Table 13. DS02 Nagasaki doses for 503-m HOB above standard ground at 21-kt yield

		Neutron dose			Secondary gamma dose			Primary gamma dose			Total gamma dose		
Ground range	Slant range	Prompt	Delayed	Total	Prompt	Delayed	Total	Prompt	Delayed	Total	Prompt	Delayed	Total
meter	meter	gray	gray	gray	gray	gray	gray	gray	gray	gray	gray	gray	gray
0	502	1.08E+1	7.97E+0	1.88E+1	7.17E+1	3.35E+0	7.50E+1	6.12E+1	1.92E+2	2.53E+2	1.33E+2	1.96E+2	3.28E+2
100	512	1.00E+1	7.18E+0	1.72E+1	6.88E+1	3.10E+0	7.19E+1	5.93E+1	1.81E+2	2.40E+2	1.28E+2	1.84E+2	3.12E+2
200	540	7.49E+0	5.38E+0	1.29E+1	5.34E+1	2.47E+0	5.58E+1	4.44E+1	1.48E+2	1.92E+2	9.78E+1	1.50E+2	2.48E+2
300	585	5.21E+0	3.45E+0	8.67E+0	3.97E+1	1.75E+0	4.14E+1	3.33E+1	1.10E+2	1.43E+2	7.30E+1	1.12E+2	1.85E+2
400	642	3.29E+0	1.97E+0	5.26E+0	2.80E+1	1.12E+0	2.91E+1	2.27E+1	7.55E+1	9.82E+1	5.06E+1	7.66E+1	1.27E+2
500	709	1.94E+0	1.03E+0	2.97E+0	1.85E+1	6.78E-1	1.92E+1	1.47E+1	4.92E+1	6.39E+1	3.31E+1	4.99E+1	8.30E+1
600	782	1.13E+0	5.22E-1	1.65E+0	1.21E+1	3.99E-1	1.25E+1	9.45E+0	3.12E+1	4.07E+1	2.16E+1	3.16E+1	5.32E+1
700	861	6.06E-1	2.49E-1	8.56E-1	8.21E+0	2.31E-1	8.44E+0	5.80E+0	1.93E+1	2.51E+1	1.40E+1	1.95E+1	3.35E+1
800	944	3.38E-1	1.20E-1	4.58E-1	5.58E+0	1.37E-1	5.72E+0	3.77E+0	1.20E+1	1.58E+1	9.36E+0	1.21E+1	2.15E+1
900	1031	1.81E-1	5.67E-2	2.37E-1	3.67E+0	8.23E-2	3.75E+0	2.30E+0	7.44E+0	9.74E+0	5.97E+0	7.52E+0	1.35E+1
1000	1119	9.82E-2	2.64E-2	1.25E-1	2.48E+0	5.06E-2	2.53E+0	1.52E+0	4.56E+0	6.08E+0	4.00E+0	4.61E+0	8.62E+0
1100	1209	5.20E-2	1.24E-2	6.45E-2	1.62E+0	3.23E-2	1.65E+0	9.35E-1	2.84E+0	3.78E+0	2.56E+0	2.87E+0	5.43E+0
1200	1301	2.83E-2	5.88E-3	3.41E-2	1.10E+0	2.10E-2	1.13E+0	6.07E-1	1.76E+0	2.37E+0	1.71E+0	1.78E+0	3.49E+0
1300	1394	1.53E-2	2.77E-3	1.81E-2	7.61E-1	1.39E-2	7.75E-1	4.03E-1	1.11E+0	1.51E+0	1.16E+0	1.12E+0	2.28E+0
1400	1487	8.26E-3	1.32E-3	9.58E-3	5.19E-1	9.37E-3	5.28E-1	2.61E-1	7.05E-1	9.66E-1	7.80E-1	7.15E-1	1.49E+0
1500	1582	4.47E-3	6.39E-4	5.11E-3	3.60E-1	6.41E-3	3.66E-1	1.71E-1	4.46E-1	6.17E-1	5.30E-1	4.53E-1	9.83E-1
1600	1677	2.44E-3	3.11E-4	2.75E-3	2.54E-1	4.43E-3	2.58E-1	1.14E-1	2.89E-1	4.04E-1	3.68E-1	2.94E-1	6.62E-1
1700	1773	1.34E-3	1.51E-4	1.49E-3	1.80E-1	3.07E-3	1.83E-1	7.75E-2	1.83E-1	2.60E-1	2.57E-1	1.86E-1	4.43E-1
1800	1869	7.38E-4	7.47E-5	8.13E-4	1.27E-1	2.15E-3	1.29E-1	5.21E-2	1.18E-1	1.70E-1	1.79E-1	1.20E-1	2.99E-1
1900	1965	4.05E-4	3.72E-5	4.43E-4	8.86E-2	1.52E-3	9.02E-2	3.50E-2	7.92E-2	1.14E-1	1.24E-1	8.07E-2	2.04E-1
2000	2062	2.25E-4	1.89E-5	2.44E-4	6.21E-2	1.08E-3	6.32E-2	2.37E-2	5.15E-2	7.52E-2	8.58E-2	5.26E-2	1.38E-1
2100	2159	1.25E-4	9.69E-6	1.35E-4	4.39E-2	7.68E-4	4.46E-2	1.62E-2	3.39E-2	5.01E-2	6.01E-2	3.47E-2	9.47E-2
2200	2257	7.05E-5	4.97E-6	7.55E-5	3.15E-2	5.51E-4	3.20E-2	1.13E-2	2.19E-2	3.32E-2	4.28E-2	2.25E-2	6.52E-2
2300	2354	3.98E-5	2.60E-6	4.24E-5	2.29E-2	3.96E-4	2.32E-2	7.96E-3	1.53E-2	2.33E-2	3.08E-2	1.57E-2	4.65E-2
2400	2452	2.24E-5	1.36E-6	2.38E-5	1.66E-2	2.87E-4	1.69E-2	5.60E-3	1.02E-2	1.58E-2	2.22E-2	1.04E-2	3.27E-2
2500	2550	1.28E-5	7.13E-7	1.35E-5	1.21E-2	2.08E-4	1.23E-2	3.93E-3	6.58E-3	1.05E-2	1.60E-2	6.79E-3	2.28E-2

Figure 47 compares the DS02 and DS86 neutron and gamma-ray dose as a function of ground range in terms of the ratio of DS02 to DS86 activation. The DS02 neutron dose varies from about 10-20% lower than the DS86 data between 0 and 1,500 m, and DS02 falls below DS86 by nearly 40% at 2,500 m. The DS02 secondary gamma-ray dose is everywhere slightly lower than the corresponding DS86 data, while the DS02 primary gamma-ray dose is greater than the DS86 data by as much as 20% at ground ranges beyond approximately 1,500 m. The reasons for these differences are similar to those attributed to the Hiroshima results. An important addition at Nagasaki is the calculated neutron and gamma-ray leakage spectra extend to higher energies and to later neutron capture times than for the weapon leakage spectrum in DS86. This results in a greater increase than is seen in Hiroshima.

The calculated neutron activations as a function of ground range at Nagasaki are summarized in Table 14. Additional data are found in Appendix D. Figure 48 compares the ^{32}P and ^{63}Ni fast neutron activations as a function of ground range. Neither ^{32}P nor ^{63}Ni activation was measured at Nagasaki. These calculated responses are included here only to show the different responses that arise from the Hiroshima and Nagasaki weapon leakage spectra. The curves drop off by about six orders of magnitude over 2,500 m ground range. Shown in Figure 49 are the ratios of the DS02 to DS86 fast neutron activation. The DS02 activation ranges from 30 to 50% lower than the DS86 data and is approximately 30% lower between about 750 m and 1,500 m ground range. Because the DS86 fluences at ground ranges less than 100 m have been estimated for this comparison, the ratios near the hypocenter are uncertain.

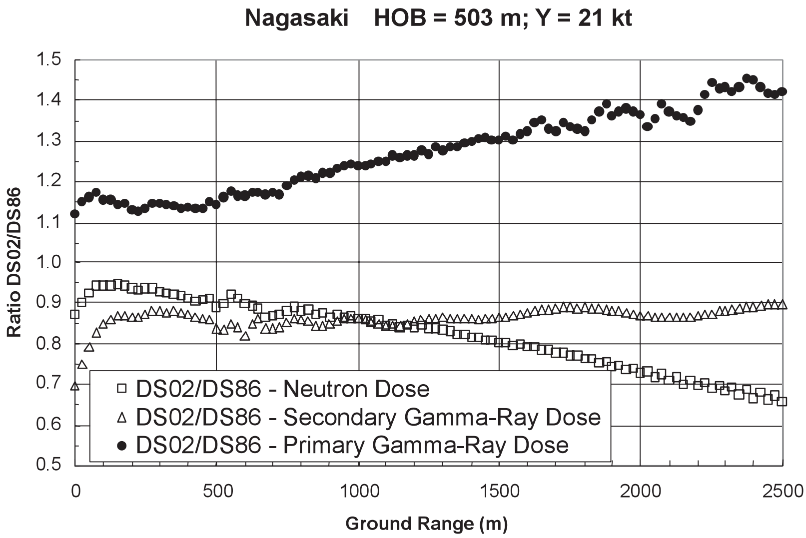

Figure 47. *Ratio of DS02/DS86 Nagasaki dose vs. ground range, HOB = 503 m, yield = 21 kt.*

Table 14. DS02 Nagasaki activation data for 503-m HOB above standard ground at 21-kt yield

Ground range	Slant range	Reaction	$^{40}Ca(n,\gamma)$	$^{35}Cl(n,\gamma)$	$^{59}Co(n,\gamma)$	$^{63}Cu(n,p)$	^{151}Eu->grd	$^{153}Eu(n,\gamma)$	$^{62}Ni(n,\gamma)$	$^{32}S(n,p)$	$^{39}K(n,\alpha)$
		Abundance	0.96941	0.7577	1.00E+0	6.92E-1	4.78E-1	5.22E-1	0.03634	9.50E-1	0.93258
		MW	40.08	35.453	5.89E+1	6.35E+1	1.52E+2	1.52E+2	58.71	3.21E+1	39.102
		Half-life	80000	301000	5.27E+0	1.00E+2	1.35E+1	8.59E+0	100.1	1.43E+1	301000
		Time units	years	years	years	years	years	years	years	days	years
		Branching ratio					6.41E-1				
		Detector height								6.5m	
meter	meter	Units in atoms (unless otherwise indicated)	^{41}Ca/g Ca	$^{36}Cl/Cl$	Bq/mg Co	^{63}Ni/g Cu	Bq/mg Eu	Bq/mg Eu	^{63}Ni/g Ni	dpm/g S	$^{36}Cl/K$
0	502		2.08E+10	1.09E-10	5.67E+0	2.51E+7	5.51E+1	6.75E+0	1.77E+10	6.93E+3	6.30E-15
100	512		1.75E+10	9.13E-11	4.80E+0	2.39E+7	4.63E+1	5.74E+0	1.49E+10	6.61E+3	6.10E-15
200	540		1.12E+10	5.85E-11	3.13E+0	1.73E+7	2.97E+1	3.82E+0	9.55E+09	4.73E+3	4.35E-15
300	585		6.04E+09	3.14E-11	1.73E+0	1.23E+7	1.60E+1	2.17E+0	5.13E+09	3.39E+3	3.15E-15
400	642		2.99E+09	1.55E-11	8.77E-1	7.83E+6	7.97E+0	1.14E+0	2.53E+09	2.14E+3	2.04E-15
500	709		1.47E+09	7.63E-12	4.40E-1	4.64E+6	3.94E+0	5.83E-1	1.25E+09	1.29E+3	1.21E-15
600	782		7.40E+08	3.84E-12	2.23E-1	2.74E+6	1.98E+0	3.00E-1	6.26E+08	7.69E+2	7.34E-16
700	861		3.67E+08	1.90E-12	1.11E-1	1.47E+6	9.84E-1	1.50E-1	3.10E+08	4.19E+2	3.99E-16
800	944		1.85E+08	9.61E-13	5.62E-2	8.48E+5	4.97E-1	7.60E-2	1.57E+08	2.40E+2	2.36E-16
900	1031		9.21E+07	4.77E-13	2.79E-2	4.49E+5	2.47E-1	3.77E-2	7.79E+07	1.31E+2	1.26E-16
1000	1119		4.57E+07	2.37E-13	1.39E-2	2.56E+5	1.22E-1	1.87E-2	3.87E+07	7.36E+1	7.38E-17
1100	1209		2.29E+07	1.19E-13	6.95E-3	1.35E+5	6.12E-2	9.36E-3	1.94E+07	3.96E+1	3.95E-17
1200	1301		1.15E+07	5.95E-14	3.49E-3	7.58E+4	3.07E-2	4.69E-3	9.72E+06	2.24E+1	2.25E-17
1300	1394		5.80E+06	3.00E-14	1.76E-3	4.24E+4	1.54E-2	2.36E-3	4.90E+06	1.26E+1	1.28E-17
1400	1487		2.95E+06	1.53E-14	8.97E-4	2.33E+4	7.85E-3	1.20E-3	2.49E+06	6.93E+0	7.16E-18
1500	1582		1.51E+06	7.84E-15	4.60E-4	1.29E+4	4.03E-3	6.18E-4	1.28E+06	3.87E+0	4.01E-18
1600	1677		7.84E+05	4.05E-15	2.38E-4	7.23E+3	2.08E-3	3.19E-4	6.62E+05	2.20E+0	2.29E-18
1700	1773		4.09E+05	2.11E-15	1.24E-4	4.07E+3	1.08E-3	1.66E-4	3.45E+05	1.24E+0	1.31E-18
1800	1869		2.15E+05	1.11E-15	6.54E-5	2.29E+3	5.70E-4	8.76E-5	1.82E+05	7.03E-1	7.44E-19
1900	1965		1.14E+05	5.91E-16	3.47E-5	1.28E+3	3.03E-4	4.65E-5	9.66E+04	3.96E-1	4.19E-19
2000	2062		6.11E+04	3.16E-16	1.86E-5	7.21E+2	1.62E-4	2.49E-5	5.17E+04	2.25E-1	2.38E-19
2100	2159		3.29E+04	1.70E-16	1.00E-5	4.09E+2	8.72E-5	1.34E-5	2.78E+04	1.29E-1	1.36E-19
2200	2257		1.79E+04	9.27E-17	5.45E-6	2.34E+2	4.74E-5	7.28E-6	1.51E+04	7.42E-2	7.87E-20
2300	2354		9.80E+03	5.07E-17	2.98E-6	1.35E+2	2.59E-5	3.98E-6	8.28E+03	4.29E-2	4.56E-20
2400	2452		5.39E+03	2.79E-17	1.64E-6	7.69E+1	1.42E-5	2.19E-6	4.55E+03	2.48E-2	2.63E-20
2500	2550		2.98E+03	1.54E-17	9.06E-7	4.45E+1	7.87E-6	1.21E-6	2.52E+03	1.43E-2	1.53E-20

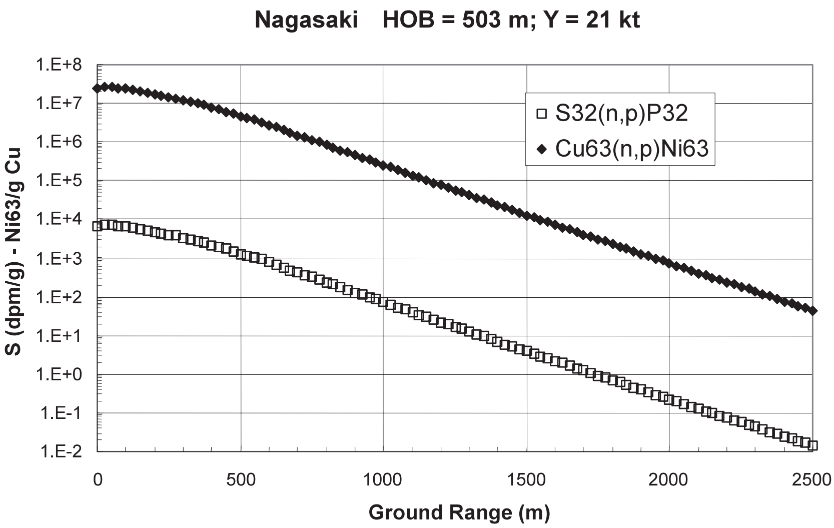

Figure 48. *Nagasaki fast neutron activation vs. ground range, HOB = 503 m, yield = 21 kt.*

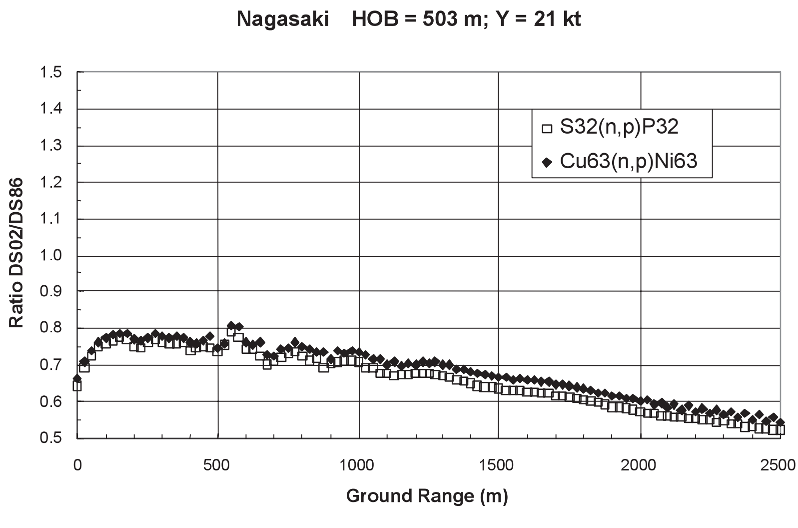

Figure 49. *Ratio of DS02/DS86 Nagasaki fast neutron activation vs. ground range, HOB = 503 m, yield = 21 kt.*

The calculated thermal activation isotopes at 1 m above ground at Nagasaki are plotted as a function of ground range in Figure 50. The activation is given in units of Bq/mg for ^{60}Co and ^{152}Eu and the number of ^{36}Cl atoms produced per Cl atom for ^{35}Cl(n,γ) ^{36}Cl reaction.

Figure 51 shows the differences between the DS02 thermal activation responses and the corresponding responses calculated in DS86. The DS02 data are lower than the DS86 activation data by as much as 40% at ground ranges between 0 and 200 m and are relatively constant at approximately 10% lower between 200 and 1,500 m and gradually drop to 20% lower at 2,500 m ground range.

As in the case of the Hiroshima analyses, the Nagasaki DS02 air-over-ground calculations were carried out using a finer energy group structure for the transport cross sections. The ENDF/B-VI cross-section data in the DS02 analysis were considerably improved since DS86 and allow better modeling of the weapon neutrons through the air.

Figure 52 shows the ratio of the calculated fast and thermal activation to the neutron dose as a function of ground range. The data were derived in the same manner described for Hiroshima and shown in Figure 45. The ^{60}Co response falls into equilibrium with the other thermal neutron responses at ground ranges beyond 500 m. This is because the ^{60}Co cross-section resonance at 132 eV is above much of the Nagasaki low energy neutron source. The fast neutron responses are essentially in equilibrium to about 1,250 m. At greater ground ranges the ^{32}P and ^{63}Ni differ by about 10%, as noted above. The Nagasaki spectrum is significantly out of equilibrium for the first 500 m from the hypocenter, and then it more rapidly comes in to equilibrium than does Hiroshima. (These calculations are used for understanding Nagasaki fluence spectrum, but no fast neutron measurements were made.)

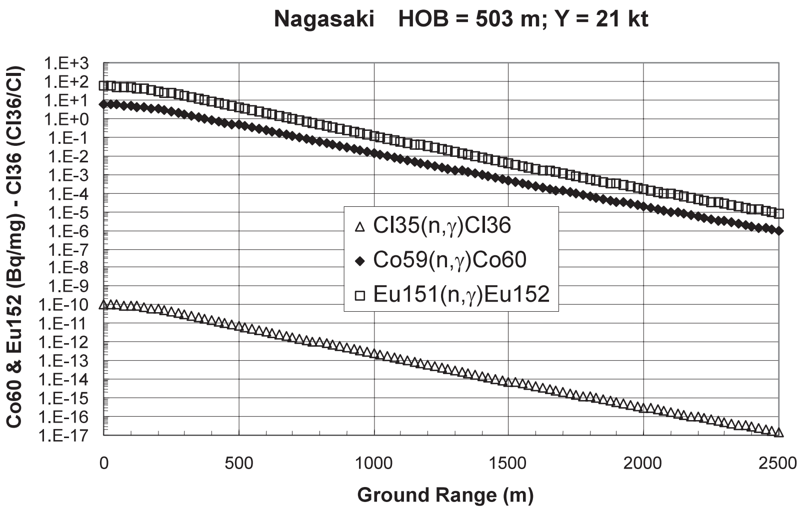

Figure 50. *Nagasaki thermal neutron activation vs. ground range, HOB = 503 m, yield = 21 kt.*

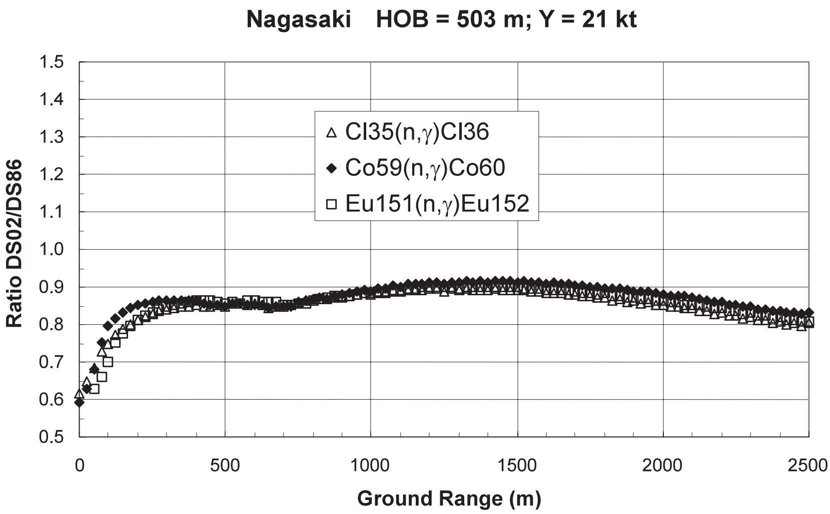

***Figure 51**. Ratio of DS02/DS86 Nagasaki thermal neutron activation vs. ground range, HOB = 503 m, yield = 21 kt.*

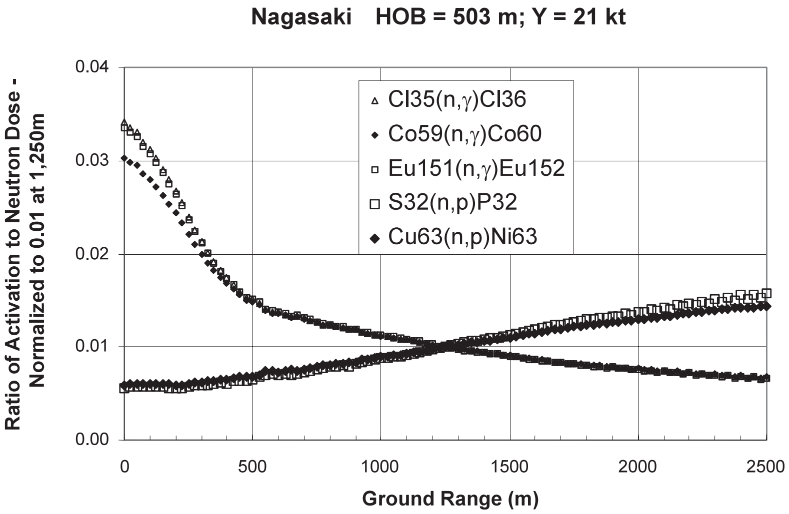

***Figure 52.** Ratio of Nagasaki activation to neutron dose vs. ground range, HOB = 503 m, yield = 21 kt.*

Conclusions

The methods and data used to calculate the Hiroshima and Nagasaki prompt and delayed radiation fluences for the DS02 study represent a considerable improvement over the methods and data used for the DS86 study. During the intervening sixteen years, enhancements were made in the radiation transport codes and the nuclear data that are used to describe the migration of the neutrons and gamma rays from the bomb location through the intervening air and into, out of and off the surface of the ground. Increased computational capability permits better descriptions of the weapon source spectra and their extension to higher neutron and photon energies. The weapon leakage spectra were generated in the same neutron and gamma-ray energy structures that were used in the transport calculations. No interpolation or fitting of the leakage spectra was necessary, assuring consistent and accurate representations of the data were used in the transport calculations.

The use of the 199 neutron and 42 gamma-ray energy group ENDF/B-VI cross-section library in the discrete ordinates calculations including 36 thermal neutron up-scatter calculations provided the most accurate descriptions of the Hiroshima and Nagasaki air-over-ground radiation environments obtained to date. Fluences calculated were folded with ENDF/B-VI activation cross-section and new kerma response functions to obtain the spatial dependencies of these data for comparison with measured results. Comparisons of activation and dose distributions were also calculated using Monte Carlo methods, and the agreement between the two analytic approaches is within ±10% for ground ranges to approximately 1,500 m. Beyond 1,500 m ground range the fractional standard deviations in the Monte Carlo estimates of the responses become larger. Better agreement would have been achieved with longer running times but would not have improved the good agreement obtained using the two transport methodologies.

The DS02 method of using the two-dimensional LAMB and DORT to calculate the delayed radiation is an improvement over the DS86 method of using LAMB and a one-dimensional ANISN calculation. The new method did not change results significantly. It is not known whether the results would change if a modern hydrodynamic code were used to calculate air density and source locations. This may be useful to study in the future.

The results reported in this chapter are state-of-the-art. They were obtained using the best available codes and data and clearly represent the best available data of the air-over-ground neutron and gamma-ray radiation environments for Hiroshima and Nagasaki. The agreement between the calculated and measured responses, as shown in the ensuing chapters, is notable. Achieving 10-20% agreement between a controlled measurement and calculation is generally quite acceptable. Achieving similar agreement between measured responses and calculations from the Hiroshima and Nagasaki events is remarkable.

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Appendix A

Neutron and Gamma Ray Energy Group Structure

Table A1. 199 neutron energy group structure

Grp No	Upper energy (eV)	Grp No	Upper energy (eV)	Grp No	Upper energy (eV)	Grp No	Upper energy (eV)	Grp No	Upper energy (eV)
1	1.9640E+07	41	2.7253E+06	81	3.6883E+05	121	2.4788E+04	161	1.0677E+01
2	1.7332E+07	42	2.5924E+06	82	3.3373E+05	122	2.4176E+04	162	8.3153E+00
3	1.6905E+07	43	2.4660E+06	83	3.0197E+05	123	2.3579E+04	163	6.4760E+00
4	1.6487E+07	44	2.3852E+06	84	2.9849E+05	124	2.1875E+04	164	5.0435E+00
5	1.5683E+07	45	2.3653E+06	85	2.9721E+05	125	1.9305E+04	165	3.9279E+00
6	1.4918E+07	46	2.3457E+06	86	2.9452E+05	126	1.5034E+04	166	3.0590E+00
7	1.4550E+07	47	2.3069E+06	87	2.8725E+05	127	1.1709E+04	167	2.3824E+00
8	1.4191E+07	48	2.2313E+06	88	2.7324E+05	128	1.0595E+04	168	1.8554E+00
9	1.3840E+07	49	2.1225E+06	89	2.4724E+05	129	9.1188E+03	169	1.4450E+00
10	1.3499E+07	50	2.0190E+06	90	2.3518E+05	130	7.1017E+03	170	1.3000E+00
11	1.2840E+07	51	1.9205E+06	91	2.2371E+05	131	5.5308E+03	171	1.1253E+00
12	1.2523E+07	52	1.8268E+06	92	2.1280E+05	132	4.3074E+03	172	1.0800E+00
13	1.2214E+07	53	1.7377E+06	93	2.0242E+05	133	3.7074E+03	173	1.0400E+00
14	1.1618E+07	54	1.6530E+06	94	1.9255E+05	134	3.3546E+03	174	1.0000E+00
15	1.1052E+07	55	1.5724E+06	95	1.8316E+05	135	3.0354E+03	175	8.7643E-01
16	1.0513E+07	56	1.4957E+06	96	1.7422E+05	136	2.7465E+03	176	8.0000E-01
17	1.0000E+07	57	1.4227E+06	97	1.6573E+05	137	2.6126E+03	177	6.8256E-01
18	9.5123E+06	58	1.3534E+06	98	1.5764E+05	138	2.4852E+03	178	6.2506E-01
19	9.0484E+06	59	1.2874E+06	99	1.4996E+05	139	2.2487E+03	179	5.3158E-01
20	8.6071E+06	60	1.2246E+06	100	1.4264E+05	140	2.0347E+03	180	5.0000E-01
21	8.1873E+06	61	1.1648E+06	101	1.3569E+05	141	1.5846E+03	181	4.1399E-01
22	7.7880E+06	62	1.1080E+06	102	1.2907E+05	142	1.2341E+03	182	3.6680E-01
23	7.4082E+06	63	1.0026E+06	103	1.2277E+05	143	9.6112E+02	183	3.2500E-01
24	7.0469E+06	64	9.6164E+05	104	1.1679E+05	144	7.4852E+02	184	2.7500E-01
25	6.7032E+06	65	9.0718E+05	105	1.1109E+05	145	5.8295E+02	185	2.2500E-01
26	6.5924E+06	66	8.6294E+05	106	9.8037E+04	146	4.5400E+02	186	1.8400E-01
27	6.3763E+06	67	8.2085E+05	107	8.6517E+04	147	3.5357E+02	187	1.5000E-01
28	6.0653E+06	68	7.8082E+05	108	8.2503E+04	148	2.7536E+02	188	1.2500E-01
29	5.7695E+06	69	7.4274E+05	109	7.9499E+04	149	2.1445E+02	189	1.0000E-01
30	5.4881E+06	70	7.0651E+05	110	7.1998E+04	150	1.6702E+02	190	7.0000E-02
31	5.2205E+06	71	6.7206E+05	111	6.7379E+04	151	1.3007E+02	191	5.0000E-02
32	4.9659E+06	72	6.3928E+05	112	5.6562E+04	152	1.0130E+02	192	4.0000E-02
33	4.7237E+06	73	6.0810E+05	113	5.2475E+04	153	7.8893E+01	193	3.0000E-02
34	4.4933E+06	74	5.7844E+05	114	4.6309E+04	154	6.1442E+01	194	2.1000E-02
35	4.0657E+06	75	5.5023E+05	115	4.0868E+04	155	4.7851E+01	195	1.4500E-02
36	3.6788E+06	76	5.2340E+05	116	3.4307E+04	156	3.7266E+01	196	1.0000E-02
37	3.3287E+06	77	4.9787E+05	117	3.1828E+04	157	2.9023E+01	197	5.0000E-03
38	3.1664E+06	78	4.5049E+05	118	2.8501E+04	158	2.2603E+01	198	2.0000E-03
39	3.0119E+06	79	4.0762E+05	119	2.7000E+04	159	1.7604E+01	199	5.0000E-04
40	2.8651E+06	80	3.8774E+05	120	2.6058E+04	160	1.3710E+01		1.0000E-05

Table A2. 42 gamma ray energy group structure

Grp No	Upper energy (MeV)	Grp No	Upper energy (MeV)
1	3.0000E+01	22	1.3300E+00
2	2.0000E+01	23	1.0000E+00
3	1.4000E+01	24	8.0000E-01
4	1.2000E+01	25	7.0000E-01
5	1.0000E+01	26	6.0000E-01
6	8.0000E+00	27	5.1200E-01
7	7.5000E+00	28	5.1000E-01
8	7.0000E+00	29	4.5000E-01
9	6.5000E+00	30	4.0000E-01
10	6.0000E+00	31	3.0000E-01
11	5.5000E+00	32	2.0000E-01
12	5.0000E+00	33	1.5000E-01
13	4.5000E+00	34	1.0000E-01
14	4.0000E+00	35	7.5000E-02
15	3.5000E+00	36	7.0000E-02
16	3.0000E+00	37	6.0000E-02
17	2.5000E+00	38	4.5000E-02
18	2.0000E+00	39	4.0000E-02
19	1.6600E+00	40	3.0000E-02
20	1.5000E+00	41	2.0000E-02
21	1.3400E+00	42	1.0000E-02
			1.0000E-03