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ABSTRACT

Extensive work has been conducted over the past few years to reassess all aspects of the radiation dosimetry for the A-bombs in Hiroshima and Nagasaki. This work has included reviews of the bomb yields, source terms, air transport of neutrons and gamma rays, neutron-induced radioactivity and thermoluminescence in exposed materials, shielding of individuals by buildings, and calculations of organ doses. The results of these theoretical and experimental activities have led to the development of a new dosimetry system which is designated as the Dosimetry System 1986 (DS86).

New DS86 estimates of tissue kerma in air and absorbed dose to fifteen organs are available for 94,787 survivors who were either outside and unshielded, outside and shielded by houses, or inside and shielded by houses (64,408 in Hiroshima and 30,379 in Nagaski). The organ doses are calculated on an age-dependent basis as follows: infants (less than 3 years old at the time of bombing, ATB), children (3 to 12 years old ATB), and adults (more than 12 years old ATB). Work in progress includes the extension of the DS86 system to Nagasaki survivors who were shielded either by terrain or by factory buildings.

The DS86 methods of dose estimation are discussed and the current DS86 results are compared with earlier dose estimates which were designated as Tentative 1965 Doses (T65D) and were used as a basis for risk assessment throughout the 1970's.

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INTRODUCTION

Various radiation effects in the A-bomb survivors and their offspring have been investigated since 1948 by a cooperative Japan-United States research organization, known as the Radiation Effects Research Foundation (RERF). A reliable estimate of radiation dose to each of the individual survivors is essential to the understanding of late health effects occurring in the various RERF investigations (Finch and Iwao, 1978). Without reliable dose estimates, meaningful assessment of carcinogenic and genetic risk is not possible.

In 1983, joint U.S.-Japan research programs and oversight committees were established to conduct a thorough review of all aspects of the radiation dosimetry for the atomic bombs in Hiroshima and Nagasaki (RERF, 1983; RERF, 1984). The review was completed in 1986 and a final two-volume report was prepared (RERF, 1987).that discusses the physical basis for the new Dosimetry System 1986 (DS86). This paper deals with the application of the DS86 methods to individual survivors in the major study populations of RERF.

MAJOR STUDY POPULATIONS

At present, DS86 estimates have been computed for a large number of survivors who are members of the Life Span Study (LSS) and *In Utero* Mortality Samples or parents of offspring in the First Generation Mortality Sample (F_1) of the RERF (see Table 1). The Adult Health Study (AHS) is a subgroup of both the LSS and *In Utero* samples (Finch and Iwao, 1978). Portions of the F_1 sample also have been used in studies of chromosome aberrations and biochemical genetic markers in offspring that may have been due to parental exposure to neutrons and gamma rays from the bombs (Shigematsu and Akiba, 1986).

Two important parameters in the radiation dosimetry for individual survivors are distance and shielding (Noble, 1967). For example, some individuals survived very close to the bombs because they were shielded by buildings. Other individuals survived because they were located at

Table 1. Major study populations.

Study	Approximate number of subjects	Year base populations established	Year studies initiated
Survivors:			
Life Span Study (LSS)	120,000	1950[a]	1958
Adult Health Study (AHS)	23,500	1950[a]	1958
In Utero Mortality	2,800	1945-46[b]	1960
Offspring of survivors:			
First Generation Mortality (F_1)	75,000	1946-85[c]	1960
Biochemical Genetics Study (BGS)	45,000	1946-85[c]	1975
Chromosome Aberrations	33,000	1946-85[c]	1967

[a]Special supplement to the 1950 National Census in Japan.

[b]Birth records from August 1945 through June 1946.

[c]Birth records from June 1946 through December 1985.

large distances from the hypocenters of the bombs. Thus, distance from the hypocenter or ground range was one of the criteria used in the selection of the major study samples (Beebe and Usagawa, 1968).

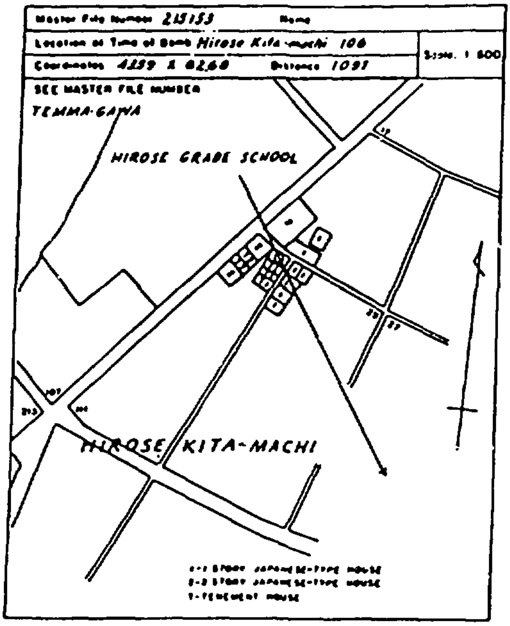
Survivors (and offspring of survivors) who were located at ground ranges of less than 2500 m are the core group of the major study samples and are referred to commonly as the proximal exposed group. Other groups used as controls are the distal exposed group of survivors who were located at ground ranges between 2500 and 10,000 m, and the not-exposed group of survivors who were located at more than 10,000 m. The not-exposed group is referred to commonly as the not-in-city group (or NIC group) because it contains a large number of individuals who were not in the cities at the times of bombing (ATB) but took up residency in Hiroshima or Nagasaki prior to 1950 (Ishida and Beebe, 1959).

SHIELDING HISTORIES

Shielding histories were compiled for proximal exposed survivors starting in 1951 in Nagasaki and 1954 in Hiroshima (see Figure 1). The strategies used in the two cities were somewhat different because there were more proximal exposed survivors in Hiroshima than Nagasaki (Noble, 1967; Beebe and Usagawa, 1968). In Nagasaki, shielding histories were compiled on all survivors who were located at ground ranges of less than 2000 m. However, the approach in Hiroshima was to take shielding histories out to 2000 m for only those survivors included in the smaller study samples (e.g., the AHS and *In Utero* samples). It was decided initially that shielding histories would only be taken on LSS subjects who were located at ground ranges of less than 1200 m. After shielding histories were compiled on all LSS subjects under 1200 m, however, the 100% criterion was extended to those LSS subjects under 1300 m, and so on, ending at 1600 m (Milton and Shohoji, 1968).

When the Tentative 1965 Doses (T65D) became available, it appeared that the radiation doses were approximately equal at 1600 m in Hiroshima and 2000 m in Nagasaki. At that time, shielding histories were available for most of the Nagasaki survivors who were located at ground

Figure 1. Example of a shielding history for a survivor exposed inside a one-story Japanese-type house in Hiroshima.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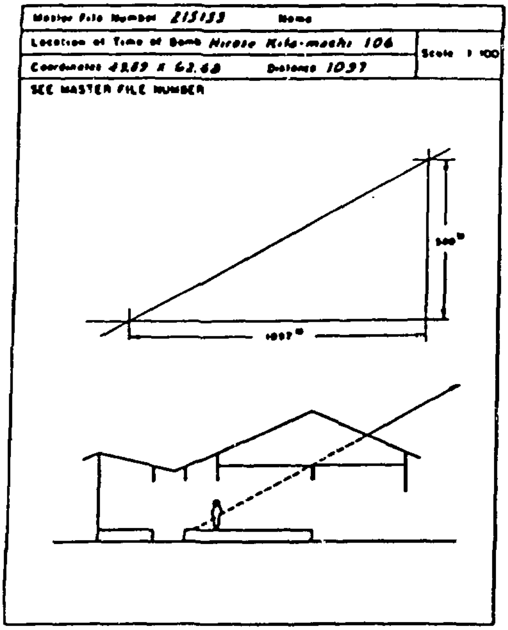
HIROSE KITA-MACHI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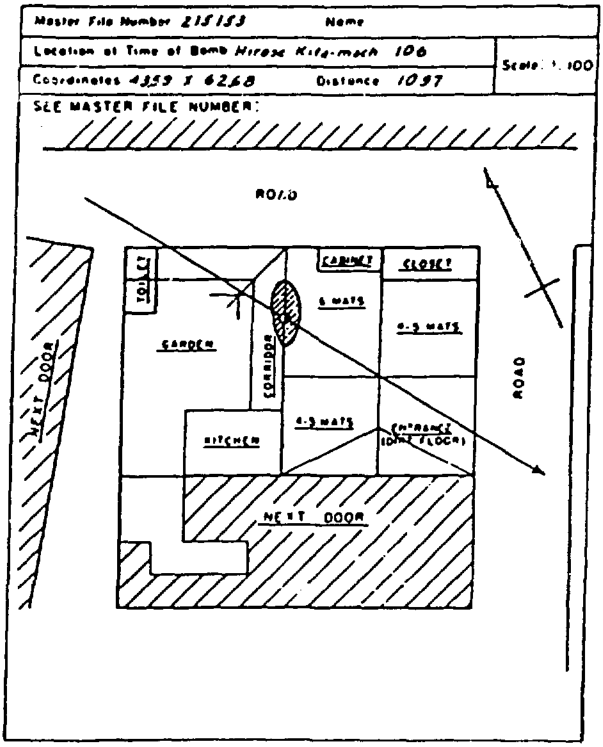
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SEE MASTER FILE NUMBER:
ROAD
TOILET
CABINET
CLOSET
6 MATS
4-5 MATS
GARDEN
CORRIDOR
ROAD
NEXT DOOR
4-5 MATS
KITCHEN
ENTRANCE (DIRT FLOOR)
NEXT DOOR

ranges of less than 2000 m. In Hiroshima, shielding histories were available for most of the LSS subjects under 1600 m, about 30% of the LSS subjects between 1600 m and 2000 m, and most other sample subjects under 2000 m (see Table 2). In both cities, there were a number of cases in which shielding histories were either incomplete or unavailable because of the migration or death of survivors before 1965. For some cases, however, information such as exposed inside-Japanese house or exposed outside-unshielded was available from earlier studies and surveys (Ishida and Beebe, 1959, p. 3).

TENTATIVE 1965 DOSES

A survivor's shielding ATB was taken into account in the T65D system by the use of transmission factors or TF's (e.g., ratios of the radiation dose inside a house to that outside the house). If TF(n) and K(n) are used to denote the transmission factor and radiation dose from neutrons, and TF(γ) and K(γ) denote the same quantities for gamma rays, then the total radiation dose to a survivor was obtained as follows:

$$K(\text{total}) = K(n) + K(\gamma) ,$$
$$K(n) = TF(n) \times K_o(n) , \qquad (1)$$
$$K(\gamma) = TF(\gamma) \times K_o(\gamma) ,$$

where $K_o(n)$ and $K_o(\gamma)$ were the radiation doses from neutrons and gamma rays in the open (e.g., outside the house). Values for $K_o(n)$ and $K_o(\gamma)$ were calculated at the appropriate ground range in either city by the use of two pairs of equations: one pair was used for neutrons and gamma rays in Hiroshima, and the other pair for neutrons and gamma rays in Nagasaki (Auxier et al, 1966).

For survivors exposed in the open without any large structures near them in any direction (i.e., outside-unshielded), the transmission factors were set equal to one (i.e., TF = 1 for both neutrons and gamma rays). The primary methods of obtaining transmission factors for other survivors were as follows:

Table 2. Inventory of shielding histories for proximal exposed survivors by shielding category.

City	Shielding category	Number	Percent
Hiroshima	Outside-unshielded	2,490	12.2
	Outside-partially shielded	547	2.7
	Outside-totally shielded by terrain	46	0.2
	Outside-totally shielded by a house	2,463	12.1
	Inside-Japanese house	14,130	69.4
	Inside-concrete building	329	1.6
	Inside-factory building	33	0.2
	Inside-air raid shelter	46	0.2
	Miscellaneous types of shielding	275	1.4
	Total all categories	20,359	100.0
Nagasaki	Outside-unshielded	513	6.1
	Outside-partially shielded	625	7.5
	Outside-totally shielded by terrain	392	4.7
	Outside-totally shielded by a house	1,125	13.5
	Inside-Japanese house	3,660	43.8
	Inside-concrete building	616	7.4
	Inside-factory building	1,047	12.5
	Inside-air raid shelter	336	4.0
	Miscellaneous types of shielding	41	0.5
	Total all categories	8,355	100.0

The nine-parameter method in which transmission factors were computed as a linear function of nine covariates describing the survivor's location inside a Japanese house plus other shielding provided by surrounding structures (Cheka et al, 1965; Milton and Shohoji, 1968, pp. 42-43).

The globe method in which transmission factors were determined by direct observation with a "spherical coordinates projector" at the position of the survivor in a scale model which simulated the survivor's exact exposure conditions ATB (Noble, 1967, pp. 28-29 and 79-86).

The ad hoc assignment of transmission factors based on a review of individual shielding histories or groups of similar shielding histories (Milton and Shohoji, 1968, pp. 8-9).

The globe method was used for survivors who were outside but either shielded by a house or by terrain and for some Nagasaki survivors who were inside concrete buildings. Several important examples of ad hoc assignments within the T65D system were as follows:

The use of average transmission factors for survivors who were known to be inside a Japanese house but for whom shielding histories were either incomplete or unavailable.

The use of transmission factors of one for survivors inside several factory buildings of light construction in Nagasaki.

The use of transmission factors of one for all survivors at ground ranges of more than 1600 m in Hiroshima and 2000 m in Nagasaki.

Transmission factors and radiation doses were neither calculated nor assigned for 3017 proximal exposed survivors because their shielding conditions were either extremely complex or unknown.

The T65D system was developed in part from measurements made at atmospheric weapon tests at the Nevada Test Site (NTS) prior to the Limited Test Ban Treaty of 1962 (Auxier, 1977). After 1962, measurements were made using other neutron and gamma-ray sources mounted on a tall 500-m tower at NTS. These sources included a small unshielded reactor, an 800-curie source of ^{60}Co, and a charged particle accelerator for producing neutrons. A variety of radiation detectors were exposed both in the open and inside Japanese-type houses to measure what is now called tissue kerma in air (ICRU, 1971; UNSCEAR, 1972, p. 404). Thus, the T65D tissue-kerma estimates for survivors served only as an approximation to the maximum absorbed dose at the surface (or skin) of the body (BEIR, 1972, p. 101).

In the 1970's, the radiation transport within the body of the survivors was calculated (Kerr, 1979) and the results made available as absorbed-dose factors or ADF's (i.e., ratios of absorbed dose in a specific organ to tissue kerma in air). The total absorbed dose, D, for an organ of interest was then obtained as follows:

$$D(\text{total}) = D(n) + D(\gamma) \;,$$

$$D(n) = ADF(n) \times K(n) \;, \qquad (2)$$

$$D(\gamma) = ADF(\gamma) \times K(\gamma) + ADF(\gamma \leftarrow n) \times K(n) \;,$$

where D(n) and $D(\gamma)$ denoted the absorbed doses from charged particles of varying linear energy transfer (LET). The product of ADF(n) × K(n), gave the high-LET absorbed dose from neutrons, $ADF(\gamma) \times K(\gamma)$ gave the low-LET absorbed dose from external gamma rays, and $ADF(\gamma \leftarrow n) \times K(n)$ gave the low-LET absorbed dose from the gamma rays produced by neutron interactions within the body (i.e., the so-called autogammas).

For leukemia, the organ of interest was the active bone marrow, and for other cancers, the various organs of interest were the female breasts, thyroid, lungs, etc. (BEIR, 1981, pp. 152-154). For *In Utero* studies, the absorbed dose to the uterus (or fetus) was needed, and for F_1 studies, the absorbed doses to the gonads (testes or ovaries) of the parents of offspring were important.

DOSE SYSTEM 1986

A modular code system was developed and installed on the RERF's mainframe computer to facilitate the application of the DS86 methods for dose estimation to individual survivors (Preston and Pierce, 1987; RERF, 1987, Vol. 1, pp. 405-431). The DS86 methods are embodied in the modular code system as follows:

> A data base for the radiation fields in the open which specifies the differential energy and angular fluences of neutrons and gamma rays at four different heights above ground and at 25-m intervals from 100 to 2500 m of ground range in both cities (RERF, 1987, Vol. 1, pp 66-142). Spline fits are used in interpolation and extrapolation of the data to the ground range of interest (Preston and Pierce, 1987).
>
> A data base for house shielding cases which describes how the differential neutron and gamma-ray fluences are modified at over 50 sites inside a Japanese house (or house cluster) and at a similar number of situations in which a survivor was outside and either partially or totally shielded by a Japanese house (RERF, 1987, Vol. 1, pp. 227-305).
>
> A data base for organ dosimetry which describes how the differential neutron and gamma-ray fluences are further modified at fifteen organ sites within the body as functions of a survivor's orientation and posture (RERF, 1987, Vol. 1, pp. 306-404). Age-dependent estimates for organ doses are available for infants (less than 3 years old ATB), children (3 to 12 years old ATB), and adults (more than 12 years old ATB).

Because of the expense of a reexamination of the shielding histories, the DS86 data base for house shielding was constructed to use computerized nine-parameter and globe data that were coded for T65D.

Unlike T65D, however, DS86 does not make use of transmission factors or absorbed-dose factors *per se*. For survivors with shielding histories, organ doses and tissue kerma in air were computed directly if the following conditions were satisfied:

> The survivor was exposed inside a Japanese house and nine-parameter data was available.
>
> The survivor was exposed outside but shielded by a Japanese house and globe data were available.
>
> The survivor was outside-unshielded and flash burns were reported on exposed portions of the skin (e.g., face or neck).

For survivors without shielding histories, it was necessary to develop supplemental procedures for indirect computation of DS86 values for organ doses and tissue kerma in air. Currently, indirect estimates have been made for the following groups:

Distal exposed survivors who have very small DS86 estimates for tissue kerma in air (i.e., less than 5 mGy or 0.5 rad).

Proximal exposed survivors who had reported flash burns and were outside-unshielded based on early records of RERF.

All proximal and distal exposed survivors who were exposed inside a Japanese house based on early records of RERF.

For indirect computation of DS86 estimates for survivors exposed inside houses without shielding histories, average transmission factors were computed from the direct DS86 estimates for survivors with nine-parameter data. In both cities, direct DS86 estimates for survivors within a ground range of 1000 m seemed to indicate somewhat greater shielding than those for survivors inside houses at larger ranges. Hence, the average transmission factors applied to distal exposed survivors were calculated using only the direct DS86 estimates for survivors at ground ranges of 1000 m or more.

At present, DS86 estimates using either direct or indirect methods are available for a total of 94,787 survivors who are members of the LSS and *In Utero* samples or parents of offspring in the F_1 sample (see Table 3). In both Hiroshima and Nagasaki, however, the number of survivors without dose estimates has increased (see Tables 4 and 5). The greatest losses in the DS86 cohort (i.e., DS86 unknown) have occured in the distal exposed groups of survivors with T65D estimates of less than 0.1 Gy or 10 rads. These survivors were primarily the distal exposed individuals who were not inside Japanese houses ATB. The questionable T65D assignment of transmission factors of one to all distal exposed individuals was not used in constructing the DS86 cohort. It is important to note here that all DS86 tissue-kerma estimates for

Table 3. Inventory of DS86 estimates for individual survivors in Hiroshima and Nagasaki.

Estimation method	Number of individuals		
	All samples	LSS sample[a]	Other samples[b]
Direct DS86 estimates[c]	23,422	18,526	4,896
Indirect DS86 estimates[d]	71,365	57,567	13,798
Total DS86 estimates	94,787	76,093	18,694
Unknown DS86	20,232	17,648	2,584
Total DS86 cohort	115,019	93,741	21,278
Not-in-city (NIC)[e]	26,616	26,580	36
Sample totals	141,635	120,321	21,314

[a] Includes most members of the AHS sample.

[b] Not included in LSS sample but a member of the *In Utero* sample or a parent of an offspring in the F_1 sample.

[c] Proximal exposed survivors with shielding histories.

[d] Proximal and distal exposed survivors without shielding histories.

[e] Not exposed group located at ground ranges of 10,000 m or more.

Table 4. Comparison of DS86 and T65D estimates of tissue kerma in air for individual survivors in Hiroshima.

DS86 estimate (Gy)	DS86 cohort totals	T65D estimate (Gy)						
		<0.1	0.1-0.5	0.5-1.0	1.0-2.0	2.0-4.0	4.0+	Unknown
<0.1	45761	45033	728					
0.1-0.5	11461	447	9985	1029				
0.5-1.0	3747		328	2277	1142			
1.0-2.0	2039			64	1117	845	13	
2.0-4.0	1074				9	598	467	
4.0+	326						326	
Unknown	12147	8227	1529	180	155	149	133	1774
T65D cohort totals	76555	53707	12570	3550	2423	1592	939	1774
Percent DS86 unknown	15.9[a]	15.3	12.2	5.1	6.4	9.4	14.2	100.0

[a]Survivors without DS86 estimates (e.g., 12147 ÷ 76555 = 0.159 or 15.9%).

Table 5. Comparison of DS86 and T65D estimates of tissue kerma in air for individual survivors in Nagasaki.

DS86 estimate (Gy)	DS86 cohort totals	T65D estimate (Gy)						
		<0.1	0.1-0.5	0.5-1.0	1.0-2.0	2.0-4.0	4.0+	Unknown
<0.1	25811	23722	2089					
0.1-0.5	2435		1180	1096	159			
0.5-1.0	974			98	677	199		
1.0-2.0	732				92	590	50	
2.0-4.0	294					74	220	
4.0+	133						133	
Unknown	8085	3519	1245	573	875	456	144	1273
T65D cohort totals	38464	27241	4514	1767	1803	1319	547	1273
Percent DS86 unknown	21.0[a]	12.9	27.6	32.4	48.5	24.6	26.3	100.0

[a]Survivors without DS86 estimates (e.g., 8085 ÷ 38464 = 0.210 or 21.0%)

individual survivors include appropriate reductions for any shielding provided by houses and other structures or by terrain.

In Nagasaki, there was also a significant percentage loss of survivors with T65D estimates of more than 0.1 Gy or 10 rads (see Table 5). This loss primarily reflects the current lack of DS86 estimates for survivors who were shielded either by factory buildings (about 1000 in Nagasaki) or by terrain (about 400 in Nagasaki). The DS86 methods originally contained a data base for terrain shielding cases, but it was deleted and replaced recently by a more refined data base. A new data base for factory shielding cases in Nagasaki also was installed recently on the RERF's mainframe computer. Work in progress at RERF includes the extension of DS86 methods to these two important shielding categories in Nagasaki (see Table 2).

DISCUSSION

One of the most significant changes of the dose reassessment effort involves the radiation fields in the open in Hiroshima (see Figure 2). For example, the new dosimetry gives larger tissue-kerma estimates for some survivors who were exposed outside-unshielded at larger ground ranges (see Table 4). In Hiroshima, the gamma-ray kerma is significantly larger than before, due in part to a change from 12.5 to 15 kt for the bomb yield, and the neutron kerma is significantly smaller for a couple of reasons. One reason is that modern source-term calculations indicate an average energy of only about 0.3 MeV for the fast neutrons from the Hiroshima bomb, whereas the T65D values were derived from measurements using fission source neutrons with an average energy of approximately 1 MeV. The second reason is that the measurements were made under dry desert-like conditions at NTS and failed to account for the very high humidity in Hiroshima and Nagasaki ATB (i.e., modern air-transport calculations indicate a reduction by a factor of two in neutron kerma because of the higher humidities, all other things being equal). In Nagasaki, the bomb yield and gamma-ray kerma in the open have remained essentially the same as before (see Figure 2). Thus, the

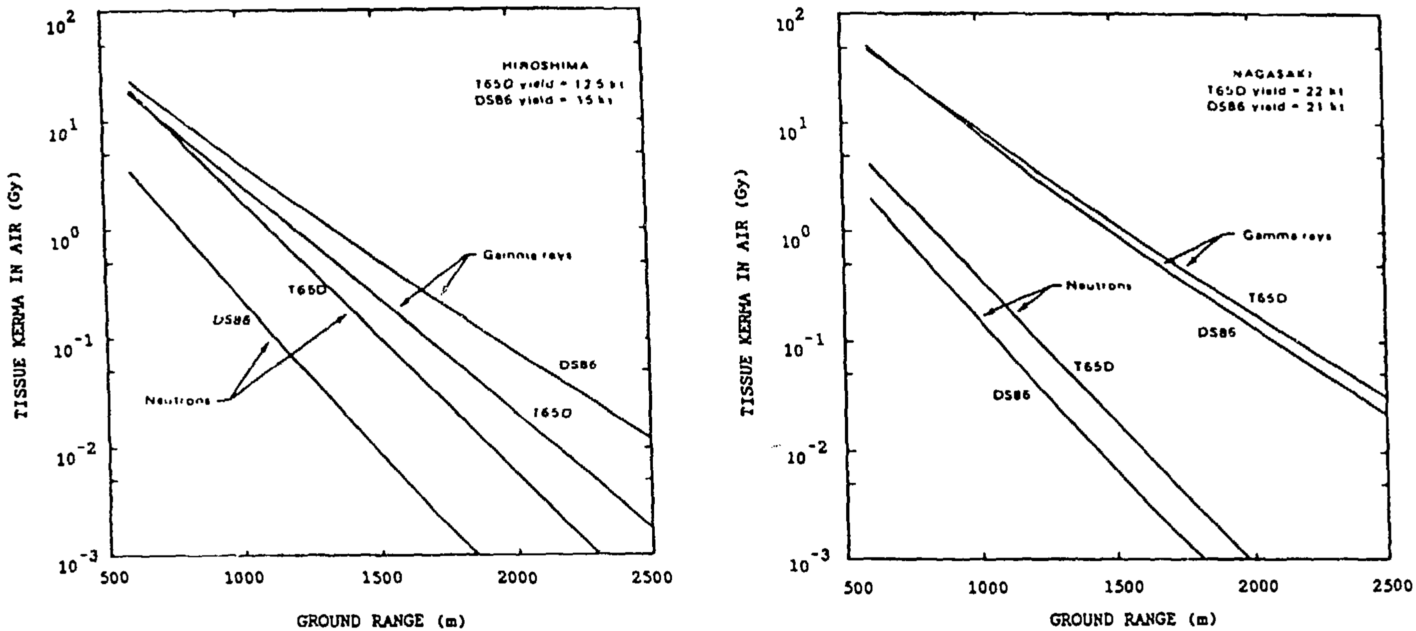

Figure 2. Comparison of values for the radiation fields in the open in Hiroshima and Nagasaki.

survivors in both cities were exposed mainly to gamma rays (i.e., neutrons are no longer a very important contributor to the radiation doses of survivors in Hiroshima).

Another major change of the dose reassessment effort involves the shielding provided by structures, particularly houses. For example, the newer estimates for the transmission of gamma rays by houses are about 50% compared to the T65D estimates of 80 to 90% (see Table 6). The T65D estimates also were derived from measurements using fission source neutrons that were too energetic (i.e., the ratio of the neutron to gamma-ray kerma was too large both in the open and inside the houses). This resulted in an inaccurately high value for transmission of gamma rays by a house because of the gamma rays produced by neutron interactions in the roof and walls of the house. Thus, the shielding provided by houses was seriously underestimated in the T65D system, and the new information has a significant effect on the dose estimates for survivors (see Tables 4 and 5). In both cities, the new tissue-kerma estimates for survivors have tended to be smaller than the T65D estimates because of the large number of survivors who were exposed inside houses or outside shielded by houses (see Table 2). On the average, the DS86 tissue-kerma estimates for survivors are about 60% less than the T65D estimates mainly due to the overestimation of the transmission of gamma rays by houses in the T65D system (see Table 6).

The desired end-result of the dose reassessment effort was reliable estimates of organ doses for the individual survivors. Organ dosimetry was not included as a part of the original T65D system, but techniques for the estimation of organ doses were added later. These techniques also were based on transport calculations for fission source neutrons that were too energetic (i.e, the average neutron energy was about 1 MeV) and the result was an underestimation of the absorbed dose from the gamma rays produced by neutron interactions in the body (i.e., the autogammas, see Table 7). It was also assumed that the radiation fields were nearly isotropic inside the houses (i.e., the body was irradiated by neutrons and gamma rays coming from all directions). The new

Table 6. Average transmission factors for houses.[a]

City	Dose system	Transmission factor, TF	
		Gamma rays	Neutrons
Hiroshima	T65D	0.90	0.31
	DS86	0.46	0.36
Nagasaki	T65D	0.81	0.35
	DS86	0.48	0.41

[a]Adapted from Preston and Pierce (1987).

Table 7. Average absorbed-dose factors for organs.[a]

Organ	Dose system	Absorbed dose factor, ADF		
		Gamma rays	Neutrons	Autogammas
Red bone marrow	T65D	0.56	0.28	0.07
	DS86	0.79	0.34	0.57
Large intestine	T65D	0.40	0.14	0.08
	DS86	0.72	0.15	0.55

[a]Adapted from Preston and Pierce (1987).

dosimetry system indicates, however, that the gamma rays were incident mainly on the side of the body facing the hypocenter (i.e., the absorbed doses to the deeper seated organs were more like those resulting from plane-beam irradiation of the body, see Table 7). Thus, the new dosimetry is capable of computing organ doses for three age groups, for several postures, and for various orientations (i.e., orientation and posture are both important in the estimation of absorbed dose to shallow organs of the body such as the testes and female breasts). The end-result is more reliable and precise estimates of organ doses for the individual survivors. On the average, however, the new organ doses are about the same as before because of compensating differences in the T65D house-transmission and absorbed-dose factors for gamma rays (see Tables 6 and 7).

ACKNOWLEDGEMENTS

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REFERENCES

Auxier,J.A.,Cheka,J.S.,Haywood,F.F.,Jones,T.D.and Thorngate,J.H., 1966, *Health Physics 12*, 425-429.

Auxier,J.A., 1977, *Ichiban: Radiation dosimetry for the survivors of the bombings of Hiroshima and Nagasaki* (Springfield, Va.: NTIS).

Beebe,G.W.and Usagawa,M., 1968, RERF Report ABCC TR 12-68.

BEIR, 1972, *The effects on populations of exposure to low levels of ionizing radiation* (Washington, D.C.: National Academy of Sciences).

BEIR, 1981, *The effects on populations of exposure to low levels of ionizing radiations* (Washington, D.C.: National Academy of Sciences).

Cheka,J.S.,Sanders,F.W.,Jones,T.D.and Shinpaugh,W.H., 1965, USAEC Report CEX-62.11 (Springfield, Va.: NTIS).

Finch,S.C.and Iwao,M.M., 1978, RERF Report RERF TR 16-78.

ICRU, 1971, *Radiation Quantities and Units, ICRU Report 19* (Washington, D.C.: International Commission on Radiation Units and Measurements).

Ishida,M.and Beebe,G.W., 1959, RERF Report ABCC TR 04-59.

Kerr,G.D., 1979, *Health Physics 37*, 487-508.

Milton,R.C.and Shohoji,T., 1968, RERF Report ABCC TR 1-68.

Noble,K.B., 1967, RERF Report ABCC TR 7-67.

Preston,D.L.and Pierce,D.A., 1987, RERF Report RERF TR 9-87.

RERF, 1983, *Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki*, edited by D.J.Thompson (Hiroshima: RERF Printing Office).

RERF, 1984, *Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki with Special Reference to Shielding and Organ Doses*, edited by H.Kato, et al (Hiroshima: RERF Printing Office).

RERF, 1987, *Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, Final Report, Vols. 1-2*, edited by W.C.Roesch (Hiroshima: RERF Printing Office).

Shigematsu,I.and Akiba,S., 1986, In *Cancer in Atomic Bomb Survivors*, edited by I.Shigematsu and A.Kagan (New York: Plenum Press), pp. 1-8.

UNSCEAR, 1972, *Ionizing radiation: Levels and Effects, Vol. 2* (New York: United Nations Publications).