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INITIAL RADIATION DOSIMETRY AT HIROSHIMA AND NAGASAKI

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"INITIAL RADIATION DOSIMETRY AT HIROSHIMA AND NAGASAKI"

W. E. Loewe*

In our deliberations at this conference, the ultimate purpose is improved radiation protection standards. Radiation protection standards result from a judgment by appropriate experts who use various kinds of data bases as itemized in Table I. These data bases vary widely in character and quality. Among them, A-bomb survivor experience is paramount because it represents a statistically large sample of whole body radiation data for humans for whom good records are available and for which there is a wide range of radiation levels.

Until 1980, additional features useful for standard setting were thought to be dose accuracies of 30% or better, and doses due to both neutrons and gamma rays occurring in a way that is susceptible to analysis for separated effects. Actually, of course, those doses were very much in error.

One may ask how much difference errors in the A-bomb survivor dosimetry can make. It has been said that the A-bomb survivor experience forms the single most important set of data upon which our protection recommendations rest. Furthermore, there remain substantial overall uncertainties in the Hiroshima and Nagasaki dose data. Now, it turns out that there are various developments currently underway, in addition to the change in the survivor dosimetry itself, which may compound with dose uncertainties to necessitate a change in protection standards. There appears to be possible (1) a general shift from absolute risk to relative risk in the epidemiological studies that are being made, which might make a change in standards of a factor of two or three; (2) a shift to cancer incidence data instead of mortality data as the preferred data base,

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Table I

Kinds of Data Bases Used by the Experts in Setting Radiation Protection Standards

Pulsed or sustained exposure

Neutrons or photons, of various energies

Human or animal

In vivo or *in vitro*

Whole body or localized radiation

Cellular or organic effects

again with a possible factor of two change in standards; and, (3) a factor of two due to the apparently rising cancer rates at Hiroshima and Nagasaki compared with the experience to date. These are fairly large factors, and may be all in the same direction: that is, to make radiation appear worse. If most were to emerge as definite, it could well be that dosimetry changes might push the relationship of biological effects data and corresponding protection standards out of the range of conservatism into the range where a change is necessary. There is a lot of leverage here, because there are tens of billion dollars to be spent in the commercial nuclear power and nuclear defense industries if protection standards were to be changed.

Figures 1 and 2 compare the pre-1980 survivor dosimetry, called T65D, with the new dosimetry, as put forth in the winter of 1980/1981 by my collaborator Ed Mendelsohn and me.* Because the basis for our dosimetry has been published in full as an archival journal article**, and because subsequent changes are either relatively small or uncertain (or both), my remarks here will use it as the reference, with occasional indications of what particular changes actually have been suggested since then.

The features in these figures that are important for this meeting are in Hiroshima, where neutrons have gone down and the gammas have gone up. Table II gives you an indication of what that means for a range in the middle of the region where most of the survivors are located. This table also shows the ratios of the sum of neutron and gamma dose. For Nagasaki the ratio has hardly changed, but for Hiroshima it has changed fairly significantly at a kilometer-and-a-half and beyond. The ratio of gammas to neutrons has changed drastically, from a factor of two in the old dosimetry to a factor of thirty or more in the new dosimetry.

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*W. E. Loewe and E. Mendelsohn, "Revised Dose Estimates at Hiroshima and Nagasaki," Health Physics 41, 663-666 (1981).

**W. E. Loewe and E. Mendelsohn, "Neutron and Gamma-Ray Doses at Hiroshima and Nagasaki," Nuc. Sci. Eng. 81, 325-350 (1982).

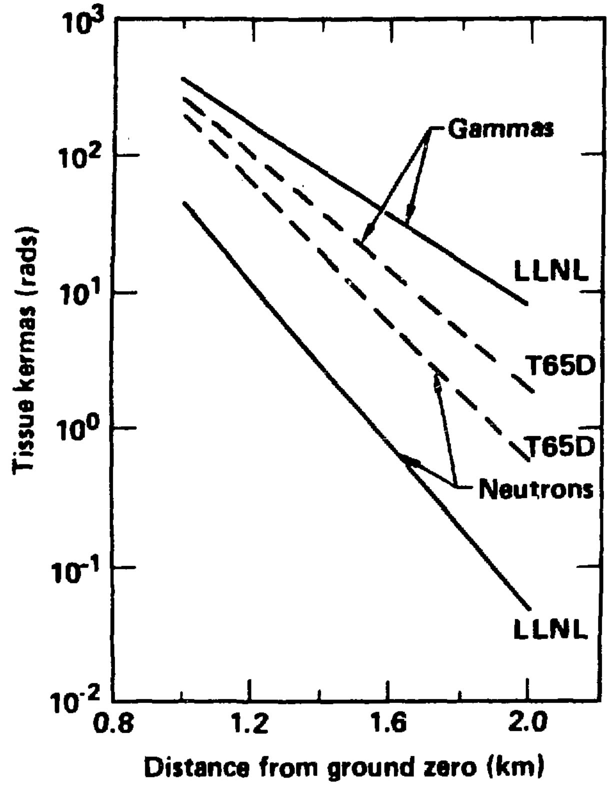


Figure 1. Free-in-air tissue kermas at Hiroshima

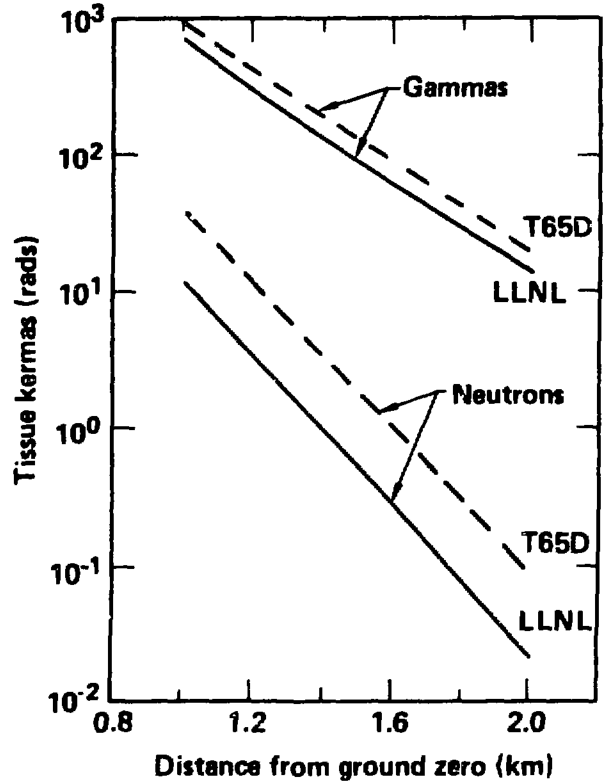


Figure 2. Free-in-air tissue kermas at Nagasaki

Table II

Comparison of Old and New Kerma Values

	(New Total Kerma)/(Old Total Kerma)		
	1.0 km	1.5 km	2.0 km
Hiroshima	0.9	1.6	3
Nagasaki	0.8	0.7	0.8

	1.5 km Ground Range at Hiroshima Gamma Kerma/Neutron Kerma
Old (T65D)	2
New (LLNL)	33

These dosimetry changes affect epidemiological results as exemplified in Figure 3, where we have leukemia mortality on the y axis and total dose (neutron plus gamma) on the x axis. In Figure 3a, with the old doses, you see an apparent difference between the two cities. As in Figure 3b, the new dose estimates cause that difference to disappear. Concomitantly, the neutrons that had been thought to account for the T65D difference between Hiroshima and Nagasaki have dropped by factors of five and ten, so that in neither city are there very many neutrons. Therefore, the analysis of the data in Figure 3a which indicated very high neutron RBE's is no longer applicable. (Neutron RBE may be high, but you cannot tell that from these data from the A-bomb survivors.) Other epidemiological data show similarly significant changes.

Summarizing, here are some of the consequences of the new dosimetry, to the extent that they are known today. You can combine Hiroshima and Nagasaki data, and that gives you better statistics which is always welcome, and particularly so here. Also, there are additional survivors irradiated (at the large ranges). You cannot infer anything about neutron biological damage from Hiroshima and Nagasaki, unless the dose estimates finally arrived at are significantly different. Therefore, there is now a call for new ways to get neutron data. Finally, it seems that now the A-bomb survivor experiences are more nearly congruent with other kinds of data than previously.

So much for the background on why we are at a Little Boy Replica Conference, today, 38 years after the Little Boy bomb exploded. I assume here that the other papers at this conference make clear the current state of knowledge about the neutron and gamma-ray leakages from the Little Boy explosion, and will simply observe that revisions to source estimates have the consequences shown in Table III, where are shown ratios of (a) dose calculations I made last year using the most recent LANL calculated source estimates, to (b) the calculated values appearing in our Nuclear Science and Engineering article previously cited. (The two calculations are otherwise identical.) The NS&E values are based on the

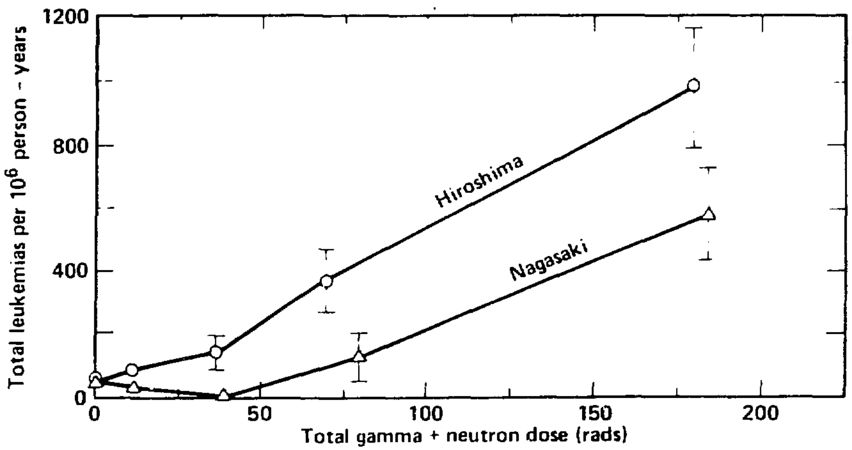


Figure 3a. Leukemia Incidence vs *Dose Using T65 Data* (By Rossi and Mays, 1978)

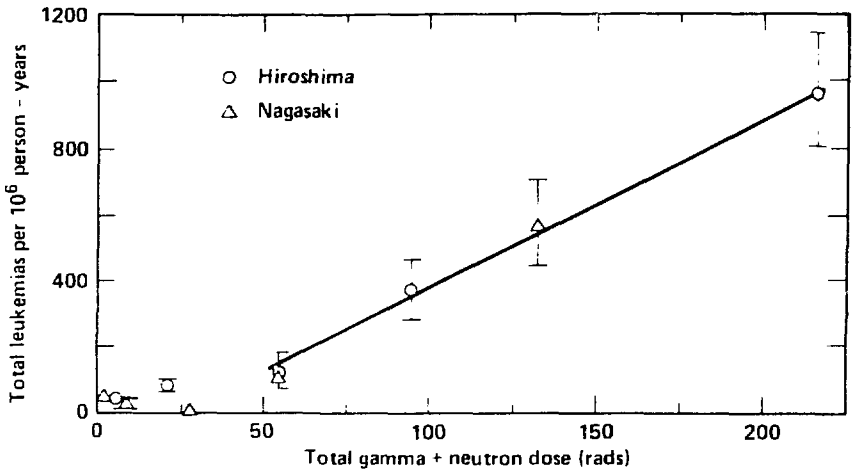


Figure 3b. Leukemia Incidence vs Dose Using LLNL Data

(*The error bars on leukemia* incidence represent one standard deviation based on the sample *size. The uncertainties* for dose values *are* not shown on this figure.)

Preeg sources that were discussed yesterday, which are from a 1D model of the bomb. The new estimates are those that Paul Whalen distributed in September 1982, based on a 2D model and including both energy and angle dependence. As seen in Table III, the anisotropy effect is fairly substantial if you are directly under the bomb, but it washes out soon, well before you get to a range of a kilometer or so where most of the survivors were located. There it settles into a 33% effect for neutrons, and the gammas show an even smaller effect. Thus, even the extremes in modern descriptions of leakage show only modest consequences to kerma. It is important that we resolve some of the discrepancies in source description that we talked about yesterday, for a variety of reasons including the pronounced effect on some diagnostic neutron activation measurements. We see, however, that there is a boundedness on that importance, which mitigates very much the need to determine neutron leakages to say, 10%, at every energy and every angle.

Although previous generations of work done by others have been somewhat different, the current estimates are generally confirmative of our NS&E results, as shown in Table IV, where the comparison is made with results presented by George Kerr of ORNL last February at the Nagasaki workshop on dosimetry. Except for neutrons at Hiroshima, there is agreement to ± 25%, with these differences due to undetermined differences in approach or parameter values. However, one difference actually is determined: ORNL uses 12.5 KT for the Little Boy yield, while we used 15 KT. Discounting this difference brings agreement to ± 17%. Neutron doses at Hiroshima, on the other hand, are very low in the ORNL estimates, for reasons that I do not know. Even if the ratios for Hiroshima neutrons shown in Table IV are increased by 20% to account for the known difference in yield, and by 33% to account for the difference in source description as shown in Table III, the resulting ratio is .7, reflecting an outstanding 30% discrepancy as yet unexplained. A matter of interest here is that, if this neutron discrepancy turns out to be resolved in favor of the ORNL values, the neutron dose at larger ranges is the same at Hiroshima and Nagasaki. In any case, it would be useful

Table III

Effect of New Sources* on KERMA at Hiroshima

Ground range (km)	Ratio of KERMA, new to NS&E	
	Neutrons	Gammas
0.2	0.59	0.82
0.4	0.61	0.84
0.6	0.64	0.85
0.8	0.66	0.86
1.0	0.67	0.87
1.2	0.67	0.88
1.4	0.67	0.88

*From LANL, Sept. 1982 (Here, angular distribution as sulphur fluence).

Table IV

F-I-A* kermas: LLNL(NS&E)/ORNL(workshop)

GR (km)	Neutrons	Secondary Gammas
Nagasaki		
1.0	1.01	1.08
1.4	1.17	0.99
1.8		0.89
Hiroshima		
1.0	0.37	1.03
1.4	0.38	0.89
1.8	---**	0.76

*F-I-A = "Free-in-air".

**No value for neutron kerma could be read at 1.8 km on the published figure from which the ORNL kermas were read.

to know whether the outstanding differences that do exist are a result of changes in cross sections or in computational methods or in material compositions or in geometrical descriptions, and to break them down into components.

Table V summarizes the major differences between the ways in which the old and the new kermas were arrived at, judged in terms of what was significant in changing the kermas. First of all, the portion of the energy spectrum of neutrons escaping the two bombs that determines atmospheric penetration, was assumed to be the same in the old dosimetry, whereas we know that the two spectra are very different. Then there were _in situ_ measurements, which I will address in more detail shortly, where neutron activation of cobalt (a trace impurity in iron) was obtained. (The cobalt was obtained from steel reinforcing bars interior to concrete support pillars on large buildings.) The calibration was done in such a way for T65D that the spectrum used in the calibration was improper, and the conversion from activation to dose thus did not turn out right--what looked like confirmation for the dose estimates was in fact inapplicable. Finally, the gammas for T65D were extrapolated from close-in data ($\leq$ 1 kilometer), and that extrapolation is something that simply does not work if you don't know how to extrapolate it correctly. Now we do a first principles calculation of two distinct components directly at the point of interest; neither component (nor their sum) would be simply extrapolatable.

Turning now to the basis for our NS&E dose estimates, we list a few pertinent facts about the two explosions in Table VI, and display the various components of the dose in Table VII. Delayed neutrons and gamma rays result from fission product decay during the first few minutes. Although fission product decay gammas contribute about half of the total gamma ray kerma along the ground at Hiroshima and Nagasaki, decay neutrons are much smaller, contributing a fraction which has not previously been quantified. Both neutrons and gamma rays leak from the bomb during explosion and contribute to kerma along the ground. In addition, the

Table V

Basis of Major Differences Between Old and New Kermas

Feature	Old	New
Energy spectrum of neutrons escaping bombs: Hiroshima vs. Nagasaki	Assumed the same	Calculated as very different
In situ neutron activations interpreted as dose	Calibration close to bare reactor source	Calibration implicit in transported bomb spectra
Gamma doses in 1-2 km range of greatest interest	Extrapolate with assumed behavior, uncertain data	Direct calculation of two distinct components

Table VI

	Hiroshima	Nagasaki
Time	0815, 8/6/45	1058, 8/9/45
Height of burst (m)	570	503
Yield (kt)	15 ± 3	22 ± 2
Bomb type	Little Boy (U gun)	Fat Man (Pu implosion)
Humidity	80%	71%

Table VII

Dose Components

	Prompt	Delayed
Neutrons	Bomb leakage	Fission products
Gammas	Bomb leakage Secondaries	Fission products

prompt neutrons generate secondary gamma rays by capture, primarily in atmospheric nitrogen, amounting to about half of the total gamma kerma along the ground.

The prompt neutron kerma along the ground is essentially determined by the intensity of leaking neutrons and by their atmospheric attenuation, which is a sensitive function of neutron intensities above roughly 0.5 MeV. Figure 4 shows leakage spectra from an isolated nucleus ("Fission"), from a bare U^{235} metal reactor (HPRR = Health Physics Research Reactor at ORNL), and from the Little Boy and Fat Man bombs. It is the verification of the Little Boy data shown here that our conference, yesterday and today, has as one of its primary subjects. Referring back to the discussion of Table V, we can now see from Figure 4 that the spectrum from the two bombs is very different. (The T65D assumption actually was equal atmospheric attenuations, but these are determined directly by the spectral behavior above about 0.5 MeV.)

Figure 5 shows that the spectral difference in neutrons between Hiroshima and Nagasaki persists beyond two kilometers; the attenuation-determining part of the spectrum is different from the source point to the furthest penetrations.

Figures 6 and 7 show the prompt gamma ray kermas along the ground for both components, illustrating the earlier implication that the bomb leakage gammas are a small contribution compared to the secondary gammas at locations of interest. The secondary gamma data in these figures are a result of the same air-over-ground transport calculations that generated the neutron data in Figures 1 and 2; the primary data came from analogous calculations.

For a well-characterized source and well-known atmospheric and ground compositions, these calculated kermas are reasonably accurate estimates, as suggested by the results of comparing similar calculations with experiment. For example, Table VIII shows the comparison for a

NEUTRON OUTPUT ENERGY SPECTRA

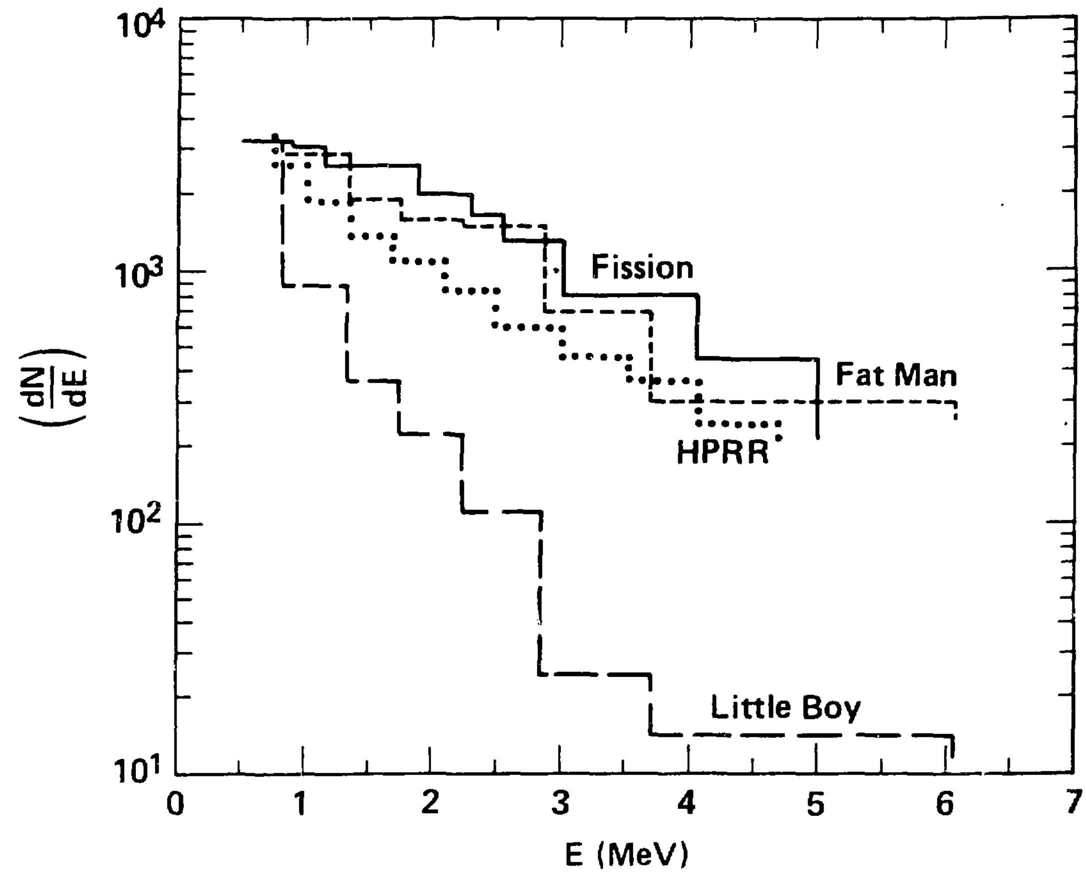


Figure 4.

COMPARISON OF NEUTRON SPECTRA AT 2 km

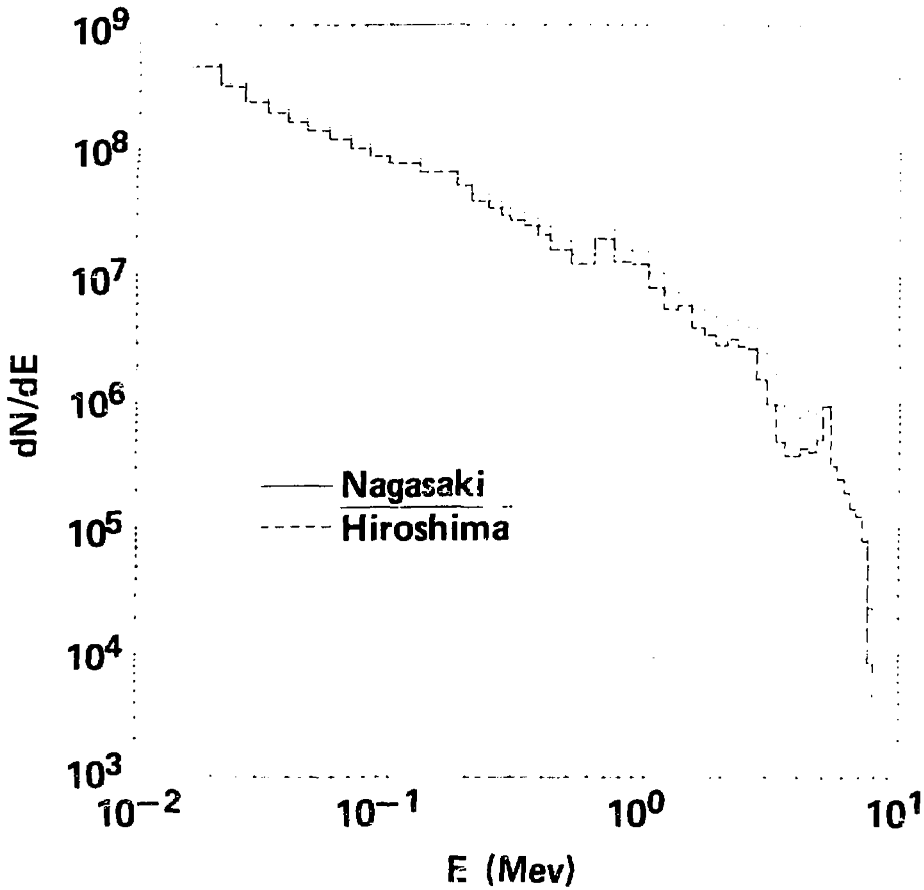


Figure 5.

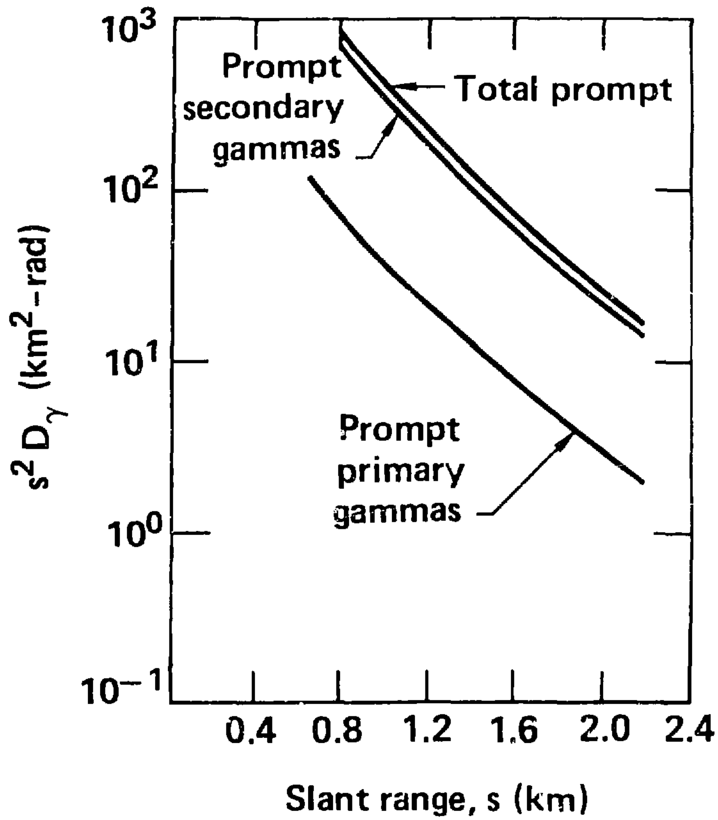

10^3
10^2
10^1
10^0
10^{-1}
$s^2 D_\gamma$ (km^2-rad)
Prompt secondary gammas
Total prompt
Prompt primary gammas
0.4
0.8
1.2
1.6
2.0
2.4
Slant range, s (km)

Figure 6.

NAGASAKI PROMPT GAMMA RAY KERMAS

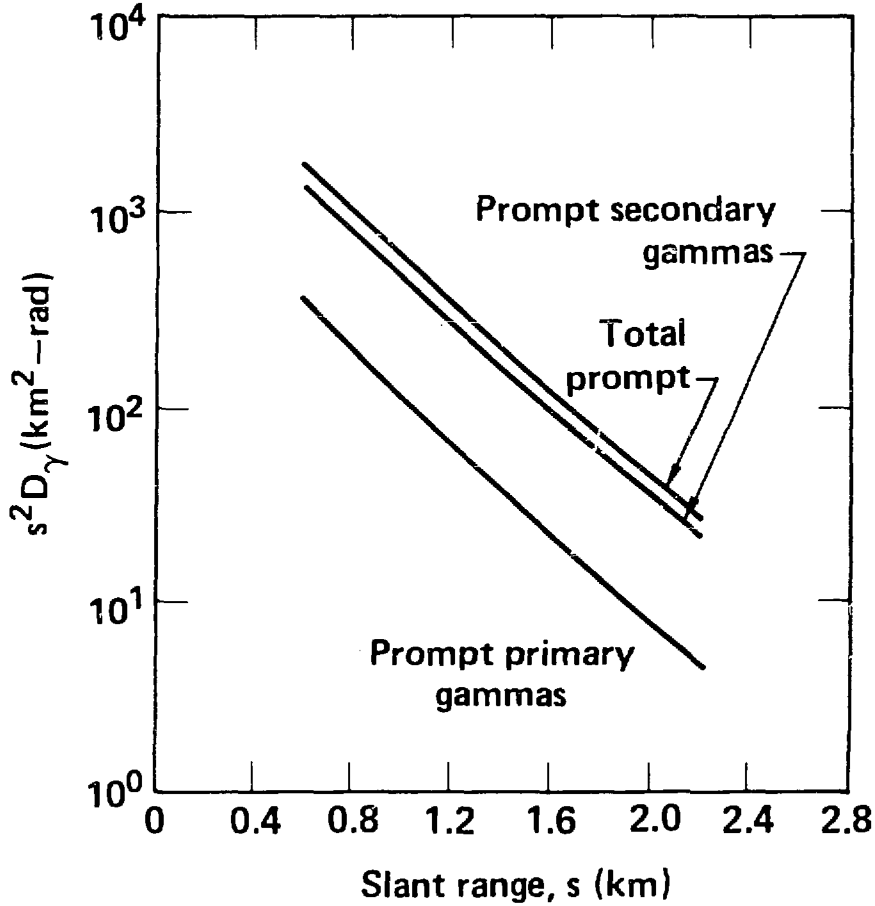


Figure 7.

source like HPRR as shown in Figure 4. It is important to note that a comparison point is available at 1.6 km, about as distant as there is any interest in neutrons and well into the middle of the interesting range for gammas. In addition to kerma comparisons, this table also shows the comparison for neutron fluences capable of activating sulphur, since sulphur activation measurements were made along the ground at Hiroshima soon after the explosion. Use of all available measured data, including older and less reliable data than in Table VIII, allows weighted averages to be formed as shown in Table IX. These two tables suggest that it is unlikely that error in the transport calculation itself will ever become the primary source of uncertainty in kerma estimates. Having said that, I should mention that others have noted a spectral discrepancy in the data underlying Table VIII. This is shown in Figure 8, and leads to the suggestion that the much softer spectrum from Little Boy might be susceptible to greater error in transported kerma than the HPRR-like data in Table VIII. I doubt both the validity of that particular discrepancy as an indicator of actual error in transport, and the importance of this energy regime to kerma at the most interesting ranges for A-bomb survivor dosimetry.

The other major component of the gamma kerma along the ground at Hiroshima and Nagasaki is due to fission product gammas. That contribution to the results shown in Figures 1 and 2 was obtained from a model developed in the mid-60's and compared exhaustively to measurements of dose and dose rate along the ground away from explosions at some 75 field tests of nuclear weapons. The model included time dependent treatment of debris cloud rise and modified atmospheric attenuation due to blast wave rearrangement of air, and provided explicit dependence of these and the associated radiation transport phenomena on explosive yield and on atmospheric pressure and density. Using this model and the calculational tools for prompt contributions just discussed, just as was done to generate the gamma kermas in Figures 1 and 2, calculated estimates can be obtained to compare with measured values from a test explosion at the Nevada Test Site that was similar to Nagasaki. The

Table VIII

Kerma Obtained for a Fission Source in Air-Over-Ground Geometry, Using Modern Cross Sections and Calculational Techniques

Range (m)	Ratio, Calc./Measured		
	Neutron Kerma*	Gamma Kerma*	Neutron Fluence >3 MeV
100	1.09	1.06	1.14
170	1.15	.91	1.02
300	1.30	.94	.98
400	1.37	.90	1.08
1080	1.13	.80	1.00
1618	.90	.91	---

*NS&E 85, 87-115 (1983).

Table IX

Averaged Estimates of Kerma Calculational Accuracy for Air-Over-Ground Radiation Transport, Expressed as Ratio of Calculation to Measurement

Range (km)	Source Spectrum: 14 MeV Source	Source Spectrum: Fission Source
1.5 km		
Neutron	1.02 ± 15%	0.97 ± 13%
Gamma ray	0.82 ± 20%	0.79 ± 8%
2.0 km		
Neutron	0.88 ± 16%	0.92 ± 19%
Gamma ray	0.73 ± 21%	0.87 ± 10%

APRD transported neutron spectrum

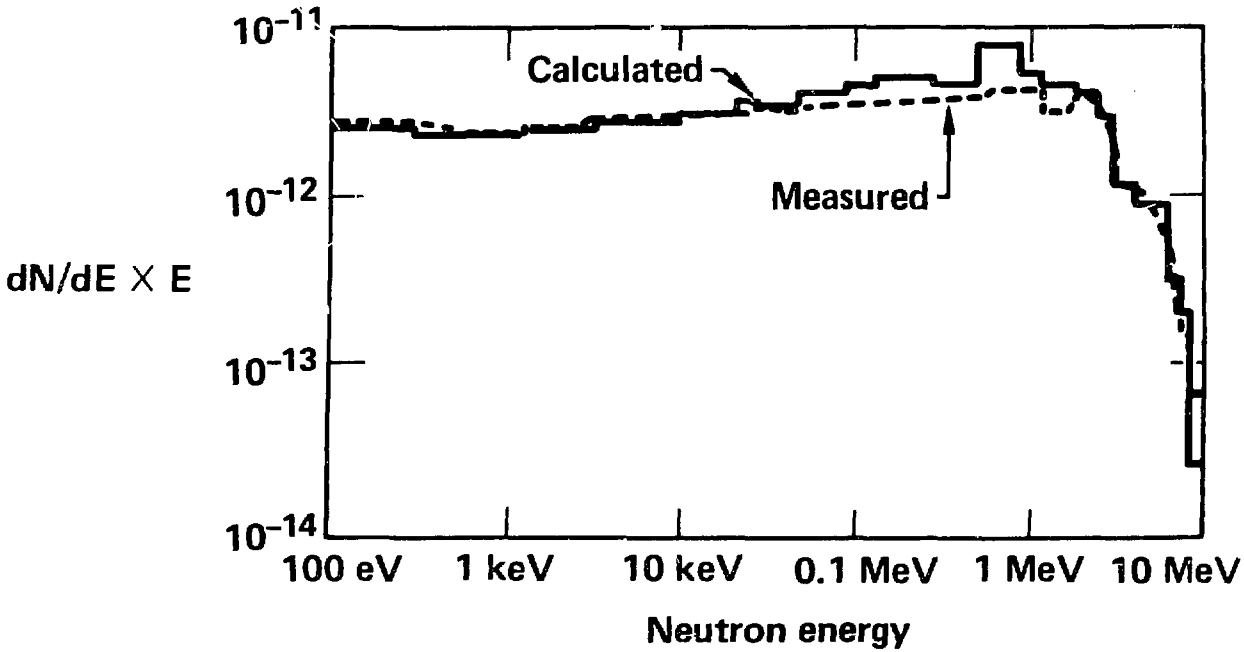


Figure 8.

results are shown in Table X, where it should be emphasized that the comparisons are made near the two ends of the range where the majority of irradiated survivors at Nagasaki were located. Recent improvements in fission product modeling by Bill Scott at SAI have changed best estimates of gamma kermas from fission products by a few percent at Hiroshima and roughly 30 percent at Nagasaki (which changes total gamma kerma by about 15%).

I have recently looked into delayed neutrons, the remaining component from Table VII to discuss and one which Ed Mendelsohn and I considered from the start as a possible contributor, although we doubted it could be a major contributor. I have used the cloud rise and hydrodynamics enhancement models from the validated gamma model just discussed, and added in a detailed air-over-ground transport calculation based on the spectrum for delayed neutrons for fission. A standard six-group time representation of source intensity was used explicitly. (Delayed neutrons are vital to controlling nuclear reactors, and as such are well measured.) Preliminary results show that there are cases where the delayed neutrons cannot be ignored, even though they are generally not very important to kerma. Finalizing computer runs are being analyzed and a draft report of this work is nearly complete.

Improved data for estimating the explosive yield of the Little Boy bomb is the other major motivation behind our conference today, and as such has received adequate attention. It seems worthwhile, however, to emphasize that a value of 15 KT with an uncertainty of $\pm$ 20% is consistent with all phenomenologically based estimates and most calculated estimates. A 20% uncertainty for Little Boy is to be compared with a 10% uncertainty in the well-measured Fat Man yield.

There are a number of direct indications that the kerma estimates we have discussed so far are at least close to the actual values in 1945. These direct indications are provided by <u>in situ</u> measurements of

Table X

Gamma Dose at Ranger F
(Nevada Atmospheric Test Similar to Nagasaki)

Slant Range (m)	Measured Dose	LLNL Dose
1105	959	926
1829	40 rads	39 rads

LLNL dose = prompt calculated by LLNL
+ fission product debris from IITRI model

changes in materials that were made by the radiations themselves. While they have their own sources of uncertainty, it is noteworthy that in situ measurements of radiation-induced material properties are free of uncertainty in the location, intensity, and energy or angle dependence of the radiation source, as well as uncertainty in meteorological conditions and terrain. Therefore, when such data are accompanied by sound estimates of absolute error (as opposed to reproducibility), they can be exceedingly valuable criteria by which to judge our kerma estimates. None, however, provide a direct measure of kerma, so that relating the property actually measured to the kerma is a step of paramount importance.

Figures 9 and 10 compare gamma ray kermas, generated by the same calculational procedure that produced the data in Figures 1 and 2, with kermas derived from measured thermoluminescence in glazed roof tiles exposed in 1945. These in situ estimates, made in the mid-60's, show generally good agreement with our calculated kermas.

Figure 11 compares calculated and measured neutron activation of cobalt located 8 cm interior to concrete support pillars for buildings at Hiroshima. The one-dimensional calculations shown were obtained with a concrete balloon containing Hiroshima atmosphere, while the two-dimensional calculations were obtained with our usual air-over-ground configuration to which has been added short concrete fences concentric to the hypocenter and having various radii. (In neither case was account taken of the contribution from fission product neutrons.) Except for the innermost measured point, agreement between measured and calculated values is fairly good. Unfortunately, we don't know the concrete compositions very well.

Figure 12 depicts the source of sulphur, appearing in a mastic between insulator interior and pole post, whose activation by neutrons was measured shortly after the explosion in 1945. Although these activations are only sensitive to neutrons above 3 MeV and were measured only within the first kilometer from the hypocenter, they are of interest

GAMMA RAY KERMAS AT HIROSHIMA

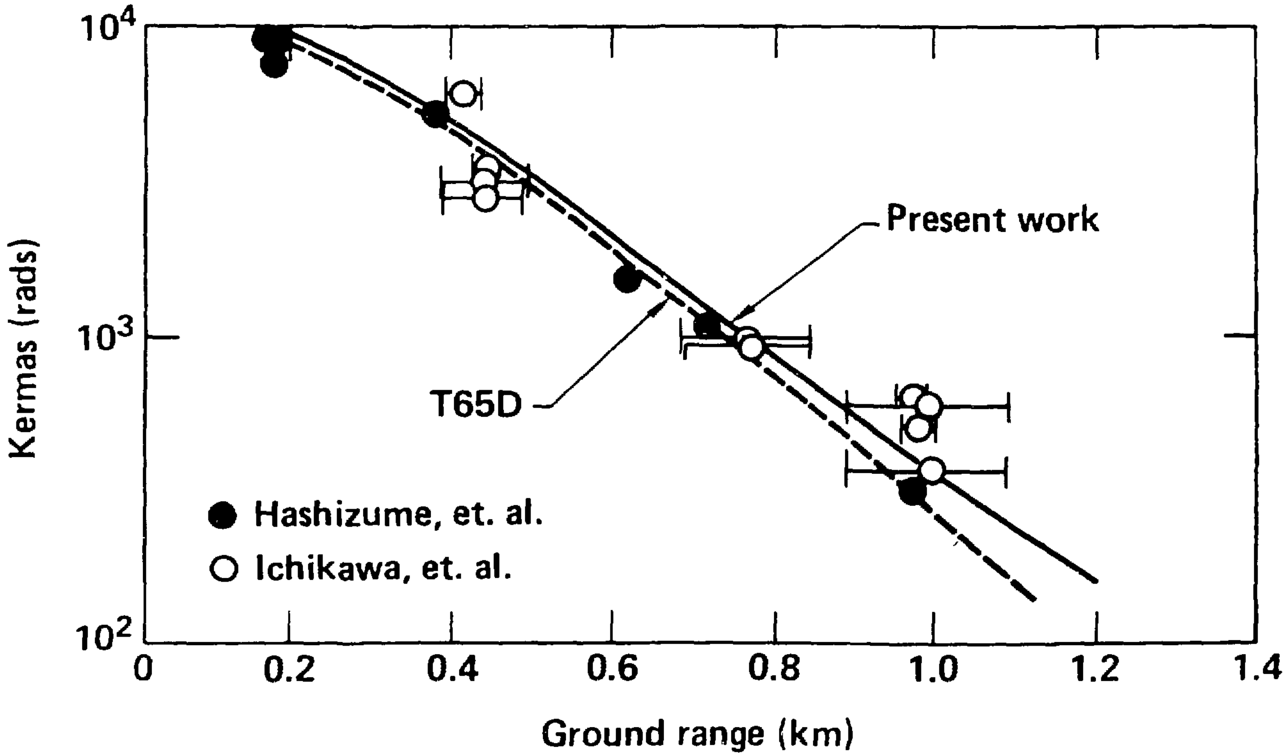
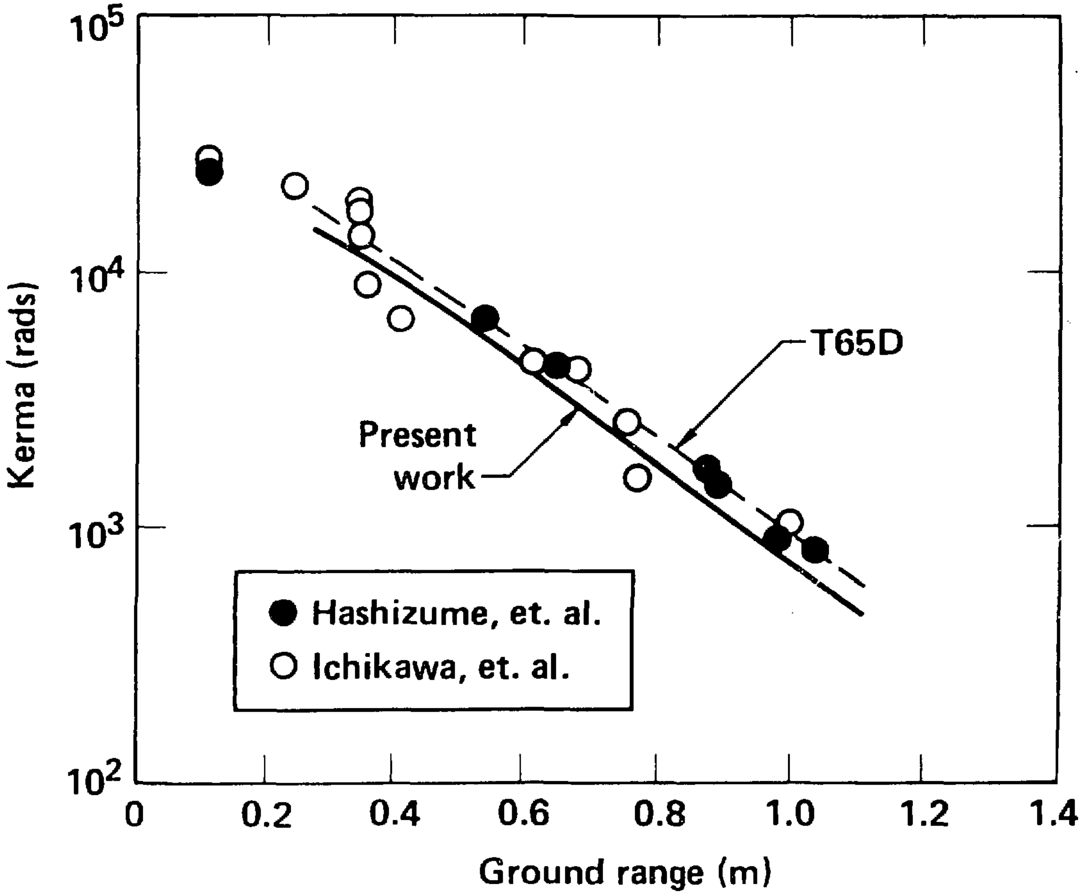


Figure 9.



10^5
10^4
10^3
10^2
Kerma (rads)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Ground range (m)
T65D
Present work
Hashizume, et. al.
Ichikawa, et. al.

Figure 10.

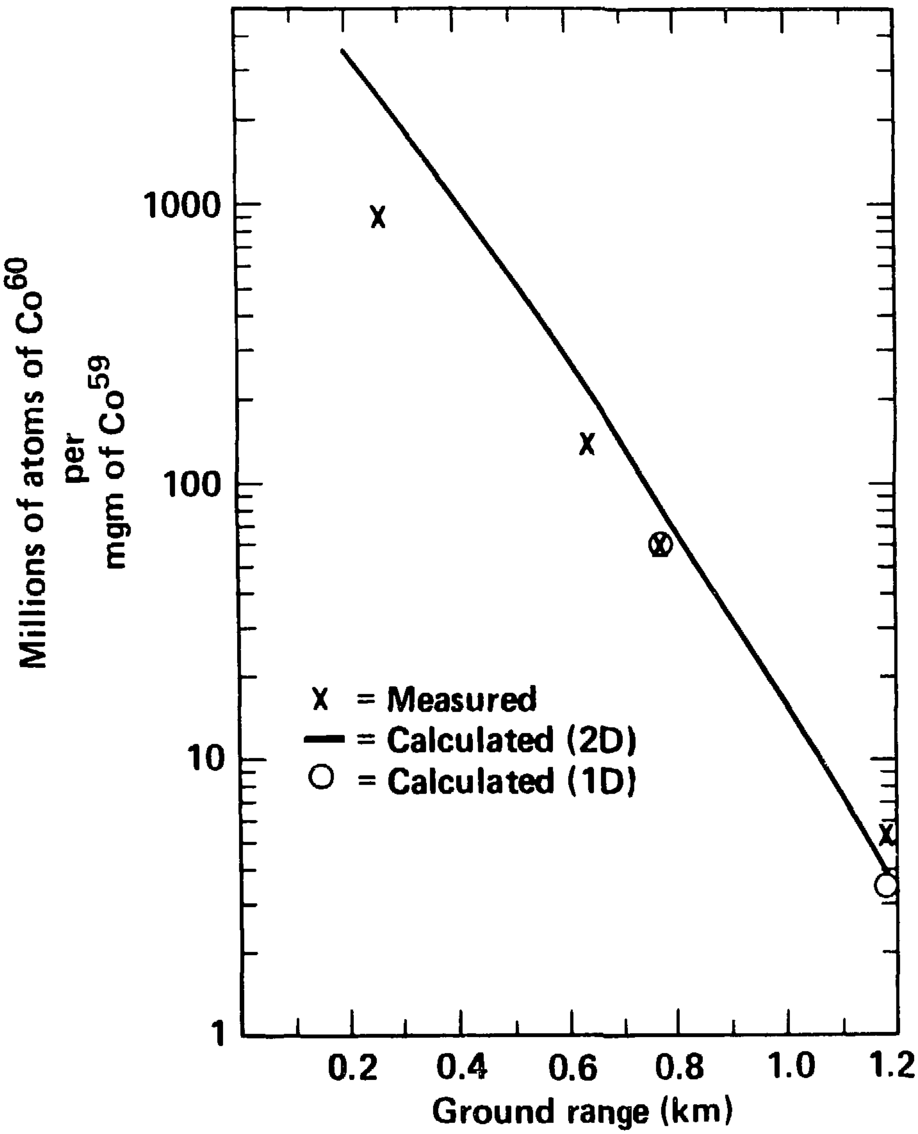
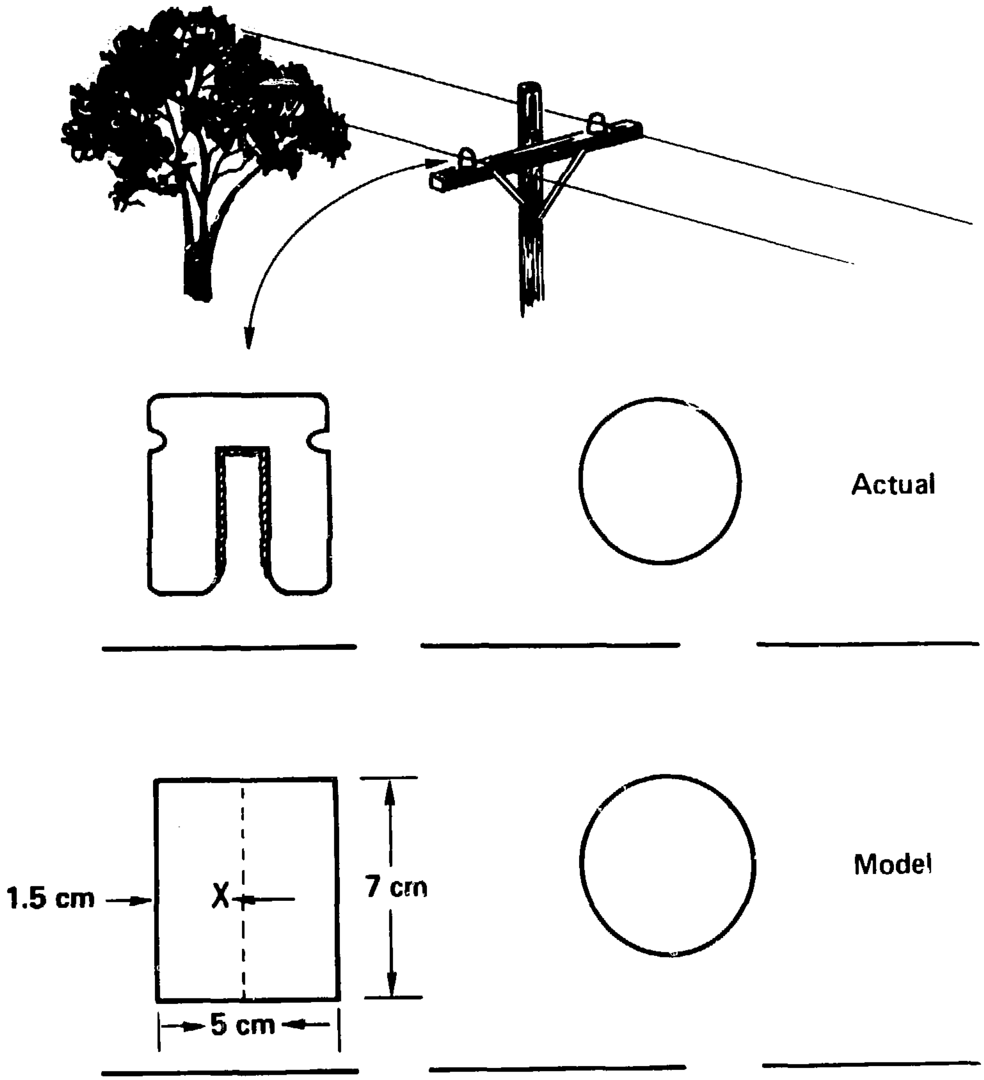

1000
100
10
1
Millions of atoms of Co60 per mgm of Co59
X = Measured
= Calculated (2D)
O = Calculated (1D)
0.2
0.4
0.6
0.8
1.0
1.2
Ground range (km)

Figure 11.

TRANSMISSION LINE INSULATORS



Porcelain, ρ = 2.6 gm/cc
(0.714 SiO_2 + 0.286 Al_2O_3)

Figure 12.

because source neutrons at 3 MeV and greater assume increasing importance to kerma with distance from the hypocenter. This is illustrated in Table XI, where it can be seen that sulphur neutrons are significant contributors to survivor kerma at some ranges. The measured sulphur activation is compared, in Figure 13, with two different kinds of calculated values, one assuming negligible attenuation by the porcelain insulators and the other using an attenuation based on measurements. One-dimensional, and preliminary three-dimensional calculations of insulator attenuations fall between these and represent fair-to-good agreement with measured activations at the closer ranges. The poor agreement at larger ranges may be due to low signal-to-noise ratios for those measurements.

There are several current efforts to make various additional in situ measurements. These include remeasurement of thermoluminescence of roof tiles and face brick using a more sensitive technique developed since the data shown in Figures 9 and 10 were taken, being again carried out by Maruyama and Ichikawa in Japan, and also by Haskell and Wrenn in the U.S. Also in Japan, the previous sulphur measurements are being reanalyzed, and activation of europium in granite and cobalt in bridge footings and on building roofs are being measured. Figure 14 shows recent work by Hashizume, comparing cobalt activations from bare iron rings on roofs with those from "re-bars" embedded in concrete. I see from this figure that concrete variability from building to building has little effect on cobalt activation, encouraging the idea that a good composition analysis on a representative concrete sample would suffice for comparisons between measured and calculated activations interior to concrete. Of course, calculations and measurements can be compared directly for the iron rings open to the air, and will be, although there is (an unsubstantiated) concern that there may be a troublesome sensitivity to the effect of immediate surroundings on the thermal neutrons actually being measured in this case.

Table XI

Contribution to Kerma of Source Neutrons
>3 MeV

Range (km)	Fraction of Total Kerma
1.0	30%
1.5	50%
2.0	70%

Only neutrons with energies >3 MeV can activate sulphur.

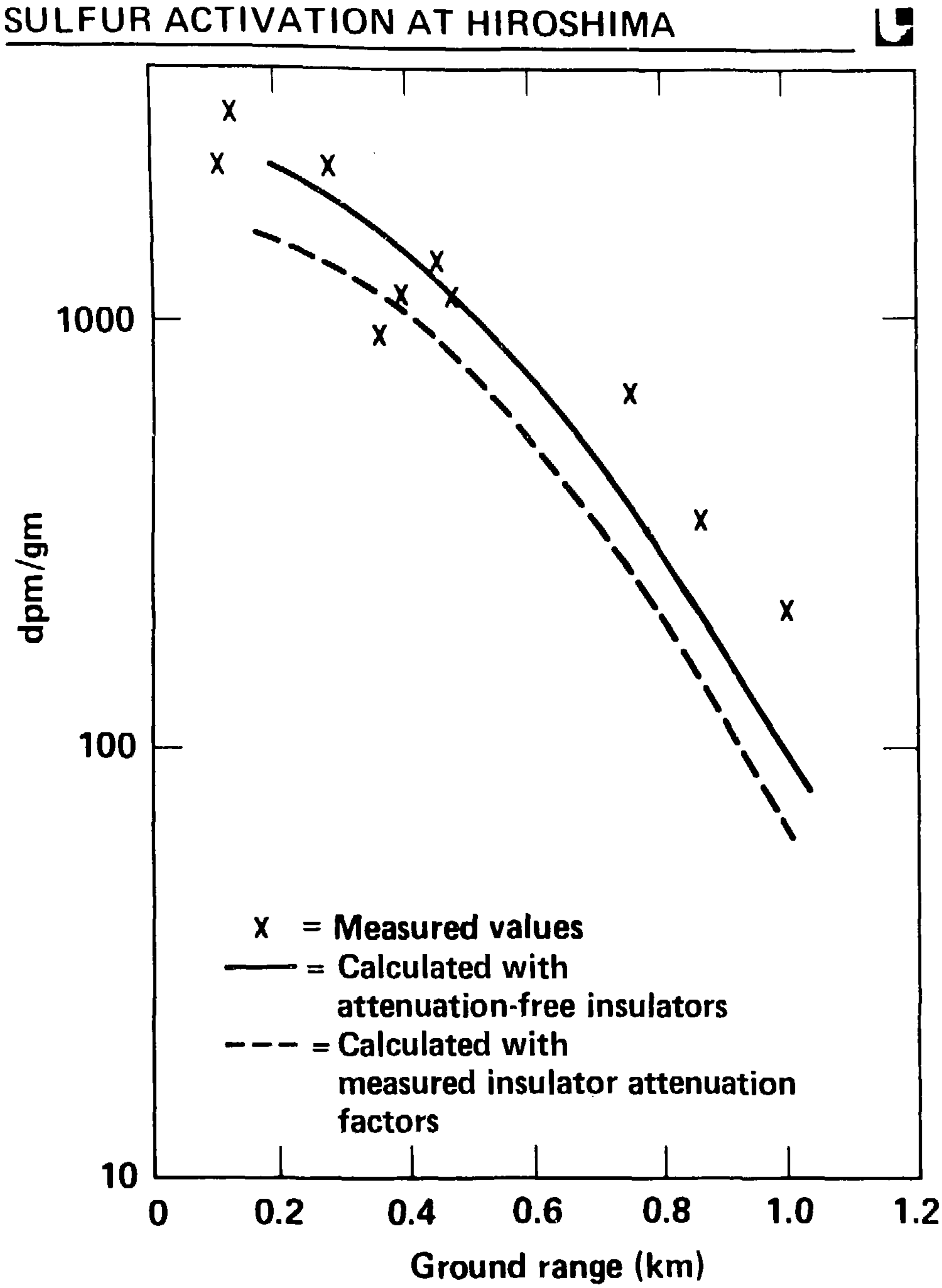

SULFUR ACTIVATION AT HIROSHIMA
dpm/gm
1000
100
10
0
0.2
0.4
0.6
0.8
1.0
1.2
Ground range (km)
X = Measured values
—— = Calculated with attenuation-free insulators
– – – = Calculated with measured insulator attenuation factors

Figure 13.

Recent Co^{60} measurements

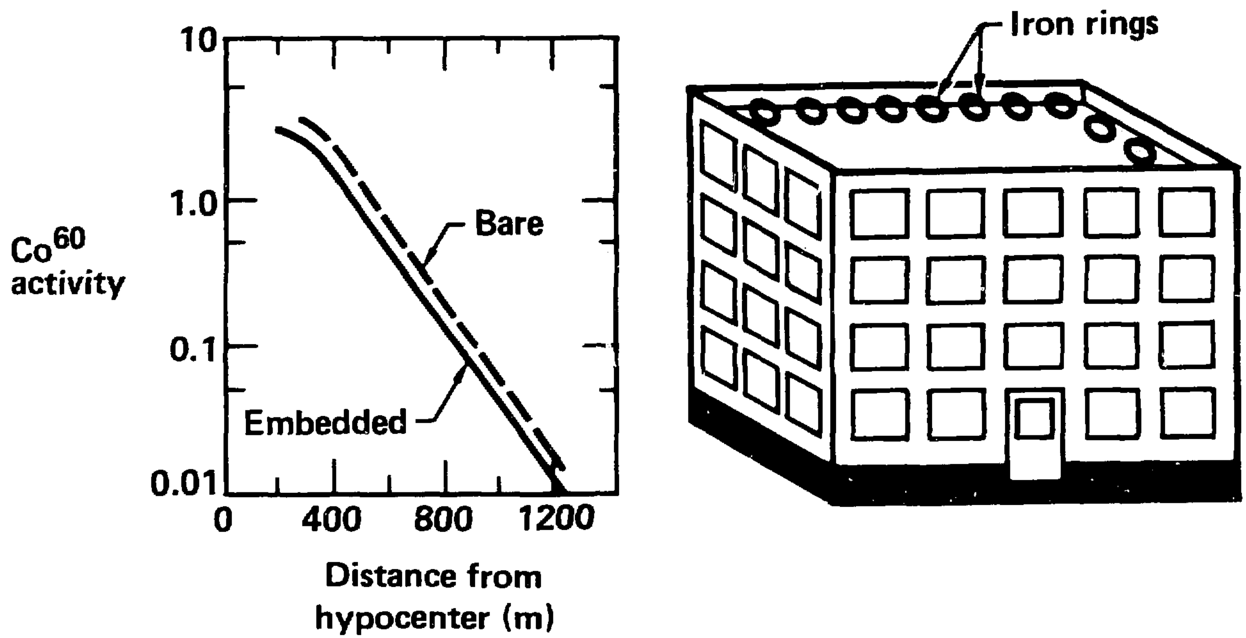


Figure 14.

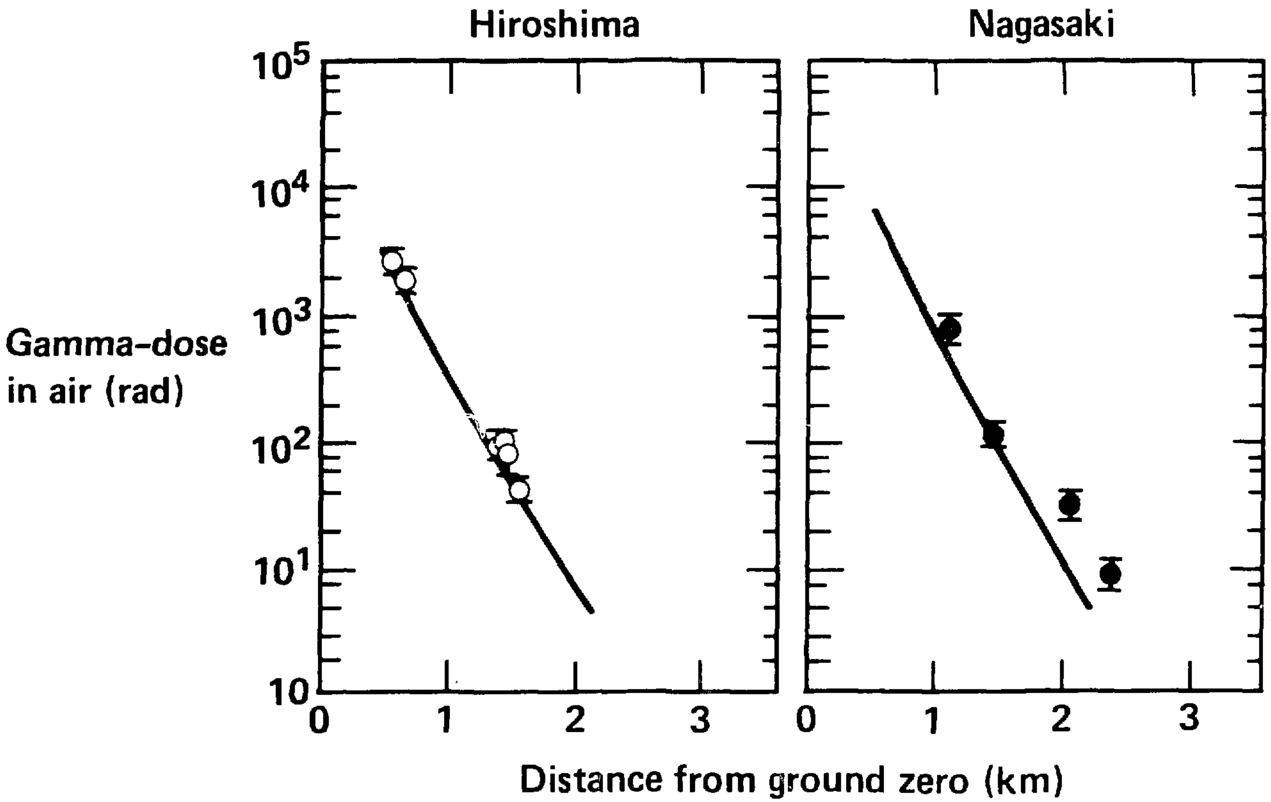
Figure 15 compares preliminary data from Dr. Maruyama using the new thermoluminescence technique which comes to us from nuclear archaeology, with the calculated values shown in Figures 1 and 2 for Hiroshima and Nagasaki. These comparisons are really interesting, because they are now well out in the range where irradiated survivors are located. Agreement is excellent at Hiroshima out to about a kilometer and a half. Almost the same is true, out to about a kilometer and a half at Nagasaki, but there is a discrepancy at larger ranges. This is preliminary data, and background corrections are important for the two Nagasaki points at large ranges, so it is at present a question whether we should worry about that discrepancy; in particular, it is difficult to explain why there should be an abrupt change in the slope beyond roughly 1.3 kilometers at Nagasaki. In any case, the excellent agreement of the data from Figures 1 and 2 with these good precision measurements out to a kilometer and a half, is impressive.

Figure 16 shows preliminary data on europium activation reported by Dr. Sakanoue in February, to which I have added the results of one preliminary calculation for a surface sample. Once again, (i.e. in addition to sulphur and cobalt activations) the agreement shows that the calculational procedure that generated both this point and the data in Figure 1 cannot be subject to substantial error, although additional calculated points and finalized measurements will be required to establish to just what degree there is confirmation here.

The final step in obtaining dose to survivor organs as a contributor to risk of Late Effects is to determine the attenuation of these radiations by buildings (for survivors indoors) and by the human body itself.

The building shielding effect is probably going to be about a factor of 1.6 greater in the gamma doses than given by T65D, as surmised by Jess Marcum three years ago, and now being confirmed by SAI with careful calculations using modern computer codes. (The change stems from

New technique extends TLD to 2 km



Maruyama 2/83 preliminary

Figure 15.

Europium at Hiroshima

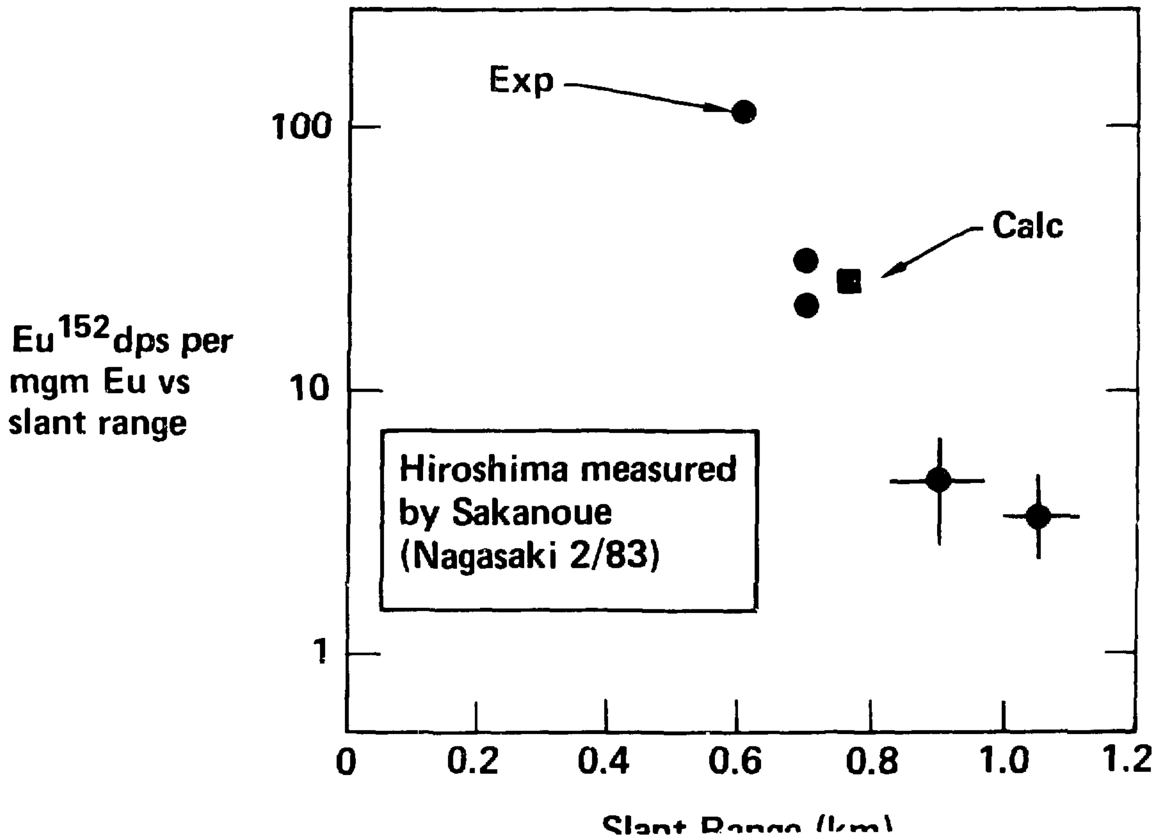


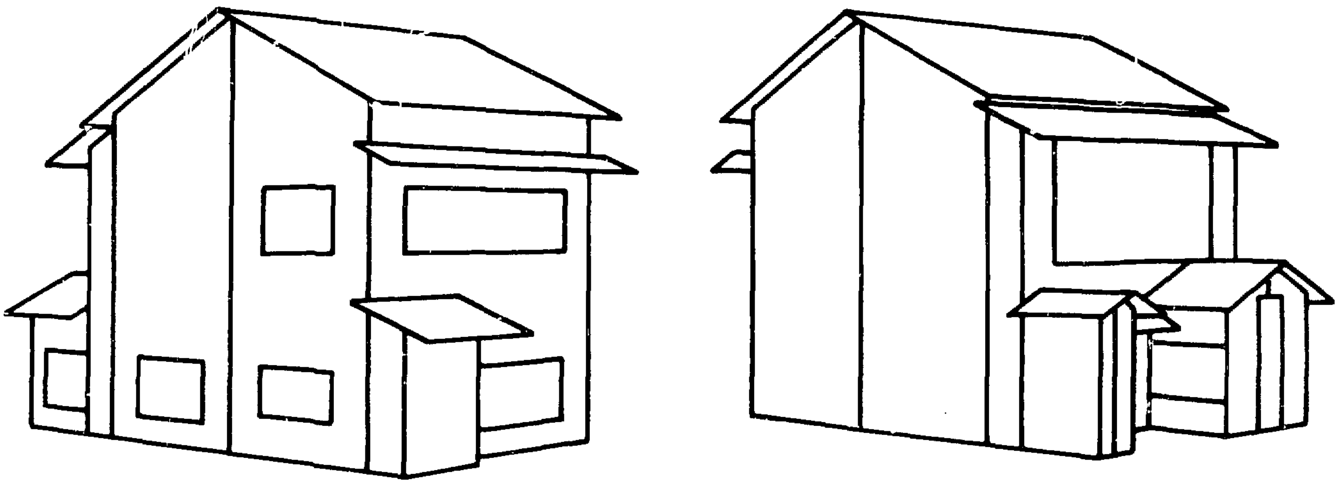
Figure 16.

an erroneous interpretation of the basic experimental data taken at Hardtack.) These computer codes are being additionally validated for this application by comparison with detailed measurements taken at the Nevada Test Site on models of Japanese houses. Figures 17 and 18 and Table XII, copied from illustrations provided by Bill Woolson of SAI, show the detailed calculational geometry of one of the model houses at which measurements were made, along with the measured and calculated neutron and gamma ray kermas at various interior locations. The agreement is excellent for these detailed House B data, which are supposed to be representative of the entire collection. Although unproven by comparison with measured values, this same calculational procedure can be expected to generate similarly accurate estimates of shielding by the body itself; the nature of the calculation is such that both shielding effects can be conveniently treated in a consistent manner.

So far, we have discussed the importance of A-bomb survivor dosimetry, and elaborated the basis for the new dosimetry sufficiently to reveal how this conference fits in and to assess current accuracies. Broadly speaking, the status today is a high degree of confidence in the essential correctness of the new results. Clearly the source descriptions are important, and we are talking about those today, but they are very well bounded as to what kinds of errors you can imagine might occur. There will be few biological inferences made until a certified dosimetry is made available. There is a national program in the United States, which was targeted for two years, about two years ago. The Japanese program, emphasizing, but not limited to, <u>in situ</u> data, is progressing with a similar time scale. (In my opinion, at least a year remains in both programs.)

These programs also imply an opportunity for quantitative evaluation of epidemiological inference from the A-bomb survivor experience, and particularly assessment of the non-statistical uncertainties. I would like to emphasize that assessment of biological as well as dosimetric non-statistical uncertainties is important.

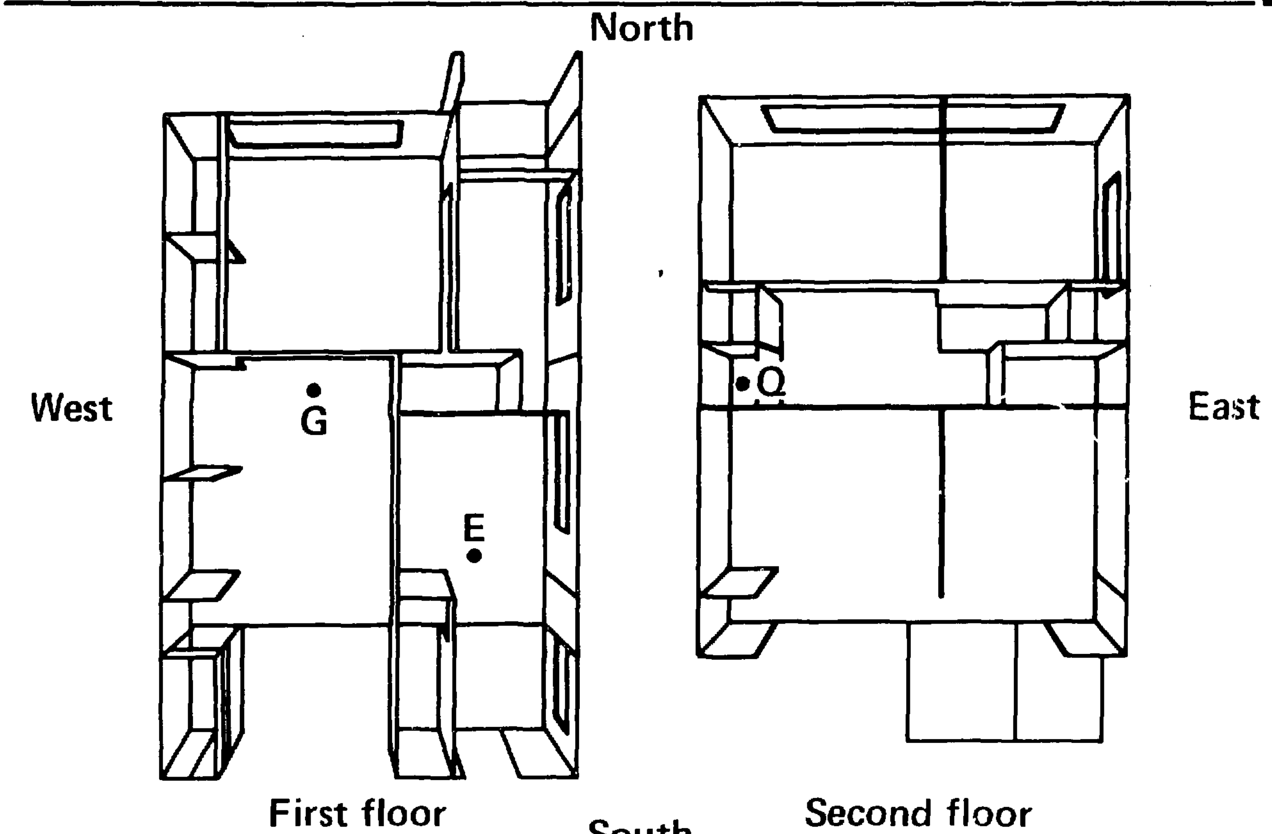
Geometry model of house type B



Data from W.A. Woolson, SAI

Figure 17.

Interior of House B showing calculated detector locations



Data from W.A. Woolson, SAI

Figure 18.

Table XII

Comparison of Calculations with Measurements of Transmission Factors for House B*

Source Location	Detector Location	Detector Height (off floor)	^{60}Co gamma		HPRR neutron	
			Measured	Calculated	Measured	Calculated
South	G	5'	0.58	0.55	0.38	0.40
East	G	5'	0.29	0.26	---	---
South	E	3'	---	---	0.50	0.43
South	Q	5'	---	---	0.44	0.40

*Data from W. A. Woolson, SAI

Table XIII gives a catch-all list of uncertainties for which quantitative estimates are needed. I would like also to emphasize the item in this table which refers to sources of radiation exposure that have occurred more than a few minutes after the explosions; for these sources, controversy is permitted by the uncertainty that exists in the quantitative contributions to overall dose that these represent. We should, with additional effort, be able to provide hard assessments that would resolve outstanding controversy based on this particular topic.

I see the dosimetry future as being occupied with building and body shielding factors, with *in situ* measurements and their interpretation and reconciliation with calculations -- to within well-established absolute experimental uncertainties, and an overall shift toward quantitative estimation of sources of uncertainty throughout the dosimetry.

I close with a list of references in Table XIV which, although not complete themselves, contain references which will generate a fairly complete body of reference information on A-bomb survivor dosimetry.

Table XIII

Some Uncertainties for Which Quantitative Estimates are Desired

- Survivor location ATB
- Building configuration, materials
- Survivor orientation and body size
- Bomb yields
- Dose calculations
- Contributions from
    - Food chain
    - Induced activity
    - Fallout
    - Rainout
    - Medical x-rays
- Dependence on
    - Heredity
    - Major illness
    - Environmental factors
    - Age
    - Sex
    - Selective effects
- Suitability of background incidence values
    - Local
    - Surrounding
    - National
- Non-normal distributions
- Incidence versus mortality registries

Table XIV

References for More Information

- Health Physics 41, 663 (1981).
- Nucl. Sci. Eng. 81, No. 3 (July 1982).
- Proceedings of the Third International Symposium on Radiation Protection, Inverness, Scotland, Society for Radiological Protection (June, 1982). (ISBN 0 9508123 07)
- Proceedings of the Symposium on Re-Evaluations of Dosimetric Factors, Hiroshima and Nagasaki, Germantown, Maryland, U.S. Dept. of Energy (CONF-810928 September 1981).
- Proceedings of the U.S.-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, Nagasaki, Japan (February, 1983).
- Nucl. Sci. Eng. 85, 87-115 (1983).