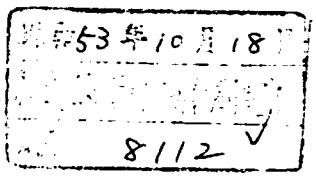
1977年報告

SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee
on the Effects of Atomic Radiation

1977 report to the General Assembly, with annexes



UNITED NATIONS
New York, 1977

NOTE

The report of the Committee without its annexes appears as Official Records of the General Assembly, Thirty-second Session, Supplement No. 40 (A/32/40).

In the text of each annex, Arabic numbers in parentheses are references listed at the end.

UNITED NATIONS PUBLICATION
Sales No. E.77.IX.1
Price: $U.S. 28.00
(or equivalent in other currencies)

Produced by UNIDO, Vienna

ANNEX F

Medical irradiation

CONTENTS

Introduction

1. The Committee has previously presented data on the medical irradiation of patients in its reports of 1958 (242), 1962 (243) and 1972 (244). Medical exposures are of particular interest since they contribute the highest man-made *per caput* doses in the population, are given with high instantaneous dose rates and cause the highest individual organ doses short of accidental exposures. From the radiation protection point of view,

they also offer the largest scope for implementing methods of dose reduction without loss of the information required. They differ from many other types of exposure in that they usually involve irradiation of limited regions of the body. They also differ in that the individuals who are irradiated are those who may expect to benefit directly from the particular treatment or examination.

2. A particularly difficult problem, however, arises when risk of medical irradiation is compared with the risk from other sources of man-made exposure or from natural background radiation. The organ doses received in diagnostic radiology may range over four orders of magnitude (from a few millirads to a few tens of rads) and will usually be given at high dose rates, compared with other man-made and natural sources. The various effects of radiation depend in a complex manner on the dose, the part of the body exposed, the dose rate and the length of time during which the total dose was received (described in Annexes H, I and J). Therefore, the detailed estimation of the risk from medical exposure is very complex; however, it is possible, by making simple assumptions about the relationship between dose and effect (as has been described in Annex A), to use the product of the number of persons in a subgroup and the dose received by a particular organ as a measure of the relative radiation detriment. The Committee has used this concept of collective dose for the estimation of the relative risk in diagnostic radiology.

3. However, since in radiotherapeutic practice, as compared with diagnostic practice, considerably higher doses are given to smaller groups of patients, and since the dose-effect relationship is likely to be different, the Committee has followed the practice of quoting, for radiotherapy the average organ dose together with the number of patients in the treated group. In this way it is hoped that there will be a clear indication that there may well be differences between the relative risk estimates from a given collective dose from diagnostic radiology and those from an equivalent numerical product for a radiotherapeutic practice. For this reason, it is important that the risks from the two practices should not be compounded or summed.

4. A vast amount of information on medical exposures was summarized in the 1958, 1962 and 1972 reports. Nevertheless, since the variation in practice and performance is large, not only from one country to another, but also between different hospitals and different radiologists, it is difficult to give a comprehensive presentation of the situation. Some of these variations arise from the differing needs of the individual patients, e.g., in the extent or duration of a particular examination; other variations occur because of the type of equipment available and the standard of the performance. The Committee has found no reason to compile data merely for recording purposes, but has tried to present information which might be useful for risk assessment, trend consideration and radiation-protection evaluation.

5. In the previous reports special emphasis was put on assessments of the annual genetically significant dose (GSD). The presentation of such data has encouraged further studies, so that it is now relatively clear to what extent medical exposures contribute to the total genetic dose in both developing and developed countries. In the developing countries the level of the GSD will usually reflect the availability of x-ray facilities. In order to meet the medical need, such services may need to be expanded. This is likely to increase the genetic dose in these countries in spite of any recommendations for good practice that are aimed at decreasing GSD.

6. The emphasis on the GSD may have detracted attention from exposure of organs other than the gonads and may therefore have led to an under-estimation of the overall risk from certain types of examination that usually cause very low gonad doses. One example is the chest examination, which involves irradiation of such radiosensitive tissues as lung, breast, marrow and sometimes also thyroid. The 1972 report, accordingly, gave more information on the dose in the active marrow. A number of groups of patients were also reported who had been identified as receiving high doses, and some had been shown to have a higher incidence of certain diseases than comparable but non-irradiated groups. In this report, further attention is given to identifying examinations in which particular organs may receive high doses. An attempt is also made to give a fuller picture of the patient's dose distribution, including data on doses in radiosensitive tissues such as bone marrow, thyroid, lung and breast.

7. In presenting data on dose levels in medical procedures, the Committee has three different purposes in mind. Firstly, it is of interest to know, for individuals, the doses to particular organs from the various types of medical irradiation and, particularly, the extent of the variation of such doses for any one type of investigation, as a basis for any attempt to weigh the radiation risks against the expectation of benefit to the individual patient and for differential cost-benefit analyses of protective measures (100). Secondly, it may be of interest to know both the individual and the collective organ doses from various medical practices as part of the presentation of man's total radiation exposure. Thirdly, the identification of some highly exposed groups may be of interest in epidemiological studies; for this purpose, the collective dose would be of interest.

8. As has been stated in paragraph 1, medical exposure is unique in the sense that the benefit is usually limited to the individuals who are irradiated. Assessments of individual doses in relation to the expected benefit are therefore usually sufficient for justification and optimization purposes. Only in special cases, e.g., public health examinations (267), or medico-legal examinations, is there an expected benefit to society in addition to that measured by the benefit to the individual. In such cases there may also be a need to assess the collective dose from a given practice as a whole.

9. The information sought for any individual is the dose to those particular organs which are considered to be at risk (see Annex G). Only then would it be possible to make a complete assessment of the radiation risk from that irradiation. Such complete information has only rarely been presented, principally for a few

therapeutic procedures, e.g. a survey of the radiation treatment of ankylosing spondylitis (see Annex G). However, the general awareness of the problem has resulted in further studies.

I. BASIC INFORMATION

A. METHOD OF DATA PRESENTATION

10. Medical irradiation comprises irradiation for both diagnostic and therapeutic purposes, and these will be treated separately in chapters II and III of this Annex. In each chapter, individual dose per unit procedure and the collective dose to various organs from different diagnostic procedures will be reported and discussed in separate sections. The individual dose will be influenced by the differences in techniques. In addition, the contributions to the collective dose will be proportional to the number of individual irradiations at a given dose level.

B. INDIVIDUAL DOSE PER UNIT PROCEDURE

11. The determination of the dose to a particular organ for a given examination, investigation or treatment may be direct: a dosimeter can be placed at representative sites in the organ of interest. More frequently, however, the method of dose determination has to be indirect: the organ may be inaccessible and measurements must be made elsewhere; calculations or further measurements are needed to determine the organ dose.

12. Measurements are normally made on the skin surface, although for the estimation of ovary dose measurements have been made in the vagina and rectum. The skin measurements combined with measurements on man-like phantoms have been used to estimate the dose to the bone marrow. The determination of the radiation doses to other organs has principally been undertaken by Monte Carlo methods (171) or by using skin measurements in conjunction with phantom measurements, percentage-depth dose data or isodose curves (239). For organs outside the main beam, scatter function curves are used (47, 86, 111, 137, 222). Alternatively, in the case of the administration of radiopharmaceuticals, calculations based on the distribution of the radiopharmaceuticals and on the physical properties of the nuclides need to be undertaken (140). Monte Carlo type calculations have also been made to facilitate such estimates (212). Considerable errors may arise in the determination of dose, but in general the direct method of measurement is expected to be subject to the least error.

13. Studies involving measurements on man-like phantoms require that such phantoms be sufficiently like Reference Man or normal patients in relevant characteristics to keep errors within reasonable limits (147). Reports such as that of the ICRP on Reference Man (101) enable anthropometric considerations as well as physiological variations to be taken into account in the choice of models or design of phantoms.

14. The difficulties in assessing the true organ doses will introduce systematic errors but will also to some extent increase the apparent spread of doses in each type of irradiation. For example, the gonad dose will vary dependent on the position of the stomach during radiological investigations of the gastro-intestinal tract (127). The doses actually received by individual patients, however, will also differ, depending upon the clinical requirements, the standards of the equipment and the skill of the operators. It has been claimed that spread of individual organ doses in each type of examination with x rays may fit a log-normal distribution (120). However, it has also been shown that, with some limitations, measured doses in x-ray examinations will fit a normal distribution (17). This will be discussed in more detail in chapter II. It seems reasonable to assume, however, that there is no *a priori* reason to expect a log-normal distribution of patient doses. Since each type of medical irradiation has a special objective (e.g., to destroy a tumour or produce an x-ray image) and is subject to optimization, it could rather be expected that the resulting doses would follow a normal distribution around the optimum value. Even this assumption, however, is usually an over-simplification.

C. COLLECTIVE DOSE PER TYPE OF PROCEDURE

1. Purpose of assessment

15. Ideally, the detriment from a unit procedure (e.g., a treatment course or a particular type of diagnostic examination) should be assessed by the weighted sum of all significant organ and tissue doses, but in practice the necessary weighting factors are not known. Lacking this information, it is still of interest to know the various organ doses, e.g., for relative risk assessments and optimization evaluations on the basis of various assumed risk factors.

16. As indicated in paragraphs 7 and 8, there is usually no need to assess collective doses from various medical practices for the purpose of justification and optimization considerations; instead, the individual doses may be used for the same purpose, because the risks and benefits relate to the same individuals. However, certain protection measures are of an administrative nature and may involve considerations of a practice as a whole. For example, in planning education and information, it may be of value to know where efforts might yield the best results. The doses to patients in dental examinations requiring two or three pictures are in general low and would not justify much attention in the individual case, but because of the very large number of examinations improved education might result in a larger reduction in the collective dose with higher individual doses but fewer individuals exposed. For this reason, national authorities may wish to have information not only on high individual doses but also on practices causing high collective doses. Also, the total collective dose from all medical practices would be of interest in the assessment of man's overall radiation exposure.

17. There is also an obvious interest in knowing the collective dose to various organs in those irradiated population groups which could be subject to epidemiological studies. The requirements are discussed in paragraph 31.

2. Limitations in the use of the collective dose as a measure of detriment from medical exposures

18. It has been shown in Annex A that for a given radiation the collective dose may be used as a relative measure of detriment if doses are so low that effects are proportional to dose and independent of dose rate. Doses are considered in this report to be sufficiently small in most diagnostic examinations so that the collective dose concept is applicable, and the relatively high dose rates utilized in these examinations are of little significance as far as the validity of the collective dose concept is concerned. However, this concept should not be extended to the case of therapeutic exposures where there is a risk of acute effects and where cell killing may reduce the risk of late deleterious effects. A further limitation arises from the fact that for some late effects of radiation it is not yet known which particular cell or tissue is at risk and therefore what tissue dose should be calculated.

3. Weighting for relevance

19. Neither collective doses nor *per caput* doses will reflect the detriment in a population if a substantial fraction of the *per caput* dose is contributed by the exposure of individuals who, for biological reasons, are not at risk. This would be the case with regard to genetic risks and carcinogenic effects when doses are received by individuals who would not be expected to be able to make the possible biological effect manifest because they are not expected to have children or to live long enough.

20. In such cases weighting procedures are called for. Weighting for the individual's child expectancy is part of the calculation of the GSD. A weighting for life expectancy could properly be an element in the derivation of a weighted *per caput* dose for the production of a particular somatic effect if sufficient data were available (see paragraph 86).

4. Assessment of collective dose

21. As was shown in Annex A, the radiation detriment from a given source k can be assessed, at least on a relative basis, by means of collective dose S_k (measured in man rad), which can be derived from the weighted product of the individual dose and the number of individuals:

$$S_k = \int_0^\infty D N_D(D)\, dD \qquad (1)$$

where $N_D(D)dD$ is the number of individuals receiving a dose in a specified organ or tissue in the range D to $D + dD$. The collective dose can apply to the world population, to a subpopulation or to one person. The defined group may comprise individuals who live at different times or individuals living in a given year, depending upon the purpose of the assessment.

22. In the context of medical irradiation, the collective dose to a certain organ, p, in the patients receiving a given type of examination or treatment, x, can be formulated as

$$S_{p,x} = K \Sigma_i D_{p,x,i} \qquad (2)$$

where K = 1 man since each group i is composed of one person.

23. In practice it is not often possible to ascertain the dose $D_{p,x,i}$ for each individual in the total number of patients involved N_x. As data can usually be obtained only for a sample n_x of individuals within the relevant patient population, some simplifying approximations to the summation over all individuals have to be made. If sampling is unbiased and can be considered representative, then the collective dose to the organ p from procedure x can be estimated by

$$S_{p,x} = (N_x/n_x)\, S_{p,x,n_x} \qquad (3)$$

where S_{p,x,n_x} is the collective dose in the sample.

24. A further approximation is required when information about doses delivered by a given procedure is only available for a different group of patients who have undergone a similar procedure but do not form part of the patient population under study. The collective dose can be estimated by

$$S_{p,x} = N_x \bar{D}^*_{p,x} \qquad (4)$$

where $\bar{D}^*_{p,x}$ is the average individual dose in the outside group for which information is available.

25. The approximation given by equation 4 is obviously not as reliable as that of equation 3, because there may be unspecified factors in the outside group that may be different in the patient population under study. This approximation would be used, for example, when the relevant average dose is available in one country and an estimate of the collective dose is required for a patient population in another country where no direct information on the individual doses is available.

26. An alternative way of presenting information on population exposures is the *per caput* dose $\bar{D}_{p,x}$, which is simply the collective dose divided by the total population size N:

$$S_{p,x} = N \bar{D}_{p,x} \qquad (5)$$

5. Accuracy of assessments

27. The accuracy of any estimate of collective dose obviously depends on the accuracy of the determination of the two main factors, i.e., the individual dose and the number of irradiated individuals. The accuracy would depend on which of the above equations is used for the calculations.

28. In the case of studies which use equation 3, i.e., when measurement data are obtained from only a sample of the patient population, it is important that such a sample group should be large enough (37). In practice it has been found that, to obtain a reliable distribution of the doses received in a particular medical practice, it is necessary to have at least 200-300 measurements (23). Obviously, it is also essential that the individuals in the sample should be selected so as to be representative of the patient population being studied.

29. In some collective dose surveys, the number of exposed individuals will be obvious, e.g., when investigating a group of individuals who have all had a particular investigation or treatment during a defined time at a limited number of centres, such as the

radium-224 patients surveyed in reference 215. However, more generally, for an estimate of the collective dose to individuals who undergo x-ray examinations in current practice, e.g., in the examination of the stomach in Japan, it is necessary to obtain data on the frequency of these examinations in the country concerned. This requires a sample to be taken over a period of time from a selected sample of the hospitals in the country. Such frequency surveys have formed part of most of the studies undertaken for the estimation of the GSD, and samples of frequency data have usually covered about 1-4 per cent of the year's radiological examinations. Some surveys have shown that fluctuations in the frequency of particular examinations throughout the year also need to be taken into account (36).

30. In the determination of the collective dose, the least error is involved if the organ doses for all the irradiated individuals are known. In this case the overall error is in the determination of the doses to the particular organ concerned. When direct measurements of the skin dose or the male gonad dose are being made during x-ray examinations, modern techniques should enable the measurement errors to be of the order of 5 per cent. In other cases the errors in the measurement or estimation of the organ dose may be considerably greater. The bigger the contribution from a particular practice to the total collective dose, the more effort should be applied to improve the precision of the dose determination. In those surveys in which only a sample of the individuals are measured, there will be, in addition to the measurement error, sampling errors for both the measurement sample selection and the frequency sample used.

D. GROUPS OF POTENTIAL EPIDEMIOLOGICAL INTEREST

31. When a group is being studied to determine the incidence of a deleterious effect caused by radiation, it is essential that an estimate be made of the incidence in a control group. The appropriate size of an exposed population for this purpose has been studied recently by Goss (65). Table 1 gives the size of collective dose needed to have a 95% chance of detecting an increased risk at the 5% level of significance. It is obvious that at low doses very large groups of patients are required, but at therapeutic dose levels it is possible to observe the required number of patients with relative ease.

TABLE 1. SIZE OF COLLECTIVE DOSE NEEDED TO GIVE A 95% PROBABILITY OF DETECTING AN INCREASED RISK

Age group and investigated risk	*Collective dose (10^3 man rad)*	*Observation period (y)*
Children		
Leukaemia	310	10
Thyroid cancer (incidence)	700	10
Other cancers	310	10
Adults		
Leukaemia	100	20
Breast cancer (females)	420[a]	20
Lung cancer	4 000	20
Other cancers	12 000	20

Source: Reference 65.

[a] Corrected by the Committee.

II. DIAGNOSTIC USES OF RADIATION

A. X-RAY DIAGNOSTIC RADIOLOGY

1. Trends in frequency and technique

32. In most countries the distribution of x-ray apparatus is non-uniform and the number of installed machines increases with population density. A study of this in Japan (115) showed a good correlation between population and number of units. The study also showed that in some areas non-trained or unlicensed staff were used to take up to 60 per cent of the radiographs made in practitioners' offices.

33. In the 1972 report of the Committee, the overall rate of increase in the number of radiological examinations reported for the 1960s by a number of countries with technically advanced medical services was reported to be between 2 and 6 per cent per year. When corrected for the increased population the growth was estimated to be about 3 per cent per year. However a more recent report from the Netherlands (175) for the same period has shown an annual growth rate of 8.5 per cent. Reports quoted by Puijlaert (176) indicate that for a number of countries the annual growth rate *per caput* for the late 1960s and early 1970s was between 5 and 15 per cent.

34. Further analysis of surveys made in the United States of America in 1964 and 1970 (27, 250, 251) indicates a number of interesting trends in frequency, technique and dose (table 2). As can be seen from the table, the trend pattern is rather complex.

TABLE 2. CHANGES IN DATA PERTAINING TO DIAGNOSTIC X-RAY PROCEDURES IN A SIX-YEAR PERIOD

United States of America, 1964 and 1970

	1964	*1970*	*Increase[a] (per cent)*
Number of persons having x-ray examinations	108 10^6	130 10^6	+ 20
Number of x-ray procedures	173 10^6	212 10^6	+ 22
Number of films exposed	506 10^6	661 10^6	+ 30
Average number of films per examination	2.2	2.4	+ 9
Fraction of thoracic examinations with two or more films	31 %	47 %	+ 52
Mean ratio of beam area to film area (in hospitals)	1.9	1.2	− 37
Estimated mean skin exposures for posterior-anterior and anterior-posterior views of the abdomen	480 mR	620 mR	+ 29[b]
Mean skin exposure per dental film	1 140 mR	910 mR	−20[c]

Sources: References 27, 250, 251.

[a] The population of the United States increased by 7 per cent over the six-year period.

[b] This increase may be due to the increased frequency of high-exposure examinations, the increase in the use of grids, and the use of higher tube potentials and currents without a corresponding increase in filtration.

[c] This decrease is due to the increased use of faster film.

TABLE 3. ESTIMATED ANNUAL NUMBER AND DISTRIBUTION OF MEDICAL X-RAY PROCEDURES BY TYPE OF FACILITY AND SUPERVISION

United States, 1964 and 1970

Type of facility	Number of medical x-ray procedures (thousands)		Per cent of medical x-ray procedures		Number of procedures supervised by radiologists (thousands)		Per cent of procedures supervised by radiologists	
	1964	1970	1964	1970	1964	1970	1964	1970
All types	118 919	144 355	100.0	100.0	72 346	100 530	60.8	69.6
Hospital	68 490	92 489	57.6	64.1	63 080	91 356	92.1	98.8
Private office	24 195	27 136	20.3	18.8	...	...	...	...
Radiologist	5 335	4 223	4.5	2.9	5 335	4 223	100.0	100.0
Other	18 860	22 913	15.8	15.9	...	...	...	...
Private group	7 861	9 903	6.6	6.9	3 931	4 951	50.0	50.0
Health agencies and others	18 374	14 826	15.5	10.3	...	...	...	...

Note: Table reproduced from reference 251.

35. The estimated number and distribution of diagnostic x-ray procedures in the United States in 1964 and in 1970 (251), by type of facility and supervision, are shown in table 3. There was a 6.5 per cent increase in the use of hospital radiological facilities, and an increase from 92.1 per cent to 98.8 per cent in the proportion of films taken in hospitals under the supervision of radiologists.

36. An analysis of the trend in the number of medical x-ray visits by age group for the years 1960, 1964 and 1970 is shown in table 4 (250). The major increases occurred in the age groups <15, ⩾45 and, particularly, >65 years. According to this information, the fractional number of patients under 30 decreased from 22.3 per cent in 1960 to 20.5 per cent in 1970.

37. The United States surveys (255) showed no significant change in the annual GSD between 1964 and 1970, in spite of the increased number of examinations and the indication of higher abdominal doses. (See paragraph 107.) An analysis of the increase in frequency of abdomen and thoracic examinations shows, however,

TABLE 4. ANALYSIS OF THE INCREASING FREQUENCY OF MEDICAL X-RAY VISITS BY AGE AND SEX

United States, 1960-1970

(Visits per 100 persons per year)

Category	July 1960-June 1961	April-June 1964	April-September 1970
Age (y)			
< 15	16.4	20.9	24.4
15-29	57.1	55.2	55.4
30-44	63.0	61.1	65.9
⩾ 45	66.5	69.8	81.5
45-64	71.2	73.6	82.3
⩾ 65	55.4	61.5	79.9
Sex			
Male	49.7	50.6	56.6
Female	46.2	49.0	55.3
Overall	47.9	49.8	55.9

Source: Reference 250.

that these examinations increased principally in the age groups above 30, which might be one explanation for the lack of significant change in GSD. Additional patient protection was used in 10 per cent and 8.5 per cent of

TABLE 6. NUMBER OF X-RAY EXAMINATIONS IN MASS

Breakdown *(10^3)*

Sex								Age (y)
								(a) *Mass chest*
		⩽ 10	11-15	16-18	19-24	25-29	30-34	35-39
Male		655	634	2 278	3 340	2 426	2 053	1 830
Female		622	606	2 296	2 201	1 849	1 565	1 432
	Total	1 277	1 240	4 574	5 541	4 275	3 618	3 262
								(b) *Mass stomach*
				⩽ 19	20-24	25-29	30-34	35-39
Male				4.7	22.2	70.9	136.1	310.1
Female				2.3	11.1	30.1	94.9	216.5
	Total			7.0	33.3	101.0	231.0	526.6
								(c) *Dental*
		0-5	6-10	11-14	15-19	20-24	25-29	30-34	35-39
Male and female		1 261	2 495	2 595	5 061	9 731	11 360	11 510	12 762

Sources: Chest screening, reference 84; stomach screening, 83; dental radiography, 138.

TABLE 5. ANALYSIS OF THE INCREASING FREQUENCY OF DIAGNOSTIC X-RAY EXAMINATIONS BY TYPE

Japan, 1958-1975

Type of examination	*Number of examinations per 1000 persons*			*Ratio*	
	a. *Radiography*				
	1959 (A)	*1969 (B)*	*1974 (C)*	*B/A*	*C/B*
Head, cervical spine	8.8	58	60	6.6	1.03
Shoulder	22	33	48	1.5	1.45
Chest	144	277	289	1.92	1.02
Barium meal	19.4	86	108	4.4	1.25
Abdomen	1.5	14	23	9.3	1.64
Barium enema	5.9	6.2	6.5	1.05	1.04
Dorsal spine	3.3	7.0	5.0	2.1	0.71
Lumbar or sacral spine	7.1	37	41	5.2	1.11
Urography, cystography	5.1	7.7	9.6	1.51	1.24
Hip and joint	8.5	14	19	1.65	1.35
Lower leg	15.8	44	56	2.8	1.27
Tomography	–	5.0	7.3		1.46
Pelvimetry, obstetrical (abdomen)	1.6	2.8	1.9	1.75	0.68
Other	13.9	54	63	3.9	1.16
Total	259	641	729	2.5	1.14
	b. *Dental radiography*				
	1958 (A)		*1974 (C)*		*C/A*
Dental x-ray examinations	13		833		64
	c. *Photofluorography*				
	1963 (A)	*1968 (B)*	*1973 (C)*	*1975 (D)*	*B/A*	*C/B*	*D/B*
Chest	434	641	486	313	1.47	0.76	0.49
Barium meal	–	18	31	40		1.72	2.22

Sources: References 74, 79, 146, 181.

the diagnostic x-ray examinations in 1964 and 1970, respectively, whereas in dental radiography the use of additional patient protection increased from 18.8 per cent to 27.2 per cent (251).

38. A survey by Bederke *et al.* (202) in 1974 in the Kopenick ward of Berlin (GDR) of out-patient radiological examinations showed that, of the 29 000 patients examined, 30 per cent were under 30 years of age. On the average, the patients had 2.5 exposures per examination; in the case of barium meals and enemas, the average was 5.0. Fluoroscopy was used in 17 per cent of the examinations, and 49 per cent of the patients had radiographs of the abdomen or pelvis with relatively high gonad doses. The total number of examinations per year was 40 000 for out-patients and about the same number for in-patients. With a total population of 131 000, that would indicate an examination rate of 67 per 100 persons per year.

39. In Japan, nation-wide radiological surveys were made in 1959, 1969 and 1974 (74, 78, 80, 81, 181). The frequency data from these surveys are summarized in table 5. There was a considerable increase in the number of x-ray examinations between 1959 and 1969; the increases according to type were by factors that ranged from 1.05 to 9.3, with an overall factor of 2.5. However, during the five years 1969-1974, the rate of increase was much reduced for many of the examination types, and the overall rate of increase in the number of examinations was assessed at about 3 per cent per year. The most important increases from the collective dose aspect are those for barium-meal examinations and for abdomen, lumbar spine and sacral spine examinations. There was also a very significant rise in the number of dental x-ray examinations (see paragraph 44).

40. Table 6 gives the frequency of mass chest and stomach screening and dental radiography by age group in Japan. The mass chest screening during school age is carried out only at the time of admission into the primary school (age 5-6) and at the second class of the junior high school (age 13-14). The largest numbers are radiographed in the 19-24 y group for chest examinations and in the 40-44 and 45-49 y groups for the stomach examinations.

SCREENING AND DENTAL RADIOGRAPHY IN JAPAN, 1974 AND 1975

by age and sex

						Total
screening, 1975						
40-44	*45-49*	*50-54*	*55-59*	*⩾ 60*		
1 762	1 559	1 109	469	537		18 652
1 407	1 273	1 094	345	438		15 128
3 169	2 832	2 203	814	975		33 780
screening, 1975						
40-44	*45-49*	*50-54*	*55-59*	*60-69*	*⩾ 70*	
492.6	496.8	369.2	224.0	205.6	51.8	2 384
331.3	331.3	279.1	193.2	207.5	39.7	1 737
823.9	828.1	648.3	417.2	413.1	91.5	4 121
radiography, 1974						
40-49		*50-59*		*⩾ 60*		
16 668		10 055		6 423		89 921

41. A comparison between the 1974 Swedish survey by Bengtsson *et al.* (17) and the 1955 survey by Larsson (128) shows that x-ray examinations (excluding dental) increased by 51 per cent between 1955 and 1974. During this period the Swedish population increased by 11 per cent, which means that the net increase was 36 per cent, or less than 2 per cent per year. The disappearance of tuberculosis as a significant problem is reflected in decreased frequencies of mass photofluoroscopy, but this trend may not be representative of other countries. There is a remarkable increase in the number of dental exposures, almost by a factor of five. The frequency data are summarized in table 7.

TABLE 7. ANALYSIS OF THE INCREASING FREQUENCY OF DIAGNOSTIC X-RAY EXAMINATIONS BY TYPE

Sweden, 1955 and 1974

Type of examination	*Number of examinations per 1000 persons*		*Ratio*
	1955 (Population 7.3 10^6)	*1974 (Population 8.1 10^6)*	*1974/1955 (Population ratio 1.11)*
Hip and femur	9.6	18.9	2.0
Pelvis	8.2	15.4	1.9
Pelvimetry	0.5	1.3	2.6
Lumbosacral region	16.1	25.0	1.6
Urography, retrograde pyelography	9.1	23.9	2.6
Urethrocystography	1.2	2.7	2.3
Stomach, small intestine	30.0	33.0	1.1
Colon	9.0	16.0	1.8
Abdomen	5.0	12.9	2.6
Obstetrical abdomen	0.6	1.4	2.3
Hysterosalpingography	1.2	0.8	0.7
Cholecystography, cholangiography	12.0	18.4	1.5
Dorsal spine	5.8	13.3	2.3
Lung, ribs, heart	79.4	161.6	2.0
Lung (photofluorography)	139	110	0.8
Dental (single exposures)	307	1 500	4.9
Other	103	195	1.9
Total (excluding dental)	430	650	1.51

Sources: References 17, 128.

42. An interesting study reported by Berry and Oliver (20) shows that in the United Kingdom of Great Britain and Northern Ireland, 18 per cent of the x-rayed patients had spoilt films, principally because of exposure or positioning faults.

43. The annual number of dental exposures per 1000 of population in Sweden increased from about 300 in 1955 to 570 in 1969 (151), i.e., by about 6 per cent per year. The subsequent increase to 1500 in 1974 (table 7) corresponds to about 20 per cent per year over that last five-year period. Of the 13 million dental films exposed in Sweden in 1974, about 3 million were exposed in bite-wing examinations of school children. Of the remaining 10 million films, about 50 per cent have been estimated to have been used in bite-wing examinations. The increasing number of bite-wing examinations is partly explained by deliberate efforts to make full-mouth examinations irrespective of whether the dentist knows beforehand that the film will be needed. This practice is defended on the basis of claimed earlier detection of small cavities. Such dental examinations are therefore health investigations rather than diagnostic examinations. The yield has been estimated to be about 10 per cent in those examinations for which there were no clinical indications, but this number is uncertain. No estimate has been made on how many of the bite-wing exposures were made without clinical indication.

44. Similar observations have been made in other countries. For example, in the 1970 United States survey (251) it was reported that there were an estimated 68 million dental x-ray visits, corresponding to an average of 340 x-ray examinations per 1000 of population. As each examination consisted of, on the average, 4.1 films, the total number was approximately 1400 films per 1000 of population, in line with the practice in Sweden. The annual number of dental exposures per 1000 of the population in Japan increased from 13 in 1958 to 855 in 1974 (146). The age distribution of the population in Japan having dental examinations during 1974 is given in table 6. The study (138) also includes information on the numbers in each age group for the different types of intra-oral examination.

45. In contrast, it has been estimated that 4 million x-ray films were used in the United Kingdom in 1973 (52), an average of only 73 per 1000 of population. This compares with an estimated 2 million films used in 1957.

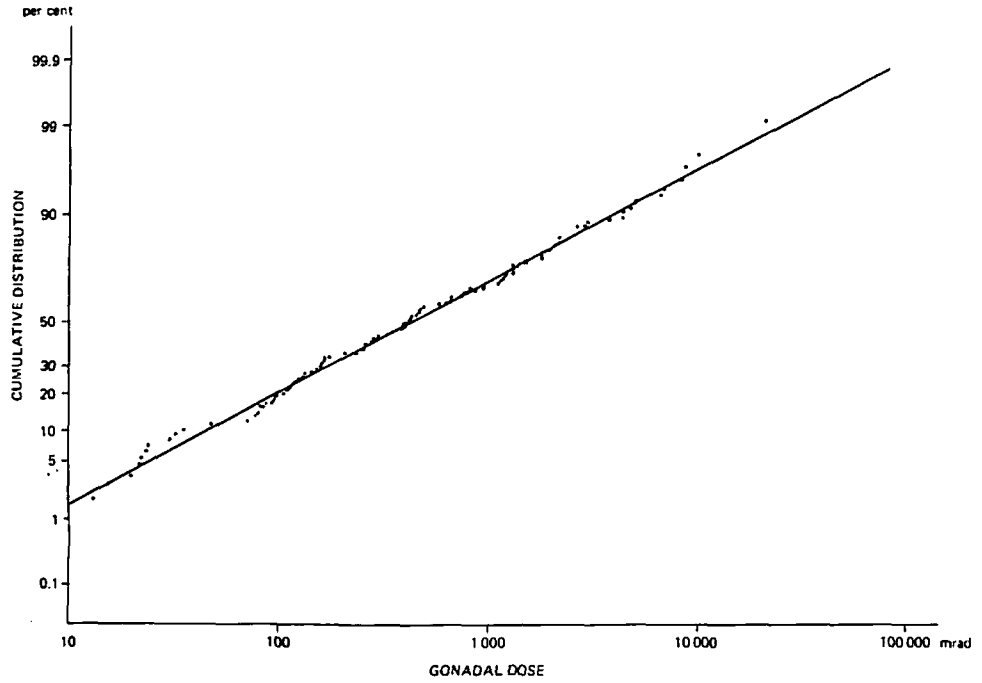
46. Interesting sociological variations in the United States in the frequency of x-ray visits for dental examinations are shown by the fact that the rate of x-ray visits per 100 of population were 11.2, 29.2 and 50.3 for those people having under 9, 9-12 and 13 or more years of education, respectively (250). This finding agrees with the findings of the 1964 survey for dental examinations, but not with those shown by the analysis of x-ray visits for medical examinations.

2. Individual dose per unit procedure

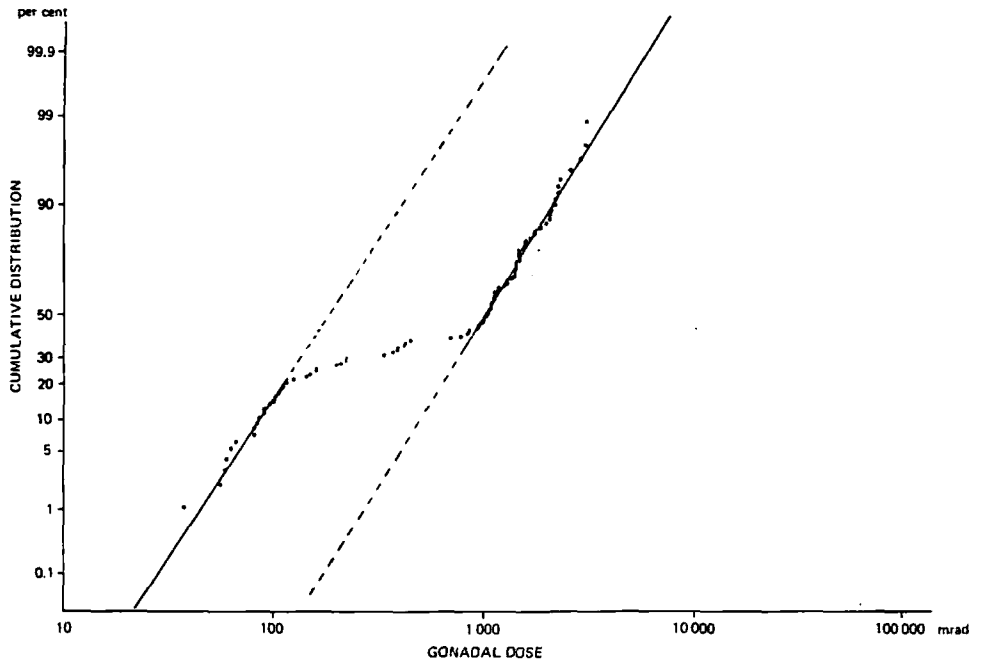
(a) *Accuracy of dose estimates and reasons for variation*

47. Previous reports of the Committee have shown that individual organ doses in each type of examination vary considerably from one clinic or individual radiologist to another. Some of this variation arises from differences in the actual extent and needs of the examination itself and some from differences in the selection of field sizes and localization of the beam. However, there is also a large variation in the skin exposures, both because of differences in the technical operation of the equipment (89), including the use of grids, and in the dimensions of the patients. Additionally, the sensitivity of the recording medium influences the results.

48. The use of equipment that measures the product of the exposure and area at the beam collimator is sometimes used as an indication of the total energy emerging from the x-ray tube towards the patient. These



(a) Intravenous pyelography; $\bar{D}$ = 1300 mrad; s = 2600 mrad; median = 370 mrad; 102 patients



(b) Lumbosacral region examination; $\bar{D}$ = 1048 mrad; s = 855 mrad; median = 1079 mrad; 93 patients. This examination type forms the unique exception to the log-normal distributions found in all other types (120)

Figure I. Cumulative distribution of male gonadal doses from intravenous pyelography and lumbosacral region examinations; $\bar{D}$ = mean dose; s = standard deviation

instruments are useful as comparative instruments between one operator and another, but do not give a true value of skin exposure. When the beam size is large and misses the patient, the recorded value obviously shows a larger variation than the skin exposure. A United States study (the NEXT program) has shown such a variation for lumbar spine and chest examinations (30, 31). A correction also has to be applied for the energy transmitted completely through the patient. A comparison undertaken for the British Committee on Radiological Units showed that there was poor agreement between exposure-area product and bone-marrow dose (48). Stieve (226) reports that the error in estimating dose using the exposure-area product may be 200 per cent.

49. The spread of individual doses in any given type of x-ray examination may be quite large even within one and the same hospital. The distribution is usually skewed, with a preponderance of doses lower than the mean. It has been suggested by Koen and Weber (120) that the distribution is sometimes log-normal, and they have illustrated this with distribution diagrams for the male gonadal dose (fig. I). For some examinations, e.g.,

of the lumbosacral region in male patients, the gonadal dose will increase by an order of magnitude when the direct beam falls on the gonads. This will be equivalent to two distinct groups of patients and hence will, when the data are plotted on probability paper, provide two distinctive but overlapping populations. Subsequently, more detailed information from the same survey (121) showed that various distributions were obtained when all the doses for a particular examination from all the hospitals surveyed were included.

50. Bengtsson *et al.* (17) have analyzed the skewed distribution in further detail. Figure II gives an example of the distribution of mean whole body absorbed dose in

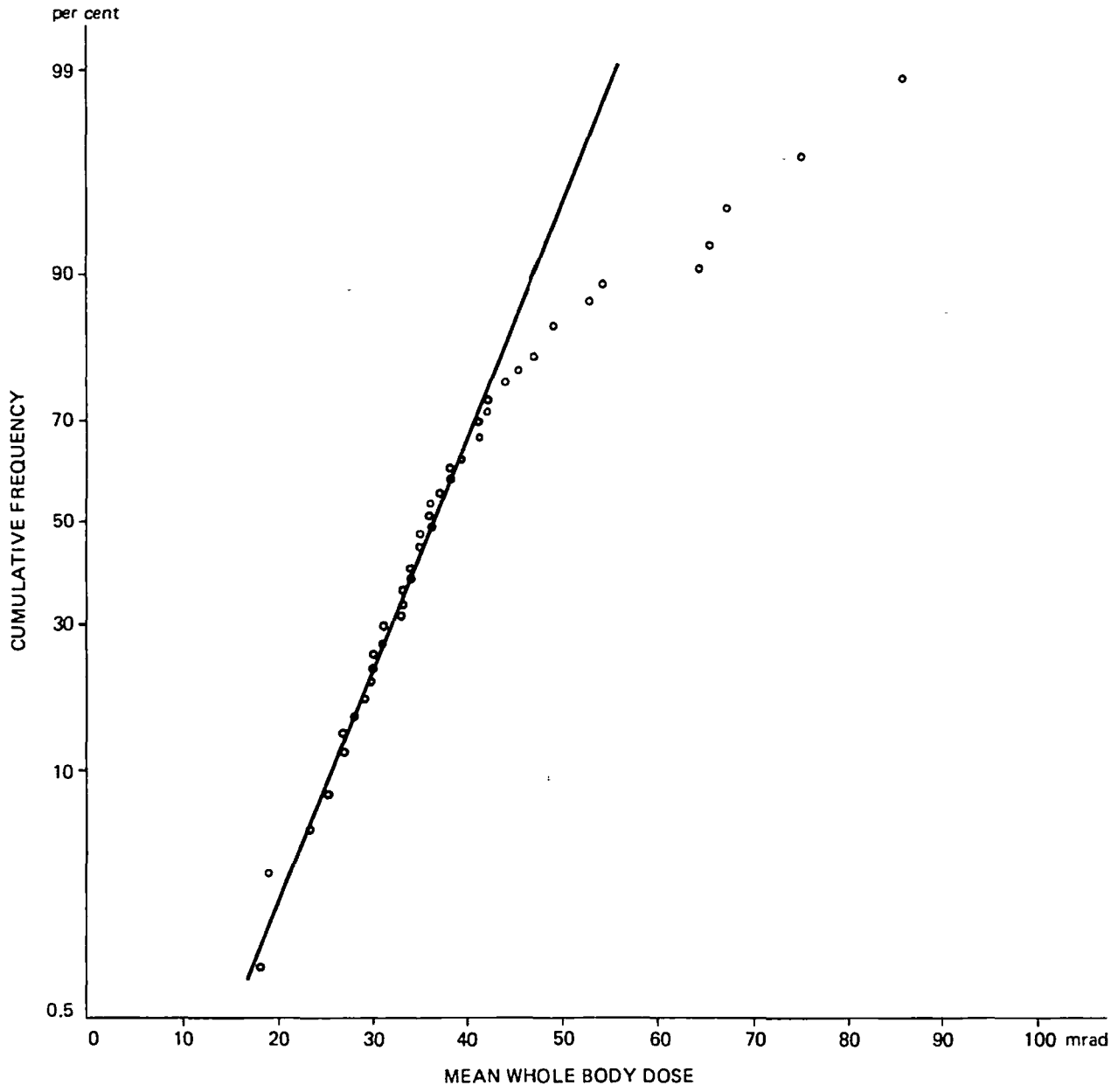


Figure II. Distribution of mean whole body dose from chest examinations at one Swedish hospital. The deviation from normal distribution results mainly from the taking of an additional film (17)

chest examinations at one Swedish hospital. The figure shows a significant deviation from the normal distribution at high patient doses. A closer review revealed that with some patients three exposures were required whereas with most patients two were sufficient. If the three-exposure cases were excluded, a good fit to a normal distribution was obtained. This illustrates (as in paragraph 49) that basically there may be a normal distribution when the number of parameters is limited, but as further parameters are introduced, the distribution may become quite complex.

51. In this Swedish study, neither chest nor stomach examinations fitted a log-normal distribution. The mean whole body dose in stomach examinations was found to follow closely a normal distribution whereas the distribution of the energy imparted to the whole body showed some deviation from a normal distribution.

(b) *Doses to various organs*

52. There is an increasing number of publications on measurements carried out during radiological procedures. Even though they may reflect particular conditions in the clinics and hospitals concerned, they are nevertheless useful in illustrating the levels of radiation dose to patients. Typical publications on patient dose are referred to in each of the following sections and in references 7, 58, 71, 116, 207 and 234. A number of reports referring to technical advances are referred to, such as those on the improved sensitivity of image recording (10, 11, 12, 55, 196). It is particularly useful if patient studies are directed at measuring the total absorbed dose to each of the organs of interest that is accumulated from all radiological studies during a particular patient's period of ill health. Examples of this are given by Trott *et al.* (238).

(i) *Incident skin dose*

53. As has been described in paragraph 12, the dose to organs in the primary x-ray beam may be derived *inter alia* from knowledge of the incident skin dose. A summary of typical skin doses for three broad groups of examinations giving rise to high, medium and low skin doses was given in the 1972 report (244) and is reproduced here as table 8 except for the entry for mammography examinations, for which new techniques requiring lower doses are now available (see paragraph 71). New data on skin exposure in diagnostic procedures were obtained during the 1970 United States survey for radiographic examinations (251) and also by studies in the Federal Republic of Germany (25). The doses are in general similar to those shown in table 8.

TABLE 8. TYPICAL SKIN DOSE IN THE PRIMARY BEAM IN DIAGNOSTIC X-RAY EXAMINATIONS

(rad)

	Per exposure		*Per examination*	
Dose group	*Median value*	*Range of average values*	*Median value*	*Range of average values*
High skin dose				
Barium swallow R			1.4	
Barium swallow F	6.4[a]		8.5	
Barium meal R	0.9	0.9-2.2	1.7	
Barium meal F	4.4[a]		2.1	6-25
Barium enema R	0.7	0.4-1.0	1.5	
Barium enema F	4.9[a]		20	5-26
Whole chest R	0.02	0.006-0.09	0.14	0.07-0.15
Whole chest F	2.0[a]		12	3-22
Mammography			6[b]	0.2-7.8[b]
Pelvimetry	2	0.8-3.8	8	6-10
Lumbosacral spine	2.7	0.5-2.9	5	5-6
Lumbar spine	1.5	0.7-2.9	4.5	
Cardiac catheterization			47	
Medium skin dose				
Head	0.4	0.3-1.5	1.5	1.4-1.9
Cervical spine	0.3	0.03-0.8	1.5	0.6-1.9
Clavicle and shoulder	0.9		0.3	0.3-0.4
Dorsal spine	1.8		2.8	2.0-4.7
Thorax	0.4		0.8	0.6-0.9
Cholecystography	0.8	0.2-1.2	2.2	1.5-2.8
Abdomen	0.2	0.15-1.3	1.2	1.0-1.4
Abdomen (obstetric)	2.0	0.4-3.9	3.2	2.7-3.8
Urography (descending)	1.2		3.2	1.7-5.0
Urography (retrograde)			2.9	1.4-2.4
Salpingography R			1.2	
Salpingography F			3.4	
Placentography			3.0	
Cystography	0.2		3.1	
Pelvis	1.4	0.4-1.7	3.3	2.1-4.5
Hip and upper femur	1.1	0.4-1.7	1.4	1.1-3.0
Dental	0.4		2.5	1.6-3.4
Angiography (head)			1.0	
Angiography (abdomen)			3.3	
Tomography (chest)			1.1	0.8-1.4
Mass survey chest	0.9		1.0	0.6-1.4
Low skin dose				
Arm and hand	0.1		0.3	0.1-1.7
Chest	0.02	0.006-0.09	0.14	0.07-0.15
Femur (lower two thirds)	0.03		0.4	
Leg and foot	0.1		0.4	0.3-0.4

Source: Reference 244.

Note: R = radiography; F = fluoroscopy.

[a] R min^{-1}.

[b] New data (see paragraph 71).

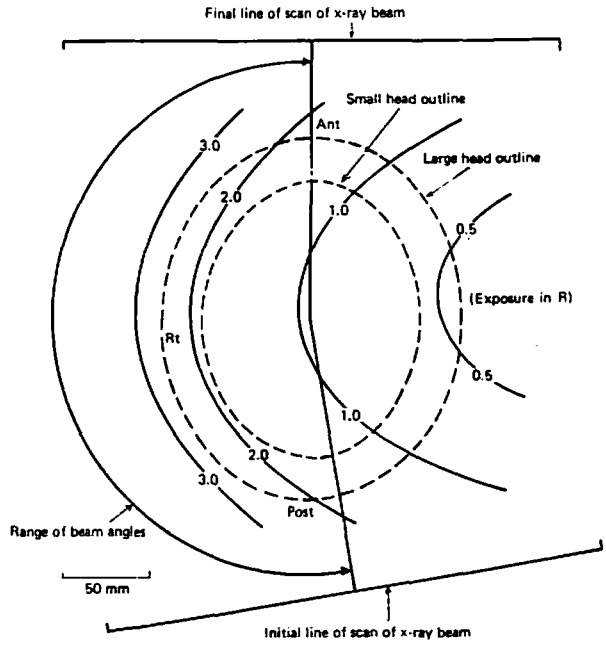


Figure III. Isodose curves in a water phantom for single complete scan (165)

54. The new technique of computerized tomography (CT) scanning utilizes a narrow beam of x rays either in a pencil or a fan shape. The skin dose to the patient per complete scan is increased as the matrix element size of the display is decreased. Typical skin doses have been measured by Perry and Bridges (165) and are shown in figure III for a single complete scan of the head. The increase in dose for subsequent consecutive scans will depend on the amount of overlap. The width of the beam is about 1 cm and the overlap may be between one third and one half of the width of the beam. The radiation dose will therefore be of the same order as in comparable x-ray examinations of the head or the trunk.

55. High skin doses have been reported for such types of examinations as cardiac catheterization, pace-maker insertions and cine investigations in voiding urethrocystography. Gough, Davis and Stacey (66) indicate mean skin doses of 47 rad in a group of 85 patients undergoing cardiac catheterization, with a maximum value of 140 rad. The frequency of undertaking this examination is not accurately known. Other surveys also indicate high doses (8, 10, 46, 153, 192). A comparison of the skin doses received in different techniques of investigations of the heart and large vessels are given in table 9 (235).

56. Recent detailed measurements (52) during 24 cardiac catheterization studies have shown a reasonable correlation between dose and exposure expressed as the current-time product. Typically, for a study involving an x-ray tube operating for 10^4 mAs a posterior skin dose of 8-20 rad was received, the anterior skin dose being 1-2 rad. The mean marrow dose, deduced from the skin dose, was 0.5-1.2 rad and the gonad dose 5-100 mrad.

57. Pace-maker insertions are controlled by x-ray fluoroscopy. Gough *et al.* (66) have reported an average skin dose of 132 rad per insertion for a group of six patients. This dose is likely to be repeated a number of times for each patient. The high skin-dose rates in cine investigations have been mentioned by several authors and may be of the order of 50 rad min^{-1} (192, 258).

(ii) *Dose to the head and thyroid, particularly from dental x-ray examinations*

58. The considerable increase in the frequency of dental x-ray examinations reported in paragraphs 41-44 merits the inclusion of recent measurements of the dose

TABLE 9. MEAN ENERGY IMPARTED TO PATIENTS DURING RADIOLOGICAL INVESTIGATIONS OF THE HEART AND LARGER VESSELS

	Typical conditions					*Dose*		
						Per procedure		*Per examination*
Method of investigation	*Skin-focus distance (cm)*	*Voltage (kV)*	*Area (cm^2)*	*Time (min)*	*Filter (mm Al)*	*(R)*	*(kg rad)*	*(kg rad)*
Fluoroscopy	60	60	200	1.5	0.5	7.5-10		8.5-11.35
Radiography								
Direct	80	70	1 200		0.5	0.25-0.5	1.64-3.3	
Lateral	60	80	800		0.5	0.5-1	2.3-4.7	
Tele	150	90	1 200		0.5	0.3	2.0	
Photofluorography	80	70	800		0.5	0.5-1	2.3-4.6	4.6-9.2
Tomography	70	70	1 200		0.5	1-2	6.8-12.6	20.4-37.8
Kymography								
Direct	80	90	720		1	8	32.9	
Lateral	70	90	720		1	12	51	
Electrokymography	60	60	50	10	1	25		7
Angiocardiography	70	110	1 200		1	0.5	3.6	55
Heart catheterization	40	70	100	22	1	30-232		145
Heart catheterization with image intensifier	40	60	400	22	3	21		58.4
Cine with image intensifier	60	70	400	22	3	12.5		32

Source: Reference 235.

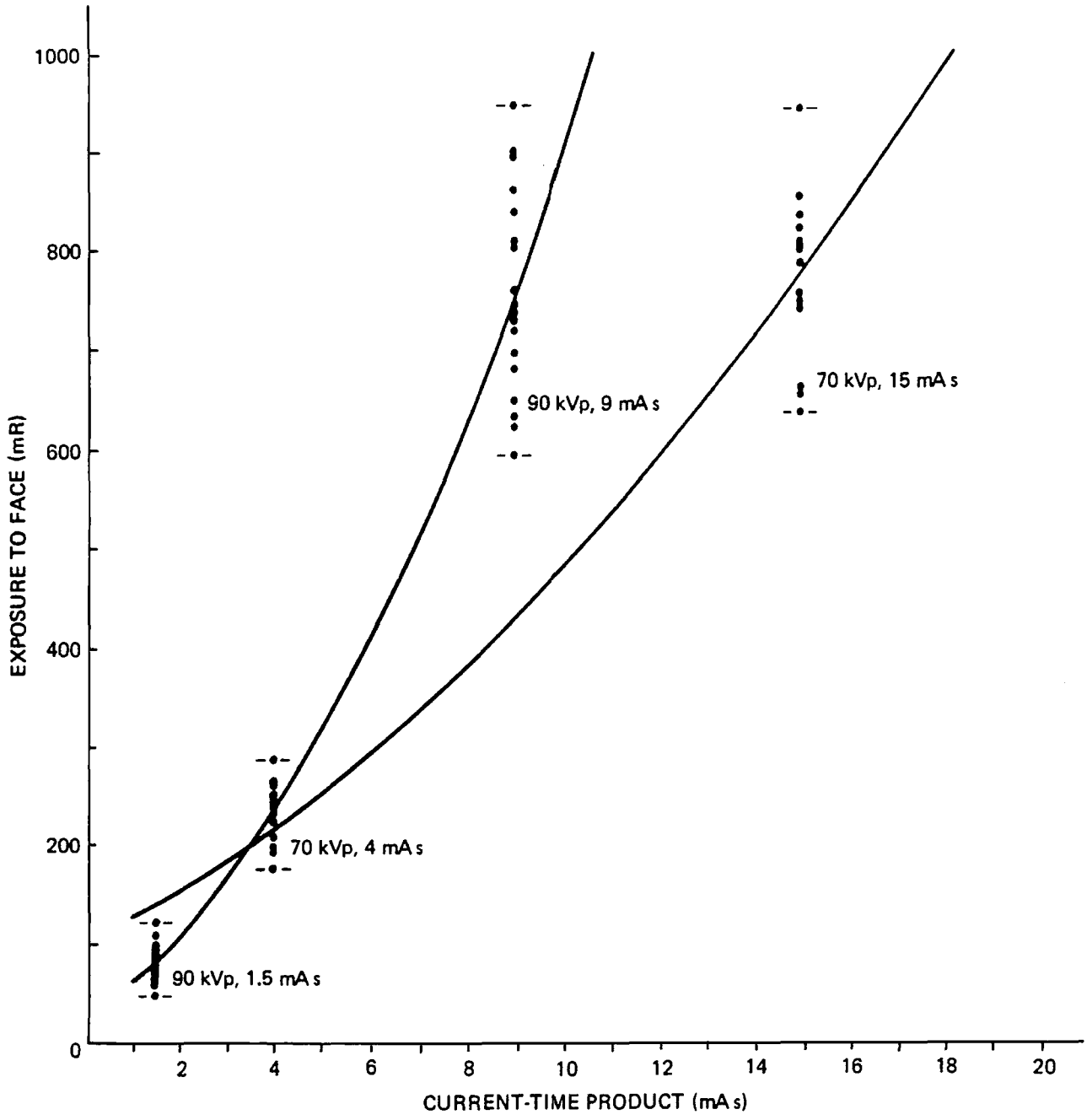


Figure IV. Dependence of exposure at the face on current-time product in dental x-ray examinations (187)

distribution from various dental x-ray techniques. The relationship between the radiation exposure and the current-time product of the x-ray tube has been investigated by Roessler and his co-workers (187), and is given in figure IV. In order to give information on the distribution of radiation over the head and neck from dental exposure, Alcox (5) measured the exposure at the skin surface over sites of interest and the reported values are given in tables 10 and 11. The exposure to the lens of the eye may be estimated from those to the infraorbital, supraorbital and nasion regions, which represent the maximum, minimum and most probable exposure to the lens. The maximum values reported are 84 mR for the two-film technique and up to 1.66 R for the whole-mouth examination. The exposure to the thyroid was between 2.4 and 9.0 mR for the two-film, and between 35 and 70 mR for the full-mouth, examination. Similar studies have been carried out for children (260). These measurements are similar to those reported in Finland by Altonen *et al.* (6), in Sweden by Bengtsson *et al.* (17), in the Union of Soviet Socialist Republics (235), and in the United States survey (251).

59. In the 1974 Japanese survey of dental practice, Maruyama *et al.* (138) made measurements on a man-like phantom of the doses received by the eyes, thyroid and gonads for a variety of dental examinations and tube voltages. The measurements, given in table 12, show the large variations in doses received caused by the different beam directions, for a current-time product of 10 mAs.

60. Measurements of the dose in the head during orthopantomography have been made in Norway by

TABLE 10. INTRA- AND EXTRA-ORAL EXPOSURES IN A TWO-FILM POSTERIOR BITE-WING EXAMINATION

	Mean measured exposure (mR)					
	Short-cone technique			*Long-cone technique*		
Anatomic location	*50 kVp 4-inch TFD*	*70 kVp 8-inch TFD*	*90 kVp 8-inch TFD*	*50 kVp 8-inch TFD*	*70 kVp 16-inch TFD*	*90 kVp 16-inch TFD*
Intra-oral						
Upper molar	152.0	204.6	258.0	252.0	156.6	141.6
Lower molar	140.0	198.3	250.0	240.0	153.1	137.3
Palate	31.0	54.9	93.0	46.0	46.5	52.0
Front of film	18.0	28.8	47.8	26.2	24.3	31.0
Back of film	7.0	7.6	23.2	6.4	9.5	11.3
Extra-oral						
Supra-orbital	4.0	4.5	5.1	2.7	2.5	2.4
Nasion	6.0	3.8	24.7	2.6	2.4	1.7
Infraorbital	50.0	35.9	84.3	19.3	11.6	9.4
TMJ area	5.0	8.0	9.4	3.4	13.5	71.7
Molar area	311.0	415.4	390.0	425.0	310.8	189.2
Philtrum	61.0	11.7	28.5	23.0	4.6	5.9
Lower lip	116.0	10.4	52.9	51.4	5.0	65.1
Thyroid	9.0	2.4	5.0	2.6	2.4	4.0
Total beam	839.0	868.0	919.0	1 139.0	659.0	525.0
Exposure per film	416.0	434.0	460.0	570.0	330.0	263.0
Number of patients	18	12	12	15	16	12

Source: Reference 5.
Note: TFD = tooth-focus distance.

TABLE 11. INTRA- AND EXTRA-ORAL EXPOSURES IN AN 18-FILM FULL-MOUTH EXAMINATION

	Mean measured exposure (mR)					
	Bisecting-angle technique			*Right-angle technique*		
Anatomic location	*50 kVp 8-inch TFD*	*70 kVp 8-inch TFD*	*90 kVp 8-inch TFD*	*50 kVp 8-inch TVD*	*70 kVp 16-inch TFD*	*90 kVp 16-inch TFD*
Intra-oral						
Upper molar	1 329.0	1 462.0	944.0	1 085.0	1.103.4	704.6
Lower molar	1 503.0	1 414.0	932.0	1 198.0	1 070.6	657.4
Palate	443.0	538.0	368.0	339.0	435.3	311.3
Extra-oral						
Supra-orbital	76.0	65.0	46.9	49.0	42.2	29.5
Nasion	163.0	156.0	190.0	90.0	57.7	35.6
Infraorbital	1 660.0	1 547.0	835.0	1 187.0	1 003.3	507.3
TMJ area	24.6	39.4	29.3	21.0	44.3	48.3
Molar area	1 726.0	1 386.0	983.0	1 149.0	995.6	417.6
Philtrum	2 095.0	2 084.0	1 329.0	2 041.0	1 387.1	831.8
Lower lip	1 820.0	1 465.0	1 042.0	1 427.0	1 053.0	539.0
Thyroid	67.0	43.0	70.0	59.0	39.2	35.4
Total beam	9 905.0	6 727.0	4 885.0	7 949.0	4 657.0	3 130.0
Exposure per film	550.0	374.0	271.0	442.0	259.0	174.0
Number of patients	15	13	12	14	13	12

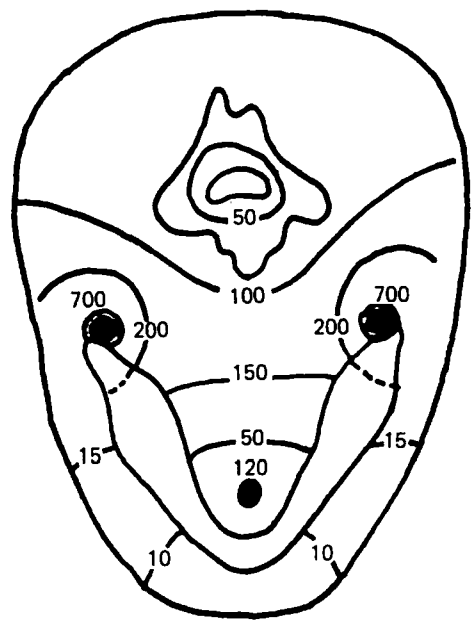
Source: Reference 5.
Note: TFD = tooth-focus distance.

TABLE 12. ABSORBED DOSES IN CRITICAL ORGANS DURING INTRA-ORAL DENTAL EXAMINATIONS
(mrad)

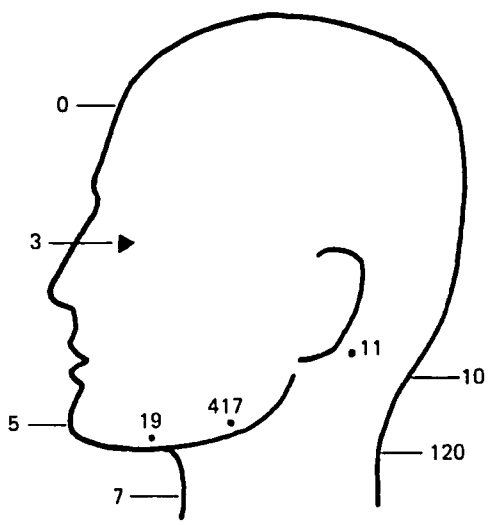
		Location of examination					
		Upper jaw			*Lower jaw*		
Organ	*Tube voltage (kV)*	*Molar and premolar*	*Canine*	*Incisor*	*Molar and premolar*	*Canine*	*Incisor*
Eye	50	85	6.25	2.00	2.00	25.0	2.75
	60	118	8.25	2.75	3.00	47.7	4.25
	70	156	10.5	3.75	4.50	86.5	6.00

Organ	Tube voltage (kV)	Location of examination: Upper jaw: Molar and premolar	Upper jaw: Canine	Upper jaw: Incisor	Lower jaw: Molar and premolar	Lower jaw: Canine	Lower jaw: Incisor
Thyroid	50	2.75	20.2	6.25	23.0	3.0	5.25
	60	3.50	26.7	8.00	33.2	5.5	9.50
	70	4.25	33.7	9.75	45.5	9.5	15.2
Testis	50	0.12	0.08	0.18	0.10	0.12	0.10
	60	0.21	0.17	0.28	0.18	0.20	0.22
	70	0.34	0.29	0.35	0.30	0.31	0.45
Ovary	50	0.0000	0.0000	0.0026	0.0000	0.0000	0.0000
	60	0.0007	0.0000	0.0055	0.0000	0.0000	0.0000
	70	0.0015	0.0000	0.0105	0.0000	0.0000	0.0000

Source: Reference 138.



(a) Dose distribution in cross-section of the head through the lower jaw. The figures are absorbed doses (mrad) in soft tissue. The rotational axes are shown as black spots



(b) Skin exposure (mR)

Figure V. Distribution of head dose and skin exposure from orthopantomography (221)

the State Institute of Radiation Hygiene (221) and by Casebow (32) in the United Kingdom. Figure V shows the cross-section dose distribution and the skin exposure from the Norwegian study. There are high-dose regions (700 mrad) around the rotational axes.

61. The Norwegian report gives the dose to the bone marrow as 1.0, 7 and 2 mrad for molar bite-wing, 10-exposure whole-mouth and orthopantomography examinations, respectively. The dose to the gonads from one exposure has been estimated as 5 μrad for adults and 25 μrad for children.

(iii) *Gonad doses*

62. Data on gonad doses in different types of examinations are presented in the review of the annual GSD in paragraphs 93 to 108.

(iv) *Thyroid doses*

63. In addition to thyroid doses from the direct radiation incident during cervical spine and barium swallow examinations, thyroid doses of the order of 1 mrad may also be received in examinations of the head, sinus and dorsal spine (17), and somewhat higher doses during dental examinations (see paragraph 58).

(v) *Bone-marrow doses*

64. In the 1972 report (244), the bone-marrow doses per examination for three major national surveys were published, and these data are reproduced here as table 13, together with data obtained in new studies in Japan, Sweden and the United States. From the data given in the previous report, the maximum values of bone-marrow dose observed for any one examination type were about two orders of magnitude greater than the mean value when the examination included fluoroscopy. When it did not involve fluoroscopy, the maximum values were about one order of magnitude greater than the mean. These effects also reflect the extent of the examination both in beam area and skin dose, i.e., the number of films and the exposure per film, which is dependent on the film-screen combination.

TABLE 13. BONE-MARROW DOSE PER EXAMINATION

Country surveys
(mrad)

Type of examination	*Germany, Federal Republic of (25)*	*Japan (73)*		*Nether-lands (259)*	*Sweden (17)*	*United Kingdom (37)*		*United States (208)*	
		1969	*1974*			*Male*	*Female*	*1964*	*1970*
Head	12-90	29	44	90	120	32	39	65	78
Cervical spine	8-51	43	37	8	38	54	49	31	52
Barium swallow	359-1 180	140	747	50	420	1 300	590		
Arm and hand									
Clavicle and shoulder		18			60	38	81		
Dorsal spine	67-208	140	370	105	470	200	220	232	247
Whole chest	7-40	9	25	10,[a] 40[b]	29	12	13	10	10
Thorax (ribs and sternum)	6-106	34	40	6	54	180	37	124	143
Barium meal	359-1 180	210	705	80	350	510	800	624	535
Cholecystography	36-590	73	237	36	150	150	150	183	168
Abdomen	39-125	59	202	93	300	120	130	183	147
Abdomen (obstetric)	56-206	72	70	56	220		210[c]		
Descending urography	200-1 160	110	262	433	240	580	450	453	420
Retrograde urography	257-386			257	300	440	330		
Salpingography	21-300	50	212	282	170		210		
Placentography									
Pelvimetry		170	98				280[d]	288	595
Cystography	168-1 160	37	116	168	680	170	940	183	147
Barium enema	50-940	210	1 114	359	940	530	1 060	624	875
Pelvis	39-138	70		138	190	130	140	116	93
Lumbar spine	56-270	150	248	140	410	270	270	336	347
Lumbosacral joint	61-651	92	140	651	100	290	220	418	450
Hip and upper femur (upper third)	21-58	43	169	47	250	57	60	97	72
Rest of femur	4-50	8							21
Leg and foot			0.3						
Dental					1	1.8	1.8	13.2	9.4
Angiography (head)						130[e]	130		
Angiography (abdomen)						380[e]	380		
Tomography (chest)						360	390		
Cardiac catheterization						190[e]	190		
Bronchogram						31	31		
Mass survey chest		35		47	90	61	101	65	44
Mass survey stomach		60							

[a] Radiography.
[b] Fluoroscopy.
[c] Foetal contribution, 500 mrad.
[d] Foetal contribution, 1100 mrad.
[e] Assuming equal frequencies of male and female examinations.

65. The basic data used in the 1957 United Kingdom survey have recently been published by Ellis, Healy, Shleien and Tucker (50). These include the conversion factors for the bone marrow site-to-skin exposure for square fields, the appropriate conversion factors for rectangular and circular fields and the computer programme for the calculation of mean bone-marrow dose. The measurement data are for 16 marrow sites irradiated at seven qualities, half-value layers (HVL) from 1.0 mm Al to 20.0 mm Al, for source-to-skin distances of 20, 40, 60 and 80 cm and for five square-field sizes from 16 to 900 cm^2.

66. An analysis of the variation of the bone-marrow dose with HVL, source-to-skin distance and beam area were also undertaken and the results are shown for a number of examinations in figures VI, VII and VIII. Reasonable agreement exists between the studies of Ellis *et al.* (50) and Epp *et al.* (54) for examinations not involving the passage of the beam through the lungs, from the anterior projection. For examinations involving this passage, the differences probably result from the fact that the mean lung densities used in the two phantoms were 0.2 and 0.3 g cm^{-3}, respectively.

67. An extensive Monte Carlo type computational study has been undertaken by Rosenstein and his co-workers (190) for the estimation of organ doses from diagnostic radiological procedures. The method involves the simulation and recording of the energy deposited by x-ray photons as they undergo physical interactions in a mathematically described heterogeneous anthropomorphic phantom. The general techniques have been developed by Snyder *et al.* (211, 212) for use in determining doses from internal radiation. Tissue-air ratios have been generated for the testes, ovaries, active bone marrow, thyroid and embryo (uterus) of a reference adult patient for several photon energies from 20 to 100 keV. From these ratios a compilation of the five organ doses per unit entrance exposure free in air (mrad R^{-1}) has been developed as a function of six beam qualities from 1.5 to 4.0 mm Al HVL for 34 projections common in diagnostic radiology. An example of the data for one of these projections is given in table 14. Similar studies using the Monte Carlo system and the Snyder phantom have been published by Kramer *et al.* (123).

68. A comparison of the Monte Carlo system (190) with that using direct ionization measurements of the

dose to the bone marrow (50) shows that there is general agreement between the two methods. The tissue-air ratios for six AP projections, when compared for the two methods, lie between 0.4 and 0.7 of each other; for three PA projections the ratios between 1 and 2.4; and for two lateral projections they are both about 0.7 of the direct measurement values (50). These differences occur because of the differences between the measure-

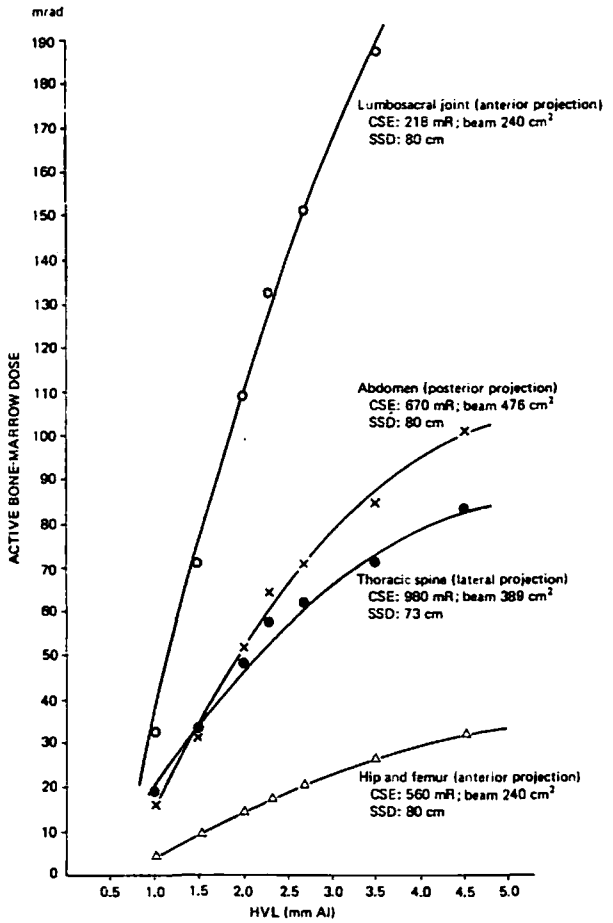


Figure VI. Dependence of active bone-marrow dose on the half-value layer (HVL) in various x-ray examinations (208)

CSE = central skin exposure
SSD = source-to-skin distance

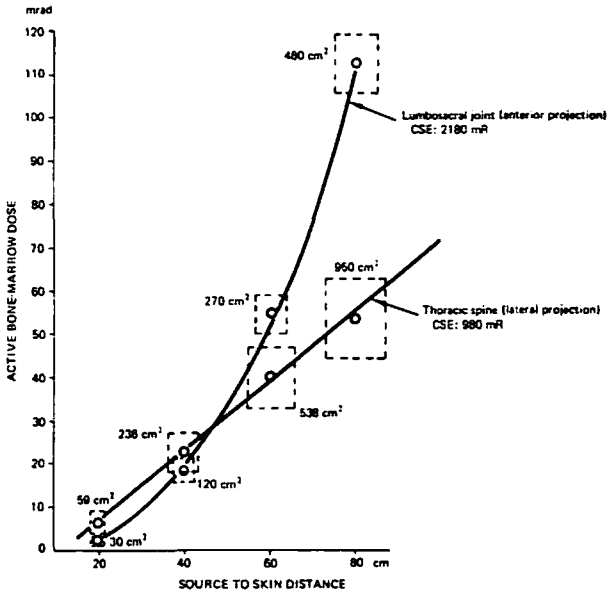


Figure VII. Dependence of active bone-marrow dose on beam area and source-to-skin distance (SSD) in thoracic spine and lumbosacral joint x-ray examinations (208). HVL constant at 2 mm Al

CSE = central skin exposure

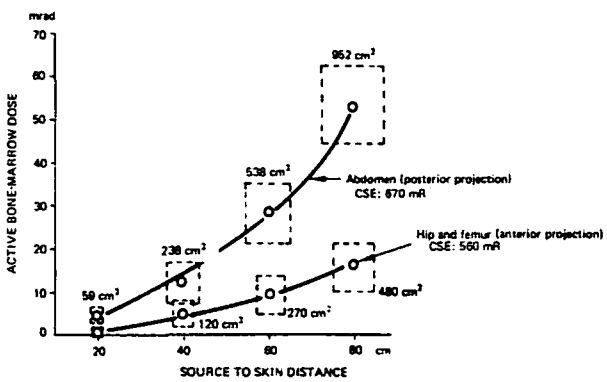


Figure VIII. Dependence of active bone-marrow dose on beam area and source-to-skin distance (SSD) in abdominal and hip and femur x-ray examinations (208). HVL constant at 2 mm Al

CSE = central skin exposure

TABLE 14. DOSES TO ORGANS DURING LUMBAR SPINE EXAMINATIONS

(Dose in millirads per 1000 mR entrance skin exposure free in air)

		Beam quality (HVL in mm Al)					
Organ	*Projection*	*1.5*	*2.0*	*2.5*	*3.0*	*3.5*	*4.0*
Testis	AP	1.1	2.2	3.7	5.6	7.8	10
	Lateral	0.2	0.4	0.7	1.1	1.6	2.3
Ovary	AP	91	139	188	238	288	336
	Lateral	15	27	41	58	76	96
Thyroid	AP	0.05	0.2	0.3	0.5	0.8	1.1
	Lateral	–	–	–	–	–	–
Active bone marrow	AP	13	21	32	46	62	81
	Lateral	8.2	13	19	27	37	48
Embryo (uterus)	AP	128	189	250	309	366	419
	Lateral	9.4	17	27	39	53	68

Notes: (a) Conditions: Source to image-detector distance, 102 cm; film size (= field size), 35.6 cm × 43.2 cm.

(b) A dash (–) signifies a value of less than 0.01 mrad.

ment phantom and the mathematical phantom, the effect of the amount of compact bone overlying any specific dosimeter and the thickness of the homogeneous mixture of bone and marrow assumed in the skeleton of the mathematical phantom. The comparisons reported made corrections for the differences in the x-ray spectra and the assumed volume and density of the lung that were used in the two studies.

(vi) *Breast doses*

69. The breasts are exposed to radiation in a number of common x-ray examinations. The highest doses to the breast are caused during urography examinations, photofluorography of the lung, examinations of the dorsal spine and stomach examinations, in the order mentioned, with doses between 100 and 540 mrad (17). Photofluorography of the lung is of special interest because of the high frequency of examinations.

70. In addition to these common examinations, special examinations may cause higher doses. Direct radiography of the female breast, i.e., mammography, is of particular interest because the technique is also being used in health investigations. The organization of a number of large population mass-screening surveys caused concern when high-dose techniques were in use and when regular re-examinations were carried out on young women. The justification for such examinations was questioned because of the increase of breast cancer that might be induced by radiation (13, 49, 182).

71. In the 1972 report the radiation dose in the breast per mammography examination was reported to be in the range 10-35 rad. However, since then considerable progress has occurred in techniques for reduction of the radiation dose. The use of the low-dose technique (very sensitive films with high-efficiency intensifying screens in vacuum packing) has enabled radiographs to be taken with a maximum skin dose to the breast of 0.1 rad (13, 173, 229, 268). With two-film techniques being accepted for screening examinations, surveys can be undertaken with a breast dose of less than 200-300 mrad. The use of xeroradiography leads to doses which are an order of magnitude higher, i.e., 1-5 rad per examination (22, 56, 191), while the use of industrial film leads to doses between 1.8 and 18 rad (13, 60, 229).

(vii) *Lung doses*

72. The density of the lungs at full inspiration is about 0.1-0.15 g cm^{-3}, while an average value of 0.25 g cm^{-3} is more appropriate when the main vessels are included. These changes make accurate assessment of the lung dose difficult. In typical x-ray examinations the transmission through the chest is about 10 per cent. Lung doses may therefore be estimated as a function of the direction of the beam from the incident skin dose. For full-size radiographs, the skin dose per exposure is about 20 mrad; for photofluorography using 70- or 100-mm cameras, the skin dose is usually about 200-300 mrad; for photofluorography using 35-mm cameras, the skin dose is usually in the range 600-1000 mrad. In the Swedish study by Bengtsson *et al.* (17), the highest dose to the lung, 800 mrad, was found in examinations of the dorsal spine. Special examinations such as cardiac catheterization cause much higher lung doses (see paragraph 56).

(viii) *Doses in other organs*

73. *Eye.* Surveys (102, 103) have shown that the radiation dose to the cornea during extensive neurological x-ray examinations may be in the range 20-80 rad. Patients who have repeated examinations may have a considerably increased risk of a radiation-induced cataract. The introduction of new x-ray units using computerized axial tomography will tend to change the mode of examination of patients with head lesions. Dose distributions in the head have been reported by Perry and Bridges (165). Doses to various parts of the head in dental examinations have been calculated or measured by several authors (5, 187, 251, 260). Casebow (32) has reported the dose to the head during orthopantomographic dental examinations.

74. *Bone.* The frequent radiography of young children with orthopaedic handicaps may cause damage to the development of bone and, in particular, produce stunted growth when the epiphysis has received a high dose (67). It is not uncommon to observe that particular patients have had over 100 radiographs of one particular joint during childhood. Estimates of dose distributions are not yet available.

75. The application of nuclear-powered pace-makers introduces problems associated with the dose to the connective tissue surrounding the pace-maker itself (108). The dose rates vary from type to type, but Kowalewsky (122) has reported that the surface dose over 10 years may vary from 385 to 1150 rad of gamma rays and from 0 to 85 rad of neutrons. Smith and Munson (209) report a first-year dose of 70 rad at the surface of a generator with a beta cell containing ^{147}Pm and a similar dose with a ^{238}Pu power source. The rate of irradiation of a bystander in close proximity to a person with a nuclear-powered pace-maker has been estimated by Cross (41) to be about 1 mrad h^{-1} at the surface of the body. Data from Stieve (226) show that the average length of implantation has been between 3 and 4 y and that the dose rate at the surface of the generator evolves as shown in figure IX (122). In

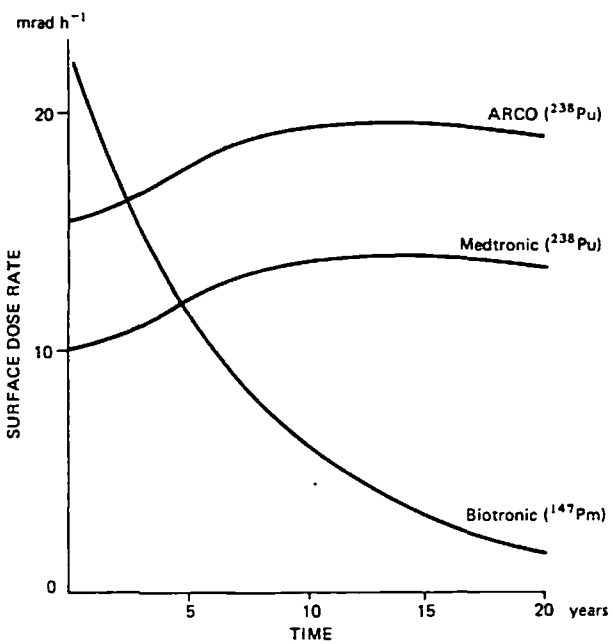


Figure IX. Dose rate at the surface of three brands of radioisotope-powered cardiac pace-makers (122)

interpreting the effect of the absorbed dose rate in figure IX, account should be taken of the relevant biological effectiveness of the neutron contribution.

(c) *Embryo and foetal exposures*

76. The surveys of pre-natally exposed children (134, 228) were summarized in the 1972 report. The practice of x-ray pelvimetry and obstetric abdomen examination has declined in frequency in a number of countries, even though recent statistical information on this is not readily available (see table 7, however). The introduction of ultrasonic scanning is probably reducing the need for x-ray and radionuclide investigations to localize the placenta (172). From the data given in the 1972 report, it can be deduced that the foetal whole-body dose is usually about 300 mrad in obstetric abdomen examinations and 620 mrad in pelvimetry examinations. The frequencies reported for the two examinations were about 2 and 1 per 1000 of population, respectively. These data give an annual collective dose to the foetus of about 1.2 man rad per 1000 of population from these two types of examination. A recent survey in Japan (1974) from Kitabatake *et al.* (119) reports, however, frequencies of 69 and 92 per 1000 pregnancies, respectively, for the two examinations.

77. Several reviews have been published (42, 150, 155, 223, 225) dealing with the levels of dose to women having child-bearing capacity at which subsequent action might be considered desirable, including termination of pregnancy. In the state of available human information on the risks of radiation during various stages of pregnancy (see Annex J, paragraphs 169-173), as well as on the normal incidence of congenital defects, it does not seem appropriate to make any absolute recommendation regarding the line of action following such medical radiation exposures. In any case, such recommendations could serve only as a guide that would have to be modified in specific instances according to the judgement of the patient's physician and consulting radiation experts and, of course according to the desires of the patient herself. The radiation dose itself, particularly from diagnostic radiologic procedures, is unlikely to be the sole determining factor in advising abortion. Decisions based on the generally small risks involved must require very careful consideration of the conditions applying in each individual case.

(d) *Comparison of procedures*

78. Tables showing mean organ doses from the various types of diagnostic x-ray procedures have frequently been published for gonad doses and mean marrow doses and for incident skin exposure (see tables 8 and 13). There has been less information on the overall exposure, including doses to a number of the most radiosensitive organs. In the Swedish survey by Bengtsson *et al.* (17), however, information is given on the doses in gonads, thyroid, active marrow, breast and lung, as well as on the energy imparted. This information is summarized in table 15.

TABLE 15. AVERAGE ORGAN DOSES IN VARIOUS DIAGNOSTIC X-RAY EXAMINATIONS IN SWEDEN

(mrad)

Examination	*Whole body*[a]	*Ovary*	*Testis*	*Active marrow*	*Thyroid*	*Breast*	*Lung*
Hip and femur	170	370[b]	1 500[b]	250	< 1[b]	< 5[b]	< 10[b]
Pelvis	125	190	310	190	< 1[b]	< 5[b]	< 10[b]
Pelvimetry	440	460	–	680[b]	< 10[b]	< 10[b]	< 50[b]
Lumbosacral region	150[b]	180[b]	100[b]	100[b]	< 1[b]	< 5[b]	< 10[b]
Lumbar spine	590	620	180	410	16	120	< 100
Urography	730	880	330	240	38	540	< 100
Retrograde pyelography	1 000[b]	800[b]	1 300[b]	300[b]	50[b]	500[b]	< 100[b]
Urethrocystography	600[b]	1 500[b]	2 000[b]	300[b]	5[b]	20[b]	20[b]
Stomach, upper GI tract	440	56	16	420	29	100	< 50
Small intestine	300	180	100	250	3	11	< 20
Colon	860	700	530	940	10	27	< 20
Abdomen	300[b]	200[b]	200[b]	300[b]	3[b]	11[b]	< 20[b]
Obstetrical abdomen	200[b]	150[b]	–	220[b]	2[b]	8[b]	< 15[b]
Hysterosalpingography	130	590	–	170	< 1[b]	< 5[b]	< 10
Cholecystography, cholangiography	130	24	6	150	3	15	< 10
Dorsal spine	300	< 100	< 20	470	1 300	170	800
Lung, ribs	30	< 3[b]	< 3[b]	29	17	55	80
Lung (photofluorography)	105	< 10[b]	< 10[b]	90	100	200	350
Lung plus heart	57	< 5[b]	< 5[b]	54	24	61	120
Cervical spine	26	< 1	< 1	38	140	< 10	< 10[b]
Shoulder, clavicle, sternum	60[b]	< 1[b]	< 1[b]	60[b]	50[b]	< 50[b]	< 10[b]
Head, sinus	97	< 1	< 1	122	790	< 10[b]	< 10[b]
Cerebral angiography	970	< 10	< 10	1 500	300	< 10[b]	< 10[b]
Femur (lower two thirds)	70[b]	50[b]	400[b]	< 1	< 1[b]	< 1[b]	< 1[b]
Lower leg, knee	30[b]	< 1	< 1	< 1	< 1	< 1	< 1
Arm	7[b]	< 1	< 1	< 1	< 1	< 1	< 1
Dental (single exposure)	2.9	0.01	0.01	1	3	0.5	0.1

Source: Reference 17.

[a] Assuming same mass as Reference Man (70 kg); not averaged over actual weight.

[b] Crude estimate.

79. The Swedish study involved measurements on about 1000 patients in 13 Swedish hospitals. The techniques employed at these hospitals were believed to be representative for the whole of Sweden since diagnostic techniques are quite uniform throughout the country. Image-intensifier television was generally used, the older fluoroscopic screen, rarely. Chest examinations were normally made without fluoroscopy. Automatic exposure control was generally used. The dominant screen-film combination would under optimum conditions require an exposure of 0.4-1 mR to give an adequate density. Examinations of gall bladder, stomach and colon, and special examinations were performed by doctors. Most other examinations were performed by specially trained nurses or x-ray technicians. The exposures were measured at various points on the patients using thermoluminescent lithium fluoride dosimeters. These were placed at the laryngeal prominence (to estimate the thyroid dose), the breast, the male gonad and the rectum (to estimate the ovary dose). For the other organs an estimate of the dose was made from the recorded exposure area product (see paragraph 48). The overall accuracy of the mean absorbed dose for a particular organ was ± 50 per cent.

80. It is seen from table 15 that the imparted energy (expressed in the table as mean whole body dose in Reference Man in mrad, but in the Swedish study reported in mJ is usually a good indicator of the significance of an exposure as regards high doses in radiosensitive organs. None of the examinations having an imparted energy of less than 200 mJ (280 mrad whole-body dose) caused an absorbed dose of more than 800 mrad in any of the organs listed, with the exception of a testis dose of 1500 mrad in examinations of hip and femur. However, some examinations simultaneously exposed several of the listed organs to the extent that the exposures might be considered more significant than indicated by the imparted energy alone. These examinations were the examinations of the lung and the dorsal spine. As can be expected, examinations of the pelvic region, e.g. pelvimetry, urethrocystography and examination of the hip and femur gave high gonad exposures in relation to the energy imparted.

3. Collective dose to various organs from different types of procedures

81. In this section, the population exposures from various procedures are reported in terms of the *per caput* dose, which, as explained in paragraph 26, is the collective dose to the population divided by the number of individuals in the population.

(a) *Accuracy of assessment*

82. Estimates of the overall error in the determination of the collective dose for a given organ may be exemplified by the case of the annual GSD. The overall error comprises the statistical error of the observations and the systematic errors incorporated in the organization of the inquiry. Statistical error estimates are available for three major studies: the 1958 United Kingdom survey (36), and the 1964 and 1970 United States surveys (27, 255). The estimated standard error in the United States surveys decreased from 37 per cent in 1964 to 15 per cent in 1970. For the United Kingdom study the error was estimated at 8 per cent. However, there have been no estimates of the systematic errors, which are difficult to assess.

(b) *Collective dose to various organs*

83. Bengtsson *et al.* (17) have calculated the *per caput* doses from the various types of diagnostic x-ray examinations in Sweden. Their data are shown in table 16. The *per caput* doses in the six listed organs are

TABLE 16. ANNUAL *PER CAPUT* DOSES TO ORGANS IN VARIOUS DIAGNOSTIC X-RAY EXAMINATIONS IN SWEDEN

(man rad per 1000 of population, or mrad per caput*)*

Examination	*Whole body*[a]	*Ovary*	*Testis*	*Active marrow*	*Thyroid*	*Breast*	*Lung*
Hip and femur	3.2	7.0[b]	28.0[b]	4.7	0.0	< 0.1[b]	< 0.2[b]
Pelvis	1.9	2.9	4.8	2.9	0.0	< 0.1[b]	< 0.2[b]
Pelvimetry	0.7	0.7	–	1.1[b]	0.0	0.0	< 0.1[b]
Lumbosacral region	0.4[b]	0.5[b]	0.3[b]	0.3[b]	0.0	0.0	0.0
Lumbar spine	13.2	14.0	4.0	9.1	0.4	2.6	< 2.2
Urography	17.2	21.0	7.8	5.6	0.9	13.0	< 2.4
Retrograde pyelography	0.3[b]	0.2[b]	0.4[b]	0.1[b]	0.0	0.2[b]	0.0
Urethrocystography	1.6[b]	4.1[b]	5.5[b]	0.8[b]	0.0	0.1[b]	0.1[b]
Stomach, upper GI tract	13.0	1.7	0.5	12.0	0.9	3.1	< 1.5
Small intestine	1.0	0.6	0.3	1.2	0.0	0.0	< 0.1
Colon	13.8	11.0	8.5	15.0	0.2	0.4	< 0.3
Abdomen	3.9[b]	2.6[b]	2.6[b]	3.9[b]	0.0	0.1[b]	< 0.3
Obstetrical abdomen	0.3[b]	0.2[b]	–	0.3[b]	0.0	0.0	0.0
Hysterosalpingography	0.1	0.5	–	0.1	0.0	0.0	0.0
Cholecystography, cholangiography	2.4	0.4	0.1	2.8	0.1	0.3	< 0.2
Dorsal spine	4.0	< 1.3	< 0.3	6.2	18.0	2.3	11.0
Lung, ribs	3.5	< 0.3[b]	< 0.3[b]	3.2	2.0	6.3	9.2
Lung (photofluorography)	11.6	< 1.1[b]	< 1.1[b]	9.9	11.0	22.0	39.0
Lung plus heart	2.7	< 0.2[b]	< 0.2[b]	2.5	1.1	2.8	5.6
Cervical spine	0.3	0.0	0.0	0.5	1.8	< 0.1	< 0.1[b]
Shoulder, clavicle, sternum	1.0[b]	0.0	0.0	1.0[b]	0.8[b]	< 0.8[b]	< 0.2[b]

Examination	Whole body[a]	Ovary	Testis	Active marrow	Thyroid	Breast	Lung
Head, sinus	4.2	0.0	0.0	5.3	34.0	< 0.4[b]	< 0.4[b]
Cerebral angiography	1.2	0.0	0.0	1.8	0.4	0.0	0.0
Femur (lower two thirds)	0.4[b]	0.3[b]	2.4[b]	0.0	0.0	0.0	0.0
Lower leg, knee	1.9[b]	< 0.1	< 0.1	0.0	< 0.1	< 0.1	< 0.1
Arm	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Dental (single exposure)	4.4	0.0	0.0	1.5	4.5	0.8	0.2
Total (rounded)	110	70[c]	65[c]	90	75	55	65

Source: Reference 17.

[a] The authors estimated the *per caput* mean whole-body dose at about 100 mrad, based on actual patient weights instead of the 70 kg assumed in this table.

[b] Crude estimates.

[c] Not including foetal exposures.

between 55 and 90 mrad y^{-1}, whereas the annual *per caput* mean whole-body dose was estimated by the authors to be about 100 mrad.

(i) *Marrow collective doses*

84. The annual *per caput* mean marrow dose (CMD) as derived in three national surveys was reported in the 1972 report. The CMD totalled 30, 32 and 189 mrad y^{-1} for the Netherlands (259), United Kingdom (37) and Japanese (73) surveys, respectively. They were undertaken in 1960, 1957 and 1969, respectively. The recent Swedish survey (see table 16) gave 90 mrad for Sweden in 1974 and a repeat of the Japanese survey gave 132 mrad for the same year. A recent assessment (208) gives the CMD for the United States as 83 mrad for the 1964 survey and 103 mrad for the 1970 survey. In table 17, the examinations making

TABLE 17. ANNUAL *PER CAPUT* DOSE TO BONE MARROW

(mrad)

Type of examination	Japan (73, 79, 80, 81, 84, 138) 1969	Japan (73, 79, 80, 81, 84, 138) 1974	Netherlands (259)	Sweden (17)	United Kingdom (37)	United States (208) 1964	United States (208) 1970
Hip and femur	0.5	1.1	0.2	4.7	0.3	0.7	0.7
Pelvis	0.3	0.5	0.9	2.9	0.3	1.4	1.1
Lumbosacral joint	0.8	–	2.2	–	0.7	4.0	5.7
Lumbar spine	4.4	5.1	1.1	9.1	1.5	6.7	8.1
Urography	1.2	2.1	3.7	5.6	2.3	9.9	10.1
Stomach, upper GI tract	115	73.2	0.1	12.0	1.2	17.9	24.3
Small intestine	–	–	2.5	–	6.0	0.7	1.0
Barium meal (photofluorography)	–	16.5	–	–	–		
Colon	10.3	7.3	3.1	15.0	2.2	13.7	21.2
Abdomen	0.8	4.4	0.6	3.9	0.8	3.6	2.9
Obstetrical abdomen	0.2	0.2		–	1.1		
Cholecystography	7.0	2.1	0.5	2.8	0.5	3.2	3.7
Dorsal spine	1.0	0.8	0.3	6.2	0.6	2.0	2.5
Lung	10.1	6.1	8.1	–	1.8	2.0	3.2
Lung (photofluorography)	20.2	9.7	3.8	9.9	7.8	7.8	3.2
Head	0.7	–	1.1	5.3	0.5	1.0	1.6
Other	16.3	3.3	1.8	12.6	4.7	8.4	13.7
Total	189	132	30	90	32.3	83	103

the greatest contributions to the CMD in the seven national surveys are listed. The large contribution from stomach examinations in Japan is striking; it is caused by the very large frequency of these examinations. A recent survey by Hashizume *et al.* (83) gives the number of photofluorographic examinations of the stomach in 1975 as $2.38\ 10^6$ and $1.74\ 10^6$ in males and females, respectively. The mean marrow dose was 453 mrad and 392 mrad, respectively, and the CMD from this examination 16.5 mrad. A similar survey of mass chest screening in Japan (84) during 1975 gave a CMD of 9.7 mrad.

85. The 1970 United States survey (208) analysed the CMD for six different age groups; whereas the CMD for the whole population was 103 mrad, the CMD for the specific age groups were:

Age group	CMD (mrad)
15-24	52
25-34	81
35-44	107
45-54	120
55-64	143
⩾ 65	151

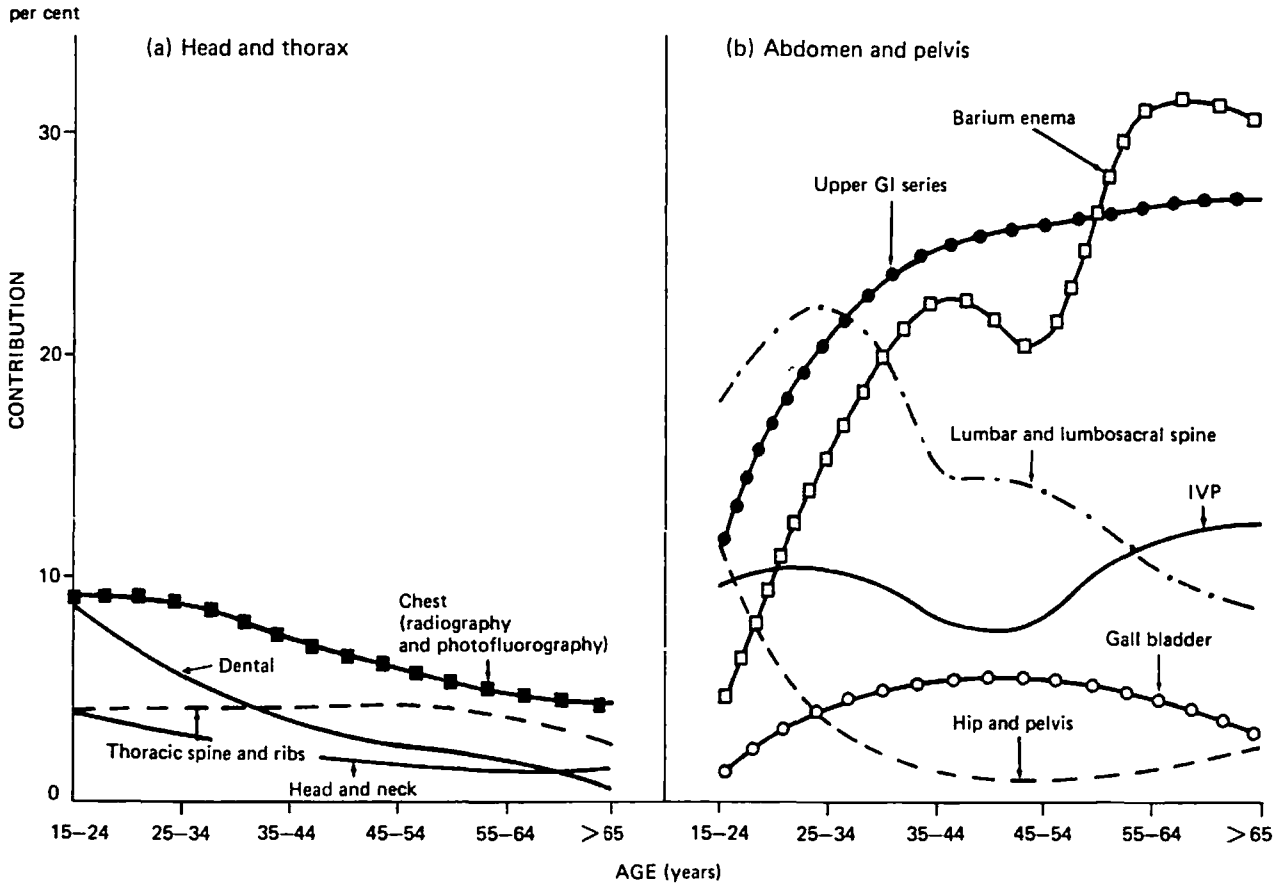


Figure X. Contribution of certain x-ray examinations to the age-specific *per caput* mean marrow dose (CMD) in the United States (208)

IVP = intravenous pyelography

The contributions made by the various examinations to these specific CMD are given in figure X. This demonstrates the variation in frequency with age of some of the major contributors to the CMD of the total population.

86. In the 1969 Japanese survey an attempt was also made to calculate a weighted mean marrow dose ("leukaemia significant dose") with weighting for reduced risk of leukaemia as a function of the age of exposure, considering the latency period for manifestation of the disease. This reduced the CMD from 189 to 169 mrad. The CMD for photofluorographic examinations of the stomach was reduced from 16.5 to 14.5 mrad by a similar weighting in the 1975 survey, and the mass chest screening CMD was reduced from 9.7 to 9.3 mrad (83).

87. An estimate of the CMD in Romania was made in 1970. The value derived was 382 mrad y^{-1}, but it would appear from the report that this value represents the dose to the marrow in the direct x-ray beam rather than the mean value in the whole active marrow.

(ii) *Breast collective doses*

88. As indicated in paragraph 71, health investigations with mammography may be expected to result in quite high breast collective doses if carried out at the level of 10 rad per examination. With 0.1 rad per examination, however, the individual breast doses would be about the same as the breast doses in photofluorographic examination of the lung (see table 15).

(iii) *Lung collective doses*

89. *Mass photofluorographic surveys of the chest.* The incidence of tuberculosis throughout the world is high; therefore, most countries have either mobile or fixed installations for taking 35-, 70- or 100-mm films of the chest as a screening or follow-up study. The radiation exposure incident on the back of patients is related to the size of the film and the optical system, and the skin exposure is usually in the range 0.5-2.0 R for 35-mm film and about 0.2-0.5 R for 70- or 100-mm film. Photofluorographic lung examinations give the highest contribution to the *per caput* lung dose in most countries (e.g., 60 per cent in Sweden). The median frequency of mass chest surveys among the countries for which data were reported to the Committee for the 1962 report was 130 per year and 1000 of population. Of the additional data presented in the 1972 report the median value was 267 examinations per year and 1000 of population. The frequency in Sweden in 1974 was 110 examinations per year and 1000 of population, a relatively low frequency. Nevertheless, the Swedish *per caput* annual lung dose from photofluorography of the lung was found to be about 40 mrad (table 16).

90. An assessment of the benefits and risks of mass chest radiography has been made by Kitabatake and his co-workers (114). In the 40 10^6 chest fluorographies carried out in 1968, about 44 500 cases of pulmonary tuberculosis were detected. Estimates were made of the number of lung cancers that might be detected and of how many of them were likely to benefit from early radical resection. An estimate of the deleterious effects produced by the irradiation was made for the next 25 years on the basis of current risk estimates. These included 46 leukaemias and 7 incurable lung cancers.

(iv) *Stomach collective doses*

91. An estimate of the collective dose to the stomach from the Japanese examinations may be deduced on the basis of the mean dose in the stomach of 4 rad per examination. This leads to an annual collective dose of 10^8 man rad. Such assessments have been made in attempts to estimate the risk of inducing cancer by the examination (113). During 2.2 10^6 fluoroscopic mass surveys, 2423 persons were found to have gastric cancers; 1042 of them were expected to survive more than five years. An estimate of the radiation-induced cancers indicated 30 leukaemias and 15 abdominal cancers during the following 25 years.

(v) *Foetal collective doses*

92. From the 1974 survey in Japan, Hashizume (82) has estimated an annual collective dose to the foetus of 0.86 man rad per 1000 of population from obstetric abdomen and pelvimetry examinations.

(c) *Annual genetically significant dose*

93. The details of the many GSD surveys have been given in the previous reports of the Committee. They are summarized in table 18.

TABLE 18. ANNUAL FREQUENCY OF X-RAY EXAMINATIONS AND GSD BY COUNTRY

Country or area	Period	Population 10^6	Annual number of x-ray examinations per 1 000 of total population: Diagnostic: Radiography	Diagnostic: Fluoroscopy	Mass surveys: Radiography	Mass surveys: Fluoroscopy	GSD (mrad): Diagnostic examinations	GSD (mrad): Mass surveys	Reference
(a) *Surveys reviewed in the 1962 report*									
Argentina									
Buenos Aires	1950-1959	6	270		80		37.0	1.90	166
Denmark	1956-1958	4.5	260		140		27.5	0.05	70
Egypt									
Alexandria	1956-1960	1.4	36		4		7.0	0.09	136
Cairo	1955-1961	.2.6	40		5		7.0	0.07	135
France	1957-1958	42	150		40	570	58.2[a]	0.02[b]	178-180
Germany, Federal Republic of									
Hamburg	1957-1958	1.8	560		130		17.7	0.05	94
Italy									
Rome	1957	1.9	500		80		43.4	0.93	21
Japan	1958-1960	90	410		320		39.0	0.08	181
Netherlands									
Leiden	1959-1960	0.1	350	200	130		6.8	0.02	15
Norway	1958	3.5	390		210		10.0	0.08	57
Sweden	1955-1957	7.3	290		140		37.8	0.40	128
Switzerland	1957	5.2	310	330	130	60	22.3	0.12	269
United Kingdom	1957-1958	50	280		95		14.1	0.01	37
(b) *Surveys reviewed in the 1972 report*									
Czechoslovakia									
Bohemia	1965-1966	4.3	517	79	331		37.0	0.44	126
Finland	1963-1964	4.5	334		266		16.8		104, 105
Germany, Federal Republic of									
Bavaria	1956-1958	9.6	601[c]		267		13.7 (15.1)[d]	0.05	203-206
Japan	1969	105	610	191	628		25.7	0.8	74
Netherlands	1967	12.6	810				20.0		16, 174
New Zealand	1963	2.5	366		113		13.1		266
	1969	2.8	400		113		13.7		152
Puerto Rico									
Southern region	1968	0.5	414				36.4		158
Western region	1968	0.4	512				48.6		157
Thailand	1970	34.7	39				5.2-1.3		142, 143
Union of Soviet Socialist Republics									
Russian SFSR	1964	82	171	439	183		27.0[f]		125
United Kingdom									
Sheffield	1964	4.5	310				8.6		139

TABLE 18 *(continued)*

Country or area	Period	Population 10^6	Annual number of x-ray examinations per 1000 of total population: Diagnostic: Radiography	Diagnostic: Fluoroscopy	Mass surveys: Radiography	Mass surveys: Fluoroscopy	GSD (mrad): Diagnostic examinations	GSD (mrad): Mass surveys	Reference
United States									
National surveys	1964	187	475	56	87		16.0[e]		63, 164
	1970	200	580	65	45		20.0[e]		247, 249, 28
Local surveys									
New York City	1962	8	630	100			50.0		161
New Orleans	1962-1963	0.9	825				75.3		106
Johns Hopkins University	1965						20.3		148
Texas	1963						16.0		38
Yugoslavia									
Slovenia	1960-1963	1.5	594	436			9.1		141

[a] From radiographic mass survey.
[b] Including fluoroscopic mass survey.
[c] In this case, one examination equals one radiograph.
[d] The figure in parentheses is a later figure that includes special children's clinics.
[e] Revised estimates (27, 255).
[f] Mean gonad dose per year rather than GSD.

94. Since the 1972 report a few further reports of investigations on the GSD in various countries and areas have become available. These may be usefully considered in two groups: countries or areas where there is an advanced technical medical service and those that only have these facilities in the largest towns and cities. A summary of these recent surveys is given in table 19 and below.

TABLE 19. ANNUAL FREQUENCY OF X-RAY EXAMINATIONS AND GSD BY COUNTRY

Recent surveys

Country or area	Period	Population (10^6)	Annual number of x-ray examinations per 1000 of total population: Diagnostic: Radiography	Diagnostic: Fluoroscopy	Mass survey: Radiography	Mass survey: Fluoroscopy	GSD (mrad): Diagnostic examinations	GSD (mrad): Mass surveys	Reference
Germany, Fed. Rep. of (Hamburg)	1974	1.8	1 530	–	128	–	41	–	129
India	1967-72	550	35	–	–	–	1.1	–	168
Iraq	1972	10	150[a]	–	88[a]	–	52	–	1
Japan	1974	105	676	134	–	–	16.5	–	74, 79, 80
Netherlands	1972	12.6	1 186	–	–	–	28	–	120
Puerto Rico	1973	3.0	502	40	56	–	46	–	61
Romania	1970	20.5	238	322	452	–	28.5	–	177
Sweden	1974-76	8.1	540	–	110	–	46	–	17
Switzerland	1971	6.3	1 350	–	–	–	42.9	–	170
Island of Taiwan (urban areas)	1972	5	43[a]	10[a]	–	–	3-4	–	261
United States	1970	195	669	–	–	–	20	–	27

[a] Estimate from data received.

(i) *France, 1976*

95. An estimate of the GSD in France, made by Reboul *et al.* (178-180) in 1959, was 58 mrad. Since then a large-scale study (163) was conducted in 1976 on the basis of 10^6 radiological examinations for the purpose of providing an estimate of the mean gonad dose received by the members of the public. The *per caput* gonad dose found in the study is about 7 estimated GSD of about 3 measures taken by the nationa suppression of obsolete fac quality of the examination authorized facilities, a decrea of the exposure received achieved.

United Sheffi

f. ose to be

(ii) *Federal Republic of Germany, 1972-1973*

96. An assessment of the GSD in the Federal Republic of Germany has been made by Stieve for 1972-1973 on the basis of reported average values of the doses from various procedures. The GSD has been estimated as 50 mrad from medical sources (25, 224). Surveys were conducted in the Hamburg region in 1958, 1972 and 1974 (94, 129). The GSD increased from 17.7 to 37 to 41 mrad, respectively while the average annual number of examinations per person increased from 0.61 to 1.16 to 1.33.

(iii) *India, 1967-1972*

97. Surveys in four representative areas of India were used to obtain data on the frequency of examination, dose per examination and child expectancy factors (228). From these data the GSD was calculated for each district in each area. The four GSDs derived were 1.89, 0.77, 0.88 and 0.93 mrad for the state of Maharashtra (1967-1968), the state of Tamil Nadu (1969-1970), the northern region (1970-1971) and the eastern region (1971-1972), respectively. In those districts where the larger x-ray facilities existed, considerably higher GSDs were obtained (table 20). The GSD was weighted

TABLE 20. CONTRIBUTION TO THE ANNUAL GSD DUE TO DIAGNOSTIC RADIOLOGY

India, 1967-1972

(mrad)

State or region and district	*Male*		*Female*		*Foetal dose*	*Annual GSD*	*District contribution to state or region annual GSD*
	Radiography	*Fluoroscopy*	*Radiography*	*Fluoroscopy*			
Maharashtra (1967-1968)							
Bombay	6.059	0.447	1.308	2.592	0.240	10.646	1.118
Poona	0.725	0.043	0.158	0.743	0.201	1.870	0.117
Nagpur	1.875	0.001	1.259	0.482	0.435	4.052	0.155
Nasik	0.822	0.006	0.083	0.009	0.037	0.957	0.152
Sangli	0.281	0.004	0.157	0.041	0.007	0.490	0.015
Nanded	0.212	0.014	0.032	0.081	0.023	0.362	0.043
Ratnagiri	0.023	0.013	0.018	0.081	0.006	0.141	0.016
Buldhana	0.014	0.003	0.001	0.001	0.002	0.021	0.003
Sholapur	0.110	0.147	0.036	2.619	0.014	2.926	0.138
Overall						1.894	
Tamil Nadu (1969-1970)							
Madras	4.1469	0.0048	1.4391	0.1646	0.2605	6.0159	0.3098
Madurai	0.3064	0.0003	0.4502	0.0418	0.0865	0.8852	0.0845
Coimbatore	0.6209	0.0005	0.2171	0.0714	0.0475	0.9574	0.1010
Thanjavur	0.1403	0.0004	0.0534	0.0022	0.0074	0.2037	0.0196
Kanya-kumari	0.1137	0.0023	0.1215	0.2185	0.0780	0.5340	0.0158
Overall						0.7664	
Northern region (1970-1971)							
Delhi	1.9751	0.0153	1.0166	0.1785	0.2590	3.4445	0.3257
Amritsar	0.7500	0.0031	0.2000	0.0037	0.0417	0.9985	0.0426
Patiala	1.0474	0.0156	0.5999	1.0706	0.3271	3.0606	0.0868
Chandigarh	7.1332	0.7060	3.0894	8.5605	3.5231	23.0122	0.1377
Himachal Pradesh	0.6457	0.0017	0.2240	0.0114	0.0359	0.9187	0.0739
Hissar	0.0533	0.0008	0.0426	0.0004	0.0077	0.1048	0.0052
Hoshiarpur	0.0064	0.0009	0.0003	0.0018	0.0003	0.0097	0.0002
Jullundar	0.4307	0.0224	0.1337	0.0017	0.0273	0.6158	0.0203
Overall						0.8772	
Eastern region (1971-1972)							
Calcutta	5.4412	0.0089	3.4016	0.6293	0.1908	9.6718	0.2478
Cuttack	1.2770	0.0080	0.5430	0.1184	0.0098	1.9562	0.0611
Patna	0.7365	0.0161	0.4203	0.0298	0.0257	1.2284	0.0356
Ranchi	0.2963	0.0038	0.0785	0.0018	0.0065	0.3869	0.0082
Shahabad	0.0254	0.0078	0.0101	0.0454	neg	0.0887	0.0028
Ganjam	0.7832	0.0008	0.1531	neg	neg	0.9371	0.0175
Sambalpur	1.2204	0.0004	0.4168	0.0012	neg	1.6388	0.0246
Saharsha	0.0006	neg	0.0103	neg	neg	0.0109	0.0002
Overall						0.9337	

Source: Reference 168.

according to the population, and an average of 1.11 mrad was obtained as representative of the country as a whole. The frequency of radiographic examinations (excluding dental and screening examinations) in India as a whole was estimated to be 35 per 1000 of population and in the four areas, 14, 25, 24 and 51, respectively. The numbers of males and females in various age groups and their child expectancy factors are given in table 21.

TABLE 21. AGE AND SEX DISTRIBUTION AND CHILD EXPECTANCY FACTORS OF THE POPULATION SURVEYED IN TABLE 20

Age (y)	*Maharashtra*		*Tamil Nadu*		*Northern region*		*Eastern region*	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
			(a) *Population by age and sex (10^3)*					
< 4	2 994	2 943	2 623	2 510	3 506	3 161	9 311	9 166
5-9	2 890	2 845	2 622	2 624	3 729	3 280	10 582	10 218
10-14	2 328	2 084	2 212	2 126	2 949	2 561	7 460	6 392
15-19	1 679	1 533	1 589	1 538	2 071	1 694	4 934	4 644
20-24	1 718	1 781	1 589	1 710	1 930	1 686	5 016	5 239
25-29	1 774	1 690	1 576	1 652	1 840	1 555	5 482	4 969
30-34	1 511	1 332	1 329	1 313	1 522	1 236	4 688	4 094
35-39	1 298	1 097	1 260	1 222	1 217	1 009	3 928	3 341
40-44	1 067	931	1 055	1 009	1 130	926	3 220	2 973
45-49	897	764	888	802	866	655	2 608	2 224
50-54	744	649	740	674	873	591	2 225	1 917
55-59	505	415	411	411	436	286	1 323	1 133
> 60	1 023	1 061	918	878	1 377	914	2 702	2 940
			(b) *Child expectancy factor*					
< 4	4.577	4.116	3.2785	3.3937	4.96	4.825	4.2465	4.1026
5-9	4.836	4.368	4.0837	4.1844	5.316	5.362	4.9274	4.8868
10-14	4.958	4.486	4.2967	4.3130	5.376	5.417	5.0118	4.9935
15-19	4.926	4.214	4.4539	4.0507	5.417	5.390	5.0653	4.8535
20-24	4.745	3.396	4.1797	3.1349	5.384	4.795	4.9127	4.1156
25-29	3.815	2.651	3.2548	1.9872	4.777	3.50	4.1391	2.9236
30-34	2.625	1.660	2.0487	1.0325	3.482	2.134	2.9155	1.7844
35-39	1.613	0.9016	1.351	0.3805	2.116	1.056	1.7630	0.8990
40-44	0.874	0.0874	0.3744	0.0639	1.048	0.368	0.8801	0.3593
45-49	0.342	0.0594	0.0627	0.0029	0.365	0.062	0.3517	0.0913
50-54	0.0579	0.0082	0.0028	0.0011	0.062	0.0	0.0903	0.0
55-59	0.0075	0.00	0.0011	0.0000	0.0	0.0	0.0	0.0
> 60	0.00	0.000	0.000	0.000	0.0	0.0	0.0	0.0

Source: Reference 168.

(iv) *Iraq, 1972*

98. A survey in Iraq during 1972 reported a total of 407 x-ray units and 146 dental x-ray units serving the population of 10^7 (1). The total radiographic exposures reported were 4.2 10^6 along with 1.5 10^5 dental x-ray exposures. The term "examination" is used in the reference to indicate exposures; thus, 2.2 "examinations" were reported per visit. A measurement survey using film badges determined the gonad dose per examination in a group of 70 patients. The age distribution and frequency of examination were derived from an analysis of 1000 patients. The GSD for 1972 was estimated to be 52 mrad, with a probable accuracy of 60 per cent. A dental survey estimated the GSD from dental radiography to be 0.3 mrad.

(v) *Japan, 1974*

99. Preliminary results are available for the GSD survey in Japan during 1974 (74, 79, 80). The GSD was estimated to be 16.5 mrad, compared with 25.7 mrad in the 1969 survey. The frequencies of the examinations were obtained from a sample of 8.5 per cent of the hospitals with >300 beds, with somewhat lower sampling fractions for the smaller hospitals. The frequency of examination for the major contributors and the resulting contributions to the GSD are given in table 22. The distribution of the GSD with age and the division between radiography and fluoroscopy are given in table 23. The values in parentheses indicate the contributions in the 1969 survey. The contribution from photofluorography for mass stomach screening was 0.15 mrad (83), and that from photofluorography for mass chest screening was 0.03 mrad (84).

(vi) *Netherlands, 1972*

100. New data on the male gonad dose per examination, the frequency of examination and child expectancy factors were used in conjunction with data from the 1967 survey to recalculate the GSD (120). It was assumed that the frequency of all examinations had increased by 10 per cent per year for each of the four years 1968-1971. The 1972 value of GSD obtained was 28 mrad, which was not significantly different from the 1967 estimate of 19-40 mrad. The measurement survey was extended and by mid-1974, 6600 measurements had been made on patients. The GSD for 1974 was estimated to be about 20 mrad (121). Further studies have also been reported on the contributions to the GSD due to various x-ray diagnostic examinations.

TABLE 22. FREQUENCY OF X-RAY EXAMINATIONS AND GSD BY SEX AND TYPE OF EXAMINATION

Japan, 1974

(Units: frequency, number of examinations per 1000 of population group; GSD, mrad)

Type of examination	Radiography				Fluoroscopy				Total		
	Male		Female		Male		Female				
	Frequency	GSD	Frequency	GSD	Frequency	GSD	Frequency	GSD	Frequency	GSD	Fraction of total GSD (%)
Chest	145	–	136	–	7	–	6	–	294	0.1	0.6
Stomach	59	0.2	46	1.1	56	0.3	43	2.0	204	3.6	22
Abdomen	12	0.3	10	0.3	2	0.2	2	0.5	26	1.3	7.9
Intestine	3	1.5	3	0.3	2	0.5	2	0.5	10	2.8	17
Lumbar, lumbosacral	23	0.7	17	0.8	0.5	–	0.3	0.2	41	1.7	10
Pelvis	2	0.4	3	0.2	0.1	–	0.1	–	5.2	0.7	4.3
Urography	3	0.1	3	0.4	0.7	0.1	0.5	0.2	7.2	0.8	4.9
Bladder	2	0.4	0.9	–	0.3	0.1	0.2	0.1	3.4	0.6	3.7
Hystero			0.7	0.1			0.1	0.1	0.8	0.2	1.2
Obstetric			1.9	0.5					1.9	0.5	3.0
Hip joint	9	2.2	10	0.9	0.1	0.1	0.1	0.2	18	3.4	21
Lower leg	34	0.5	20	–	0.5	–	0.3	–	55	0.6	3.7
Other	75.1	–	57.9	–	5.6	–	4.4	–	143	0.1	0.6
Total	367.1	6.4	309.4	4.7	74.8	1.5	59	3.9	809.5	16.4	100

Sources: References 74, 79, 80.

Note: A dash (–) signifies that the GSD was less than 0.05 mrad.

TABLE 23. GSD FROM X-RAY EXAMINATIONS BY AGE AND SEX

Japan, 1974

(mrad)

Type of examination	0-14 y		15-29 y		30-44 y		⩾ 45 y		Total
	Male	Female	Male	Female	Male	Female	Male	Female	
Radiography	1.51 (1.32)	1.16 (0.61)	4.22 (7.23)	3.24 (4.31)	0.63 (1.45)	0.32 (0.30)	0.02 (0.02)	0.0	11.1 (15.2)
Fluoroscopy	0.20 (0.41)	0.53 (0.64)	1.04 (2.64)	3.00 (5.62)	0.22 (0.54)	0.39 (0.61)	0.01 (0.01)	0.002	5.4 (10.5)
Total	1.71 (1.73)	1.69 (1.25)	5.26 (9.87)	6.24 (9.93)	0.85 (1.99)	0.71 (0.91)	0.03 (0.03)	0.002	16.5 (25.7)

Sources: References 74, 80

Note: Values in parentheses are the 1969 dose values (74).

(vii) *Puerto Rico*

101. In Puerto Rico a repeat in 1973 on the same basis as the 1968 survey included new frequency data derived from questionnaires about one week's work in all the hospitals (61). The new gonad doses per examination that are reported show apparent decreases compared with those in the 1968 survey, but these recent values would appear to be based on very few measurements. The frequency of lumbar spine and abdominal examinations, particularly in females, has increased the contribution to the GSD from these examinations by factors of three and two respectively. There was however no significant change in the overall GSD, which was estimated to be 46 mrad, compared with 43 mrad in the 1968 survey.

(viii) *Romania, 1970*

102. The frequency of the use of x rays in Romania during the period 1953 to 1970 increased from 429 to 1012 examinations per 1000 of population. This increase has predominantly been in radiography (37 to 238) and photofluorography (54 to 452), with a slight decrease in fluoroscopic examinations (338 to 322). A measurement survey has been conducted in which direct patient measurements using thermoluminescent detectors have been made during 5370 radiological, 8750 fluoroscopic and 9370 photofluorography examinations. The GSD has been estimated for the first time and a value of 28.5 mrad obtained (177).

(ix) *Sweden, 1974*

103. From preliminary data reported by Bengtsson *et al.* (17), it is possible to analyze the changes that have occurred in the factors from which the GSD in Sweden was derived in the 1962 report by the Committee. The results of this analysis are shown in table 24.

TABLE 24. ANALYSIS OF THE INCREASE IN THE GSD

Sweden, 1955-1974

Type of examination	Ratio of examination frequency 1974/1955	Ratio of gonad doses 1974/1955		GSD (mrad)					
				1955			1974		
		Male	Female	Male	Female	Foetus	Male	Female	Foetus
Lumbosacral region	1.55	0.18	1.16	6.30	1.36	0.14	1.75	2.44	0.25
Pelvimetry	2.59	–	0.46[a]	–	0.28	6.40	–	0.33	1.35
Urography	2.59	0.27	0.95	3.48	1.77	0.16	2.43	4.36	0.39
Pelvis	1.86	0.36	0.95	2.70	0.40	0.03	1.80	0.71	0.05
Abdomen	2.63	0.15	0.17	1.78	0.93	0.11	0.70	0.42	0.05
Colon	1.76	1.71	0.46	0.56	2.03	0.21	1.68	1.64	0.17
Hip and femur	2.70	1.38	1.42	2.19	0.25	0.01	8.16	0.96	0.04
Urethrocystography	2.25	0.54	0.77	1.57	0.14	0.02	1.90	0.24	0.03
Femur[b]	–	–	–	1.40	0.02	0.01	–	–	–
Obstetrical abdomen	2.33	–	0.57	–	0.06	1.20	–	0.08	1.59
Subtotal				20.0	7.2	8.3	18.4	11.2	3.9
Other	1.42	(No change assumed)		0.3	1.8	0.2	0.4	2.6	0.3
Total				20.3	9.0	8.3	18.8	13.8	4.2
Total of male, female and foetus totals for the year				37.8			36.8		
Enhanced 1974 totals due to an assumed shift in age distribution							24.4	16.5	5.0
Total of enhanced totals							46		

Source: Reference 131.

[a] For the mother; the ratio for the foetus is 0.03.

[b] Not included in comparison; no data for 1974.

104. It can be seen from table 7 that the total frequency of examinations (excluding dental exposures) increased by 50 per cent from 1955 to 1974. Table 24 shows that the increase in the types of examination which give the highest contributions to the GSD has been higher, nearly 100 per cent. The mean gonad doses in the various types of examinations have sometimes, but not always, been substantially reduced. The result is that the male contribution to the GSD has not changed despite the increased number of examinations. The female contribution, however, has increased approximately in proportion to the higher number of examinations, since there has been no apparent dose reduction in the types of examinations which give the highest contributions (e.g., urography and examinations of the lumbar spine). Due to improved techniques, the foetal contribution has decreased despite an increase in the number of pelvimetries. In total, the annual genetically significant dose from x-ray diagnostic procedures in Sweden has not changed significantly from the value of 38 mrad assessed for 1956, assuming no shift in the age distribution within the types of examinations giving the highest contributions. Bengtsson *et al.* (17), however, take into account an enhancement due to shift towards younger patients, corresponding to a factor of 1.2 for females and 1.3 for males. If this correction is made on the results in table 24, the annual GSD will be assessed at about 46 mrad.

(x) *Switzerland, 1971*

105. A radiological survey of the frequency of 60 types of x-ray examinations was carried out during two weeks of September 1971 and information recorded on 60 000 patients in 1567 hospitals (170). The total number of films used in 1971 was estimated to be $15\ 10^6$, compared with $5\ 10^6$ in 1957. The total number of examinations in 1971 was estimated to be $8.55\ 10^6$, increasing annually at the rate of 3-4 per cent. The number of examinations *per caput* of the population increased from 0.96 in 1957 to 1.35 in 1971. The GSD for 1971 was estimated to be 42.9 mrad; the breakdown by type of examination is given in table 25. A calculation shows that by using suitable gonad shielding the GSD could be reduced by 20 per cent to 34.9 mrad.

TABLE 25. BREAKDOWN OF GSD BY TYPE OF EXAMINATION

Switzerland, 1971

Type of examination	Contribution to GSD	
	(mrad)	(%)
Pelvis without pregnancies	9.24	21.5
Descending urography	8.74	20.4
Hip and femur	6.24	14.5
Lumbar vertebrae	3.81	8.9
Barium meal	2.19	5.1
Barium enema	1.91	4.5
Urography	1.29	3.0
Obstetric abdomen	1.06	2.5
Abdomen without pregnancies	1.01	2.3
Pelvimetry	0.52	1.2
Other	6.89	16.1
Total	42.90	100

Source: Reference 170.

(xi) *Island of Taiwan, 1972*

106. A survey was conducted over eight months of 1972 in five hospitals in the city of Hsineku, considered

to be representative of the five major cities on the island of Taiwan, where the urban population is 5 10^6 (261), about one half of the total population. The method of estimating the frequency of examination and the gonad dose per examination was simplified. It would appear from the reference that the radiation dose incident to the gonad region was integrated, using a thermoluminescent detector, for all patients examined radiographically over a period of one month on five x-ray units at the five chosen hospitals. A separate detector was used for those patients having fluoroscopic examinations. A mean gonad dose was used for all examination types, and the age distribution of those examined was used in the calculation of the GSD for 1972, which was found to be 3-4 mrad.

(xii) *United States surveys in 1964 and 1970*

107. The dosimetry of the United States surveys in 1964 and 1970 has been revised, and the new national estimates of the GSD in those years from radiographic examinations only are 16 and 20 mrad, respectively (251, 255). The contribution from screening examinations was not included. The main examinations and their contributions (per cent) to the 1970 total were as follows: lumbar spine, 18; urography, 16; pelvis, 12; abdomen KUB and flat plate, 10; other abdominal examinations, 20; barium enema, 10; hip, 5. The frequency of x-ray examinations is given in table 26.

TABLE 26. FREQUENCY OF X-RAY EXAMINATIONS BY TYPE OF EXAMINATION

United States, 1970

Type of examination	*Frequency (number of examinations per 1000 of population)*
Head and neck	49.8
Chest	
Radiography	251.7
Photofluorography	53.7
Not categorized	32.5
Cholecystography, and cholangiography	20.7
Lumbar and dorso-lumbar spine	18.7
Upper GI tract	29.1
Upper abdomen not categorized	8.0
Abdomen KUB and flat plate	17.5
Urography	20.7
Barium enema	17.8
Pelvis, lumbo-pelvis	10.6
Lower abdomen not categorized	22.7
Upper extremities	50.9
Lower extremities	62.6
Two-area examinations	1.8
Total	668.8

Source: Reference 251.

(xiii) *Projections of GSD for other countries*

108. Three new estimates of GSD (India, Iraq and Taiwan) have been reported for populations that have limited radiological facilities. Low frequencies of radiological examinations correlate in principle with small GSD, unless very high individual doses are involved. A WHO staff report (64) describes the present status of radiological services in several countries of the eastern Mediterranean area. The report compared the average of one diagnostic x-ray unit per 72 000 people with the United States situation of one unit per 1000 people, and the film consumption of 0.063 film per person-year with the United States value of 2.46 films per person-year.

4. Groups of epidemiological interest

109. Collective doses to special patient groups are of particular interest when they can be used for epidemiological studies. Annex G describes in detail the use of such information, from past medical practices, for the assessment of carcinogenesis risks.

110. The organs of special interest in these investigations, for which dose information are required, are:

Public health investigations:

Dental	Skin, thyroid, hypothalamus, lens of the eye; particularly for patients having regular whole-mouth x-ray examinations
Mass surveys of the chest	Lung, heart, thyroid, bone marrow; particularly for patients with a history of chronic chest disease
Mammography	Breast; particularly for groups of high breast-cancer risk

Clinical investigations:

Barium meal	Stomach, bone marrow, small intestine, pancreas; particularly for patients having multiple fluoroscopic examinations
Barium enema	Large intestine, particularly for patients with chronic diseases such as ulcerative colitis
Urography	Kidney, particularly in patients with chronic disease or kidney failure
Children with orthopaedic handicaps	Epiphyses of bones, gonads, bone marrow
Foetal irradiation	Whole body of foetus
Cardiac catheterization	Heart, lung, bone marrow; particularly in children
Pace-maker insertions	Heart, lung, bone marrow and connective tissues in vicinity of nuclear-powered pace-makers; particularly in patients under 40 years of age
Dynamic investigations	Organs in the chest for cardiac investigations and the kidneys, large intestine, bladder and gonads for pelvic examinations
Neurological examinations	Eye, thyroid, hypothalamus

5. Potential means of dose reduction

111. ICRP publications 15, 16 and 21 (97, 98) and certain WHO publications (112, 216) indicate general ways in which the patient dose in diagnostic radiology may be reduced without loss of useful information. In addition to these, there are a number of national publications giving general guidance on procedures likely to reduce patient doses. These may be summarized as follows: implementation of the "ten-day rule" in the United Kingdom (193), guidelines on use of gonad shielding in the United States (252, 253), radiological protection in dental practice in France, the United Kingdom and United States (162, 241, 149, respectively), and general radiation dose reductions (26, 40, 144, 154, 201, 218, 233, 256).

112. Useful surveys have been carried out on aspects of dose reduction, such as the rate of retakes of x-ray examinations in hospitals in Japan (117) and in two large hospitals in the United States (29).

113. Investigations have been made on the effect of positioning for radiographic examinations and the resulting gonad dose (62), and on the design and effectiveness of gonad shields (33). Absorbed dose measurements of male gonad doses have been made in phantoms representing various age groups by Warner (257). Studies of the range of gonad doses for particular examinations in the German Democratic Republic indicate that the maximum tends to be about twice the mean value (202). The reduction in gonad dose during mass chest screening by appropriate use of shields, particularly when examining children, has been demonstrated by Hashizume in the Japanese 1975 survey report (84).

114. Comparisons of the radiation exposure of patients using various types of apparatus have also been studied, e.g., on the exposure reduction obtained by using image intensifiers instead of fluoroscopy (87).

115. Questionnaires aimed at determining how much the public knows about radiation-dose reduction have produced answers that indicate that further education, not only of radiological personnel, but also of the general public is required (195, 240). General descriptions of examination techniques, such as those produced in the German Democratic Republic (200, 217), may help.

116. The introduction of new techniques, such as pulsed fluoroscopy and electronic retention of the resultant image, should reduce the radiation dose by a factor of five in the case of stomach examinations (156). However, Gustafsson (69) has reported that, in a comparison of 1974 techniques with those used in 1960, the mean energy imparted (integral dose) for stomach examinations has remained the same despite the advances in techniques (figure XI). In barium enema examinations, the mean energy imparted has increased by 50 per cent from 1960 to 1974 (69).

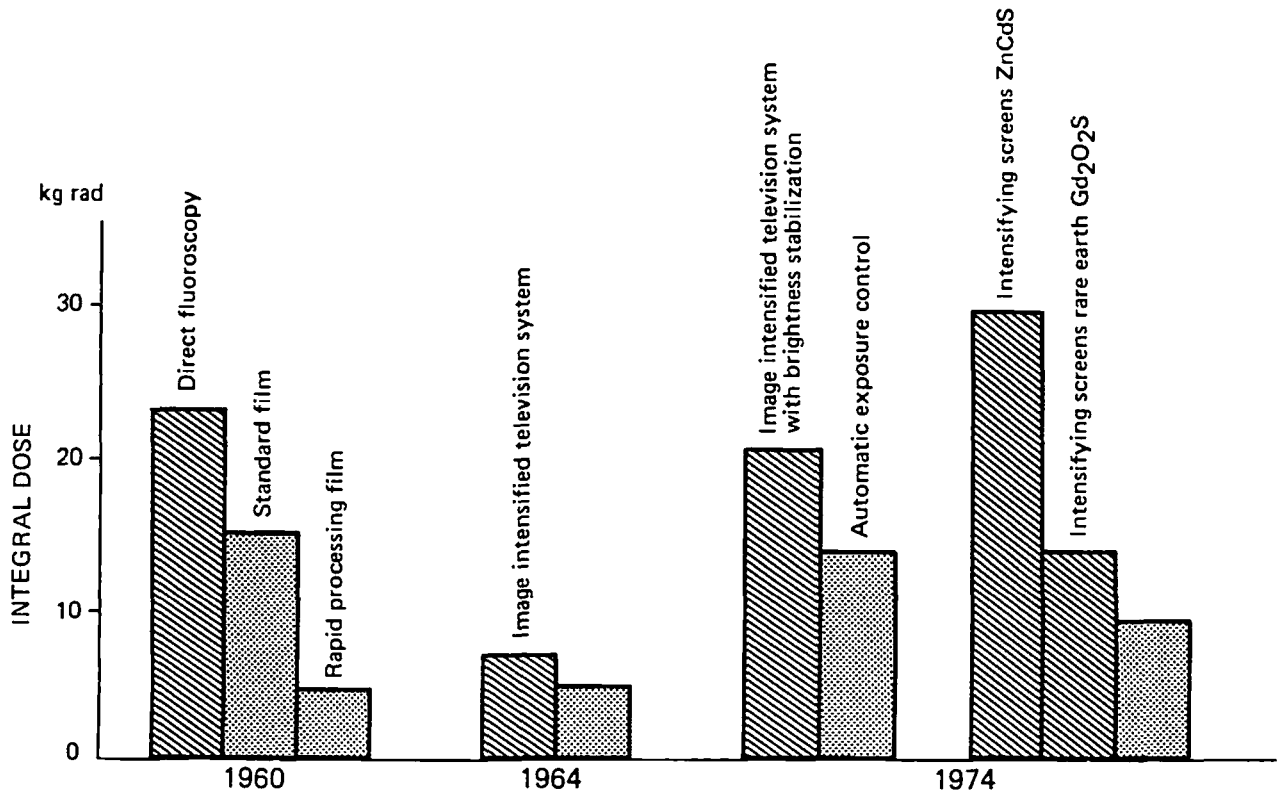


Figure XI. Comparison of mean energy imparted in stomach examinations by various techniques, 1960-1974

B. DIAGNOSTIC USES OF RADIOPHARMACEUTICALS

1. Trends in frequencies and techniques

117. In the 1972 report attention was drawn to the fact that in certain countries the number of diagnostic examinations using radiopharmaceuticals was doubling approximately every three years. This trend is continuing, and therefore it is important that more data should be presented so that estimates of organ dose and GSD may be calculated. Most examinations using radiopharmaceuticals give organ doses of about the same order as or less than complementary x-ray examinations (99, 238). Examination of the thyroid using ^{131}I is the main exception, but with the introduction of alternative *in vitro* techniques, the number of *in vivo* tests using ^{131}I is likely to decline (172). The growth of radioisotope uses in developing countries is being monitored by IAEA (96); from their data it may be possible to assess the effect of the introduction and general availability of short-lived radiopharmaceuticals and the changes in demand resulting from new x-ray facilities, such as computerized axial tomography.

118. The annual frequency of radionuclide examinations was given in the 1972 report for a number of countries for the late 1960s as 2-10 per 1000 of population. With a doubling time of three years, it is now, in several places, approaching and even exceeding 10 per 1000 of population as can be seen in figure XII and in table 27 (93), which show the increase in the annual number and frequency of application of radiopharmaceuticals in West Berlin (91, 92, 93 186), and in table 28, which show similar data for the German Democratic Republic (202). Table 29 shows the reduction in the frequency of ^{131}I-uptake tests in the German Democratic Republic in the last few years due to the introduction of *in vitro* techniques.

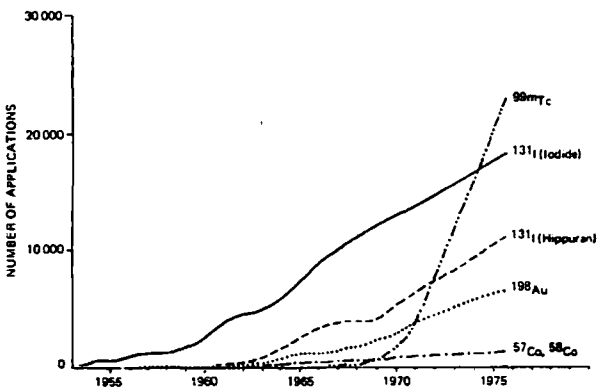


Figure XII. Trend in the annual number of applications of certain radionuclides in West Berlin, 1953-1975 (93)

TABLE 27. SURVEY OF THE DEVELOPMENT OF NUCLEAR MEDICINE IN WEST BERLIN, 1955-1975

(1975 population approximately 2.2 10^6)

Year	Number of all radionuclide applications	Frequency (per 1000 of population)	Distribution by purpose of application (%)	
			Diagnostic	Therapeutic
1955	729	0.32	90.5	9.5
1960	4 220	1.92	91.0	9.0
1965	15 228	6.92	97,1	2.9
1970	30 236	13.87	98.1	1.9
1975	64 720	32.29	99.2	0.8

Source: Reference 93.

TABLE 28. SURVEY OF THE DEVELOPMENT OF NUCLEAR MEDICINE IN THE GERMAN DEMOCRATIC REPUBLIC, 1965-1974

(1974 population approximately 17 10^6)

Year	Number of all radionuclide applications	Frequency (per 1000 of population)	Distribution by purpose of application (%)	
			Diagnostic	Therapeutic
1965	25 913	1.5	96.96	3.04
1966	31 895	1.9	97.06	2.94
1967	42 461	2.5	97.67	2.33
1970	71 378	4.2	98.79	1.21
1971	77 172	4.5	98.75	1.25
1972	131 021	7.7	99.20	0.80
1973	137 128	8.0	98.94	1.06
1974	167 483	9.9	99.16	0.84

Source: Reference 202.

TABLE 29. TRENDS IN THE ^{131}I-UPTAKE TESTS IN THE GERMAN DEMOCRATIC REPUBLIC, 1958-1974

(Administered activity 25-30 μCi)

Year	Number of tests	Fraction of all radionuclide diagnostic examinations (%)	Frequency of test (per 1000 of population)	Number of performing facilities
1958	729			2
1960	2 818			6
1965	10 192	40.6		11
1970	20 092	28.5		14
1971	21 902	27.8		15
1972	26 326	21.6		16
1973	25 170	18.5		16
1974	24 969	15.0	1.47	17

Source: Reference 202.

119. The introduction of new nuclides in radiopharmaceuticals giving lower doses for some types of examinations has to some extent minimized the increase in dose that would be expected from the rapid increase in the number of radiopharmaceutical examinations. This is illustrated in figure XIII, which shows how the change from ^{198}Au to ^{99m}Tc in liver scans has reduced the gonad dose per examination by a factor of three so that the collective dose has increased but little, even though the total number of examinations has increased substantially (151). Roedler *et al.* (186) have calculated the achievable dose reduction for examined or critical organs and gonads by selection of suitable radiopharmaceuticals (see table 30). The most promising dose reductions have been made possible by the introduction in the mid 1960s of ^{99m}Tc, which is now in increasing use all over the world.

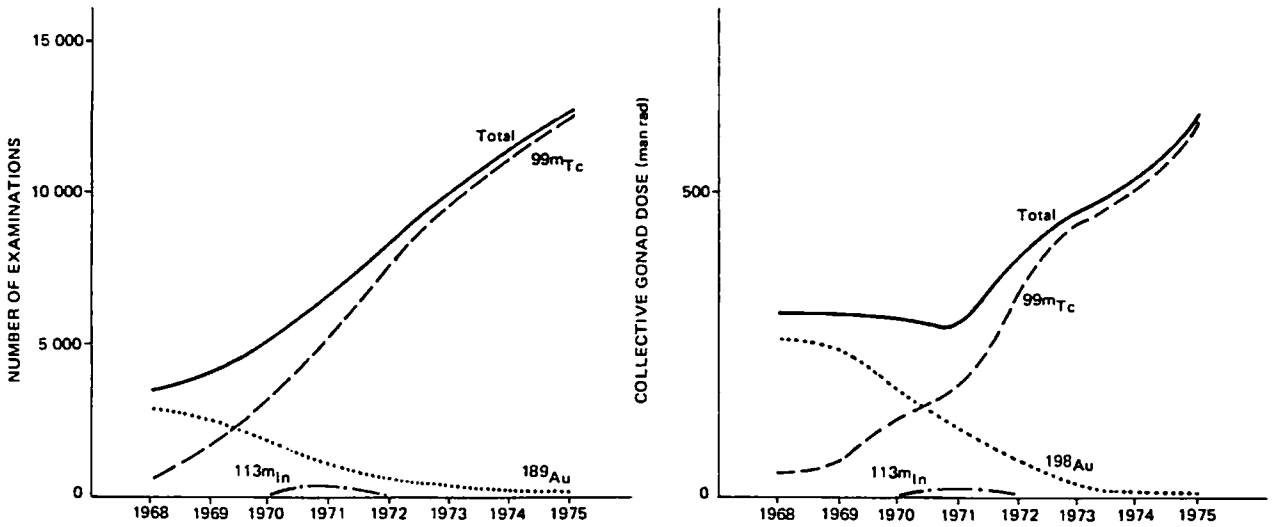


Figure XIII. Trend in the annual number of examinations and collective gonad dose for liver scans in Sweden 1968-1975 (151)

TABLE 30. DOSE REDUCTION FOR EXAMINED OR CRITICAL ORGAN AND GONADS BY REPLACEMENT OF CONVENTIONAL RADIOPHARMACEUTICALS

Radiopharmaceutical[a]			*Dose reduction coefficient*		
Conventional	*Replacement*	*Diagnostic method*	*Examined or critical organ*		*Gonads*
^{131}I iodide (43)	^{99m}Tc pertechnetate (1 000)	Thyroid scanning	Thyroid	0.013	2.6
	^{132}I iodide (25)	Function test (30%)	Thyroid		
^{198}Au colloid (240)	^{99m}Tc S-colloid (1 500)	Liver scanning	Liver	0.063	0.13
^{58}Co vitamin B_{12} (0.9)	^{57}Co vitamin B_{12} (0.5)	Schilling test	Liver	0.12	0.11
^{131}I MAA (220)	^{99m}Tc MAA (3 000)	Lung scanning (66%)	Lung	1.1	0.071
	^{133}Xe (15 000)	Lung scanning (34%)	Lung		
^{131}I HSA (10$^+$)	^{99m}Tc HSA (100)	Blood volume	Total body	0.088	0.1
^{131}I HSA (10$^+$)	^{99m}Tc HSA (500)	Placental localization	Total body	0.44	0.5
^{131}I HSA (100$^+$)	^{99m}Tc HSA (1500)	Myelography	Total body	0.13	0.15
^{197}Hg BMHP (360)	^{99m}Tc S-colloid (1500)	Spleen scanning	Spleen	0.15	0.069
^{85}Sr nitrate (330)	^{99m}Tc polyphosphate (10 000)	Bone scanning	Skeleton	0.11	0.2
^{203}Hg BMHP (400)	^{99m}Tc DTPA (3 000)	Kidney scanning	Kidney	0.0009	0.0096
^{203}Hg chlormerodrine (180)	^{99m}Tc DTPA (3 000)	Kidney scanning	Kidney	0.017	0.053

Source: Reference 186.

[a] The mean administered activity in microcuries is given in parentheses.

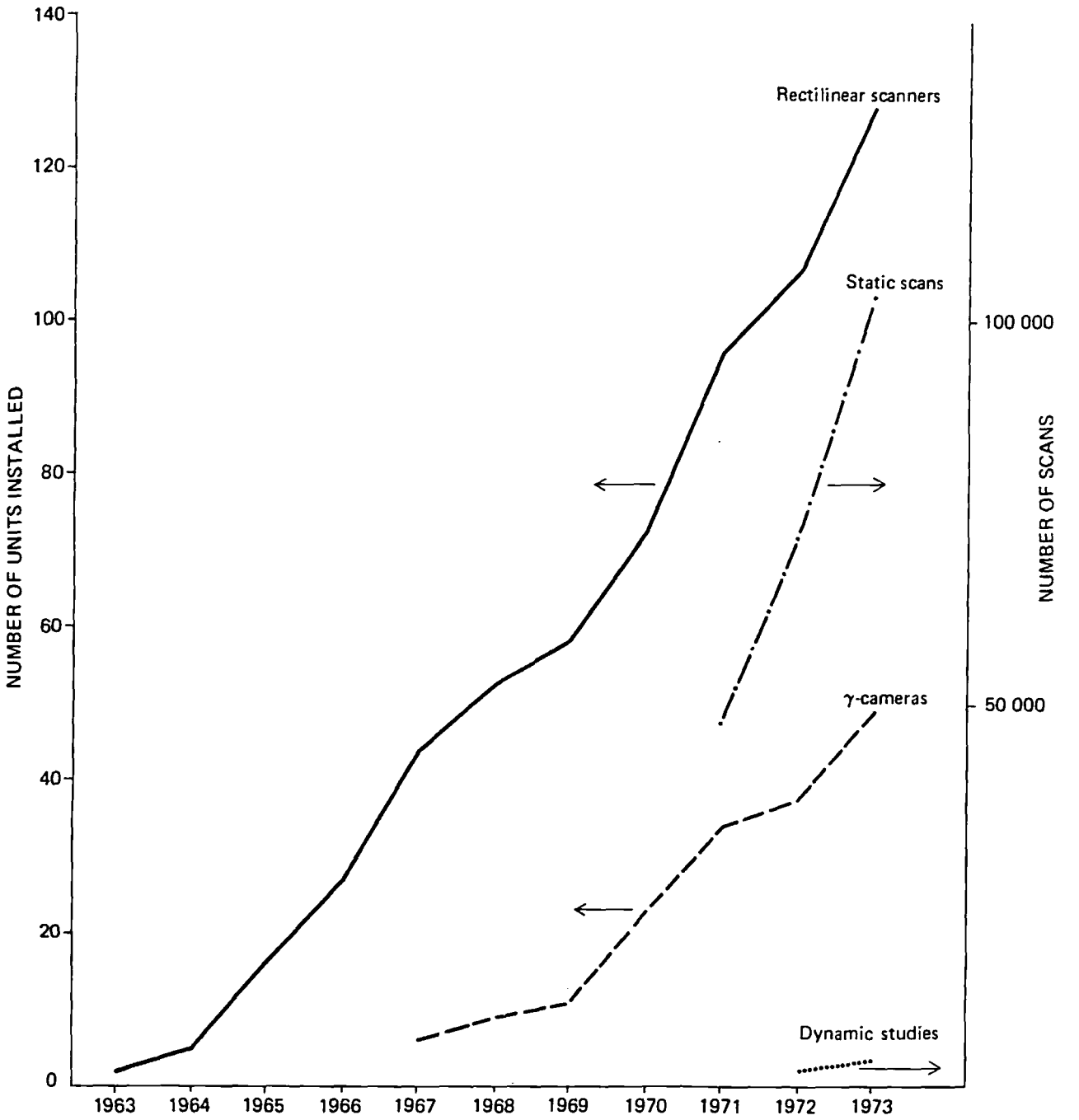


Figure XIV. Number of scanners and γ-cameras installed in the United Kingdom, 1963-1973, and total number of static scans and dynamic studies carried out, 1971-1973 (172, 188, 189)

120. Part of the increase in frequency of examinations in the United Kingdom is due to the increased availability of imaging equipment; the increase in scanners and cameras in England and Wales is shown for the period 1963-1973 in figure XIV (172, 188, 189). In a population of 50 10^6, the number of scans, also shown in figure XIV, doubled every two years and by 1973 amounted to 2 per 1000 of population.

121. The most common single type of radionuclide examination is the thyroid function (uptake) test with ^{131}I. In many countries it accounts for about one third of all radionuclide examinations, while in technologically advanced countries this proportion has declined to about 10 per cent of the total, as can be seen from Table 31 (96). The use of *in vitro* T3 and T4 tests to replace *in vivo* uptake studies is significantly reducing

TABLE 31. RELATIVE PROPORTION OF IODINE-131 THYROID UPTAKE STUDIES IN VARIOUS COUNTRIES

Country	*Fraction of all radionuclide investigations (%)*
Argentina	40
Brazil	47
Denmark (1973/74)	9
Hungary	27
India	38
Israel	18
Mexico	23
Poland	30
Sweden (1968)	19
Sweden (1974)	12
United States[a]	8
Yugoslavia	22

Source: Reference 96.

[a]Data from 65 academic divisions of nuclear medicine (231).

TABLE 32. FREQUENCY OF ^{131}I-UPTAKE STUDIES AND THE ACTIVITY ADMINISTERED IN VARIOUS COUNTRIES

Country	*Population (10^6)*	*Frequency (per 1000 of population)*	*Administered activity (μCi)*	
			Range	*Mean (population weighted)*
Argentina	24.0	0.66	5-100	44
Brazil	91.3	0.18	20-70	41
Denmark (1973)	5.06	0.89	–	20
Hungary	10.3	1.40	0.5-50	16
India	537.0	0.013	7-40	16
Israel	2.82	2.29	6-35	21
Sweden	7.9	1.14	2.5-35	9
Mexico	48.9	0.12	5-50	14
Poland	32.5	0.46	5-60	13
United States (1966)	195.0	1.54	2.5-100	37
Yugoslavia	20.4	0.66	5-100	31

Source: Reference 96.

TABLE 33. FREQUENCY OF ^{131}I THYROID SCANS AND THE ACTIVITY ADMINISTERED IN VARIOUS COUNTRIES

Country	*Population (10^6)*	*Frequency (per 1000 of population)*	*Administered activity (μCi)*	
			Range	*Mean (population weighted)*
Argentina	24.0	0.23	50-100	80
Brazil	91.3	0.093	15-300	71
Denmark	5.06	0.23	–	78
Hungary	10.3	0.36	15-50	32
India	537.0	0.003	20-100	41
Israel	2.82	1.38	10-50	31
Sweden	7.9	1.53	4-100	41
Mexico	48.9	0.077	50-180	116
Poland	32.5	0.14	10-100	50
United States (1966)	195.0	0.78	10-150	57
Yugoslavia	20.4	0.63	20-100	45

Source: Reference 96.

the radiation dose to this group of patients in the United Kingdom (172). The introduction of the use of ^{123}I for thyroid imaging would reduce the dose by a factor of about 10 compared with ^{131}I (254).

122. It is possible to complete the picture of the use of ^{131}I by presenting some data compiled by IAEA (96) on the use of radionuclides in 11 countries for periods around 1970. Tables 32 and 33 give the frequencies, the average administered activities and the range of activities in these countries for thyroid uptake studies and thyroid scans with ^{131}I. It has already been shown (table 31) that thyroid uptake studies dominate the number of radionuclide examinations in many countries. It can be seen from table 32 that, with the exception of India, there is relatively little variation in the frequency of uptake studies, the range being 0.12-2.29 per 1000 of population. Table 33 shows that there is on the average one ^{131}I thyroid scan for every two uptake tests. The administered activities range between 9 and 44 μCi for the uptake studies and between 31 and 116 μCi for the scans. It is important to obtain more recent information on these aspects, as the situation is likely to have changed significantly in the last eight years.

2. Individual dose per unit procedure

(a) *Administered activity*

123. As with x-ray examinations, the doses received during radiopharmaceutical examinations vary from hospital to hospital. In this case, however, comparisons are somewhat easier because the choice of nuclide, chemical substance, mode of administration and administered activity define the dose for any particular investigation of disease. Interesting comparisons may therefore be made on the basis of the administered activity, once the other factors are kept constant, which is usually the case within each type of examination and for each nuclide.

124. Data are available from Sweden on the average activity used in each type of examination and on the lowest and highest average activities used in particular clinics. On the basis of the reported average activity, the highest organ dose (in the average procedure) has been calculated, together with the gonad dose. The results are shown in tables 34 and 35 for 1968 and 1974 (151). The doses have been calculated using data from Swedish compilations (59).

125. Tables 34 and 35 may be compared with tables 36 and 37, where similar information is presented for Denmark (1973-1974) and the United States (1966) (219, 248). There is a great degree of similarity in the practices for the corresponding years. These recent data give a relatively clear picture of the magnitude of radionuclide examinations in technologically developed countries for the year 1974. The variation in administered activities in three of the most common types of examinations is shown in table 38.

TABLE 34. DATA ON THE USE OF RADIONUCLIDES FOR DIAGNOSTIC PURPOSES

Sweden, 1968

Type of examination	Radionuclide	Chemical form	Administration method	Administered activity per examination (μCi)			Critical organ dose per examination (mrad)	Critical organ	Number of examinations	Frequency (per 1000 of population)	Gonad dose	
				Average	Lowest	Highest					Per examination (mrad)	Per 1000 of population (man rad)
Thyroid scan	^{131}I,	Iodide	PO	41	4	100	73 000	Thyroid	12 091	1.53	96	0.147
	^{125}I	Iodide	PO	42	30	50	31 000	Thyroid	766	0.097	16	0.002
	^{99m}Tc	Pertechnetate	PO	1 700	1 000	2 100	430	Thyroid	610	0.077	14	0.001
Thyroid[a]	^{131}I	Iodide	PO	980	750	1 000			89	0.011	2 300	0.026
Brain scan	^{131}I	RIHSA	IV	353	94	500	12 000	Thyroid	40	0.005	1 600	0.008
	^{99m}Tc	Pertechnetate	IV	10 000	3 720	14 000	1 700	Lower intestine	1 033	0.130	170	0.022
Lung scan	^{131}I	MAA	IV	235	130	325	1 200	Lung	391	0.049	150	0.007
Skeleton scan	^{85}Sr	Chloride	IV	53	30	200	1 500	Skeleton	545	0.069	400	0.028
Liver scan	^{198}Au	Colloid	IV	182	100	300	7 800	Spleen	2 894	0.365	90	0.033
	^{99m}Tc	S-colloid	IV	2 800	600	3 000	800	Liver	590	0.075	64	0.005
	^{131}I	Rose Bengal	IV	128	100	300	240	Liver	96	0.012	92	0.001
Marrow scan	^{198}Au	Colloid	IV	921	300	2 000	39 000	Spleen	193	0.024	450	0.011
Pancreas scan	^{75}Se	Methionine	IV	210	200	250	12 000	Kidney	38	0.005	2 200	0.011
Profile scan	^{131}I	Iodide	PO	220	50	241	430 000	Thyroid	138	0.017	510	0.009
Thyroid function	^{131}I	Iodide	PO	9	2.5	35	16 000	Thyroid	9 002	1.14	21	0.024
	^{125}I	Iodide	PO	16	6	127	12 000	Thyroid	251	0.032	6	0.000
Brain circulation	^{131}I	RIHSA	IA	156	50	263	5 300	Thyroid	99	0.013	720	0.009
Circulation test	^{133}Xe	Sol	IM	109	20	300	2 800	Adipose tissue	1 231	0.155	(100)	0.016
Lung function	^{133}Xe	Sol	IV	1 720	500	4 900	34	Trachea	811	0.102	1	0.000
Blood volume	^{131}I	RIHSA	IV	11	1	115	380	Thyroid	954	0.120	50	0.006
	^{125}I	RIHSA	IV	3	1	8	8	Blood	818	0.103	2	0.000
Potassium determination	^{42}K	Chloride	PO	150	50	107	950	GI tract	292	0.037	200	0.007
Iron metabolism	^{59}Fe	Citrate	PO	5	3	40	760	Spleen	377	0.048	72	0.003
Schilling test	^{60}Co	Vitamin B_{12}	PO	0.4	0.24	0.5	730	Liver	523	0.066	260	0.017
	^{58}Co	Vitamin B_{12}	PO	0.4	0.05	0.7	150	Liver	1 430	0.181	57	0.010
	^{57}Co	Vitamin B_{12}	PO	0.4	0.16	0.75	35	Liver	1 436	0.181	2	0.000
Renography	^{131}I	Iodide	IV	50	50	50	120	Gonads	121	0.015	120	0.002
	^{131}I	Hippurate	IV	23	10	200	40	Bladder	5 176	0.654	1	0.000
	^{125}I	Hippurate	IV	14	1	100	3	Kidney	2 849	0.360	1	0.000
Other	–	–	–	–	–	–	–	–	2 728	0.345	(50)	0.017
Total									47 616	6.02	70	0.422

Source: Reference 151.

[a]Cancer patients.

TABLE 35. DATA ON THE USE OF RADIONUCLIDES FOR DIAGNOSTIC PURPOSES

Sweden, 1974

Type of examination	Radionuclide	Chemical form	Administration method	Administered activity per examination (μCi)			Critical organ dose per examination (mrad)	Critical organ	Number of examinations	Frequency (per 1000 of population)	Gonad dose	
				Average	Lowest	Highest					Per examination (mrad)	Per 1000 of population (man rad)
Thyroid scan	^{131}I	Iodide	PO	86	4	1 000	153 000	Thyroid	10 101	1.22	202	0.246
	^{125}I	Iodide	PO	25	11	40	18 500	Thyroid	265	0.032	10	0.000
	^{99m}Tc	Pertechnetate	IV	1 810	600	5 000	920	Thyroid	3 647	0.439	30	0.013
Brain scan	^{99m}Tc	Pertechnetate	IV	10 950	5 000	15 000	1 860	Lower intestine	10 894	1.31	185	0.242
	^{99m}Tc	DTPA	IV	14 360	14 000	14 700	5 600	Bladder	1 382	0.166	280	0.047
Lung scan	^{131}I	MAA	IV	767	300	1 500	3 900	Lung	200	0.024	490	0.012
	^{99m}Tc	MAA	IV	1 780	1 000	3 000	90	Blood	2 084	0.251	20	0.005
Skeleton scan	^{85}Sr	Chloride	IV	66	40	100	1 900	Skeleton	831	0.100	500	0.050
	^{99m}Tc	Phosphate	IV	8 670	4 000	15 000	1 765	Bladder	3 926	0.473	135	0.064
Liver scan	^{198}Au	Colloid	IV	138	120	175	5 900	Spleen	162	0.020	68	0.001
	^{99m}Tc	S-colloid	IV	2 050	500	5 000	585	Liver	10 600	1.28	47	0.060
Marrow scan	^{198}Au	Colloid	IV	833	500	1 000	35 000	Spleen	97	0.012	410	0.005
Pancreas scan	^{75}Se	Metionine	IV	240	200	250	13 500	Kidney	328	0.039	2 500	0.098
	^{99m}Tc	S-colloid	IV	2 000	2 000	2 000	570	Liver	236	0.028	46	0.001
Profile scan	^{131}I	Iodide	PO	479	100	950	936 000	Thyroid	155	0.019	1 100	0.021
Thyroid function	^{131}I	Iodide	PO	12	2	30	21 000	Thyroid	11 796	1.42	28	0.040
Thyroid[a]	^{131}I	Iodide	PO	279	200	357			346	0.042	640	0.027
Circulation test	^{133}Xe	Sol	IM	319	8	1 400	8 200	Adipose tissues	259	0.031	(300)	0.009
Lung function	^{133}Xe	Sol	IV	2 517	263	10 500	50	Trachea	2 652	0.319	1	0.000
Blood volume	^{131}I	RIHSA	IV	4.4	1.5	6	150	Thyroid	1 546	0.186	20	0.004
	^{125}I	RIHSA	IV	4.6	0.7	10	12	Blood	695	0.084	3	0.000
Iron metabolism	^{59}Fe	Chloride	PO	6.9	0.6	20	1 050	Spleen	484	0.058	100	0.006
Schilling test	^{58}Co	Vitamin B_{12}	PO	0.57	0.05	0.8	210	Liver	727	0.088	80	0.007
	^{57}Co	Vitamin B_{12}	PO	0.44	0.05	0.5	38	Liver	1 682	0.203	2	0.000
Renography	^{131}I	Hippurate	IV	32	6	200	56	Bladder	11 475	1.38	1	0.001
	^{125}I	Hippurate	IV	17	6	40	4	Kidney	8 311	1.00	1	0.001
	^{131}I	RIHSA	IV	10	10	10	340	Thyroid	110	0.013	45	0.001
Other	–	–	–	–	–	–	–	–	10 774	1.30	(50)	0.065
Total									95 765	11.5	80	0.922

Source: Reference 151.

[a] Cancer patients.

TABLE 36. DATA ON THE USE OF RADIONUCLIDES FOR DIAGNOSTIC PURPOSES

Denmark, 1973/74

Type of examination	*Radio-nuclide*	*Chemical form*	*Number of examin-ations*	*Frequency (per 1000 of popu-lation)*	*Administered activity per examination (μCi)*	*Gonad dose*	
						Per examin-ation (mrad)	*Per 1000 of population (man rad)*
Thyroid scan	^{131}I	Iodide	1 187	0.235	78	183	0.043
	^{99m}Tc	Pertechnetate	2 605	0.515	1 493	25	0.013
Brain scan	^{99m}Tc	Pertechnetate	8 624	1.70	11 890	200	0.340
Lung scan	^{133}I	MAA	334	0.066	293	187	0.012
	^{99m}Tc	Microspheres	714	0.141	1 467	19	0.003
Skeleton scan	^{99m}Tc	Phosphate	1 409	0.278	10 250	154	0.043
Liver scan	^{99m}Tc	S-colloid	2 463	0.487	1 689	56	0.027
Pancreas scan	^{75}Se	Methionine	46	0.009	263	2 740	0.025
Thyroid function	^{131}I	Iodide	4 525	0.894	20	47	0.042
	^{99m}Tc	Pertechnetate	447	0.088	1 000	17	0.001
Circulation test	^{133}Xe	Sol	2 112	0.417	90	(100)	0.042
Lung function	^{133}Xe	Sol	123	0.024	2 852	1	0.000
Iron metabolism	^{59}Fe	Citrate	140	0.028	10	145	0.004
Schilling test	^{58}Co	Vitamin B_{12}	1 101	0.218	0.54	80	0.017
	^{57}Co	Vitamin B_{12}	932	0.184	0.44	2	0.000
Renography	^{131}I	Hippuran	7 539	1.49	36	1	0.001
	^{125}I	Hippuran	2 638	0.521	26	1	0.000
Kidney clearance	^{51}Cr	EDTA	1 019	0.201	82	1	0.000
Other	–	–	10 741	2.12	–	(50)	0.106
Total			48 699	9.62		75	0.719

Source: Reference 219.

TABLE 37. DATA ON THE USE OF

United

Type of examination	*Radio-nuclide*	*Chemical form*	*Adminis-tration method*	*Administered activity per examination (μCi)*		
				Average	*Lowest*	*Highest*
Thyroid scan	^{131}I	Iodide	PO	57	10	150
Brain scan	^{99m}Tc	Pertechnetate	IV	7 937	600	15 000
Liver scan	^{198}Au	Colloid	IV	175	60	500
	^{131}I	Rose Bengal	IV	158	55	400
Lung scan	^{131}I	Albumin	IV	260	100	350
Skeleton scan	^{85}Sr	Chloride	IV	105	50	300
Thyroid function	^{131}I	Iodide	PO	37	2.5	100
Blood volume	^{131}I	RIHSA	IV	5.5	0.5	22.5
Vitamin B_{12} absorption	^{60}Co	Vitamin B_{12}	PO	0.5	0.1	1.4

Source: Reference 248.

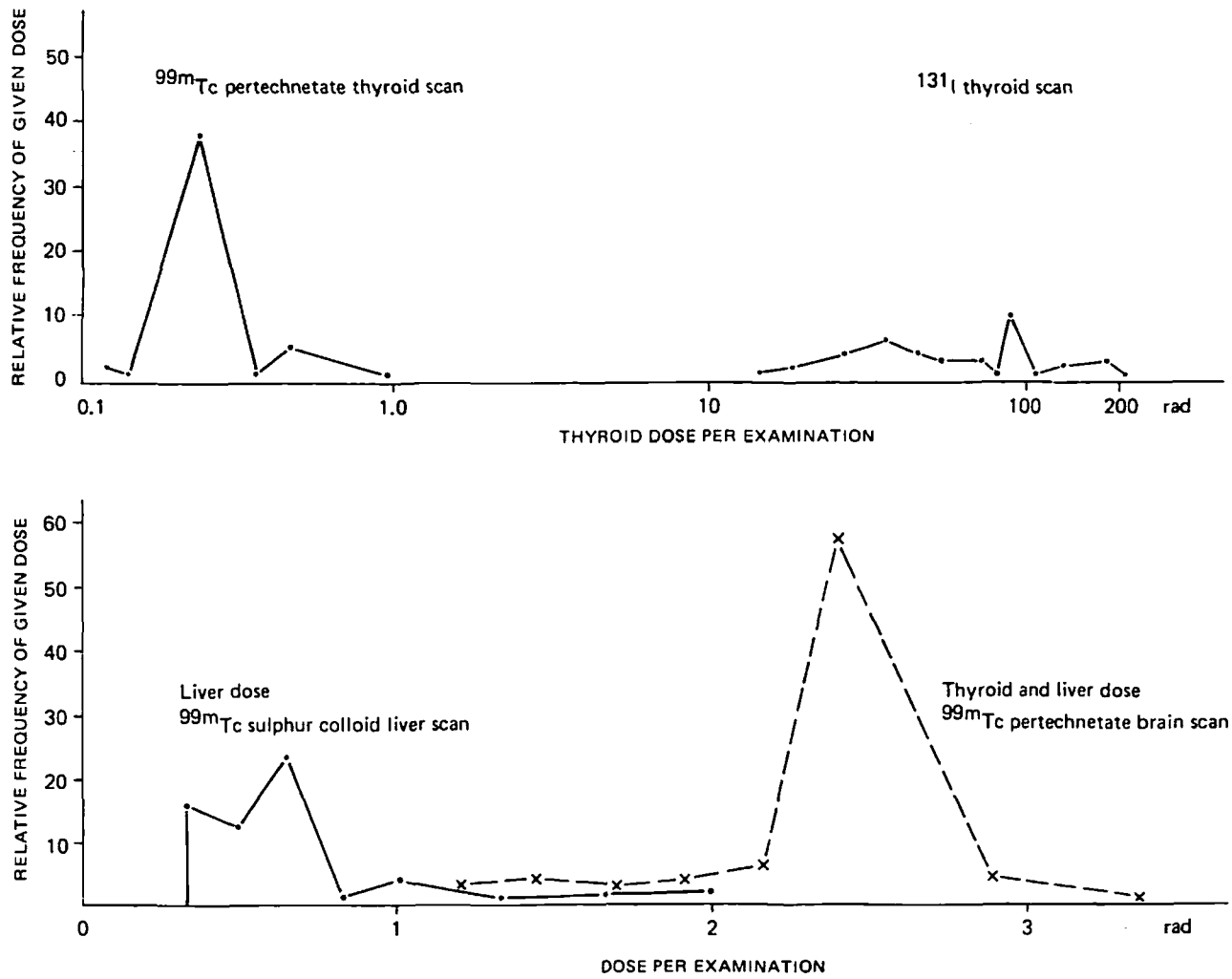


Figure XV. Frequency distribution of doses to thyroid and liver in radiopharmaceutical examinations given in England and Wales (172)

(b) *Dose per examination*

126. A number of publications give estimates of organ doses per unit of administered activity (18, 24, 43, 44, 59, 85, 90, 95, 99, 110, 124, 125, 132, 133, 140, 183, 184, 185, 211, 213, 245, 246). The estimates are given for normal individuals as well as for patients who, because of metabolic changes caused by the disease, may receive somewhat different organ doses. In a number of examinations with ^{131}I or with other radionuclides, such as ^{99m}Tc, which are readily taken up by the thyroid, it is customary to reduce the thyroid dose by blocking the thyroid (51). The dose estimates then critically depend upon the assumptions about thyroid blocking. The biokinetic data compiled by Kaul *et al.* (109) are particularly useful in calculating the absorbed doses from various radiopharmaceuticals when differences from the normal have to be taken into account.

States, 1966

Critical organ dose (mrad)	Critical organ	Number of examinations	Frequency (per 1000 of population)	Gonad dose	
				Per examination (mrad)	Per 1000 of population (man rad)
101 500	Thyroid	153 089	0.78	133	0.104
1 350	Lower intestine	63 078	0.32	135	0.043
7 500	Spleen	41 855	0.21	87	0.018
296	Liver	19 721	0.10	114	0.012
1 330	Lung	22 840	0.120	166	0.020
2 970	Bone	6 232	0.032	792	0.025
65 000	Thyroid	301 052	1.54	86	0.132
190	Thyroid	101 994	0.52	25	0.013
913	Liver	16 486	0.085	325	0.028

TABLE 38. ADMINISTERED ACTIVITY IN THREE COMMON RADIOPHARMACEUTICAL EXAMINATIONS

(μCi per examination)

Country	Examination			
	Thyroid scan		Thyroid uptake	Brain scan
	^{131}I	^{99m}Tc	^{131}I	^{99m}Tc
Denmark (1973/74)	78	1 490	20	11 890
West Berlin (1975)	–	1 035	–	9 380
Sweden (1968)	41	1 700	9	10 000
Sweden (1975)	57	1 840	9	10 990
United Kingdom (1973)	41	900	–	9 500
United States (1966)	57	–	37	7 940

Sources: References 93, 151, 172, 219, 248.

127. Typical radiation doses received from radiopharmaceutical examinations are given in the eighth column of table 34 for the organs listed in the ninth column. The distribution of typical doses in all the centres in England and Wales have been reported by Potter (172), and are given in figure XV. It is important to note that the dose to the thyroid is two orders of magnitude lower when ^{99m}Tc pertechnetate is used instead of ^{131}I.

128. Roedler *et al.* (186) have made a critical review of the dose factors reported in the literature. Because of the high frequency of thyroid examinations with ^{131}I, the dose factors for this nuclide are of particular interest. A number of authors have assessed the gonadal dose per unit administered activity of ^{131}I at more than 2 mrad μCi^{-1}. Roedler *et al.* suggest that the dose factor is only 0.2 mrad μCi^{-1}. A comparison of some current estimates of the dose factor to organs for a number of examinations is made in table 39 and the corresponding dose per examination given in table 40.

TABLE 39. RANGE AND NOMINAL VALUE OF ABSORBED DOSE PER UNIT ADMINISTERED ACTIVITY IN THE MOST FREQUENTLY PERFORMED RADIOPHARMACEUTICAL EXAMINATIONS

(mrad μCi^{-1})

Type of examination	Radionuclide	Chemical form	Organ	Range		Nominal value
				From literature	Recalculated	
Thyroid scan or function	^{131}I	Iodide	Thyroid	68-3 400	840-3 700	2 000
			Gonads	0.024-8.5	0.10-0.33	0.2
			Skeleton	0.3-1.4	0.20-0.59	0.4
Thyroid scan Brain scan	^{99m}Tc	Pertechnetate	Thyroid	0.1-0.6	0.56	0.6
			Gonads	0.01-0.04	0.019	0.02
			Skeleton		0.018	0.02
Thyroid function	^{132}I	Iodide	Thyroid	0.37-50	4-90	30
			Gonads	0.18-0.20	0.061-0.14	0.1
			Skeleton		0.068-0.11	0.1
Kidney function	^{131}I	*o*-Iodohippurate	Kidney	0.07-1	0.22-0.65	0.5
			Gonads	0.016-0.25	0.0053-0.0087	0.01
			Skeleton		0.0057-0.0076	0.007
Bone scan	^{85}Sr	Nitrate/chloride	Gonads	2.9-40	2.8-3.3	3
			Skeleton	2.9-52	11	10
	^{87m}Sr	Nitrate/chloride	Gonads		0.02	0.02
			Skeleton	0.071-0.6	0.05	0.05
	^{99m}Tc	Polyphosphate	Gonads		0.02	0.02
			Skeleton		0.04	0.04

TABLE 39 *(continued)*

Type of examination	*Radio-nuclide*	*Chemical form*	*Organ*	*Range*		*Nominal value*
				From literature	*Recalculated*	
Kidney scan	^{203}Hg	BMHP	Kidney	690-760		(500)
			Gonads			(10)
			Skeleton			(10)
	^{203}Hg	Chlor-merodrine	Kidney	0.66-580	87	90
			Gonads	0.02-1.9	1.7-1.9	2
			Skeleton		1.7	2
	^{99m}Tc	DTPA	Kidney	0.042		(0.04)
			Gonads	0.01-0.02		(0.02)
			Skeleton			(0.02)
Spleen scan	^{197}Hg	BMHP	Spleen	0.17-30		(10)
			Gonads	0.05-0.4		(0.5)
			Skeleton			(0.5)
	^{99m}Tc	S-colloid	Spleen	0.02-0.45	0.053	0.1
			Gonads	0.012-0.023	0.0021-0.0061	0.005
			Skeleton	0.026-0.034	0.011	0.01
Liver scan	^{198}Au	Colloid	Liver	20-1 000	30-39	40
			Gonads	0.11-1.4	0.035-0.38	0.3
			Skeleton	2.7-50	0.28-0.49	0.5
	^{99m}Tc	S-colloid	Liver	0.002-0.53	0.35	0.4
			Gonads	0.012-0.023	0.002-0.006	0.005
			Skeleton	0.02-0.14	0.011	0.01
	^{113m}In	Colloid	Liver	0.05-0.6	0.44	0.5
			Gonads		0.001-0.003	0.002
			Skeleton	0.02-0.5	0.007	0.01
Pancreas scan	^{75}Se	Methionine	Pancreas	0.24-12	13	15
			Gonads	1-11	10	10
			Skeleton		8.3	10
Blood (plasma) volume	^{131}I	HSA	Total body	0.25-12.3	1.7	2
			Gonads	1.7-4	2.0	2
			Skeleton		1.7	2
	^{99m}Tc	HSA	Total body	0.002-0.02	0.014-0.016	0.02
			Gonads	0.005-0.08	0.019-0.022	0.02
			Skeleton		0.018-0.021	0.02
Erythrocyte volume or survival time	^{51}Cr	Chromate	Total body	0.25-3	0.34	0.4
			Gonads	0.03-3	0.43	0.4
			Skeleton	2	0.35	0.4
Lung scan	^{131}I	MAA	Lung	0.67-9.8	4.0	4
			Gonads	0.074-2	0.29	0.3
			Skeleton		0.28	0.3
	^{99m}Tc	MAA	Lung	0.047-0.4	0.2-0.36	0.3
			Gonads		0.012-0.057	0.002
			Skeleton		0.01-0.012	0.01
Iron kinetics	^{59}Fe	Citrate	Spleen	14-230	130	150
			Gonads	3-350	50	50
			Skeleton	1.3-18	16	15

Source: Reference 185.

TABLE 40. ABSORBED DOSE PER EXAMINATION IN THE MOST FREQUENTLY PERFORMED RADIOPHARMACEUTICAL EXAMINATIONS

Type of examination	*Radio-nuclide*	*Chemical form*	*Average administered activity (μCi)*	*Absorbed dose per examination (mrad)*			
				Examined and/or critical organ		*Gonads*	*Skeleton*
Thyroid scan or function	^{131}I	Iodide	25	Thyroid	50 000	5	10
Thyroid scan	^{99m}Tc	Pertechnetate	1 000	Thyroid	600	20	20
Thyroid function	^{132}I	Iodide	25	Thyroid	750	2.5	2.5
Kidney function	^{131}I	*o*-Iodohippurate	20	Kidney	10	0.2	0.14
Bone scan	^{85}Sr	Nitrate/chloride	100	Skeleton	1 000	300	1 000
	^{87m}Sr	Nitrate/chloride	1 000	Skeleton	50	20	50
	^{99m}Tc	Polyphosphate	10 000	Skeleton	400	400	200

Type of examination	Radio-nuclide	Chemical form	Average administered activity (μCi)	Absorbed dose per examination (mrad)			
				Examined and/or critical organ		Gonads	Skeleton
Kidney scan	^{203}Hg	BMHP	100	Kidney	50 000	1 000	1 000
	^{203}Hg	Chlormerodrine	150	Kidney	13 500	300	300
	^{99m}Tc	DTPA	3 000	Kidney	120	60	60
Brain scan	^{99m}Tc	Pertechnetate	10 000	Thyroid	6 000	200	200
Spleen scan	^{197}Hg	BMHP	300	Spleen	3 000	150	150
	^{99m}Tc	S-colloid	1 500	Spleen	150	7.5	15
Liver scan	^{198}Au	Colloid	150	Liver	6 000	45	75
	^{99m}Tc	S-colloid	1 500	Liver	600	7.5	15
	^{113m}In	Colloid	1 000	Liver	500	2	10
Pancreas scan	^{75}Se	Methionine	200	Pancreas	3 000	2 000	2 000
Blood (plasma) volume	^{131}I	HSA	10	Total body	20	20	20
	^{99m}Tc	HSA	100	Total body	2	2	2
Erythrocyte volume or survival time	^{51}Cr	Chromate	100	Total body	40	40	40
Lung scan	^{131}I	MAA	200	Lung	800	60	60
	^{99m}Tc	MAA	3 000	Lung	900	6	30
Iron kinetics	^{59}Fe	Citrate	15	Spleen	2 250	750	225

Source: Reference 185.

129. To calculate an approximate value for the annual collective dose, the data from England and Wales (population 50 10^6) for 1973 may be averaged and combined with the number of examinations carried out. The collective doses for five examinations are given in table 41.

TABLE 41. COLLECTIVE DOSE FROM RADIOPHARMACEUTICAL EXAMINATIONS IN ENGLAND AND WALES

Type of examination	Radio-nuclide	Chemical form	Average administered activity (μCi)	Organ	Collective dose (10^3 man rad)	Annual number of examinations
Brain scan	^{99m}Tc	Pertechnetate	9 500	Stomach	101	44 000
				Thyroid	101	44 000
Liver scan	^{99m}Tc	S-colloid	2 000	Liver	14	20 000
Thyroid scan	^{99m}Tc	Pertechnetate	900	Thyroid	2	10 000
				Stomach	2	10 000
	^{131}I		41	Thyroid	467	4 600
Lung scan	^{99m}Tc	MAA	1 800	Lung	4	8 600
Placental localization	^{113m}In	Chloride	700	Foetus	.040	2 900

Source: Reference 172.

130. Only very little new information is available since the 1972 report on the GSD from radionuclide examinations. The survey in West Berlin has been updated (186) and the GSD in 1970 was estimated to be 0.2 mrad, compared with 0.1 mrad in 1968. The change is primarily due to the increased number of examinations. This is in line with the GSDs reported in 1972 by the Committee, which were in the range 0.01-0.4 mrad.

III. THERAPEUTIC USES OF RADIATION

A. TREATMENT WITH EXTERNAL BEAMS AND SEALED SOURCES

1. General

131. High radiation doses have been used in radiotherapy for the treatment of two major classes of disease, the first being skin and other non-neoplastic diseases, for which radiation doses of up to 1000-2000 rad have been given. The majority of these treatments are for skin diseases, for which a low-energy, fairly non-penetrating radiation has been used.

132. The second class of disease treated by irradiation has been neoplastic disease, which includes all the various forms of cancer and other invasive and malignant diseases. For the treatment of these diseases, radiation doses of up to 6000-7000 rad are given to localized tumours; in the ease of more generalized neoplastic diseases, such as leukaemia, extra corporeal irradiation may be given. These high doses are necessary to cause a destructive effect on the tumour cells. It is inevitable in these treatments thatlarge radiation doses will also be received by some of the healthy tissues lying within the treatment volume or in the path of any of the treatment beams. The seriousness of the primary disease, however, necessitates that little consideration be given to any

deleterious late effects of radiation that might occur many years after a successful treatment. Nevertheless, it is important to obtain estimates of the radiation dose within healthy organs and tissues irradiated in the treatment régime, so that estimates of the frequency of such late effects may be made.

2. Trends in radiotherapy practice

133. In the 1972 report of the Committee it was estimated that in many industrialized countries about one half of the new cancer cases arising each year are treated with radiotherapy and that this proportion does not seem to change appreciably even with the increased use of chemotherapy. Elsewhere, the treatment of cancer will rise in importance as other causes of death such as malnutrition, malaria and tuberculosis are gradually eliminated by the improvement of living conditions and the availability of medical care. These estimates seem to remain valid.

134. For the treatment of non-neoplastic disease, alternative treatment forms not involving radiation have been recommended, and a drastic decrease in the number of such treatments took place in the 1960s (118, 232), which is illustrated by table 42. X rays were regularly used for the treatment of skin lesions, particularly dermatological conditions, in the years 1930 to 1960. Since that time a great reduction in the number of patients treated has occurred and lower tube voltages have been used, meaning less penetration of the beam.

TABLE 42. PERCENTAGE OF THERAPEUTIC IRRADIATIONS PERFORMED IN CONNECTION WITH NON-NEOPLASTIC DISEASE IN JAPAN AND SWEDEN, 1956-1972

Country	*1956*	*1965*	*1970*	*1972*
Japan (118)	72	22	12[a]	10
Sweden (171)	88	49	14	10

[a] Representing 1722 patients.

135. The technological development in radiotherapy equipment over the last 25 years has been aimed at providing radiation beams capable of penetrating adequately to deep-seated tumours and of producing higher dose rates. Thus, orthovoltage x-ray units operating at 250 kV and ^{226}Ra sources used in brachytherapy have been replaced by electron accelerators (4-20 MeV) and telecurie units containing gamma-ray emitting sources such as ^{60}Co with activities of up to 10 kCi. This trend is illustrated by the installation in Sweden of cancer therapy machines (table 43).

TABLE 43. CHANGE IN USE OF RADIOTHERAPHY EQUIPMENT AT ONE LARGE SWEDISH CANCER CLINIC, 1956-1970

	Annual number of treatments	
Year	*Using 250-kV and short-distance ^{226}Ra and ^{60}Co units*	*Using accelerators and telecurie units*
1956	49 582	0
1965	30 145	21 633
1970	11 281	46 941

Source: Reference 151.

3. Dose data in radiotherapy

136. Radiotherapy of non-neoplastic diseases has been reasonably well controlled and recorded. The radiation doses received by the skin of such patients are therefore reliably known. Information about the filters and tube voltages employed is less likely to be available. This is exactly the information required for deducing the penetration of the beam and hence the dose to organs below the irradiated skin surface. These doses will usually be less well known than the dose to the irradiated skin surface. Calculations of doses to an organ outside the direct beam will be less accurate, particularly if there is a possibility that the organ might on occasions be just outside or just inside the main beam. These variations may occur due to slightly different positions of the patient when the treatment is undertaken; for example, irradiation of children for thymic enlargement may have been carried out with the thyroid just in or just out of the beam (88) (see Annex G).

137. The complexity of the treatments and the generally somewhat higher doses delivered for neoplastic disease make careful dosimetric control a necessity, and,

TABLE 44. RADIOTHERAPY OF NON-NEOPLASTIC DISEASE:

	Head and trunk only							
	Children				*Adults*			
	Males		*Females*		*Males*		*Females*	
Condition treated	*Number*	*Mean dose (rad)*	*Number*	*Mean dose (rad)*	*Number*	*Mean dose (rad)*	*Number*	*Mean dose (rad)*
Skin conditions								
Growths	27	14.6	21	10.0	52	4.8	80	7.6
Allergic and inflammatory	10	10.8	13	23.3	201	10.4	230	7.9
Ringworm	5	92.0	1	62.5	2	36.0	–	–
Other	1	49.0	1	5.6	38	6.9	38	4.3
Glandular enlargements	–	–	2	6.2	7	5.5	1	5.9
Ankylosing spondylitis	–	–	–	–	70	83.6	14	59.5
Arthritic and rheumatic	–	–	–	–	23	27.1	29	22.0
Artificial menopause	–	–	–	–	–	–	74	51.5
Deafness	5	9.4	2	8.6	7	3.5	10	3.7
Other non-neoplastic	1	2.6	2	282.0	15	20.9	35	27.6

Source: Reference 37.

Note: The data in this table were produced by a computer programme that was adapted to make an approximate estimate of the bone-marrow dose from small treatment areas which receive high doses.

because of the need to provide a follow-up service, the records of such patients are generally well kept. It is, therefore, reasonably easy to determine the radiation doses to particular organs retrospectively. The potential groups of interest would be composed of patients with long survival after treatment.

4. Information of epidemiological interest

138. The following determinations of dose to given organs have been carried out for epidemiological surveys:

Bone-marrow dose and whole-body integral dose in the treatment of ankylosing spondylitis (39, 107, 269)

Dose to the stomach and pancreas in the treatment of ankylosing spondylitis (14)

Dose to the kidney in patients treated for stomach ulcers (35, 236)

Dose distribution through the head and neck for children treated for tinea capitis (2, 3, 4, 72, 159, 160, 199, 263, 264)

Thyroid dose for children treated for thymic enlargement (88)

Skin dose in patients treated for skin disease and neoplastic disease with rodent ulcers and basal cell carcinoma occurring in the treatment area (9, 237)

Bone-marrow dose in the treatment of metropathia haemorrhagica (45, 210).

139. As leukaemia has been associated with the irradiation of the bone marrow and a number of surveys of patients treated for non-neoplastic disease have reported an increase in the incidence of leukaemia, considerable effort has been made to derive bone-marrow doses. In its 1972 report, the Committee reproduced data from the British survey (37) on bone-marrow doses from treatment of non-neoplastic disease in the years 1957-1958, assessed by measurements and a computer programme (50). Since further information is lacking, these data are again presented in table 44 to illustrate the fact that the mean marrow

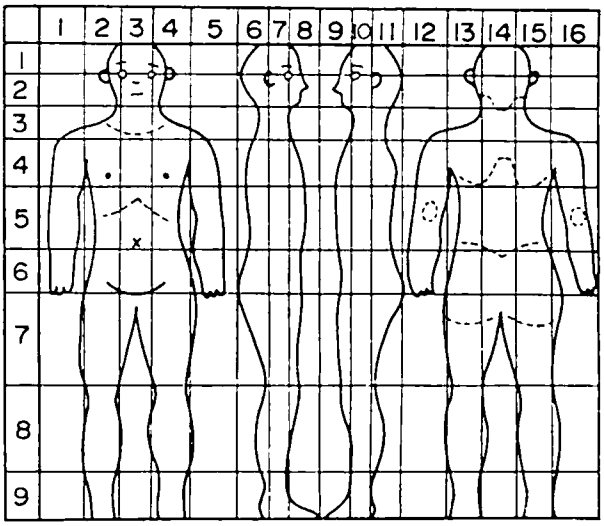


Figure XVI. Grid reference system for defining irradiation position (see tables 45 and 48) (76)

doses may range from less than 1 to nearly 300 rad per treatment course, with values of about 10 rad not being infrequent. Recent measurements and calculations based on depth-dose studies published by Hashizume (76) provide tabular information from which the bone-marrow dose may be calculated for any particular radiotherapeutic treatment. Figure XVI shows the grid reference system used to indicate the particular part of the body that is irradiated. By selecting a particular pair of grid reference numbers in the first two columns of table 45 one can find, for the particular types of radiation given in the other column headings the values of direct plus scatter radiation $M + S$ and of the marrow dose T from the generalized leakage radiation from the source per unit of dose at the skin. These data are useful in that they give the values for 250-kV x rays, ^{60}Co gamma rays, 6-MV x rays and 15-MeV electrons. As predicted in earlier United Kingdom work, the marrow dose per treatment course calculated for 250-kV x rays tends to exceed the bone-marrow dose from any other energy source.

MEAN BONE-MARROW DOSE PER TREATMENT COURSE

All cases							
Children				*Adults*			
Males		*Females*		*Males*		*Females*	
Number	*Mean dose (rad)*	*Number*	*Mean dose (rad)*	*Number*	*Mean dose (rad)*	*Number*	*Mean dose (rad)*
91	4.3	125	1.7	110	2.3	185	3.3
26	4.2	18	16.8	600	3.5	578	3.2
6	76.0	2	31.3	4	18.0	3	18.0[a]
1	49.0	1	5.6	65	4.0	115	1.4
–	–	2	6.2	7	5.5	1	5.9
–	–	–	–	70	83.6	14	59.5
–	–	–	–	33	18.9	42	15.1
–	–	–	–	–	–	74	51.5
5	9.4	2	8.6	7	3.5	10	3.7
1	2.6	2	282.0	23	13.6	37	26.2

[a] Assumed male value in absence of data

TABLE 45. ACTIVE BONE-MARROW DOSE IN ADULTS IN DIFFERENT IRRADIATION CONDITIONS

(mrad per rad at the skin)

Irradiation position[a]		*^{60}Co gamma rays*		*X rays*				*15-MeV electrons*	
				Conventional		*6-MV*			
Vertical number	*Lateral number*	*M + S*	*T*	*M + S*	*T*	*M + S*	*T*	*M + S*	*T*
1	2, 4	290	250	280	30	295	150	200	175
	13, 15	300	370	350	35	305	250	200	180
	14	320	360	370	35	330	250	230	180
	3, 7, 10	295	240	360	30	320	170	230	135
2	2, 4	70	265	95	30	75	180	25	130
	13, 15	70	380	95	40	75	260	25	195
	3	140	305	180	45	150	300	0	105
	7, 10, 14	180	360	220	45	175	340	30	220
3	3, 7, 10, 14	120	385	170	40	125	260	0	195
	1, 5, 12, 16,	25	340	35	30	30	235	0	175
	13, 15	45	450	70	45	50	300	25	220
	2, 4	40	380	55	35	45	265	25	190
4	2, 4	230	505	315	40	235	340	100	260
	13,15	250	560	320	50	255	380	100	300
	3	500	475	710	50	510	315	200	250
	14	750	530	1 200	55	760	350	650	285
	12, 15, 16	120	380	170	40	120	255	20	200
	6, 7, 10, 11	200	300	240	30	205	210	220	170
5	6, 7, 10, 11	260	285	380	30	270	195	0	145
	14	830	345	1 350	55	840	380	105	290
	3	480	425	700	40	485	285	0	220
	13, 15	60	340	85	50	60	365	0	265
	2, 4	65	415	90	40	70	285	0	210
	1, 5, 12, 16	50	385	70	40	55	260	0	190
6	6, 7, 10, 11	330	345	430	30	335	235	230	175
	14	720	595	1 150	60	730	400	95	300
	3	370	475	520	45	375	320	0	230
	13, 15	340	680	490	60	345	320	300	340
	2, 4	160	440	220	40	165	160	30	220
	1, 5, 12, 16	50	385	70	35	50	300	0	170
7	3, 14	70	395	95	40	70	195	0	210
	2, 4, 7, 10, 13, 15	70	290	95	30	70	160	30	150
8	2, 4, 7, 10, 13, 15	1	235	5	25	1	26	0	115
9	2, 4, 7, 10, 13, 15	0	40	0	10	0	0	0	26

Source: Reference 76.

Note: See paragraph 139 for an explanation of the use of this table.

[a] As defined by the grid reference system in figure XVI.

140. The *per caput* marrow dose (CMD) and dose weighted for the incidence of leukaemia (LSD) in the remainder of the patient's life were 206 and 37 mrad, respectively, for the practice in Japan during 1971. Table 46 shows that the contributions to the CMD were about 60 per cent from ^{60}Co units, 30 per cent from accelerators and 10 per cent from conventional x-ray machines. The skin treatment of non-neoplastic disease gives only 1.3 per cent of the total CMD (table 46). The use of the product of the average dose and the number of patients treated is a better measure of the possible detriment to the irradiated group than the *per caput* dose to the whole population. The average bone-marrow dose was 120 rad to the 177 000 patients treated for neoplastic disease and 0.15 rad to the 1 965 000 patients treated for non-neoplastic disease. This latter dose may be compared with the average dose from the treatment of non-neoplastic disease in the United Kingdom in 1957-1958 of 103 rad to the 6000 persons treated (37).

141. The number of patients treated by brachytherapy in Japan (78) in 1974 was 21 650 (table 47a). The population doses are given in table 47b, the CMD and LSD being 43 and 7.7 mrad, respectively.

142. The average doses and the sizes of the patient populations studied in some epidemiological surveys are to be found in Annex G.

5. Genetically significant dose

143. The gonad dose and GSD received from radiotherapeutic practice was given in the 1962 and 1972 reports for a few countries. The GSD from the treatment of non-neoplastic disease ranged from 0.9 to 12.1 mrad; of neoplastic disease, from 0.5 to 2.5 mrad. Recent data by Hashizume (75, 77) are in the form of a tabulation of the gonad dose for different kinds of radiotherapeutic irradiation (table 48). The doses are given in terms of the leakage radiation L and the scattered radiation S per field area of 100 cm^2, and in some cases in terms of the primary beam.

144. The GSD in Japan for 1971 from the treatment of non-neoplastic disease was 0.7 mrad; of neoplastic disease, suitably corrected for the expected number of children in these ill patients, 0.26 mrad. The GSD

TABLE 46. *PER CAPUT* MARROW DOSE (CMD) AND LEUKAEMIA SIGNIFICANT DOSE (LSD) IN JAPAN, 1971

(mrad)

Source	Age (y)	Male		Female	
		CMD	LSD	CMD	LSD
^{60}Co gamma rays	⩽ 14	1.5	0.71	0.93	0.30
	15-29	1.1	0.33	3.2	0.80
	30-44	4.2	0.87	28	5.0
	⩾ 45	20	2.0	70	11.5
	Subtotal	27	3.9	102	18
Conventional x rays (HVL Cu 0.5-2 mm)	⩽ 14	0	0	0.12	0.03
	15-29	0.42	0.10	0.30	0.09
	30-44	0.26	0.04	0.86	0.17
	⩾ 45	1.6	0.12	5.2	0.91
	Subtotal	2.3	0.26	6.5	1.2
Superficial x rays (HVL Al < 2 mm)	⩽ 14	0.37	0.37	0.59	0.59
	15-29	0.19	0.19	0.98	0.97
	30-44	0.03	0.03	0.34	0.23
	⩾ 45	0.019	0	0.15	0.04
	Subtotal	0.61	0.59	2.1	1.8
High-energy x rays (4-30 MV)	⩽ 14	0.74	0.36	0.72	0.19
	15-29	0.37	0.13	4.0	0.83
	30-44	1.2	0.25	8.0	1.6
	⩾ 45	7.0	0.62	35.6	5.9
	Subtotal	9.3	1.36	48.4	8.5
High-energy electrons (8-35 MeV)	⩽ 14	0.33	0.29	0.10	0.04
	15-29	0.007	0.004	0.21	0.13
	30-44	0.26	0.051	0.60	0.19
	⩾ 45	5.5	0.14	1.5	0.38
	Subtotal	6.0	0.48	2.4	0.74
	Total	45	6.6	161	30

Source: Reference 76.

TABLE 47a. POPULATION DOSE FROM BRACHYTHERAPY IN JAPAN, 1974

Number of patients by sex, age, radiation source and source position

	Male	Female	Total
Age (y)			
⩽ 14	400	1 320	1 720
15-29	180	460	640
30-44	560	3 240	3 800
⩾ 45	1 720	13 770	15 490
Radiation source			
^{226}Ra	1 120	9 780	10 900
^{222}Rn	280	210	490
^{137}Cs	160	1 400	1 560
^{60}Co	260	5 910	6 170
^{90}Sr	1 040	1 490	2 530
Source position			
Mouth	1 590	1 000	2 590
Maxilla	70	270	340
Neck	70	70	140
Breast	40	110	150
Cervix	–	13 000	13 000
Femur	40	0	40
Other	1 050	4 340	5 390
Total	2 860	18 790	21 650

Source: Reference 78.

contributions from treatments by various types of apparatus and by age group are given in table 49, and the distributions by age for neoplastic and non-neoplastic diseases are given in table 50. The GSD from brachytherapy in 1974 was estimated to be 0.012 mrad (table 47) (78).

145. The GSD from the treatment of non-neoplastic disease in the region of Munich (Federal Republic of Germany) has been estimated. One report (198) estimates that the contribution to the GSD in clinics is 0.4 mrad, and the other (197) estimates that the contribution in private practice is 0.2 mrad. These

TABLE 47b. POPULATION DOSE FROM BRACHYTHERAPY IN JAPAN, 1974

GSD, CMD and LSD by sex and age

	GSD (10^{-3} mrad)		*CMD (mrad)*		*LSD (mrad)*	
Age (y)	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*
⩽ 14	10.7	1.033	0.077	0.120	0.075	0.119
15-29	0.003	0.155	0.415	0.144	0.088	0.081
30-44	0.465	0.001	6.390	0.100	1.327	0.031
⩾ 45	0	0.001	33.280	2.724	5.469	0.493
Subtotal	11.178	1.190	40.149	3.088	6.959	0.724
Total	12.4		43.2		7.7	

Source: Reference 78.

TABLE 48. GONAD DOSE IN ADULTS IN

(mrad per rad

				X rays			
		^{60}Co gamma rays		*HVL 1.5 mm Cu*		*HVL 1.0 mm Al*	
Irradiation position[a] (V-L)	*Sex*	L	S	L	S	L	S
4-2	M	0.75	0	0.08	0	0.04	0
	F	0.55	0.01	0.04	0	0.01	0
6-2	M	1.2	0.06	0.07	0.13	0.05	0.07
	F[b]	420	1.3	125	2.4	12	0.25
7-3	M[b]	960	0.03	820	0.25	800	0.2
	F	1.0	0.11	0.03	0.25	0.05	0.14

Source: Reference 75.

Note: L = leakage radiation; S = scattered radiation.

[a] See figure XVI.

[b] The values in this line are the gonad doses due to the primary beam (of zero area).

TABLE 49. GENETICALLY SIGNIFICANT DOSE IN JAPAN, 1971

Breakdown by source, age and sex

(mrad)

Source	*Age (y)*	*Male*	*Female*	*Total*
^{60}Co gamma-ray units	⩽ 14	0.047	0.046	
	15-29	0.088	0.018	
	30-44	0.030	0.011	
	⩾ 45	0.000	0.000	
	Subtotal	0.17	0.075	0.245
Conventional x-ray units (HVL 1.5 mm Cu)	⩽ 14	0.000	0.010	
	15-29	0.013	0.000	
	30-44	0.002	0.000	
	⩾ 45	0.000	0.000	
	Subtotal	0.015	0.010	0.025
Superficial x-ray units (HVL 1.5 mm Cu)	⩽ 14	0.030	0.31	
	15-29	0.002	0.34	
	30-44	0.001	0.002	
	⩾ 45	0.000	0.000	
	Subtotal	0.033	0.65	0.683
High-energy x-ray units (4-30 MV)	⩽ 14	0.003	0.007	
	15-29	0.011	0.004	
	30-44	0.000	0.000	
	⩾ 45	0.000	0.000	
	Subtotal	0.014	0.011	0.025
High-energy electron accelerators (8-35 MeV)	⩽ 14	0.000	0.000	
	15-29	0.000	0.000	
	30-44	0.000	0.000	
	⩾ 45	0.000	0.000	
	Subtotal	0.000	0.000	
	Total	0.23	0.75	0.98

Source: Reference 75.

TABLE 50. GENETICALLY SIGNIFICANT DOSE IN JAPAN, 1971

Breakdown by type of disease, age and sex

(mrad)

	Male		*Female*	
Age (y)	*Non-neoplastic*	*Neoplastic*	*Non-neoplastic*	*Neoplastic*
⩽ 14	0.041	0.039	0.31	0.061
15-29	0.006	0.097	0.34	0.022
30-44	0.001	0.029	0.002	0.011
⩾ 45	0.000	0.000	0.000	0.000
Total	0.048	0.17	0.65	0.094

Source: Reference 75.

estimates may be compared with the 1961 estimate by Holthusen *et al.* (94), which was 2.2 mrad from both clinic and private practice.

B. THERAPEUTIC USES OF RADIOPHARMACEUTICALS

146. The therapeutic use of radiopharmaceuticals is mainly restricted to the use of ^{131}I for the treatment of hyperthyroidism, heart disease and thyroid cancer and the use of ^{32}P for the treatment of polycythemia vera. In the 1950s and early 1960s, colloidal solutions of ^{198}Au were used for serious pleural and peritoneal effusions and the patients concerned usually had limited prognosis. However, the use of this form of treatment has mainly been discontinued. The frequencies of treatments reported in West Berlin in 1970 and 1975 (93), in Sweden in 1974 and 1969 (151) and in the United States in 1966 (248) are given in table 51.

1. Iodine-131 therapy for hyperthyroidism and heart disease

147. The main use of ^{131}I therapy is for the treatment of hyperthyroidism; in the United States in 1966 (248), about three quarters of all patients treated with ^{131}I were in this category. The administered activity is usually in the range 2-10 mCi and sometimes repeated

DIFFERENT IRRADIATION CONDITIONS

at the skin)

				Electrons			
20-MV		*8-MV*		*25-MeV*		*15-MeV*	
L	S	L	S	L	S	L	S
0.3	0	0.15	0	0.05	0	0.04	0
0.2	0	0.1	0	0.03	0	0.02	0
0.4	0	0.2	0	0.1	0	0.04	0
750	0.02	650	0.04	400	0.24	0.04	0
780	0	720	0.03	1 000	0	1 000	0
0.3	0.03	0.2	0	0.1	0	0.06	0

administrations are given. A thyroid dose of about 4000 rad is often used as the treatment objective. The bone-marrow dose per unit of administered activity received has been estimated as 1.7 rad mCi^{-1} (68) and the gonad dose as 0.45-0.6 rad mCi^{-1} (19). For the treatment of heart disease, the activities are usually about 25 mCi, with similar bone-marrow and gonad doses per unit of administered activity.

148. Surveys were made by Pochin (167), Saenger (194) and Werner *et al.* (262) in populations of 59 000, 36 000 and 32 000 patients, respectively, who had received ^{131}I for the treatment of thyrotoxiosis. Typical mean bone-marrow doses of 7-15 rad had been received. The approximate total collective dose to the bone marrow in these three series would therefore be 1.4 10^6 man rad, assuming a mean dose to the bone marrow of 11 rad.

2. Iodine-131 therapy for cancer of the thyroid

149. For the treatment of cancer of the thyroid, a very high initial activity, often about 200 mCi, is administered. Subsequently, in order to suppress any further thyroid activity or to destroy any metastatic spread of the cancer, further administrations are given, often of the order of 100 mCi. Because these subsequent centres have very little uptake, most of the administered activity is excreted in the urine. The initial dose to the bone marrow per unit of administered activity is 1.7 rad mCi^{-1} (130), but subsequent administrations will give lower doses (169).

TABLE 51. RECENT SURVEYS OF THE FREQUENCY OF THERAPY WITH RADIOPHARMACEUTICALS

(Number of treatments per 1000 of population)

Radio-pharma-ceutical	*Disease treated*	*West Berlin*		*Sweden*		*United States*
		1970	*1975*	*1969*	*1974*	*1966*
^{131}I	Thyroid diseases	0.172	0.132	0.235	0.294	0.127
^{32}P	Polycythemia vera	0.011	0.015	0.031	0.038	0.017
Other		0.097	0.113	0.011	0.012	0.028
	Total	0.28	0.26	0.28	0.34	0.17

Sources: References 93, 151, 248.

150. Pochin (168) has reviewed a group of 215 patients who had been treated for inoperable thyroid carcinoma during the period 1949-1967. The group was studied in relation to the subsequent cancer risk. The collective dose to the bone marrow in the group was 27 000 man rad. It should be noted that cancer of the thyroid can be treated successfully, and patients often survive many years after the first treatment.

3. Polycythemia vera patients treated with ^{32}P

151. The treatment of polycythemia vera consists of repeated administrations of ^{32}P over a period of years at

activities of 4-8 mCi. The bone-marrow dose is 30 rad mCi^{-1} for intravenous administration. The gonad dose is in the range 2.6-7.0 rad mCi^{-1} (133). High mean bone-marrow doses of the order of 600 rad per treatment may be received (34, 214).

152. Modan and Lilienfeld (145) show that the collective dose for such patients treated by ^{32}P is sufficiently high to make epidemiological studies interesting. Of an original series of 1222 cases, 228 were treated by ^{32}P. The collective dose to the bone marrow for the group of 228 cases was 132 750 man rad.

153. Details of further studies are contained in Annex G.

IV. WASTE DISPOSAL OF MEDICALLY USED RADIOPHARMACEUTICALS

154. Much of the short-lived activity incorporated in radiopharmaceuticals used in a diagnostic investigation decays either before or during the investigation, and only a small fraction of the total activity is eventually disposed of as waste. The principal route of disposal is as liquid waste. However, therapeutically used radiopharmaceuticals do provide a substantial source of waste activity, particularly in the treatments using ^{131}I. In the case of treatments for hyperthyroidism, some 30 per cent of the activity may be released in the urine. Following the first treatment of a cancer of the thyroid, some 50-60 per cent of the administered activity (about 100 mCi) will be excreted in the urine. Further treatments, particularly of metastases, lead to the excretion of about 90 per cent or more of the administered radioactive iodine. In some countries the urine from such patients is not stored but is released as liquid waste into the sewers.

155. Few countries have complete records of the activity released to the sewers from medical establishments. The total activity administered to the patients may be used as an upper estimate. In Denmark, the total use of radionuclides has risen from 181 Ci in 1970 to 298 Ci, in 1974 (220), the total activity remaining after one year being 48 Ci and 15 Ci, respectively. The total use of ^{131}I has remained steady at about 20 Ci per year. By using the frequency data in the Danish report (53) and assuming that on the average 5 mCi of ^{131}I was used in each hyperthyroid treatment and 200 mCi in each cancer patient, one can account for about 13 Ci of ^{131}I, of which about 8 Ci would probably be excreted as urine into the sewers.

156. It is difficult to estimate the radiation doses received by the public from such releases. However, the families of the patients would be those who would be at greatest risk, and they would also receive a radiation dose directly from the activity remaining in the patient. Estimates of this dose have been made by Stieve and Kaul (227).

V. CONCLUSIONS

157. Diagnostic radiology in many technically developed countries has been growing at a rate between 5 and 15 per cent per year. Because of increasing medical requirements, the growth rate in developing countries is likely to be greater. The use of radiopharmaceuticals for diagnostic purposes has been expanding rapidly over the last decade, and many countries are reporting a doubling of the number of tests every three to five years. Radiotherapeutic practice indicates that less treatment is being carried out for non-malignant conditions using radiation, while treatment for malignant conditions is now primarily carried out using high-energy radiation from accelerators or teletherapy units.

158. Considerable information is now available on radiation doses to the skin and the gonads received in individual x-ray examinations, while the knowledge about doses to bone marrow and some other organs is currently expanding. Further information is still required, however, particularly in the case of specialized examinations. With this further knowledge it will be possible to assess the detriment that may be associated with such examinations. Consideration would then have to be given to the basis for the comparison of the benefits that are received by a patient with the estimated detriment.

159. A satisfactory amount of information is now available regarding the radiation doses to organs received during investigations involving the use of radiopharmaceuticals. In general, these doses to particular organs are of the same order or smaller than those incurred during x-ray examinations of the same region or function.

160. Published recommendations of a number of national and international bodies have made available useful information about methods of reducing radiation doses to patients, but the implementation of these recommendations is not yet universal. There is a need to encourage the estimation of the radiation doses received by organs during medical radiological procedures as a means of identifying those practices likely to give rise to high patient doses.

161. Studies of the frequency of examinations should be combined with studies of organ doses to provide collective dose estimates for each technique and investigation. Collective doses may then be used to assess relative detriments, with some limitations due to the range of individual doses, the age group and the effects under consideration. Suggestions as to possible groups of patients that may be at greater risk have been made on the basis of the known radiation doses, and further studies of this type would be of particular interest for epidemiological research.

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