Chapter 9

DOSIMETRY SYSTEM 1986

William A. Woolson, Stephen D. Egbert, and Michael L. Gritzner
Science Applications International Corporation

In May 1983, the authors proposed a dosimetry system for use by the Radiation Effects Research Foundation (RERF) that would incorporate the new findings and calculations of the joint United States-Japan working groups on the reassessment of A-bomb dosimetry. The proposed dosimetry system evolved from extensive discussions with RERF personnel, numerous meetings of the scientists from Japan and the United States involved in the dosimetry reassessement research, and requirements expressed by epidemiologists and radiobiologists on the various review panels. The dosimetry system proposed was based on considerations of the dosimetry requirements for the normal work of RERF and for future reseach in radiobiology, the computerized input data on A-bomb survivors available in the RERF data base, the level of detail, precision, and accuracy of various components of the dosimetric estimates, and the computer resources available at RERF in Hiroshima. These discussions and our own experience indicated that, in light of the expansion of computer and radiation technologies and the desire for more detail in the dosimetry, an entirely new approach to the dosimetry system was appropriate. This resulted in a complete replacement of the T65D system as distinguished from a simpler approach involving a renormalization of T65D parameters to reflect the new dosimetry.

The proposed dosimetry system for RERF and the plan for implementation was accepted by the Department of Energy (DOE) Working Group on A-bomb Dosimetry chaired by Dr. R. F. Christy. The dosimetry system plan was also presented to the binational A-bomb dosimetry review groups for critical comment and was discussed at joint US-Japan workshop.

A prototype dosimetry system incorporating preliminary dosimetry estimates and applicable to only a limited set of A-bomb survivors was installed on the RERF computer system in the fall of 1984. This system was successfully operated at RERF and provided an initial look at the impact of the new dosimetry.[1] The experience gained by the use of this prototype paved the way for an improved system called Dosimetry System 1986 (DS86), which incorporated further developments in dosimetry and treated a more extensive set of survivors in the RERF data base.

The fourth joint US-Japan dosimetry workshop, held in Hiroshima on 16 and 17 March

1986, reviewed the results and findings of the research to assess the A-bomb dose estimates and their incorporation into DS86. As a result, the US-Japan A-bomb radiation dosimetry committees formally approved replacement of T65D with DS86 for use by RERF for computation of doses to A-bomb survivors. The purpose of this chapter is to provide a description of DS86.

Atomic Bomb Survivor Dosimetry

RERF maintains records on paper produced from interviews with survivors; the records contain comprehensive descriptions of A-bomb survivor location, orientation, and shielding at the time of the bomb (ATB) for most proximally exposed and some distally exposed Life Span Study survivors of the Hiroshima and Nagasaki A-bombs (Appendix 7-2).[2] The term "survivor" is used by RERF, and by Science Applications International Corporation (SAIC), to mean a person whose record is in the RERF data bases. "Proximally exposed" is defined as a person exposed within 1600 m from the hypocenter at Hiroshima and 2000 m at Nagasaki. A description of the Life Span Study and other survivor data bases used by RERF can be found in the report by Beebe and Usagawa.[3] The extent of the file information for most distally exposed survivors (i.e., persons exposed beyond 1600 m at Hiroshima and 2000 m at Nagasaki) is simply their location and placement into one of nine shielding categories. These records for proximally and distally exposed survivors provide the basic data for estimates of their radiation doses.

The dosimetry method used by RERF since 1965, which is being replaced by DS86, is called Tentative 1965 Dose (T65D). The T65D method was based entirely on experimental data obtained from nuclear weapon tests explosions at the Nevada Test Site, from Operation BREN experiments, and from fixed-source shielding experiments.[4] T65D used a simple two-parameter formula to calculate the free-in-air (FIA, see Editor's Note) neutron and gamma-ray kerma as a function of slant range from the burst point. Shielding was treated by multiplying the FIA kerma by radiation transmission factors (TF, see Chapter 7) which depended on the situation of the survivor. Some time after the T65D system was introduced, an additional TF was developed to account for absorption in the body when doses were required for specific organs. The T65D formula for the FIA kerma at a ground range, R, from the hypocenter is:

$$D = G_o \frac{e^{-\frac{\sqrt{H^2+R^2}}{L}}}{H^2 + R^2} \tag{1}$$

where G_o and L are the two parameters of the formula and H is the height of burst. The values of G_o, L, and H are given in Table 1.

The parameters for the formula were derived from experimental data obtained during nuclear tests at the Nevada Test Site and from other experimental results.[4] Values for G_o and L for gamma rays at Nagasaki were obtained from least squares solution to kerma versus range at early Nevada tests of devices similar to the device used at Nagasaki.[5,6] The value of G_o for neutron kerma at Nagasaki was obtained by assuming the same ratio of G_o for gamma rays to G_o for neutrons used by York in the earlier T57D dosimetry system.[6,7] The value of L for neutrons at Nagasaki was obtained from weapon test data corrected for air-ground interface effects by data from Operation BREN.[6] Operation BREN consisted of a series of

Table 1. T65D Free-In-Air Kerma Parameters

City	Height of Burst m	Neutrons G_o rad m²	Neutrons L m	Gamma Rays G_o rad m²	Gamma Rays L m
Hiroshima	570	8.70×10^{10}	198	3.45×10^{10}	250
Nagasaki	500	1.30×10^{10}	198	2.75×10^{10}	250

experiments in which an unshielded reactor or a ^{60}Co source was suspended on a tower about 465 m above the ground and kerma measurements were made at various heights above the ground and inside simulated Japanese houses at various ground ranges.[4] The value of G_o for neutron kerma at Hiroshima was drived by factoring G_o into two components:[4-6]

$$G_o = D_1 \, B \tag{2}$$

where

D_1 = dose leakage 1 m from an experimental facility called the Ichiban reactor assembly that was normalized to the yield of fission neutrons produced by the Hiroshima bomb ($D_1 = 1.25 \times 10^{10}$ rad), and

B = dose buildup factor obtained from Operation BREN experiments (B = 6.96).

The value of L for neutrons at Hiroshima was assumed to be the same value as that for Nagasaki.[6] The value of L for gamma-ray kerma at Hiroshima was never fully explained. The best reference[5] states, "The relaxation length, L, was measured for similar gamma-ray spectra in BREN and weapons tests and is 250 m." The value of G_o for gamma rays at Hiroshima was obtained from BREN data by assuming that the neutron kerma was equal to the gamma-ray kerma at 825 m slant range (if fission product gamma rays were 33% of the total gamma-ray kerma from a weapon source at this distance) in Nevada air.[5]

If houses, other structures, or the terrain gave significant shielding of the bomb radiations, a TF was applied to reduce the kerma. It was computed, in most instances, by one of two methods: the nine-parameter formula or the globe technique. The nine-parameter formula was used for survivors in Japanese residential houses and the globe technique was applied to survivors who were outside and shielded by either terrain or structures and to survivors inside heavily shielded concrete buildings (Appendix 7-2).[2,4] The nine-parameter formula and the globe technique required computerized input data for each survivor representing, in some way, his particular shielding configuration.

The nine parameter formula was developed from an analysis of the Operation BREN house shielding experiment.[6] Kerma measurements at various locations inside the simulated Japanese houses were divided by the kerma measured at the same distance without the houses present to produce kerma TF. Regression analysis of the TF was performed with a number of different parameters describing the shielding characteristics of the location to determine the most significant parameter in capturing the variation of kerma transmission with location. The result was the nine parameters and the so-called nine-parameter formula, which provides TF for neutrons and gamma rays as a function of the values of the nine parameters. RERF Shielding Section personnel then examined the elevation and plan drawings of the survivor location available in the shielding history for each survivor, calculated each of the nine parameters, and had them entered into a computer file for the survivor. Over one-half of the proximally exposed survivors have nine-parameter data. A description of the nine parameters may be found in Chapter 7 and Appendix 7-2.

The globe technique, used for survivors out of doors and shielded by terrain or nearby houses, was based on determining which portions of angular space seen by the detector were blocked by shields.[4] To determine this blockage, a spherical projector called the globe was used by RERF personnel with scale house models. The projector consisted of a spherical transparent plastic ball with lines representing azimuthal and polar intervals etched on the surface. A small light was placed in the center of this ball; then, when the ball was placed at the survivor location in the model, it would project these lines onto the scale house model so that the amount of angular space blocked could be tallied. The tallied results were then entered into the computer data file for the survivor. For survivors shielded by terrain, the elevation angle of the horizon at 45° azimuth was measured at the survivor location from which the angular space blocked and the globe parameters were determined. The model for the angular distribution of the incident radiation at Hiroshima and Nagasaki was derived from angular data measured at the HARDTACK series of Nevada weapon tests.[4] The TF describing the shielding by houses and terrain was determined in T65D by reducing the modeled incident angular distribution according to the globe data for the survivor.

Loewe and Mendelsohn[9] calculated the FIA kerma for Hiroshima and Nagasaki using the bomb leakage radiation computed by Preeg[10] as a source and state-of-the-art computer codes and nuclear cross sections validated by comparison with Nevada test Operation BREN and other experimental data. They found significant differences when comparing their results to T65D. Their calculated neutron kerma was lower by nearly an order of magnitude at Hiroshima and a factor of two at Nagasaki. The gamma-ray kerma calculated by Loewe and Mendelsohn was higher than T65D by a factor of four at 2000 m at Hiroshima. An analysis of the T65D house TF calculated by the nine-parameter formula was performed by Marcum[11] who estimated that the gamma-ray TF used in T65D were high by nearly a factor of two. These findings of Loewe and Mendelsohn and Marcum were substantiated by other investigators.[12,13] The principal causes of the errors in the T65D dosimetry are the following:

1. T65D did not treat the high humidity at Hiroshima and Nagasaki. The high moisture content of the humid air in August in Japan reduced the neutron kerma compared to that in dryer air such as found at the Nevada Test Site. Failure to account for this difference caused T65D to overestimate the neutron kerma, other things being equal.
2. The experimental data used to construct the T65D Hiroshima neutron and gamma-ray kerma was inadequate and inappropriate. Devices similar to the bomb exploded at Nagasaki were fired at tests, permitting collection of experimental information; but no device such as that exploded at Hiroshima was ever tested. The generation of the dosimetry parameters for Hiroshima was, therefore, by assumption in the case of L for

neutrons and G_o for gamma rays and by inference from Operation BREN data in the case of G_o for neutrons and L for gamma rays and from the Ichiban critical assembly for G_o for neutrons. The neutron spectrum emitted from the bare reactor used in BREN was much different from the spectrum at Hiroshima, and the fission-product gamma-ray component of the radiation at Hiroshima could not be adequately treated from Operation BREN experiments.

3. Operation BREN experimental data used to construct the house TF for T65D had a very high ratio of neutron fluence to gamma-ray fluence compared with the ratio at Hiroshima and Nagasaki.

The excessive number of neutrons in Operation BREN experiments caused a much larger number of capture gamma rays to be produced in house materials. These gamma rays were detected along with the attenuated incident gamma rays, causing a higher measured TF than actually occurred in Hiroshima and Nagasaki. The research program to reevaluate the dosimetry of the A-bomb survivors was intended to remedy these deficiencies and lead to the development of DS86.

The computerized data base for T65D TF models was produced by RERF Shielding Section personnel who coded information contained in the paper file records. The method required calculating and coding data specified by the T65D developers in procedure manuals (Appendix 7-2).[2] In response to additional data requirements for the new dosimetry, Fujita[14] produced a computer file describing the orientation and posture of the survivors with nine-parameter or globe shielding descriptions. These computerized data are readily available for each survivor and can be used by a dosimetry methodology without the necessity of reexamining the individual survivor records and codifying new data.

In contrast to T65D, which relied on experimental data, the DS86 was produced entirely from computer-based models employing Monte Carlo simulations and numerical methods. The overall DS86 model involves the integration of several separate components, each individually calculated. These are (1) the sources of radiation emitted from the A-bomb on detonation, (2) the FIA field produced by the prompt and delayed radiation sources, (3) the shielding by houses, terrain, and factory buildings, and (4) the attenuation of the radiation through the body to specific organs.

The methods and codes used to calculate these components represent the current technical state-of-the-art procedure for each step. They have been individually validated to the extent feasible by comparison with experimental data, as described in the preceding chapters and as summarized later. Research in each technical area (e.g., prompt and delayed radiation transport to the FIA field, house and terrain shielding, and body shielding) focused on producing the best validated calculations with identifiable precision for each component. That research did not necessarily consider as a primary objective the eventual use or incorporation of the results into a dosimetry system for RERF.

The objective of the dosimetry system was to integrate these individual components, exploit their full capability to meet the data requirements for RERF studies, operate on the RERF computer system, and only employ, as a constraint, the computerized data bases produced for the T65D system.

Since DS86 was to be constructed from computer models and data, there was an apparent broad range in the level of detail about the doses that the system could furnish. For example, a simple renormalization and scaling of the T65D parameters could have been implemented. On the other hand, a lengthy state-of-the-art calculation could have been, in theory, performed for each survivor in the data base. The first option, however, would not realize the full sophistication of the new dosimetry work nor meet the data and accuracy requirements for RERF. The latter would not be feasible for the RERF computer facility.

The final system uses stored data bases obtained from detailed state-of-the-art computations for each component of the dose estimate. These data bases maintain the full differential level of detail on radiation energies and directions of the original calculations. Given the available computerized information for a survivor, the system then selects the most appropriate elements from each data base and combines them to give a fully detailed representation of the radiation environment for the free field at the survivor's ground range, for the shielded exposure site, and for each of 15 body organs. The information that can be obtained for each survivor about the radiation to which each of his organs was exposed consists of the kerma and the fluence spectrum for each neutron and gamma ray, prompt and delayed, radiation component.

Thus, DS86 is a complete replacement of T65D. It not only reflects the revised dosimetry, but also considers more detail of the survivor configuration and provides more dosimetric data than the T65D system.

DS86 SYSTEM DESCRIPTION

DS86 is designed as a modular data base processor. That is, depending on the input data for a survivor, various elements of several data bases are combined to provide the dosimetric variables requested by the user. Separate stand-alone data bases containing the components of the free-field (unshielded) radiation, the house shielding, and the body shielding are retrieved, manipulated, and integrated to provide the dose for an individual survivor, as depicted in Figure 1. As shown in the figure, the computerized data available for the survivor are processed and used to determine the free-field radiation environment, based on the city and ground range. The survivor's nine-parameter or globe data are then processed and used by the shielding model to compute the effect of the shielding. Finally, the body shielding calculation is performed for each organ selected, based on the size, sex, orientation, and posture of the survivor, by converting the house-shielded radiation into the kerma and fluence at the organ site in the body. The output from the system is then used by RERF researchers for their study of the health effects of radiation. A summary description of this process is presented in Table 2. Some of the terms in Table 2 will be explained in the following.

The data base processing performed by DS86 (often referred to as "coupling") may be visualized as converting (or transferring) from one radiation field to another. The radiation field is described by the quantity $\phi(E,\Omega)$. There are two equivalent ways of interpreting this quantity. In one, the one used here, $\phi(E,\Omega)\, dE\, d\Omega$ is the fluence[15] of neutrons (or gamma rays) with energies in the infinitesimal range dE containing the energy E and with direction of motion within an infinitesimal cone of solid angle $d\Omega$ containing the direction of a unit vector Ω. In the other, often used in radiation transport studies,[16] $\phi(E,\Omega)\, dE\, d\Omega$ is the track

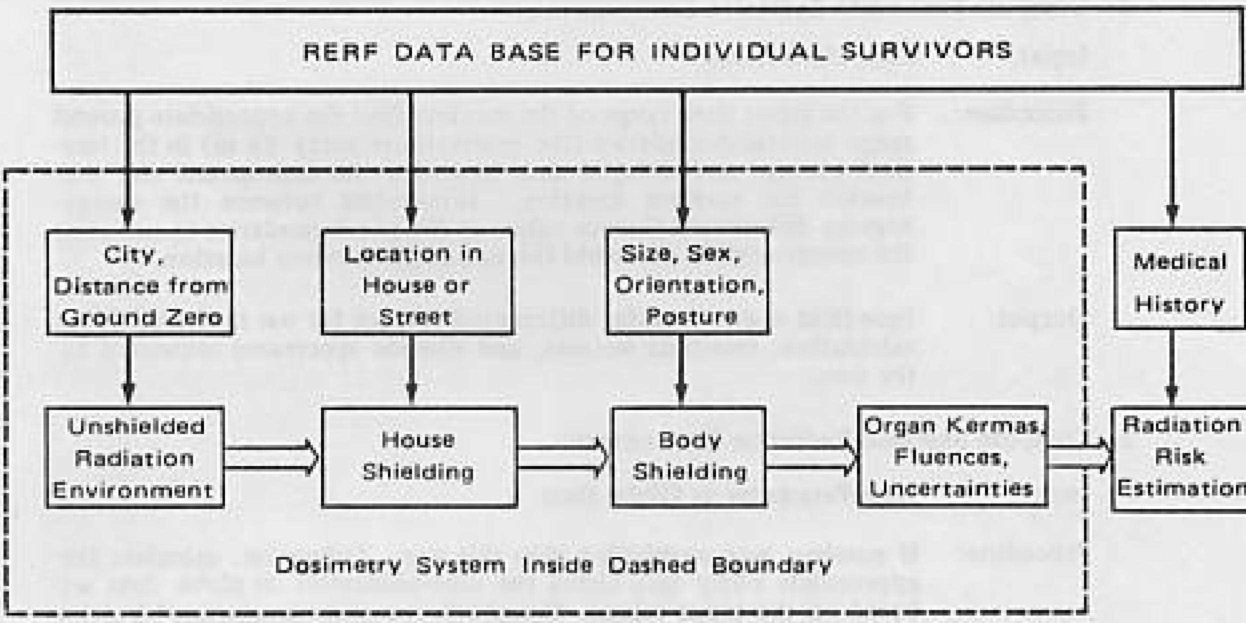


Figure 1. Dosimetry sytem for RERF, Hiroshima and Nagasaki, Japan

length per unit volume with energies and directions as just specified.

The conversion process performed by DS86 involves a transfer of fluence from energy E in the direction of Ω to energy E′ in the direction of Ω′ and is represented by:

$$\phi(E', \Omega') = \int\int\int \phi(E, \Omega)\, T(E, \Omega \rightarrow E', \Omega')\, dE\, d\Omega\, dS \qquad (3)$$

where $T(E,\Omega \rightarrow E',\Omega')$ is called the transfer function and defines the conversion of a unit fluence at E,Ω to fluence at E′Ω′. All of the field values, $\phi(E,\Omega)$, on a surface, S, surrounding the point where $\phi(E',\Omega')$ is desired are used in the calculation. The house shielding computation converts the free-field radiation field into the shielded radiation field; the body shielding computation converts the house-shielded radiation field into the organ-site radiation field. Note that the transfer function accounts for the full shielding effect since absorption, downscattering to lower energy, and generation of secondary gamma rays by neutrons are all implicitly treated in Equation 3.

DS86 computes three sets of fluences, shown in Figure 2, using this conversion process: the free-field, the house-shielded, and the body-shielded fluences. The data bases for these computations consist of the transfer functions T_f, T_h, and T_b for free-field, in-house, and in-body transport which are also depicted in Figure 2. Details concerning each component can be found in the preceding chapters of this report.

Each data base contains many separate data sets, each of which corresponds to a complete transfer function for different configurations or cases, such as ground range in the free-field data base, type of house and location within the house for the house-shielding data base,

Table 2. DS86 Process Description

1. Compute Free-Field Radiation Environment

Input:	City, Slant Range
Procedure:	For the input slant range of the survivor find the appropriate ground range interval boundaries (the intervals are every 25 m) in the free-field prompt and delayed data bases for the appropriate city that bracket the survivor location. Interpolate between the energy-angular differential fluence values at the two boundaries to calculate the energy-angular free-field fluence at the survivor location.
Output:	Free-field energy-angular differential fluence for use in the shielding calculation; free-field kermas, and fluence spectrums requested by the user.

2. Compute Shielded Radiation Environment

Input:	Nine-Parameter or Globe Data
Procedure:	If survivor was unshielded skip this step. Otherwise, calculate the appropriate entry into either the nine-parameter or globe data set based on the input values. Couple the particle simulation histories from the data set with the free-field fluence values to calculate the shielded energy-angular differential fluence at the survivor location.
Output:	House shielded energy-angular differential fluence for use in body shielding organ dosimetry computation, shielded kermas and fluence spectrums requested by the user.

3. Compute Radiation Environment at the Organ Site

Input:	Survivor Sex, Age, Orientation, and Posture
Procedure:	For each organ site selected by the user do the following. Skip sex differentiated organs when the sex of survivor does not match. Select the "standing" or "kneeling" phantom based on posture (the "standing" phantom is used for the prone posture). Extract from the appropriate data set for the age and posture entry, the particle simulation histories and couple to the shielded (or free field if no shielding present) energy-angular differential fluence for the orientation of the survivor. Calculate the organ specific kermas and fluence spectrum.
Output:	Organ kerma and fluence spectrum

and organ site, posture, etc., in the body-shielding data base. From the survivor input data presented in Table 3, DS86 selects the most appropriate data set from each data base to calculate the doses for the survivor.

The overall coupling process from free field to particular organ is depicted in Figure 3, which shows the interface between the house or house cluster and the free field and the interface between the body and the house. As described in Chapters 7 and 8, the transfer functions $T(E,\Omega \rightarrow E',\Omega')$ for house and body shielding are represented in the dosimetry system as a set of Monte Carlo particle transport histories that simulate the propagation of radiation through the house and body. The transfer process, formally described by Equation 3, is performed in DS86 as a summation over the appropriate set of Monte Carlo particle histories for the particular case that starts at some E,Ω on the coupling surface (either FIA-

FLUENCE	DATA BASE
FREE-FIELD FLUENCE $\phi_f(E_f,\Omega_f,R_f) = \int S(E_s,\Omega_s)\,T_f(E_s,\Omega_s \rightarrow E_f,\Omega_f,R_f)$	$\phi_f(E_f,\Omega_f,R_f)$
HOUSE SHIELDED EXPOSURE FLUENCE $\phi_h(E_h,\Omega_h,L_h,R_f) = \int \phi_f(E_f,\Omega_f,R_f)\,T_h(E_f,\Omega_f \rightarrow E_h,\Omega_h,L_h)$	$T_h(E_f,\Omega_f \rightarrow E_h,\Omega_h,L_h)$
BODY SHIELDED ORGAN FLUENCE $\phi_o(E_o,L_o,L_h,R_f) = \int \phi_h(E_h,\Omega_h,L_h,R_f)\,T_b(E_h,\Omega_h \rightarrow E_o,L_o)$	$T_b(E_h,\Omega_h \rightarrow E_o,L_o)$

R_f = ground range (distance from hypocenter), L_h = Location In-House, L_o = Location of Organ
$S(E_s,\Omega_s)$ = radiation source produced by bomb

Figure 2. Dosimetry system fluence and data bases

Table 3. Input to Dosimetry System from RERF Data Base

All Survivors
City, sex, ground range, slant range, age
Shielding category
Orientation, posture
Survivors with Nine Parameters
Nine-parameter subset: FS, US, FN, SP[a]
Type of house, treatment of house
Survivors with Globe Data
Terrain or house shielding
Globe numbers
Distance to front and back shielding

[a] Definitions of parameters are given in Chapter 7.

house or house-man in Figure 3) and ends at $E'\Omega'$ either at the house-man surface or in the organ, respectively.

During the transport simulation from the free field to the body, secondary gamma rays are produced by the neutrons (both prompt and delayed) in the house materials and in the body. These secondary gamma rays are computed by DS86 and carried through the computation to the organ site. Thus, DS86 starts with the four major free-field radiation components described in Table 4 and ends with eight components at the organ site; the additional four components being the gamma rays produced in the house and in the body by prompt and delayed neutrons.

Radiation fluences are contained in DS86 as a series of 58 energy groups (37 neutron and 21 gamma ray) and 240 solid angle bins. This highly differential set of data from DS86

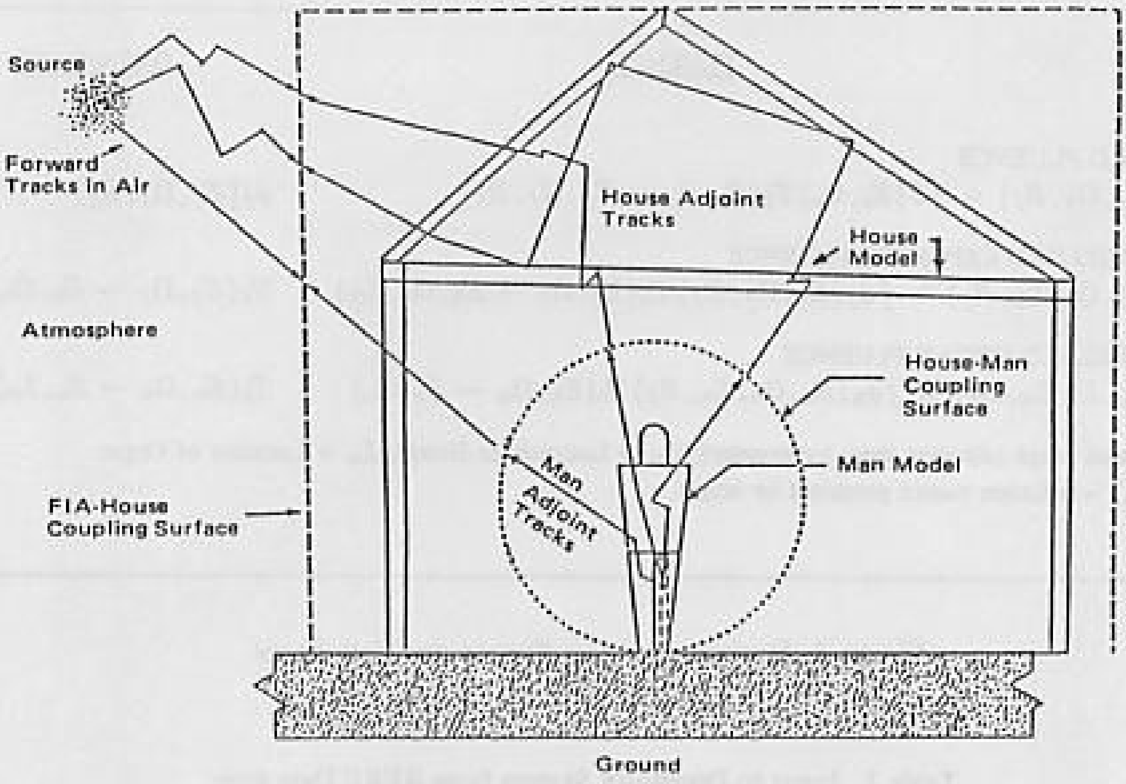


Figure 3. Illustration of the overall DS86 coupling process

Table 4. Free-Field Radiation Components

1. Prompt Neutrons	Prompt fission neutrons that escaped the bomb
2. Early Gamma Rays	
a. Prompt gamma rays	Prompt fission gamma rays, secondary gamma rays from bomb materials that escaped the bomb
b. Secondary gamma rays from prompt neutrons	Secondary gamma rays from inelastic and capture reactions in air and ground materials induced by prompt neutrons
3. Late Gamma Rays	
a. Fission product	Gamma rays from radioactive decay of fission products entrained in the fireball
b. Secondary gamma rays from delayed neutrons	Secondary gamma rays from inelastic and capture reactions in air and ground materials induced by delayed neutrons
4. Delayed Neutrons	Neutrons emitted from neutron decay of fission products entrained in the fireball

Table 5. Output from DS86

Free Field	House Shielded	Body Shielded
Prompt neutron kerma	Shielded prompt neutron kerma	Organ prompt neutron kerma
Early gamma-ray kerma[a]	Shielded early gamma-ray kerma	Organ early gamma-ray kerma
Late gamma-ray kerma[b]	Shielded late gamma-ray kerma	Organ late gamma-ray kerma
Delayed neutron kerma	Shielded delayed neutron kerma	Organ delayed neutron kerma
Neutron fluence	Shielded prompt neutron house secondary gamma-ray kerma	Organ prompt neutron house secondary gamma-ray kerma
Gamma-ray fluence	Shielded delayed neutron house secondary gamma-ray kerma	Organ delayed neutron house secondary gamma-ray kerma
	Shielded neutron fluence	Organ prompt neutron body secondary gamma-ray kerma
	Shielded gamma-ray fluence	Organ delayed neutron body secondary gamma-ray kerma
		Organ neutron fluence
		Organ gamma-ray fluence

[a] "Early gamma ray" includes prompt gamma rays and prompt neutron air/ground secondary gamma rays.

[b] "Late gamma ray" includes fission product gamma rays and delayed neutron air/ground secondary gamma rays.

is too detailed for direct use in RERF studies. DS86 reduces the angle-differential fluence data to a set of kermas and distributions of the fluence in energy for output to RERF. The distribution of the fluence in energy, or the fluence spectrum, is the integral over solid angle of the distribution in both energy and solid angle:

$$\phi(E) = \int_{4\pi} \phi(E,\Omega)\, d\Omega \tag{4}$$

The response function, K(E), used to convert the fluence spectrum to kerma in tissue is that recommended by Kerr and described in Chapter 3. The kerma, K, is calculated by:

$$K = \int K(E)\, \phi(E)\, dE \tag{5}$$

The output provided by DS86 is given in Table 5. The neutron and gamma-ray fluences are summations over all neutron and gamma-ray components. This set of kermas and fluences should be of most use at RERF. Notice, however, that the design of DS86 permits simple modifications in order to extract information in the form of other functions of the fluence (in the way that kerma is a function of the fluence) that may be desired during special research projects.

The quantity finally desired for epidemiological studies with the RERF system is the absorbed dose in each organ. For the organs and under the conditions considered here, the conditions for charged-particle equilibrium are met, and the absorbed dose is (to good approximation) equal to the kerma (see Editor's Note).

DS86 DATA BASES

DS86 relies on extensive data bases to compute the doses for each survivor. These data bases were calculated and modeled during the course of research performed for the present reassessment. The full description of the individual data bases is contained in previous chapters of this report.

These models and data bases used in DS86 have been validated by comparison with experimental data. Some of this experimental data, such as that from the BREN house-shielding experiments, were produced during the development of T65D. Other data from the Nevada Test Site were used for free-field prompt and delayed radiation validation. The Comet assembly, a static mock-up of the Hiroshima device, was used for the source term validation as described in Chapter 2. Perhaps the most important validation data, the thermoluminescence (TL) dosimetry of bricks and roof tiles (Chapter 4) and the measurements of neutron-induced radioactivities (Chapter 5), comes from Hiroshima and Nagasaki. A summary of the models and their validation is given in Table 6. A comparison, described in Appendix 4-11, of recent TL data at Hiroshima and Nagasaki with DS86 and T65D is given in Figure 4.

Table 6. Dosimetry System Data Bases

System Data Base	Data Base Calculational Method	Experimental Validation [a]
Source	Coupled radiation hydrodynamics	Comet Assembly measurements Hiroshima: sulfur activation
Free-field radiation		Thermoluminescence data from Hiroshima and Nagasaki
Prompt	Two-dimensional discrete ordinates	Army pulsed reactor measurements, Nevada Test Site measurements
Delayed	Phenomenological fireball and shock hydrodynamic models one-dimensional transport with correction factors	Nevada Test Site measurements
House shielding	Adjoint Monte Carlo	BREN house shielding experiments
Body shielding	Adjoint Monte Carlo	AFRRI experiments ORNL gamma-ray attenuation

[a] References to experiments can be found in the appropriate report of this series.

A summary and highlights of these data bases used by DS86 is provided in Tables 7 to 9. Table 9 lists the organs and body types for which DS86 currently can calculate doses. The list does not contain any reference to the fetus. For the present, when a fetal dose is needed, it is assumed to be the same as the dose to the uterus. Studies are under way to model the fetus at one or more stages of fetal life.

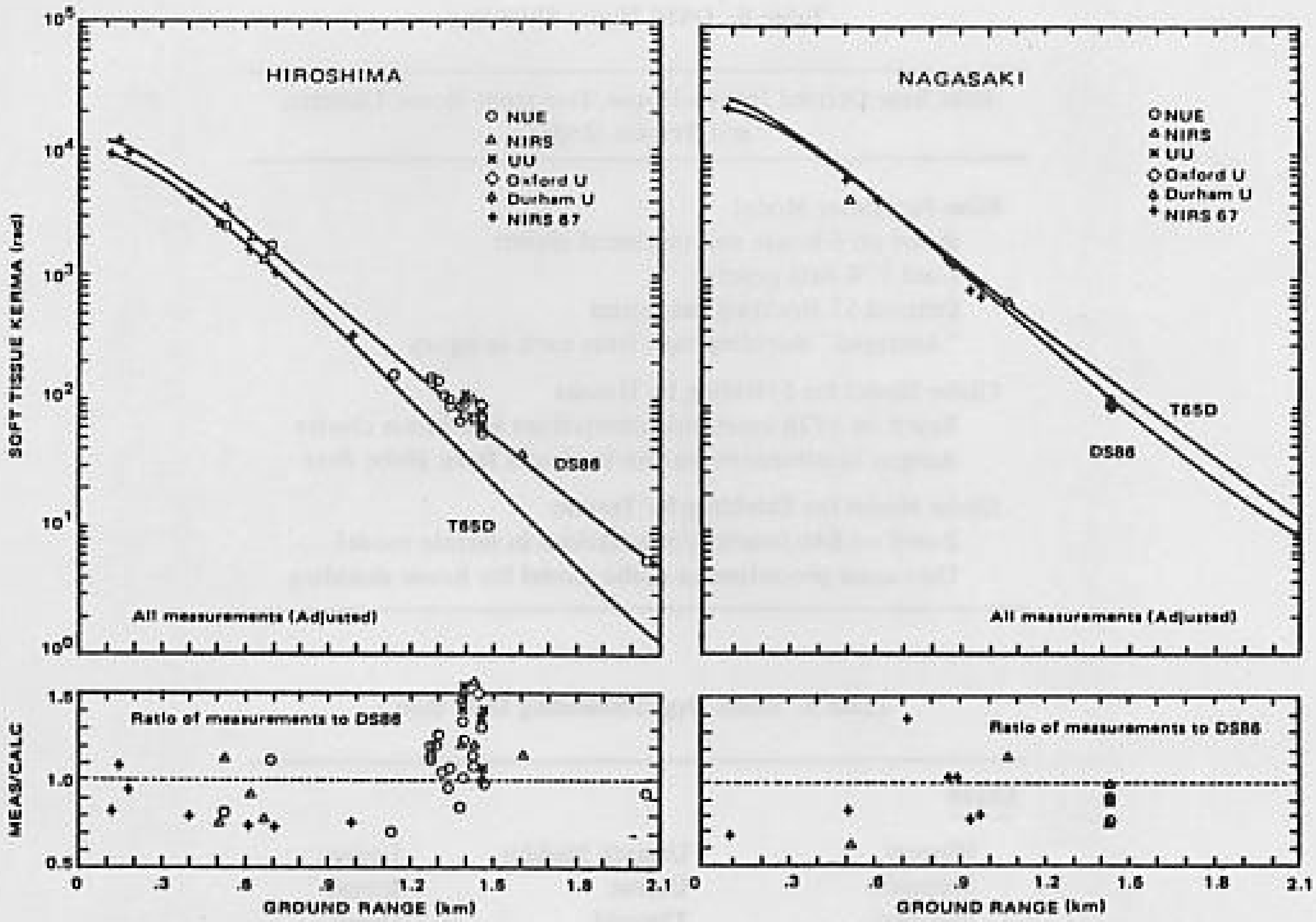


Figure 4. Comparison of DS86 and T65D dosimetry with thermoluminescent dosimetry measurements at Hiroshima and Nagasaki (from Appendix 4-11)

Table 7. DS86 Free-Field Data Base

Yield	
Hiroshima 15 kt, Nagasaki 21 kt.	
Prompt neutrons, early gamma rays	
Two-dimensional discrete ordinates calculations by Pace (See Chapter 3)	
Multi-region averaged cross sections	
Delayed neutrons, late gamma rays	
STLAMB hydrodynamic model	
Fine group one-dimensional transport discrete ordinates transport	
Adjoint Monte Carlo air-over-ground correction factors	
Integral mass scaling (with correction factor for neutrons)	
Scaled source term based on Dickens, and Fisher and Engle measurements for fission product gamma rays	
Delayed neutron source from evaluation by England	
Resolution of Fluences	
Energy	37 neutron groups, 21 gamma-ray groups
Solid angle	240 solid angle bins
Ground ranges	Every 25 m from 100 m to 2500 m

Table 8. DS86 House Shielding

Data Base Derived from 6-House, Tenement House Clusters, and Terrain Model
Nine-Parameter Model
Based on 6-house and tenement cluster
Used 976 data points
Derived 57 shielding categories
"Averaged" shielding tape from each category
Globe Model for Shielding by Houses
Based on 1920 locations/orientations in 6-house cluster
Assigns location/orientation in cluster from globe data
Globe Model for Shielding by Terrain
Based on 640 location/orientations in terrain model
Uses same procedure as globe model for house shielding

Table 9. DS86 Organ-Shielding Data Base

Organ		
Marrow	Urinary bladder	Lungs
Stomach	Uterus	Breast
Pancreas	Thyroid	Ovary
Liver	Brain	Testes
Large intestine	Eye lens	Skeleton
Size		**Orientation**
Adult (15-year-old western man)		Standing
Child (5-year-old western boy)		Kneeling
Infant (1-year-old)		Prone

DS86 UNCERTAINTY ASSESSMENT

At the present time, the analysis of the uncertainty in the revised dosimetry model embodied in DS86 is incomplete. Uncertainties associated with some of the components of the system have been described in earlier chapters. However, the overall system uncertainty analysis has not been performed. Pending completion of this work, the following temporary uncertainty model has been incorporated into DS86.

DS86 was structured to accommodate propagation of uncertainty through the components of the system, including provision to account for correlation among components. The statistical model incorporated into DS86 uses fractional standard deviations (FSD) and correlation coefficients and makes no assumptions concerning the distribution of quantities (e.g., normal or lognormal). Input to the model, at the present time, is largely based on uncertainties reported by the various investigators and judgement, where necessary, by the authors of DS86. Thus, the uncertainties calculated by DS86 at the present time should be used with caution.

To describe the temporary uncertainty model, we start with the total kerma estimate in an organ of a single survivor. This kerma is the sum of eight kermas from components of the radiation field (Table 5). The equation for the total kerma is written as:

$$K = K_1 + K_2 + \cdots + K_8 \tag{6}$$

Each component kerma has an uncertainty associated with the computed value. In DS86, this uncertainty is described with the term fractional standard deviation (FSD) and defined as the ratio of the standard deviation of the distribution of values to the mean value. The FSD of the i-th kerma component is written as:

$$F_i = \frac{\sigma_i}{K_i} \tag{7}$$

where σ_i is the standard deviation. It is not implied that σ_i be associated with any particular probability distribution; it is simply the square root of the second moment about the mean of that distribution, regardless of the form of the distribution. The FSD (F) of the total kerma is:

$$F = [\sum_{i=1}^{8} \sum_{j=1}^{8} F_i F_j \rho_{ij} \frac{K_i K_j}{K^2}]^{\frac{1}{2}} \tag{8}$$

where the ρ_{ij} are the correlation coefficients; they have values in the range -1 to 1, and ρ_{ii} = 1 for all i. Before returnings to the correlation coefficients the estimate of the FSD for each kerma component (F_i) is discussed.

Recall that the calculation of kerma for each organ in DS86 involves the source, a free-field, house-shielding, and body-shielding transfer function. If these successive fields are substituted in Equation 3, then a multiple integral of the product of many factors must be evaluated. If the overall uncertainty arises from independent uncertainties in these factors (e.g., the air density in the free field and the composition of the house materials in the house shielding) and there are N such factors, then it is possible to write neglecting higher order terms that:

$$\rho_{ij} F_i F_j = \sum_{n=1}^{N} \rho_{ij}^n F_i^n F_j^n \tag{9}$$

where n is a superscript, not an exponent. Then the right-hand side summation can be substituted into Equation 8. Here $\rho^n{}_{ij}$ is the correlation coefficient for the n-th factor between dose components i and j; and the respective FSD for the n-th factor are $F^n{}_i$ and $F^n{}_j$.

Given this model for the uncertainty assessment in DS86, the correlation coefficients $\rho^n{}_{ij}$ and the FSD $F^n{}_i$ and $F^n{}_j$ must be determined . Values for the FSD for several contributing factors to the uncertainty have been given in the preceding chapters. However, little information is available on the correlation coefficients. If one assumes that the correlation coefficients are all positive, then one can get bounds on the uncertainty from two models: an upper bound from a model assuming complete correlation and a lower bound from a model assuming no correlation. These models would result in the correlation coefficients given in Table 10. The approach in DS86 was to provide both these bounds and, in addition, provide uncertainty in the kerma based on estimated correlations. At present, these correlations are only estimates based on experience and have little analytical support. Examples of the estimated correlations among the radiations are given in Table 11. Associated estimated FSD derived from data in preceding chapters are given in Table 12. When the formal uncertainty assessment for the revised dosimetry program is completed, these values can be easily modified and expanded with values supported by the research.

Table 10. Upper and Lower Bound Uncertainty

Upper Bound Model (Total Correlation)	Lower Bound Model (No Correlation)
$\rho_{ij}^{n} = 1$	$\rho_{ij}^{n} = 0,\ i \neq j$
all n all i, j	$\rho_{ij}^{n} = 1$, all i

Table 11. Example Correlation Estimates [a]

Effect	Among kerma components single survivors		Total kerma among two survivors		
	Value	Dose components	Same city	Different city	Remarks
Yield	1.0	All components	1.0	0	May be correlation for different cities if Hiroshima yield inferred from Nagasaki
Neutron output	1.0	Prompt neutron and early gamma rays	M	M	Same code used for both output computations
Air density	L	All components	L	0	
Air moisture	L	Prompt neutrons and delayed neutrons	M	0	
Hydrodynamic model for delayed radiation	L	Delayed neutrons and late gamma rays	M	M	
Fission product debris source	–	None	M	S	
Hypocenter location	L	All components	−1. to 1.	0	Depends on relative location to hypocenter
Air transport calculation	M	All components	L	L	
House location	L	All components	0	0	
House materials	M	Prompt neutrons, early and late gamma rays, delayed neutrons	S	S	

→

Table 11. Continued

Effect	Among kerma components single survivors		Total kerma among two survivors		
	Value	Dose components	Same city	Different city	Remarks
	S	Prompt neutrons and prompt house secondary gamma rays			
Survivor location	M	All components	S	S	
Shielding calculation	L	Between neutron components	M	M	
		Between gamma-ray components			
Man materials	M	All components	S	S	
Man orientation	M	Prompt, delayed neutrons, early and later gamma rays	O	O	
	S	All above, with house secondary gamma rays			
Man shielding calculations	L	Same type of radiation	L	L	

[a] Value	Correlation
0	None
S	Small correlation (~.2)
M	Medium correlation (~.5)
L	Large correlation (~.7)
+1	Total

The FSD of kerma estimates for some sample cases will be presented later. Here, runs of DS86 with the data in Tables 11 and 12 result in FSD of 16% for the total FIA kerma at Hiroshima and 13% at Nagasaki, with the difference being due to the uncertainty in the yield. The FSD in the computed organ kerma, with values in the 25 to 35% range, is dominated by the uncertainty in the location of the survivor in the house. Comparison of the FSD calculated with the estimated correlations described above to FSD computed with the totally-correlated and totally-uncorrelated models (Table 10) indicates the estimated FSD are close to the totally-correlated values. The similarity occurs because the largest uncertainties (yield and location) are positively correlated among the kerma components. The totally-correlated model could probably be used in DS86 as a conservative but reasonable estimate of the kerma uncertainty. This would eliminate the need to determine more precise values of the correlation coefficients.

Risk analysis using the A-bomb data involves combining kerma estimates for individual survivors into those for cohorts. There are correlations in the kerma estimates among the survivors grouped in these cohorts. These correlations depend principally on whether the survivors are in the same or different cities. Estimated survivor-to-survivor correlations for the same kerma factors are given in Table 11. These values could be used for preliminary uncertainty analyses prior to the availability of better values.

Table 12. Example FSD Estimates for Survivors in Houses

Effect	Neutrons		Gamma Rays		
	Prompt	Delayed	Early	Late	Neutron-induced
Yield, Hiroshima	10%	12%	10%	12%	---Similar to neutron FSD---
Yield, Nagasaki	5	6	5	6	
Neutron output	5	–	5	–	
Air density	5	7	3	3	
Air moisture	5	5	1	1	
Hydro model	–	10	–	10	
Fission source	–	20	–	10	
Air transport calculations	5[a]	20	5	10	
Hypocenter location	10	10	6	4	
House location	5	5	3	2	
House materials	5	5	5	5	5
Survivor location	10-20 (30)	10-20 (30)	10-20 (30)	10-20 (30)	10
Shielding calculation method	5	5	5	5	10
Man materials	5	5	5	5	5
Man orientation	10-15 (15-25)	10-15 (15-25)	8-12 (10-15)	8-12 (10-15)	5-15
Body shielding calculation method	5	5	5	5	10

Values in parentheses indicate shielding orientation is unknown.
[a] Pending resolution of the neutron activation data (Chapter 5)

SURVIVOR CATEGORIES TREATED BY DS86

Potentially, DS86 treats any survivor exposed within 2500 m from the hypocenter who was either in the open and unshielded, in a Japanese residence or tenement house, or in the open shielded by a house and with globe shielding data. Late in 1987, models to calculate dose for survivors who were shielded by terrain and have globe parameters or who were in a factory will be added. However, most of the coded shielding data exists only for survivors in the so-called "proximally" exposed class, which includes survivors within 1600 m from the hypocenter in Hiroshima and within 2000 m in Nagasaki. A tabulation of the number of proximally exposed survivors in the RERF Life Span Study whose dose can be computed by DS86 is given in Table 13. Excluded from DS86 calculations are proximal survivors in heavily shielded structures, such as concrete buildings, and other survivors with unusual shielding configurations, such as those in streetcars or air-raid shelters ATB.

The kerma for the distally exposed group (those beyond 1600 m at Hiroshima and 2000 m at Nagasaki) without detailed shielding histories are not computed by DS86. They can be estimated by several techniques, depending on the level of detail required. A simple procedure is applicable for analyses in which only the kerma at the survivor's location (i.e., including house shielding but excluding body shielding) is desired. First, averaged TF are

Table 13. Proximally Exposed Survivors with Shielding Histories Treated by DS86

Shielding Configuration	Method	Hiroshima	Nagasaki	Total
Open - No shielding	FIA	998	759	1757
Japanese house	9 Parameter	7385	2380	9765
Tenement house	9 Parameter	3779	740	4519
Open, shielded by house	Globe	2606	494	3100
Open, shielded by terrain[a]	Globe	0	315	315
Factory[b]	?	25	664	689
Not treated[c]	–	525	1084	1609

[a]Terrain model to be implemented late 1987.
[b]Factory model in development, to be implemented late 1987, some listed may be excluded from dose estimation.
[c]Proximally exposed survivors with shielding histories not treated by DS86. Includes those in concrete buildings, streetcars, etc.

produced for the broad shielding categories assigned to the distal survivors (e.g., survivors inside residential houses, or survivors outside houses but shielded by them) from the DS86 data for the proximally exposed survivors. These average TF can be fitted to functions of ground range, if a ground range effect is exhibited, and extrapolated to the larger ranges of the distal group. The FIA kerma can also be fitted to functions of ground range. The FIA kerma fits and the average TF can be incorporated into a relatively simple computer model to estimate nonorgan kerma for distal survivors groups.

As part of the planned update late in 1987, a more detailed model for distally exposed survivors will be added to DS86. This model will provide the same data output available for proximally exposed survivors with shielding histories. The model will simply select a data set from the shielding base for the given shielding category of the survivor that represents the average configuration or location. The body shielding computations will be performed with an orientation independent coupling. Uncertainty estimates, using an analysis of the proximally exposed survivors, for both house and body shielding calculation will be increased to account for the unkown location and orientation information.

EXAMPLE CASE HISTORIES

To illustrate the revised dosimetry, DS86 results for four cases in the RERF data base are presented and discussed. A summary of pertinent information obtained from the computerized data for each case is shown in Table 14. Two nine-parameter and two globe examples are provided. Figures 5 to 8 exhibit the plan drawing in the RERF paper files depicting the survivor's location and orientation, the DS86 selected model from the house clusters, and the TF calculated by taking the ratio of the DS86 computed kermas to the FIA kermas. The DS86 kermas and organ doses for these cases are given in Table 15.

The plan view from the history file for Case 1 (Figure 5) shows the survivor on the bottom floor of a two-storied house ATB. The box enclosing the survivor location was added to emphasize that location and does not represent shielding. The arrow in the drawing points

Table 14. Example Case Data

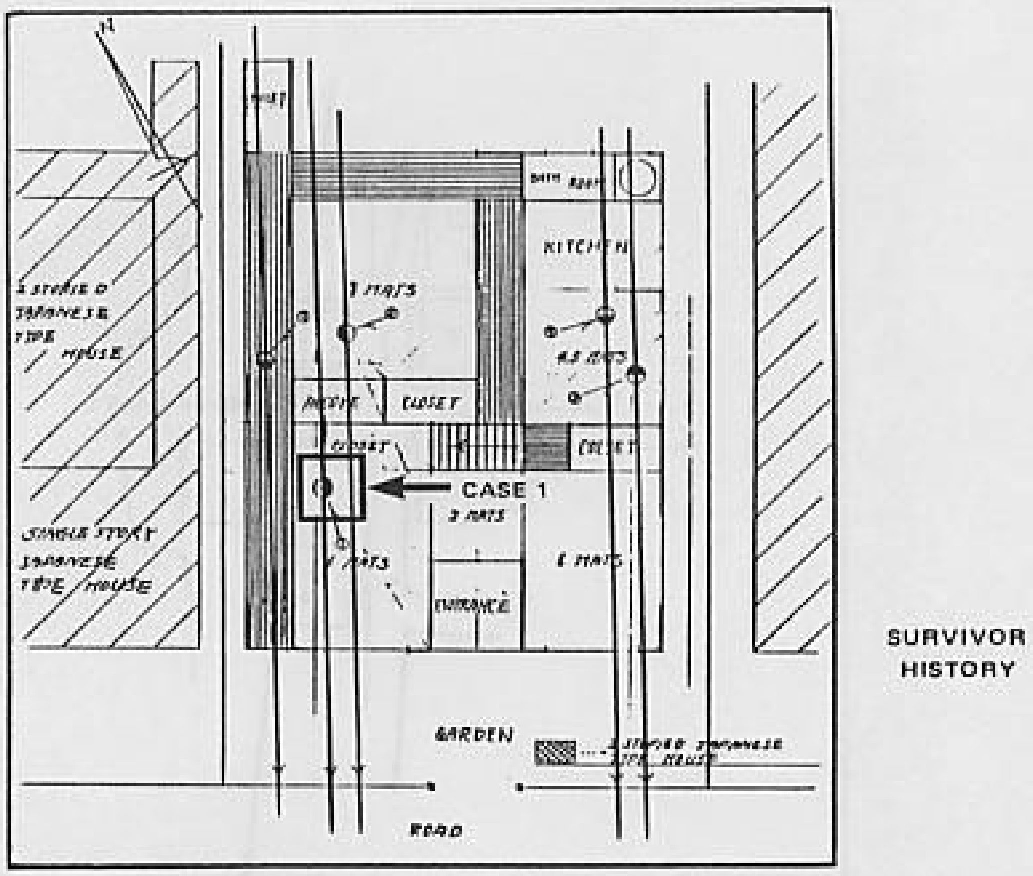
	Case 1	Case 2	Case 3	Case 4
City	Hiroshima	Nagasaki	Hiroshima	Hiroshima
Ground range	1485 m	1279 m	1727 m	1476 m
Shielded data	9 Parameter	9 Parameter	Globe	Globe
Sex	Male	Male	Female	Male
Age	32	51	35	53
Posture	Standing	Prone face down	Standing	Standing
Orientation [a]	270°	Head at 180°	60°	90°

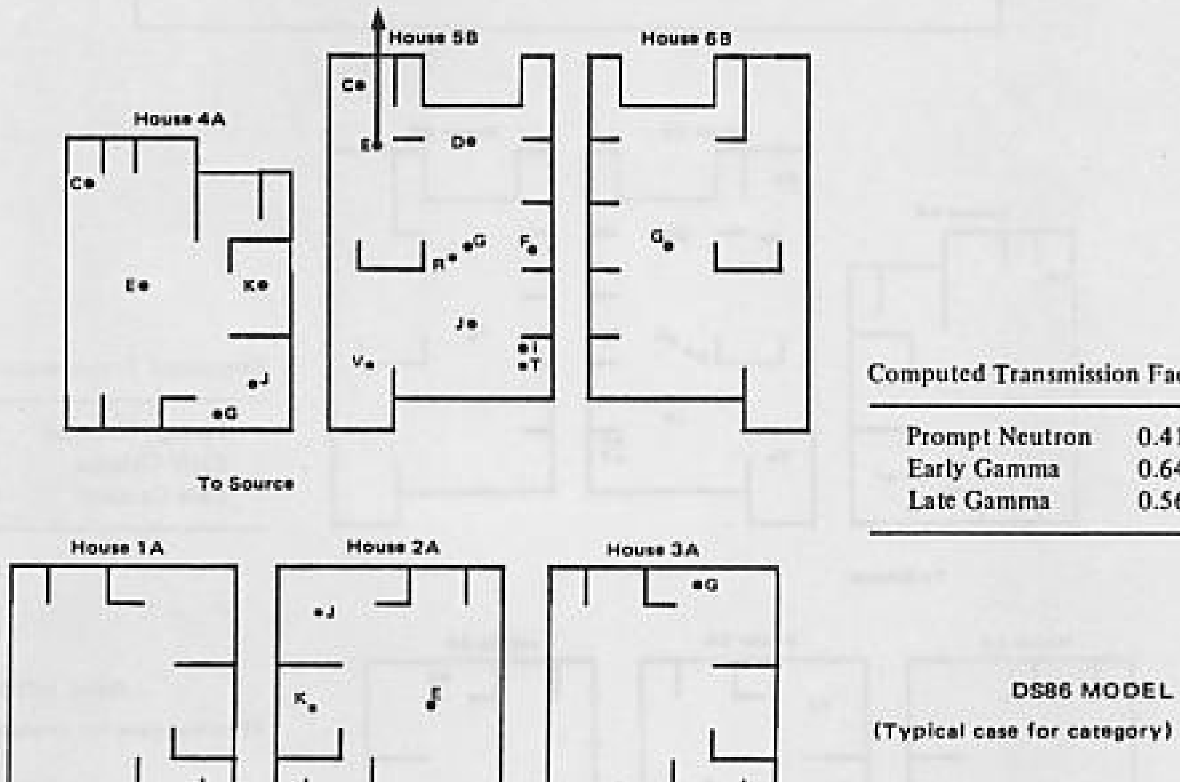
[a] Degrees clockwise of face from line to ground zero.

Table 15. FIA Kerma, Kerma after Shielding by House, and Organ Dose Computed by DS86. Values are in Rad

	Case 1 Hiroshima at 1485 m			Case 2 Nagasaki at 1279 m			Case 3 Hiroshima at 1727 m			Case 4 Hiroshima at 1476 m		
	Total	Neutrons	Gamma Rays	Total	Neutrons	Gamma Rays	Total	Neutrons	Gamma Rays	Total	Neutrons	Gamma Rays
FIA	52.66 (.16)	0.93 (.18)	51.73 (.17)	228.73 (.13)	2.47 (.16)	226.26 (.13)	20.21 (.16)	0.20 (.18)	20.01 (.16)	54.83 (.16)	0.99 (.18)	53.85 (.17)
Shielded	31.18 (.23)	0.37 (.27)	30.80 (.23)	104.12 (.28)	0.92 (.22)	103.20 (.28)	7.50 (.24)	0.07 (.28)	7.43 (.24)	20.51 (.24)	0.46 (.28)	20.05 (.24)
Skeleton	22.17 (.25)	0.13 (.30)	22.04 (.25)	79.63 (.30)	0.37 (.27)	79.26 (.30)	5.80 (.26)	0.02 (.30)	5.78 (.26)	15.64 (.26)	0.14 (.30)	15.50 (.26)
Marrow	24.50 (.25)	0.11 (.30)	24.38 (.25)	82.49 (.30)	0.35 (.27)	82.14 (.30)	6.58 (.26)	0.02 (.30)	6.56 (.26)	14.56 (.26)	0.15 (.30)	14.41 (.26)
Bladder	23.61 (.26)	0.08 (.32)	23.53 (.26)	66.14 (.32)	0.13 (.34)	66.01 (.32)	6.51 (.27)	0.02 (.32)	6.49 (.27)	15.41 (.27)	0.07 (.32)	15.34 (.27)
Brain	25.63 (.25)	0.15 (.32)	25.48 (.25)	83.88 (.31)	0.34 (.30)	83.54 (.31)	6.44 (.26)	0.03 (.32)	6.41 (.26)	18.90 (.26)	0.17 (.32)	18.72 (.26)
Breasts	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	6.90 (.27)	0.05 (.32)	6.85 (.27)	0.00 (.00)	0.00 (.00)	0.00 (.00)
Eyes	29.35 (.26)	0.23 (.32)	29.12 (.26)	75.88 (.32)	0.36 (.34)	75.53 (.32)	7.06 (.27)	0.04 (.32)	7.01 (.27)	17.59 (.27)	0.23 (.32)	17.36 (.27)
Large intestine	21.96 (.25)	0.05 (.32)	21.90 (.25)	65.79 (.31)	0.13 (.31)	65.66 (.31)	5.04 (.26)	0.01 (.32)	5.03 (.26)	12.77 (.26)	0.05 (.32)	12.72 (.26)
Liver	23.96 (.25)	0.13 (.32)	23.83 (.25)	66.17 (.31)	0.22 (.30)	65.94 (.31)	5.37 (.26)	0.02 (.32)	5.35 (.26)	11.41 (.26)	0.08 (.32)	11.33 (.26)
Lungs	23.99 (.25)	0.12 (.32)	23.87 (.26)	79.50 (.31)	0.30 (.30)	79.20 (.31)	5.90 (.26)	0.02 (.32)	5.87 (.26)	13.93 (.26)	0.11 (.32)	13.81 (.26)
Ovaries	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	6.35 (.26)	0.01 (.32)	6.33 (.26)	0.00 (.00)	0.00 (.00)	0.00 (.00)
Pancreas	19.53 (.25)	0.05 (.32)	19.48 (.25)	66.99 (.31)	0.15 (.31)	66.83 (.31)	4.45 (.26)	0.01 (.32)	4.44 (.26)	11.11 (.26)	0.06 (.32)	11.05 (.26)
Stomach	18.90 (.26)	0.08 (.32)	18.82 (.26)	64.21 (.32)	0.15 (.34)	64.06 (.32)	6.68 (.27)	0.02 (.32)	6.66 (.27)	16.14 (.27)	0.10 (.32)	16.04 (.27)
Testes	24.71 (.26)	0.13 (.32)	24.58 (.26)	57.09 (.32)	0.20 (.34)	56.89 (.32)	0.00 (.00)	0.00 (.00)	0.00 (.00)	14.51 (.27)	0.12 (.32)	14.39 (.27)
Thyroid	26.89 (.25)	0.17 (.32)	26.72 (.25)	68.40 (.31)	0.26 (.30)	68.13 (.31)	7.56 (.26)	0.03 (.32)	7.54 (.26)	18.19 (.26)	0.15 (.32)	18.04 (.26)
Uterus	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	0.00 (.00)	5.47 (.26)	0.01 (.32)	5.46 (.26)	0.00 (.00)	0.00 (.00)	0.00 (.00)

Values in parentheses are the estimated fractional standard deviation (FSD).

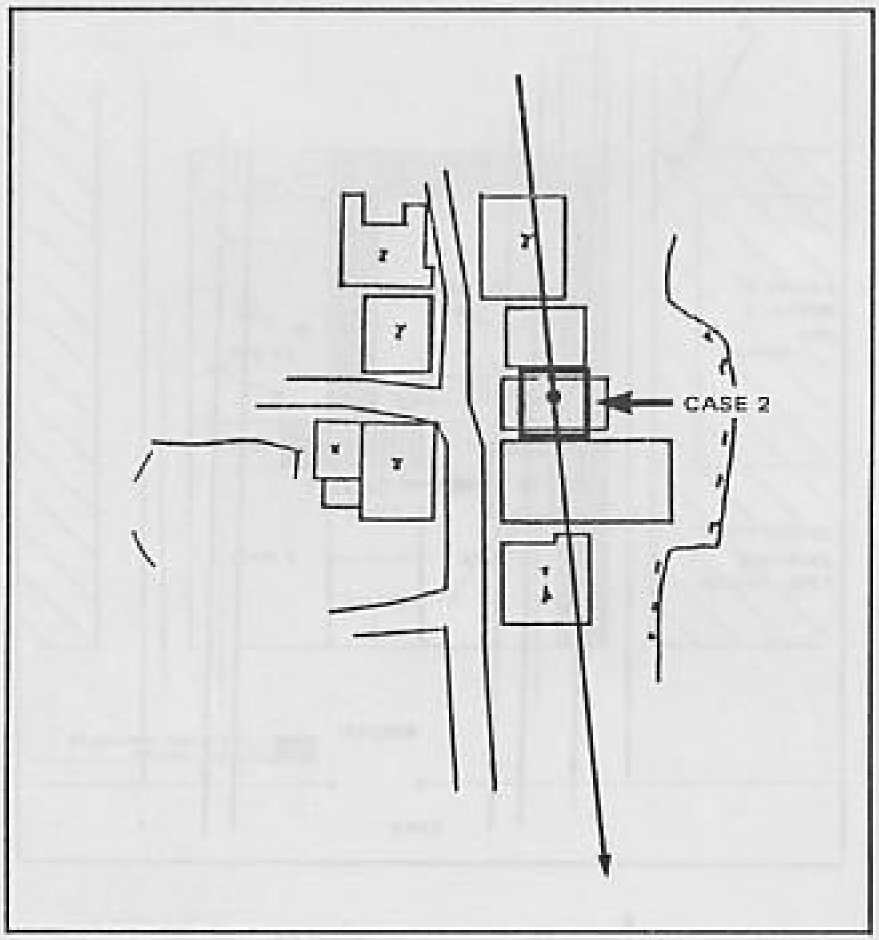




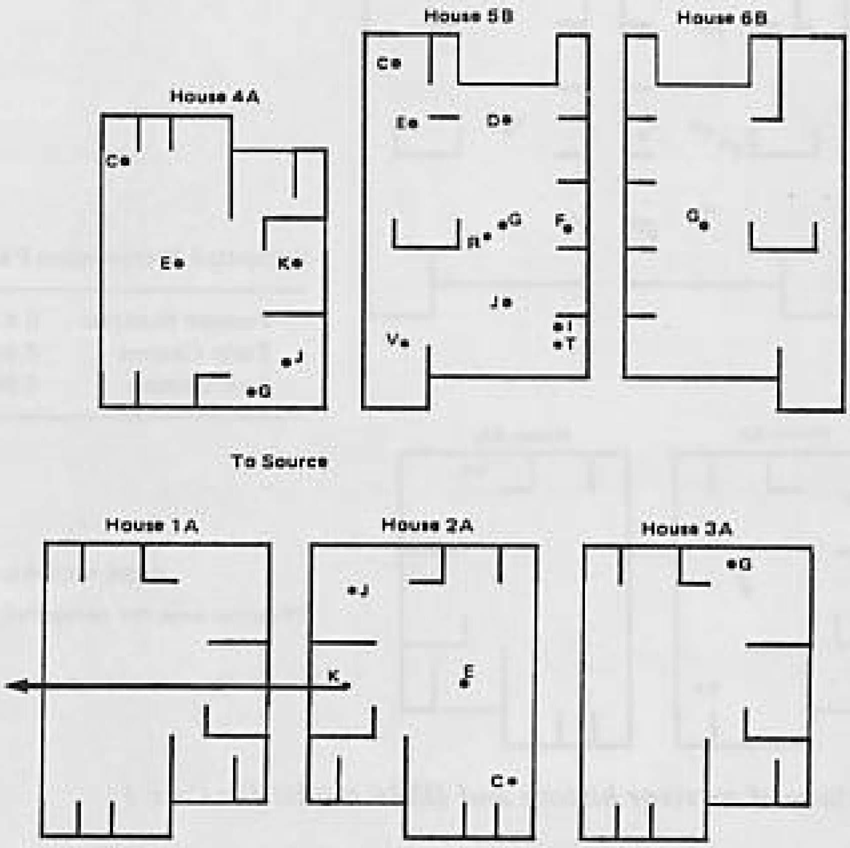
Computed Transmission Factor	
Prompt Neutron	0.41
Early Gamma	0.64
Late Gamma	0.56

Figure 5. Comparison of survivor history and DS86 model for Case 1

The figure on the top is part of the information on some survivors contained in the RERF files, "Case 1" points to the position, indicated by a small circle, of the survivor; the darkened portion of the circle indicates the face. The arrow through the circle points to the hypocenter. The figure on the bottom is how the situation was approximated by DS86; the arrow tail locates the survivor and the arrow points to the hypocenter.



SURVIVOR HISTORY

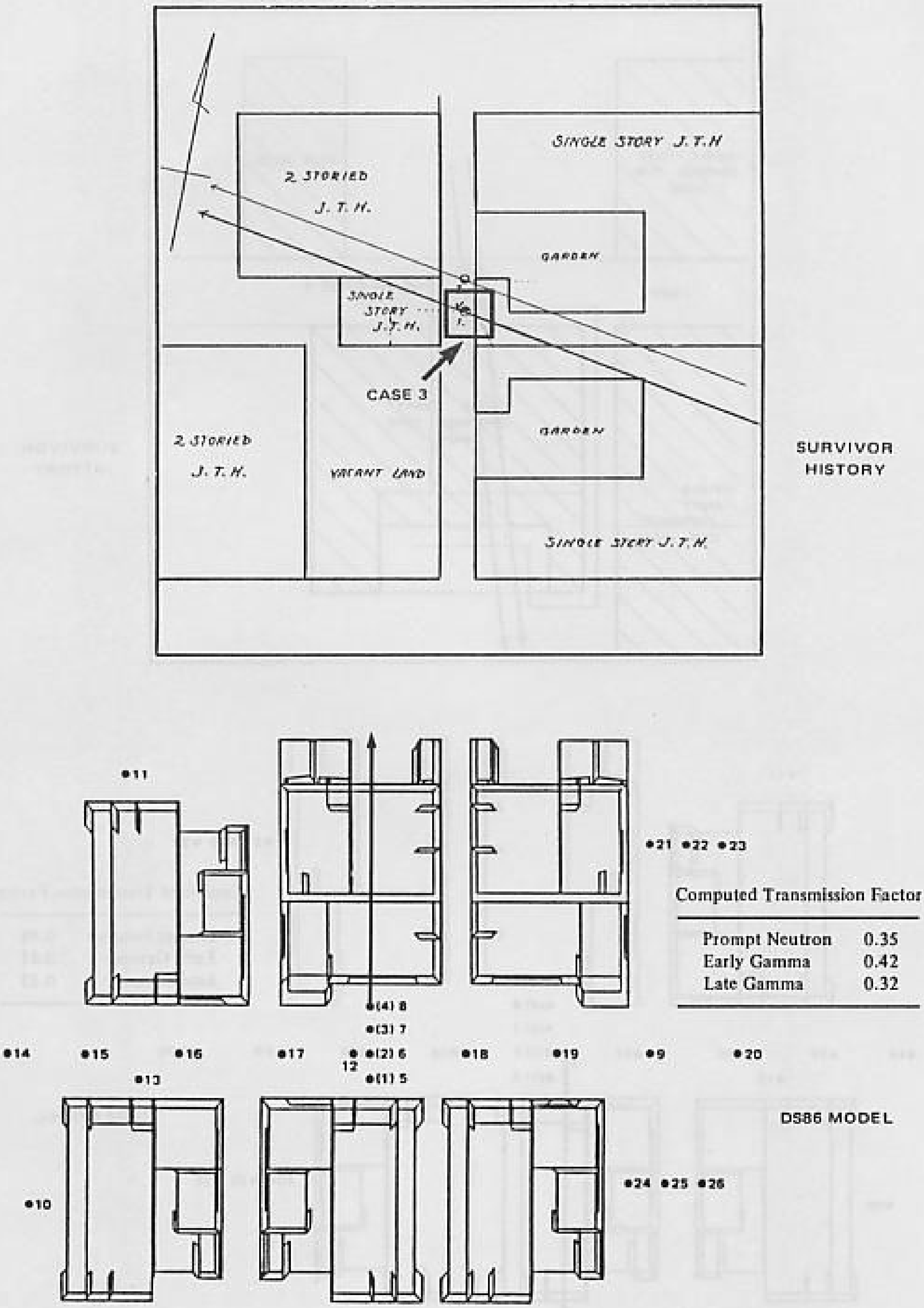


Computed Transmission Factor	
Prompt Neutron	0.38
Early Gamma	0.48
Late Gamma	0.43

DS86 MODEL
(Typical case for category)

Figure 6. Comparison of survivor history and DS86 model for Case 2

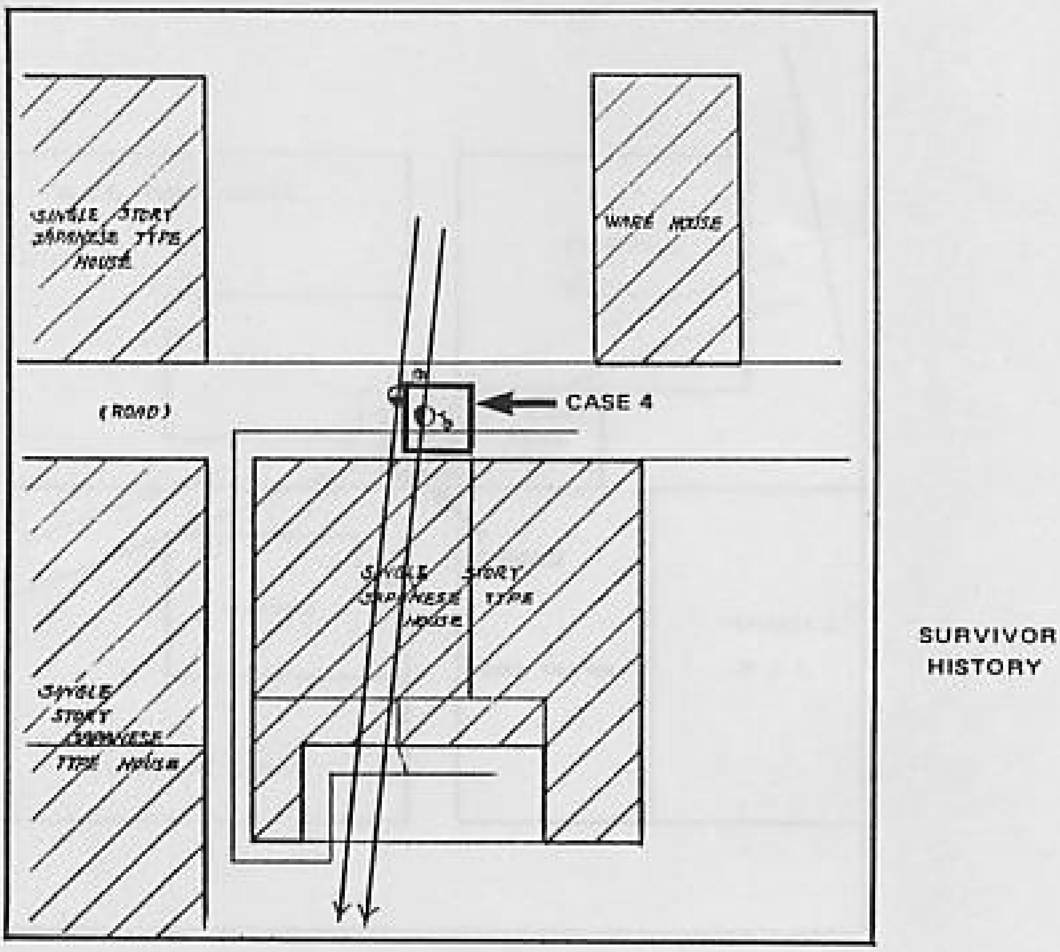
See Footnote Figure 5.

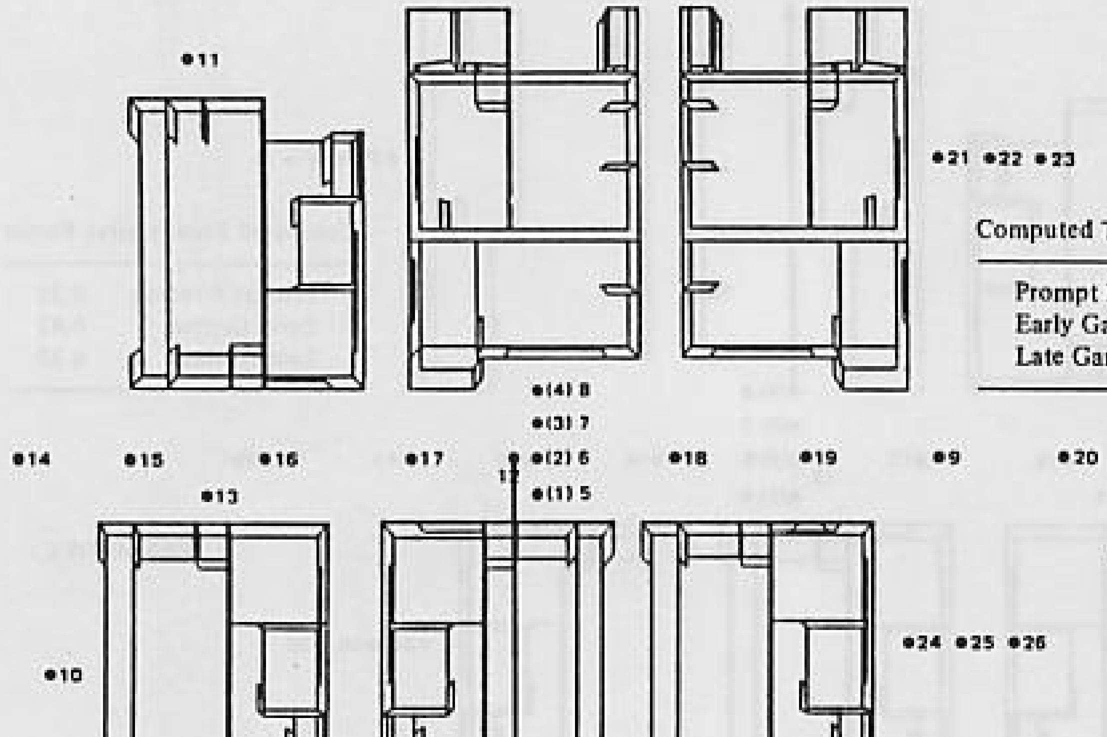


Computed Transmission Factor	
Prompt Neutron	0.35
Early Gamma	0.42
Late Gamma	0.32

Figure 7. Comparison of survivor history and DS86 model for Case 3

See Footnote Figure 5.





Computed Transmission Factor	
Prompt Neutron	0.46
Early Gamma	0.41
Late Gamma	0.33

Figure 8. Comparison of survivor history and DS86 model for Case 4

See Footnote Figure 5.

toward the hypocenter. The darkened portion of the circle pinpointing the location represents the face and indicates that the survivor was facing sideways to the hypocenter, which was properly recorded in the computer data base (Table 14). The DS86 shielding model for this location is a composite of several locations in the house cluster geometries that have the same subset of nine parameters as discussed in Chapter 7. One of the locations and orientations relative to the hypocenter from the six-house cluster that is part of the composite is shown on the bottom of Figure 5. It is a reasonable configuration compared to the actual case. The location and orientation combinations in the DS86 model for this nine-parameter subset all place the survivor on the ground floor of a two-story house and relatively close to the wall facing the hypocenter. Although DS86 does not use TF in any of its calculations, they can be calculated by taking the ratio of the kerma with shielding present to the FIA kerma (Table 15), and they are presented at the bottom of the figure for comparison with the other examples.

The plan drawing from the history file for Case 2 is shown in Figure 6. This survivor was prone, with his face down and away from the hypocenter. He was in a one-story house with another house shielding his line-of-sight to the hypocenter. A typical location and orientation from the DS86 composite data set for the survivor's nine parameters is depicted on the bottom of Figure 6. Primarily because of the additional shielding by the neighboring house, the TF are less than Case 1, although differences in the cities and in the ground ranges also affect the comparison.

Case 3 depicts a survivor who was outside and was shielded in the line-of-sight by a two-story Japanese house (Figure 7). This survivor's shielding was described by the globe procedure. The actual location and direction selected by DS86 for this case is shown on the bottom of Figure 7 and exhibits a situation in the model similar to the actual one. The TF are low because of the lower elevation of the line-of-sight at the large ground range (1727 m at Hiroshima) and the close proximity to the house.

The plan drawing for Case 4 (Figure 8) indicates the survivor was in the open and shielded by a single-story house. Based on his globe data, the DS86 selected the model shown on the bottom of Figure 8.

The tabulated kermas and doses in Table 15 summarize the dosimetry for each survivor. These values are sums over the kermas and doses from the individual radiation components. To show the relative magnitude of the components, the kermas and doses are given in Table 16 for Case 1 for the FIA kerma, the kerma for shielding just by the house, and the organ doses for the marrow and brain. The doses are dominated by the early and late gamma-ray components. The data in Table 15 also provide the FSD that was estimated with the uncertainty model. The FSD for total FIA kerma is 16% for Hiroshima and 13% for Nagasaki. The FSD for kermas behind shielding vary according to the method, nine-parameter or globe, and the uncertainty associated with the data set selected for the survivor. The estimated FSD for the organ doses results from the propagation of the uncertainty through the calculations for the free field and the house and body shielding and differs according to the organ involved and the configuration of the survivor (Tables 11 and 12).

A more detailed presentation of the DS86 uncertainty results is shown in Table 17 for Case 1 (Hiroshima) and Case 2 (Nagasaki). The bracketed values are the estimated FSD already presented. These are computed with correlations presented in Table 11. The values

Table 16. Case 1, Detailed Dosimetry

	Kerma values (rad)			
	FIA	House shielded	Marrow	Brain
Neutrons				
Prompt	0.917	0.368	0.1104	0.151
Delayed	0.020	0.006	0.0013	0.0019
Total neutrons	0.937	0.374	0.112	0.153
Gamma rays				
Early	23.4	14.9	11.8	12.5
Late	28.3	15.7	12.2	12.7
Prompt neutron house secondaries	–	0.18	0.14	0.142
Delayed neutron house secondaries	–	0.01	0.008	0.008
Prompt neutron body secondaries	–	–	0.16	0.145
Delayed neutron body secondaries	–	–	0.008	0.008
Total gamma rays	51.7	30.8	24.4	25.5
Total neutrons and gamma rays	52.6	31.2	24.5	25.6

Table 17. Estimates of Fractional Standard Deviations (FSD); in Percent

Component	Total	Total neutrons	Total gamma rays
Case 1 Hiroshima			
FIA	13.3[a] (16.4)[b] 16.9[c]	17.7 (19.0) 18.1	13.6 (16.5) 17.0
House shielded	18.7 (23.2) 25.5	26.7 (27.0) 27.2	18.9 (23.3) 25.6
Marrow	20.1 (25.0) 27.7	29.4 (29.7) 29.8	20.2 (25.0) 27.7
Case 2 Nagasaki			
FIA	11.0 (12.9) 13.6	14.9 (125.8) 16.2	11.1 (12.9) 13.6
House shielded	23.1 (28.2) 32.1	21.3 (22.0) 22.4	23.3 (28.4) 32.2
Marrow	24.6 (30.1) 34.3	26.9 (27.4) 27.9	24.7 (30.2) 34.4

[a]Uncorrelated FSD estimate.
[b]FSD estimate with correlations in Table 11.
[c]Total correlation FSD estimate.

on either side of this value are the totally uncorrelated FSD (left-hand side) and the totally correlated FSD (right-hand side). The data indicate that the biggest increase in FSD occurs for the house shielding. This is due to the large FSD associated with uncertainties in the location of the survivor in or near the house as specified to DS86 through the nine-parameter or globe data. Since complete and detailed drawings exist in RERF files depicting the survivor's location and surrounding neighborhood (see Appendix 7-2),[2] the largest reduction in the uncertainty of the dosimetry from DS86 can be accomplished by a better description of the survivor configuration in a new computer data base.

The data also indicate that the nominal value of the FSD is close to the totally-correlated estimate, which results from the large correlation among kerma components for the factors with large uncertainty.

REFERENCES

1. Preston, D. L., 1985. Report presented at the Third U.S.-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, March 12-14, 1985, Pasadena, CA.
2. Woolson, W. A., 1984. *Available Data for House Shielding Estimates of Japanese A-bomb Survivors*. La Jolla, CA: Science Applications International Corporation, report SAIC-84/1417.
3. Beebe, G. W. and Usagawa, M., 1968. *The Major ABCC Samples*. Hiroshima: Radiation Effects Research Foundation, ABCC report 12-68.
4. Auxier, J. A., 1977. *ICHIBAN: Radiation Dosimetry for the Survivors of the Bombings of Hiroshima and Nagasaki*. Washington: Department of Energy.
5. Auxier, J. A., Cheka, J. S., Hubbell, H. H., Jr., Jones, T. D., Perdue, P. T., and Thorngate, J. H., 1965. Ichiban studies. In *Health Physics Division Annual Progress Report for Period Ending July 31, 1965*, section 18, pp. 153-159. Oak Ridge, TN: Oak Ridge National Laboratory, report ORNL-3849.
6. Auxier J. A., Cheka, J. S., Haywood, F. F., Jones, T. D., and Thorngate, J. H., 1966. Free-field radiation-dose distributions from the Hiroshima and Nagasaki bombings, Health Physics 12:425-429.
7. Ritchie, R. H., and Hurst, G. S., 1959. Penetration of weapons radiation application to the Hiroshima-Nagasaki studies. Health Physics 1:390-404.
8. Cheka, J. S., Sanders, F. W., Jones, T. D., and Shinpaugh, W. H., 1965. Distribution of Weapons Radiation in Japanese Residential Structures. Oak Ridge, TN: Oak Ridge National Laboratory, report CEX-62, 11.
9. Loewe, W. E., and Mendelsohn, E., 1980. *Revised Estimates of Dose at Hiroshima and Nagasaki, and Possible Consequences for Radiation Induced Leukemia (Preliminary)*. Livermore, CA: Lawrence Livermore National Laboratory, report D-80-14.
10. Preeg, W. E., 1976. Letter to C. P. Knowles, R & D Associates. Los Alamos, NM: Los Alamos National Laboratory. Also published as an appendix to; Whalen, P. P., 1982. Status of the Los Alamos efforts related to Hiroshima and Nagasaki dose calculations. In *Reevaluations of Dosimetric Factors, Hiroshima and Nagasaki*, V. P. Bond and J. W. Thiessen, Eds., pp. 111-130. Washington: Department of Energy report CONF-810928.
11. Marcum, J., 1981. *House Attenuation Factors for Radiation at Hiroshima and Nagasaki*. Marina del Rey, CA: R & D Associates, unpublished report.
12. Kerr, G. D., 1982. Findings of a recent Oak Ridge National Laboratory review of dosimetry for the Japanese A-bomb survivors. In *Reevaluations of Dosimetric Factors, Hiroshima and Nagasaki*, V. P. Bond and J. W. Thiessen, Eds., pp. 52-97. Washington; Department of Energy report CONF-810928.
13. Woolson, W. A., Marcum, J., Scott, W. H., and Staggs, V. E., 1982. Building-transmission factors. In *Reevaluations of Dosimetric Factors, Hiroshima and Nagasaki*, V. P. Bond and J. W. Thiessen, Eds., pp. 179-200. Washington: Department of Energy report CONF-810928.
14. Fujita, S., 1985. Data presented at the Third U.S.-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, March 12-14, 1985, Pasadena, CA.
15. International Commission on Radiation Units and Measurements, 1980. *Radiation Quantities and Units*. Bethesda, MD: ICRU, report 33.
16. Bell, G. I., and Glasstone, S., 1979. *Nuclear Reactor Theory*, p. 5f. Robert E. Krieger Publishing Co.