Medical X-ray Exposure Among Hiroshima and Nagasaki A-bomb Survivors

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広島・長崎における原爆被爆者の医療用X線被爆

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要　約

原爆被爆者の後障害に関する長期的調査において，附随的な照射源である医療用X線について調査研究を行なつた．調査は主としてＡＢＣＣ一予研成人健康調査受診者について実施した．成人健康調査対象者のうち広島では平均23%，長崎では12%が，ＡＢＣＣにおける定期診察前3カ月以内に，その他の医療機関でX線検査を受けていた．成人健康調査における被爆者は対照者に比べて医療用X線検査を受ける頻度が有意に高かつたが，これら2群間に放射線影響の差が生じるほどの線量差ではなかつた．医療用X線による集積線量は，広島では爆心地より2,200m，長崎では3,200mの距離における原爆による線量とほぼ同じであつた．ＡＢＣＣにおけるX線検査による線量は，個々の成人健康調査対象者について計算されており，検査を実施するごとにその線量を記入して，各対象者の原爆による線量との比較検討ができるようにしている．各対象者が他の病医院で受けた透視検査，間接撮影ならびに放射線治療は，将来の参考のために記録保存されている．

1948年以来，広島・長崎における放射線診療活動は着実に増大し，両市間に著しい差がある．1946～63の間における骨髄の集積線量は広島で1269g-radおよび長崎で454g-radであつた．生殖腺線量は，男ではそれぞれ118および37.4mrad，女ではそれぞれ1652および413mradであつた．皮膚線量は，両市でそれぞれ43.5および12.8radであつた．

Early in the use of X-ray, dose from examinations was afforded little attention except in unusual cases of heavy exposures, and for physicians who were heavily exposed during their examinations of patients. During the 1930's the possibility of genetic damage from relatively small doses of X-ray was recognized.

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The advent of nuclear reactors prompted greater concern for population exposure. After the end of World War II, skin and gonad dose from diagnostic procedures was investigated. In the late 1950's attention was focused on dose to the bone marrow because of its possible contribution to the development of leukemia.

During investigations of late A-bomb radiation effects by the Atomic Bomb Casualty Commission (ABCC), it was obvious that other sources of ionizing radiation might be concomitantly acting as contaminants. Medical X-ray is the most prevalent source of such exposure. Some diagnostic and most therapeutic X-ray exposures result in significantly high doses to patients. It is also possible that, because of experiencing the A-bomb, some individuals might receive more medical X-ray examinations than other members of the Hiroshima and Nagasaki populations.

With the inauguration of the ABCC—Japanese National Institute of Health (JNIH) Adult Health Study in 1957, a fixed sample of the Hiroshima and Nagasaki populations originally consisting of 20,000 members came under detailed biennial surveillance.[1] The sample is illustrated in Table 1. The Adult

Table 1. Composition of Adult Health Study Sample, 1958, by Sex, City, and Exposure Group[1]

Exposure Component	Group Number	Hiroshima			Nagasaki			Total		
		Male	Female	Total	Male	Female	Total	Male	Female	Total
Within 2000 meters										
with symptoms	1	1312	2116	3428	678	887	1565	1990	3003	4993
without symptoms	2	1312	2116	3428	677	883	1560	1989	2999	4988
Distal Exposed*	3	1313	2120	3433	674	885	1559	1987	3005	4992
Nonexposed	4	1313	2120	3433	676	883	1559	1989	3003	4992
Total		5250	8472	13722	2705	3538	6243	7955	12010	19965

*For Hiroshima, 3000–3499 m.; for Nagasaki, 3000–3999 m.

Health Study population is part of a random sample of 100,000 Hiroshima and Nagasaki subjects being observed for abnormalities and cause of death.[2] The Adult Health Study is unique and permits detailed observations of this relatively large number of survivors who were instantaneously exposed to various doses of ionizing radiation at varying distances from the hypocenters. It also affords an unusual opportunity to assess the degree to which its members have been exposed to other sources of ionizing radiation. Being part of a random sample, it is representative of the city populations.

During the early years of these follow-up investigations, some technical procedures used in Hiroshima and Nagasaki radiologic practice caused patients to receive relatively high doses compared to members of other populations. For example, frequent use of fluoroscopy when film was scarce and use of lower kVp and less added filtration resulted in relatively high doses. Use of radiation therapy for benign disease was another concomitant in these ongoing programs. It was therefore imperative to study in detail the individual exposures of Adult Health Study participants, both at ABCC and in other institutions, and to estimate exposure of the general populations of Hiroshima and Nagasaki, as well.

Dosimetry studies elsewhere are of general interest and concern populations of countries, or are restricted to roentgenology of patients in some radiology departments. National dose estimates for Japan and those for other institutions could not validly be applied to the populations of the cities who experienced the A-bombs. Therefore, the dosimetry investigations subsequently described differed markedly from dosimetry studies elsewhere.

In 1961 this detailed ongoing investigation of medical X-ray exposure among Adult Health Study subjects and the general populations of Hiroshima and Nagasaki was begun. The primary purposes of these studies were to: (1) determine the frequency with which Adult Health Study subjects were being examined and treated with X-ray in other institutions, (2) ascertain the frequency of medical X-ray exposure according to A-bomb exposed and nonexposed groups, (3) establish characteristics of radiologic practice in both cities, (4) estimate the cumulative effect of medical X-ray since 1945, (5) compare the overall magnitude of medical X-ray exposure with that of the A-bombs, (6) calculate and update doses received during Adult Health Study subjects' repeated examinations at ABCC, and (7) provide dose data for their estimated exposures in other institutions. The latter two are sources for reference in evaluating causes of diseases or abnormalities among A-bomb exposed possibly associated with exposure to ionizing radiation. Numerous adjunct studies were also a part of this program.

Method

Dose to Adult Health Study subjects in other hospitals and clinics was first assessed. Most institutions retain films and records for limited periods according to Japanese law.[3] Study of ABCC roentgenologic procedures was postponed in favor of those of other institutions lest their records no longer be available. Detailed assessments of ABCC procedures and their use among Adult Health Study participants were later made. Continuous monitoring of dose from all X-ray procedures experienced by Adult Health Study subjects in other hospitals is obviously impossible; they have been assessed periodically with slightly varying procedures each time.

Basically, studies of Adult Health Study subjects' exposures in other hospitals consisted of:

1. Subject surveys—at ABCC subjects reported diagnostic and therapeutic exposures, and occupational exposures, indicating their time and place.

2. Hospital and clinic surveys—personnel of hospitals where subjects were exposed, verified the exposures and furnished the technical factors used.

3. Dosimetry: The verified diagnostic procedures were reproduced at ABCC, using the same technical factors and a phantom human. Hospital units were surveyed for radiation output and quality to correct for any discrepancies between them and the experimental X-ray apparatus. Radiation treatments were evaluated for output and quality using the units of the hospitals which performed them. Air doses or skin doses and, when possible, depth doses were estimated according to hospital records.

Additional surveys of community institutions established trends in radiologic practice for earlier years during which no dosimetry was performed, to assist estimations of dose to the Hiroshima and Nagasaki populations. Substudies including those of basic phantom dosimetry, active bone marrow distribution, and fluoroscopy exposure were supportive to this program.

Equipment

A. X-ray Apparatus

The following ABCC X-ray apparatus were used:

1. General Electric (GE) radiography-fluoroscopy unit, type 8, 130 kVp, 500 mA; KX-8 transfor-

mer; Regent table with Scholz spot-filmer; side-rail suspension of overhead radiography tube with tomography and stereoscopy capabilities.

2. GE Fluoricon image intensifier, 6–9 inch tube, with mirror, vidicon closed-circuit television, overhead crane tube suspension; 150 kVp, 500 mA.

3. Franklin head radiography unit, 100 kVp, 200 mA.

Thirteen fluoroscopy and seven photofluorography units in Hiroshima institutions were used in additional phantom dosimetry.

B. Electrometers

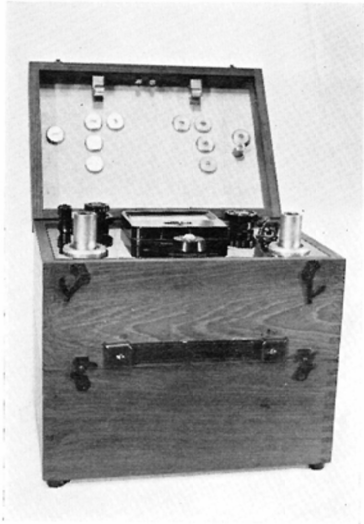

Fig. 1. Baldwin-Farmer Electrometer

Fig. 2. EIL electrometer with 35 cc chamber[4,6]

1. A Baldwin-Farmer electrometer (Fig. 1) with Memorial ionization chambers was used for bone marrow and gonadal dose measurements.

2. An Electronic Instruments, Limited (EIL), Model 37A electrometer[4] (Fig. 2) was used to monitor radiation output and to verify surface doses. Dose rate and cumulated dose are obtainable with this apparatus.

3. Victoreen condenser R meters, Models 70 and 570 were used to assess output and dose from therapy apparatus.

C. Ionization Chambers

1. Memorial 1 cc ionization chambers (Fig. 3) were used with the Baldwin-Farmer electrometer. Their relatively small size permitted their placement in marrow cavities or regions thereof. The measurable dose range with this equipment was 10–500 mR. Their characteristics included high sensitivity, relatively uniform response throughout the diagnostic energy range, and freedom from directional dependence.[5]

2. Electronic Instruments, Limited, 35 cc ionization chambers[6] were used with the EIL electrometer (Fig. 2). Surface doses and radiation output were obtained with them. The range of measurable dose

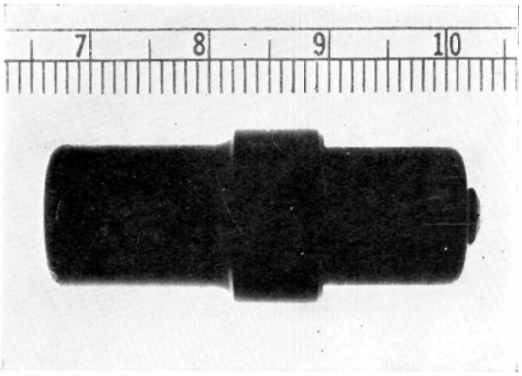

Fig. 3.Memorial ionization chamber.[5]

with this equipment was 0.1–1.5 × 10^5 mR.

3. Victoreen ionization chambers of 25, 100 and 250 R capacity were used with Victoreen condenser R meters to measure output and dose from high energy X-ray and cobalt-60 therapy apparatus.

D. Standards

1. Reference chamber, Baldwin-Farmer, 1 volt/R, 0.6 cc capacity.

2. Radium standard, Victoreen, 2 mg.

E. Film Monitors

Eastman Type-M industrial film was used to monitor surface dose during fluoroscopy and spot-filming. Packaged in light-tight envelopes, films were joined to form jackets which were affixed to a phantom human.

F. Densitometers

1. MacBeth-Ansco Color Densitometer, Model No. 12

2. MacBeth Quantalog Densitometer, Model TD-102

G. Radiation Output and Quality Monitor

A portable enclosure accommodating a 35 cc EIL ionization chamber and a remotely controlled revolving aluminum disk with 0, and 0.5, 1.0, 2.0, 2.5, 3.0, 4.0, and 5.0 mm thicknesses of aluminum was used

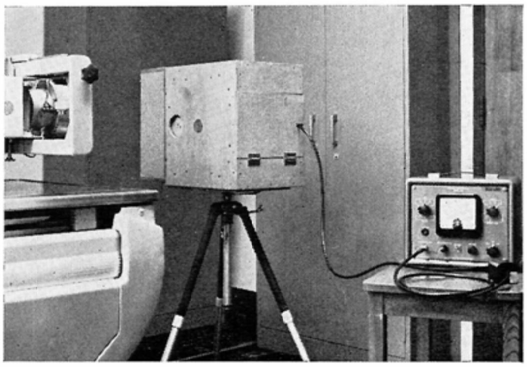

Fig. 4. Wooden box containing remotely controlled disk of varying thickness of aluminum for assessment of output and quality of radiation.

to assess radiation quality by half-value layer approximation, and radiation output of hospitals' and clinics' apparatus (Fig. 4).

H. Phantom Materials

1. Small block phantoms of plain Mix-D material were used for basic studies of response of ionization chambers and electrometers (Figs. 5a, b).

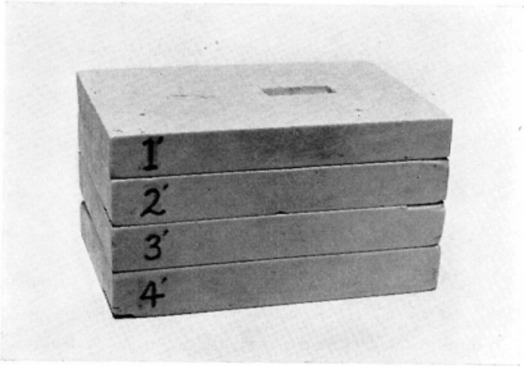

Fig. 5a. Plain Mix-D material to accommodate Memorial ionization chambers.

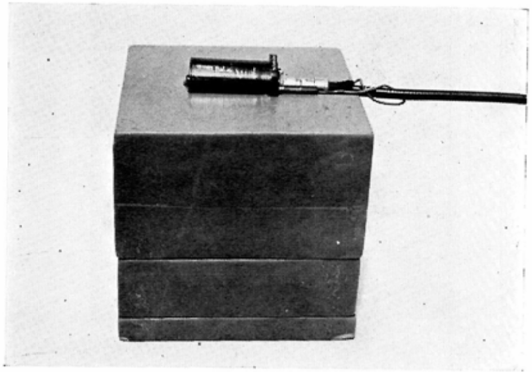

Fig. 5b. Plain Mix-D material accommodating EIL chamber at surface.

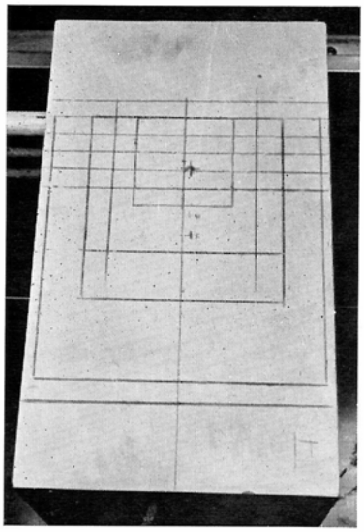

Fig. 6a. Plain Mix-D phantom with inscriptions on superior surface of varying field sizes.

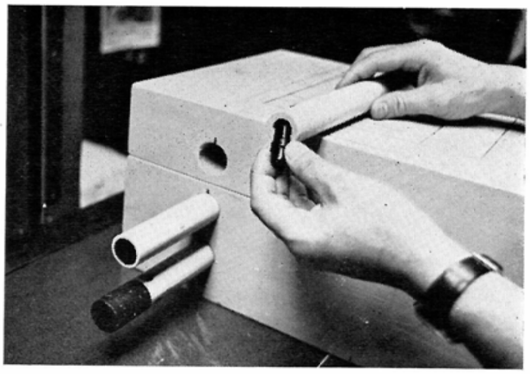

Fig. 6b. Receptacles inserted into Mix-D phantom.

2. A large Mix-D block phantom in two sections with spaces at 5, 10, and 15 cm depths for Memorial ionization chambers within it was used in measurements of depth dose and scattered radiation near the margin of the direct beam of X-ray (Figs. 6a, b).

Lathe-turned Mix-D chamber receptacles exactly fit the 2.8 cm holes in this phantom. One end of each receptacle also consisted of bone equivalent material (54% paraffin, 38% calcium phosphate, and 8%

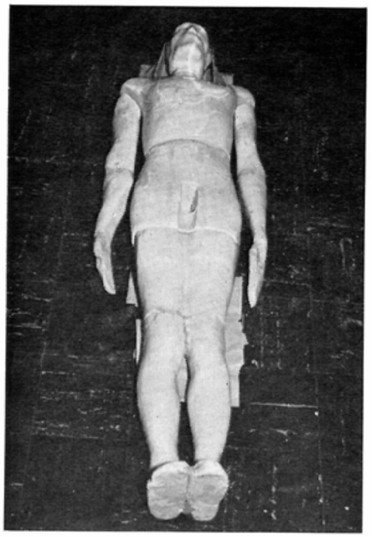

Fig. 7. Entire Mix-D phantom containing skeleton.

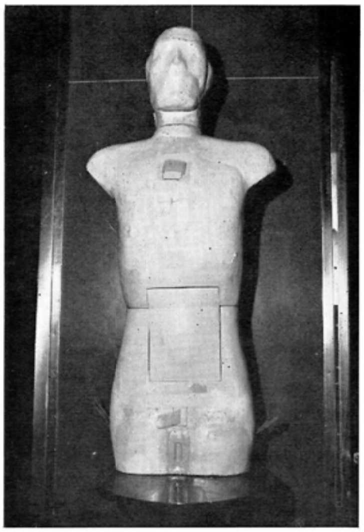

Fig. 9. Skull, thorax, and abdomen of phantom with insert containing simulated stomach and duodenum.

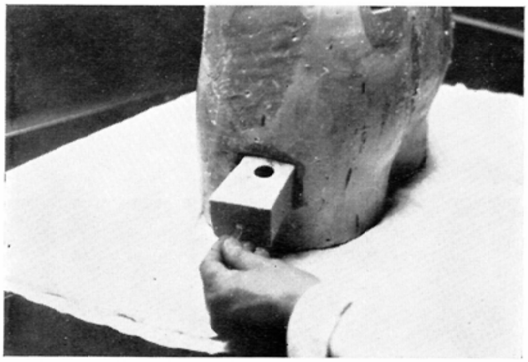

Fig. 8. Pelvis and hip of phantom with insert accommodating ionization chamber removed.

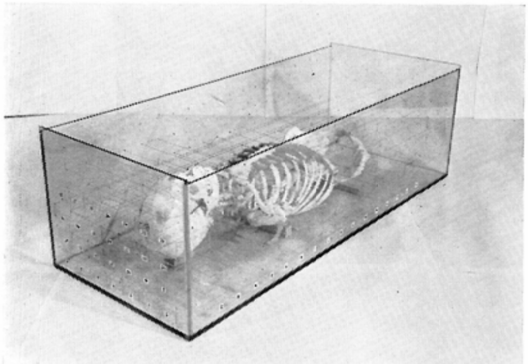

Fig. 10. Lattice system to describe active bone marrow distribution.[18]

carbon) in 2, 4, and 7 mm thicknesses to represent bone cortices.

3. A phantom human simulated an average-size adult Japanese, 162 cm in height, consisting of Mix-D, containing a complete human skeleton, with beeswax-impregnated cellulose for lung tissue (Fig. 7).

A drawer system accommodated the Memorial ionization chambers, after the method of Laughlin, et al.[7] (Fig. 8).

Chamber locations included: Skull vertex; C-4, T-6, T-12, L-5 vertebrae; body of sternum; lateral portions of both sixth ribs; both iliac crests; trochanteric regions of both femurs; symphysis pubis; the female gonads, and one position for the male gonads. A removable Mix-D abdominal block allowed insertion of a similar block containing a simulated stomach and duodenum (Fig. 9) for monitoring fluoroscopic procedures.

4. A skeleton phantom described quantities of active bone marrow by a 3-dimensional lattice to facilitate dose calculations according to X-ray beam size and projection (Fig. 10).

Results

Since ABCC roentgenological techniques have been relatively uniform with time and technical factors for examinations are routinely recorded in detail and permanently filed, there was no immediate need to study doses they incurred. Attention was devoted instead to Adult Health Study subjects' exposures in other institutions lest records thereof be discarded because of the five-year period required by law.[3] In the meantime, gonad and bone marrow doses for the frequently performed ABCC examinations were estimated[8] according to another investigator's data.[9,10]

A. ABCC Subjects' Exposure in Other Institutions

1. Subject Surveys

The first subject survey in 1961, established the frequency of Adult Health Study subjects' medical, dental and occupational exposure elsewhere, and the methods by which they might best be surveyed. For economy of time and effort of the existing ABCC staff, nurses in the medical clinic interviewed subjects in the initial survey.[11] One-thousand eight-hundred and sixty-two subjects reported receiving 1456 exposures to diagnostic X-ray on 1080 occasions. Only one radiation therapy exposure was reported—in Hiroshima. The period of subjects's memory recall was one year, and the survey lasted 3 months. The study indicated a higher frequency of medical X-ray among those proximally exposed (Groups 1 and 2) and showed subjects could not accurately recall examination details beyond a 3- or 4-month recall period. This study also pointed out the need for trained interviewers for such surveys. The data obtained were not sufficiently dependable to form a base for subsequent hospital surveys and dosimetry.

In a second subject survey[12] from 15 July to 16 November 1962, 406, of 2503 ABCC subjects interviewed in the Department of Radiology, each reported receiving 1 to 4 X-ray examinations. These responses were not analyzed for reliability. The period of recall was 3-months, and radiation therapy was excluded because only one subject reported such exposure in the previous survey. One Nagasaki and 14 Hiroshima subjects, all employed in the medical profession, reported occupational exposure. This survey's data were the basis for the first hospital and clinic survey and dosimetry.

The third survey of ABCC subjects[13] was for medical, dental and occupational exposures in other institutions, and was conducted in the Department of Radiology from 1 February 1964 to 31 January 1965. Within a 3-month recall period, 5293 Hiroshima subjects reported 1506 occasions; 2221 Nagasaki subjects, 244 occasions of exposure to medical X-ray. Twenty-eight percent in Hiroshima and 11% in Nagasaki reported exposure in other institutions—more marked a difference by city than in 1962. Chest examinations were most frequent; fluoroscopy was very infrequent in Nagasaki—and only for upper gastrointestinal series. Hiroshima subjects reported 150 occasions of radiation therapy, 102 (68%) of which were for benign disease (Table 2). Of the remaining 48 (32%), only 10% were thought by subjects to have been for malignant disease. Only two Nagasaki subjects reported exposure to radiation therapy. These differences by city could not be traced to artifacts in study methods and were attributed to basic differences in radiologic practice. In Hiroshima only, subjects who experienced the A-bomb (Groups 1–3) reported a small but significantly greater frequency of exposure to diagnostic procedures than those who did not

Table 2. Distribution of Subjects Reporting Radiation Therapy by Body Site and Disease, Hiroshima[13]

			Diseases				
Region	Organ	Total Subjects	Benign		Malignant	Unknown Tumor	Unknown
Head	Hypophysis	2)					
	Eyes	2)					
	Parotid gland	2)	Rhinitis	1	Cancer 1	Tumor 3	4
	Nose	1)					
	Tongue	1)					
	Mandible	1)					
Neck	Lymph node	27)	Goiter	11			
	Thyroid	11)	Lymphadeni		Cancer 2		1
	Larynx	3)	tis	27			
Chest	Breast	4)	Pneumonia	2			
	Lung	3)	Fibroadenoma	1	Cancer 3		1
	Trachea	1)	Asthma	1			
	Intercostal nerve	1)	Neuralgia	1			
Abdomen	Uterus	18)					
	Spleen	3)					
	Stomach	3)	Myoma	9			
	Kidney	2)	Peritonitis	2			
	Ovary	2)	Ulcer	1	Cancer 9	Tumor 1	10
	Peritoneum	2)	Tuberculosis	1			
	Vagina	1)	Appendicitis	1			
	Appendix	1)	Hemorrhoid	1			
	Rectum	1)	Neuralgia	1			
	Anus	1)					
	Bladder	1)					
	Mesentery	1)					
Extremity							
and	Knee	1)	Arthritis	1			
Spine	Foot	1)	Periostitis	1			1
	Periosteum	1)	Spondylitis	1			
	Spine	1)					
Skin	Hand	6)					
	Feet	3)	Athlete's				
	Pubis	3)	foot	18			
	Neck	1)	Eczema	7			
	Shoulder	1)	Keloid	5			
	Anal region	1)	Wounds	3			
	Scrotum	1)	Ringworm	3			
	Unknown	27)					
Other	Unknown	6	(Hypertension	1			
			(Sterility	2			
Total		150		102	15	4	29

(Group 4), but there were no significant differences by distance from hypocenter or history of radiation symptoms. The data of this study were used in a subsequent survey of hospitals and clinics and for dosimetry.

2. Hospital and Clinic Surveys

The first hospital and clinic survey,[14] from 20 November 1962 to 18 January 1963 in Hiroshima and from 4 to 8 February in Nagasaki, was based on a previous subject survey.[12] A wide variety of equipment and techniques was encountered, complicating calculations of dose per exposure (Table 3), particularly for fluoroscopic examinations. Numbers of examinations by body site, sex, institution and city are shown in Figure 11.

Table 3. Diagnostic X-ray Apparatus by Manufacturer, Type, and Examining Facility Hiroshima + Nagasaki[14]

	Hospitals			Clinics		
Manufacturer	Transformer	Condenser	Total	Transformer	Condenser	Total
A	18	0	18	12	6	18
B	16	0	16	6	3	9
C	5	0	5	3	0	3
D	3	0	3	5	6	11
E	0	0	0	5	1	6
F	2	0	2	0	0	0
G	6	0	0	4	3	7
Total	50	0	50	35	19	54

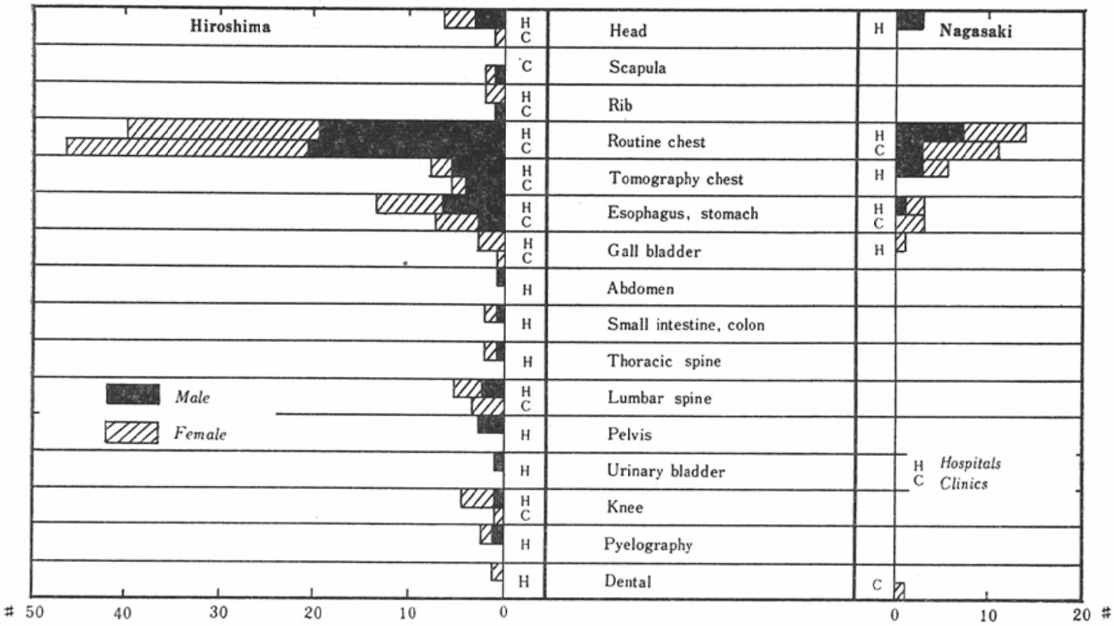

Fig. 11. Number of examinations by site, sex, and city[14]

A wider distribution of body sites was encountered in Hiroshima partially due to the greater number of Hiroshima subjects. Chest radiography predominated in both cities, and detailed analysis of exposure factors was made for this type of examination. In Hiroshima generally higher kVp

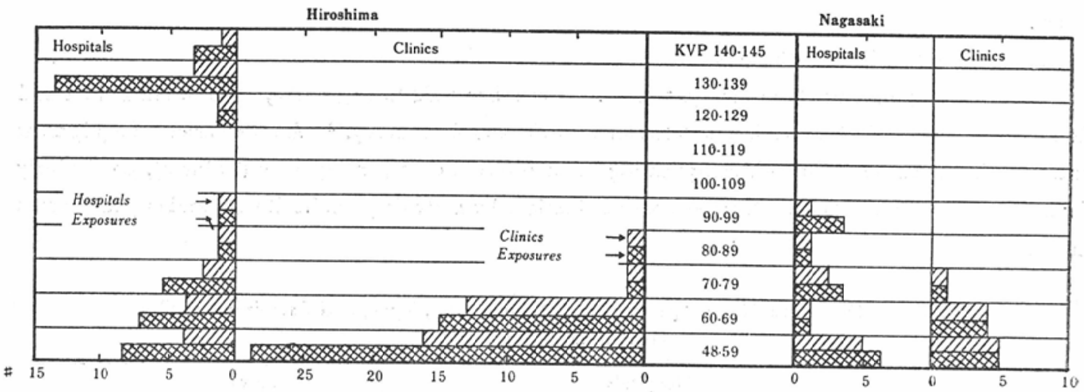

Fig. 12. Number of chest exposures by kVp, facility and city[14]

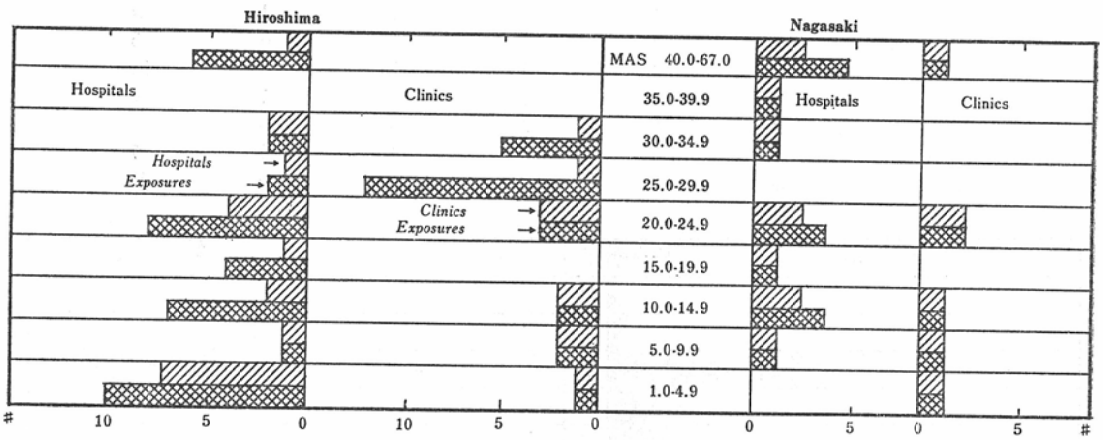

Fig. 13. Number of chest exposures by mas, facility and city[14]

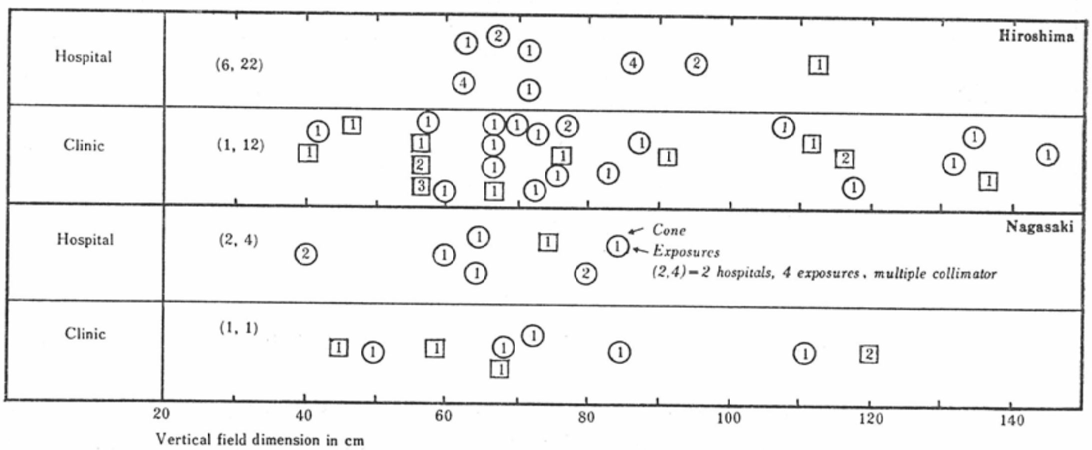

Fig. 14. Comparison of field sizes and cone configuration[14]

and lower mAs were used in hospitals than in clinics (Figs. 12, 13).

Clinics in both cities used longer exposure times than hospitals. Round cones were most popular; multiple plane collimators were more frequent in hospitals; square cones, in clinics, in both cities (Fig. 14).

Eleven by fourteen inch film was more frequently used for males, 10 × 12 inch, for females. Added filtration used is shown in Table 4.

Table 4. Added Filtration, Diagnostic X-ray Apparatus[14]

Added Filtration	Hiroshima		Nagasaki	
	Hospitals	Clinics	Hospitals	Clinics
Number of apparatus	34	41	16	13
None	1	3		1
0.2 mm Al		1		
0.3 mm Al	1			
0.5 mm Al	9	27	8	8
1.0 mm Al	13*	7	7	3
1.5 mm Al	3	1		1
2.0 mm Al	6		1	
2.5 mm Al			2	
5.0 mm Al		2		
0.1 mm Cu + 0.5 mm Al	1			
0.2 mm Cu + 1.0 mm Al	1*			

*Additional technique: One hospital uses 0.2 mm Cu + 1.0 mm Al filter for high KV chest radiography

In Japan, 2.0 mm aluminum equivalent was legally required. Concerning added filtration, and assuming inherent filtration to be 0.5 mm aluminum equivalent, as many as 93 installations were not meeting the legal requirement, five of which used no filters at all. A detailed summary of numbers of subjects, for all examinations, by exposures, by type of institution, and city was compiled. The study provided detailed data as a basis for dosimetry.

The second hospital and clinic survey, based on an earlier subject survey,[13] was conducted from 1 July to 31 August 1965 in Hiroshima, and from 13 to 28 September 1965 in Nagasaki. Results have been reported separately for radiography and fluoroscopy[15] and for photofluorography.[16] The body sites examined using radiography and fluoroscopy[15] are shown in Figure 15, by sex, facility and city.

Chest radiography again outnumbered other examinations. In 1962, the number of examinations per subject was 0.09 in Hiroshima; 0.05 in Nagasaki;[14] comparable figures for 1964[15] were 0.1 in Hiroshima; 0.06 in Nagasaki. In Hiroshima in 1962[14] upper gastrointestinal series were much less frequent than chest radiography; in 1964[15] their frequencies were more nearly the same. In Nagasaki their frequencies remained unchanged. Numbers of films per examination were 1.96 in Hiroshima and 1.69 in Nagasaki. The Hiroshima value agreed with the ratio of 1.90 for Hiroshima Red Cross Hospital.[17] Previously, ratios of total examinations to total films were 1.3 in Hiroshima and 1.23 in Nagasaki.[15]

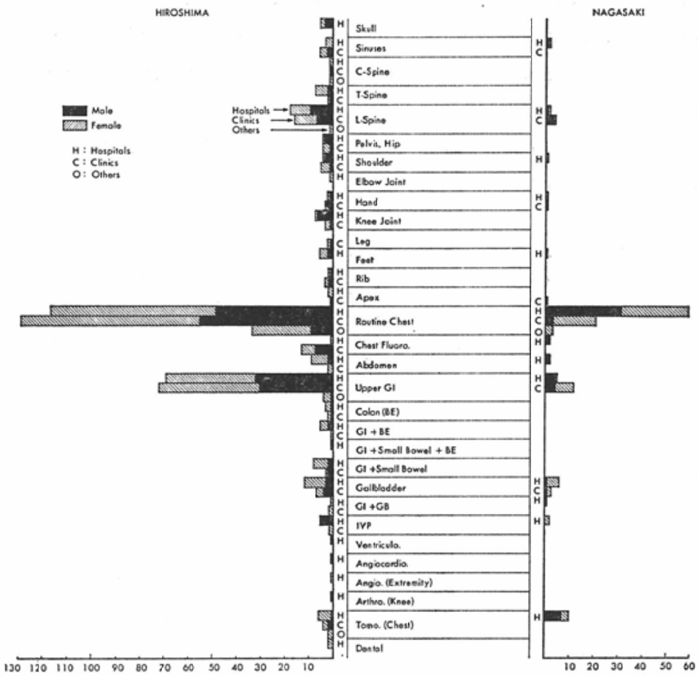

Fig. 15. Number of examinations by body site, sex, and city[15]

Table 5. Added Filtration in Diagnostic X-ray Apparatus for Routine Chest Examinations by City[15]

Added Filtration	Hiroshima			Nagasaki		
	Hospitals	Clinics	Others	Hospitals	Clinics	Others
None	1	2	0	0	0	0
0.5 mmAL	14	48	1	6	15	0
1.0 mm AL	6	17	2	2	1	0
1.5 mmAL	4	1	0	1	0	1
2.0 mmAL	1	1	0	2	0	1
2.5 mmAL	0	0	0	1	0	0
3.0 mm AL	1	0	0	0	0	0
0.2 mm AL + 0.1 mm Cu	1	0	0	0	0	0
1.0 mm AL + 0.1 mm Cu	1	0	0	0	0	0
1.0 mm AL + 0.2 mm Cu	1	0	0	0	0	0
0.5 mm AL + 0.3 mm Cu	0	0	0	1	0	0
Total Apparatus	30	69	3	13	16	2

Chest radiography and upper gastrointestinal series were the most frequent examinations in both cities. Age and sex distributions for chest radiography were essentially the same as in the previous study.[14] The 48–59 kVp range in the previous survey increased to 60–79 kVp. The testes were infrequently exposed by the direct beam, but the ovaries frequently were. Added filtration used is shown in Table 5.

Table 6. Anode Position for Routine Chest Examinations by City[15]

Anode Position	Hospitals	Exposures	Clinics	Exposures	Others	Exposures
		HIROSHIMA				
Head	15	53	23	40	1	2
Foot	12	57	24	44	2	31
Horizontal	4	14	16	36	0	0
Unknown	0	0	6	12	0	0
		NAGASAKI				
Head	4	18	3	4	0	0
Foot	6	16	2	3	2	3
Horizontal	3	27	9	12	0	0
Unknown	0	0	2	2	0	0

Assuming 0.5 mm equivalent inherent filtration, as many as 122 units appeared not to have been complying with the legal requirement of 2.0 mm effective filtration.[8] Three of these apparatus had no filters. Positions of the anodes of the X-ray tubes are shown in Table 6.

Though the anode is preferably caudad to minimize gonadal dose, only half the tubes were so positioned, and a considerable number were horizontal. As in the previous study,[14] 10 × 12 inch film was more frequently used for females, though 11 × 14 inch film was generally the more frequent.

Upper gastrointestinal series exposure factors were analyzed in detail. There was a nearly equal distribution of this type of examination by age. KVP used in hospitals was higher than that in clinics for both fluoroscopy and spot-filming; for spot-filming, lower mAs was used in hospitals than clinics. For fluoroscopy, 3 mA was most frequent in both cities; 4.0 mA was used in some Hiroshima institutions. Few facilities kept good records of their fluoroscopy times. Five and 10 minute fluoroscopy times predominated, especially in Hiroshima clinics. Though most Hiroshima hospitals used 5 minutes or less for an upper gastrointestinal series, a few reported times of 20 or 30 minutes. Fluoroscopy times were shorter for hospitals than clinics in Hiroshima, but the reverse was true in Nagasaki. Spot radiography occurred approximately five times per examination in both cities. Seventy-seven units had less than 1.5 mm added aluminum filtration; one, had none.

Exposure factors for other examinations were also analyzed. As in an earlier survey,[12] Hiroshima subjects not in the city (Group 4) at the time of the bomb were less often exposed to medical X-ray than were survivors (Groups 1–3), but such exposure did not correlate with distance from hypocenter or acute radiation symptoms. Nevertheless, this suggested a need for more information concerning individual medical X-ray exposures of survivors to strengthen studies of atomic radiation effect.

A survey of institutions for technical factors in photofluorography was reported separately.[16] This was also based on an earlier survey[13] in which 674 of 5293 Hiroshima and 96 of 2221 Nagasaki subjects reported photofluorography exposure. Only 88 of the Hiroshima subjects could identify the institutions responsible, because the majority of Hiroshima examinations were performed by mobile units. The institutions responsible for the examinations were traced through schools, employers and health centers. Seventy-eight percent of Hiroshima and 74% of Nagasaki reported examinations were confirmed. Photofluorography data for the institutions identified were studied concurrently with those of radiography adn fluoroscopy.[15] (Table 7).

Table 7. Occasions of Confirmed Exposure to Chest Photofluorography[16]

Organization Sponsoring Photofluorography or Location		Number	Periods Exposure Confirmed	Interval from Confirmed Exposure to Interview		
				<3 Months	>3 Months	Outside City
Hiroshima	Specified by subject	88	1 July – 31 August, 1965*	48	8	0
	Not specified by subject ...	595	28 February – 10 June, 1966	414	93	3
	Total	683		462	101	3
Nagasaki	Specified by subject	98	13–28 September, 1965	72	10	0

*Combined survey with Radiology

Photofluorographic apparatus was classified by type, manufacturer, examining facility, sponsoring organization, number of exposures, and by city. Two or three manufacturers predominated in both cities. More than $^1/_3$f of the Hiroshima but only one-fifth of the Nagasaki units were mobile. Only three subjects in Hiroshima reported stomach examinations, though four of the 52 Hiroshima units were performing this type of examination in addition to chest photofluorography. Seventy-five to 85 kVp was most frequently used in both cities, whereas 60 kVp had been most frequent for chest radiography[15]. Square cones predominated and the gonads were not in the direct X-ray beam except in the case of one Hiroshima unit with a round cone. All units had filters and 0.5 or 1.0 mm aluminum was most frequently added. Japanese regulations required a 2.0 mm aluminum equivalent. Because of wide variations in cooling oils and tube windows in use, no further investigation of filtration was made. Anodes were positioned cranially in most Hiroshima installations; equally cranially or caudally, in Nagasaki. Whereas 35 mm film was mainly used in the past, 60 or 70 mm films predominated at the time of this survey[16]. Condenser units of 1.0 μF capacity with wave-tail cut-offs were most popular. There were 17 Hiroshima and nine Nagasaki transformer units, and 30 mAs was most frequently employed. Exposure techniques of the units responsible for the three stomach survey examinations were ascertained. In Hiroshima a large number of mobile units belonging to a few private organizations performed most of the chest photofluorography; in Nagasaki, most examinations were by companies and schools. Many Nagasaki ABCC subjects had chest photofluorography at a hospital belonging to a large shipbuilding company. Frequency of photofluorography peaked in May-June and October-November in both cities, as was the case for photofluorography at a large Hiroshima hospital.[17] Relatively few examinations occurred in those over 60-years of age, unlike the chest radiography which was frequent in this age group.[14,15]

3. Active Bone Marrow Distribution

To define the quantity of active bone marrow irradiated according to beam margins and various projections and depths, active marrow distribution was calculated according to a 3-dimensional lattice consisting of 5 cm cubes, an example of which is shown in Table 8.[18]

The active marrow values of Ellis[19] were applied to this distribution lattice and results are shown in Table 9.

Table 8. A Method for Determining Active Bone Marrow[18]

Section	Cube Number	Part	%
H	17	Clavicle (right)	40
	18	C7	20
	18	T1	80
	18	T2	60
	18	T3	40
	18	Rib 1 (right)	5
	18	Rib 1 (left)	5
	18	Rib 2 (right)	5
	18	Rib 2 (left)	5
	18	Clavicle (right)	10
	18	Clavicle (left)	10
	19	Rib 1 (left)	93
	19	Clavicle (left)	40
	20	Scapula (left)	20
	20	Rib 2 (left)	30
	20	Rib 3 (left)	5
	20	Clavicle (left)	40
	21	Scapula (left)	15
	21	Humerus (left)	40
	21	Clavicle (left)	10
	24	Rib 1 (right)	2
	25	Sternum	33
	26	Rib 1 (left)	2
I	2	Scapula (right)	3
	2	Rib 5 (right)	2
	2	Rib 6 (right)	5
	3	Scapula (right)	3
	3	Rib 5 (right)	5
	3	Rib 6 (right)	15
	3	Rib 7 (right)	3
	4	Rib 6 (right)	2
	4	Rib 6 (left)	2
	4	T5	3
	4	T6	3
	5	Scapula (left)	3
	5	Rib 5 (left)	5
	5	Rib 6 (left)	15
	5	Rib 7 (left)	3
	6	Scepula (left)	3
	6	Rib 5 (left)	2
	6	Rib 6 (left)	5
	9	Scapula (right)	17
	9	Rib 4 (right)	15
	9	Rib 5 (right)	30
	9	Rib 6 (right)	10
	10	Rib 5 (right)	9
	11	Rib 5 (right)	10
	11	Rib 5 (left)	10
	11	Rib 6 (right)	8
	11	Rib 6 (left)	8
	11	Rib 7 (right)	2
	11	Rib 7 (left)	2
	11	T4 (anterior)	60
	11	T4 (posterior)	20
	11	T5	97
	11	T6	97
I	11	T7	10
	12	Rib 5 (left)	9
	13	Scapula (left)	17
	13	Rib 4 (left)	15
	13	Rib 5 (left)	30
	13	Rib 6 (left)	10
	15	Scapula (right)	5
	15	Humerus (right)	60
	16	Scapula (right)	5
	16	Rib 2 (right)	5
	16	Rib 3 (right)	32
	16	Rib 4 (right)	23
	16	Rib 5 (right)	3
	17	Rib 2 (right)	5
	18	T4	10
	19	Rib 2 (left)	5
	20	Scapula (left)	5
	20	Rib 2 (left)	5
	20	Rib 3 (left)	32
	20	Rib 4 (left)	23
	20	Rib 5 (left)	3
	21	Scapula (left)	5
	21	Humerus (left)	60
	23	Rib 3 (right)	2
	24	Rib 2 (right)	15
	24	Rib 3 (right)	8
	25	Sternum	27
	26	Rib 2 (left)	15
	26	Rib 3 (left)	8
	27	Rib 3 (left)	2
J	2	Scapula (right)	2
	2	Rib 8 (right)	10
	3	Scapula (right)	2
	3	Rib 7 (right)	22
	3	Rib 8 (right)	20
	3	Rib 9 (right)	9
	4	Rib 7 (right)	3
	4	Rib 7 (left)	3
	4	Rib 8 (right)	3
	4	Rib 8 (left)	3
	4	Rib 9 (right)	2
	4	Rib 9 (left)	2
	4	T7	5
	4	T8	8
	5	Scapula (left)	2
	5	Rib 7 (left)	22
	5	Rib 8 (left)	20
	5	Rib 9 (left)	9
	6	Scapula (left)	2
	6	Rib 8 (left)	10
	9	Rib 6 (right)	15
	9	Rib 7 (right)	30
	9	Rib 8 (right)	15
	11	Rib 7 (right)	3
	11	Rib 7 (left)	3
	11	Rib 8 (right)	5

Table 9. Distribution of Active Bone Marrow (G)[18]

Cube No.	Skull Vertex	←Craniad					Transverse sections				Caudad→				Ischium; Prox. Femur		Cube total
	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	
1●																		
2							1.10	0.99	1.18	0.59	0.14							4.00
3		2.49	1.24			0.76	1.86	2.95	1.96	0.90				14.41	7.63			34.20
4		4.97	6.22				0.83	2.48	4.32	2.56	1.31	0.95	0.96	9.78	36.19			70.55
5		2.49	1.24			0.76	1.86	2.95	1.96	0.90				14.41	7.63			34.20
6							1.10	0.99	1.18	0.59	0.14							4.00
7●																		
8						2.53										1.60		4.13
9						3.83	6.71	2.93	2.11	2.48	0.34			9.32	8.56	10.00	4.00	50.28
10	2.49	8.70	4.97	2.49		3.32	0.43				0.44	0.71	0.48	26.16	24.77	13.05	5.83	93.82
11	4.97	2.49		3.01	2.00	12.17	31.37	26.60	32.19	46.52	18.75	20.23	22.17	58.32	9.05			289.90
12	2.49	8.70	4.97	2.49		3.32	0.43				0.44	0.71	0.48	26.16	24.77	13.05	5.83	93.82
13						3.83	6.71	2.93	2.11	2.48	0.34			9.32	8.56	10.00	4.00	50.28
14						2.53										1.60		4.13
15						8.60	7.26											15.86
16						9.20	3.38	2.27	2.67	1.48	0.23			8.16	6.23			33.62
17	2.49	4.97	2.49	3.50		5.15	0.13			0.10					6.23	10.72	2.33	38.11
18	4.97		2.49	13.78	19.17	18.52	0.91				0.87	1.19				7.00	4.66	73.56
19	2.49	4.97	2.49	3.50		5.15	0.13			0.10					6.23	10.72	2.33	38.11
20						9.20	3.38	2.27	2.67	1.48	0.23			8.16	6.23			33.62
21						8.60	7.26											15.86
22●																		
23							0.06	0.51	0.85									1.42
24	1.24	4.97	1.24	3.32	0.74	0.04	0.62	0.42	0.24	0.15								12.98
25	2.49	4.97	2.49	1.23	1.23	7.70	6.32	5.85	3.51									35.79
26	1.24	4.97	1.24	3.32	0.74	0.04	0.62	0.42	0.24	0.15								12.98
27							0.06	0.51	0.85									1.42
28●																		
Section totals	24.87	54.69	31.08	36.64	23.88	105.25	82.53	55.07	58.04	60.48	23.23	23.79	24.09	184.20	152.08	77.74	28.98	

(Cubical compartments)

●No active bone marrow

Grand total: 1,046.64 g

Source: Active Bone Marrow Distribution in the Adult, Brit J Radiol 39: 735—9, 1966

They were used to calculate bone marrow integral dose from diagnostic procedures.

4. Dosimetry

Dose to the gonads and bone marrow from chest roentgenography at ABCC and other institutions were calculated in 1963,[20] according to the data of Epp, et al.[9] The latter were applicable only to ABCC examinations as far as technical exposure factors were concerned. The data of Epp, et al.[9,10] were unsuitable for those of other institutions in the two cities, whose exposure factors varied widely. Gonad dose at ABCC was nil because of collimation and shielding; doses for ABCC and other institutions are shown in Tables 10 and 11.

Table 10. Bone Marrow Integral Dose, PA and Lateral Chest Examinations ABCC, Hiroshima*[20]

	Male		Female	
	PA	LAT.**	PA	LAT.**
Bone marrow dose per exposure (gm-rad)	3.1	2.6	2.8	2.5
Total number of subjects		148		

*1–16 November 1962

**No correction for kvp or added filtration.

Table 11. Estimated Gonadal and Bone Marrow Integral Dose, PA Chest Examinations—Community Hospitals and Clinics, Hiroshima[20]

	Hospitals		Clinics	
	Male	Female	Male	Female
Gonadal dose per exposure (mr)	(20)	(20)	(10)	(15)
	0.03	1.1	0.03	0.6
Gonads in direct beam	—	(6)	—	(5)
	—	3.4	—	1.7
Gonads not in direct beam	(20)	(14)	(10)	(10)
	0.03	0.1	0.03	0.03
Bone marrow dose per exposure (gm-rad)	(20)	(20)	(10)	(15)
	3.5	3.3	2.3	3.0

Number of subjects on whom dose was determined shown in parentheses.

The first phantom dosimetry was based on a Hiroshima and Nagasaki hospital and clinic survey,[14] and performed in 1963.[21] All reported[12] and confirmed[14] X-ray examinations were duplicated at ABCC using a phantom human containing Memorial ionization chambers (See Apparatus). Gonad positions were also designated in the lattice describing active bone marrow distribution. Direct beam size was based on film size, cone size and FFD.

Bone marrow integral and gonadal doses for examinations of all subjects are contained in the original report.[21] Mean bone marrow and gonadal doses for chest examinations are shown in Table 12.

Doses were somewhat lower than those reported in the literature, but no error such as variation in phantom density, or anode position were found responsible for this.

Bone marrow integral dose as referred to here represents the average energy dissipated in the bone

Table 12. PA Chest Examinations, Mean Gonadal and Bone Marrow Integral Dose Per Exposure[21]

Dose		Hospitals		Clinics	
		Male	Female	Male	Female
Gonadal Inside beam (mR)	Mean dose	0.023	0.27	0.33	0.66
	Exposures	3	9	4	16
Outside beam	Mean dose	0.0029	0.053	0.034	0.0046
	Exposures	20	18	22	11
Bone marrow (g-rad)	Mean dose	3.70	3.22	4.09	2.86
	Exposures	23	27	26	27

marrow due to exposure to a diagnostic X-ray procedure. To obtain this energy, the measured absorbed dose produced at various points in the bone marrow was weighted by the amount of active bone marrow so as to produce a measure of the energy which was absorbed in the active marrow. These procedures are according to those of Laughlin, et al.[7] A total active marrow of 1046 grams was assumed.[18]

The second phantom dosimetry study, based on an earlier hospital and clinic survey,[15] dealt with a large number of chest examinations, and dose calculations were made with the aid of an electronic computer.[22] Exposures were made with a GE 130 kVp, 300 mA radiographic apparatus; cones describing 58, 85 and 110 cm diameter field sizes at 183 cm FFD; at 50, 70, 90 and 130 kVp; with 0.5, 1.0 and 2.0 mm added aluminum filtration. For depth doses at locations other than those of the 16 ionization chambers in the phantom human, measurements were made in a large two-piece Mix-D block phantom (See Apparatus), varying field sizes, kVp, filtration, and FFD—at 5, 10 and 15 cm depths. Scattered radiation dose was also measured in the latter phantom at 2, 4, 6 and 8 cm from beam edge, for 10, 20 and 30 cm^2 fields, at 5, 10 and 15 cm depths, and 60, 80 and 100 kVp. Values for a 30 cm × 30 cm field were used. Doses to cubical compartments and gonad positions in the bone marrow lattice[18] were the products of depth-dose ratios and ionization chamber readings. Bone absorption was assumed to be 10%—the mean obtained from study of 2 to 4 mm thicknesses of bone equivalent material. Ionization chamber doses at marrow and gonad positions were used when inside the beam. Gonad and bone marrow doses, when outside the direct beam, were obtained from scattered radiation dose data using the Mix-D block phantom. Contribution by dose outside the beam was no more than 5%. An example of ionization chamber dose readings according to added filtration and kVp is shown in Table 13.

An IBM Model 1440 electronic computer was used in this study, and details of methods were described in the original report.[22] The average overall error in these procedures was estimated to be 5%. Examples of dose tables and curves derived from computer analyses are shown in Tables 14 to 17 and Figure 16.

Following corrections for differences in radiation output and quality between X-ray units in the hospitals and clinics and the experimental unit at ABCC, bone marrow, gonadal and skin dose data were applied to individual exposures received by ABCC subjects in the community hospitals and clinics. The mean bone marrow integral and gonadal doses are shown in Tables 18 and 19.

Gonadal dose ranges were large compared to those of bone marrow dose, because gonads varied in

Table 13. Chamber Dose by Location, Added Filtration and kvp in PA Chest Examination[22] (Unit: mR/mas, Field Size: No Cone, FFD: 183 cm)

Chamber	0.5 mm Al				1.0 mm Al				2.0 mm Al			
	50 kvp	70	90	130	50	70	90	130	50	70	90	130
Skull	0.067	0.270	0.593	1.638	0.062	0.232	0.552	1.510	0.050	0.208	0.476	1.330
C-spine/4	0.508	1.316	2.732	5.480	0 428	1.242	2.471	4.841	0.315	1.006	2.074	4.029
Sternum	0.044	0.193	0.447	1.238	0.041	0.174	0.412	1.148	0.035	0.161	0.399	1.077
R-rib	0.355	0.932	1.765	3.564	0.304	0.787	1.421	3.238	0.221	0.653	1.264	2.664
L-rib	0.253	0.774	1.473	3.298	0.212	0.647	1.308	2.960	0.176	0.561	1.119	2.646
T-spine/6	0.229	0.842	1.820	4.090	0.195	0.766	1.683	3.808	0.163	0.679	1.471	3.381
T-spine/12	0.352	1.099	2.418	5.359	0.305	0 954	2.155	4.917	0.249	0.840	1.857	4.222
L-spine/5	0.189	0.619	1.358	3.225	0.166	0.583	1.165	2.974	0.125	0.526	1.081	2.758
R-ovary	0.068	0.266	0.599	1.525	0.060	0.253	0.551	1.415	0.047	0.222	0.451	1.294
L-ovary	0.064	0.244	0.548	1.412	0.054	0.229	0.512	1.303	0.049	0.207	0.444	1.186
R-iliac	0.471	1.226	2.105	4.642	0.393	1.081	2.077	4.197	0.300	0.924	1.715	3.706
L-iliac	0.569	1.449	2.429	5.129	0.433	1.161	2.164	4.440	0.316	1.029	1.888	3.903
Pubic	0.021	0.100	0.225	0.681	0.018	0.090	0.215	0.622	0.016	0.087	0.200	0.560
Testis	0.006	0.031	0.072	0.230	0.006	0.027	0.070	0.216	0.005	0.024	0.066	0.196
R-femur	0.007	0.033	0.074	0.227	0.006	0.030	0.073	0.206	0.006	0.029	0.069	0.197
L-femur	0.007	0.032	0.072	0.222	0.006	0.029	0.068	0.204	0.006	0.028	0.066	0.194

Table 14. Bone Marrow Integral Dose in PA Chest Examination by kvp, Field Size and Filtration, Obtained by Computer, Inside Beam[22] (g-mR/mAs)

kvp	Field 1			Field 2			Field 3			Field 4			Field 5		
	0.5 mmAl	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
50	344	281	210	335	268	201	227	187	141	173	144	108	163	135	101
55	466	388	309	440	361	286	301	248	189	231	191	146	217	179	136
60	604	513	426	560	470	386	382	318	247	294	246	192	275	229	178
65	758	652	558	696	593	501	470	395	313	363	307	244	339	285	227
70	925	804	700	846	732	630	562	480	388	436	374	304	406	347	282
75	1111	971	850	1020	889	771	672	578	474	523	451	371	486	418	345
80	1304	1145	1003	1207	1059	920	787	683	568	614	535	446	569	496	414
85	1500	1324	1153	1406	1241	1076	905	794	672	708	623	528	655	577	489
90	1698	1506	1299	1615	1433	1235	1026	910	784	804	716	617	743	664	571
95	1921	1707	1470	1832	1632	1407	1159	1032	893	911	814	704	840	754	651
100	2155	1915	1647	2055	1836	1584	1298	1159	1003	1021	915	792	942	847	732
105	2898	2131	1831	2282	2045	1765	1442	1288	1113	1136	1018	880	1047	942	813
110	2650	2353	2020	2513	2257	1949	1590	1420	1223	1254	1123	968	1155	1039	894
115	2911	2580	2213	2746	2471	2135	1742	1554	1330	1374	1230	1054	1266	1137	973
120	3181	2812	2410	2980	2685	2321	2897	1689	1434	1497	1337	1138	1380	1236	1050
125	3458	3049	2610	3215	2899	2508	2055	1824	1535	1623	1444	1219	1495	1334	1124
130	3744	3289	2813	3449	3111	2694	2215	1959	1632	1749	1550	1297	1612	1433	1196
135	4038	3533	3019	3681	3321	2879	2377	2093	1724	1877	1657	1372	1731	1530	1264
140	4340	3781	3227	3912	3528	3062	2541	2226	1811	2007	1762	1442	1851	1626	1329

Table 15. Bone Marrow Integral Dose in PA Chest Examination, by KVP, Field Size and Filtration, Obtained by Computer, Outside Beam[22] (g-mR/mAs)

	Field 1			Field 2			Field 3			Field 4			Field 5		
kvp	0.5 mmAl	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
50	0	0	0	0	0	0	4	4	3	5	5	4	4	4	3
55	0	0	0	0	0	0	6	5	4	7	7	5	6	6	5
60	0	0	0	1	1	1	7	7	5	10	9	7	9	8	6
65	0	0	0	1	1	1	10	9	7	13	11	9	11	10	8
70	0	0	0	1	1	1	12	11	9	16	14	11	14	13	10
75	0	0	0	1	1	1	15	14	11	19	17	14	17	15	13
80	0	0	0	2	1	1	18	16	14	23	20	17	20	18	15
85	0	0	0	2	2	2	21	19	16	26	23	20	24	21	18
90	0	0	0	2	2	2	25	22	19	30	27	24	27	25	22
95	0	0	0	2	2	2	28	25	22	34	30	27	31	28	25
100	0	0	0	2	2	2	32	28	25	38	34	30	35	31	28
105	0	0	0	3	3	2	35	31	28	42	37	34	38	34	31
110	0	0	0	3	2	2	38	34	31	46	41	37	42	37	34
115	0	0	0	3	3	3	41	37	33	49	44	39	45	40	37
120	0	0	0	3	3	3	44	39	35	53	47	42	49	43	39
125	0	0	0	4	3	3	47	42	37	56	50	44	52	46	41
130	0	0	0	4	3	3	50	44	39	59	52	46	55	48	43
135	0	0	0	4	3	3	52	46	40	62	54	47	57	50	44
140	0	0	0	4	4	3	54	47	41	64	56	48	59	52	45

Values increase by field number (size) except for field 5 which is lower than field 4 due to amount of active marrow near field margin.

Table 16 Bone Marrow Integral Dose in PA Chest Examination, by KVP, Field Size and Filtration, Obtained by Computer, Total Dose[22] (gmR/mAs)

	Field 1			Field 2			Field 3			Field 4			Field 5		
kvp	0.5 mmAl	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
50	344	281	210	335	268	202	231	191	144	179	148	112	168	139	104
55	466	388	309	440	361	286	306	253	193	238	198	151	223	184	141
60	604	513	426	561	470	387	390	325	252	304	254	198	284	237	184
65	758	652	558	697	594	502	479	404	320	376	318	253	350	295	235
70	925	804	700	847	733	631	575	491	397	452	388	315	420	359	292
75	1111	971	850	1021	890	772	687	591	485	542	468	385	503	434	357
80	1304	1145	1003	1208	1060	921	805	699	582	636	555	463	590	514	429
85	1500	1324	1153	1407	1242	1077	926	813	688	734	647	548	679	599	508
90	1698	1506	1299	1617	1435	1237	1050	932	803	835	743	641	771	688	593
95	1921	1707	1470	1834	1634	1409	1187	1057	915	945	844	731	871	782	676
100	2155	1915	1647	2057	1839	1586	1330	1187	1028	1059	949	822	977	878	760
105	2398	2131	1831	2285	2048	1767	1477	1319	1141	1178	1055	914	1085	976	844
110	2650	2353	2020	2516	2260	1951	1629	1454	1253	1299	1164	1004	1197	1077	928
115	2911	2580	2213	2749	2474	2137	1784	1591	1363	1424	1273	1093	1312	1178	1009
120	3181	2812	2410	2984	2688	2324	1942	1728	1470	1550	1383	1179	1429	1279	1089
125	3458	3049	2610	3218	2902	2511	2102	1865	1572	1679	1493	1263	1547	1380	1166
130	3744	3289	2813	3452	3114	2697	2265	2002	1671	1809	1603	1343	1667	1481	1239
135	4038	3533	3019	3685	3325	2882	2429	2138	1764	1939	1711	1419	1788	1580	1309
140	4340	3781	3227	3916	3532	3065	2594	2273	1853	2071	1818	1490	1910	1678	1374

Table 17. Gonadal Dose in PA Chest Examination by KVP, Field Size and Filtration[22] (mR/mAs,FFD:183cm)

kvp	Field Size	0.5 mmAl		1.0 mmAl		2.0 mmAl	
		Male	Female	Male	Female	Male	Female
50	S	.054	.076	.048	.068	.039	.057
	R	.009	.076	.009	.068	.008	.057
	Q	.003	.066	.002	.057	.002	.048
	P	.001	.021	.001	.019	.001	.016
	O	.000	.006	.000	.005	.000	.004
	N	.000	.002	.000	.001	.000	.001
	M	.000	.000	.000	.000	.000	.000
	L	.000	.000	.000	.000	.000	.000
70	S	.214	.321	.191	.290	.187	.262
	R	.045	.321	.039	.290	.035	.262
	Q	.013	.255	.012	.241	.010	.215
	P	.004	.093	.003	.085	.003	.075
	O	.001	.034	.001	.032	.001	.028
	N	.000	.009	.000	.009	.000	.008
	M	.000	.003	.000	.002	.000	.002
	L	.000	.001	.000	.001	.000	.001
90	S	.423	.698	.405	.600	.380	.563
	R	.100	.698	.097	.600	.092	.563
	Q	.032	.574	.031	.532	.030	.448
	P	.010	.266	.010	.253	.009	.246
	O	.003	.079	.003	.075	.003	.073
	N	.001	.023	.001	.022	.001	.022
	M	.000	.007	.000	.007	.000	.007
	L	.000	.002	.000	.002	.000	.002
130	S	.940	1.73	.901	1.62	.786	1.37
	R	.311	1.73	.292	1.62	.265	1.37
	Q	.111	1.47	.104	1.36	.095	1.24
	P	.040	.733	.037	.623	.034	.563
	O	.014	.268	.013	.227	.012	.205
	N	.005	.099	.005	.082	.004	.076
	M	.002	.037	.002	.032	.002	.029
	L	.001	.014	.001	.012	.001	.011

Table 18. Mean Bone Marrow Integral Dose from PA Chest Examination in Hiroshima and Nagasaki[22]
(Unit: g-rad/Exposure)

Type of Machine	Hiroshima		Nagasaki		Total
	Hospital	Clinic	Hospital	Clinic	
Transformer	3.68(155)	7.47(73)	3.87(78)	4.17(15)	4.61(321)
Condenser		4.77(91)		4.28(9)	4.73(100)
Total	3.68(155)	5.97(164)	3.87(78)	4.21(24)	4.64(421)

Number of exposures in parentheses.

location inside and outside the X-ray beam. Smaller doses, particularly gonadal, occurred more frequently in hospitals than clinics. A higher gonadal dose was incurred among clinics in Hiroshima. Ovarian doses were similar to those of Epp, et al;[9,10] testis doses, varicd from equal to 1/10 thoseof the latter. Mean bone marrow intergral dose was about twice that of Epp.[9,10]

Bone marrow, gonadal and skin doses in roentgenography of body sites other than chest were similarly

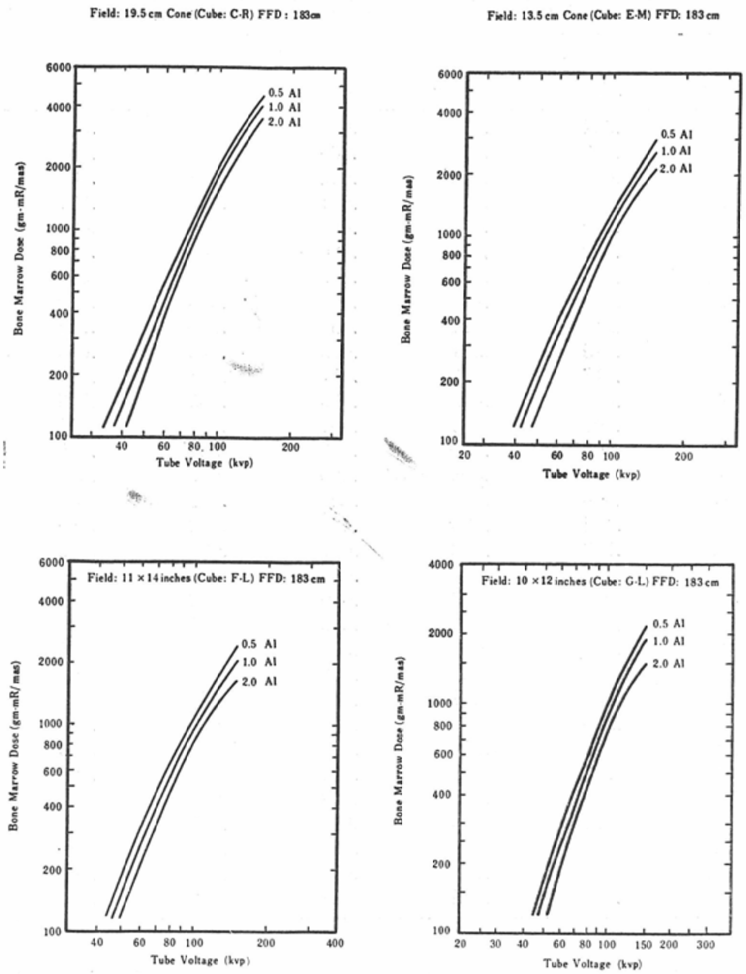

Fig. 16. Bone marrow integral dose[22]

Table 19. Mean Gonadal Dose from PA Chest Examination in Hiroshima and Nagasaki[22]
(Unit: mrad/Exposure)

Type of Machine	Sex	Hiroshima Hospital	Hiroshima Clinic	Nagasaki Hospital	Nagasaki Clinic	Total
Transformer	M	.051 (56)	.40 (29)	.014 (40)	.19 (4)	.12 (129)
	F	.42 (99)	1.02 (44)	.065 (38)	.50 (11)	.49 (192)
Condenser	M	—	.26 (45)	—	.0008 (1)	.26 (46)
	F	—	.64 (46)	—	.11 (8)	.56 (54)
Total	M	.051 (56)	.32 (74)	.014 (40)	.16 (5)	.16 (175)
	F	.42 (99)	.82 (90)	.065 (38)	.34 (19)	.51 (246)

Number of exposures in parentheses.

studied using phantom dosimetry, based on an earlier institution survey,[15] with computations by electric calculators.[23] Mean bone marrow integral and gonad dose per exposure and examination in the two cities are included in tables, and had rather wide standard deviations. Gonad doses were similar to those of

Table 20. Average Bone Marrow Integral, Gonadal and Skin Doses of Adult Health Study Subjects from Photofluorography, Hiroshima and Nagasaki[26]

Unit Type	Number of Examinations			Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad)		Skin Dose (mrad)
	Male	Female	Total		Male	Female	
Condenser	233	269	502	38.9	0.115	0.178	658
Transformer	92	57	149	46.6	0.714	8.42	604
Total	325	326	651	Mean 40.7	0.285	1.62	646

Epp,[10] but generally lower than those of Heller[24] and the Adrian Committee.[25] These data assisted in dose estimates for Adult Health Study subjects and other members of the Hiroshima and Nagasaki populations.

Six Hiroshima photofluorographic units representative of those in use in both cities were studied using phantom dosimetry.[26] Six-hundred and fifty-one exposures verified in a previous survey[15] were reproduced. Results are shown in Table 20.

B. Adult Health Study Subjects' Exposure by ABCC Examinations

1. Dose to the Gonads and Bone Marrow in Radiographic Examinations at ABCC

Doses to the gonads and bone marrow in radiography at ABCC[8] were published for reference until detailed studies of ABCC examinations could be undertaken. The dose tables are based on the data of Epp, et al.[9,10]

2. Dose from Routine Roentgenography and Fluoroscopy[27]

Bone marrow integral, gonadal and skin doses were measured for all examinations conducted in the ABCC Department of Radiology using phantom dosimetry, the appropriate X-ray unit, and the average exposure factors for each type of examination. Results are shown in a comprehensive table.[27] It was again shown that magnitude of gonadal dose depended mainly on whether the gonads were in the direct X-ray beam.

3. Cumulative Doses to Individual Adult Health Study Subjects from ABCC Roentgenological Examinations[28]

At the time of each subject's roentgenological examination, technical factors are routinely recorded and permanently filed in the ABCC Department of Radiology. Such data for all past examinations of each Adult Health Study subject were transcribed together with the appropriate average dose per examination, and skin, bone marrow integral and gonadal doses were cumulated, updated and coded and periodically analyzed.

Adjunct Studies

1. Radiologic Practice Since the Atomic Bombs, Hiroshima and Nagasaki[29]

For the years since 1945 during which no dosimetry was performed, activity of radiologic practice was assessed according to yearly totals of roentgenograms, radiographic, fluoroscopic and photofluorographic examinations, and numbers of treatments by X-ray and telecobalt. Radiation therapy for benign or malignant disease was ascertained from hospital records. Institutions were first classified according to estimated numbers of films consumed per year. Large hospitals were those using more than 10,000 films per year. Because of their relative importance, all large hospitals—14 in Hiroshima and 11 in Nagasaki—and a 40% random sample of nearly 500 small institutions in both cities were surveyed. The results are

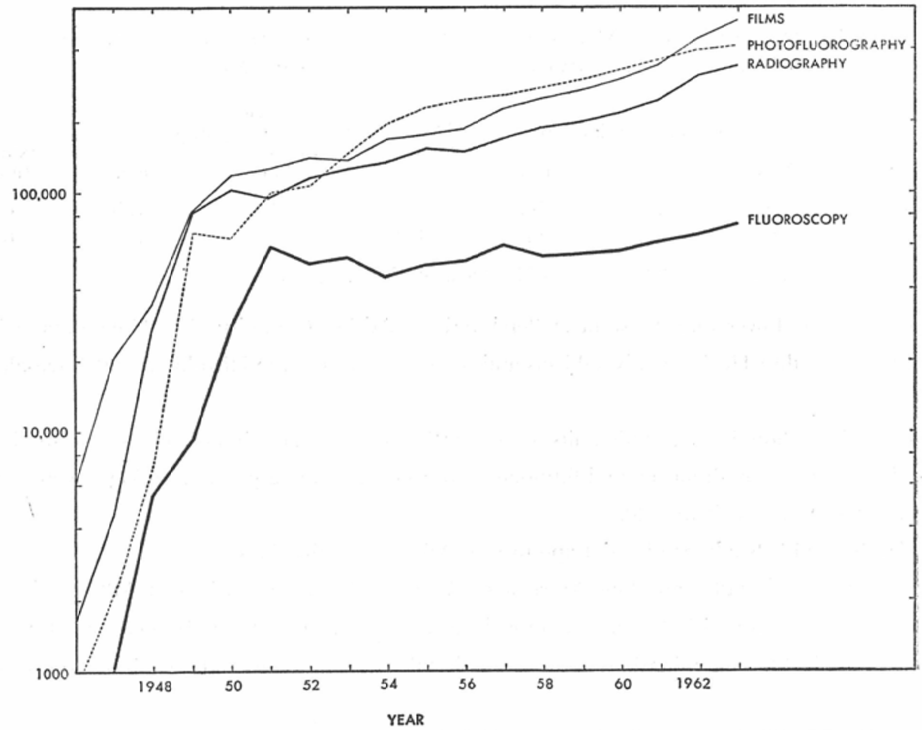

Fig. 17. Films and frequency of medical X-ray examinations by year-Hiroshima[29]

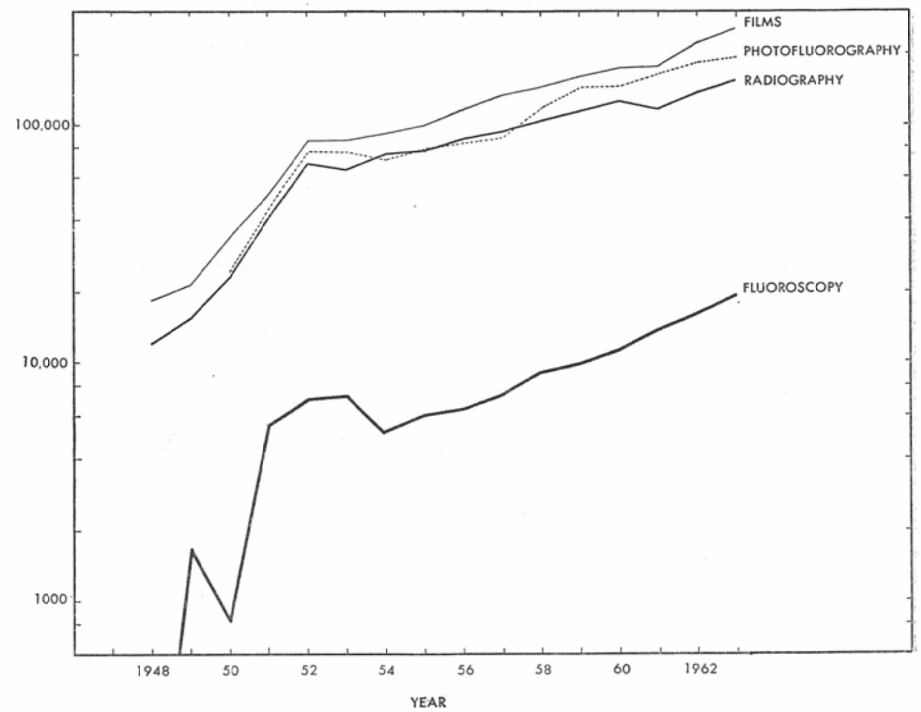

Fig. 18. Films and frequency of medical X-ray examinations by year-Nagasaki[29]

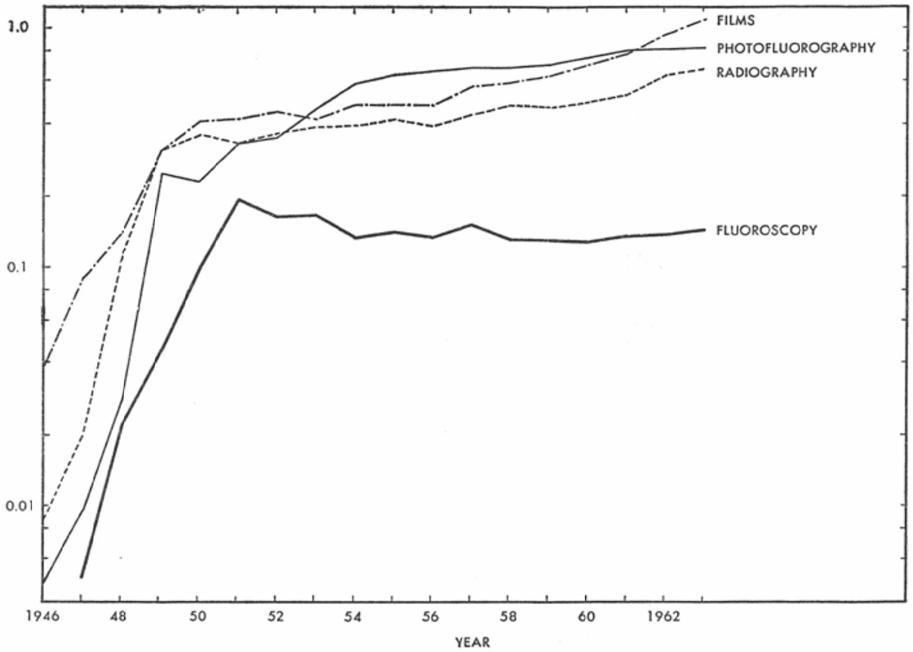

Fig. 19. Films and frequency of medical X-ray examinations per capita by year-Hiroshima[29]

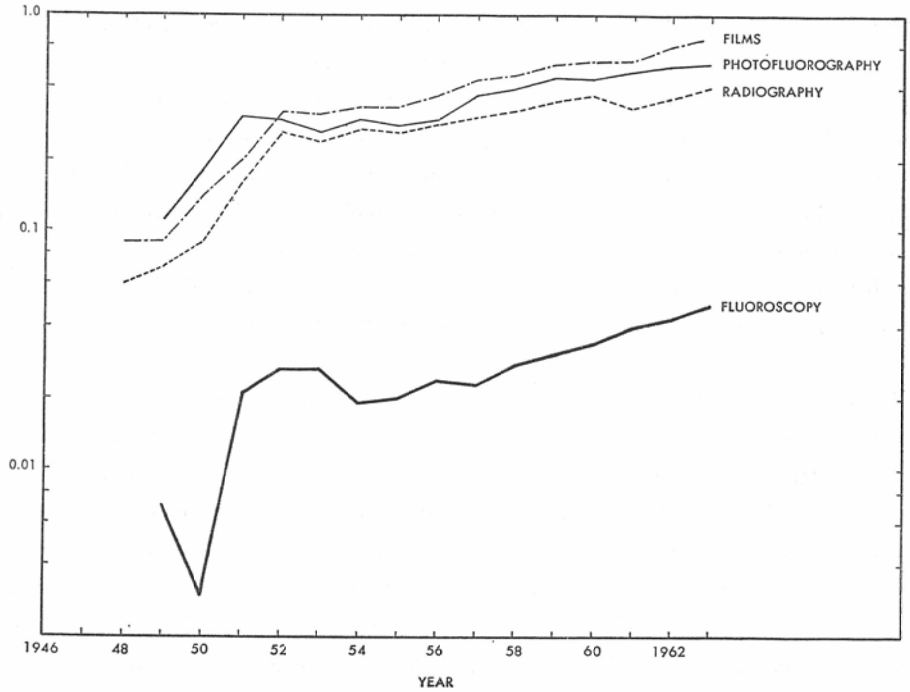

Fig. 20. Films and frequency of medical X-ray examinations per capita by year-Nagasaki[29]

Table 21. Radiation Therapy: Number of Treatments* by Year and City[29]

Year	Hiroshima	Nagasaki
1945	—	—
1946	—	—
1947	0.3	—
1948	0.4	—
1949	0.2	—
1950	0.5	—
1951	10.1	—
1952	9.1	0.8
1953	9.7	1.0
1954	11.3	0.8
1955	10.9	1.0
1956	11.9	8.5
1957	18.3	10.1
1958	16.3	10.1
1959	17.6	10.6
1960	20.4	18.2
1961	21.3	20.2
1962	22.1	23.3
1963	23.5	13.6

*Thousands
Large hospitals only

shown in Figures 17—20 and Table 21.

First an abrupt, then a steady increase in activity of radiologic practice was detected. The data assisted in estimating dose to ABCC subjects and the general populations of Hiroshima and Nagasaki.

2. Radiologic Practice and Medical Records in a Large General Hospital in Hiroshima[17]

Numbers of yearly roentgenograms, radiographic, fluoroscopic and photofluorographic examinations and treatments by X-ray and telecobalt were ascertained from the well-kept records of a large general hospital in Hiroshima, as a measure of the activity of its radiologic practice, for comparison with that of Hiroshima institutions in general. From 1949 to 1963, a sharp rise in numbers of films and a moderate rise in numbers of radiologic and fluoroscopic examinations was detected, paralleling the values for Hiroshima City.[29] There was only a slight rise in fluoroscopic examinations and a decline in radiation therapy over these years.

3. Estimation of Exposure Pattern and Bone Marrow and Gonadal Dose During Fluoroscopy[30]

Dose from fluoroscopic procedures is difficult to assess because of widely varying and continuously changing exposure factors. To assist dose estimations for these procedures, pattern of exposure and dose during upper gastrointestinal series by 10 radiologists using their own conventional fluoroscopic units and techniques were monitored with industrial type X-ray films in light-tight "jackets" fixed to a phantom human. Dose was correlated with optical density using standard films exposed to known quantities of radiation. For fluoroscopy and spot-filming, surface doses were plotted in histograms, according to a lattice describing distribution of active bone marrow.[18] Bone marrow and gonadal doses incurred by the 10 examiners were thus established. The results also aided in the assessment of fluoroscopic procedures in use in the community.

4. Exposure Pattern, Surface, Bone Marrow Integral and Gonadal Dose from Fluoroscopy[31]

Use of image intensifiers by radiologists and conventional equipment by nonradiologists performing upper gastrointestinal series, barium enemas and chest fluoroscopy were also assessed. Bone marrow integral, gonadal and surface doses were included. Differences in exposure patterns and doses were demonstrated according to types of examiners and equipment.

5. Radiation Output and Quality of Diagnostic X-ray Apparatus in Community Hospitals and Clinics[32]

An apparatus consisting of a remotely controlled revolving disk with various thicknesses of aluminum filters, and a 35 cc ionization chamber (See Apparatus), was used to measure the radiation output and quality of X-ray units in Hiroshima and Nagasaki hospitals. Values were compared with those of the ABCC experimental apparatus to correct for discrepancies before performing phantom dosimetry. There was moderately good correlation between kVp and radiation output.

6. Quantitative Estimate of Anode Effect in Diagnostic X-rays[33]

This detailed study was prompted by the relatively low gonadal doses encountered in some ABCC examinations for which, theoretically at least, the positions of the anodes of X-ray tubes could have been responsible. Using 14 × 17 inch medical X-ray films, densitometers, and dosimeters, 13 radiographic units of different manufacture, tube type and age were monitored when operating at various kVp, mAs, and focal spot sizes. Standard films were correlated with optical density and dose. The 14 × 17 inch films were assessed for density and the dose incurred—the effects of anode position. Dose distributions in air were compared with those in a phantom. The importance of maintaining the proper position of the tube was demonstrated, and quantitative estimates are included in the report.

Application of Community Hospital and Clinic Data

Activity of radiologic practice since 1945 was assessed according to the numbers of radiographic, fluoroscopic and photofluorographic examinations and radiation treatments performed, in a survey of hospitals in 1963.[29] The results are summarized in Table 21 and Figures 17—20.

Relative frequencies and mean dose per examination for radiography, fluoroscopy and photofluorography were determined by body site during a survey of Adult Health Study subjects.[12] These are shown in Tables 22—24. Only a very few subjects received more than one examination; therefore, the values are relatively independent of this factor.

For radiography, fluoroscopy and photofluorography, the product of mean dose and numbers of examinations were calculated for each year from 1947 to 1963 as shown in Tables 25–30, column I.

The population of Hiroshima and Nagasaki, by year, from 1944 to 1964 is shown in Table 31. Using the population data for each city, per capita bone marrow integral, gonadal and skin doses were calculated for these years, as shown is Tables 25–30, column II. These data are shown graphically in Figures 21–28.

Ratios by which radiography, fluoroscopy and photofluorography contributed to bone marrow, skin and gonadal doses were estimated. Photofluorography contributes to the total dose from medical examinations because of its frequent use. Though relatively infrequently used, fluoroscopy contributes significantly because of the relatively high dose it incurs. The results are shown in Tables 32–34.

Table 22. Average Bone Marrow Integral, Gonadal and Skin Doses by Radiography, Adult Health Study Subjects

Examination	Number of Examinations			Examinations × Dose/Examination			
				Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad)		Skin Dose (rad)
	Male	Female	Total		Male	Female	
Skull	3	2	5	207	0.03	0.02	3.09
Sinuses	3	7	10	109	0.03	0.07	5.90
C-spine	1	2	3	91	0.01	0.02	1.62
T-spine	3	6	9	480	1.38	12.8	15.3
L-spine	19	21	40	5360	492.0	4910.0	204.0
Pelvis	4	4	8	534	394.0	956.0	13.7
Shoulder	4	6	10	57	0.04	11.2	1.19
Chest	145	215	360	1800	23.2	131.0	15.4
Rib	3	2	5	226	1.8	7.48	6.1
Abdomen	4	9	13	510	47.6	1350.0	24.6
Gallbladder	9	19	28	848	66.5	272.0	60.4
IVP	5	4	9	1040	76.5	2020.0	30.0
Tomography, chest	10	12	22	1420	6.9	13.6	31.9
Ventriculography	1	0	1	100	0.01	—	3.84
Knee	7	3	10	10	3.5	0.36	—
Extremities	9	8	17	17	0.09	0.08	—
Total	230	320	550	12800	11100	9680	417
Sex Ratio	0.42	0.58	1.00	Mean 23.3	4.84	30.2	0.757

Table 23. Average Bone Marrow Integral, Gonadal and Skin Doses by Fluoroscopy and Spot Filming, Adult Health Study Subjects

Exam.	Flx Time (min)	No. of Exam.			Bone Marrow Integral Dose per Exam. (g-rad)	Gonadal Dose per Exam (mrad)		Skin Dose per Exam (mrad)	Bone Marrow Dose (g-rad) × No. of Exam.	Gonadal Dose (mrad) × No. of Exam.		Skin Dose (mrad) × No. of Exam.
		Male	Female	Total		Male	Female			Male	Female	
Chest	1	9	7	16	37.2	0.34	1.52	1270	595	3.06	12.2	20300
Upper GI	5	71	91	162	359.0	26.3	535.0	16500	58200	1870.0	48700.0	2670000
Upper GI+BE	8	2	4	6	647.0	135.0	1600.00	25300	3880	270.0	9600.0	152000
Upper GI+Small Bowel+BE	11	1	0	1	935.0	242.0	2670.00	34100	935	242.0	—	34100
Upper GI+Small Bowel	8	4	7	11	647.0	135.0	1600.0	25300	7120	540.0	11200.0	278000
Upper GI+Gall-bladder	5	2	2	4	359.0	26.3	535.0	16500	1440	52.6	1070.0	66000
BE	5	2	3	5	601.0	333.0	3010.0	12800	3010	666.0	9030.0	64000
Total		91	44	205					75100	3640	79600	3290000
Sex Ratio		.44	.56	1.00				Mean	367	40.0	698	16000

Table 24. Average Bone Marrow Integral Gonadal and Skin Doses from Photofluorography, Adult Health Study Subjects

Unit Type	Number of Examinations Male	Female	Total	Average Dose Per Examination: Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Female	Skin Dose (mrad)	Dose × Examinations: Bone Marrow Integral Dose (grad)	Gonadal Dose (mrad) Male	Female	Skin Dose (mrad)
Transformer	77	51	128	46.6	0.714	8.42	604	5960	55.0	429.0	77310
Condenser	187	223	410	38.9	0.115	0.178	658	15949	21.5	39.7	770000
Total	264	274	538					21910	76.5	469	347000
Sex Ratio	0.49	0.51	1.00				Mean	40.7	0.289	1.71	645

Table 25. Products of Examinations and Doses; and Dose Per Capita from Radiography, Hiroshima

Year	Examination Numbers	I Dose × Examinations: Bone Marrow Integral Dose (g-rad × 10^3)	Gonadal Dose (mrad × 10^3) Male	Female	Skin Dose (rad × 10^3)	II Dose per Capita: Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Female	Skin Dose (rad)
1946	1544	36	3.14	27.0	1.17	0.23	0.048	0.302	0.00757
1947	4468	104	9.08	78.3	3.38	4.66	0.968	6.04	0.0151
1948	27389	638	55.7	480.0	20.7	2.56	0.532	3.32	0.0833
1949	83938	1960	171.0	1470.0	63.5	7.22	1.500	9.36	0.235
1950	102541	2390	208.0	1800.0	77.6	8.39	1.74	10.9	0.273
1951	97731	2280	199.0	1710.0	74.0	7.69	1.60	9.97	0.250
1952	112976	2630	230.0	1980.0	85.5	8.39	1.74	10.9	0.273
1953	125613	2930	255.0	2200.0	95.1	9.09	1.89	11.8	0.295
1954	132146	3080	269.0	2310.0	100.0	9.09	1.89	11.8	0.295
1955	150322	3500	306.0	2630.0	114.0	9.79	2.03	12.7	0.318
1956	145060	3380	295.0	2540.0	110.0	.9.09	1.89	11.8	0.295
1957	169918	3960	345.0	2980.0	128.0	10.3	2.13	13.3	0.333
1958	188786	4400	384.0	3310.0	143.0	11.2	2.32	14.5	0.363
1959	199306	4640	405.0	3490.0	151.0	11.0	2.27	14.2	0.356
1960	211579	4930	430.0	3710.0	160.0	11.4	2.37	14.8	0.371
1961	240100	5590	488.0	4210.0	182.0	12.3	2.57	16.0	0.401
1962	301735	7030	613.0	5290.0	228.0	14.9	3.10	19.3	0.484
1963	331810	7730	675.0	5810.0	251.0	15.8	3.29	20.5	0.515

Dose per examination: Bone marrow integral, 23.3 g-rad; Gonadal: Male, 4.84 mrad, female 30.2 mrad; Skin 0.757 rad

Sex ratio: Male .42
Female .58

Table 26. Products of Examinations and Doses; and Dose per Capita from Fluoroscopy, Hiroshima

		I Dose × Examinations				II Dose per Capita			
Year	Examination Numbers	Bone Marrow Integral Dose (g-rad × 10^3)	Gonadal Dose (mrad × 10^3) Male	Female	Skin Dose (rad × 10^3)	Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Female	Skin Dose (rad)
1946									
1947	1023	375	18.0	400	16.4	3.67	0.40	6.98	0.16
1948	5484	2010	96.5	2140	87.7	7.34	0.80	14.0	0.32
1949	9200	3380	162.0	3600	147.0	11.0	1.20	20.9	0.48
1950	28701	10500	505.0	11200	459.0	36.7	4.00	69.8	1.60
1951	58465	21500	1030.0	22900	935.0	69.7	7.60	133.0	3.04
1952	50497	18500	889.0	19700	808.0	58.7	6.40	112.0	2.56
1953	53652	19700	944.0	21000	858.0	58.7	6.40	112.0	2.56
1954	44393	16300	781.0	17400	710.0	47.7	5.20	90.7	2.08
1955	49938	18300	879.0	19500	799.0	51.4	5.60	97.7	2.24
1956	50150	18400	883.0	19600	802.0	47.7	5.20	90.7	2.08
1957	58711	21500	1030.0	22900	939.0	55.1	6.00	105.0	2.40
1958	52988	19400	933.0	20700	848.0	47.7	5.20	90.7	2.08
1959	54271	19900	955.0	21200	868.0	47.7	5.20	90.7	2.08
1960	55295	20300	973.0	21600	885.0	47.7	5.20	90.7	2.08
1961	60808	22300	1070.0	23800	973.0	51.4	5.60	97.7	2.24
1962	65308	24000	1150.0	25500	1040.0	51.4	5.60	97.7	2.24
1963	71140	26100	1250.0	27800	1140.0	55.1	6.00	105.0	2.40

Dose per examination: Bone marrow integral, 367 g-rad; Gonadal: Male, 40.0 mrad, female 698 mrad; Skin 16.0 rad

Sex ratio: Male .44
Female .56

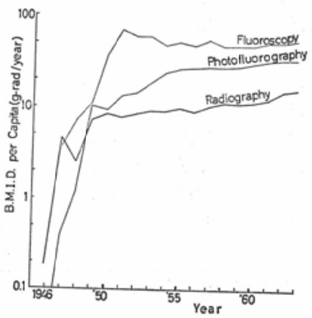

Fig. 21. Bone Marrow Integral Dose per Capita by Year Hiroshima

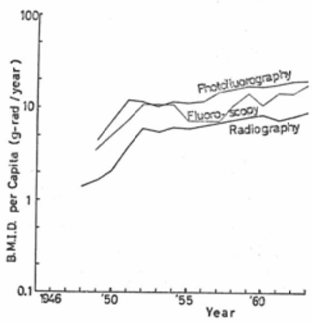

Fig. 22. Bone Marrow Integral Dose per Capita by Year Nagasaki

Table 27. Products of Examinations and Doses: and Dose Per Capita from Photofluorography, Hiroshima

		I Dose × Examinations				II Dose per Capita			
Year	Examination Numbers	Bone Marrow Integral Dose (g-rad × 10^3)	Gonadal Dose (mrad × 10^3) Male	Gonadal Dose (mrad × 10^3) Female	Skin Dose (rad × 10^3)	Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Gonadal Dose (mrad) Female	Skin Dose (rad)
1946	852	34.7	0.121	0.743	0.55	0	0	0	0
1947	2105	85.7	0.299	1.84	1.36	0.407	0.00283	0.0174	0.0065
1948	7129	290.0	1.01	6.22	4.60	1.22	0.00849	0.0523	0.0194
1949	68992	2810.0	9.80	60.2	44.5	10.2	0.0708	0.436	0.161
1950	64890	2640.0	9.21	56.6	41.9	9.36	0.0651	0.401	0.148
1951	99595	4050.0	14.1	86.8	64.2	13.4	0.0934	0.576	0.213
1952	107288	4370.0	15.2	93.6	69.2	14.3	0.0991	0.610	0.226
1953	145014	5900.0	20.6	126.0	93.5	18.3	0.127	0.785	0.290
1954	196831	8010.0	28.0	172.0	127.0	24.0	0.167	1.03	0.381
1955	229109	9320.0	32.5	200.0	148.0	26.1	0.181	1.12	0.413
1956	247969	10100.0	35.2	216.0	160.0	26.9	0.187	1.15	0.426
1957	262943	10700.0	37.3	229.0	170.0	27.7	0.192	1.19	0.439
1958	273280	11100.0	38.8	238.0	176.0	27.3	0.190	1.17	0.432
1959	292401	11900.0	41.5	255.0	189.0	28.1	0.195	1.20	0.445
1960	322893	13100.0	45.9	282.0	208.0	30.5	0.212	1.31	0.484
1961	357999	14600.0	50.8	312.0	231.0	32.6	0.226	1.40	0.516
1962	388472	15800.0	55.2	339.0	251.0	33.4	0.232	1.43	0.529
1963	408017	16600.0	58.0	356.0	263.0	33.8	0.235	1.45	0.536

Dose per examination: Bone marrow integral, 40.7 g-rad; Gonadal: Male, 0.289 mrad, female 1.71 mrad; Skin, 645 mrad

Sex ratio: Male .49
Female .51

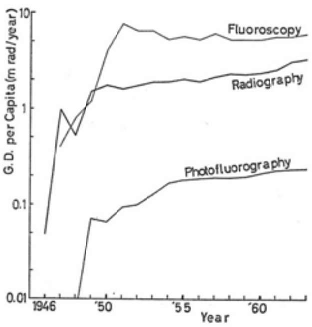

Fig. 23. Gonadal Does per Capita by Year (Male) Hiroshima

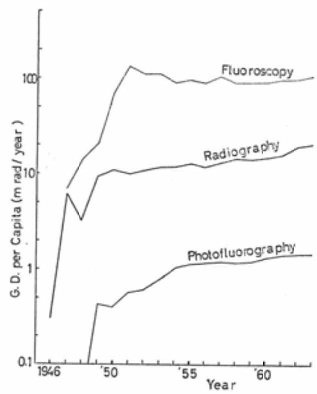

Fig. 24. Gonadal Dose per Capita by Year (Female) Hiroshima

Table 28. Products of Examinations and Doses; and Dose Per Capita from Radiography, Nagasaki

Year	Examination Numbers	I Dose × Examinations: Bone Marrow Integral Dose (g-rad × 10^3)	I: Gonadal Dose (mrad × 10^3) Male	I: Gonadal Dose (mrad × 10^3) Female	I: Skin Dose (rad × 10^3)	II Dose per Capita: Bone Marrow Integral Dose (g-rad)	II: Gonadal Dose (mrad) Male	II: Gonadal Dose (mrad) Female	II: Skin Dose (rad)
1946									
1947									
1948	12694	296	25.8	222	9.61	1.40	0.290	1.81	0.0454
1949	15679	365	31.9	275	11.9	1.63	0.339	2.11	0.0530
1950	23109	538	47.0	405	17.5	2.10	0.436	2.72	0.0681
1951	41551	968	84.5	729	31.5	3.73	0.774	4.83	0.121
1952	69454	1620	141.0	1220	52.6	6.06	1.26	7.85	0.197
1953	65759	1530	134.0	1150	49.8	5.59	1.16	7.25	0.182
1954	75490	1760	153.0	1320	57.1	6.29	1.31	8.15	0.204
1955	78691	1830	160.0	1380	59.6	6.06	1.26	7.85	0.197
1956	86941	2030	177.0	1520	65.8	6.52	1.36	8.46	0.212
1957	93859	2190	191.0	1640	71.1	6.99	1.45	9.06	0.227
1958	104130	2430	212.0	1820	78.8	7.46	1.55	9.66	0.242
1959	114224	2660	232.0	2000	86.5	8.16	1.69	10.6	0.265
1960	126066	2940	256.0	2210	95.4	8.62	1.79	11.2	0.280
1961	116195	2710	236.0	2040	88.0	7.69	1.60	9.97	0.250
1962	136533	3180	278.0	2390	103.0	8.39	1.74	10.9	0.273
1963	156839	3650	319.0	2750	118.0	9.32	1.94	12.1	0.303

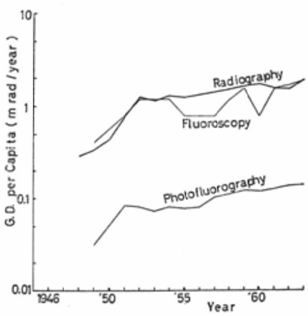

Fig. 25. Gonadal Dose per Capita by Year (Male) Nagasaki

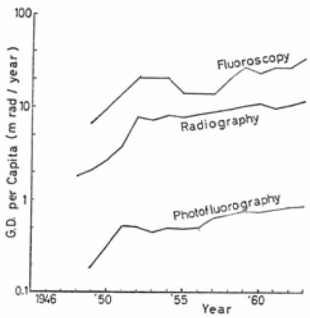

Fig. 26. Gonadal Dose per Capita by Year (Female) Nagasaki

Table 29. Products of Examinations and Doses; and Dose Per Capita from Fluoroscopy, Nagasaki

		I Dose × Examinations				II Dose per Capita			
Year	Examination Numbers	Bone Marrow Integral Dose (g-rad × 10³)	Gonadal Dose (mrad × 10³) Male	Gonadal Dose (mrad × 10³) Female	Skin Dose (rad × 10³)	Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Gonadal Dose (mrad) Female	Skin Dose (rad)
1946									
1947									
1948	86	31.6	1.51	33.6	1.38	0	0	0	0
1949	1717	630	30.2	671.0	27.5	3.67	0.40	6.98	0.16
1950	833	306	14.7	326.0	13.3	0	0	0	0
1951	5411	1990	95.2	2120.0	86.6	7.34	0.80	14.0	0.32
1952	7068	2590	124.0	2760.0	113.0	11.0	1.20	20.9	0.48
1953	7358	2700	130.0	2880.0	118.0	11.0	1.20	20.9	0.48
1954	5159	1890	90.8	2020.0	82.5	11.0	1.20	20.9	0.48
1955	6008	2200	106.0	2350.0	96.1	7.34	0.80	14.0	0.32
1956	7430	2730	131.0	2900.0	119.0	7.34	0.80	14.0	0.32
1957	7254	2660	128.0	2840.0	116.0	7.34	0.80	14.0	0.32
1958	9172	3370	161.0	3590.0	147.0	11.0	1.20	20.9	0.48
1959	9976	3660	176.0	3900.0	160.0	14.7	1.60	27.9	0.64
1960	11576	4250	204.0	4520.0	185.0	11.0	0.80	14.0	0.32
1961	13873	5090	244.0	5420.0	222.0	14.7	1.60	27.9	0.64
1962	16153	5930	284.0	6310.0	258.0	14.7	1.60	27.9	0.64
1963	19433	7130	342.0	7600.0	311.0	18.4	2.00	34.9	0.80

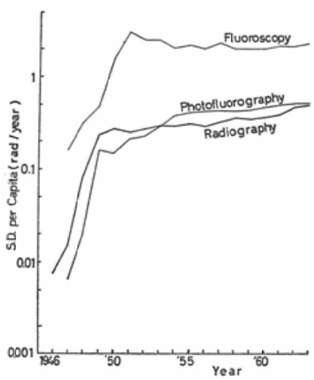

Fig. 27. Skin Dose per Capita by Year Hiroshima

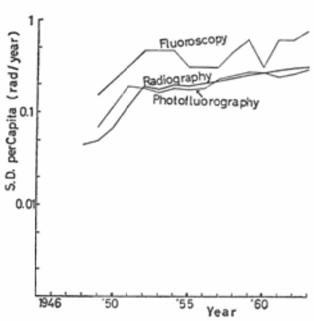

Fig. 28. Skin Dose per Capita by Year Nagasaki

Table 30. Products of Examinations and Doses; and Dose Per Capita from Photofluorography, Nagasaki

Year	Examination Numbers	I Dose × Examinations: Bone Marrow Integral Dose (g-rad × 10^3)	Gonadal Dose (mrad × 10^3) Male	Gonadal Dose (mrad × 10^3) Female	Skin Dose (rad × 10^3)	II Dose per Capita: Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Gonadal Dose (mrad) Female	Skin Dose (rad)
1946									
1947									
1948									
1949	24998	1020	3.55	21.8	16.1	4.48	0.0311	0.192	0.071
1950	45009	1830	6.39	39.2	29.0	7.33	0.0509	0.314	0.116
1951	76932	3130	10.9	67.1	49.6	12.2	0.0849	0.523	0.194
1952	76964	3130	10.9	67.1	49.6	11.8	0.0821	0.506	0.187
1953	71749	2920	10.2	62.6	46.3	10.6	0.0736	0.453	0.168
1954	79727	3240	11.3	69.5	51.4	11.8	0.0821	0.506	0.187
1955	84739	3450	12.0	73.9	54.7	11.4	0.0792	0.488	0.181
1956	88566	3600	12.6	77.2	57.2	11.8	0.0821	0.506	0.187
1957	117060	4760	16.6	102.0	75.5	15.1	0.105	0.648	0.239
1958	129027	5250	18.3	113.0	83.2	16.3	0.113	0.698	0.258
1959	142557	5800	20.2	124.0	91.9	17.9	0.125	0.767	0.284
1960	146979	5980	20.9	128.0	94.8	17.5	0.122	0.750	0.278
1961	162267	6600	23.0	141.0	105.0	18.7	0.130	0.802	0.297
1962	183956	7490	26.1	160.0	119.0	19.9	0.139	0.855	0.316
1963	197787	8050	28.1	172.0	128.0	20.4	0.142	0.872	0.323

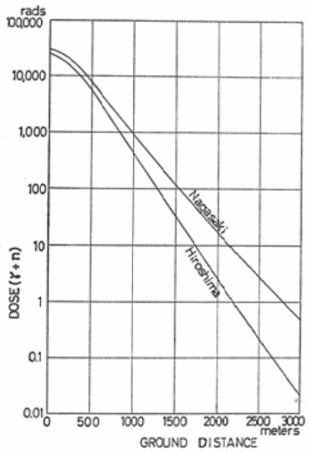

Fig. 29. A-Bomb Air Dose (T65D)[34] (Hiroshima, Nagasaki)

Table 31. Populations of Hiroshima and Nagasaki by Year[29]

Year	Hiroshima	Nagasaki
1944	336,483	240,000
1945	136,578	153,212
1946	171,204	186,119
1947*	222,434	195,174
1948	246,134	213,698
1949	270,863	229,823
1950*	285,712	247,248
1951	297,758	258,392
1952	310,172	266,374
1953	325,732	274,809
1954	337,837	277,900
1955*	357,287	303,724
1956	375,926	307,835
1957	389,473	315,496
1958	407,460	322,912
1959	442,223	327,070
1960*	431,336	344,079
1961	448,956	350,230
1962	473,876	376,048
1963	491,105	395,652
1964	504,326	399,258

Sources: Hiroshima City Office
Nagasaki City Health Center Annual Reports
*National Census

Table 32. Contributing Ratio of Types of Examinations to Total Medical Dose by Year, Hiroshima

	Bone Marrow Integral Dose			Gonadal Dose						Skin Dose		
				Male			Female					
Year	Rad	Flx	Photo	Rad	Flx	Photo	Rad	Flx	Photo	Rad	Flx	Photo
1946	0.50	0.00	0.50	0.96	0.00	0.04	0.97	0.00	0.03	0.68	—	0.32
1947	0.18	0.66	0.15	0.33	0.66	0.01	0.16	0.83	0.00	0.16	0.78	0.06
1948	0.22	0.68	0.10	0.36	0.63	0.01	0.18	0.81	0.00	0.18	0.78	0.04
1949	0.24	0.41	0.34	0.50	0.47	0.03	0.29	0.70	0.01	0.25	0.58	0.17
1950	0.15	0.68	0.17	0.29	0.70	0.01	0.14	1.86	0.00	0.13	0.79	0.07
1951	0.08	0.77	0.15	0.16	0.83	0.01	0.07	0.93	0.00	0.07	0.87	0.06
1952	0.10	0.73	0.17	0.20	0.78	0.01	0.09	0.90	0.00	0.09	0.84	0.07
1953	0.10	0.69	0.21	0.21	0.77	0.02	0.09	0.90	0.01	0.09	0.82	0.09
1954	0.11	0.60	0.29	0.25	0.72	0.03	0.12	0.88	0.01	0.11	0.76	0.14
1955	0.11	0.59	0.30	0.25	0.72	0.03	0.12	0.87	0.01	0.11	0.75	0.14
1956	0.11	0.58	0.32	0.24	0.73	0.03	0.11	0.88	0.01	0.10	0.75	0.15
1957	0.11	0.59	0.30	0.24	0.73	0.03	0.11	0.88	0.01	0.10	0.76	0.14
1958	0.13	0.56	0.32	0.28	0.69	0.03	0.14	0.85	0.01	0.12	0.73	0.15
1959	0.13	0.55	0.33	0.29	0.68	0.03	0.14	0.85	0.01	0.13	0.72	0.16
1960	0.13	0.53	0.34	0.30	0.67	0.03	0.15	0.84	0.01	0.13	0.71	0.17
1961	0.13	0.53	0.34	0.30	0.67	0.03	0.15	0.84	0.01	0.13	0.70	0.17
1962	0.15	0.51	0.34	0.34	0.63	0.03	0.17	0.82	0.01	0.15	0.68	0.17
1963	0.15	0.52	0.33	0.34	0.63	0.03	0.17	0.82	0.01	0.15	0.69	0.16

Table 33. Contributing Ratio of Types of Examinations to Total Medical Dose by Year, Nagasaki

	Bone Marrow Integral Dose			Gonadal Dose						Skin Dose		
				Male			Female					
Year	Rad	Flx	Photo	Rad	Flx	Photo	Rad	Flx	Photo	Rad	Flx	Photo
1946												
1947												
1948	0.90	0.10	0.00	0.94	0.06	0.00	0.87	0.13	0.00	0.87	0.13	0.00
1949	0.18	0.31	0.51	0.49	0.46	0.05	0.28	0.69	0.02	0.21	0.50	0.29
1950	0.20	0.11	0.68	0.69	0.22	0.09	0.53	0.42	0.05	0.29	0.22	0.48
1951	0.16	0.33	0.51	0.44	0.50	0.06	0.25	0.73	0.02	0.19	0.52	0.30
1952	0.22	0.35	0.43	0.51	0.45	0.04	0.30	0.68	0.02	0.24	0.53	0.23
1953	0.21	0.38	0.41	0.49	0.47	0.04	0.28	0.70	0.01	0.23	0.55	0.22
1954	0.26	0.27	0.47	0.60	0.36	0.04	0.39	0.59	0.02	0.30	0.43	0.27
1955	0.24	0.29	0.46	0.58	0.38	0.04	0.36	0.62	0.02	0.28	0.46	0.26
1956	0.24	0.33	0.43	0.55	0.41	0.04	0.34	0.65	0.02	0.27	0.49	0.24
1957	0.23	0.28	0.50	0.57	0.38	0.05	0.36	0.62	0.02	0.27	0.44	0.29
1958	0.22	0.30	0.48	0.54	0.41	0.05	0.33	0.65	0.02	0.26	0.48	0.27
1959	0.22	0.30	0.48	0.54	0.41	0.05	0.33	0.65	0.02	0.26	0.47	0.27
1960	0.22	0.32	0.45	0.53	0.42	0.04	0.32	0.66	0.02	0.25	0.49	0.25
1961	0.19	0.35	0.46	0.47	0.49	0.05	0.27	0.71	0.02	0.21	0.53	0.25
1962	0.19	0.36	0.45	0.47	0.48	0.04	0.27	0.71	0.02	0.21	0.54	0.25
1963	0.19	0.38	0.43	0.46	0.50	0.04	0.26	0.72	0.02	0.21	0.56	0.23

Table 34. Contributing Ratio of Types of Examinations to Total Medical Dose by Year, Hiroshima and Nagasaki

	Bone Marrow Integral Dose			Gonadal Dose						Skin Dose		
				Male			Female					
Year	Rad	Flx	Photo	Rad	Flx	Photo	Rad	Flx	Photo	Rad	Flx	Photo
1946	0.50	0.00	0.50	0.96	0.00	0.04	0.97	0.00	0.03	0.68	0.00	0.32
1947	0.19	0.65	0.16	0.33	0.66	0.01	0.16	0.83	0.00	0.16	0.78	0.06
1948	0.29	0.63	0.09	0.45	0.54	0.01	0.24	0.75	0.00	0.24	0.72	0.04
1949	0.23	0.39	0.38	0.50	0.47	0.03	0.29	0.70	0.01	0.24	0.56	0.20
1950	0.16	0.59	0.25	0.32	0.66	0.02	0.16	0.83	0.01	0.15	0.74	0.11
1951	0.10	0.69	0.21	0.20	0.79	0.02	0.09	0.91	0.91	0.09	0.82	0.09
1952	0.13	0.64	0.23	0.26	0.72	0.02	0.12	0.87	0.01	0.12	0.78	0.10
1953	0.13	0.63	0.25	0.26	0.72	0.02	0.12	0.87	0.01	0.11	0.77	0.11
1954	0.14	0.53	0.33	0.32	0.65	0.03	0.16	0.83	0.01	0.14	0.70	0.16
1955	0.14	0.53	0.33	0.31	0.66	0.03	0.15	0.84	0.01	0.14	0.70	0.16
1956	0.13	0.52	0.34	0.31	0.66	0.03	0.15	0.84	0.01	0.13	0.70	0.17
1957	0.13	0.53	0.34	0.31	0.66	0.03	0.15	0.84	0.01	0.13	0.70	0.16
1958	0.15	0.50	0.36	0.34	0.63	0.03	0.17	0.82	0.01	0.15	0.67	0.18
1959	0.15	0.49	0136	0.35	0.62	0.03	0.18	0.81	0.01	0.15	0.66	0.18
1960	0.15	0.48	0.37	0.36	0.61	0.03	0.18	0.81	0.01	0.16	0.66	0.19
1961	0.15	0.48	0.37	0.34	0.62	0.03	0.17	0.81	0.01	0.15	0.66	0.19
1962	0.16	0.47	0.37	0.37	0.60	0.03	0.19	0.80	0.01	0.17	0.65	0.19
1963	0.16	0.48	0.36	0.37	0.60	0.03	0.19	0.80	0.01	0.17	0.66	0.18

Table 35. Dose Per Capita, Radiography

City	Year	Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Gonadal Dose (mrad) Female	Skin Dose (rad)
Hiroshima	1946—1963	163	33.9	211	5.16
	1954—1963	115	23.9	149	3.73
Nagasaki	1946—1963	96	19.9	125	3.12
	1954—1963	75.5	15.7	98	2.45

Table 36. Dose Per Capita, Photofluorography

City	Year	Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Gonadal Dose (mrad) Female	Skin Dose (rad)
Hiroshima	1946—1963	358	2.48	15.3	5.66
	1954—1963	290	2.02	12.5	4.60
Nagasaki	1946—1963	207	1.44	8.88	3.29
	1954—1963	161	1.12	6.89	2.55

Table 37. Dose Per Capita, Fluoroscopy

City	Year	Bone Marrow Integral Dose (g-rad)	Gonadal Dose (mrad) Male	Gonadal Dose (mrad) Female	Skin Dose (rad)
Hiroshima	1946—1963	749	81.6	1425	32.6
	1954—1963	503	54.8	957	21.9
Nagasaki	1946—1963	151	16.0	279	6.4
	1954—1963	118	12.4	216	4.96

Table 38. Cumulative Dose Per Capita Radiography + Fluoroscopy + Photoflurography

City	Year	Bone Marrow Integral	Gonad Male	Gonad Female	Skin
		g-rad	mrad		rad
Hiroshima	1946—63	1269	118	1652	43.5
	1954—63	908	80.7	1118	30.3
Nagasaki	1946—63	454	37.4	413	12.8
	1954—63	405	29.2	321	9.96

A prime purpose of these investigations was a comparison of the magnitude of dose from medical X-ray with that of the A-bomb, and a majority of the studies was directed toward this goal. Periodic surveys, dosimetry and assessment of activity of radiologic practice over a 16-year period contributed data for these comparisons. Prescinding from factors such as radiation energies, instantaneous versus intermittent exposure, dose fractionation and tissue recovery, gross nevertheless useful comparisons can be made.

Two periods 1946–1963 and 1954–1963 were chosen to illustrate the per capita dose data, as shown in Tables 35–38.

The data for the recent period are probably more accurate than those for the earlier one, largely be-

Table 39. Comparison of A-Bomb, ABCC Examination, and Therapy Doses and Reported Fluoroscopy, Selected Cases

	Cancer	A-Bomb rad	ABCC Skin rad	Radiation Therapy R	Fluoroscopy Examinations Reported
		A-Bomb Dose>ABCC Dose			
1	Lung	340	0.8	4140	1
2	Breast	Unknown	1	4000	>30
3	Breast	364	3	13800	1
4	Breast	588	1	10800	3
5	Thyroid	153	0.4	6500	2
		A-Bomb Dose = ABCC Dose			
6	Breast				
	Lung	31	18	16600	
7	Breast		0.3	12920	1
8	Gastric	36	20		1(1)
9	Gastric	64	66		
		A-Bomb Dose<ABCC Dose			
10	Lung	2	21	3850	
11	Gastric		10	4000	
12	Gastric		22	2379	8
13	Gastric	7	115		
14	Gastric		8		20

( ) = Confirmed

cause of record-keeping. Comparison of doses for these two periods underscores the dose increase with the increase in activity of radiologic practice. Since 1946, cumulative mean bone marrow dose was estimated as 1 rad in Hiroshima and 0.5 rad in Nagasaki. These values approximate A-bomb dose at 2200 meters from the hypocenter in Hiroshima, and 3200 meters in Nagasaki, as seen from the A-bomb dose curves[34] shown in Figure 29.

Each Adult Health Study subject is routinely interviewed in the ABCC Department of Radiology for fluoroscopic, photofluorographic and therapeutic exposures he has received in other hospitals and clinics, since his last ABCC examination. Coded dose data for individual subjects are retrieved for analysis, an example of which is shown in Table 39.

Skin doses are included for comparison purposes. Gonadal and bone marrow doses of course are more practical, the latter for future reference in cases of development of leukemia. Three categories of subjects with carcinoma were selected to illustrate A-bomb doses exceeding; equalling; and less than ABCC skin doses. The subjects in this example received their medical exposure because of malignancies, but a minority of populations also receive radiation therapy for benign disease.

Table 40 shows computer data comparing A-bomb with ABCC bone marrow integral, gonadal and skin doses, numbers of fluoroscopy examinations and courses of radiation therapy among subjects with gastric cancer.

Such data, including radiation therapy doses, have been calculated for all participants of the Adult Health Study and are reference material in cases of development of diseases and abnormalities attributable to exposure to ionizing radiation. Medical X-ray exposure data are routinely updated as subjects are

Table 40. A-Bomb, ABCC Examination Doses and Reported Therapy and Fluoroscopy Per Subject by Computer (Gastric Cancer)

MF No.	ABCC Dose T65D rad	Gonad mrad	Bone g-rad	Skin rad	Fluoroscopy	Radiation Treatments
Hiroshima						
207713	–	346.82	1282.80	36.799		2
202183	–	73.85	408.08	10.244		1 (1)
222844	0	157.50	676.00	16.793	2	
260477	0	77.63	342.54	8.713	20	
234384	52	2195.98	1322.59	33.141	1	
243085	36	1380.01	833.60	20.444	1 (1)	
264824	0	2177.62	1000.83	22.188	8	2 (2)
314687	–	748.98	739.46	13.549	3 (1)	
434689	5	542.61	372.10	3.071	3	2
863743	–	5363.84	1827.12	46.144	2	
Nagasaki						
022363	0	0.16	16.06	.138	1 (1)	
055287	182	611.78	388.74	9.647	1 (1)	

( ) = Confirmed

reexamined.

Discussion

Community use of medical X-ray increased abruptly, then steadily, since immediately after World War II. Marked differences in frequencies of radiologic examinations were found between the two cities. Examinations of Adult Health Study subjects in other hospitals and clinics were more than twice as frequent in Hiroshima as in Nagasaki. The technical factors used differed markedly by city. Use of fluoroscopy increased more in Hiroshima than in Nagasaki. In a large minority of institutions, in both cities, insufficient added filtration was being used, and films per examination increased throughout the period of observation. Collimation was efficient for photofluorography, but gonads were often unnecessarily exposed during radiography in both cities. X-ray tubes apparently had been positioned without intent of taking advantage of the anode effect, either with respect to minimizing gonadal dose or gaining penetration of denser body parts. A small increase in number of mass gastric survey examinations was reported in Hiroshima. Occupational exposure was very infrequent. Radiation therapy—though an infrequent source of exposure—was reportedly more often administered for benign rather than malignant conditions, in Hiroshima. In Nagasaki, it was rarely reported as a source of exposure.

Doses from X-ray examinations in Hiroshima and Nagasaki hospitals varied with those previously reported, but were generally of the same order as other reported data. Doses for the Hiroshima and Nagasaki general populations are useful reference data in evaluation of Life-Span Study participants for late-radiation effects and for whom no individual doses can be calculated. They are also of value in assessing the cumulative exposure of individual Adult Health Study participants who are repeatedly examined in other hospitals and clinics as well.

From the data available, the exact reason for the differences in dose to the populations of the two cities is not clear, but socioeconomic reasons may be largely responsible. Until this comprehensive study was performed, the order of medical X-ray dose among survivors was unknown. Using population data and estimates of numbers of roentgenologic examinations, cumulative per capita doses from these procedures were calculated. A gross comparison of their mean bone marrow doses with A-bomb dose estimates[34] showed they approximated at 2200 meters and 3200 meters from the hypocenters in Hiroshima and Nagasaki respectively. A-bomb doses at these distances were of a very low order.[34] This comparison excluded consideration of factors such as the energies of exposure sources. The eventual effects of the instantaneous A-bomb exposures as opposed to any from multiple low dose exposures of medical procedures over many years remain to be seen. However, the Adult Health Study offers a unique opportunity to observe any possible differences which may become manifest later.

One of the most important considerations in the studies of late-radiation effects from the A-bombs was whether survivors were receiving radiologic exposures more frequently than other members of the Hiroshima and Nagasaki populations, thereby introducing an important concomitantly acting contaminant during evaluations of late-radiation effects. There was a significantly greater number of diagnostic exposures among the survivors, but the difference was small, and there was no correlation between frequency of examinations and distance from hypocenters or reported radiation symptoms. Medical X-ray exposure therefore need not be regarded as a cause of bias in comparing exposure groups of the Adult Health Study for possible late-radiation effects. The cumulative effect of medical X-ray on individuals in all exposure groups of the Adult Health Study is still an important consideration in evaluating them for possible effects of ionizing radiation.

A minority of Adult Health Study A-bomb survivors, for various clinical reasons, receive relatively large numbers of X-ray examinations. Doses from these procedures not infrequently exceed in magnitude those they received from the A-bombs. For those who eventually develop disease or abnormalities attributable to A-bomb exposure, a comparison of such sources of exposure and their respective doses will be essential in the evaluation of their disease. Average doses from all ABCC roentgenological procedures[27] are being used to estimate cumulative dose for each Adult Health Study subject's ABCC exposures. The frequency of their medical X-ray exposures elsewhere are being carefully documented for future reference.

Leukemia is a well know late-radiation effect of the A-bombs. Many Adult Health Study subjects are approaching ages when malignancies and other diseases can be expected to occur in larger numbers. It is important that they be carefully observed for subtle differences in rates or manifestations of disease. Procedures initiated in these studies permit comparison of medical X-ray's frequency and dose with A-bomb doses of individual Adult Health Study subjects to assist in the evaluation of abnormalities and diseases attributable to A-bomb exposure.

Summary

Medical X-ray exposure was studied as a possible contaminant in the long-term evaluations of A-bomb survivors for late-radiation effects. Participants in the ABCC-JNIH Adult Health Study were the focus for these investigations. An average of 23 percent of Hiroshima and 12% of Nagasaki Adult Health Study subjects received X-ray examinations in other institutions during the 3-month preceding

their visits to ABCC. Medical X-ray examinations were significantly more frequent among A-bomb survivors than comparison subjects in the Adult Health Study, but not to an extent to cause bias between these two categories. The magnitude of cumulated medical X-ray dose approximated that of the A-bomb at distances from the hypocenters of 2200 meters in Hiroshima and 3200 meters in Nagasaki. ABCC X-ray examination doses were calculated for each Adult Health Study subject, and routinely updated with each examination for comparison with each subject's A-bomb dose. Each subject's reported exposures to fluoroscopy, photofluorography and radiation therapy in other hospitals are recorded for future reference.

Activity of radiologic practice in Hiroshima and Nagasaki increased steadily since 1948, and was markedly different by city. For the years 1946–63 bone marrow integral dose was 1269 and 454 g-rad in Hiroshima and Nagasaki respectively. Gonadal doses were 118 and 37.4 mrad for males and 1652 and 413 mrad for females of Hiroshima and Nagasaki respectively. Corresponding skin doses were 43.5 and 12.8 rad for the two cities respectively.

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