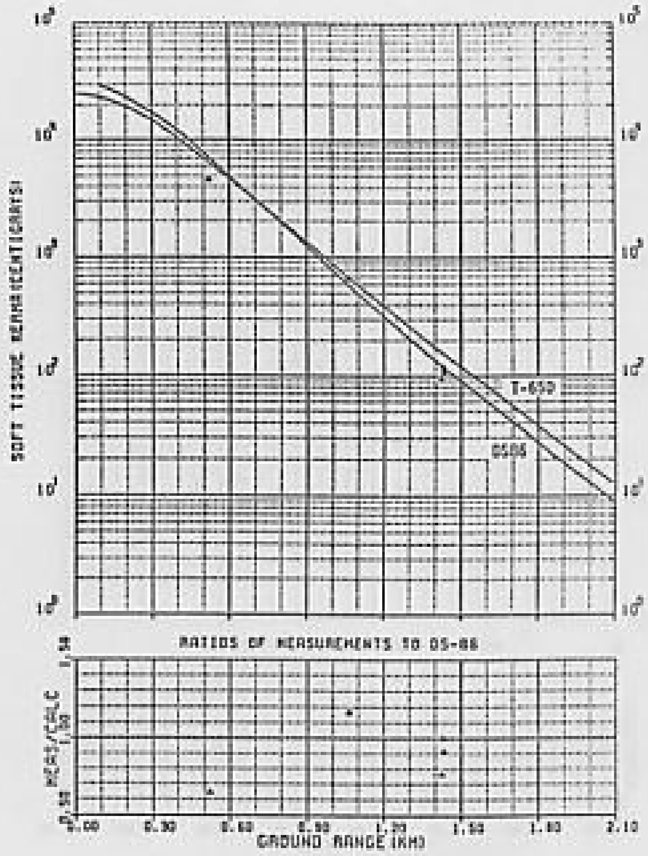

Figure 27. Free field kerma in soft tissue vs ground range at Nagasaki, new map. NIRS measurements (adjusted)

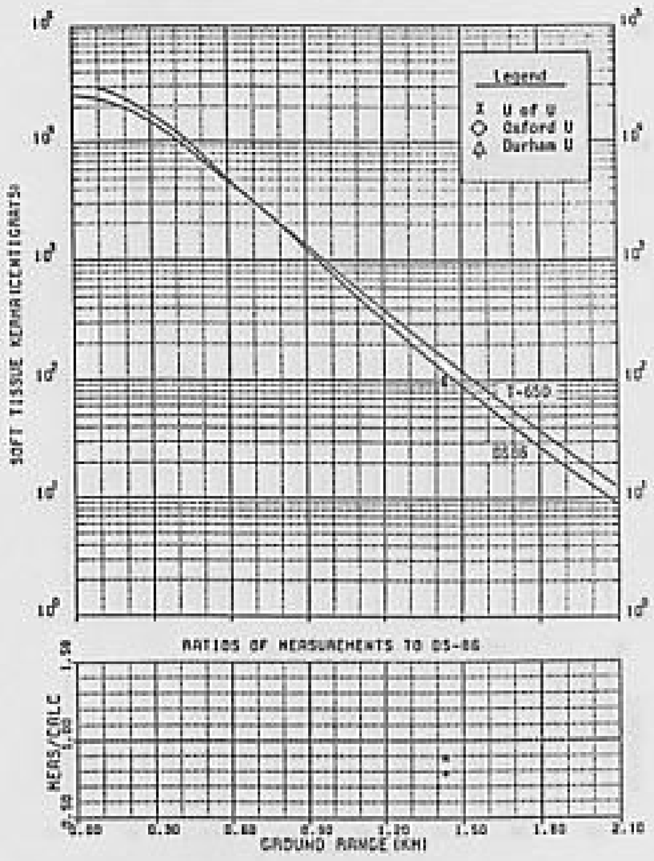

Figure 28. Free field kerma in soft tissue vs ground range at Nagasaki; new map. Anglo-American measurements (adjusted)

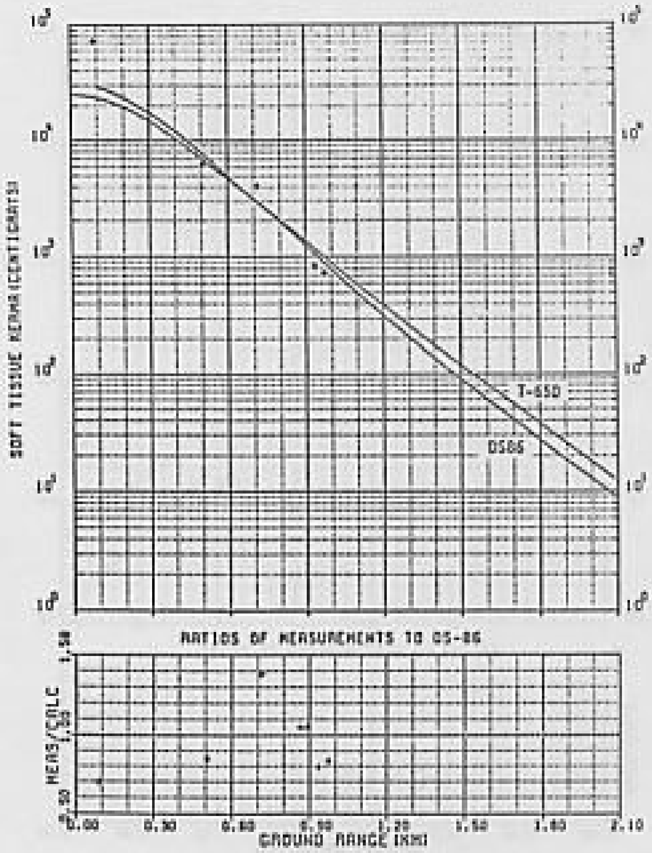

Figure 29. Free field kerma in soft tissue vs ground range at Nagasaki; new map. NIRS-67 measurements (adjusted)

the measurement to calculation ratios for Nagasaki. Subsequent figures provide corresponding results for individual laboratories. As in the case of Hiroshima, the recent measurements strongly support DS86 over T65D, though the NIRS 1967 values support the two systems to approximately the same degree. Any change to improve agreement would increase the discrepancy between the two system, especially beyond 1000 m.

In conclusion, the agreement between calculated gamma-ray dose and that measured by TL dosimetry methods is good at Nagasaki, where calculations exceed measurements by only 10% on the average. Also, a comparison of calculated and measured shielding provided by a residential structure at Nagasaki supports shielding models used in DS86. Agreement is not as good at Hiroshima, where measurements exceed calculations by 10 to 50%. However, the largest population of experimental results and the most consistent results relative to the calculations provide the 10% comparison. Whereas, the poorer agreement is associated with less consistent data or data obtained by experimental methods still open to question or is outside the range which is considered reasonably obtainable given the requirement for intercity consistency and consistency with weapon test data. Thus, though some discrepancies remain unexplained, particularly at Hiroshima, it is reasonable to conclude that the thermoluminescence dose measurements support the DS86 gamma-ray fluence data to the exclusion of those of T65D, and that no further adjustment of the DS86 data are warranted based on TL calculation-measurement comparison within uncertainties.

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