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Incidence of Leukemia in Atomic Bomb Survivors Belonging to a Fixed Cohort in Hiroshima and Nagasaki, 1950—71

Radiation dose, years after exposure, age at exposure, and type of leukemia

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The leukemogenic effect of atomic radiation was examined in relation to age at the time of the bomb (ATB), calendar time, and type of leukemia over the period 1950-71. Confirmed cases of leukemia in the Leukemia Registry, a fixed cohort of 109,000 subjects and the T65 dose calculations provided the basis for the analysis. Calendar time was divided into three periods, 5-10, 10-15, and 15-26 years after the bombs. The larger the exposure dose and the younger the age ATB, the greater was the effect in the early period and the more rapid was the decline in risk in subsequent years. In the oldest group, aged 45 or over ATB, the increase in risk appeared later and was sustained in the period 1960-71. Chronic granulocytic leukemia contributed substantially to the total leukemogenic effect initially but made little contribution after 1955. Sensitivity to the leukemogenic effect of atomic radiation not only depended on age ATB but its expression varied by type of leukemia and with time after exposure.

Although the effect of atomic radiation on the incidence of leukemia in the atomic survivors is now greatly reduced and apparently on the wane, in the period 1966-71 the incidence was still greater than expected, especially in Hiroshima. In the Nagasaki sample, no case of leukemia was observed among the high-dose subjects from July 1966 to the end of 1971.

INTRODUCTION

In the study of radiation leukemogenesis in man, continued surveillance of atomic bomb survivors plays a vital role. Although radiation from the atomic bombs was delivered at a high dose-rate and the experience will probably never yield direct estimates of risk in the low-dose region which is of the greatest interest and controversy, its size, demographic composition, range of dose, and varying neutron and gamma

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components make this experience the single most important source of information on radiation leukemogenesis in man. As stated in recent major reviews of the effects of radiation upon man, the dose-response curves for leukemia among survivors of the two bombs are of both practical and scientific significance, but the uncertainty concerning the shape of the Nagasaki curve urgently needs to be resolved.[1-4] Estimates of public health hazards also depend on the knowledge of such parameters as latency, maximum effect, and duration of effect. With some 30 years having elapsed since the bombs were dropped it is important to know whether the incidence still remains elevated in this population.

The last report emanating from the Leukemia Registry at Atomic Bomb Casualty Commission (ABCC) which provides information on the incidence of leukemia among A-bomb survivors by type of leukemia, dose, and city was for the period 1950-66.[5] Recent mortality reports include information on deaths attributed to leukemia on death certificates for 1950-70 in the Extended Life Span Study (LSS) sample.[6,7] An excess risk of leukemia mortality was still observed in 1965-70 for those who received 200 or more rad from the bombs in 1945.[7]

The present report on Leukemia Registry data provides an analysis of the leukemogenic effect in terms of the type of leukemia, radiation dose, age ATB, and calendar time in the LSS cohort for the period 1950-71.

METHODS AND MATERIALS

The Leukemia Registry is operated as a joint effort of the Departments of Hematology of the Schools of Medicine of both Hiroshima University and Nagasaki University, and the Departments of Medicine, Pathology, and Epidemiology and Statistics of the Radiation Effects Research Foundation (RERF).[8] It is believed to provide an almost complete ascertainment of the cases of leukemia developing in Hiroshima and Nagasaki since the bombs. The procedures governing the screening of cases for the Leukemia Registry, the diagnostic review and classification made by participating hematologists, and the standardization of diagnosis in the two cities have been described previously.[9] Cases now registered as leukemia have been reviewed by many senior American and Japanese hematologists. The classification by type is essentially that of Wintrobe.[10] Cases of leukosarcoma were excluded from the leukemia classification in the present analysis.

In the absence of accurate information of the migration of A-bomb survivors in and out of Hiroshima and Nagasaki, RERF investigators have come to rely on fixed cohorts of survivors drawn from the supplementary schedules prepared at the time of the 1950 National Census. In the previous report[5] use was made of the Master Sample from which the LSS sample supplemented by about 35,000 survivors was drawn. However, the LSS cohort[6] is used as the basis for the present report. It includes 82,000 atomic bomb survivors and 27,000 others not in the city ATB, and mortality surveillance on this cohort is complete for the period 1950-72.

Ascertainment of leukemia mortality in the LSS cohort by means of the Japanese family registration system is virtually complete even for those who have migrated from the area monitored for leukemia incidence under the Leukemia Registry procedures.

The present dosimetry system (T65D)[11] provides estimates of gamma and neutron doses (tissue kerma in air) in rad for exposed individuals. The dose estimate used here is the simple sum of gamma and neutron doses and is designated as the "T65 total dose". The dosimetry system has not yet been extended to individuals in certain complex shielding situations ATB. For 2,500 individuals who were exposed in this fashion or were of indeterminate location ATB, dose remained undetermined at the time of this analysis.

Among the 109,000 members of the LSS sample there were 149 definite and probable cases in the Leukemia Registry with onset through December 1971, of which 13 developed before 1 October 1950 (See Appendix I). Therefore, the present analysis of incidence in the LSS cohort makes use of 136 cases of all types of leukemia with onset dates between 1 October 1950 and 31 December 1971.

Table 1 gives the distribution of the cohort of 109,000 by average dose and city.

Table 1.
Composition of Extended Life Span Study sample by dose and city

T65 Total dose (rad)	Average dose (rad) Gamma	Neutron	Total	Sample No.	%
			Hiroshima		
No estimate	—	—	—	1444	1.76
600*	428.0	172.0	600.0	202	.25
400-599	348.9	125.5	474.4	303	.37
200-399	210.8	69.5	280.3	1026	1.25
100-199	108.5	30.3	138.8	1723	2.10
50-99	56.9	13.4	70.3	2720	3.31
1-49	9.3	2.3	11.6	24589	29.91
<1	0.0	0.0	0.0	29977	36.46
NIC	—	—	—	20231	24.61
Total	—	—	—	82215	100.00
			Nagasaki		
No estimate	—	—	—	1067	4.00
600*	587.0	13.0	600.0	155	0.58
400-599	463.9	8.8	472.7	224	0.84
200-399	263.5	3.9	267.5	1019	3.82
100-199	142.9	1.3	144.2	1394	5.22
50-99	70.5	0.2	70.7	1314	4.92
1-49	10.2	0.0	10.2	10470	39.22
<1	0.0	0.0	0.0	4705	17.62
NIC	—	—	—	6350	23.78
Total	—	—	—	26698	100.00

Note: Based on Jablon and Kato,[7] 600 rad total dose was set arbitrarily for those whose T65 total dose was estimated at more than 600 rad. (Hiroshima 428 rad gamma, 172 rad neutron: Nagasaki, 587 rad gamma, 13 rad neutron)

RESULTS

Incidence of leukemia (all forms) during 1950-71 by dose. Figure 1 shows the number of confirmed leukemia cases in the fixed cohort (109,000 subjects) of A-bomb survivors and controls by dose, two major types of leukemia and year of onset.

The annual incidence of leukemia among the survivors who received a high dose of atomic radiation (100 rad or more) has declined gradually since the peak was reached in 1952. The trend was similar to that in the survivors who received 1-99 rad. Chronic leukemia was more common in those who received 1-99 rad than in those who received 100 rad or more and than in those who received less than 1 rad and the controls.

Figure 2 shows the crude annual incidence rate of leukemia (all forms) in the LSS sample during October 1950-December 1971 by city and total dose category. It seems

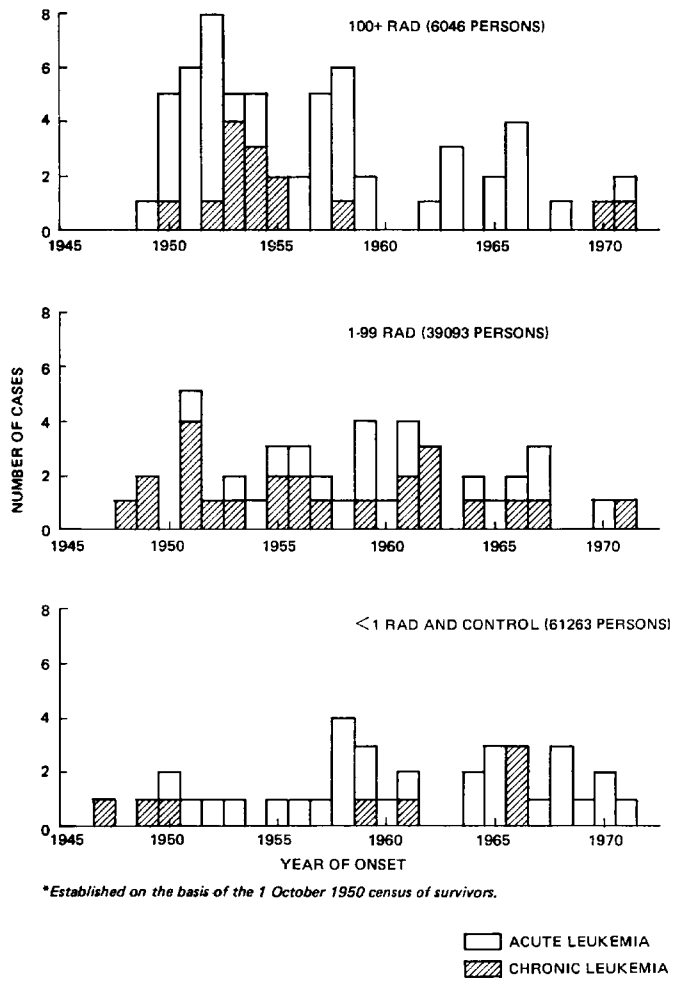

Fig. 1. Distribution of definite and probable leukemia in the fixed cohort* of atomic bomb survivors and controls in Hiroshima and Nagasaki by year of onset, dose and chronicity of leukemia (1947-1971).

that the risk was slightly greater in Hiroshima than in Nagasaki in every dose category, except less than 50 rad. No significant excess risk of leukemia was seen in Nagasaki survivors of the low dose region of less than 100 rad. Table 2 shows the crude annual incidence and relative risk of leukemia (all forms) in both cities combined by dose and four periods of the time after exposure. It appears that the absolute and relative risks among those who received 100 rad or more were still significantly elevated during the period October 1965-December 1971. It seems clear that the leukemo-

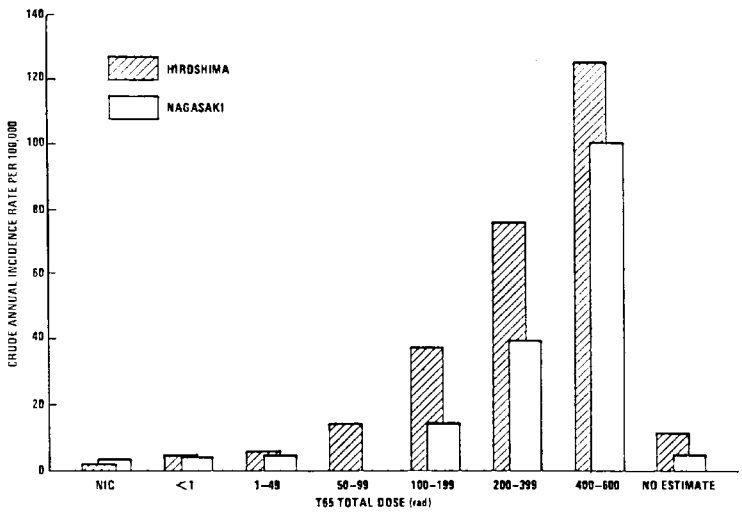

Fig. 2. Crude annual incidence rate of leukemia (all forms) in the Extended Life Span Study sample by city and dose, October 1950-December 1971.

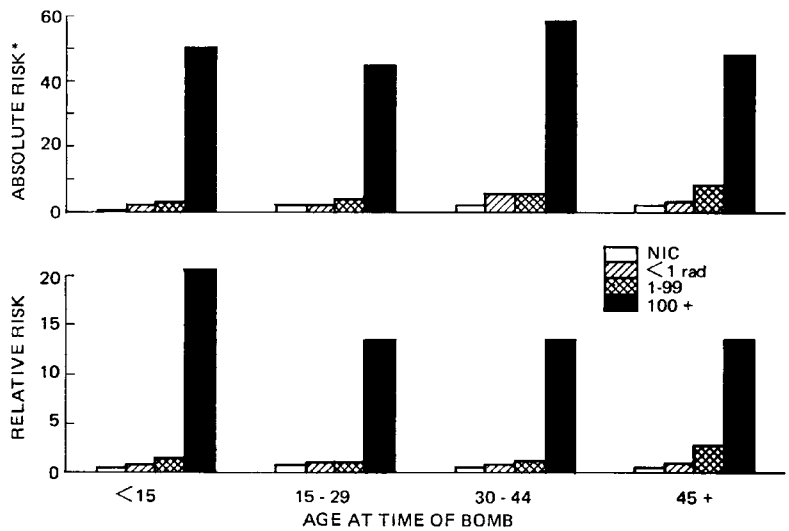

Fig. 3. Comparison of absolute and relative risk for incidence of leukemia in Hiroshima and Nagasaki by dose and age ATB.

Table 2.
Crude annual incidence of leukemia (all types) and comparison of observed and expected numbers in the Extended Life Span Study sample in Hiroshima and Nagasaki by year and month of onset and dose, October 1950-December 1971

	NIC	T65 Total dose (rad)			
		<1	1-99	≧100	No estimate
			Oct. '50—Sep. '55		
Person years	96048	169303	191396	29520	11953
No. of cases (O)	1	4	12	28	1
No. of exp.* (E)	9.26	15.59	17.09	2.87	1.17
O/E	.11	.26	.70	9.76	.86
Relative risk**	.4	1.0	2.7	37.5	3.3
Rate***	1.04	2.36	6.27	94.85	8.37
			Oct. '55—Sep. '60		
Person years	126391	160634	181996	28162	11228
No. of cases (O)	3	7	10	15	1
No. of exp.* (E)	8.93	11.45	12.84	2.01	.77
O/E	.34	.61	.78	7.46	1.30
Relative risk**	.6	1.0	1.3	12.2	2.1
Rate***	2.37	4.36	5.49	53.26	8.91
			Oct. '60—Sep. '65		
Person years	119991	151799	171861	26792	10749
No. of cases (O)	2	4	12	7	2
No. of exp.* (E)	6.74	8.34	9.47	1.75	.70
O/E	.30	.48	1.27	4.00	2.86
Relative risk**	.6	1.0	2.6	8.3	6.0
Rate***	1.67	2.64	6.98	26.13	18.61
			Oct. '65—Dec. '71		
Person years	141858	178474	201326	31555	12906
No. of cases (O)	4	8	7	8	0
No. of exp.* (E)	6.80	8.27	9.66	1.61	.67
O/E	.59	.97	.73	4.97	0
Relative risk**	.6	1.0	.8	5.1	0
Rate***	2.82	4.48	3.48	25.35	0

*** Rate: per 100,000 per year
* Adjusted for sex, age ATB and city
** The ratio for O/E in those exposed to less than 1 rad as standard

genic effect of radiation had not yet entirely disappeared even 20-26 years after exposure. This is especially true in Hiroshima. There was no case of leukemia among the high-dose Nagasaki subjects of the LSS sample from July 1966 to the end of 1971.

Incidence of leukemia during 1950-71 by age ATB. Table 3 and Figure 3 show absolute and relative risks of leukemia excluding chronic lymphocytic leukemia during

Table 3.
Crude annual incidence of leukemia (all types) and comparison of observed and expected numbers in the Extended Life Span Study sample in Hiroshima and Nagasaki by age ATB dose, October 1950-December 1971

	NIC	T65 Total dose (rad)			
		<1	1-99	≧100	No estimate
			<15 Age ATB		
Person years	155640	210105	250098	31641	11624
No. of cases (O)	1	5	9	16	1
No. of exp.* (E)	7.55	10.04	12.31	1.53	.56
O/E	.13	.50	.73	10.46	1.79
Relative risk**	.3	1.0	1.5	20.9	3.6
Rate***	.64	2.38	3.60	50.57	8.60
			15—29		
Person years	137769	169071	188617	42012	20277
No. of cases (O)	4	5	9	19	2
No. of exp.* (E)	9.77	11.40	13.16	3.22	1.46
O/E	.41	.44	.68	5.90	1.37
Relative risk**	.9	1.0	1.5	13.4	3.1
Rate***	2.90	2.96	4.77	45.23	9.86
			30—44		
Person years	116550	155162	169649	25578	9303
No. of cases (O)	3	9	10	15	0
No. of exp.* (E)	9.15	12.31	12.73	2.01	.78
O/E	.33	.73	.79	7.46	0
Relative risk**	.5	1.0	1.1	10.2	0
Rate***	2.57	5.80	5.89	58.64	0
			≧45		
Person years	74331	125874	138216	16793	5633
No. of cases (O)	2	4	13	8	1
No. of exp.* (E)	5.82	9.64	10.64	1.42	.50
O/E	.34	.41	1.22	5.63	2.00
Relative risk**	.8	1.0	3.0	13.7	4.9
Rate***	2.69	3.18	9.41	47.64	17.75

*** Rate: per 100,000 per year
* Adjusted for sex and city
** The ratio for O/E in those exposed to less than 1 rad as a standard

1950-71 by dose for four age ATB groups. The absolute risk with no adjustment for sex and city was significantly greater among those exposed to 100 rad or more in every age ATB group, and the rate for the high-dose group varied little by age ATB.

On the other hand, the relative risk for the high-dose group (100 rad or more), in comparison with that for those who received less than 1 rad, was about 20 for those

under age 15 ATB, but from 10 to 15 for those who were 15-29, 30-44, and 45 or over ATB.

Incidence of leukemia by dose, age ATB, and calendar time. Table 4 and Figure 4 give the leukemia risk by dose, age ATB, and calendar time. The larger the exposure dose and the younger the age ATB, the greater was the effect of radiation in the early period and the more rapid was the decline in risk in subsequent years. On the other hand, the leukemogenic effect among those of older age ATB occurred later and decreased more slowly. In the interval 5 to 10 years after the bombs, incidence was particularly high among heavily exposed males under age 45 ATB. In the period 10 to 15 years after the bombs differences by age ATB and sex were no longer remarkable. In the period 15 to 26 years after the bombs, the risk remained high

Table 4.
Comparison of standardized annual incidence of leukemia excluding CLL in the Extended Life Span Study sample Hiroshima and Nagasaki by dose, age ATB and latent period: Oct. 1950-Dec. 1971

T65 Total dose (rad)	Age ATB <15 No.	<15 Rate*	15-29 No.	15-29 Rate*	30-44 No.	30-44 Rate*	≧45 No.	≧45 Rate*
I. Oct. 1950-Sept. 1955								
NIC	0	.00	1	4.86	0	.00	0	.00
<1	0	.00	2	5.15	1	2.00	1	1.92
1-99	2	4.07	2	5.85	3	7.03	5	11.64
100-199	4	134.65	1	10.80	1	32.36	0	.00
≧200	8	208.37	10	249.95	4	146.58	0	.00
No estimate	1	62.88	0	.00	0	.00	0	.00
Total	15	9.21	16	14.35	9	8.00	6	5.32
II. Oct. 1955-Sept. 1960								
NIC	0	.00	1	4.37	0	.00	2	10.70
<1	2	4.30	0	.00	4	9.48	1	2.37
1-99	4	7.61	1	1.47	3	7.28	2	4.89
100-199	1	41.44	2	72.41	0	.00	2	85.85
≧200	3	65.54	1	8.13	4	154.48	2	92.31
No estimate	0	.00	1	20.64	0	.00	0	.00
Total	10	6.62	6	4.69	11	9.32	9	8.74
III. Oct. 1960-Sept. 1971								
NIC	1	.97	2	3.38	3	5.14	0	.00
<1	3	2.83	3	3.21	4	6.48	2	5.84
1-99	3	1.99	6	6.84	4	4.06	6	10.69
100-199	0	.00	3	30.76	1	16.20	1	36.24
≧200	0	.00	2	17.41	5	93.39	3	100.29
No estimate	0	.00	1	5.55	0	.00	1	34.78
Total	7	1.75	17	6.00	17	7.04	13	8.84

* Rate for 100,000 population per year adjusted for sex and city.

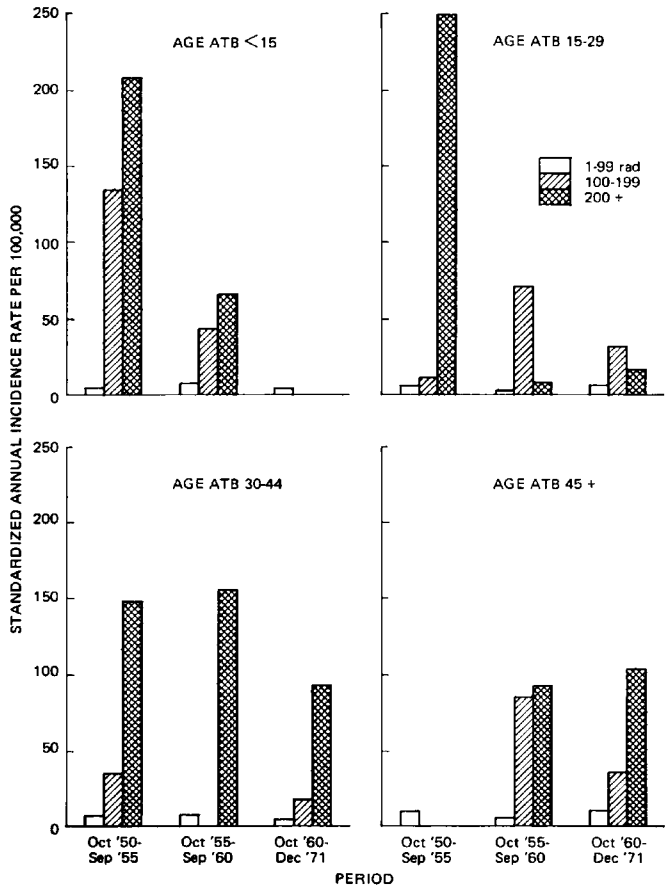

Fig. 4. Comparison of standardized annual incidence of leukemia excluding CLL by dose, age ATB and calendar time after bombings, Oct. 1950-Dec. 1971.

only among those who were heavily exposed at ages 30 or over ATB. These conclusions are based on statistical tests making use of the procedure of Otake.[12] Thus, the effect of radiation varied with age ATB and with time after the bombs.

Incidence of acute leukemia and chronic granulocytic leukemia by dose, age ATB, and calendar time. Table 5 and 6 provide separate analyses for acute leukemia of all kinds and for chronic granulocytic leukemia. Figure 5 is an extract of Table 5 depicting the risk of acute leukemia by calendar time and age ATB for only the high dose groups. Figure 6 gives parallel information for chronic granulocytic leukemia.

For acute leukemia, the leukemogenic effect is seen earlier in those who were younger ATB, and later in those who were older ATB. For chronic granulocytic leukemia, on the other hand, the leukemogenic effect of radiation is very largely confined to the early period, 5 to 10 years after the bombs. Although the chronic granulocytic leukemia effect varied inverssely with age ATB, the difference in risk by age ATB was neither so marked nor so consistent as was the case for acute leukemia.

Table 5.

Comparison of standardized annual incidnce of acute leukema in the Extended Life Span Study sample Hiroshima and Nagasaki by dose, age ATB and latent period: Oct. 1950-Dec. 1971

T65 Total dose (rad)	Age ATB <15 No.	<15 Rate*	15-29 No.	15-29 Rate*	30-44 No.	30-44 Rate*	≧45 No.	≧45 Rate*
I. Oct. 1950-Sept. 1955								
NIC	0	.00	1	4.86	0	.00	0	.00
<1	0	.00	2	5.15	1	2.00	1	1.92
1-99	1	2.48	2	5.85	1	2.13	0	.00
≧100	7	100.82	8	81.79	2	26.16	0	.00
No. estimate	1	62.88	0	.00	0	.00	0	.00
Total	9	5.90	13	10.91	4	3.44	1	.79
II. Oct. 1955-Sept. 1966								
NIC	0	.00	1	4.37	0	.00	2	10.70
<1	1	2.15	0	.00	4	9.48	1	2.37
1-99	2	4.98	1	1.47	3	7.28	0	.00
≧100	4	53.88	3	37.81	4	66.52	3	64.79
No estimate	0	.00	1	20.64	0	.00	0	.00
Total	7	4.77	6	4.69	11	9.32	6	6.19
III. Oct. 1960-Sept. 1971								
NIC	1	.97	2	3.38	3	5.14	0	.00
<1	2	2.18	2	1.67	2	2.64	2	5.84
1-99	3	1.99	3	3.65	1	.99	3	5.13
≧100	0	.00	4	17.28	5	41.28	4	66.38
No estimate	0	.00	1	5.55	0	.00	0	.00
Total	6	1.50	12	4.12	11	4.69	9	6.22

* Rate for 100,000 population per year adjusted for sex and city.

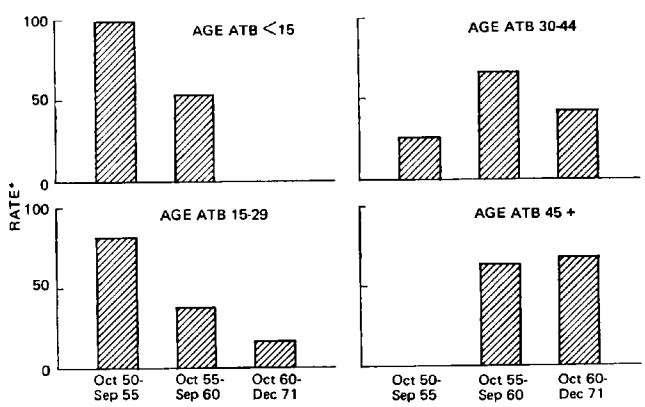

Fig. 5. Comparison of standardized annual incidence rate of acute leukemia in those who received 100 rad or more by age ATB and calendar time after bombings, October 1950-December 1971.

Table 6.
Comparison of standardized annual incidence of chronic granulocytic leukemia in the Extended Life Span Study sample Hiroshima and Nagasaki by dose, age ATB and latent period: Oct. 1950-Dec. 1971

T65 Total dose (rad)	Age ATB <15 No.	Age ATB <15 Rate*	Age ATB 15-29 No.	Age ATB 15-29 Rate*	Age ATB ≧30 No.	Age ATB ≧30 Rate*
I. Oct. 1950-Sept. 1955						
NIC	0	.00	0	.00	0	.00
<1	0	.00	0	.00	0	.00
1-99	1	1.59	0	.00	7	8.13
≧100	5	72.16	3	55.63	3	25.89
No estimate	0	.00	0	.00	0	.00
Total	6	3.32	3	3.44	10	4.36
II. Oct. 1955-Sept. 1960						
NIC	0	.00		.00	0	.00
<1	1	2.15	0	.00	0	.00
1-99	2	2.63	0	.00	2	2.66
≧100	0	.00	0	.00	1	9.83
No estimate	0	.00	0	.00	0	.00
Total	3	1.85	0	.00	3	1.33
III. Oct. 1960-Dec. 1971						
NIC	0	.00	0	.00	0	.00
<1	1	.66	1	1.55	1	.73
1-99	0	.00	3	3.20	6	4.13
≧100	0	.00	1	6.83	1	6.24
No estimate	0	.00	0	.00	1	10.85
Total	1	.25	5	1.87	9	2.15

* Rate for 100,000 population per year adjusted for sex, age ATB and city.

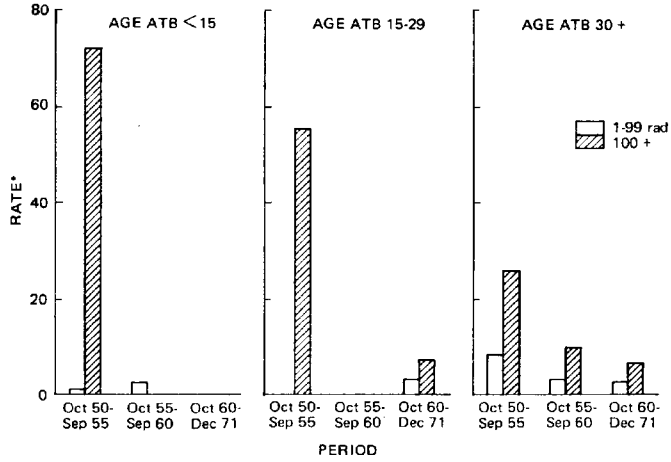

Fig. 6. Comparison of standardized annual incidence rate of chronic granulocytic leukemia by dose, age ATB and calendar time after bombings, October 1950-December 1971.

After 10 years chronic granulocytic leukemia occurred only sporadically, and thus the decline in risk was much more rapid with the passage of time than was observed for acute forms of leukemia, especially for those who were younger ATB. Although the excess risk of chronic granulocytic leukemia was somewhat maintained in the older age groups 15 to 26 years after the bombs, it was not as large as that for acute leukemia.

Additional detail on type of leukemia for the high dose groups (100 or more rad) is given in Table 7 by age ATB and calendar time. During the period between 1950 and 1955 acute granulocytic leukemia was notably infrequent among those under 15 ATB in comparison with other age ATB groups. In contrast, the frequency of acute lymphocytic leukemia and "other types" of acute leukemia seemed to be especially elevated in the two younger age groups, but the frequency of chronic granulocytic leukemia was elevated among those under 45 ATB. By 1960, incidence of all forms of

Table 7.

Comparison of crude annual incidence* among those who received 100 rad or more in the Extended Life Span Study sample in Hiroshima and Nagasaki by dose, age ATB and type of leukemia

	Age ATB				
	<15	15-29	30-44	≧45	Total
	Oct. 1950--Sept. 1955				
Person years	7,597	10,121	6,489	5,311	29,518
AGL	0. (0)	39.5 (4)	30.8 (2)	0. (0)	20.3 (6)
ALL	52.7 (4)	29.6 (3)	0. (0)	0. (0)	23.7 (7)
AL (Other type)	39.5 (3)	9.9 (1)	0. (0)	0. (0)	13.6 (4)
CGL	65.9 (5)	29.7 (3)	46.2 (3)	0. (0)	37.3 (11)
All type of leuk.	158.0 (12)	108.7 (11)	77.1 (5)	0. (0)	94.9 (28)
	Oct. 1955—Sept. 1960				
Person years	7,476	9,964	6,225	4,496	28,161
AGL	13.4 (1)	0. (0)	64.3 (4)	44.5 (2)	24.9 (7)
ALL	13.4 (1)	10.0 (1)	0. (0)	0. (0)	7.1 (2)
AL (Other type)	40.1 (3)	10.0 (1)	0. (0)	22.2 (1)	17.8 (5)
CGL	0. (0)	0. (0)	0. (0)	22.2 (1)	3.6 (1)
All type of leuk.	66.9 (5)	20.1 (2)	64.3 (4)	89.0 (4)	53.3 (15)
	Oct. 1960—Dec. 1971				
Person years	16,569	21,926	12,866	6,985	58,346
AGL	0. (0)	4.6 (1)	15.5 (2)	43.0 (3)	8.6 (5)
ALL	0. (0)	4.6 (1)	15.5 (2)	14.3 (1)	6.9 (4)
AL (Other type)	0. (0)	9.1 (2)	7.8 (1)	0. (0)	5.1 (3)
CGL	0. (0)	4.6 (1)	7.8 (1)	0. (0)	3.4 (2)
All type of leuk.	0. (0)	22.8 (5)	46.6 (6)	57.3 (4)	24.0 (14)

* Rate for 100,000 population per year.

( ) shows number of cases.

leukemia had almost disappeared among those under 15 ATB. The risk of acute granulocytic and lymphocytic leukemia was greater among the older age groups than in the 15-29 age group and the risk of chronic granulocytic leukemia and other types of acute leukemia was still high between 1960 and 1971. It appears that the risk of leukemia by type among the high dose group differs by age at onset and years after exposure.

DISCUSSION

Over the past 25 years, many American and Japanese scientists have reported on the incidence of leukemia as a late effect of atomic radiation.[5,13-30]

It is known from the work of Folly et al.[13] that the leukemogenic effect of atomic radiation began to be expressed before 1950, and the Leukemia Registry presented evidence that the effect on atomic bomb survivors peaked in 1951-53, 6-8 years after the bombs. Tomonaga[22] reported that the highest incidence of leukemia among proximally exposed survivors was observed during 1950-52, but it subsequently decreased and in the period 1960-65 the incidence among all exposed subjects was almost the same as that for all Japan. He concluded that the effect of atomic bomb radiation on the incidence of leukemia had almost disappeared by 1965.

The early peaking and long period of subsidence characteristic of the effect experienced by the atomic bomb survivors is also seen in the follow-up data of Court-Brown and Doll on patients with ankylosing spondylitis treated by X-ray.[31] In their data the effect was greatest 3 to 5 years therapy, which would correspond to the years 1948-50 for atomic bomb survivors. They reported that the incidence of leukemia among these patients declined 15 years after X-ray treatment. Only one leukemia death in their series was reported during 15-24 years after X-ray treatment.

However, the present report showed that the leukemogenic effect of atomic radiation, which has been declining since the peak was reached in 1951-52, was still evident in the period 1965-71, especially among Hiroshima survivors. This applies for both acute and chronic granulocytic leukemia. It seems that the latency of leukemia in the high-dose group is longer in atomic bomb survivors than in the patients of Court-Brown and Doll[31] who were treated by X-ray.

Earlier reports on leukemia among atomic bomb survivors have indicated that younger persons were far more vulnerable to the leukemogenic effect of atomic radiation than older persons. Tomonaga[22] and Bizzozero et al.[24] reported that the 1945-55 risk of acute and chronic granulocytic leukemia among the proximally exposed was significantly high in subjects who were younger ATB. Jablon and Kato[7] in their recent report on the mortality of the LSS sample for the period 1950-70 using death certificate diagnoses have suggested that it is not only the younger atomic bomb survivors who are especially sensitive to the leukemogenic effect of atomic radiation but also those aged 50 or over ATB. Court-Brown[32] has contrasted this relationship with that seen in his follow-up study of patients with ankylosing spondylitis treated by X-

ray, among whom the excess risk rose with age at treatment.

The present evidence, however, showed that the absolute risk for the high-dose group varied little by age ATB, but the relative risk for the high-dose was greater in those under age 15 ATB than in those over age 15 ATB.

The influence of age ATB, calendar time, and atomic radiation dose on the pattern of incidence by type of leukemia is rather complex, and the available data are too scanty to support the development of a precise numerical model. A schematic diagram (Figure 7) will have to suffice. It appears that age ATB plays an important role in radiation leukemogenesis in relation to latency period and type of leukemia. The diagram indicates that onset of acute leukemia tended to be earlier in those who were young ATB than in those who were older ATB. The epidemiologic pattern for development of leukemia in the high-dose group was different by type of leukemia and age ATB.

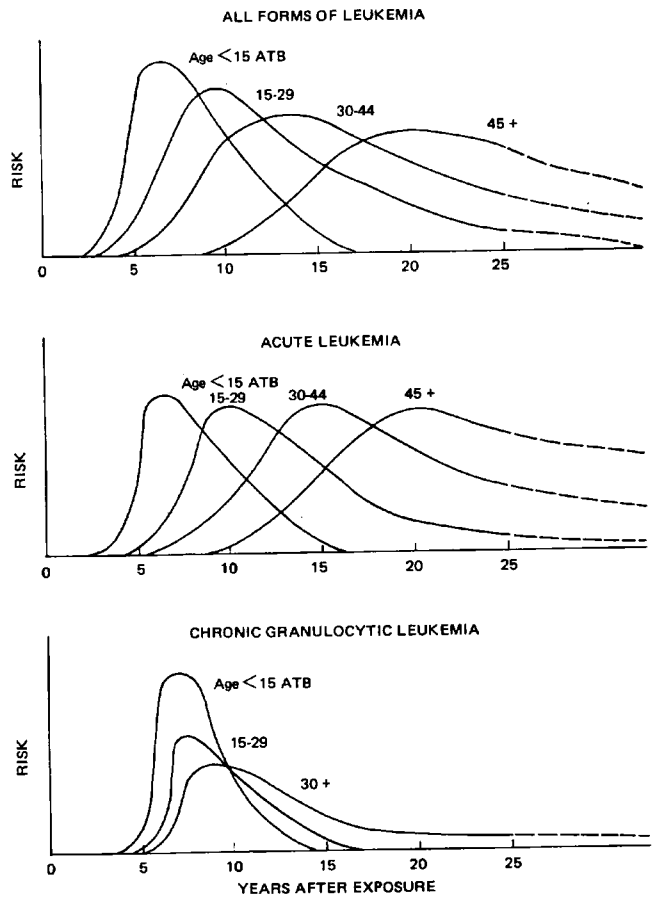

Fig. 7. Schematic model of influence of age at time of bombing (ATB) and calendar time on leukemogenic effect of radiation (heavily exposed survivors).

Several recent analyses of the Hiroshima and Nagasaki mortality data on all forms of leukemia suggest that the most appropriate dose-response function may be linear for the neutron dose and quadratic for the gamma dose.[33-37] The Leukemia Registry data were studied from this standpoint and the result has been reported elsewhere.[38]

By 30 June 1972, there were 1,559 registered cases of definite and probable leukemia in the Leukemia Registry. Of the 1,559 cases, 422 were atomic bomb survivors. In general, chronic granulocytic leukemia was more common in Hiroshima than in Nagasaki and the reverse was true for chronic lymphocytic leukemia. Otherwise, the two cities had essentially the same distribution by type of leukemia if the atomic bomb survivors were ignored. No case of chronic lymphocytic leukemia was registered among those who received 1 rad or more in either city until 1971. An analysis on all registered cases in the Leukemia Registry will also be reported separately in the near future.

Appendix I—A

List of definite and probable leukemia in the Extended Life Span Study sample in Hiroshima and Nagasaki, Oct. 1950-Dec. 1971

City	MF#	Sex	Age ATB	Dx.	Onset Mo.-Yr.	Age at onset	Dose Gamma	Dose Neutron	Total	Underlying cause of death 8th ICD
A. Cases whose onset was before Oct. 1, 1950										
Hiroshima	230-904	F	3	ASL	9-'50	8	95	39	134	207
〃	253-946	M	10	ALL	8-'49	14	271	117	388	207
〃	254-072	F	27	CGL	8-'49	31	7	1	8	207
〃	274-811	F	43	CGL	4-'47	45	0	0	0	207
〃	298-814	F	57	CGL	7-'49	61	0	0	0	207
〃	400-108	M	36	CGL	6-'48	39	66	11	77	207
〃	401-007	F	29	CGL	12-'48	33	No estimate			207
〃	401-749	F	43	CGL	6-'49	48	34	4	38	782
〃	404-059	F	62	CGL	12-'48	66	No estimate			207
Nagasaki	089-495	M	37	CGL	2-'45	37	373	15	388	207
〃	092-522	M	4	CGL	7-'50	9	0	0	0	207
〃	093-189	F	9	AML	7-'50	40	572	9	581	283
〃	150-037	F	5	ALL	4-'50	10	399	4	403	207

* Dx. AGL : Acute granulocytic leukemia
ALL : Acute lymphocytic leukemia
AML : Acute monocytic leukemia
ASL : Acute stem cell leukemia
Eryth : Erythroleukemia
AL (Unk.) : Acute leukemia, but type unknown
CGL : Chronic granulocytic leukemia
CLL : Chronic lymphocytic leukemia

Appendix I—B

List of definite and probable leukemia in the Extended Life Span Study sample in Hiroshima and Nagasaki, Oct. 1950-Dec. 1971

City	MF#	Sex	Age ATB	Dx.	Onset Mo.-Yr.	Age at onset	Dose Gamma	Dose Neutron	Total	Underlying cause of death 8th ICD
B. Cases whose onset was between Oct. 1950—Dec. 31, 1971										
Hiroshima	203-645	M	27	AML	10-'61	44	17	3	20	207
〃	204-593	M	39	AGL	02-'57	51	578	152	730	207
〃	207-250	F	26	AGL	05-'63	44	99	22	121	207
〃	210-807	M	34	ALL	05-'69	57	—	NIC	—	204
〃	215-003	M	5	ASL	12-'59	19	400	113	513	207
〃	215-158	M	6	CGL	07-'53	14	719	231	950	207
〃	217-276	M	40	ASL	01-'64	59	0	0	0	207
〃	219-903	F	20	ALL	08-'51	26	555	77	632	207
〃	220-344	M	45	CGL	07-'51	51	29	15	44	207
〃	221-690	M	47	CGL	07-'63	65	No estimate			207
〃	223-171	F	31	CGL	07-'55	41	19	3	22	207
〃	224-283	F	40	AGL	03-'57	51	0	0	0	207
〃	224-353	F	32	Eryth.	04-'68	55	264	86	350	207
〃	225-604	F	20	ASL	10-'50	25	0	0	0	207
〃	226-325	F	40	CGL	08-'67	62	35	6	41	*
〃	228-438	F	27	ASL	05-'63	45	272	107	379	207
〃	229-440	M	30	ALL	10-'71	56	110	70	180	*
〃	230-457	M	43	AML	02-'58	56	0	0	0	207
〃	232-852	M	20	CGL	10-'61	37	0	0	0	207
〃	234-775	F	15	AL(Uhk)	10-'57	27	133	31	164	207
〃	235-561	F	2	ALL	06-'52	08	106	28	134	207
〃	235-908	F	58	AGL	01-'66	78	268	53	321	207
〃	236-470	M	17	ALL	03-'51	22	66	15	81	207
〃	237-140	F	40	AGL	06-'63	58	268	67	335	207
〃	237-312	F	27	ALL	07-'58	40	No estimate			207
〃	239-088	F	40	ALL	09-'56	51	1	0	1	207
〃	239-904	M	14	AGL	08-'52	21	No estimate			207
〃	241-290	M	17	AML	06-'58	30	122	32	154	207
〃	244-309	M	18	ALL	08-'51	24	315	117	432	207
〃	244-696	F	8	AML	07-'51	14	108	20	128	283
〃	246-019	M	2	ASL	07-'64	21	35	11	46	207
〃	246-121	M	43	ASL	01-'59	57	15	1	16	207
〃	246-760	F	36	ALL	10-'66	57	263	187	450	207
〃	247-315	M	34	AGL	08-'71	60	0	0	0	*
〃	247-610	F	50	AL(Unk)	07-'61	66	1	0	1	207
〃	247-781	F	54	CGL	05-'51	60	83	14	97	207
〃	248-051	M	29	CGL	06-'52	36	195	41	236	207
〃	248-293	M	7	CGL	08-'55	17	277	73	350	205
〃	249-266	M	15	CGL	01-'62	31	25	6	31	207

B. (Con'td)

City	MF#	Sex	Age ATB	Dx.	Onset Mo.-Yr.	Age at onset	Dose Gamma	Dose Neutron	Total	Underlying cause of death 8th ICD
Hiroshima	250-835	F	33	AGL	06-'58	45	27	4	31	207
〃	251-085	M	42	AGL	08-'56	54	182	46	228	207
〃	251-153	F	67	CGL	10-'62	84	7	0	7	207
〃	251-483	F	27	AML	08-'67	49	0	0	0	207
〃	251-896	M	13	CGL	03-'59	27	36	6	42	207
〃	252-750	M	56	AGL	07-'55	66	0	0	0	207
〃	255-436	M	32	CGL	07-'66	52	0	0	0	207
〃	256-175	F	52	CGL	02-'52	58	62	10	72	207
〃	256-655	M	29	CGL	08-'53	37	158	50	208	207
〃	257-863	M	51	CGL	03-'51	57	17	7	24	207
〃	258-029	M	33	CGL	12-'52	41	104	33	137	207
〃	259-273	M	46	ALL	12-'59	60	0	0	0	207
〃	259-369	M	54	CGL	10-'57	66	7	0	7	199
〃	273-693	F	34	CGL	03-'62	51	46	25	71	*
〃	275-949	M	51	CGL	02-'58	64	197	41	238	207
〃	278-624	M	56	CGL	03-'56	66	10	4	14	207
〃	281-520	F	17	AML	06-'66	38	11	4	15	207
〃	282-239	M	37	CGL	04-'52	44	261	65	326	470
〃	282-609	F	45	CGL	09-'61	61	38	7	45	207
〃	283-686	M	14	CGL	04-'55	24	32	16	48	207
〃	287-421	M	10	AGL	08-'70	35	0	0	0	205
〃	287-971	F	30	CGL	06-'66	50	2	1	3	*
〃	288-499	F	4	ASL	03-'59	18	57	25	82	207
〃	288-953	F	15	AGL	05-'54	24	177	43	220	207
〃	290-030	F	41	AML	03-'53	49	0	0	0	207
〃	291-742	F	16	ALL	05-'68	38	0	0	0	204
〃	296-939	M	34	CGL	12-'54	43	183	129	312	207
〃	299-918	F	3	AGL	01-'56	13	0	0	0	207
〃	300-716	F	50	AGL	05-'66	71	209	62	271	287
〃	303-571	M	41	Eryth.	10-'58	55	0	0	0	207
〃	304-216	M	8	CGL	03-'66	29	0	0	0	207
〃	323-563	M	22	CGL	11-'50	28	196	140	336	207
〃	328-122	M	29	AL(Unk)	12-'59	43	—	NIC	—	207
〃	329-638	M	26	ASL	06-'52	33	0	0	0	207
〃	333-985	F	18	CGL	06-'70	43	156	38	194	*
〃	345-911	F	21	CGL	07-'64	40	62	35	97	207
〃	356-305	F	13	AML	02-'59	26	74	44	118	207
〃	357-718	M	18	AML	03-'68	41	—	NIC	—	205
〃	359-932	F	14	CGL	01-'59	28	0	0	0	207
〃	381-845	M	14	AGL	05-'70	39	—	NIC	—	206
〃	400-073	F	9	ALL	06-'59	23	24	5	29	207
〃	400-257	M	7	ALL	12-'60	23	17	2	19	207

B. (Cont'd)

City	MF#	Sex	Age ATB	Dx.	Onset Mo.-Yr.	Age at onset	Dose Gamma	Dose Neutron	Total	Underlying cause of death 8th ICD
Hiroshima	400-538	F	24	AML	06-'53	31	464	109	573	207
〃	400-885	F	37	AGL	07-'57	49	256	192	448	207
〃	400-893	F	55	ALL	08-'62	72	98	22	120	207
〃	401-117	M	63	AGL	01-'58	76	655	212	867	207
〃	401-275	M	10	ALL	11-'51	17	459	136	595	283
〃	402-246	F	47	AGL	07-'65	67	0	0	0	207
〃	403-932	F	49	CGL	02-'51	54	35	10	45	014
〃	404-230	M	18	AGL	12-'51	25	—	NIC	—	207
〃	412-613	F	43	AGL	08-'52	50	206	136	342	207
〃	419-405	F	34	AGL	05-'53	42	47	8	55	011
〃	421-559	M	5	CGL	11-'54	15	95	20	115	207
〃	422-531	M	0	ALL	09-'53	08	1054	1015	2069	207
〃	424-873	F	40	ALL	12-'58	53	0	0	0	207
〃	428-601	F	2	ALL	11-'54	11	8	1	9	207
〃	437-743	M	52	AML	09-'63	70	33	5	38	207
〃	438-796	F	49	AGL	08-'57	61	88	26	114	207
〃	443-071	M	44	CGL	07-'53	52	9	0	9	207
〃	461-455	F	35	CGL	06-'71	60	359	84	443	*
〃	468-806	M	50	AML	02-'60	65	—	NIC	—	207
〃	868-404	F	43	ALL	12-'64	62	—	NIC	—	207
Nagasaki	001-434	M	29	AGL	10-'51	35	146	2	148	207
〃	006-089	M	33	AGL	03-'52	40	865	36	901	207
〃	008-880	M	39	AGL	09-'65	59	244	5	249	207
〃	009-812	M	43	AGL	08-'58	56	600	11	611	207
〃	015-622	M	23	AGL	05-'70	48	1	0	1	205
〃	017-420	F	17	AGL	09-'57	29	2	0	2	207
〃	020-266	F	20	ASL	04-'65	40	161	2	163	283
〃	020-844	F	16	CGL	07-'71	42	15	0	15	*
〃	020-938	F	18	AGL	08-'52	25	922	14	936	207
〃	027-064	F	17	ALL	07-'64	36	251	5	256	207
〃	071-643	F	8	AML	11-'61	24	0	0	0	207
〃	074-449	M	3	CGL	09-'54	12	242	2	244	207
〃	080-200	F	1	AGL	06-'65	21	6	0	6	207
〃	082-569	M	47	CGL	08-'61	63	13	0	13	207
〃	085-466	M	15	AML	08-'55	26	2	0	2	207
〃	089-268	M	16	ALL	09-'65	36	No estimate			207
〃	089-544	M	3	AGL	09-'58	16	478	7	485	207
〃	089-834	F	18	ALL	01-'56	28	251	5	256	207
〃	090-238	M	50	AGL	06-'66	71	322	3	325	207
〃	090-305	F	39	AGL	08-'68	62	—	NIC	—	207
〃	091-006	M	55	AML	04-'58	68	162	1	163	207

B. (Cont'd)

City	MF#	Sex	Age ATB	Dx.	Onset Mo.-Yr.	Age at onset	Dose Gamma	Dose Neutron	Total	Underlying cause of death 8th ICD
〃	093-182	M	3	CGL	07-'55	13	458	5	463	207
〃	093-337	M	1	ALL	08-'53	09	143	2	145	207
〃	095-814	M	1	ALL	11-'57	14	273	3	276	207
〃	096-678	M	15	ALL	11-'50	20	422	11	433	207
〃	099-740	F	15	AGL	02-'52	22	272	7	279	283
〃	102-764	M	37	CLL	05-'66	58	0	0	0	204
〃	103-308	M	14	CGL	12-'56	25	19	0	19	207
〃	106-227	M	49	Eryth.	10-'65	69	0	0	0	200
〃	127-878	F	4	ASL	03-'54	12	530	9	539	207
〃	138-391	M	2	AML	09-'51	09	211	2	213	207
〃	161-013	F	42	AGL	02-'67	64	7	0	7	207
〃	166-205	F	55	AGL	04-'67	77	2	0	2	205
〃	183-895	F	51	ALL	01-'58	63	—	NIC	—	207
〃	660-955	M	17	AML	05-'65	37	—	NIC	—	207

* Alive as of Dec. 31, 1971

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