



---

Studies of the Mortality of A-Bomb Survivors: 3. Description of the Sample and Mortality, 1950-1960

Author(s): Seymour Jablon, Morihiro Ishida, Mitsuru Yamasaki

Source: *Radiation Research*, Vol. 25, No. 1 (May, 1965), pp. 25-52

Published by: Radiation Research Society

Stable URL: <http://www.jstor.org/stable/3571892>

Accessed: 05/01/2010 15:42

---

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at <http://www.jstor.org/page/info/about/policies/terms.jsp>. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at <http://www.jstor.org/action/showPublisher?publisherCode=rrs>.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact [support@jstor.org](mailto:support@jstor.org).



*Radiation Research Society* is collaborating with JSTOR to digitize, preserve and extend access to *Radiation Research*.

<http://www.jstor.org>

## Studies of the Mortality of A-Bomb Survivors

### 3. Description of the Sample and Mortality, 1950-1960<sup>1</sup>

SEYMOUR JABLON,<sup>2</sup> MORIHIRO ISHIDA, AND  
MITSURU YAMASAKI

*National Institute of Health of the Japanese Ministry of Health and Welfare, and Atomic Bomb  
Casualty Commission, Japan*

#### INTRODUCTION

The Life-Span Study is a basic component of the program of studies of the survivors of the Nagasaki and Hiroshima atomic bombs conducted jointly by the Japanese National Institute of Health (JNIH) and the Atomic Bomb Casualty Commission (ABCC). Details of the sampling procedures and methods of follow-up have been specified in previous reports (1, 2) and will be only briefly mentioned here. The sample consists of nearly 100,000 persons whose names were drawn from various censuses and listings, notably supplementary schedules to the 1950 Japanese National Census. All eligible persons who were located within 2500 meters of the hypocenters at the time of the bombing (ATB) and whose names were found on the listings are included in the sample. More distally located persons and persons not in the cities at the bombing were sampled at random from among those eligible to provide comparison groups. Each sample member has been the subject of field interview to ascertain eligibility and to obtain details of exposure.

Mortality information is obtained from the family registers (*koseki*) maintained by Japanese municipal offices, and cause of death from an abstract of the Japanese Vital Statistics Death Schedules. Tests have shown that these sources provide information for more than 99% of deaths (1). Cause of death as given on the schedule is coded according to the World Health Organization International Classification of Diseases (3).

<sup>1</sup> This is the third report on a study conducted by the National Institute of Health of the Japanese Ministry of Health and Welfare (JNIH) in cooperation with the Atomic Bomb Casualty Commission (ABCC) in Japan. The ABCC is a research agency of the U. S. National Academy of Sciences-National Research Council and is supported by Contract AT-49-1-GEN-72 of the U. S. Atomic Energy Commission.

<sup>2</sup> Present address: Division of Medical Sciences, National Academy of Sciences-National Research Council, Washington 25, D. C.

The radiation dose received by survivors is estimated by methods developed by the Health Physics Division of Oak Ridge National Laboratory (ORNL) (4, 5). It is possible to prepare dose estimates only for those persons exposed in certain standard shielding situations (fortunately, the majority are included), but the program to create estimates for all persons within 2000 meters of the hypocenter is still far from complete at this time. Separate estimates are made for gamma dose and first-collision neutron dose. The thousands of dose estimates that have already been made indicate that, for persons who were in the open or in wooden houses, the logarithm of estimated total dose received (adding the gamma and neutron doses, one to one) is nearly linearly related to distance from the hypocenter, decreasing from values in the neighborhood of 500 rads at 1000 meters to about 10 rads at 2000 meters (2).

#### *Data Presented in This Report*

The whole sample of nearly 100,000 persons was successively accumulated in three groups, called Selections I, II, and III (1, 2). Report 1 (1) of the present series presented mortality data through September 1958 on Selection I, numbering about 20,000 persons (1212 deaths). In Report 2, data for Selection II, numbering about 70,000 persons, through September 1959, were added, and the whole body of data was analyzed jointly (7303 deaths). For the present report, the data have again been increased to 8614 deaths. Mortality data for Selection III (9222 persons) through September 1960 have been included; for two thirds of Selection I the period October 1958 to September 1960 has been added to the observation base, and for one third of Selection II the single year October 1959 to September 1960 has been added.

In addition to the mortality data presented, certain characteristics of the sample under study are described.

#### DESCRIPTION OF THE SAMPLE

##### *Age and Distance*

Table I shows the age composition of the sample for males and females for each city separately and for the two cities combined. Males in the age range 20 to 39 ATB are notably deficient in both city samples, since few of the residents of these cities who were in military service were present in the cities ATB. The sample of persons not present in the cities ATB, like the sample in the distance zone 2500+ meters, has been matched by age and sex to the group under 2000 meters, and hence for all groups the male samples have the same abnormal age distribution.

##### *Foreign Residence*

As might be expected, the survivors and those not present in the cities ATB differ markedly with respect to a history of foreign residence prior to the A-bombing

TABLE I  
 NIH-ABCC LIFE-SPAN STUDY SAMPLE BY CITY, SEX, AGE AT TIME OF BOMB, AND DISTANCE  
 FROM HYPOCENTER

Age	Grand total	Distance (meters)									
		Male					Female				
		Total	<2000	2000-2499	2500+	Not in city	Total	<2000	2000-2499	2500+	Not in city
<i>Hiroshima</i>											
Total	74,352	30,697	8,836	4,773	8,794	8,294	43,655	12,503	6,748	12,474	11,930
0-19	28,203	13,269	3,694	2,216	3,672	3,687	14,934	4,218	2,321	4,197	4,198
20-39	21,213	6,219	1,799	819	1,784	1,817	14,994	4,258	2,199	4,253	4,284
40-59	19,908	9,104	2,701	1,346	2,700	2,357	10,804	3,217	1,710	3,205	2,672
60+	5,028	2,105	642	392	638	433	2,923	810	518	819	776
<i>Nagasaki</i>											
Total	25,037	11,007	3,059	2,053	3,025	2,870	14,030	3,744	3,089	3,717	3,480
0-19	12,509	5,737	1,538	1,268	1,506	1,425	6,772	1,877	1,347	1,853	1,695
20-39	6,359	2,191	661	217	654	659	4,168	1,110	836	1,112	1,110
40-59	5,139	2,664	756	458	759	691	2,475	606	728	602	539
60+	1,030	415	104	110	106	95	615	151	178	150	136
<i>Hiroshima + Nagasaki</i>											
Total	99,389	41,704	11,895	6,826	11,819	11,164	57,685	16,247	9,837	16,191	15,410
0-19	40,712	19,006	5,232	3,484	5,178	5,112	21,706	6,095	3,668	6,050	5,893
20-39	27,572	8,410	2,460	1,036	2,438	2,476	19,162	5,368	3,035	5,365	5,394
40-59	25,047	11,768	3,457	1,804	3,459	3,048	13,279	3,823	2,438	3,807	3,211
60+	6,058	2,520	746	502	744	528	3,538	961	696	969	912

(Fig. 1). The difference, although more marked for males, characterizes females as well and is very great in the age range 20 to 59. Not only were many males not present in the cities ATB in military service, as contrasted with few of the survivors, but also after the war many civilians repatriated from Korea, China, and South East Asia settled in Hiroshima and Nagasaki.

### *Shielding*

The survivors in Hiroshima and Nagasaki differ as to shielding situation, especially at the closer distances. Within 1200 meters of the hypocenter very many Nagasaki survivors were rather heavily shielded (Fig. 2). The differences between

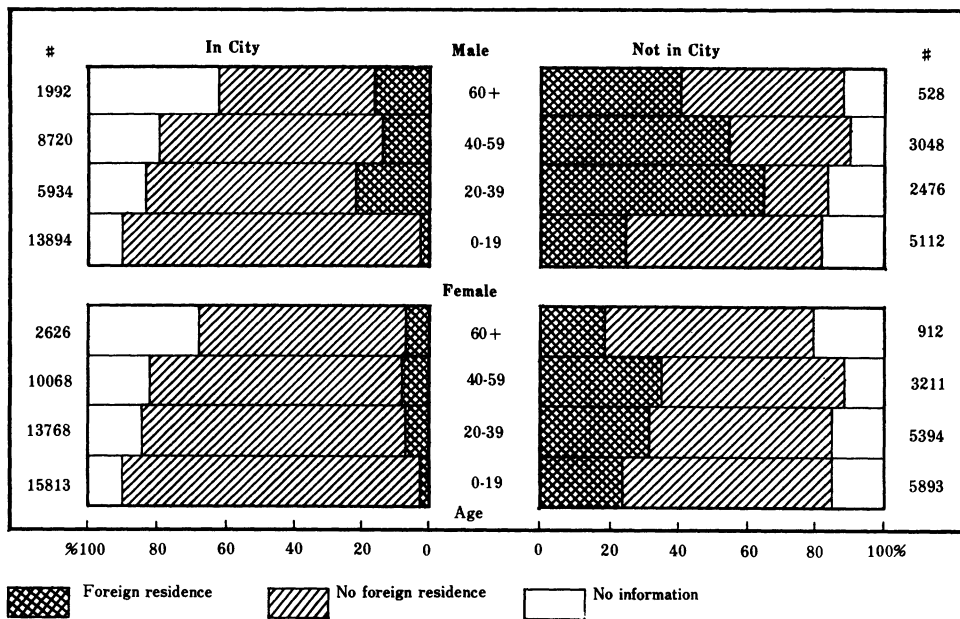


FIG. 1. Per cent with history of foreign residence, by sex and age, for persons in city and not in city ATB

males and females are small within each city, but the intercity differences are of much greater magnitude. The largest part of the difference between the cities results from the fact that air-raid shelters were much more widely used in Nagasaki than in Hiroshima. In Hiroshima, only 63 survivors under 2000 meters were in air-raid shelters, whereas there were 693 in Nagasaki—in a survivor population only half as large as that in Hiroshima.

### Radiation Dose

The relation between the estimated radiation dose and distance is, in each city, rather close (Fig. 3). The specific method of dose calculation used to date has been designated T57 by ORNL. The T57 estimates are asserted to have a probable error of a factor of 2. The uncertainty derives in part from lack of precision in knowledge of the exact location of survivors, based on interview, and in large part from uncertainty as to the actual yields of the weapons—that is, the air-dose curves. Errors in the air-dose curves would not interfere with the utility of the T57 dose estimates as indexes of relative risk among the survivors in a single city but would drastically affect comparisons between Hiroshima and Nagasaki. It is hoped that newer and more reliable dose estimates will be available before long, but for the present the T57 estimates must be employed.

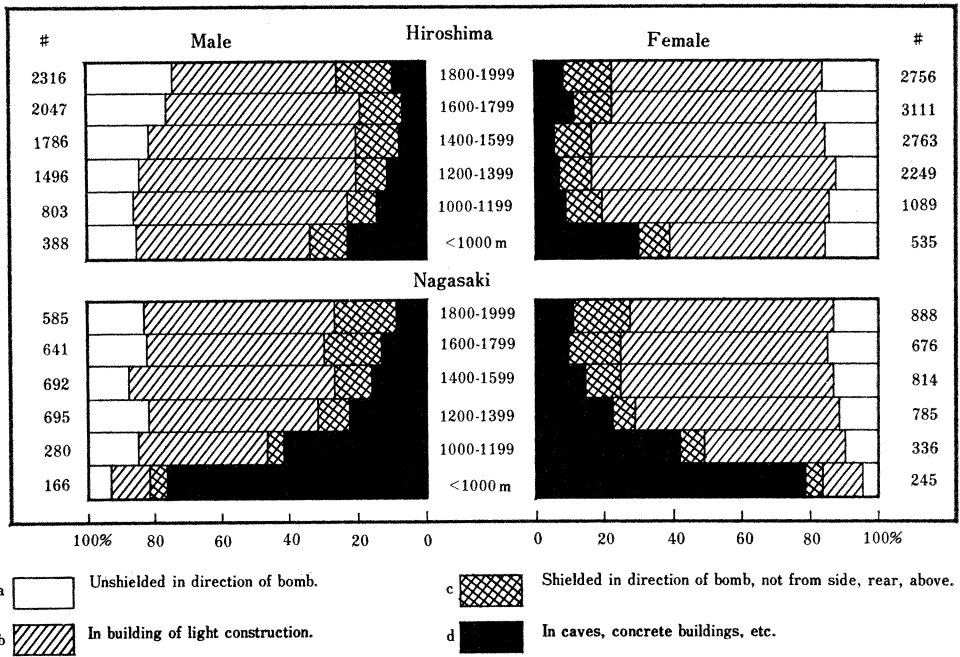


FIG. 2. Relation of shielding category to distance from hypocenter by city and sex

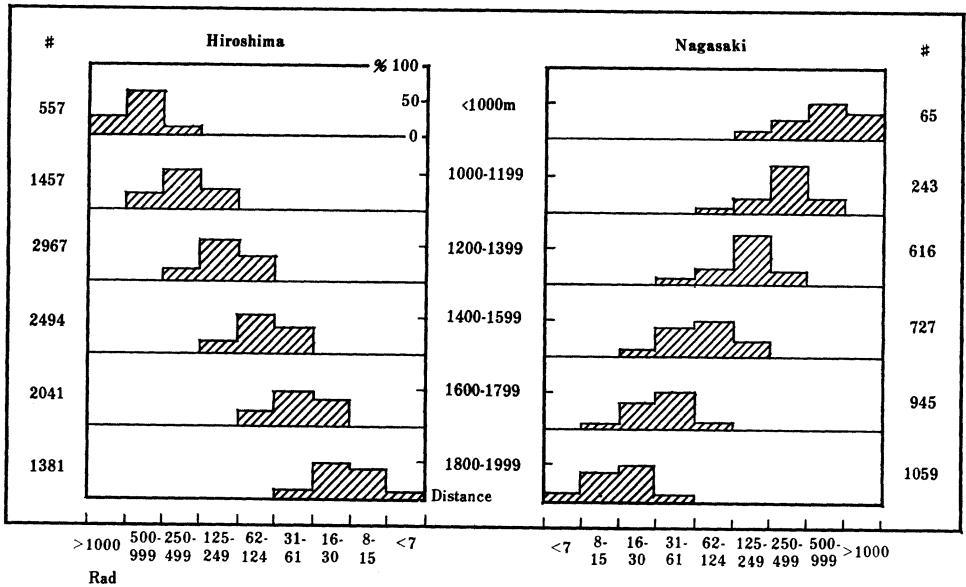


FIG. 3. Relation of T57 dose estimate to distance from hypocenter by city

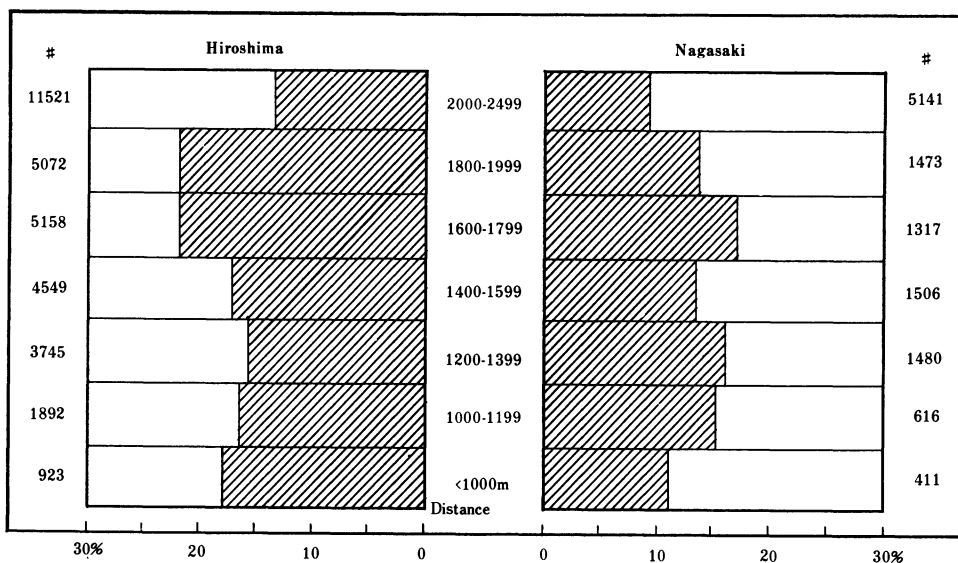


FIG. 4. Per cent with history of burns by distance from hypocenter and city

### Burns

Almost all recorded burns were flash burns, and hence flash and fire burns are not distinguished here. The frequency of burns does not begin to decrease with increasing distance until at least 1800 meters (2000 in Hiroshima), and in both cities it is maximal at intermediate distances. This results from the fact that at the nearest distances shielding was almost a prerequisite to survival.

The difference previously noted between the two cities as to the proportion of survivors in heavy shielding at the closer distances is reflected in Fig. 4 by a much lower frequency of burns in Nagasaki than in Hiroshima, particularly among survivors within 1000 meters.

### Acute Radiation Injury

One or more signs of acute radiation injury (epilation, purpura, oropharyngeal lesions) were reported by 8.8% of the survivors in Hiroshima and 11.8% in Nagasaki. From Fig. 5, it is apparent that, for those within 1000 meters, acute injury was nearly twice as frequent in Hiroshima as in Nagasaki—about 72%, as contrasted with 37%. In the zone 1000 to 1199 meters, acute injury occurred in about 50% in both cities. Thus, for Nagasaki survivors the acute injury rate in the most closely exposed survivors (<1000 meters) not only is half of the rate in Hiroshima survivors at comparable distances, but also is less than the rate in Nagasaki survivors in the ring 1000 to 1199 meters, and, in fact, less than in the ring 1200 to 1399 meters.

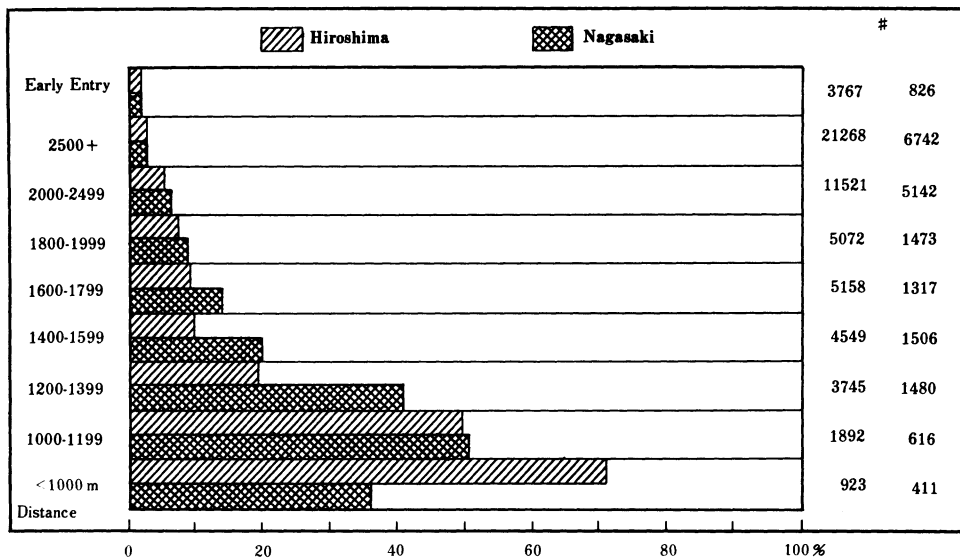


FIG. 5. Relation of history of acute radiation injury to distance from hypocenter by city

This finding is consistent with the fact, noted above, that a very high proportion of Nagasaki survivors at the closer distances were heavily shielded.

At distances of 1400 meters and more, the proportions with acute injury in Nagasaki are larger than in Hiroshima. At these greater distances, only small proportions in either city had very heavy shielding, so this factor may be ignored in the comparison of the cities. These findings are consistent with the physical estimates that, at fixed distances, the air dose of radiation was greater in Nagasaki than in Hiroshima (5).

Although the variation with distance in the proportion with acute injury seems not unreasonable out to, say, 1600 meters, beyond this point the decline is rather slow. The proportion never reaches zero, remaining at about 1% even for the so-called "Early Entry" cases—persons who were not within 10,000 meters of the hypocenter but who entered the cities within a month after the bombings. As remarked by Oughterson and Warren (6), the various signs and symptoms of radiation injury may be caused by factors other than radiation.

The occurrence of acute injury is shown in relation to the T57 dose estimate in Fig. 6. Notable features of the data are the rather small change in the proportion injured as dose changes in the ranges 0 to 249 rads in Hiroshima, and 0 to 124 rads in Nagasaki; the fact that even at the highest estimated dose levels substantial fractions of the survivors in Hiroshima were *not* noted to have signs; and the discrepancies between Hiroshima and Nagasaki in the proportions reported to have

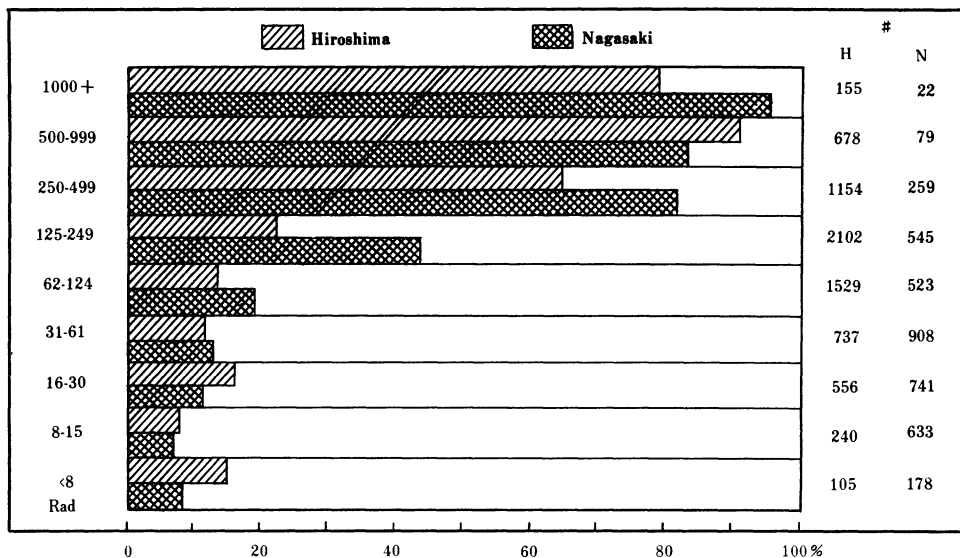


FIG. 6. Relation of history of acute radiation injury to T57 dose estimate by city

signs in the dose ranges 125 to 249 rads and 250 to 499 rads. In the range 125 to 249 rads, the percentages are 22.8 and 43.5 in Hiroshima and Nagasaki, respectively; in the range 250 to 499 rads they are 54.6 and 72.6. In both cases the differences are highly reliable ( $P < 0.001$ ), for the samples are reasonably large. In the two highest dose ranges, however, the intercity differences are not significant. It seems possible that the T57 dose estimates for Hiroshima and Nagasaki are not comparable, and it may be noted that, if the Hiroshima dose estimates are halved, or the Nagasaki estimates doubled, then the corresponding bars of Fig. 6 would fall into better accord. In this connection, Brill *et al.*, in a report (7) on the ABCC leukemia investigations, present data indicating that rads, as estimated by T57, were about twice as potent in Nagasaki as in Hiroshima.

The most plausible explanation of the high, and relatively dose-independent, frequency of acute injury at low dose levels is that the majority of "radiation signs" at these levels were, in fact, caused by other factors than the radiation from the bombs. Interestingly enough the Joint Commission data quoted by Oughterson and Warren (6) are similar in showing that the percentage of survivors with radiation signs did not reach zero even out to a distance of 5 km from the hypocenter.

Analysis of the occurrence of acute radiation injury in relation to sex showed little or no difference for fixed distance from the hypocenter or T57 dose estimate, but there were large and highly significant ( $P < 0.001$ ) differences associated with age at the time of the bombing (ATB). The data are summarized in Fig. 7, where

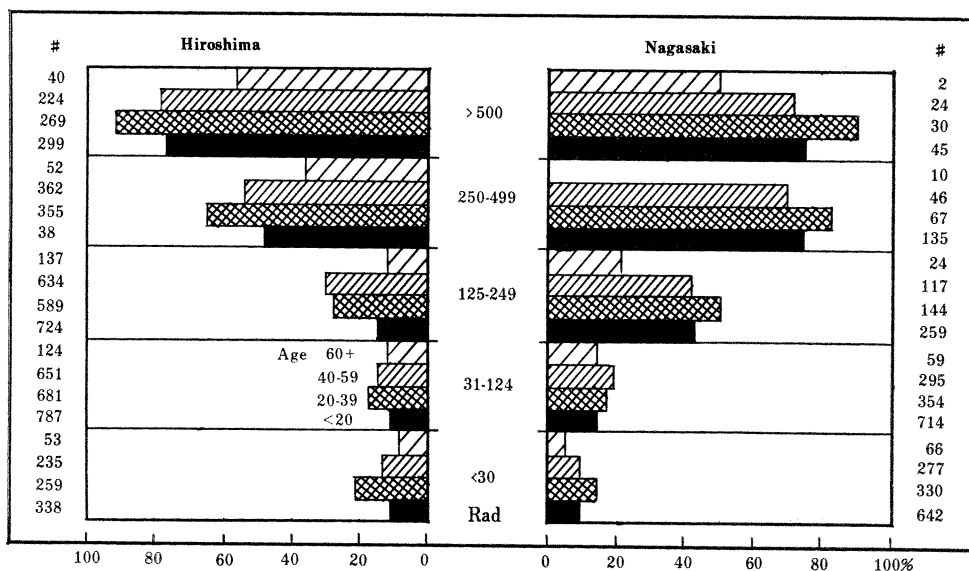


FIG. 7. Relation of history of acute radiation injury to age by T57 dose estimate and city

the survivors have been grouped into four dose classes, although statistical tests were made in relation to the nine dose classes of Fig. 6. In the majority of dose classes, those who were 20 to 39 ATB had the highest prevalence of acute radiation injury, and those aged 60 and over the least. In general, the proportion with injury increases from age group 0 to 19 to age group 20 to 39, then falls off successively in the groups 40 to 59 and 60 and over. At least three explanations come readily to mind, any one or combination of which may account for the observation:

1. There may be age variation in biological sensitivity to radiation.
2. There may be age-related differences in the probability of death after the development of acute injury. Since the JNIIH-ABCC Mortality Sample is made up entirely of survivors to October 1950, excessive mortality prior to that date in very young or old persons who had acute injury would be reflected in the present data as an apparent lowering of the proportion of survivors who reported signs.
3. There may be age-related variation in the probability of eliciting a history of radiation signs on questioning after a lapse of some years.

The results of animal experiments (e.g., ref. 8) make plausible both of the first two possible explanations; no direct evidence can be adduced for the third, but the possibility cannot be ignored. It seems safest, then, to regard the present data primarily as descriptive of that part of the Mortality Sample characterized by a history

of acute radiation injury, rather than contributory to knowledge regarding age, sex, and dose variation in the occurrence of such injury.

#### RESULTS AND DISCUSSION

During the period under study, 8614 deaths were observed, 8.7% of the sample of 99,393 persons. Table II shows the distribution of these deaths by underlying cause as given on the death certificate. Tuberculosis was responsible for a larger proportion of the deaths in Nagasaki than in Hiroshima for both sexes (15% versus 8% for males, and 12% versus 7% for females), reflecting both the younger average age of the Nagasaki sample and the fact that Kyushu generally and Nagasaki Prefecture in particular are well known to have unusually high death rates from tuberculosis. Thus, in 1958, the crude mortality rate for tuberculosis in Nagasaki Prefecture was more than 50% greater than the average for all Japan and was in fact, by a considerable margin, the greatest among the forty-six prefectures (9).

The most frequent cause of death was vascular lesions affecting the central nervous system, varying from 16% to 21% in the four sex-by-city groups. Malignant neoplasms (including leukemia) accounted for about 17% of the Hiroshima mortality, in both sexes alike; in Nagasaki the figure was 13%. Arteriosclerotic and degenerative heart disease accounted for 4 to 5% of mortality in all groups. Finally, a fairly large number of deaths was assigned to the class of ill-defined and unknown causes which are lumped into rubric B45 of the Abbreviated List of the International Statistical Classification: 9.8% and 7.5% in males in Hiroshima and Nagasaki, respectively, and 14.5% and 12.7% in females in the two cities. The much greater frequency of death attributed to cerebrovascular disease than to arteriosclerotic heart disease is, of course, typical of Japan.

Mortality rates are shown in Table III for each city for males and females separately. It is of some interest that the Nagasaki rates exceed those in Hiroshima, for both sexes, at almost all ages. Especially for females, the age-standardized average mortality rates in Nagasaki far exceed those in Hiroshima.

#### MORTALITY IN RELATION TO DISTANCE FROM THE HYPOCENTER

Table IV shows the number of person-years of observation and the mean age for each of the distance classes 0 to 1399 meters, 1400 to 1999 meters, 2000 to 2499 meters, 2500 meters and over, and those not in the cities at the time of the bomb. The reasons for selecting the particular distances 1400, 2000, and 2500 meters as dividing points vary. In the original sample selection the group beyond 2500 meters was age- and sex-matched to those at less than 2000 meters, as was the nonexposed group. The additional cut at 1400 meters is made because current estimates of radiation dose, the data on prevalence of acute symptoms, and the leukemia mortality rates alike indicate that those within 1400 meters were subject to rather sub-

TABLE II

NUMBER OF DEATHS, OCTOBER 1950-SEPTEMBER 1960, BY UNDERLYING CAUSE, CITY, AND SEX

ISC	Underlying cause	Male		Female	
		Hiroshima	Nagasaki	Hiroshima	Nagasaki
Total		3,476	1,042	3,119	977
001-019	Tuberculosis, all forms	285	160	229	117
020-138	All other diseases classified as infective and parasitic	54	16	49	16
140-205	Malignant neoplasms	611	134	537	127
210-239	Benign and unspecified neoplasms	16	10	36	8
260	Diabetes mellitus	28	3	23	2
290-293	Anemias	11	5	9	2
330-334	Vascular lesions affecting central nervous system	659	185	653	153
410-416	Chronic rheumatic heart disease	19	4	19	12
420-422	Arteriosclerotic and degenerative heart disease	195	41	162	56
430-434	Other disease of heart	82	15	67	15
440-447	Hypertension, with or without mention of heart	48	15	60	32
480-483	Influenza	10	2	4	2
490-493	Pneumonia	93	35	70	27
500-502	Bronchitis	37	8	30	15
540, 541	Ulcer of stomach and duodenum	94	36	46	13
560, 561, 570	Intestinal obstruction and hernia	22	8	23	4
543, 571, 572	Gastritis, duodenitis, enteritis, and colitis	63	20	84	21
581	Cirrhosis of liver	56	19	38	19
590-594	Nephritis and nephrosis	88	24	106	32
610	Hyperplasia of prostate	4	0	0	0
640-689	Deliveries and complications of pregnancy, childbirth, and the puerperium	0	0	21	14
750-759	Congenital malformations	5	0	5	0
780-795	Senility without mention of psychosis, ill-defined and unknown causes	342	78	452	124
	All other diseases	328	139	259	117
E800-E962	Accidents	206	50	69	20
E963, E970-E979	Suicide and self-inflicted injury	108	31	65	27
E964, E965, E980-E999	Homicide and operations of war	12	4	3	2

TABLE III  
 NUMBER OF DEATHS AND DEATH RATES, OCTOBER 1950-SEPTEMBER 1960, BY TEN-YEAR AGE GROUPS, CITY, AND SEX

Age	City	Male			Female		
		Person-years	Deaths		Person-years	Deaths	
			Number	Rate/10 <sup>A</sup>		Number	Rate/10 <sup>A</sup>
All ages	Hiroshima	262,635	3,476	123 <sup>a</sup>	375,216	3,119	77 <sup>a</sup>
	Nagasaki	98,727	1,042	131 <sup>a</sup>	127,182	977	100 <sup>a</sup>
0-9	Hiroshima	9,717	20	21	10,164	9	9
	Nagasaki	3,664	9	25	3,624	1	3
10-19	Hiroshima	54,960	65	12	54,117	31	6
	Nagasaki	22,224	31	14	24,220	45	19
20-29	Hiroshima	53,141	185	35	70,808	148	21
	Nagasaki	26,481	100	38	36,042	81	22
30-39	Hiroshima	24,597	106	43	65,888	171	26
	Nagasaki	10,136	47	46	21,993	63	29
40-49	Hiroshima	34,618	255	74	65,142	272	42
	Nagasaki	11,608	90	78	16,212	97	60
50-59	Hiroshima	43,295	667	154	56,559	501	89
	Nagasaki	13,840	229	165	13,559	140	103
60-69	Hiroshima	29,448	975	331	32,985	645	196
	Nagasaki	8,235	291	353	7,641	205	268
70-79	Hiroshima	11,083	918	828	15,874	860	542
	Nagasaki	2,291	208	908	3,198	227	710
80+	Hiroshima	1,776	285	1605	3,679	482	1310
	Nagasaki	248	37	1492	693	118	1703

<sup>a</sup> Age-standardized to the combined male and female experience in both cities.

stantial doses of radiation: Most had more than 100 rads, although a relatively small proportion may have had lower doses as a result of shielding. In the zone 1400 to 2000 meters, however, many survivors apparently had very low doses, and therefore to treat all survivors below 2000 meters in a single group is to run the risk that radiation effects observable in those who had high doses will become unobservable because of the diluting effect of a large group of survivors among whom effects, if present, are at a very low level. In any case, as can be seen below, the distance 1400 meters is very suitable as a dividing point for the detection of radiation leukomogenesis, and it seems plausible that it would be equally effective for other conditions.

The Hiroshima males, on the average, are about 2.5 years older than Nagasaki males; for females the difference, in the same direction, is 5.0 years. In Hiroshima, average age varies but little among the distance groups, and even by sex. In Nagasaki, mean age is reasonably homogeneous by distance group and by sex except for the zone 2000 to 2499 meters (where the sample was not age-matched), for which the males are younger and the females older than the average.

TABLE IV

PERSON-YEARS AT RISK AND AVERAGE AGE AT OBSERVATION BY DISTANCE FROM HYPOCENTER, CITY, AND SEX

City	Sex	Distance (meters)					Not in city
		Total	<1400	1400-1999	2000-2499	2500+	
<i>Person-years at risk</i>							
Hiroshima	Male	262,635	23,527	54,699	42,185	77,463	64,761
	Female	375,216	34,731	78,123	60,585	112,744	89,033
Nagasaki	Male	98,727	10,224	17,172	18,237	27,044	26,050
	Female	127,182	12,419	21,490	27,811	33,663	31,799
<i>Average age</i>							
Hiroshima	Male	37.7	39.9	37.7	36.7	38.3	36.8
	Female	39.0	38.7	39.3	38.9	39.2	38.5
Nagasaki	Male	34.2	34.2	35.2	31.4	35.0	34.8
	Female	34.0	32.0	34.2	36.0	33.4	33.4

The survivors who were within 1400 meters of the hypocenter evidently had high rates of mortality for all causes as well as for certain particular causes of death, notably leukemia (Table V). It is equally apparent that the nonexposed component of the sample (those not in the cities at the time of the bomb) had quite favorable mortality experience.

Results of statistical tests are shown in Table V by asterisks on those death ratios that differ significantly from 100. The tests reported are chi-square tests on a single degree of freedom which compared the result in a specific distance class with all other distance classes combined, for the same city-sex group. Exact tests were made where expected values were less than four cases. The tests were two-tailed. In scanning the four sex-city groups for a given distance class, it may be recalled that:

1. The probability that, by chance, all four groups will simultaneously have ratios larger or smaller than 100 is one-eighth; so the fact that all groups are in the same direction is not, of itself, demonstrative of high or low mortality in that distance class.

2. The probability that, by chance, a single test (or more) among four will be "significant" at the 5% level is 0.1855. However, the probability that all four groups will depart from 100 in the same direction *and* one or more be significant at the 5% level is 0.0232.

3. The probability that, by chance, one test among four will be significant at the 1% level is 0.039; at the 0.1% level, 0.004. The probability that two or more will be significant at the 5% level is 0.014.

TABLE V  
AGE-STANDARDIZED DEATH RATIOS\* IN RELATION TO DISTANCE FROM HYOCENTER, BY CITY AND SEX

City	Sex	Deaths				Distance (meters)				Deaths	Distance (meters)				Not in city
		<1400	1400-1999	2000-2499	2500+	<1400	1400-1999	2000-2499	2500+		<1400	1400-1999	2000-2499	2500+	
<i>All causes</i>															
Hiroshima	Male	3,476	111.5*	95.4	103.7	104.9	90.2**	326	90.6	80.5	93.7	134.0**	83.0		
	Female	3,119	118.7**	99.0	104.2	100.8	90.5**	136	114.8	112.1	103.9	87.7	96.6		
Nagasaki	Male	1,042	106.1	90.0	113.6*	102.1	93.1	85	77.1	53.8*	126.9	118.6	102.2		
	Female	977	117.1	98.2	97.2	106.2	92.8	49	105.0	60.5	108.2	131.9	83.3		
<i>Trauma (E800-E999)</i>															
<i>Tuberculosis (001-019)</i>															
Hiroshima	Male	3,143	113.9*	96.8	104.9	102.0	90.9**	285	155.5**	117.0	99.4	87.6	79.1*		
	Female	2,973	119.4**	98.4	104.3	101.0	90.5**	229	92.7	115.4	139.3*	105.5	56.7**		
Nagasaki	Male	933	111.0	95.2	113.2	99.3	90.9	160	112.1	101.3	121.3	102.1	79.1		
	Female	915	116.9	100.3	97.1	105.8	91.9	117	74.1	105.7	107.4	91.9	107.5		
<i>Other infective and parasitic diseases (020-198)</i>															
<i>Leukemia (204)</i>															
Hiroshima	Male	54	59.5	104.5	125.0	110.8	80.5	31	549.8**	77.3	20.3	75.5	26.6*		
	Female	49	209.8*	87.0	61.6	115.1	78.5	25	649.4**	37.7	49.0	78.9	0 **		
Nagasaki	Male	16	62.5	0	119.0	176.2	91.5	11	720.7**	54.1	44.8	34.0	0 *		
	Female	16	166.7	37.7	64.4	184.7	81.3	4	465.1*	0	0	95.2	103.1		
<i>Malignant neoplasms except leukemia (140-203, 206)</i>															
<i>Benign and unspecified neoplasms (210-239)</i>															
Hiroshima	Male	580	107.5	95.7	122.8*	97.0	87.8	16	127.4	146.2	38.8	122.0	56.7		
	Female	512	153.5**	94.2	97.4	97.7	89.9	36	65.8	118.0	149.0	83.1	83.4		
Nagasaki	Male	123	105.0	93.2	120.1	88.2	101.7	10	0	162.2	202.0	111.5	0		
	Female	123	120.7	80.3	136.7*	79.4	86.6	8	142.9	74.6	50.8	196.1	51.5		

		<i>All anemia (290-293)</i>				<i>Vascular lesions of central nervous system (330-334)</i>							
Hiroshima	Male	11	99.0	125.5	109.9	120.8	40.0	659	105.3	92.6	98.0	104.3	100.6
	Female	9	241.0	155.4	135.1	73.0	0	653	106.2	95.0	102.4	96.8	104.6
Nagasaki	Male	5	454.5	0	98.0	0	152.7	185	115.8	78.3	125.4	97.4	95.1
	Female	2	909.1*	0	0	0	0	153	89.2	90.8	102.5	117.8	88.2
<i>Diseases of heart (410-434)</i>													
Hiroshima	Male	296	105.6	101.1	107.0	102.1	88.3	48	114.4	85.6	61.8	129.6	96.2
	Female	248	113.6	91.3	94.2	105.1	101.0	60	90.7	94.9	102.8	107.5	96.4
Nagasaki	Male	60	99.8	138.6	61.2	133.7	64.2	15	103.1	97.4	116.6	75.9	112.7
	Female	83	96.9	146.0	85.2	87.5	97.1	32	105.8	122.2	86.7	130.5	66.9
<i>Influenza, pneumonia, bronchitis (480-502)</i>													
Hiroshima	Male	140	145.3	109.9	104.0	84.4	90.2	184	117.5	102.8	103.8	117.9	62.1**
	Female	104	111.9	86.7	143.6*	87.7	91.5	156	96.5	94.1	108.2	124.8*	69.6*
Nagasaki	Male	45	108.1	114.8	114.3	81.7	94.8	66	53.2	101.5	126.2	115.7	77.8
	Female	44	131.1	78.2	74.1	148.4	86.9	40	188.0	99.7	89.2	81.9	107.1
<i>Disease of liver (580-583)</i>													
Hiroshima	Male	79	93.3	76.3	138.0	78.9	126.9	88	73.8	83.5	73.8	119.6	121.0
	Female	54	63.2	139.5	112.2	97.9	71.7	106	125.3	129.5	99.9	107.2	55.8*
Nagasaki	Male	35	158.7	60.6	94.5	82.7	130.3	24	50.5	83.0	86.2	90.5	152.3
	Female	30	184.3	96.3	96.9	109.0	71.1	32	85.5	90.3	69.6	128.0	117.2
<i>Ulcer of stomach and duodenum and certain other diseases of digestive system (540, 541, 543, 550-572)</i>													
<i>Nephritis and nephrosis (590-594)</i>													

\* Age-standardized death ratio is one hundred times the quotient of observed deaths divided by those expected. Expected deaths for distance classes are calculated by applying ten-year age-specific death rates for the specified sex and city to the age distribution of person-years within the distance class.

The death ratio differs significantly from 100 at the (\* = 5%, \*\* = 1%) level.

Therefore, if but a single asterisk appears in a column, heterogeneity is not demonstrated unless all four ratios in that column depart from 100 in the same direction. However, if two or more asterisks appear in a column, in any combination, there is "significant" evidence of heterogeneity, whatever the directions be. Of course, interpretation of the meaning of the heterogeneity will depend on whether the departures are in the same direction or not.

#### *All Causes*

Beyond the evident high mortality in those within 1400 meters, and low mortality among those nonexposed, there is a suggestion of relatively favorable experience among those from 1400 to 1999 meters and less favorable beyond 2000 meters.

In the zone 1400 to 1999 meters, the mortality ratios are less than 100 for each sex in each city, and the observation base in this zone is about twice as large as that in the within 1400-meter zone. In consequence, if the two zones be merged, the evidence of increased mortality rates among survivors close to the hypocenter is diluted out. In fact, the mortality ratios become, for Hiroshima males and females, respectively, 100.2 and 104.5, and in Nagasaki, 95.1 and 103.8. None of these differs significantly from 100.

No explanation of the low mortality ratios in the zone 1400 to 1999 meters can be offered, and the observation may indeed merely be fortuitous, since no statistical significance attaches to any of the differences from 100.

#### *Trauma (E800-E999)*

The only remarkable observation with regard to trauma is the very high mortality ratio among Hiroshima males in the zone beyond 2500 meters from the hypocenter, where 130 deaths were observed, whereas but 97.0 would be expected at rates for Hiroshima males generally. Observed deaths exceeded expectation in every 10-year age class from age 10 to age 69, although the greatest discrepancy was at ages 20 to 29, where 36 deaths were observed, 21.9 expected.

#### *All Natural Causes (001-795)*

The patterns of mortality ratios in relation to distance are similar for natural causes to those for all causes, but are somewhat more consistent by city and sex. Those within 1400 meters have more observed than expected deaths, those not in the cities ATB, fewer. Within any distance class, the ratios for the four sex-city groups are rather close.

From Table VI, where observed and expected deaths from natural causes are shown by age, it is apparent that the ratio of observed to expected mortality in those within 1400 meters, although elevated for most ages, is maximal at ages 30 to 39. As ages increases, the ratio slowly declines, toward 100 at age 70. Below age 30, there is a modest elevation at ages 20 to 29, none at 10 to 19, but a high ratio at

TABLE VI

OBSERVED AND EXPECTED DEATHS FROM ALL NATURAL CAUSES (001-795) BY DISTANCE FROM HYPOCENTER, AGE, CITY, AND SEX

Age at observation		Distance (meters)											
		<1400				1400+				Not in city			
		Male		Female		Male		Female		Male		Female	
		Hiroshima	Nagasaki	Hiroshima	Nagasaki	Hiroshima	Nagasaki	Hiroshima	Nagasaki	Hiroshima	Nagasaki	Hiroshima	Nagasaki
Total	Observed	333	89	287	77	2,183	625	2,046	639	627	219	640	199
	Expected	292.3	80.2	240.4	65.9	2,160.6	611.9	2,025.3	632.5	690.0	240.9	707.3	216.5
0-9	Observed	5	2	3	0	6	3	2	0	1	1	0	0
	Expected	1.0	0.5	0.4	0.0	8.7	4.1	3.7	0.0	2.3	1.5	0.9	0.0
10-19	Observed	2	5	4	3	22	13	18	34	8	3	4	3
	Expected	2.3	1.6	2.1	3.1	21.9	14.3	17.4	26.8	7.8	5.1	6.5	10.1
20-29	Observed	11	9	12	10	65	48	88	33	32	9	17	18
	Expected	8.3	8.1	12.2	8.3	70.5	41.2	76.5	37.3	29.2	16.6	28.2	15.3
30-39	Observed	16	5	23	9	52	31	109	34	12	3	22	13
	Expected	8.0	5.3	14.8	6.0	48.7	21.9	99.0	34.6	23.2	11.8	40.2	15.4
40-49	Observed	31	14	32	6	142	41	185	63	39	25	46	23
	Expected	21.8	9.7	23.8	6.8	134.2	46.2	178.2	62.1	55.9	24.1	61.0	23.1
50-59	Observed	74	13	43	9	405	139	350	96	120	57	78	27
	Expected	63.2	21.5	46.1	9.6	398.6	131.6	320.4	92.8	137.2	56.0	104.5	29.5
60-69	Observed	102	27	66	19	656	184	430	141	171	64	130	39
	Expected	95.5	22.1	57.3	15.1	633.4	180.3	442.0	140.2	200.1	72.7	126.7	43.7
70-79	Observed	72	12	75	19	649	140	550	155	172	48	213	47
	Expected	73.5	10.0	61.0	13.3	646.6	139.9	567.5	156.3	172.9	50.0	209.5	51.4
80+	Observed	20	2	29	2	186	26	314	83	72	9	130	29
	Expected	18.6	1.5	22.6	3.6	198.0	32.4	320.6	82.4	61.4	3.1	129.7	28.0

ages 0 to 9. This last age group, in fact, covers only ages 5 to 9 and consists wholly of persons less than age 5 ATB, since those aged 0 to 4 in August 1945 were 5 to 9 at the beginning date of observation for this study, October 1950. Among the nonexposed, the ratios of observed to expected deaths, in general, are related to age inversely to the <1400-meter group. The ratio is minimal at ages 30 to 39, then rises slowly to ages 70 to 79. Below age 30, the ratio differs little from 100.

Since there is no reason to suspect *radiation* effects among survivors who were beyond, say, 2500 meters or even 2000 meters from the hypocenter, the fact that mortality ratios in the nonexposed are lower than those in survivors in every distance zone argues for some basic difference between survivors and the nonexposed immigrants. Such a basic difference might be social-economic in nature, or, alternatively, it is possible that other effects of the bomb than radiation are involved: blast,

burns, social disorganization, and economic disruption. It is conceivable that such a "disaster effect" manifests itself in a persistent elevation of mortality rates in survivors almost independently of distance. If such a generalized elevation exists, a further elevation attributable specifically to radiation might or might not be superimposed. Such a radiation effect could be detected, then, only by comparisons of survivors who received fairly large amounts of radiation with others whose estimated radiation dose was small.

#### *Tuberculosis (001-019)*

The patterns of tuberculosis mortality (Table V) are inconsistent in relation to distance class, except for the generally (and significantly) low rates in the nonexposed. Among Hiroshima males within 1400 meters, the ratio is significantly elevated (43 deaths observed versus 27.7 expected), and excess mortality is found in every age group from 30 to 79. Among the nonexposed, the patterns by age are dissimilar in precise detail in the four sex-city groups: The significant deficit for Hiroshima males derives almost entirely from ages 30 to 49 (8 deaths observed, 24.3 expected); but in Nagasaki males, where the over-all ratio is identical with that in Hiroshima males (but not significant because of smaller numbers), the deficit is at ages 20 to 39 (6 observed, 14.9 expected). For Hiroshima females, where the deficit is highly significant, it is found by age in the ranges 20 to 29 (5 versus 11.8) and 40 to 59 (7 versus 19.1) but *not* at 30 to 39 (11 versus 13.6). No doubt if hundreds of comparisons are made, as is true here, it would be surprising if no slightly queer results were to be found. In any case, the general conclusion follows that deficits in deaths attributed to tuberculosis among the nonexposed are for the most part confined to the age range 20 to 49.

#### *Other Disease Classed as Infective or Parasitic (020-138)*

A small proportion of the deaths (only 1.6%) were attributed to infectious or parasitic disease, other than tuberculosis. The patterns by distance do not seem remarkable. Only a single significant difference was found, among Hiroshima female survivors within 1400 meters, where 9 deaths were observed, whereas but 4.3 would be expected. The excess was distributed over the entire age range.

#### *Leukemia (204)*

Comment on the leukemia data is hardly required. The well-known large excess of leukemia mortality among survivors within 1400 meters is clearly to be seen.

#### *Malignant Neoplasms Other Than Leukemia (140-203, 205)*

Mortality ratios are significantly elevated in survivors within 1400 meters, but the pattern is not simple. Although the ratios exceed 100 for every sex-city group, only for Hiroshima females is the elevation significant—indeed, highly significant.

For Hiroshima females, the ratio in the zone 2000 to 2499 meters is less than 100, but for every other group the ratio is elevated in this zone, significantly so for Hiroshima males and for Nagasaki females. Significant differences are not found in other distance classes.

For Hiroshima females within 1400 meters, excesses of observed over expected deaths are found throughout the age range. Sixty-nine deaths were observed in total versus 45.0 expected, and for the five age decades from 30 to 79 the observed and expected values are: 30 to 39, 4 versus 2.1; 40 to 49, 12 versus 7.7; 50 to 59, 21 versus 13.7; 60 to 69, 18 versus 12.4; 70 to 79, 10 versus 7.1. Similarly, for Nagasaki females in the zone 2000 to 2499 meters the number of deaths observed exceeds the number expected in every decade age group, beginning at age 30. For Hiroshima males in that distance zone, however, the age pattern is different: Most of the excess mortality is found at ages 60 to 79, where 80 deaths were observed, only 63.4 expected.

Among the nonexposed, age patterns are inconsistent among the sex-city groups:

	<i>Hiroshima</i>		<i>Nagasaki</i>	
	<i>Male</i>	<i>Female</i>	<i>Male</i>	<i>Female</i>
Age <60				
Observed	47	46	16	20
Expected	48.9	58.7	12.3	15.3
Age 60+				
Observed	64	59	17	5
Expected	77.5	58.1	20.1	13.6

For all groups except Hiroshima females the pattern is similar: no deficit below age 60, but fewer deaths than expected at ages 60 and over. Among Hiroshima females, however, the pattern is reversed.

It must be remembered that, not only is the nonexposed group selected by the fact of immigration, which alone may have large effects on mortality rates, but also there may be variation by sex, city, age, and social class in the accuracy with which underlying cause is stated on the death certificate. Either of these causes may explain the peculiarities of the data.

#### *Anemias (290-293)*

According to the formal pattern established for this analysis, there is no significant evidence of heterogeneity by distance for deaths ascribed to anemia (in the zone under 1400 meters, there is but a single asterisk, and the departures of the ratios from 100 are not all in the same direction). A previous study (1), however, has indicated that, in both cities, some deaths probably due to leukemia have been ascribed to aplastic anemia on death certificates.

TABLE VII  
OBSERVED AND EXPECTED DEATHS FROM ALL CAUSES AND MALIGNANT NEOPLASMS EXCEPT  
LEUKEMIA AGE-STANDARDIZED DEATH RATIOS BY DISTANCE FROM HYPOCENTER AND  
SEX, HIROSHIMA PLUS NAGASAKI

Distance (meters)	Male			Female		
	Deaths		Ratio	Deaths		Ratio
	Observed	Expected		Observed	Expected	
	<i>All causes</i>					
Total	3,571	3,477.0	102.7	3,210	3,122.4	102.8
<1000	73	56.3	129.7*	55	39.8	138.2
1000-1199	142	112.1	126.7**	102	80.5	126.7*
1200-1399	242	245.8	98.5	228	204.9	111.3
1400-1599	281	293.0	95.9	256	270.8	94.5
1600-1799	309	338.4	91.3	283	275.0	102.9
1800-1999	304	317.3	95.8	280	283.0	98.9
2000-2499	820	772.1	106.2	810	795.0	101.9
2500+	1,400	1,342.1	104.3	1,196	1,173.4	101.9
	<i>Malignant neoplasms except leukemia</i>					
Total	559	544.2	102.7	505	489.3	103.2
<1000	7	9.0	77.8	10	6.5	153.8
1000-1199	24	18.4	130.4	24	13.9	172.7**
1200-1399	41	39.8	103.0	46	33.7	136.5*
1400-1599	36	46.8	76.9	36	43.7	82.4
1600-1799	53	53.2	99.6	59	44.6	132.3*
1800-1999	52	48.0	108.3	25	42.3	59.1**
2000-2499	144	117.8	122.2**	129	119.0	108.4
2500+	202	211.3	95.6	176	185.8	94.7

The death ratio differs significantly from 100 at (\* = 5%, \*\* = 1%) level.

The mortality ratios for all causes, and for certain malignant neoplasms, for the two cities combined, are shown in greater detail by distance in Tables VII and VIII. The survivors, both males and females, who were less than 1200 meters from the hypocenter have significantly elevated mortality ratios with respect to all causes (Table VII). This is quite definite, but the elevation is not present beyond 1200 meters. It will be recalled from Fig. 3 that persons exposed within 1200 meters for whom dose estimates could be made, almost without exception, are estimated to have received more than 125 rads, and in fact, for the majority, more than 250 rads.

The mortality ratios for deaths from all causes are affected by the inclusion of deaths from leukemia, of which there are in both cities 30 in survivors within 1200 meters. For survivors within 1000 meters, leukemia accounted for 15 deaths out of 128, or 11.7%. Since the leukemia rate is well known to be elevated in the heavily irradiated, the question arises whether the high mortality ratios of the most closely

TABLE VIII  
OBSERVED AND EXPECTED DEATHS FROM MALIGNANT NEOPLASMS OF DIGESTIVE ORGANS,  
PERITONEUM, AND UTERUS AND AGE-STANDARDIZED DEATH RATIOS BY DISTANCE  
FROM HYPOCENTER AND SEX, HIROSHIMA AND NAGASAKI

Distance (meters)	Male			Female		
	Deaths		Ratio	Deaths		Ratio
	Observed	Expected		Observed	Expected	
<i>Digestive organs and peritoneum</i>						
Total	425	408.5	104.0	268	266.2	100.7
<1000	4	6.8	58.8	1	3.3	30.3
1000-1199	19	13.9	136.7	12	7.4	162.2
1200-1399	30	30.1	99.7	23	18.4	125.0
1400-1599	24	35.2	68.2	21	23.9	87.9
1600-1799	43	39.8	108.0	39	24.4	159.8**
1800-1999	40	35.9	111.4	12	23.1	51.9*
2000-2499	112	87.9	127.4**	60	64.4	93.2
2500+	153	158.9	96.3	100	101.3	98.7
<i>Uterus</i>						
Total				114	111.7	102.1
<1000				5	1.6	312.5*
1000-1199				4	3.3	121.2
1200-1399				13	7.8	166.7
1400-1599				8	10.0	80.0
1600-1799				6	10.2	58.8
1800-1999				8	9.5	84.2
2000-2499				32	26.8	119.4
2500+				38	42.5	89.4
<i>Other than leukemia, digestive organs, and uterus</i>						
Total	134	135.6	98.8	123	111.2	110.6
<1000	3	2.2	136.4	4	1.5	266.7
1000-1199	5	4.4	113.6	8	3.2	250.0*
1200-1399	11	9.7	113.4	10	7.6	131.6
1400-1599	12	11.6	103.4	7	9.8	71.4
1600-1799	10	13.3	75.2	14	10.0	140.0
1800-1999	12	12.1	99.2	5	9.5	52.6
2000-2499	32	29.9	107.0	37	27.7	133.6
2500+	49	52.4	93.5	38	41.9	90.7

The death ratio differs significantly from 100 at (\* = 5%, \*\* = 1%) level.

exposed survivors, seen in Table VII, can be explained entirely on the basis of leukemia. If the ratios are adjusted to deaths from all causes except leukemia, they become, for males and females, respectively: within 1000 meters, 110.9 and 123.6; 1000 to 1199 meters, 115.8 and 114.7. Although not one of these ratios exceeds 100

significantly, a combined test (sum of signed square roots of chi-square) gives a normal deviate of 2.62, corresponding to a two-tail probability less than 0.01. Therefore, the excessive mortality in the zone within 1200 meters is not wholly attributable to leukemia.

The elevation of the mortality ratio for all causes within 1200 meters of the hypocenter is found both in Hiroshima and in Nagasaki: For males and females combined, the data are:

	<i>Deaths &lt;1200 meters from hypocenter</i>		
	<i>Observed</i>	<i>Expected</i>	<i>Ratio</i>
Hiroshima	276	224.6	122.9***
Nagasaki	96	64.2	149.5***

Thus, not only is the elevation roughly parallel in the two cities, but it is very highly significant in each ( $P < 0.001$ ).

The mortality ratios for malignant neoplasms exclusive of leukemia vary irregularly with distance from the hypocenter, but, in general, are high for those within 1400 meters. However, significantly low ratios are observed for females at 1800 to 1999 meters, whereas significantly elevated ratios are seen for males at 2000 to 2499 meters and for females at 1600 to 1799 meters. Although late radiation effects might explain the elevations within 1400 meters, the variation at greater distances probably reflects the interplay of complicated socioeconomic factors in the two cities. These may also affect the ratios within 1400 meters, so that it is far from sure that the data are indicative of radiation effects.

The ratios for deaths from malignant neoplasms of the digestive organs and peritoneum are elevated, but not significantly, for both sexes in the ring 1000 to 1199 meters (Table VIII). Again, beyond 1400 meters rather irregular patterns are seen that are inconsistent by sex.

Malignancies of the uterus are not numerous, but they occur more frequently in the survivors closer than 1400 meters. If the three closest distance zones are combined, the observed number of deaths—22—differs significantly at the 1% level from the expected number of 12.65. The standardized death ratio is 173.9.

For all other malignancies, death ratios in both male and female closely exposed survivors are elevated, but not significantly for males. For females, although only the detailed comparison in the zone 1000 to 1199 meters is significant, combined tests of the two closest areas (all under 1200 meters) or three closest areas (all under 1400 meters) reveal highly significant elevations ( $P < 0.01$ ).

#### *Mortality in Relation to Calendar Time*

Table IX shows the observed and expected number of deaths from all causes and their ratio by biennium. Expected numbers were calculated on the basis of the whole experience, including that of the nonexposed.

TABLE IX

OBSERVED AND EXPECTED DEATHS FROM ALL CAUSES AND STANDARDIZED DEATH RATIOS BY DISTANCE FROM HYPOCENTER, BIENNIUM, AND SEX, HIROSHIMA PLUS NAGASAKI

Time period	Male			Female		
	Deaths		Ratio	Deaths		Ratio
	Observed	Expected		Observed	Expected	
<i>&lt; 1400 meters</i>						
1951-52	97	78.0	124.4*	97	60.8	159.5***
1953-54	103	84.3	122.2*	91	65.5	138.9**
1955-56	95	89.9	105.7	75	69.8	107.4
1957-58	98	94.8	103.4	69	74.0	93.2
1959-60	64	67.3	95.1	53	55.1	96.2
<i>1400-1999 meters</i>						
1951-52	159	181.8	87.5	152	154.3	98.5
1953-54	203	195.0	104.1	152	168.0	90.5
1955-56	185	205.4	90.1	174	179.9	96.7
1957-58	216	214.5	100.7	218	191.7	113.7
1959-60	131	152.0	86.2	123	134.8	91.2
<i>2000-2499 meters</i>						
1951-52	148	155.5	95.2	191	150.7	126.7***
1953-54	175	161.9	108.1	157	161.2	97.4
1955-56	194	167.1	116.1	170	172.9	98.3
1957-58	187	168.3	111.1	183	181.6	100.8
1959-60	116	119.3	97.2	109	128.5	84.8
<i>2500+ meters</i>						
1951-52	296	257.2	115.1*	240	216.2	111.0
1953-54	305	273.3	111.6	206	235.1	87.6
1955-56	295	291.0	101.4	265	255.4	103.8
1957-58	321	303.6	105.7	305	271.7	112.3*
1959-60	183	217.0	84.3*	180	195.1	92.3
<i>Not in city</i>						
1951-52	79	95.5	82.7	70	78.3	89.4
1953-54	169	180.9	93.4	155	163.8	94.6
1955-56	237	259.6	91.3	202	247.1	81.7**
1957-58	248	272.7	90.9	242	262.7	92.1
1959-60	214	232.2	92.2	217	221.6	97.9

The death ratio differs significantly from 100 at (\* = 5%, \*\* = 1%, \*\*\* = 0.1%) level.

It is apparent that the excessive mortality previously noticed in persons who were within 1400 meters of the hypocenter is very largely confined to the first four years of observation in the Life-Span Study (October 1950 to September 1954). Within other distance categories, although irregularities are to be seen, there is no sharp decline in relative mortality after 1954 similar to that which occurs for males and

TABLE X  
OBSERVED AND EXPECTED DEATHS FROM MALIGNANT NEOPLASMS EXCEPT LEUKEMIA AND  
STANDARD DEATH RATIOS BY DISTANCE FROM HYPOCENTER, BIENNIUM, AND  
SEX, HIROSHIMA PLUS NAGASAKI

<i>Time period</i>	<i>Male</i>			<i>Female</i>		
	<i>Deaths</i>		<i>Ratio</i>	<i>Deaths</i>		<i>Ratio</i>
	<i>Observed</i>	<i>Expected</i>		<i>Observed</i>	<i>Expected</i>	
<i>&lt; 1400 meters</i>						
1951-52	17	12.6	134.9	13	10.2	127.5
1953-54	14	13.7	102.2	24	10.9	220.2***
1955-56	13	14.5	89.7	16	11.6	137.9
1957-58	13	15.3	85.0	13	12.4	104.8
1959-60	15	11.0	136.4	14	9.0	155.6
<i>1400-1999 meters</i>						
1951-52	19	28.9	65.7	18	24.7	72.9
1953-54	35	30.7	114.0	22	26.5	83.0
1955-56	30	32.0	93.8	20	28.3	70.7
1957-58	26	33.1	78.5	34	29.9	113.7
1959-60	31	23.3	133.0	26	21.1	123.2
<i>2000-2499 meters</i>						
1951-52	21	23.8	88.2	26	23.0	113.0
1953-54	30	25.1	119.5	24	24.3	98.8
1955-56	32	25.6	125.0	30	25.7	116.7
1957-58	36	25.6	140.6*	28	27.0	103.7
1959-60	25	17.7	141.2	21	18.9	111.1
<i>2500+ meters</i>						
1951-52	44	41.2	106.8	26	35.0	74.3
1953-54	40	43.6	91.7	21	37.7	55.7**
1955-56	44	45.8	96.1	54	40.3	134.0*
1957-58	49	47.5	103.2	45	42.6	105.6
1959-60	25	33.2	75.3	30	30.1	99.7
<i>Not in city</i>						
1951-52	8	11.3	70.8	7	10.2	68.6
1953-54	20	26.6	75.2	20	34.2	58.5
1955-56	44	40.8	107.8	35	37.6	93.1
1957-58	38	43.2	88.0	36	39.8	90.5
1959-60	34	37.0	91.9	32	34.1	93.8

The death ratio differs significantly from 100 at (\* = 5%, \*\* = 1%, \*\*\* = 0.1%) level.

females alike within 1400 meters. Females in the zone 2000 to 2499 meters had conspicuously high mortality in 1951-1952, but not at all in 1953-1954.

From Table X, where similar data are shown for mortality from malignant neoplasms excluding leukemia, it is apparent that the time patterns for malignancy are

not the same as those for all causes. In particular, whereas the ratios for those within 1400 meters fell, in general, from 1951 to 1958, they rose abruptly in 1959-1960, a rise that finds no parallel in the ratios for deaths from all causes. For the survivors within 1400 meters, mortality from malignancy was indeed high during 1951-1954, but it was also high in 1959-1960 (significantly for the sexes combined), a time period when there was actually a deficiency in deaths from all causes. Among males in the zone 2000 to 2499 meters, there was an increasing trend for mortality from neoplasms during the ten-year period, while mortality from all causes in this group moved irregularly up and then down.

No obvious explanation for the decline of the all-causes mortality ratio with time in those exposed within 1400 meters can be offered. Tuberculosis mortality fell during the ten-year period, and faster in the survivors than in the nonexposed (2), but this affected all survivors, and, moreover, for both sexes the excess of observed over expected mortality for the period 1951-1954 far exceeds the excess for tuberculosis: 37.5 versus 14.5 for males, 60.9 versus 9.9 for females.

Since the rapid decline in mortality ratios is characteristic only of the survivors within 1400 meters, it might be thought that leukemia would provide an explanation; but this is not so. For males and females combined, the number of deaths attributed to leukemia in those within 1400 meters were 14, 10, 3, 10, and 4 in the successive biennia, so that, although leukemia has declined, only a small part of the decrease in total mortality is attributable to leukemia.

The decrease with time in mortality ratios in the survivors within 1400 meters appears to be associated with many causes of death. It is in part, but not entirely, attributable to decrease in tuberculosis and leukemia.

In summary, the time patterns of mortality ratios for deaths from all causes show, for the survivors within 1400 meters, a great excess of mortality in the early years, disappearing by 1955. For malignant neoplasms, on the other hand, there is excessive mortality not only from 1951 to 1954, but also again in 1959-1960. If radiation effects account for these observations, the data for total mortality are suggestive of effects that were wearing off, much as the leukemia effect is known to do. However, the data on malignancy may suggest a long period of incubation for some neoplastic late radiation effects which are becoming manifest only by 1959-1960. Such an interpretation is suggested by the Hiroshima Tumor Registry data (10), which indicated high rates for malignancy in closely exposed Hiroshima survivors for the period 1957-1959.

#### *Mortality in Relation to Estimated Radiation Dose*

Table XI shows the observed and expected numbers of deaths and age-standardized death ratios for all causes and for malignant neoplasms exclusive of leukemia in relation to the T57 dose estimate. The tables are restricted to the experience in survivors who were within 2000 meters of the hypocenter, since it is only within that distance range that dose estimates are made. However, the expected numbers

TABLE XI

OBSERVED AND EXPECTED DEATHS FROM ALL CAUSES AND MALIGNANT NEOPLASMS EXCEPT LEUKEMIA BY T57 DOSE ESTIMATE AND SEX, HIROSHIMA AND NAGASAKI

T57 dose estimate (rads)	Male			Female		
	Deaths		Ratio	Deaths		Ratio
	Observed	Expected		Observed	Expected	
	<i>All causes</i>					
Total	1,351	1,362.9	99.1	1,204	1,154.0	104.3
500+	44	46.7	94.2	29	29.2	99.3
250-499	75	66.6	112.6	51	49.2	103.7
125-249	104	126.1	82.5*	134	132.7	101.0
62-124	116	132.6	87.5	107	138.0	77.5**
31-61	97	126.2	76.9**	107	125.0	85.6
<31	120	151.5	79.2**	126	149.9	84.1*
Unknown	795	713.2	111.5***	650	530.0	122.6***
	<i>Malignant neoplasms except leukemia</i>					
Total	213	215.2	99.0	200	184.7	108.3
500+	6	8.0	75.0	10	5.5	181.8
250-499	15	11.2	133.9	13	8.8	147.7
125-249	16	21.3	75.1	32	22.5	142.2*
62-124	18	22.0	81.8	13	24.0	54.2*
31-61	16	19.4	82.5	19	19.8	96.0
<31	19	22.1	86.0	21	23.1	90.9
Unknown	123	111.2	110.6	92	81.0	113.6

The death ratio differs significantly from 100 at (\* = 5%, \*\* = 1%, \*\*\* = 0.1%) level.

of deaths were obtained by applying to the specific age distributions in a dose class the sex-, age-, and city-specific mortality rates for the whole experience.

The mortality ratios plainly are disturbed by the fact that mortality is excessive among those for whom dose is unknown. This results from the fact that shielding studies could not be made for persons who died during the early years of the study. In consequence of this bias, the death ratios appear low for those persons for whom dose estimates are available. Nevertheless, the death ratios, in general, are higher for the persons with high estimated dose than for those with low estimated dose. Among females, the ratios for the three dose classes above 125 rads exceed those for the classes below 125 rads; for males, the ratios for the two classes higher than 250 rads exceed those below that value.

The ratios for mortality from malignant neoplasms exclusive of leukemia are, for females, much higher at doses exceeding 125 rads than for lower doses. However, for males, a similar elevation associated with high dose is not seen.

## SUMMARY

1. The sample of 99,393 persons for the Life-Span Study has been completed, and each member has been traced for survival to the period 1958–1960.

2. The survivors and the members of the nonexposed component of the sample differ markedly with respect to history of foreign residence prior to the A-bombing, the nonexposed much more frequently reporting such residence.

3. At the closer distances to the hypocenter shielding was, on the average, greater in Nagasaki than in Hiroshima. In consequence, burns and acute radiation injury were more prevalent in Hiroshima than in Nagasaki for survivors within 1000 meters.

4. For the third analysis 8614 deaths were observed in the sample. The causes most frequently assigned to the deaths were vascular lesions of the central nervous system and malignant neoplasms.

5. The nonexposed members of the sample had lower mortality ratios than did the survivors at all distances.

6. Mortality ratios for survivors within 1400 meters were higher than for survivors at greater distances for all causes, all natural causes, tuberculosis (Hiroshima males), leukemia, and other malignant neoplasms.

7. Mortality ratios from all causes in those located within 1400 meters of the hypocenter were especially high in 1951–1952, and declined thereafter. Ratios for death from malignant neoplasms in the same group declined from 1951–1952 to 1957–1958, then increased in 1959–1960.

RECEIVED: August 31, 1964

## REFERENCES

1. G. W. BEEBE, M. ISHIDA, and S. JABLON, Studies of the mortality of A-bomb survivors. 1. Plan of study and mortality in the medical subsample (Selection I), 1950–1958. *Radiation Res.* 16, 253–280 (1962).
2. S. JABLON, M. ISHIDA, and G. W. BEEBE, Studies of the mortality of A-bomb survivors. 2. Mortality in Selections I and II, 1950–1959. *Radiation Res.* 21, 423–445 (1964).
3. World Health Organization, *Manual of the International Statistical Classification of Diseases, Injuries, and Causes of Death*, 1955 revision, Geneva, 1957.
4. R. H. RITCHIE and G. S. HURST, Penetration of weapons radiation: Application to the Hiroshima-Nagasaki studies. *Health Phys.* 1, 390–404 (1959).
5. E. T. ARAKAWA, Radiation dosimetry in Hiroshima and Nagasaki atomic bomb survivors. *New Engl. J. Med.* 263, 488–493 (1960).
6. A. W. OUGHTERSON and S. WARREN, *Medical Effects of the Atomic Bomb in Japan*, McGraw-Hill Book Company, New York, 1956.
7. A. B. BRILL, M. TOMONAGA, and R. M. HEYSSEL, Leukemia in humans following exposure to ionizing radiation: A summary of the findings in Hiroshima and Nagasaki and a comparison with other human experience. *Ann. Intern. Med.* 56, 590–609 (1962).

8. H. I. KOHN and R. F. KALLMAN, Age, growth and the LD<sub>50</sub> of X-rays. *Science* **124**, 1078 (1956).
9. Division of Health and Welfare Statistics, Welfare Minister's Secretariat: Vital Statistics 1958, Japan, 1958.
10. T. HARADA and M. ISHIDA, Neoplasms among A-bomb survivors in Hiroshima: First report of the Research Committee on Tumor Statistics, Hiroshima City Medical Association, Hiroshima, Japan. *J. Natl. Cancer Inst.* **25**, 1253-1264 (1960).