Transport Calculations

The delayed radiation calculations used the same air and ground materials and densities that were used in the prompt radiation transport calculations. (Tables 3 and 4). The ENDF/B-VI cross sections in the Vitamin-E (174 neutron and 38 gamma-ray energy group structure) were used for the delayed neutron transport (P_3 Legendre expansion for scattering). Apart from the lack of thermal upscatter, these data have practically the same energy group structure as the Vitamin-B-6 prompt cross sections described in the Prompt Radiation section of this chapter. Calculations were performed using the DORT code in the manner described above for each snapshot in time. The spatial meshing (in units of meters) used in the calculations is given in Table 9. The delayed gamma calculation was carried out using DABL-69, 23 gamma-ray energy groups and P_5 Legendre expansion for scattering (Ingersoll et al. 1995; White et al. 2000).

Table 9. Spatial meshing used in the DORT code for delayed radiation calculations

Axial mesh #	Ground mesh midpoint	Axial mesh #	Air mesh midpoint	Axial mesh #	Air mesh midpoint	Radial mesh #	Mesh midpoint
1	-.4500	14	.20	102	1025.00	1	3.125
2	-.3500	15	.60	103	1050.00	2	12.50
3	-.2500	16	1.00	104-119	Δ=25.00	3	25.00
4	-.1750	17	1.60	120	1475.00	4-120	Δ=25.00
5	-.1250	18	4.00	121	1500.00	121	2475.00
6	-.0875	19	9.00	122	1531.25	122	2500.00
7	-.0625	20	15.00	123	1575.00	123	2531.25
8	-.0450	21	22.00	124	1625.00	124	2575.00
9	-.0350	22	28.62	125-130	Δ=50.00	125	2625.00
10	-.0250	23	37.50	131	1925.00	126-130	Δ=50.00
11	-.0150	24	50.00	132	1975.00	131	2925.00
12	-.0075	25-98	Δ=12.50			132	2975.00
13	-.0025	99	987.50				
		100	1000.00				
		101	1009.38				

Adjustments to Hiroshima Delayed Neutrons (HOB and Yield)

The Hiroshima delayed neutron calculation of 1993 was adjusted to account for the increased height of burst and higher yield used in DS02. The 1993 delayed calculations were made for a 580-m HOB and 15-kt yield. DS02 is at 600-m HOB and 16-kt yield.

The delayed neutron HOB adjustment was determined from neutron doses obtained using the ATR code (Kaul et al. 1992). The doses were determined at the two burst heights with a ^{235}U fission source at every 25-m mesh. The ratio that was obtained is illustrated in Table 10 for a few ground distances. Note that the largest adjustment due to the change in the height of burst is directly under the burst. For most survivors the delayed neutron doses are adjusted downward by 1-8% depending on range. The delayed neutrons contribute ~5% of the total neutron dose at Hiroshima, thus the impact of this adjustment is very small.

The 1993 Hiroshima delayed neutron results were also increased by a factor of 16/15 to account for the change in the yield. The hydrodynamic enhancement from the increased yield was ignored, since it would result in an increase of only a few percent for the delayed neutrons and a very minimal change in the total neutron dose or any of the activation data.

Table 10. Delayed neutron 600/580 m HOB correction factor vs. ground range

GR (m)	Neutron	GR (m)	Neutron
0	0.834	1500	0.952
500	0.873	2000	0.973
1000	0.922	2500	0.990

Data from Delayed Calculations of 1993 and 2002

As part of a major effort to determine if changes in cross sections and energy-group structure could cause a significant change in dose and activation, the delayed radiation at Hiroshima and Nagasaki had been recalculated in 1993. Because the primary interest then was thermal neutron activation and corresponding neutron dose changes, most of the studies of delayed radiation focused on neutrons. For each of the 12 delayed neutron DORT calculations at each city, the fluences were saved in a set of three DORT output files (scalar fluence, angular fluence and uncollided fluence). These files were then processed into the VISTA format. This process was completed in 1993 for the delayed neutrons at both cities using bomb parameters of a 580-m HOB and a 15-kt yield at Hiroshima and 503-m HOB and 21-kt yield at Nagasaki.

The 1993 project ended with a preliminary recalculation of the Hiroshima delayed gamma rays using the new fission gamma sources. The results showed there was no significant change from the calculation of the DS86 delayed gamma rays. The Nagasaki delayed gamma-ray recalculation was not carried out in 1993. It was decided to defer these calculations until the neutron problem was resolved. Then, a complete dosimetry system, including the delayed gamma rays, would be recalculated.

In 2002, the Hiroshima (600-m HOB and 16-kt yield) and Nagasaki (503-m HOB and 21-kt yield) delayed gamma calculations were recalculated. Eighteen DORT calculations for each city were run. Each DORT output file set was processed into a VISTA format file, and all 18 were summed for each city into a total delayed radiation VISTA file.

Figure 35 shows results of time-dependent delayed primary gamma radiation calculations at 1,500-m ground range for Hiroshima. Figure 36 shows the same results on a semi-log graph. Figure 37 and Figure 38 show results for delayed neutrons and delayed secondary gamma rays. Each plot has at least six dose rate calculation curves displayed. Three curves are generated by assuming the debris is located on a point along the central axis (labeled “point”). The other three curves are generated by placing the debris at the hottest ring in the fireball after it moves away from the central axis (labeled “torus”). The curves labeled with “86” and “02” are generated using the version of LAMB for the DS02 calculations with the height and yield of the DS86 and DS02, respectively (i.e. 580 m 15 kt; 600 m 16 kt). The curve labeled “93” was calculated during the 1993 study using the version of LAMB available for DS86 and with the DS86 height and yield. The delayed gamma plots also include the DS86 time dependent curve from page 89, Volume 2 of the DS86 Final Report (Roesch 1987).

The integrated doses are obtained by summing the doses from the point source model at early

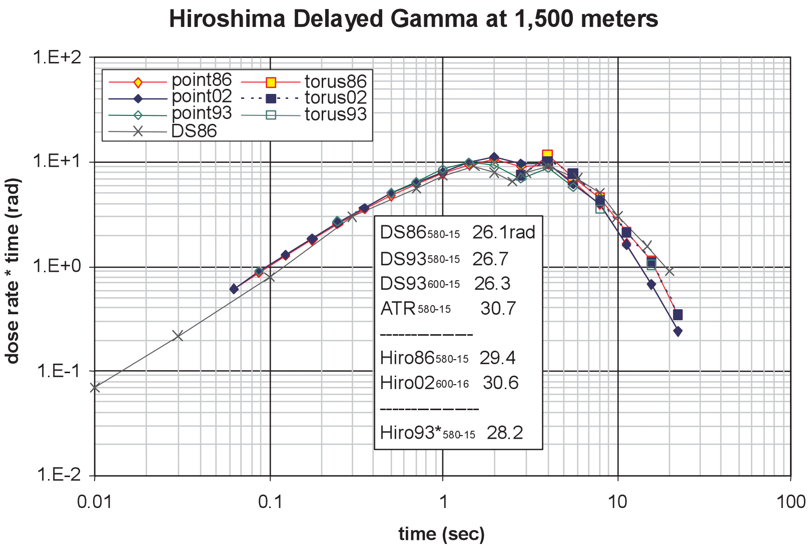


Figure 35. *Time-dependent delayed gamma-ray radiation at 1,500 m ground range for Hiroshima; integrated dose (rads) given for several calculation assumptions.*

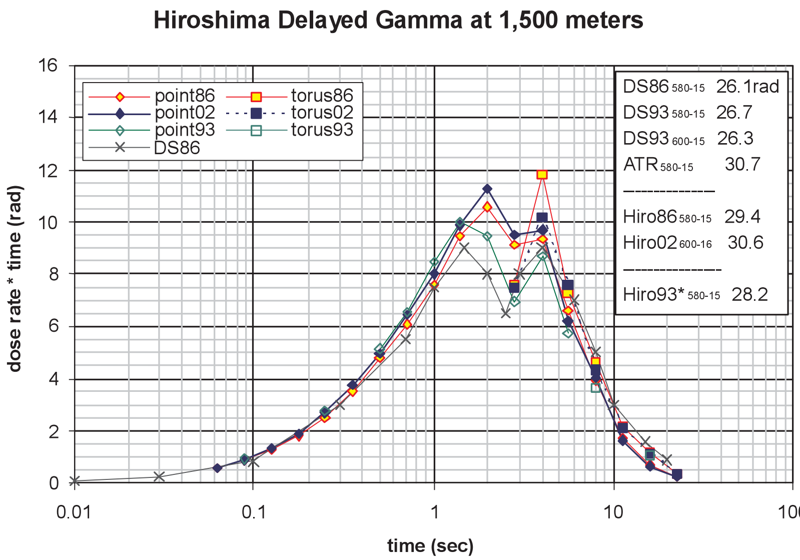


Figure 36. *Time-dependent delayed gamma ray radiation at 1,500 m ground range for Hiroshima.*

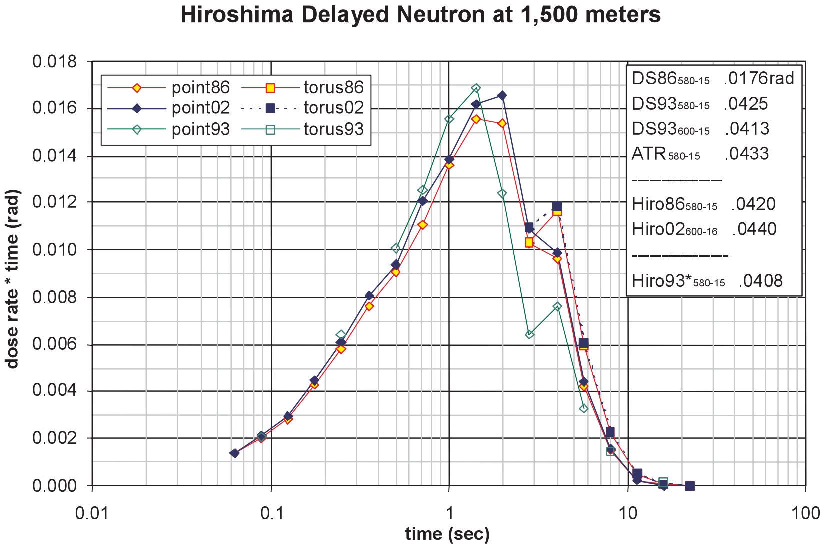


Figure 37. *Time dependent delayed neutron dose at 1,500 m; integrated dose (rads) given for several calculation assumptions.*

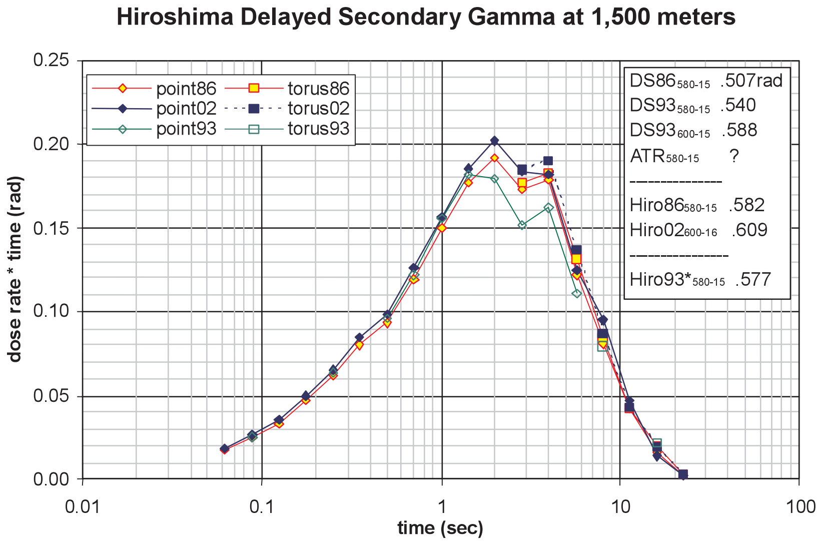
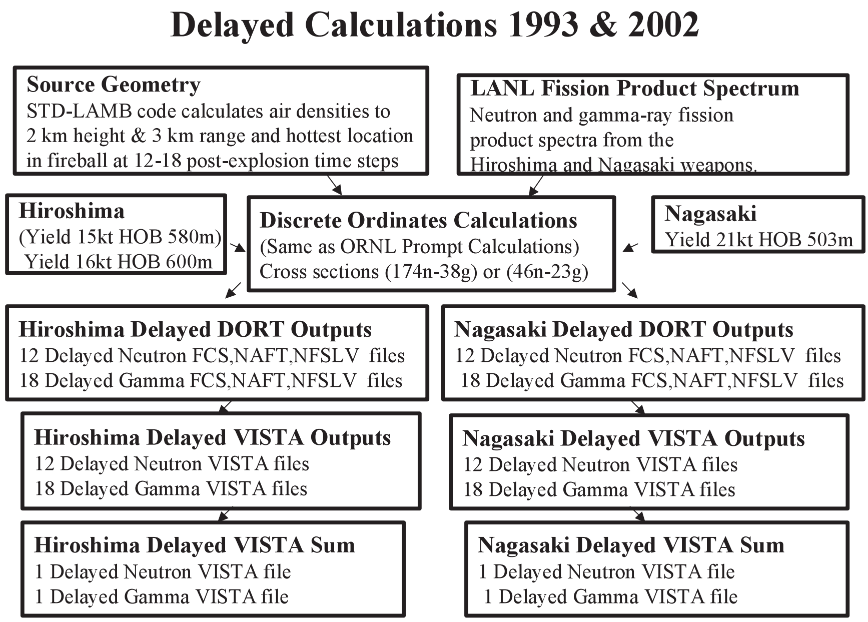


Figure 38. *Time dependent delayed secondary gamma ray dose at 1,500 m; integrated dose (rads) given for several calculation assumptions.*

times and from the torus source at late times. The results, from the displayed curves are given, labeled as Hiro86, Hiro02 and Hiro93. The Hiro02 results are used for DS02. These doses are compared to doses that were obtained previously, labeled DS86, DS93, and DS93*. They refer to results from the DS86 report and 1993 delayed radiation calculations at 580- and 600-m HOBs, respectively. Doses calculated by the ATR code are also given.

While there are some differences in the arrival of the shock and the peak dose rate, the most important changes in the integrated dose come from the new LANL delayed radiation sources and the increased yield in DS02. The Hiro02 (DS02) delayed calculations are reasonable and consistent with previous results, considering the changes that have been made. 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 following flow chart shows the sequence of the delayed radiation calculations that produced the data for DS02.



Combining Prompt and Delayed Radiation

The prompt and delayed fine group VISTA fluences from the neutron and gamma sources are combined for three purposes:

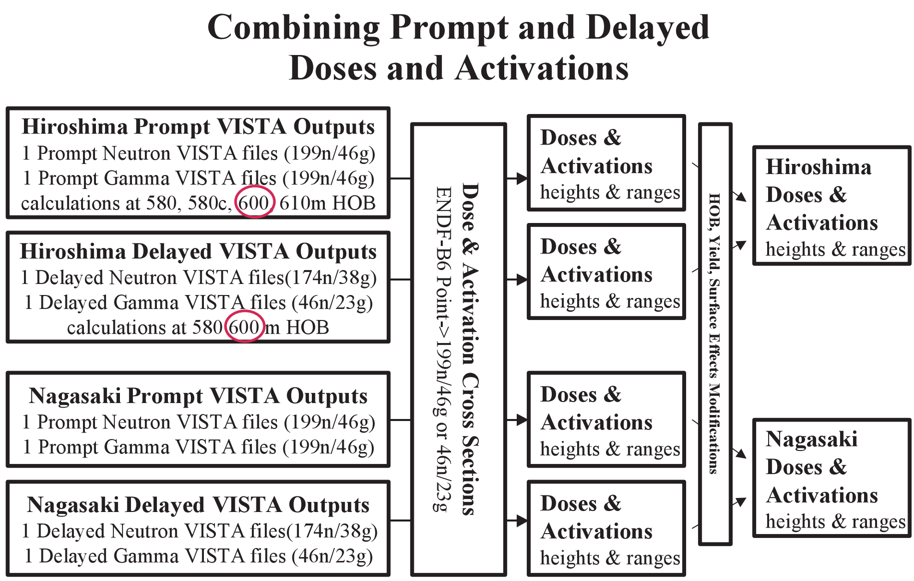
1) to compare the fine group free-in-air total doses and activations with previous results from DS86 and lightly shielded measurements,
2) to generate coarse-group fluences for use in the MASH code (Johnson 1999) to calculate

activation at sample locations for comparison with shielded measurements, and
3) to generate coarse-group fluences for use in survivor dosimetry calculations with the DS02-code.

The fine-group free-in-air doses and activation data were generated directly from each of the fine group fluences. Each fine group VISTA file for Hiroshima and Nagasaki (primary and secondary, prompt and delayed) was folded with the fine group dose and activation responses given in this chapter. The prompt results, calculated for a 1-kt yield, were scaled to the appropriate yields of 16 or 21 kt for Hiroshima and Nagasaki, respectively. Adjustments were made for Hiroshima delayed neutrons to account for the change in the height of burst from 580 m to 600 m and the increase in yield from 15 to 16 kt. The delayed gamma rays were calculated at the accepted heights of burst and yields for both cities, so scaling of these data was not necessary. The corresponding doses and activation data were summed and compared to the DS86 doses and activation data at the same height of burst and distances from the hypocenter.

The DS86 doses and activation data were calculated using coarse group responses that were available from ENDF-B/V in 1986 and the early 1990's. Tables of the doses and activations at 1 m above the ground were generated for comparison with surface measurements and dose tables in the DS86 report. For sulfur activation, a height above ground of 6.5 m was used, because all of the sulfur measurements were made on the electrical insulators located at the top of the poles. The DS86 and DS02 doses and activation data are summarized in tabular form in Appendix D. DS86 fluences within 100 m of the hypocenter were never saved. Therefore the DS86 values at 0, 25, 50, and 75 m were estimated.

The radiation environments at both Hiroshima and Nagasaki were also calculated in air-over-concrete geometries, and the Hiroshima calculations were performed for heights of burst of 580, 600, 610 m. The doses and activation data from these calculations are included in a database of results that can be used in combination with the standard DS02 calculations to estimate dose and activation for a various bomb yields, heights, and environments. The following flow chart illustrates this process:



For shielding studies, the VISTA fluence files were collapsed into the DABL-69 cross-section group structure (46-neutron/23 gamma) commonly used in the MASH shielding code (Johnson 1999). The fine-group dose and activation responses were also collapsed to the DABL-69 group structure by using the Hiroshima 1 m above ground fine-group fluences. This was done at many ground ranges between 0 and 2,500 m, and the energy dependent responses were averaged. There is very little deviation about the mean response in each energy group. These collapsed responses are given in Appendix E. The four VISTA files for each city are summed to generate the total VISTA fluence file. The fluences are given for ground ranges between 0 and 2,500 m at heights of 1, 4, 9, 14, and 22 m.

The VISTA files were also collapsed and combined into an expanded version of the DLC-31 group structure (Bartine et al. 1977) for use in the RERF survivor Dosimetry Systems, DS86 and DS02. This Dosimetry System group structure is described in the DS86 Final Report (Roesch 1987). The prompt and delayed data are kept in 102 separate groups (37 prompt neutron, 21 prompt gamma-ray, 21 delayed gamma-ray and 23 delayed neutron groups). The responses were collapsed to DLC-31 group structure in the same manner as described in the preceding paragraph. These collapsed responses are given in Appendix E.

Comparisons of DS02 and DS86 Dose and Activation Data

The range dependencies of the dose and activation at Hiroshima and Nagasaki are summarized in this section. The data referred to as “DS02” are those obtained during the most recent reassessment of the atomic bomb radiation environments at the two cities. The “DS86” data are those obtained in a previous study and discussed in Roesch (1987).

The dose and activation data reported here were obtained by folding the total (prompt plus delayed) neutron and gamma-ray fluences as a function of ground range with the new fluence-to-dose conversion factors (see Part A of Chapter 12 and activation response functions, respectively). The DS02 data for Hiroshima are reported for a weapon HOB of 600 m and a yield of 16 kt. The DS86 data were obtained for a HOB of 580 m and a yield of 15 kt. For Nagasaki, DS86 and DS02 were calculated at a HOB of 503 m and a yield of 21 kt. The rationale for increasing the HOB and weapon yield at Hiroshima is discussed in Chapter 1. All of the results reported here are from the DS02 reassessment. Where comparisons are made with the DS86 data, they are so indicated.

Hiroshima

The calculated total neutron and gamma-ray primary and secondary doses as a function of ground range are plotted in Figure 39. The separate contributions of the prompt and delayed neutron, primary and secondary gamma-ray and total gamma-ray doses are summarized in Table 11. The prompt, delayed and total contributions to the doses are given at a height of 1 m above the ground in 100-m intervals at ground ranges between 0 and 2,500 m.

Shown in Figure 40 is the comparison of the DS02 and DS86 neutron and gamma-ray doses as a function of ground range expressed as the ratio of DS02 to DS86 activation. The DS02 and DS86 neutron doses differ by about ±10% between 0 and 2,500 m with DS02 falling below DS86 between 0 and 300 m and between 2,000 and 2,500 m. Between 300 and 2,000 m, the DS02 dose

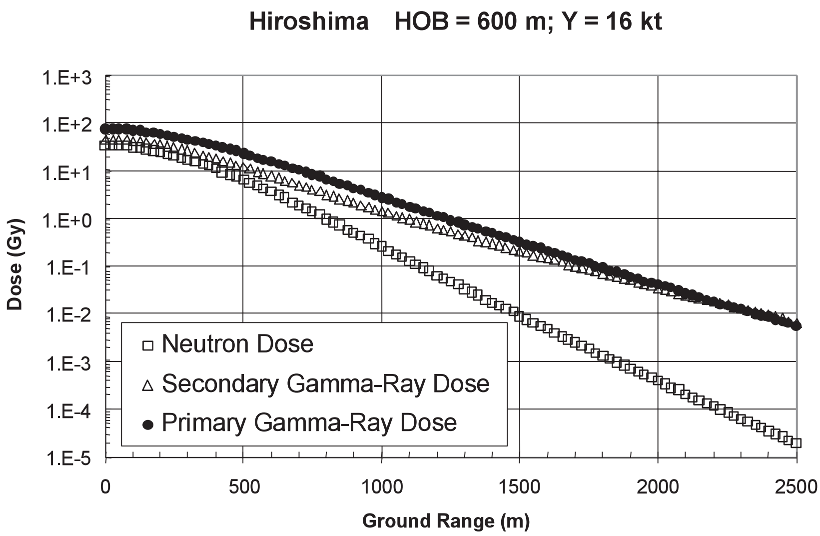


Figure 39. *Hiroshima dose vs. ground range, HOB = 600 m, yield = 16 kt.*

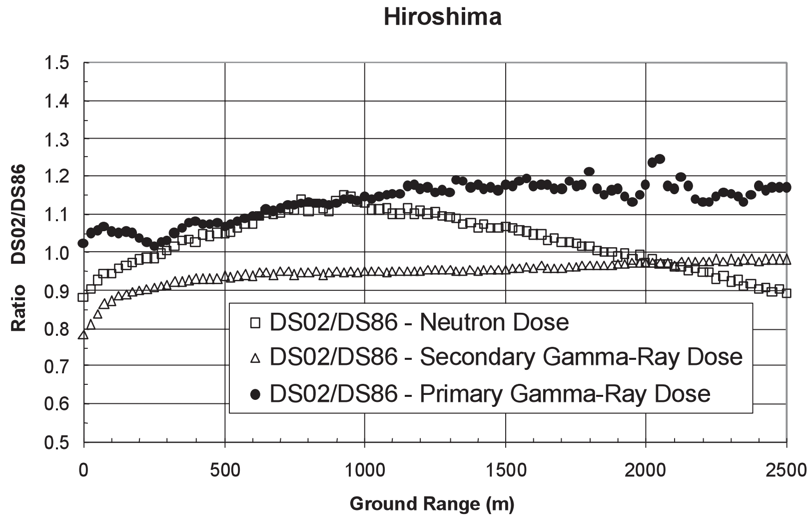


Figure 40. *Ratio of DS02/DS86 Hiroshima dose vs. ground range.*

Table 11. DS02 Hiroshima doses for 600-m HOB above standard ground at 16-kt yield

Ground range	Slant range	Neutron dose			Secondary gamma dose			Primary gamma dose			Total gamma dose		
		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	599	3.16E+1	2.96E+0	3.45E+1	4.45E+1	1.51E+0	4.61E+1	6.18E-1	7.38E+1	7.44E+1	4.52E+1	7.53E+1	1.20E+2
100	607	2.93E+1	2.73E+0	3.20E+1	4.18E+1	1.42E+0	4.32E+1	7.22E-1	7.10E+1	7.17E+1	4.25E+1	7.24E+1	1.15E+2
200	632	2.29E+1	2.16E+0	2.51E+1	3.42E+1	1.18E+0	3.53E+1	6.86E-1	5.96E+1	6.02E+1	3.48E+1	6.07E+1	9.56E+1
300	670	1.60E+1	1.48E+0	1.75E+1	2.54E+1	8.84E-1	2.63E+1	5.90E-1	4.61E+1	4.67E+1	2.60E+1	4.70E+1	7.30E+1
400	720	1.02E+1	9.19E-1	1.11E+1	1.76E+1	6.13E-1	1.82E+1	5.02E-1	3.39E+1	3.44E+1	1.81E+1	3.46E+1	5.27E+1
500	780	5.98E+0	5.09E-1	6.48E+0	1.17E+1	4.00E-1	1.21E+1	3.91E-1	2.32E+1	2.36E+1	1.21E+1	2.36E+1	3.57E+1
600	848	3.33E+0	2.76E-1	3.61E+0	7.55E+0	2.53E-1	7.81E+0	2.90E-1	1.55E+1	1.58E+1	7.84E+0	1.58E+1	2.36E+1
700	921	1.80E+0	1.49E-1	1.95E+0	4.92E+0	1.60E-1	5.08E+0	2.07E-1	1.02E+1	1.04E+1	5.12E+0	1.04E+1	1.55E+1
800	999	9.24E-1	7.20E-2	9.96E-1	3.18E+0	9.95E-2	3.28E+0	1.50E-1	6.58E+0	6.73E+0	3.33E+0	6.68E+0	1.00E+1
900	1081	4.80E-1	3.62E-2	5.17E-1	2.08E+0	6.29E-2	2.15E+0	9.98E-2	4.22E+0	4.32E+0	2.18E+0	4.28E+0	6.47E+0
1000	1166	2.42E-1	1.77E-2	2.60E-1	1.38E+0	4.08E-2	1.42E+0	7.09E-2	2.73E+0	2.80E+0	1.45E+0	2.77E+0	4.22E+0
1100	1253	1.20E-1	8.29E-3	1.29E-1	9.21E-1	2.66E-2	9.48E-1	4.98E-2	1.75E+0	1.80E+0	9.71E-1	1.78E+0	2.75E+0
1200	1341	6.25E-2	3.99E-3	6.65E-2	6.26E-1	1.77E-2	6.44E-1	3.59E-2	1.13E+0	1.16E+0	6.62E-1	1.15E+0	1.81E+0
1300	1431	3.18E-2	1.92E-3	3.37E-2	4.27E-1	1.20E-2	4.39E-1	2.57E-2	7.21E-1	7.47E-1	4.53E-1	7.33E-1	1.19E+0
1400	1523	1.62E-2	9.05E-4	1.71E-2	2.92E-1	8.15E-3	3.01E-1	1.73E-2	4.71E-1	4.88E-1	3.10E-1	4.79E-1	7.89E-1
1500	1615	8.60E-3	4.41E-4	9.04E-3	2.03E-1	5.65E-3	2.08E-1	1.25E-2	3.06E-1	3.18E-1	2.15E-1	3.12E-1	5.27E-1
1600	1708	4.51E-3	2.11E-4	4.72E-3	1.40E-1	3.92E-3	1.44E-1	8.72E-3	2.00E-1	2.09E-1	1.49E-1	2.04E-1	3.53E-1
1700	1802	2.39E-3	1.02E-4	2.49E-3	9.80E-2	2.73E-3	1.01E-1	6.08E-3	1.31E-1	1.37E-1	1.04E-1	1.33E-1	2.37E-1
1800	1897	1.28E-3	5.06E-5	1.33E-3	6.88E-2	1.92E-3	7.07E-2	4.24E-3	8.99E-2	9.41E-2	7.30E-2	9.18E-2	1.65E-1
1900	1992	6.86E-4	2.47E-5	7.11E-4	4.85E-2	1.36E-3	4.99E-2	3.02E-3	5.75E-2	6.05E-2	5.16E-2	5.88E-2	1.10E-1
2000	2088	3.73E-4	1.24E-5	3.86E-4	3.45E-2	9.68E-4	3.54E-2	2.32E-3	3.87E-2	4.10E-2	3.68E-2	3.96E-2	7.64E-2
2100	2184	2.05E-4	6.28E-6	2.11E-4	2.46E-2	6.93E-4	2.53E-2	1.68E-3	2.54E-2	2.71E-2	2.63E-2	2.61E-2	5.24E-2
2200	2280	1.13E-4	3.19E-6	1.16E-4	1.76E-2	4.98E-4	1.81E-2	1.20E-3	1.66E-2	1.78E-2	1.88E-2	1.71E-2	3.59E-2
2300	2377	6.25E-5	1.64E-6	6.41E-5	1.26E-2	3.58E-4	1.30E-2	8.53E-4	1.15E-2	1.24E-2	1.35E-2	1.19E-2	2.53E-2
2400	2474	3.48E-5	8.46E-7	3.56E-5	9.05E-3	2.59E-4	9.31E-3	6.09E-4	7.94E-3	8.55E-3	9.66E-3	8.20E-3	1.79E-2
2500	2571	1.94E-5	4.38E-7	1.99E-5	6.53E-3	1.88E-4	6.72E-3	4.37E-4	5.38E-3	5.82E-3	6.97E-3	5.57E-3	1.25E-2

is larger than the earlier calculated DS86 neutron dose. The DS02 secondary gamma-ray dose is everywhere 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 1,200 m.

The differences among the doses can be attributed to several causes including

1) the energy and angularity of the Hiroshima weapon neutron and gamma-ray sources,
2) the increased inelastic scattering of fast (greater than 3 MeV) neutrons,
3) the increase in forward scattering of the moderate energy (0.5-1.0 MeV) neutrons,
4) the increase in the DS02 height of burst to 600 m, and
5) the change in the yield from 15 to 16 kt.

The calculated neutron activations as a function of ground range at Hiroshima are summarized in Table 12. Figure 41 shows the ^{32}P and ^{63}Ni fast neutron activation production as a function of ground range, and Figure 42 shows the ratios of the DS02 to DS86 fast neutron activation as a function of ground range. The DS02 activation ranges from 10 to 40% lower than the DS86 data and is 10-15% lower between approximately 750 m and 1,500 m ground range. Several factors contribute to the differences between DS86 and DS02. Since the publication of DS86, both the ^{63}Cu(n,p)^{63}Ni and ^{32}S(n,p)^{32}P activation cross sections have been re-evaluated, and the new data have been incorporated into the ENDF/B-VI (Ver. 2) library used for the DS02 calculations. The angular distribution of the neutrons emitted from the weapon was more carefully calculated for the DS02 study, and more neutron-leakage angles were incorporated into the discrete ordinates transport calculations used to obtain the data. Another major factor is the increased inelastic scattering of fast neutrons in air that is predicted by newer cross-section data. Some of the difference can, of course, be attributed to the changes in the height of burst and weapon yield.

The calculated thermal activation isotopes at 1 m above ground at Hiroshima are plotted as a function of ground range in Figure 43. 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. All of the thermal neutron activation curves fall off exponentially. Additional data are given in Appendix D.

Figure 44 shows the differences between the DS02 thermal activation responses and the responses calculated in DS86. The DS02 data are lower than the DS86 activation data by as much as 20% at ground ranges between 0 and 500 m and peak at 30% higher at approximately 1,200 m and drop to approximately 10% higher at 2,500 m ground range. Part of this is caused by the change in the height of burst and yield in the DS02 calculations. Also, the 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 45 shows the ratio of the fast and thermal activation to the neutron dose as a function of ground range. For the purpose of comparing the data, the ratios of the activation to the neutron dose have been arbitrarily normalized to 0.010 at 1,250 m ground range. This figure shows that at Hiroshima the spectrum is continually changing with range and that the fast and thermal neutrons are not in equilibrium. The thermal neutron activation responses reach equilibrium with each other at ground ranges beyond approximately 300 m. The fast neutron responses are in equilibrium with each other out to 1,250 m, then they are quite different beyond approximately 1,500 m. The high-energy neutrons continue to become more energetic as they transport via the cross-section windows of air found at 2.5 and 5 MeV.

Table 12. DS02 Hiroshima activation data for 600-m HOB above standard ground at 16-kt yield

Ground range	Slant range	Reaction	^{40}Ca(n,γ)	^{35}Cl(n,γ)	^{59}Co(n,γ)	^{63}Cu(n,p)	^{151}Eu->grd	^{153}Eu(n,γ)	^{62}Ni(n,γ)	^{32}S(n,p)	^{39}K(n,α)
		Abundance	0.96941	0.7577	1	0.6917	0.4782	0.5218	0.03634	0.9502	0.93258
		MW	40.08	35.453	58.9332	63.54	151.96	151.96	58.71	32.064	39.102
		Half-life	80000	301000	5.2714	100.1	13.542	8.593	100.1	14.262	301000
		Time units	years	years	years	years	years	years	years	days	years
		Branching ratio					0.641				
		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	599		4.88E+10	2.54E-10	1.47E+1	1.14E+7	1.31E+2	2.01E+1	4.14E+10	2.38E+3	1.86E-15
100	607		4.45E+10	2.31E-10	1.34E+1	1.14E+7	1.19E+2	1.83E+1	3.78E+10	2.42E+3	1.92E-15
200	632		3.43E+10	1.78E-10	1.03E+1	9.49E+6	9.17E+1	1.40E+1	2.91E+10	2.04E+3	1.94E-15
300	670		2.28E+10	1.19E-10	6.84E+0	7.12E+6	6.10E+1	9.32E+0	1.93E+10	1.56E+3	1.97E-15
400	720		1.34E+10	6.98E-11	4.02E+0	5.27E+6	3.59E+1	5.47E+0	1.14E+10	1.19E+3	1.75E-15
500	780		7.19E+09	3.74E-11	2.16E+0	3.58E+6	1.92E+1	2.93E+0	6.10E+09	8.23E+2	1.29E-15
600	848		3.62E+09	1.88E-11	1.09E+0	2.28E+6	9.64E+0	1.47E+0	3.06E+09	5.44E+2	1.07E-15
700	921		1.74E+09	9.05E-12	5.25E-1	1.44E+6	4.64E+0	7.10E-1	1.48E+09	3.46E+2	7.79E-16
800	999		8.17E+08	4.24E-12	2.46E-1	8.43E+5	2.17E+0	3.33E-1	6.92E+08	2.07E+2	5.22E-16
900	1081		3.78E+08	1.96E-12	1.14E-1	5.05E+5	1.01E+0	1.55E-1	3.20E+08	1.28E+2	3.68E-16
1000	1166		1.74E+08	9.02E-13	5.26E-2	2.82E+5	4.62E-1	7.11E-2	1.47E+08	7.23E+1	2.34E-16
1100	1253		8.00E+07	4.15E-13	2.43E-2	1.57E+5	2.13E-1	3.28E-2	6.78E+07	4.13E+1	1.35E-16
1200	1341		3.73E+07	1.93E-13	1.13E-2	9.10E+4	9.91E-2	1.53E-2	3.15E+07	2.42E+1	7.96E-17
1300	1431		1.74E+07	9.03E-14	5.29E-3	5.09E+4	4.63E-2	7.16E-3	1.47E+07	1.36E+1	4.64E-17
1400	1523		8.21E+06	4.25E-14	2.49E-3	2.79E+4	2.18E-2	3.37E-3	6.95E+06	7.75E+0	2.73E-17
1500	1615		3.96E+06	2.05E-14	1.20E-3	1.61E+4	1.05E-2	1.62E-3	3.35E+06	4.50E+0	1.55E-17
1600	1708		1.93E+06	9.98E-15	5.86E-4	9.12E+3	5.11E-3	7.90E-4	1.63E+06	2.57E+0	8.91E-18
1700	1802		9.49E+05	4.91E-15	2.89E-4	5.12E+3	2.51E-3	3.88E-4	8.02E+05	1.46E+0	5.22E-18
1800	1897		4.73E+05	2.45E-15	1.44E-4	2.87E+3	1.25E-3	1.94E-4	4.00E+05	8.32E-1	2.99E-18
1900	1992		2.39E+05	1.24E-15	7.27E-5	1.63E+3	6.32E-4	9.78E-5	2.02E+05	4.78E-1	1.74E-18
2000	2088		1.22E+05	6.31E-16	3.71E-5	9.41E+2	3.23E-4	4.99E-5	1.03E+05	2.77E-1	9.88E-19
2100	2184		6.31E+04	3.27E-16	1.92E-5	5.36E+2	1.67E-4	2.58E-5	5.33E+04	1.60E-1	5.74E-19
2200	2280		3.30E+04	1.71E-16	1.01E-5	3.06E+2	8.74E-5	1.35E-5	2.79E+04	9.22E-2	3.33E-19
2300	2377		1.75E+04	9.06E-17	5.33E-6	1.75E+2	4.63E-5	7.16E-6	1.48E+04	5.30E-2	1.94E-19
2400	2474		9.38E+03	4.85E-17	2.85E-6	1.00E+2	2.48E-5	3.83E-6	7.92E+03	3.05E-2	1.12E-19
2500	2571		5.06E+03	2.61E-17	1.54E-6	5.77E+1	1.34E-5	2.06E-6	4.27E+03	1.77E-2	6.48E-20

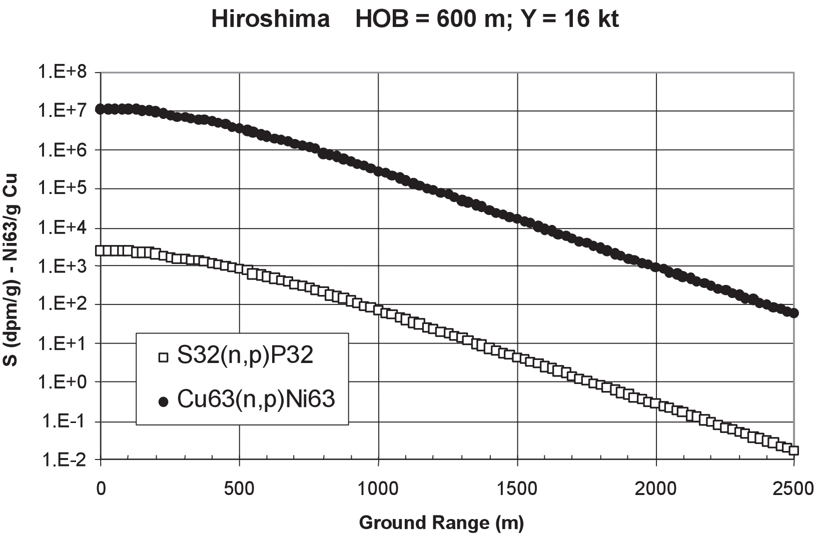


Figure 41. *Hiroshima fast neutron activation vs. ground range, HOB = 600 m, yield = 16 kt.*

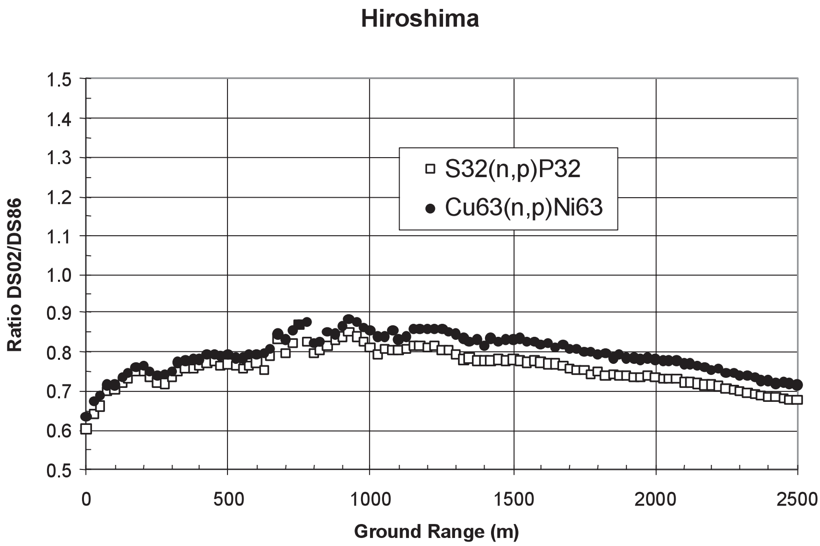


Figure 42. *Ratio of DS02/DS86 Hiroshima fast neutron activation vs. ground range.*

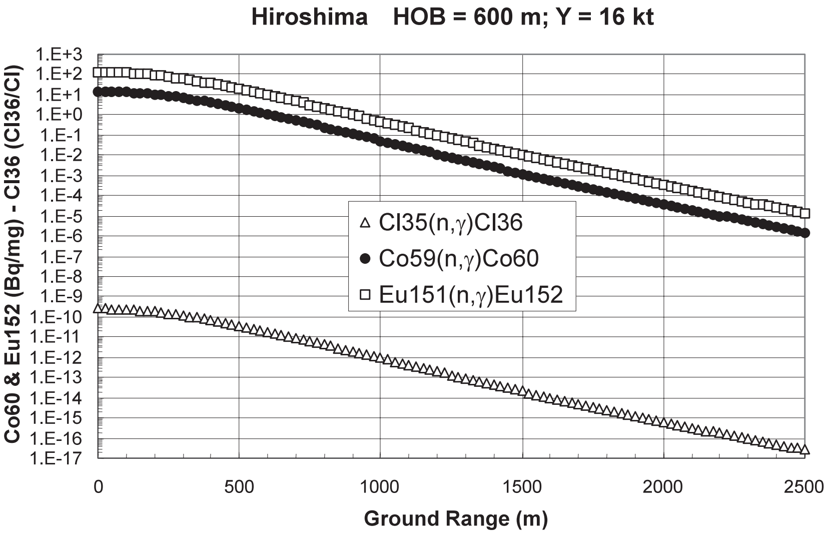


Figure 43. *Hiroshima thermal neutron activation vs. ground range, HOB = 600 m, yield = 16 kt.*

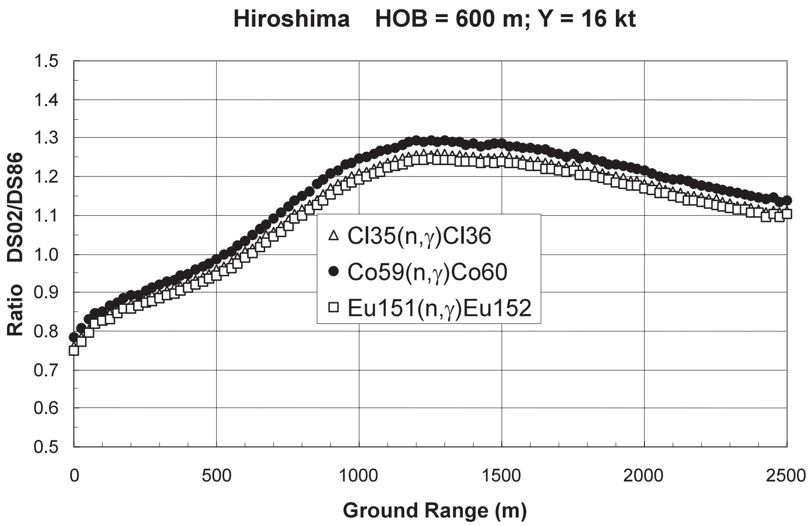


Figure 44. *Ratio of DS02/DS86 Hiroshima thermal neutron activation vs. ground range, HOB = 600 m, yield = 16 kt.*

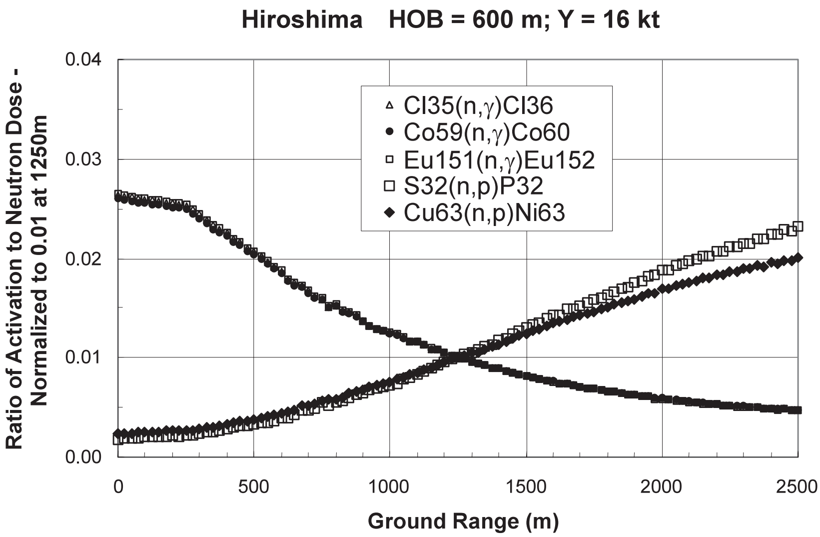


Figure 45. *Ratio of Hiroshima activation to neutron dose vs. ground range, HOB = 600 m, yield = 16 kt.*

Nagasaki

The calculated total neutron and gamma-ray primary and secondary doses as a function of ground range are plotted in Figure 46. The separate contributions of the prompt and delayed neutron, primary and secondary gamma-ray and total gamma-ray doses are summarized in Table 13. The prompt, delayed and total contributions to the doses are given at a height of 1 m above the ground in 100-m intervals at ground ranges between 0 and 2,500 m.

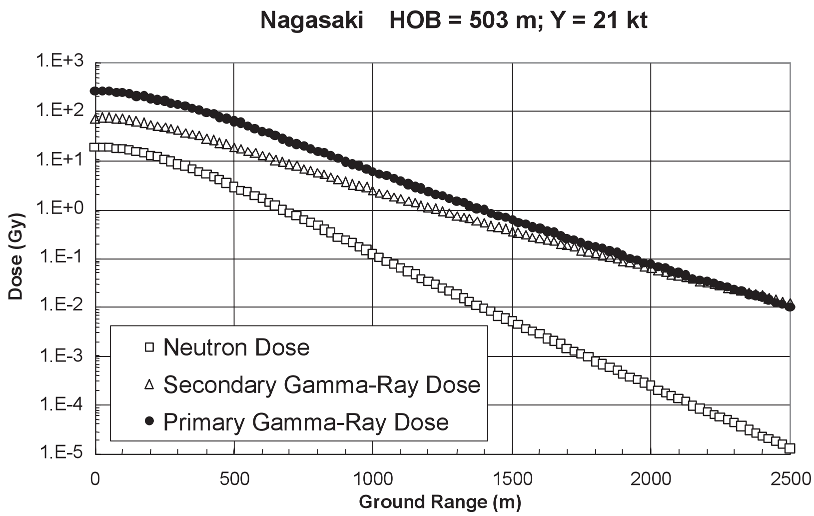


Figure 46. *Nagasaki dose vs. ground range, HOB = 503 m, yield = 21 kt.*