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INCIDENCE OF LEUKEMIA IN A FIXED COHORT OF ATOMIC BOMB SURVIVORS AND CONTROLS, HIROSHIMA AND NAGASAKI OCTOBER 1950 - DECEMBER 1978

広島・長崎の被爆者と対照者からなる固定集団における白血病発生 1950年10月 —1978年12月

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In the continued interest of accurately defining the late effects of the atomic bombs, the qualitative and quantitative characteristics of the A-bomb radiation exposure doses are periodically refined. If warranted by future dose assessments, the data reported here will be reanalyzed and subsequently reported.
原爆の後影響を引き続いて正確に究明する目的をもって，原爆放射線被曝線量の質的・量的特質について定期的に改良を加えている．今後線量評価によって，その必要性が起これば，本報の資料を再解析の上，改めて報告する．

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広島・長崎の被爆者と対照者からなる固定集団における白血病発生 1950年10月 −1978年12月

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SUMMARY

The previous RERF incidence report on the leukemogenic effect of radiation in atomic bomb survivors was based on leukemia cases detected in the Life Span Study (LSS) extended cohort through 1971. The present analysis extends these observations through 1978 with the addition of 53 cases and seeks a better understanding of the duration and magnitude of the risk. The effect of age at the time of the bomb (ATB) has been reanalyzed based on the improved dosimetry which stems from the relocation of the epicenter of the Nagasaki bomb. A total of 202 leukemia cases have been identified in the LSS extended cohort of A-bomb survivors and their controls in Hiroshima and Nagasaki for the period October 1950-December 1978. As the onset of 13 cases was prior to October 1950, the present analysis of leukemia incidence is confined to 189 cases in Hiroshima and Nagasaki.

The analysis again demonstrates that the risk of all types of leukemia has increased with dose in both cities except among individuals who received less than 100 rad in kerma total dose in Nagasaki. The shape of the dose-response curve is different in the two cities and between

要 約

被爆者の放射線による白血病誘発効果に関する発生率についての放影研の前回の報告は，寿命調査拡大集団で1971年までに発生した白血病症例を基にしたものである．今回の解析は観察期間を1978年まで延長し，53例が追加されたので，白血病のリスクについてその影響の認められる期間や程度についてより理解を深めることになった．長崎の原爆の爆央の移動によって改良された線量測定に基づいて，原爆時年齢への影響を再解析した．1950年10月から1978年12月までの間に，寿命調査拡大集団に属する広島・長崎の被爆者とその対照者から202名の白血病を確認した．このうち13名は発病が1950年10月以前であったので，今回の白血病発生に関する解析は広島・長崎の189名について行った．

長崎でカーマ総線量が100rad未満の者を除けば，両市とも全病型の白血病のリスクは線量の増加とともに上昇することが今回の解析でも再び確認された．線量反応曲線の形状は両市及び二つの主要病型

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the two major types of leukemia (acute leukemia and chronic granulocytic leukemia), though the average marrow total dose is quite similar in each total kerma dose class in the two cities. The present findings are quite consistent with those described in the previous report.

The excess risk among survivors who received 100 rad or more kerma total dose has gradually declined with years after exposure in both cities. It had disappeared among Nagasaki survivors by 1970 (25 years after exposure) but the risk was still high even after 1970 among exposed survivors in Hiroshima who were 30 years of age or older ATB. The leukemogenic effect of radiation differs in relation to dose, age ATB, and duration after exposure between Hiroshima and Nagasaki survivors. The analysis has again supported previous observations that the leukemogenic effect of radiation in those individuals exposed at younger ages ATB was greater in the early postbomb period and declined more rapidly in subsequent years, while the effect in older individuals ATB appeared later and persisted longer. It is probable that the excess risk among those survivors exposed to 100 rad or more kerma total dose will disappear from this cohort in the near future.

INTRODUCTION

Evidence on radiation carcinogenesis in man has increased through studies of A-bomb survivors in Hiroshima and Nagasaki and individuals who received medical X-ray or were occupationally exposed to ionizing radiation.[1,2]

Reports from ABCC-RERF and the Hiroshima and Nagasaki University Medical Schools have appeared periodically since 1952 on the leukemogenic effect of radiation in Hiroshima and Nagasaki A-bomb survivors.[3-9] The previous report[6] from RERF was based on the incidence of leukemia in a fixed cohort of A-bomb survivors and their controls in Hiroshima and Nagasaki through 1971.

The present report extends these observations to 1978 with the ascertainment of 53 additional cases in the subsequent seven years of follow-up observation. In addition, a revised dosimetry (T65DR) has become available for use based on the relocation of the epicenter of the Nagasaki A-bomb recommended by Kerr and Solomon.[10] These two factors have prompted the authors to

(急性白血病と慢性骨髄性白血病)で異なるが，両市の各カーマ総線量区分でみると平均骨髄総線量はほぼ等しかった．今回の所見は前回の報告に記述された結果と全く同様であった．

カーマ総線量が100rad以上の被爆者の過剰リスクは両市とも被爆後の年数の経過とともに徐々に減少した．長崎の被爆者では1970年まで(被爆25年後)に過剰リスクは消失したが，広島の被爆者で原爆時年齢が30歳以上の者では1970年以後も高いリスクが認められた．放射線による白血病の誘発効果は広島と長崎の被爆者の間に線量，原爆時年齢，被爆後の経過年数との関係についてみると差異が認められた．放射線の白血病誘発効果は，原爆時年齢が若い者ほどその影響は早期に出現し，その後年数の経過とともに急速に低下したが，原爆時年齢が高い者ではその影響は遅れて出現し，引き続き長期にわたって継続して認められるという前回の観察結果が今回の解析でも再び裏付けられた．カーマ総線量が100rad以上の被爆者の白血病の過剰リスクは，この固定集団において近い将来消失するであろうことはほぼ確実である．

緒　言

人間の放射線誘発癌に関する立証は，広島・長崎の被爆者，医療用X線を受けた者，電離放射線を職業上被曝した者についての研究を通じて増加している．[1,2]

ABCC-放影研，広島・長崎大学の医学部から1952年以来広島・長崎の被爆者における放射線による白血病誘発効果について定期的に報告されている．[3-9] 放影研からの前回の報告[6]は，1971年までに広島・長崎の被爆者とその対照からなる固定集団から発生した白血病に基づいている．

今回の報告は，前回の報告後7年間観察期間を延長し，1978年までに確認された53例の追加症例を加えて検討した．更に，Kerr と Solomon[10] が勧告した長崎の原爆の爆央を移動して計算された改訂線量測定(T65DR と呼称)の使用が可能になった．これら二つの要因によって，著者らは白血病誘発効果の

reappraise the magnitude of the leukemogenic effect, the dose-response relationship, and the influence of age on the excess risk over time in each city.

MATERIALS AND METHODS

The LSS extended sample[11] which is the basis of this report consists of about 109,000 subjects, of whom 82,000 are A-bomb survivors and 27,000 were not in either city (NIC) ATB. The estimates of individuals exposure dose in Nagasaki employed in this report are based on the relocated epicenter.[10] The RERF Department of Epidemiology and Statistics has calculated anew the exposure doses of the individuals in this sample in both Hiroshima and Nagasaki by a standardized rounding procedure. If the kerma total dose for a survivor was calculated to be 600 rad or more, in order to avoid distortion arising from probable erroneous estimates,[12] in Hiroshima the gamma dose for that survivor was arbitrarily set at 439 rad and the neutron dose at 161 rad, while in Nagasaki the gamma dose was set at 587 rad and the neutron dose at 13 rad. There were 205 such cases in Hiroshima and 160 in Nagasaki. This decision grew out of a case-by-case reexamination of the improbably high estimates not compatible with survival. The individual bone marrow doses were calculated, using Kerr's proposed formulas[13] for bone marrow dose/kerma dose conversion factors for Japanese A-bomb survivors.

It should be noted that a degree of uncertainty still surrounds both the quantity and the quality of radiation released by these two nuclear devices. Some recent estimates[14] suggest that the kerma total dose is somewhat higher in Hiroshima and somewhat lower in Nagasaki than T65DR presumes. This would presumably reduce to some degree the apparent city differences in the present analysis of leukemia incidence data using T65DR.

Ascertainment of leukemia cases is almost complete in the fixed cohort of A-bomb survivors and their controls comprising the LSS extended sample in Hiroshima and Nagasaki. Case detection is based on the ABCC-RERF Leukemia Registry which screens information from various sources. For all reported cases confirmation of diagnosis is made by hematologists after obtaining pertinent clinical records and hematologic materials. The registration procedure requires confirmation of

程度，線量反応関係，両市における過剰リスクの経年的にみた年齢の影響について再評価することにした．

材料及び方法

本報告の基になる寿命調査拡大対象[11]は，被爆者82,000名と原爆時市内不在者27,000名の約109,000名から構成されている．本報告に用いた長崎の被爆者の個人の推定被曝線量は移動した爆央に基づいている．[10]放影研疫学統計部は，広島・長崎両市の個々の対象者の被曝線量を基準とした丸め法により新たに計算した．被曝者のカーマ総線量が600rad 以上と計算された場合には，誤りと思われる推定値から起こる歪みを避けるため，[12]広島では任意にその被爆者のガンマ線量を439rad，中性子線量を161rad とし，長崎ではガンマ線量を587rad，中性子線量を13rad と規定した．このような事例は広島205例，長崎160例である．この決定は生存不可能なほど，ありそうもない高い線量推定値の者についての，個別の検討による再調査によって行った．個人の骨髄線量は，Kerr が提案した日本人の被爆者の骨髄線量/カーマ線量変換係数の公式[13]を用いて計算した．

二つの原子爆弾から放出された放射線の線量と線質については，今なお不確実性があることに留意すべきである．最近の幾つかの推定[14]では，T65DR よりもカーマ総線量は広島では若干高く，長崎では若干低いことが示唆された．このことは，T65DR を用いた今回の白血病発生の資料についての解析によって示された明らかな都市別の差異を，多分ある程度減少させることになろう．

広島・長崎の寿命調査拡大対象を構成している被爆者とその対照からなる固定集団に発生した白血病の確認はほぼ完全である．症例の探知は，種々の情報源からの資料を選別しているABCC-放影研白血病登録に基づいている．すべての報告例について適切な臨床記録と血液学的資料を入手した後，血液学専門医によって診断の確認が行われた．広島・長崎

TABLE 1 DISTRIBUTION OF LSS EXTENDED SAMPLE AND AVERAGE MARROW DOSE (GAMMA, NEUTRON, & TOTAL) BY CITY & TOTAL KERMA DOSE

表1 寿命調査拡大対象集団と平均骨髄線量(ガンマ線量，中性子線量，総線量)の分布：都市及びカーマ総線量別

Total Kerma Dose (rad)	Average Marrow Dose (rad)			Subjects	%
	Gamma	Neutron	Total		
		Hiroshima			
Unknown	?	?	?	1429	1.7
400-600	225.0	39.1	264.1	510	0.6
200-399	122.6	19.5	142.1	1028	1.3
100-199	62.8	8.6	71.4	1740	2.1
50- 99	32.6	3.9	36.5	2783	3.4
1- 49	5.1	0.6	5.7	26844	32.7
< 1	0.0	0.0	0.0	27577	33.6
NIC	–	–	–	20170*	24.6
Total				82081	100.0
		Nagasaki			
Unknown	?	?	?	957	3.6
400-600	291.0	3.3	294.3	377	1.4
200-399	149.6	1.3	150.9	992	3.7
100-199	81.3	0.6	81.9	1388	5.2
50- 99	39.6	0.0	39.6	1442	5.4
1- 49	5.6	0.0	5.6	11171	41.9
< 1	0.0	0.0	0.0	4004	15.0
NIC	–	–	–	6348	23.8
Total				26679	100.0

**Selected in 1950, 1951, & 1953.* 1950年，1951年，1953年に抽出

the diagnosis on every possible case of leukemia even among those individuals who died outside of Hiroshima or Nagasaki cities. The procedures for the diagnostic review and registration of leukemia cases have been described elsewhere.[15] By the end of November 1979, review of all possible leukemia cases reported through the end of December 1978 was completed. Leukosarcoma was excluded from the present analysis. Among the 109,000 individuals in the LSS extended sample, 202 developed leukemia with onset before the end of December 1978. Of these, in 13 cases onset was before 1 October 1950 and thus the present analysis of incidence is confined to 189 cases compared to 136 cases in the previous report.[6]

Table 1 shows the distribution of the LSS extended sample by average marrow dose (gamma rays, neutrons, and total), city, and kerma total dose classification. Hiroshima survivors were exposed to mixed gamma and neutron radiation

両市外で死亡した者を含め，すべての白血病の疑いのある症例の診断の確認が登録要領に要求されている．白血病の診断の確認と登録要領は別に記述されている．[15] 1978年12月までに報告された白血病の疑いのある全症例の検討は，1979年11月までに完了した．今回の解析からは白血肉腫は除外した．寿命調査拡大対象者109,000名から，1978年12月以前に発病した白血病症例は202名であった．そのうち，13例の発病は1950年10月以前であったので，今回の白血病発生についての解析は，前回の報告[6]が136例であったのに対し189例であった．

寿命調査拡大対象者のカーマ総線量区分別にみた都市別，平均骨髄線量(ガンマ線，中性子線，合計)の分布を表1に示した．広島の被爆者は，それぞれ

TABLE 2 CRUDE ANNUAL INCIDENCE RATE OF LEUKEMIA IN LSS EXTENDED SAMPLE BY CITY, TYPE OF LEUKEMIA, & DOSE, OCTOBER 1950-DECEMBER 1978

表2　寿命調査拡大対象集団の白血病粗年間発生率：都市，白血病病型及び線量別，1950年10月－1978年12月

Total Kerma Dose (rad)	Average Marrow Total Dose (rad)	Person-years	Incidence Rate of Leukemia (10^{-5})		
			Acute	Chronic Granulocytic	All Types
		Hiroshima			
Unknown	?	33651	8.9 (3)	5.9 (2)	14.9 (5)
400-600	264	12088	99.3 (12)	16.5 (2)	115.8 (14)
200-399	142	24748	40.4 (10)	36.4 (9)	76.8 (19)
100-199	71	41273	26.7 (11)	7.3 (3)	33.9 (14)
50- 99	37	66441	9.0 (6)	7.5 (5)	16.6 (11)
1- 49	6	648409	3.4 (22)	2.6 (17)	6.0 (39)
< 1	0	664462	4.5 (30)	1.2 (8)	5.7 (38)
NIC	–	467781	1.7 (8)	0.2 (1)	1.9 (9)
Total		1958853	5.2 (102)	2.4 (47)	7.6 (149)
		Nagasaki			
Unknown	?	23088	4.3 (1)	0.0 (0)	4.3 (1)
400-600	295	8885	67.5 (6)	11.3 (1)	78.8 (7)
200-399	151	25084	27.9 (7)	4.0 (1)	31.9 (8)
100-199	82	35021	11.4 (4)	0.0 (0)	11.4 (4)
50- 99	40	36060	0.0 (0)	0.0 (0)	0.0 (0)
1- 49	6	273013	2.9 (8)	1.5 (4)	4.4 (12)
< 1	0	98931	2.0 (2)	0.0 (0)	2.0 (3*)
NIC	–	158419	3.2 (5)	0.0 (0)	3.2 (5)
Total		658501	5.0 (33)	0.9 (6)	6.1 (40)

Number of cases in parentheses　( )内は症例数

**One case of chronic lymphocytic leukemia included*　慢性リンパ性白血病1例を含む

in every kerma total dose category, while Nagasaki survivors received little neutron exposure in the low dose categories and significant but still small neutron exposure in the high dose categories.

RESULTS

Annual Incidence Rate of Leukemia by Dose, City, and Type of Leukemia

Table 2 and Figure 1 show the crude annual incidence rate in the LSS extended sample during 1950-78 by dose, city, and two major types of leukemia. Note, first, that the risk of all types of leukemia increases with dose in both cities, except for Nagasaki survivors who received less than 100 rad in kerma total dose. Second, the risk of chronic granulocytic leukemia increases among individuals who received less than 50 rad in kerma total dose in Hiroshima, but

のカーマ総線量区分でガンマ線と中性子線の混合放射線に被曝したが，長崎の被爆者は低線量域でわずかの中性子線を受けたが，高線量域では有意な小量の中性子線に被曝した．

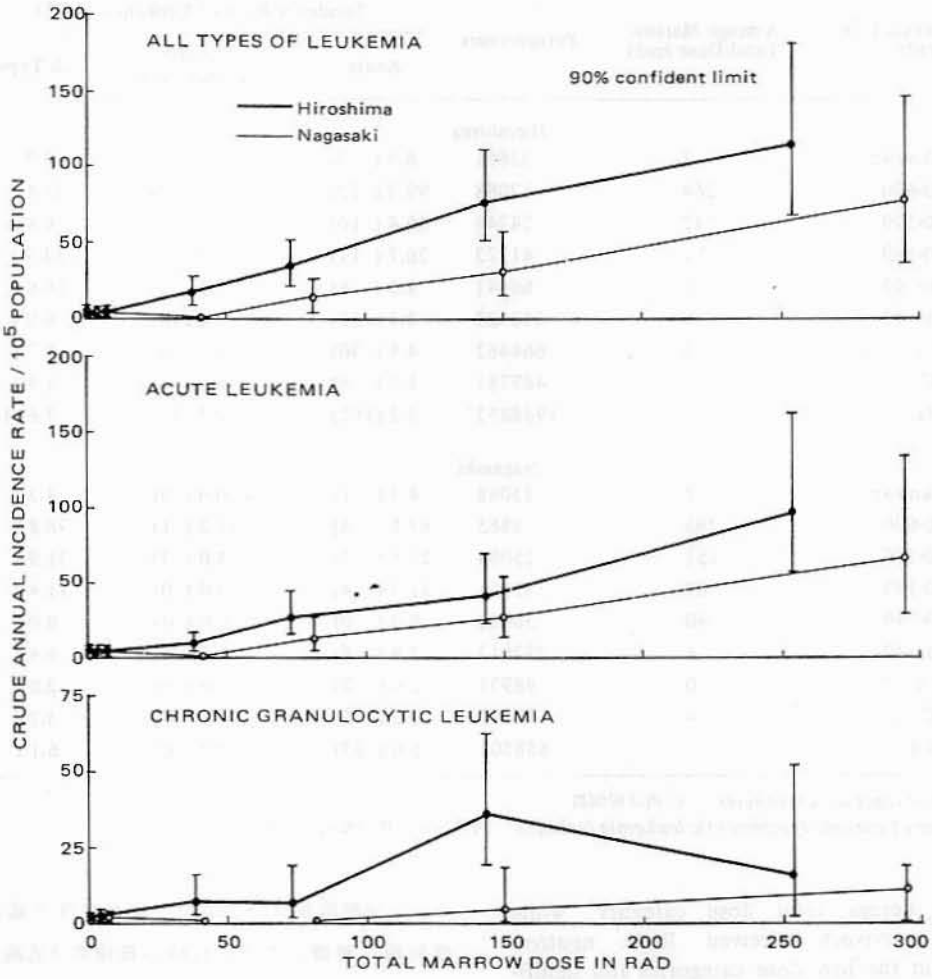
結　果

線量，都市，及び病型別にみた白血病の年間発生率

線量別，都市別，二つの主要病型別にみた寿命調査拡大対象における1950－78年の粗年間白血病発生率を表2と図1に示した．まず，カーマ総線量が100 rad 未満の長崎の被爆者を除けば，全白血病のリスクは線量の増加とともに増加することが認められた．次に，広島ではカーマ総線量が50rad 未満の者でも，慢性骨髄性白血病のリスクは増加しているが，長崎

FIGURE 1 CRUDE ANNUAL INCIDENCE RATE OF LEUKEMIA AMONG A-BOMB SURVIVORS IN LSS EXTENDED SAMPLE BY MARROW TOTAL DOSE, CITY, AND TYPE OF LEUKEMIA, 1950-78

図1　寿命調査拡大対象集団における白血病粗年間発生率：
骨髄総線量，都市及び白血病病型別，1950－78年



in Nagasaki the risk is significantly increased only among survivors who received 200 rad or more in kerma total dose. In summary, the shape of the dose-response curves is different between the two cities and for the two major types of leukemia. Although the radiation dose was calculated anew for Nagasaki survivors, the findings are quite similar to those given in the previous report.[6]

Annual Incidence Rate of All Types of Leukemia by Dose, City, Age ATB, and Period

Table 3 gives the standardized annual incidence rate adjusted for age ATB and the age ATB specific annual incidence rate for three dose classes, the two cities, and six periods. The

ではカーマ総線量が200rad 以上を受けた者のみに，リスクの有意の増加が認められた．要約すると，白血病の二つの主要病型と都市によって線量反応曲線の形状は異なっている．長崎の被爆者については放射線量を新たに計算したが，結果は前回の報告[6]の場合と全く同様であった．

線量，都市，原爆時年齢，及び期間別にみた全病型白血病の年間発生率

三つの線量区分別，都市別，六つの期間別にみた原爆時年齢を補正した標準化年間発生率と原爆時年齢別特殊年間発生率を表3に示した．高線量と

TABLE 3 AGE ATB SPECIFIC ANNUAL INCIDENCE RATE (PER 100,000) FOR ALL TYPES OF LEUKEMIA IN LSS EXTENDED SAMPLE BY CITY, DOSE, & PERIOD (5-YEAR INTERVALS), OCTOBER 1950-DECEMBER 1978

表3　寿命調査拡大対象集団における全病型白血病の原爆時年齢別にみた特殊年間発生率（100,000人当たり）：都市，線量及び期間別（5年区間），1950年10月－1978年12月

Kerma Dose & (Average Marrow Total Dose)	Age ATB	Period						
		Oct. 1950-Sep. 1955	Oct. 1955-Sep. 1960	Oct. 1960-Sep. 1965	Oct. 1965-Sep. 1970	Oct. 1970-Sep. 1975	Oct. 1975-Dec. 1978	Total
				Hiroshima				
100 +	< 15	190.7 (7)	55.3 (2)	0.0 (0)	0.0 (0)	28.9 (1)	0.0 (0)	49.8 (10)
(123.5)	15-29	149.1 (7)	43.2 (2)	44.0 (2)	44.8 (2)	23.1 (1)	0.0 (0)	55.2 (14)
	30-44	99.3 (4)	77.1 (3)	27.0 (1)	86.2 (3)	125.6 (4)	0.0 (0)	74.6 (15)
	45 +	0.0 (0)	100.1 (3)	40.9 (1)	109.7 (2)	82.9 (1)	192.5 (1)	63.7 (8)
	Total	112.8 (18)	66.1 (10)	28.1 (4)	52.7 (7)	57.4 (7)	13.7 (1)	60.2 (47)
	Rate*	109.8	68.9	28.0	60.2	65.1	48.1	60.8
1–99	< 15	4.9 (2)	7.4 (3)	5.0 (2)	0.0 (0)	2.5 (1)	0.0 (0)	3.5 (8)
(8.6)	15-29	3.0 (1)	0.0 (0)	9.1 (3)	3.1 (1)	6.3 (2)	14.9 (3)	5.4 (10)
	30-44	8.6 (3)	8.9 (3)	6.2 (2)	6.5 (2)	24.6 (7)	11.8 (2)	10.8 (19)
	45 +	14.0 (5)	6.6 (2)	12.4 (3)	0.0 (0)	15.1 (2)	16.5 (1)	10.2 (13)
	Total	7.6 (11)	5.8 (8)	7.7 (10)	2.5 (3)	10.6 (12)	8.7 (6)	7.0 (50)
	Rate	7.6	5.7	8.2	2.4	12.1	10.8	7.5
Control	< 15	0.0 (0)	3.0 (2)	0.0 (0)	3.0 (2)	1.5 (1)	2.4 (1)	1.6 (6)
(0.0)	15-29	6.1 (3)	1.8 (1)	1.8 (1)	7.4 (4)	5.7 (3)	3.0 (1)	4.3 (13)
	30-44	2.1 (1)	7.3 (4)	3.8 (2)	6.0 (3)	15.1 (7)	18.0 (5)	7.9 (22)
	45 +	2.3 (1)	4.3 (2)	2.7 (1)	0.0 (0)	9.6 (2)	0.0 (0)	3.2 (6)
	Total	2.5 (5)	4.0 (9)	1.9 (4)	4.5 (9)	7.0 (13)	6.2 (7)	4.2 (47)
	Rate	2.6	4.1	2.1	4.1	8.0	5.9	4.3
				Nagasaki				
100 +	< 15	129.1 (5)	52.5 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	32.9 (7)
(135.6)	15-29	74.6 (4)	18.9 (1)	38.3 (2)	0.0 (0)	0.0 (0)	0.0 (0)	24.0 (7)
	30-44	40.6 (1)	42.7 (1)	44.9 (1)	0.0 (0)	0.0 (0)	0.0 (0)	24.8 (3)
	45 +	0.0 (0)	65.9 (1)	0.0 (0)	106.8 (1)	0.0 (0)	0.0 (0)	31.0 (2)
	Total	74.2 (10)	38.6 (5)	24.1 (3)	8.4 (1)	0.0 (0)	0.0 (0)	27.5 (19)
	Rate	61.1	45.0	20.8	26.7	0.0	0.0	28.2
1–99	< 15	0.0 (0)	4.4 (1)	4.4 (1)	0.0 (0)	4.5 (1)	0.0 (0)	2.3 (3)
(9.5)	15-29	6.4 (1)	6.5 (1)	0.0 (0)	6.8 (1)	13.8 (2)	0.0 (0)	5.9 (5)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	10.3 (1)	0.0 (0)	0.0 (0)	1.8 (1)
	45 +	0.0 (0)	0.0 (0)	13.1 (1)	17.8 (1)	26.0 (1)	0.0 (0)	7.5 (3)
	Total	1.6 (1)	3.4 (2)	3.6 (2)	5.7 (3)	8.1 (4)	0.0 (0)	3.9 (12)
	Rate	1.6	2.7	4.4	8.7	11.1	0.0	4.4
Control	< 15	0.0 (0)	0.0 (0)	5.9 (1)	0.0 (0)	0.0 (0)	0.0 (0)	1.0 (1)
(0.0)	15-29	0.0 (0)	0.0 (0)	6.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	1.2 (1)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	23.3 (2)	25.5 (2)	0.0 (0)	8.0 (4)
	45 +	0.0 (0)	14.9 (1)	0.0 (0)	0.0 (0)	35.7 (1)	0.0 (0)	7.1 (2)
	Total	0.0 (0)	2.1 (1)	4.3 (2)	4.5 (2)	7.2 (3)	0.0 (0)	3.1 (8)
	Rate	0.0	3.7	3.2	5.8	15.3	0.0	4.3

Number of cases in parentheses ( )内は症例数．

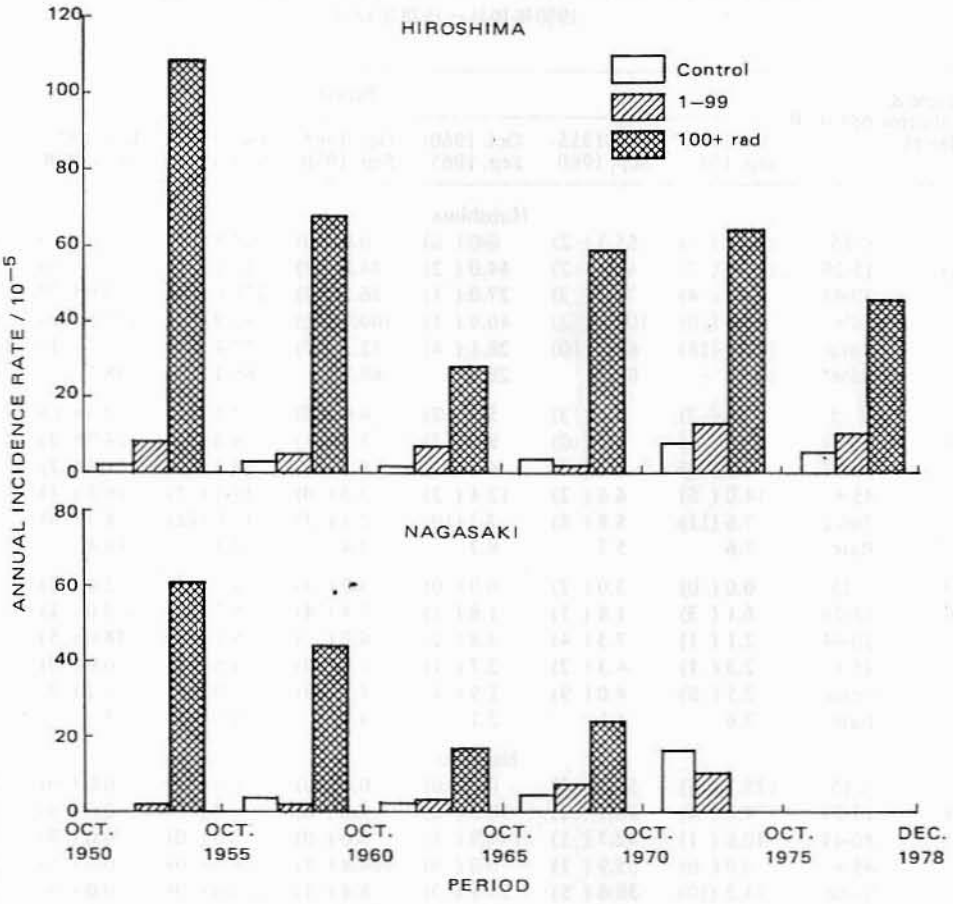
**Rate = Standardized annual incidence rate adjusted for age ATB* 発生率：原爆時年齢を補正した標準化年間発生率

Standard population = 10,000 population for each age ATB category. 標準母集団：各原爆時年齢群当たり人口10,000人．

Control = 0 rad & NIC 対照：0 rad と市内不在者

FIGURE 2 STANDARDIZED ANNUAL INCIDENCE RATE FOR ALL TYPES OF LEUKEMIA IN LSS EXTENDED SAMPLE BY CITY, DOSE, AND PERIOD, 1950-78

図2　寿命調査拡大対象集団における全病型白血病の標準化年間発生率: 都市，線量及び期間別，1950－78年

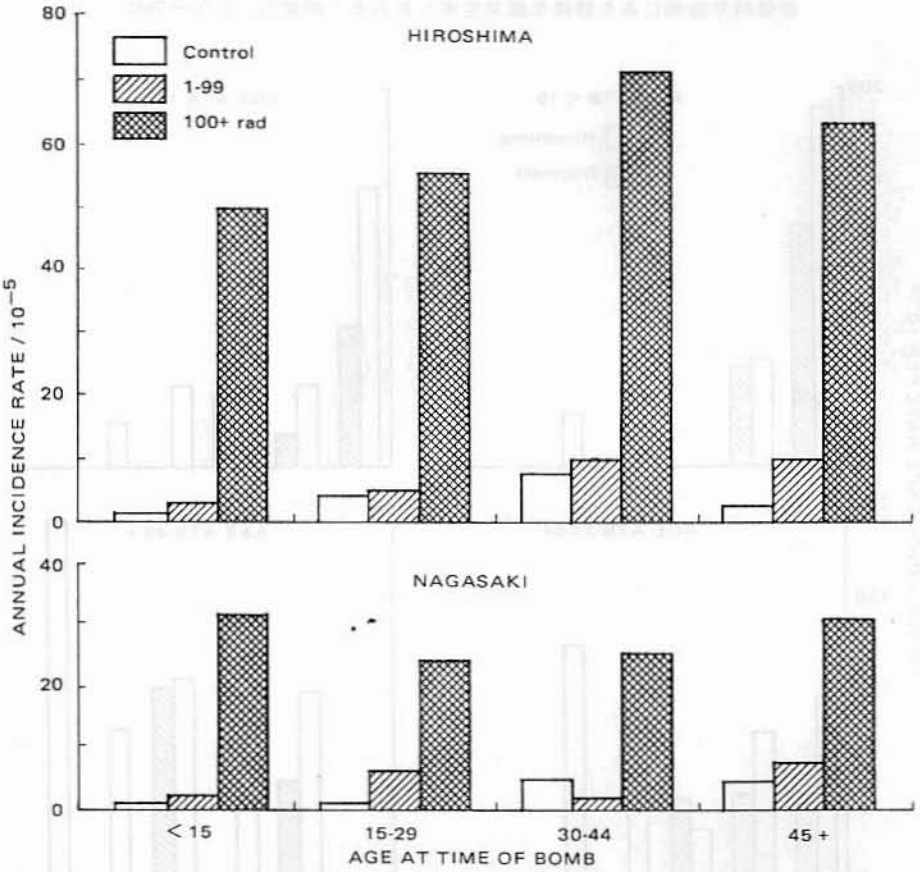


average marrow total dose in the high and low dose calsses is 123.5 rad in Hiroshima and 135.6 rad in Nagasaki among those individuals who received 100 rad or more in kerma total dose and 8.6 rad in Hiroshima and 9.5 rad in Nagasaki among those survivors who received 1-99 rad. Figure 2 shows the trend of the standardized annual incidence rate for all types of leukemia by dose and city. The excess risk in individuals who received 100 rad or more in kerma total dose has declined with time after exposure in both cities. In Hiroshima the downward trend has been slow and the effect extends to 1978, but in Nagasaki the excess risk declined sharply with time after exposure and disappeared by 1970 (25 years after exposure). Thus, the pattern of disappearance of the leukemogenic

低線量の領域の平均骨髄線量は，カーマ総線量が100 rad 以上の者では，広島123.5rad，長崎135.6rad であり，1－99rad の者では，広島8.6rad，長崎9.5 rad であった．図2には，線量別，都市別にみた全病型白血病の標準化年間発生率を示した．カーマ総線量が100rad 以上の者の過剰リスクは両市とも被爆後の時間の経過とともに減少した．広島ではその減少傾向は遅くその影響は1978年まで続いたが，長崎ではその過剰リスクは被爆後の時間の経過とともに急速に減少し，1970年(被爆25年後)までに消失した．したがって被爆後の時間の経過とともに，白血

FIGURE 3 AGE ATB SPECIFIC ANNUAL INCIDENCE RATE FOR ALL TYPES OF LEUKEMIA IN LSS EXTENDED SAMPLE BY CITY AND DOSE, 1950-78

図3　寿命調査拡大対象集団における全病型白血病の原爆時年齢別にみた特殊年間発生率：都市及び線量別，1950－78年

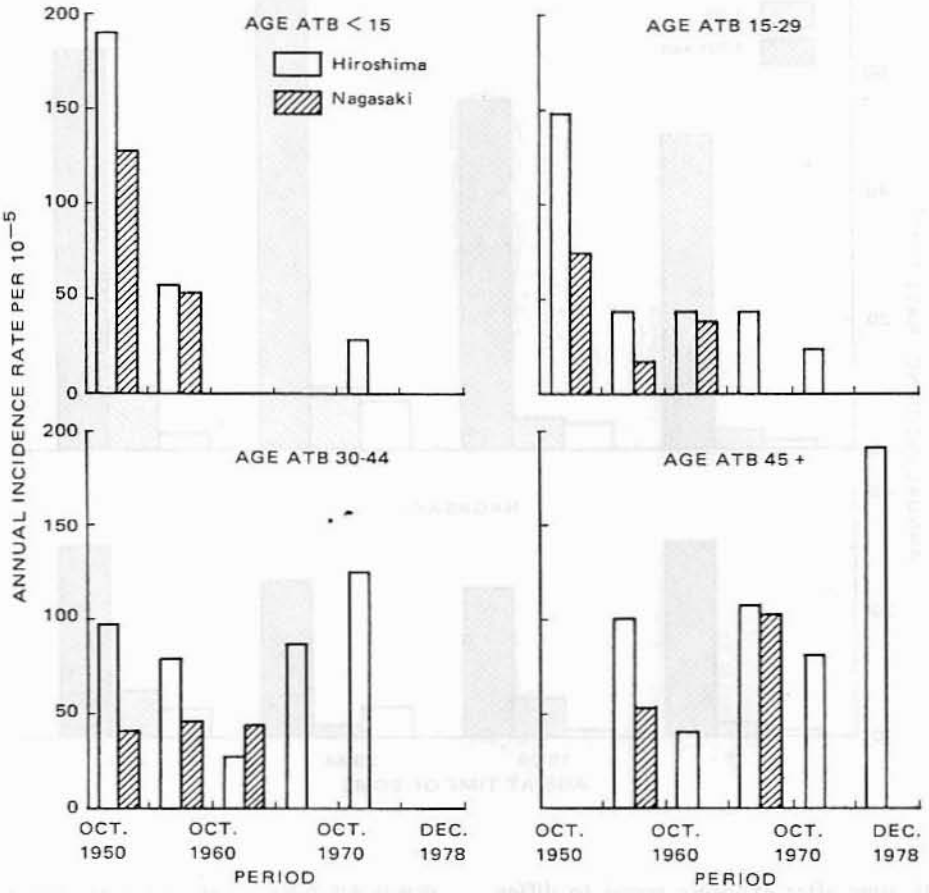


effect with time after exposure seems to differ by city. Figure 3 gives the age ATB specific annual incidence rate for all types of leukemia during 1950-78 by dose and city. The excess risk in individuals who received 100 rad or more in kerma total dose did not differ significantly among the four age ATB categories. Figure 4 shows the age ATB specific annual incidence rate for all types of leukemia among individuals who received 100 rad or more in kerma total dose by city and period. When the age ATB specific annual incidence rates are examined for dose and years after exposure, it is noted that the larger the excess risk among those of younger age ATB who received 100 rad or more in kerma total dose, the greater the effect of radiation in the early period and the more rapid the decline in risk up to 1960. The effect among those

病誘発効果の消失する様式は都市別に異なるようである．図3には線量別，都市別にみた1950－78年間の全病型白血病の原爆時年齢別特殊年間発生率を示した．カーマ総線量が100rad 以上で被曝した者の過剰リスクは，四つの原爆時年齢区分の間に有意な差異が認められなかった．図4には，市別，期間別にカーマ総線量が100rad 以上で被曝した者の全病型白血病の原爆時年齢別特殊年間発生率を示した．原爆時年齢別特殊年間発生率を線量，被爆後の経過年数について検討してみると，カーマ総線量が100rad 以上の者では原爆時年齢が若い者ほど，より大きい過剰リスクが認められ放射線の影響が初期において著しかったが，1960年までにリスクは急速に減少した．しかし原爆時年齢が30歳以上の者の影響は，

FIGURE 4 AGE ATB SPECIFIC ANNUAL INCIDENCE RATE FOR ALL TYPES OF LEUKEMIA AMONG SURVIVORS WHO RECEIVED 100 RAD OR MORE BY CITY AND PERIOD, 1950-78

図4　カーマ総線量が100rad 以上の被爆者における全病型白血病の原爆時年齢別にみた特殊年間発生率：都市及び期間別，1950－78年

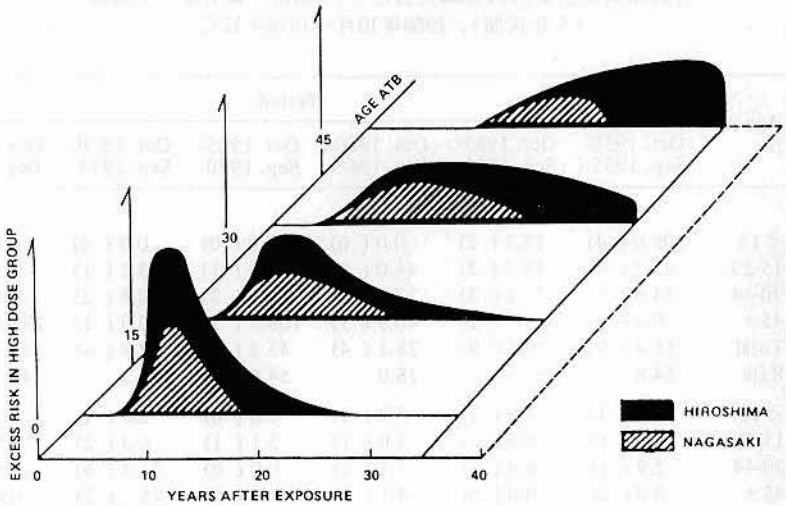


persons who were 30 years or more of age ATB, however, is of lesser magnitude, but it is more prolonged. The effect among individuals who were 45 years or more of age ATB did not appear until 1955 (10 years after exposure) and the risk has been the highest in the most recent 3 years in Hiroshima. The risk has been greater in Hiroshima than in Nagasaki for most age ATB groups and for most periods. After 1970, an excess risk in survivors who received 100 rad or more in kerma total dose is apparent only in Hiroshima survivors whose age ATB was 30 or more. Again, the leukemogenic effect to age ATB and years after exposure differs by city. A schematic diagram of the leukemogenic effect of radiation in A-bomb survivors by age ATB, elapsed years

その程度がより少ないが持続した．原爆時年齢が45歳以上の者では1955年（被爆10年後）までは出現せず，広島では最も最近の3年間のリスクが最大となっている．リスクはほとんどの原爆時年齢群と期間で広島が長崎よりも大きい．1970年以後は，カーマ総線量が100rad 以上の被爆者の過剰リスクは，原爆時年齢が30歳以上の広島の被爆者においてのみ明らかであった．原爆時年齢と被爆後の経過年数によって，白血病の誘発効果が都市別に異なることが再び観察された．図5には原爆時年齢，被爆後の経過年数，都市別にみた被爆者における放射線による白血病

FIGURE 5 SCHEMATIC DIAGRAM OF THE LEUKEMOGENIC EFFECT OF RADIATION BY AGE ATB AND ELAPSED YEARS AFTER EXPOSURE (LATENT PERIOD)

図 5　原爆時年齢及び被爆後経過年数(潜伏期)別にみた放射線による白血病誘発効果の模型図



after exposure and city is given in Figure 5. It is expected that radiation-induced leukemia in the high dose group will disappear almost completely within 40 years after exposure to the A-bomb.

誘発効果の模型を示した．高線量群における放射線誘発による白血病は，原爆被爆後40年以内にほぼ完全に消失すると推測される．

Annual Incidence Rate of Acute Leukemia by Dose, City, Age ATB, and Period

Table 4 shows the annual incidence rate of acute leukemia by dose, city, age ATB, and six periods. The excess risk in individuals who received 100 rad or more in kerma total dose has declined with elapsed years after exposure in both cities. The pattern of the leukemogenic effect and its disappearance with time after exposure by age ATB and city is quite similar to that observed for all types of leukemia.

線量，都市，原爆時年齢及び期間別にみた急性白血病の年間発生率

線量別，都市別，原爆時年齢別及び六つの期間別にみた急性白血病の年間発生率を表4に示した．カーマ総線量が100rad 以上の者の過剰リスクは，両市とも被爆後の年数の経過とともに減少した．原爆時年齢別，都市別にみた白血病誘発効果と，その被爆後の時間の経過とともに消失する様式は，全病型白血病について観察されたものと全く同様であった．

Annual Incidence Rate of Chronic Granulocytic Leukemia by Dose, City, Age ATB, and Period

Table 5 gives the annual incidence rates for chronic granulocytic leukemia by dose, city, age ATB, and six periods. An excess risk among survivors who received 100 rad or more kerma total dose became apparent in both cities 5-10 years after exposure. In Nagasaki, a greater risk was seen 5-10 years after exposure among those whose age ATB was less than 15. Although the observed number of chronic granulocytic

線量，都市，原爆時年齢及び期間別にみた慢性骨髄性白血病の年間発生率

線量別，都市別，原爆時年齢別及び六つの期間別にみた慢性骨髄性白血病の年間発生率を表5に示した．カーマ総線量が100rad 以上の被爆者の過剰リスクは，被爆5－10年後に両市とも明らかであった．長崎では，リスクの増加は原爆時年齢15歳未満の者で被爆5－10年後に認められた．資料を都市別，原爆

TABLE 4 AGE ATB SPECIFIC ANNUAL INCIDENCE RATE (PER 100,000) OF ACUTE LEUKEMIA IN LSS EXTENDED SAMPLE BY CITY, DOSE, & PERIOD (5-YEAR INTERVALS), OCTOBER 1950-DECEMBER 1978

表 4　寿命調査拡大対象集団における急性白血病の原爆時年齢別にみた特殊年間発生率（100,000人当たり）：都市，線量及び期間別（5年区間），1950年10月－1978年12月

Kerma Dose & (Average Marrow Total Dose)	Age ATB	Period						
		Oct. 1950-Sep. 1955	Oct. 1955-Sep. 1960	Oct. 1960-Sep. 1965	Oct. 1965-Sep. 1970	Oct. 1970-Sep. 1975	Oct. 1975-Dec. 1978	Total
				Hiroshima				
100 +	< 15	109.0 (4)	55.3 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	29.9 (6)
(123.5)	15-29	85.2 (4)	43.2 (2)	44.0 (2)	22.4 (1)	23.1 (1)	0.0 (0)	39.4 (10)
	30-44	24.8 (1)	77.1 (3)	27.0 (1)	86.2 (3)	62.8 (2)	0.0 (0)	49.7 (10)
	45 +	0.0 (0)	66.7 (2)	40.9 (1)	109.7 (2)	82.9 (1)	192.5 (1)	55.7 (7)
	Total	56.4 (9)	59.5 (9)	28.1 (4)	45.2 (6)	32.8 (4)	13.7 (1)	42.2 (33)
	Rate	54.8	60.6	28.0	54.6	42.2	48.1	43.7
1–99	< 15	2.5 (1)	4.9 (2)	5.0 (2)	0.0 (0)	2.5 (1)	0.0 (0)	2.7 (6)
(8.6)	15-29	3.0 (1)	0.0 (0)	3.0 (1)	3.1 (1)	6.3 (2)	9.9 (2)	3.8 (7)
	30-44	2.9 (1)	8.9 (3)	3.1 (1)	0.0 (0)	21.1 (6)	5.9 (1)	6.8 (12)
	45 +	0.0 (0)	0.0 (0)	4.1 (1)	0.0 (0)	15.1 (2)	0.0 (0)	2.3 (3)
	Total	2.1 (3)	3.6 (5)	3.9 (5)	0.8 (1)	9.7 (11)	4.4 (3)	3.9 (28)
	Rate	2.1	3.5	3.8	0.8	11.3	4.0	3.9
Control	< 15	0.0 (0)	1.5 (1)	0.0 (0)	1.5 (1)	1.5 (1)	2.4 (1)	1.1 (4)
(0.0)	15-29	6.1 (3)	1.8 (1)	0.0 (0)	7.4 (4)	5.7 (3)	3.0 (1)	4.0 (12)
	30-44	2.1 (1)	7.3 (4)	3.8 (2)	2.0 (1)	8.6 (4)	18.0 (5)	6.1 (17)
	45 +	2.3 (1)	4.3 (2)	2.7 (1)	0.0 (0)	4.8 (1)	0.0 (0)	2.7 (5)
	Total	2.5 (5)	3.0 (8)	1.4 (3)	3.0 (6)	4.9 (9)	6.2 (7)	3.4 (38)
	Rate	2.6	3.7	1.6	2.7	5.2	5.9	3.5
				Nagasaki				
100 +	< 15	77.4 (3)	52.5 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	23.5 (5)
(135.6)	15-29	74.6 (4)	18.9 (1)	38.3 (2)	0.0 (0)	0.0 (0)	0.0 (0)	24.0 (7)
	30-44	40.6 (1)	42.7 (1)	44.9 (1)	0.0 (0)	0.0 (0)	0.0 (0)	24.8 (3)
	45 +	0.0 (0)	65.9 (1)	0.0 (0)	106.8 (1)	0.0 (0)	0.0 (0)	31.0 (2)
	Total	59.4 (8)	38.6 (5)	24.1 (3)	8.4 (1)	0.0 (0)	0.0 (0)	24.6 (17)
	Rate	48.2	45.0	20.8	26.7	0.0	0.0	25.8
1–99	< 15	0.0 (0)	0.0 (0)	4.4 (1)	0.0 (0)	4.5 (1)	0.0 (0)	1.6 (2)
(9.5)	15-29	6.4 (1)	6.5 (1)	0.0 (0)	6.8 (1)	6.9 (1)	0.0 (0)	4.7 (4)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	10.3 (1)	0.0 (0)	0.0 (0)	1.8 (1)
	45 +	0.0 (0)	0.0 (0)	0.0 (0)	17.8 (1)	0.0 (0)	0.0 (0)	2.5 (1)
	Total	1.6 (1)	1.7 (1)	1.8 (1)	5.7 (3)	4.0 (2)	0.0 (0)	2.6 (8)
	Rate	1.6	1.6	1.1	8.7	2.9	0.0	2.7
Control	< 15	0.0 (0)	0.0 (0)	5.9 (1)	0.0 (0)	0.0 (0)	0.0 (0)	1.0 (1)
(0.0)	15-29	0.0 (0)	0.0 (0)	6.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)	1.2 (1)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	11.7 (1)	25.5 (2)	0.0 (0)	6.0 (3)
	45 +	0.0 (0)	14.9 (1)	0.0 (0)	0.0 (0)	35.7 (1)	0.0 (0)	7.1 (2)
	Total	0.0 (0)	2.1 (1)	4.3 (2)	2.3 (1)	7.2 (3)	0.0 (0)	2.7 (7)
	Rate	0.0	3.7	3.2	2.9	15.3	0.0	3.8

See footnote Table 3. 表3の脚注参照

TABLE 5 AGE ATB SPECIFIC ANNUAL INCIDENCE RATE (PER 100,000) OF CHRONIC GRANULOCYTIC LEUKEMIA IN LSS EXTENDED SAMPLE BY CITY, DOSE, AND PERIOD (5-YEAR INTERVALS), OCTOBER 1950-DECEMBER 1978

表5　寿命調査拡大対象集団における慢性骨髄性白血病の原爆時年齢別にみた特殊年間発生率（100,000人当たり）：都市，線量及び期間別（5年区間），1950年10月－1978年12月

Kerma Dose & (Average Marrow Total Dose)	Age ATB	Period						
		Oct. 1950-Sep. 1955	Oct. 1955-Sep. 1960	Oct. 1960-Sep. 1965	Oct. 1965-Sep. 1970	Oct. 1970-Sep. 1975	Oct. 1975-Dec. 1978	Total
				Hiroshima				
100 +	< 15	81.7 (3)	0.0 (0)	0.0 (0)	0.0 (0)	28.9 (1)	0.0 (0)	19.9 (4)
(123.5)	15-29	63.9 (3)	0.0 (0)	0.0 (0)	22.4 (1)	0.0 (0)	0.0 (0)	15.8 (4)
	30-44	74.5 (3)	0.0 (0)	0.0 (0)	0.0 (0)	62.8 (2)	0.0 (0)	24.9 (5)
	45 +	0.0 (0)	33.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	8.0 (1)
	Total	56.4 (9)	6.6 (1)	0.0 (0)	7.5 (1)	24.6 (3)	0.0 (0)	17.9 (14)
	Rate	55.0	8.4	0.0	5.6	22.9	0.0	17.2
1－99	< 15	2.5 (1)	2.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.9 (2)
(8.6)	15-29	0.0 (0)	0.0 (0)	6.1 (2)	0.0 (0)	0.0 (0)	5.0 (1)	1.6 (3)
	30-44	5.8 (2)	0.0 (0)	3.1 (1)	6.5 (2)	3.5 (1)	5.9 (1)	4.0 (7)
	45 +	14.0 (5)	6.6 (2)	8.2 (2)	0.0 (0)	0.0 (0)	16.5 (1)	7.8 (10)
	Total	5.5 (8)	2.2 (3)	3.9 (5)	1.7 (2)	0.9 (1)	4.4 (3)	3.1 (22)
	Rate	5.6	2.3	4.4	1.6	0.9	6.9	3.6
Control	< 15	0.0 (0)	1.5 (1)	0.0 (0)	1.5 (1)	0.0 (0)	0.0 (0)	0.5 (2)
(0.0)	15-29	0.0 (0)	0.0 (0)	1.8 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	4.0 (2)	6.5 (3)	0.0 (0)	1.8 (5)
	45 +	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	4.8 (1)	0.0 (0)	0.5 (1)
	Total	0.0 (0)	0.4 (1)	0.5 (1)	1.5 (3)	2.2 (4)	0.0 (0)	0.8 (9)
	Rate	0.0	0.4	0.5	1.4	2.8	0.0	0.8
				Nagasaki				
100 +	< 15	51.6 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	9.4 (2)
(135.6)	15-29	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	45 +	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	Total	14.8 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	2.9 (2)
	Rate	12.9	0.0	0.0	0.0	0.0	0.0	2.4
1－99	< 15	0.0 (0)	4.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.8 (1)
(9.5)	15-29	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	6.9 (1)	0.0 (0)	1.2 (1)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	45 +	0.0 (0)	0.0 (0)	13.1 (1)	0.0 (0)	26.0 (1)	0.0 (0)	5.0 (2)
	Total	0.0 (0)	1.7 (1)	1.8 (1)	0.0 (0)	4.0 (2)	0.0 (0)	1.3 (4)
	Rate	0.0	1.1	3.3	0.0	8.2	0.0	1.8
Control	< 15	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
(0.0)	15-29	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	30-44	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	45 +	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	Total	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
	Rate	0.0	0.0	0.0	0.0	0.0	0.0	0.0

See footnote Table 3. 表3の脚注参照

TABLE 6 AGE ATB SPECIFIC ANNUAL INCIDENCE RATE (PER 100,000) OF LEUKEMIA AMONG SURVIVORS WHO RECEIVED 100 RAD OR MORE IN KERMA TOTAL DOSE, BY TYPE OF LEUKEMIA & PERIODS, HIROSHIMA & NAGASAKI, OCTOBER 1950-DECEMBER 1978

表6　カーマ総線量が100rad以上の被爆者における白血病の原爆時年齢別にみた特殊年間発生率（100,000人当たり）：白血病病型及び期間別，広島・長崎，1950年10月－1978年12月

Item	Age ATB			
	< 15	15-29	30-44	45 +
		Total Period		
Person-years	41326	54559	32205	19011
CGL	14.5 (6)	7.3 (4)	15.5 (5)	5.3 (1)
AGL	2.4 (1)	12.8 (7)	27.9 (9)	36.8 (7)
ALL	12.1 (5)	9.2 (5)	6.2 (2)	5.3 (1)
AL	12.1 (5)	9.2 (5)	6.2 (2)	5.3 (1)
		October 1950-September 1955		
Person-years	7545	10060	6489	5346
CGL	66.3 (5)	29.8 (3)	46.2 (3)	0.0 (0)
AGL	0.0 (0)	39.8 (4)	30.8 (2)	0.0 (0)
ALL	53.0 (4)	29.8 (3)	0.0 (0)	0.0 (0)
AL	39.8 (3)	9.9 (1)	0.0 (0)	0.0 (0)
		October 1955-September 1960		
Person-years	7429	9908	6230	4516
CGL	0.0 (0)	0.0 (0)	0.0 (0)	22.1 (1)
AGL	13.5 (1)	0.0 (0)	64.2 (4)	44.3 (2)
ALL	13.5 (1)	10.1 (1)	0.0 (0)	0.0 (0)
AL	26.9 (2)	20.2 (2)	0.0 (0)	22.1 (1)
		October 1960-September 1970		
Person-years	14597	19349	11485	6446
CGL	0.0 (0)	5.2 (1)	0.0 (0)	0.0 (0)
AGL	0.0 (0)	10.3 (2)	26.1 (3)	46.5 (3)
ALL	0.0 (0)	5.2 (1)	8.7 (1)	15.5 (1)
AL	0.0 (0)	10.3 (2)	8.7 (1)	0.0 (0)
		October 1970-December 1978		
Person-years	11755	15242	8001	2703
CGL	8.5 (1)	0.0 (0)	25.0 (2)	0.0 (0)
AGL	0.0 (0)	6.6 (1)	0.0 (0)	74.0 (2)
ALL	0.0 (0)	0.0 (0)	12.5 (1)	0.0 (0)
AL	0.0 (0)	0.0 (0)	12.5 (1)	0.0 (0)

Number of cases in parentheses. ( )内は症例数.

CGL – Chronic granulocytic leukemia, 慢性骨髄性白血病 *AGL – Acute granulocytic leukemia,* 急性骨髄性白血病

ALL – Acute lymphocytic leukemia, 急性リンパ性白血病 *AL – Other types of acute leukemia.* その他の病型の急性白血病

leukemia cases is small, on classifying the data by city, age ATB, and period, the pattern of radiation induction of chronic granulocytic leukemia appears to differ by city.

Annual Incidence Rate of Leukemia among Survivors Who Received 100 rad or more by Subtype of Leukemia and Age ATB

Table 6 presents the age ATB specific incidence rates of leukemia among Hiroshima and Nagasaki survivors who received 100 rad or more kerma total dose by four age ATB groups, subtype of leukemia, and four periods. As shown in the upper panel, the risk of acute granulocytic leukemia increases with age ATB, but the risk of acute lymphocytic leukemia, other types of acute leukemia, and chronic granulocytic leukemia do not differ significantly among the four age ATB groups during the total period.

As shown in the lower panel, it also appears that the risk of myelogenous leukemia (acute and chronic leukemia), acute lymphocytic leukemia, and other types of acute leukemia was greater in the younger age ATB group in the early years, and has become greater in the older age ATB group only as the years after exposure have elapsed. After 1970 radiation was effective for induction of only acute granulocytic leukemia among those aged 45 years or more ATB. The radiation induction of incidence of all common types of leukemia except chronic lymphocytic leukemia thus depends upon age ATB and elapsed years after exposure.

DISCUSSION

Our earlier publications describe the leukemogenic effect of exposure to the A-bomb in relation to quality and quantity of radiation, years after exposure, age at exposure, and type of leukemia in a fixed cohort during the period from October 1950 to December 1971.[6,7] The present analysis extends these observations on the incidence of leukemia through 1978 and 53 cases have been added to the previous report through the extension of the observation period by seven years.

In the present study our interest focused on the following issues:

Will an extension of the observation period

時年齢別，期間別に分類すると，慢性骨髄性白血病の観察数は少なかったけれども，慢性骨髄性白血病の放射線誘発の様式は，都市別に差異がある．

白血病病型及び原爆時年齢別にみた100rad以上の被爆者の白血病の年間発生率

四つの原爆時年齢群別，白血病病型別及び四つの期間別にみたカーマ総線量が100rad以上の広島・長崎の被爆者の原爆時年齢別特殊年間発生率を表6に示した．最上段に示したように，急性骨髄性白血病のリスクは原爆時年齢の増加とともに増加しているが，急性リンパ性白血病，その他の病型の急性白血病及び慢性骨髄性白血病のリスクは，全期間で四つの原爆時年齢群の間に有意な差異が認められなかった．

下段に示したように，骨髄性白血病（急性と慢性），急性リンパ性白血病，その他の病型の急性白血病のいずれのリスクも早期には原爆時年齢が若い群により大きく，被爆後の年月の経過により，原爆時年齢が高い群により大きくなることは明らかである．1970年以後は，原爆時年齢が45歳以上の者の急性骨髄性白血病のみに放射線の誘発効果を認めた．慢性リンパ性白血病を除き，すべての一般的な白血病の病型についての放射線誘発効果は，原爆時年齢と被爆後の経過年数に依存している．

考　察

前回の報告では，1950年10月から1971年12月までの間に固定集団から発生した白血病について，原爆の被曝による白血病の誘発効果を放射線の線質，線量，被爆後の経過年数，原爆時年齢及び白血病の病型との関係について報告した．[6,7] 今回の解析では1978年まで白血病発生の観察を延長し，観察期間を7年間延長したので前回の報告後53例が追加された．

今回の研究では下記の事項に重点を置いた．

観察期間を延長することによって，長崎の低線

reveal an increased risk of leukemia among Nagasaki survivors who received low doses?

Will the excess risk observed in the Hiroshima survivors through 1971 persist after 1971, and will it reappear in the Nagasaki survivors who have shown no apparent effect since July 1966?

If an excess risk persists in the high dose group, what age groups and what types of leukemia will show this excess?

Are there any differences from the previously predicted model in the pattern of development of radiation-induced leukemia in relation to time, type of leukemia, and age ATB?

The results presented here demonstrate that the risk of all types of leukemia increased with dose in both cities, except among individuals who received less than 100 rad kerma total dose in Nagasaki. The excess risk is greater in Hiroshima than in Nagasaki in every kerma total dose category, although the average marrow total dose (sum of the gamma and neutron dose) is quite similar in the same kerma total dose class in Hiroshima and Nagasaki. The average marrow total dose is about 123-136 rad among those survivors who received 100 rad or more kerma total dose and about 9-10 rad among those who received 1-99 rad kerma total dose. Although the present analysis uses the new dosimetry system for Nagasaki, the results are consistent with those previously reported.

Again, chronic lymphocytic leukemia was not detected among survivors who received 1 rad or more in this fixed cohort during 1950-78. According to the RERF Leukemia Registry and a case report,[16] only two cases of chronic lymphocytic leukemia have been identified in the 33 years (to 1978) since the bombs among survivors who received 100 rad or more kerma total dose. Radiation does not appear to induce chronic lymphocytic leukemia in this population.

Examination of radiation leukemogenesis to years after exposure revealed a steady decline with time in the excess risk among individuals who received 100 rad or more kerma total dose. In Hiroshima, the risk has declined slowly with elapsed years after exposure. In Nagasaki, the excess risk among individuals who received 100 rad or more kerma total dose was remarkable in 1950-55, but has declined sharply since, and no

量被爆者の白血病のリスクの増加が認められるか.

1971年まで広島の被爆者に認められた過剰リスクが1971年以後も続いているか，また，1966年7月以後明白な影響の認められない長崎の被爆者で過剰リスクが再び現れるか.

もし，過剰リスクが高線量群で続いているならば，どの年齢群でどの白血病病型がこの過剰を示しているか.

経年別，白血病の病型別，原爆時年齢別にみた放射線誘発白血病の発現様式についての前回の予測模型に相違があるか.

今回報告した結果では，長崎のカーマ総線量が100 rad 未満の者を除けば，全病型白血病のリスクは両市とも線量の増加とともに増加した．過剰リスクはすべてのカーマ総線量区分で広島が長崎より大きかったが，平均骨髄総線量（ガンマ線と中性子線の線量の和）は広島・長崎とも，同じカーマ総線量では全く同様であった．平均骨髄総線量は，カーマ総線量が100rad 以上の被爆者では約123－136rad，カーマ総線量が1－99rad の者では約9－10rad であった．今回の解析は，長崎では新しい線量測定法を用いたが，結果は前回の報告と同様であった．

今回もまた，1950－78年の間に固定集団中の1 rad 以上の被爆者には慢性リンパ性白血病は探知されなかった．放影研白血病登録と症例報告[16]によれば，カーマ総線量が100rad 以上の被爆者から，被爆後33年間（1978年まで）に2例の慢性リンパ性白血病が確認された．この集団では，放射線は慢性リンパ性白血病を誘発しないと思われる．

被爆後経年的に放射線誘発白血病を検討してみると，カーマ総線量が100rad 以上の者では過剰リスクは年数の経過とともに一貫して減少していることが示された．広島ではそのリスクは被爆後の年数の経過とともにゆっくり減少したが，長崎ではカーマ総線量が100rad 以上の者の過剰リスクは1950－55年の間に顕著であったが，その後急速に減少し1970年（被爆

excess risk has been seen since 1970 (25 years after exposure). The risk remains high, however, among similarly exposed Hiroshima survivors who were 30 years of age or older ATB. The latent period for radiation-induced leukemia seems to differ between Hiroshima and Nagasaki survivors.

When the leukemogenic effect of radiation to age ATB is examined by city and dose, the excess risk in those survivors who received 100 rad or more kerma total dose does not seem to be significantly different by age ATB, although the excess risk in every age ATB category is greater in Hiroshima than in Nagasaki. Again, the magnitude of the effect by age ATB seems to differ by city.

When the leukemogenic effect of radiation to age ATB and elapsed years after exposure was examined for those who received 100 rad or more kerma total dose, latency was found to be shorter in the younger age ATB group and delayed in the older age ATB group, especially in Hiroshima survivors, although there are some city differences in the pattern of disappearance of the leukemogenic effect with time after exposure.

Analysis of the incidence of acute leukemia reveals that the risk was significantly elevated in both cities among those individuals who received 100 rad or more kerma total dose. The maximal latent period of radiation-induced acute leukemia appears to be shorter among younger individuals ATB than among the oldest individuals ATB and the duration of the effect is prolonged in older age ATB subjects. The pattern of latency of radiation-induced acute leukemia to age ATB also seems to differ by city.

The incidence rate of chronic granulocytic leukemia has increased with dose from doses of less than 50 rad kerma total dose in Hiroshima survivors but in Nagasaki only among individuals who received 200 rad or more kerma total dose. In Hiroshima, the peak incidence was seen 5 to 10 years after exposure among all age ATB groups except in the group aged 45 or more ATB. A prolonged leukemogenic effect in subsequent years was suggested only in Hiroshima survivors. In Nagasaki, however, an excess risk in similarly exposed persons was seen only during the period between 1950-55 among those who were less than age 15 ATB. Again, the pattern of dose

25年後)以後は過剰リクスがみられなかった．しかし，同様な線量に被曝した原爆時年齢30歳以上の広島の被爆者では，その過剰リスクは高いまま持続した．放射線誘発白血病の潜伏期は，広島と長崎の被爆者の間には相違があるように思われる．

都市別，線量別に原爆時年齢についての放射線による白血病誘発効果を検討してみると，カーマ総線量が100rad 以上の被爆者の過剰リスクは，原爆時年齢別に有意な差異がないようであるが，すべての原爆時年齢区分において過剰リスクは広島が長崎よりも大きかった．この場合もまた，原爆時年齢別にみた影響の程度は都市別に相違があるようである．

原爆時年齢と被爆後の経過年数についての放射線の白血病誘発効果をカーマ総線量100rad 以上の者について検討してみると，その潜伏期は原爆時年齢が若年の群では短く高齢者群では遅れているが，特に広島の被爆者でこの傾向が認められ，被爆後の白血病誘発効果の経時的消失の様式は都市別に若干差異がある．

急性白血病の発生の解析では，カーマ総線量が100 rad 以上の者では，両市ともリスクは有意に増加した．放射線により誘発された急性白血病の最大潜伏期は，原爆時年齢がより若年の者は高齢である者より短く，その影響の持続期間は高年齢者の方が長かった．原爆時年齢別にみた放射線により誘発された急性白血病の潜伏期の様式は，都市別に相違があるように思われる．

慢性骨髄性白血病の発生率は，広島ではカーマ総線量50rad 未満でも線量とともに増加したが，長崎ではカーマ総線量が200rad 以上の者のみに線量とともに増加した．広島では，発生のピークは原爆時年齢45歳以上の者を除くすべての年齢群で被爆 5 －10年後に認められた．広島の被爆者においてのみその後も持続した白血病誘発効果が示唆された．しかし長崎では，同様に被爆した者の過剰リスクは，原爆時年齢が15歳未満の者に1950－55年の期間においてのみ認められた．ここでもまた，放射線により誘発

response and development of radiation-induced chronic granulocytic leukemia differs by city.

Kneale and Stewart[17] have suggested that the cohort of A-bomb survivors who were children ATB is biased because only the fittest survived the high death rate from infection following the loss of immunological competence they postulate to be a part of the "preleukemic condition". But a previous analysis[18] of the excess risk of leukemia among survivors who were children ATB and the present analysis suggest that the leukemogenic effect among survivors who received 100 rad or more kerma total dose does not differ by age ATB except for acute granulocytic leukemia. Although Court Brown and Doll[19] reported that the excess risk of leukemia increases with age in ankylosing spondylitis patients after X-ray treatment, an increased risk with age ATB has been observed only for acute granulocytic leukemia in A-bomb survivors.

When the incidence of leukemia during 1975-78 was examined among individuals who received 100 rad or more kerma total dose, only one case of acute granulocytic leukemia was observed in Hiroshima survivors whose age ATB was 45 or more. It seems unlikely that a greater excess risk of leukemia among survivors who received 100 rad or more kerma total dose at age ATB of more than 45 will be detected in the future because only 20% of these individuals were still alive at the end of 1978. In Nagasaki, there has been no evidence of an excess risk of leukemia since July 1966 in individuals who received 100 rad or more kerma total dose. If an excess risk of leukemia does not reappear in the future among subjects exposed at younger age to 100 rad or more kerma total dose, it is speculated that radiation-induced leukemia will disappear among A-bomb survivors some 35-40 years after exposure to the A-bomb. It is important to confirm this prediction through future investigations.

された慢性骨髄性白血病の線量反応と発現の様式は，都市別に相違のあることが認められた．

Kneale と Stewart[17] は，原爆時小児であった被爆者の固定集団は，"前白血病状態"の一部とみなされる免疫機能の喪失に続く感染による高い死亡率にもかかわらず生き残った強健な者のみであるという偏りがあることを示唆した．しかし，原爆時小児であった被爆者の白血病の過剰リスクについての前回の解析[18]と今回の解析では，カーマ総線量が100 rad以上の被爆者の白血病誘発効果は，急性骨髄性白血病を除けば，原爆時年齢で差異がないことが示唆された．Court Brown と Doll[19] は，X線治療後の強直性脊椎炎の患者に認められた白血病の過剰リスクは年齢の増加とともに増加することを報告したが，被爆者では原爆時年齢とともにリスクが増加したのは急性骨髄性白血病のみであった．

1975－78年の白血病発生について，カーマ総線量が100rad以上の者について検討してみると，急性骨髄性白血病が1例のみ原爆時年齢45歳以上の広島の被爆者に観察された．原爆時年齢が45歳以上でカーマ総線量が100rad以上の被爆者の白血病の過剰リスクの増加は，将来発見されることはないように思える．なぜならば，1978年末までにこれらの者はわずかに20%しか生存していなかった．長崎のカーマ総線量が100rad以上の者では，1966年7月以降白血病の過剰リスクは認められていない．もし，カーマ総線量が100rad以上の若年被爆者に将来白血病の過剰リスクが再び現れない場合は，原爆後約35－40年で被爆者における放射線誘発白血病は消失するものと推測される．今後の調査を通じてこの推測を確認することが重要である．

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