IONIZING RADIATION: LEVELS AND EFFECTS

A report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, with annexes

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NOTE

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Annex B

DOSES FROM MEDICAL IRRADIATION

CONTENTS

Introduction

1. The population exposure due to the medical uses of ionizing radiation and of radio-isotopes was last reviewed by the Committee in its 1962 report (148). The present annex summarizes the information published therein and reviews the data that have since become available on radiation exposure from diagnostic x-ray examinations, from x- and gamma-ray therapy and from the diagnostic and therapeutic use of radio-active materials prepared for administration as radio-pharmaceuticals or used as sealed sources.

2. For each of these types of exposure, the following aspects have been considered:

(*a*) The number of examinations carried out in various centres and the gonad and genetically-significant doses arising from them;

(*b*) The mean bone-marrow dose (see however paragraphs 11 and 73);

(*c*) The skin dose from the various x-ray examinations or the dose to the organ of reference in the case of radio-pharmaceuticals.

3. The data are presented and analysed so as to identify and assess the trends currently developing in medical radiology and to suggest the epidemiological studies to which particular groups of patients may lend themselves. This requires determining the procedures that contribute significantly to population doses and the effects that changes in radiological practice or technical advances will have on the magnitude of the radiation doses.

4. A number of groups of patients have already been identified as receiving high doses, and some of them have been shown to have an incidence of certain diseases higher than in comparable but non-irradiated groups. Similar groups of patients may be identified as a result of particular radiation dose surveys. For example, guided by the findings of the British survey of medical irradiation (25), Doll and Smith (33) studied women in whom artificial menopause had been induced for the treatment of metropathia and showed an incidence of leukæmia about four times as high as that in the control group.

5. The annexes of previous Committee reports (147-149) and annex H of this report contain the results of studies on other groups of patients exposed for medical reasons to x-rays and radio-active materials who were studied to determine the incidence of long-term effects of radiation. These include studies of patients undergoing diagnostic examinations:

(*a*) Children irradiated *in utero* (139-141);

(*b*) Patients investigated using thorium products as a contrast medium (46, 88); and

(*c*) Patients receiving multiple fluoroscopic examinations of the chest (85).

The following groups of patients, who have undergone radio-therapy, were also investigated:

(*a*) Ankylosing spondylitis;

(*b*) Children receiving thymic irradiation;

(*c*) Patients treated for metropathia (33);

(*d*) Patients treated for cancer of the breast (1);

(*e*) Patients having stomach ulcers (23, 145);

(*f*) Children irradiated for ringworm (150);

(*g*) Children treated for retinoblastoma (125);

and so were two groups of patients treated with radiopharmaceuticals:

(*h*) Patients treated with ^{131}I for hyperthyroidism (136);

(*i*) Patients treated with ^{32}P for polycythæmia vera.

6. All radiological procedures carried out on patients involve a certain degree of risk of harm which must be balanced against the value of the procedure to the patients' state of health.

7. *Genetically-significant dose.* The same definition of the *genetically-significant dose* (GSD) given in the 1958 (147) and 1962 (148) reports of the Committee will be used here. The GSD is "the dose which, if received by every member of the population, would be expected to produce the same total genetic injury to the population as do the actual doses received by the various individuals". This annual dose is the weighted population dose commitment from a year of radiological practice. It is delivered at a rate considerably higher than that of any other dose commitment received by the population from other sources.

8. The definition of GSD is based on the following assumptions and considerations that will not be discussed here but are considered in greater detail in annex E:

(*a*) The relevant tissue dose is that accumulated to the gonads;

(*b*) The dose-effect relationship is linear without threshold:

(*c*) The rate of delivery of radiation can be neglected:

(*d*) Differences in sensitivity of the gamete with age and sex are ignored.

9. The appendix to this annex gives the formulæ used to obtain the GSD from the frequency of the particular examination in a certain age group of the population, the corresponding gonad doses and the appropriate weighting factors that take into account the child expectancy of the individual, relative to the average child expectancy in the population. It is important to appreciate that many of the individuals examined may have life and child expectancies quite different from the population average, because of the effect that the diseases for which they are being examined have on these expectancies.

10. *Mean marrow dose.* Observations on the induction of leukæmia in the survivors of nuclear explosions, in patients treated with radio-therapy, and in children irradiated *in utero* have indicated a strong correlation between the incidence of leukæmia and the mean dose received by the whole body or by the active bone marrow. If it is assumed that active bone marrow is uniformly sensitive and that the relationship between frequency of leukæmias and dose is linear, doses to any part of the bone marrow can be averaged over the whole bone marrow and the whole population to give a *per caput mean marrow dose* (CMD).

11. Certain limitations in our present knowledge should, however, be indicated:

(*a*) While the induction of leukæmia appears to be associated with irradiation of the active bone marrow, neither the mechanism of induction nor the specific cells, or cell stages, at risk are known;

(*b*) There is very little quantitative information on the distribution of bone marrow in the skeleton, the relative proportion of active relative to fatty bone marrow in the various bones and the variations of these proportions with age. Most observations have been only qualitative in nature and all the numerical information on the total marrow distribution is based on the 13 cadavers investigated by Mechanik (91) in the 1920s and the recent work of Hashimoto (54, 58, 95) on 10 Japanese cadavers. In this review it is assumed that the whole marrow is active in children and that the active-marrow distribution at age 40 applies to all adults (paragraph 75);

(*c*) The relevance of the concomitant irradiations of the 700 grammes of lymphocytes in the body is unknown;

(*d*) The effect of partial irradiation of the bone marrow may be quite different biologically from a uniform dose to the whole marrow in view of the protective and regenerative capacities of unirradiated tissue. The quantitative importance of this effect is unknown in regard to the incidence of leukæmia following irradiation in man, although it has been thoroughly demonstrated in animals.

12. The mean marrow dose to an individual i from a certain exposure j of a given type of examination x may be calculated as the average dose to the whole of the active marrow

$$d_{Mijx} = \frac{1}{W_i} \int d_{jx} \Delta w$$

where Δw is the mass element and W_i the total mass of the individual's active marrow. If the examination type x comprises k_x exposures and involves N_x patients of a total population of N individuals, the *per caput* mean marrow dose (CMD) in that population is

$$D_{Mx} = \frac{1}{N} \sum_{i=1}^{N_x} \sum_{j=1}^{k_x} d_{Mijx}$$

13. In practice the individual mean marrow dose d_M may be derived from the following relationship

$$d_{Mijx} = \sum_r \left(\frac{m}{M}\right)_r (f_s d_s)_r$$

where d_{Mijx} is averaged over the total active marrow M by summing for each fraction of marrow exposed r, the product of the fraction of active marrow exposed m/M, the fraction of the dose to the skin reaching the element of marrow f_s, and the actual skin dose d_s.

14. In a survey conducted in Japan (58) a weighting factor was applied to the calculation of the bone-marrow dose to give a "leukæmia-significant" dose. The weighting factors were based on the fact that the incidence of leukæmia in the population exposed to the nuclear explosions at Hiroshima was a function of time after exposure (paragraph 76).

15. *Radiation quantities.* In the original papers referred to in this review, various radiation quantities have been used, namely, exposure, absorbed dose, and dose equivalent. For the sake of consistency these will be converted throughout to absorbed dose on the basis of an absorbed dose of one rad corresponding to an exposure of one roentgen and to a dose equivalent of one rem. For gonad-dose measurements in the range of qualities used in diagnostic radiology, some investigators (57, 118, 119) have used a conversion of about 0.94 rad per roentgen.

16. The dosimetry of the radiation absorbed in the bone marrow is made complex by the need to take into account the fact that the marrow is enclosed in the spaces between bone trabeculæ. Both the distribution of the sizes of these spaces and the thickness of the trabeculæ vary in the various parts of the skeleton. The average dose to the marrow at any given site will depend on the number and energy of the photo-electrons emitted from the bone trabeculæ and, therefore, on the quality of the radiation used. A conversion factor from roentgen to rad units must be based on a particular model of marrow distribution and will be a function of radiation quality. Such factors have been used in some of the bone-marrow dose surveys (25, 58).

I. Diagnostic x-ray examinations

A. Growth of diagnostic radiology

17. The growth of diagnostic radiology must be considered in relation to the changes in its contribution to population exposure. The factors affecting the total growth are:

(*a*) The number of examinations of each type being carried out;

(*b*) The types of procedure being carried out;

(*c*) Changes in the complexity of the procedures; and

(*d*) Changes in the technical facilities available, viz. the use of image intensification, cine procedures and biplane apparatuses.

However, the changes in the GSD and the CMD will also depend on whether the doses received by the patient during the particular procedures increase or decrease. The awareness of the radiological staff of the importance of the protection of the patient is probably the greatest factor in the control of population exposure.

18. The over-all increase in the number of radiological examinations has been assessed as 4 per cent per year in New Zealand (1959-1963) (156), 6 per cent per year in Sweden (1965-1969) (152), 2 per cent per year in the United Kingdom (1958-1961) (99), whereas (21, 106) the increase was a little over 3 per cent per year in the United States during the 1960s. These figures, however, include the effect of increasing population. When this is excluded, the rate of examination appears to have increased about 3 per cent per year during the 1960s. A useful study in the United States (60) illustrates the changes in frequency and age distribution of 10 diagnostic radiation categories over the years 1963, 1966 and 1968. This survey was carried out in 228 general hospitals having patients staying for short periods. The average annual observed increment for each of the 10 categories was 1.7 per cent and the total annual increment was approximately twice this value. This study emphasizes the need to study over a period of years the variation in the age-specific frequency of a particular examination and the changes in the over-all pattern of diagnostic investigations, such as may be due to the increasing popularity of a particular examination. Such studies have been recommended by the World Health Assembly (122) to Member States and relevant data are included in the report of an expert committee on the medical uses of radiation (157).

19. *Services in developing countries.* Valid statistics from developing countries are not currently available but every indication shows that there is a great difference between the facilities provided in such countries and those available in the more technically advanced countries. Therefore such services need to be expanded with appropriate emphasis given to modern techniques and good patient protection (77). In developing countries, x-ray facilities are often only available in the main cities and even in industrialized countries there are often large but sparsely populated areas where such services are very limited. It is likely that a large proportion of the world population does not have easy access to modern x-ray facilities. It is obvious, therefore, that the rates of increase quoted in paragraph 18 are relevant only to countries in which a highly sophisticated medical care system is already in existence. In countries in which medical care and preventive medicine are not as developed, the rate of increase is expected to be many times higher during the next decade.

B. Limitations of radiological surveys

20. The design of surveys for the estimation of the GSD or of the CMD received by a particular population was considered by the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) in 1955 (42) and 1959 (43) and involves the consideration of the following factors:

(*a*) The method of obtaining the data on the frequency of examinations and the size of the sample required for that purpose;

(*b*) The selection of the number of patients for whom doses are to be measured or estimated and the choice of centres at which this is to be done;

(*c*) The actual method of measuring or estimating the dose for each type of examination. Since examinations may involve a number of irradiated fields of differing area, focal skin distance and radiation quality, sufficient numbers must be studied to constitute a reliable average of each type of examination, particularly for those that make the greatest contribution to the GSD or the CMD;

(*d*) For the estimation of the GSD, the expectation of subsequent parenthood according to age within each group of patients undergoing a particular type of examination; and

(*e*) For the estimation of bone-marrow doses, the distribution of the active bone marrow.

21. Each of the above parameters introduces into the final result some sampling error the magnitude of which will decrease as the size of the sample increases. On the other hand, a systematic bias towards lower doses may result from the presence of an observer or from the foreknowledge of the subsequent dose estimation. An analysis of these factors is given in the following paragraphs.

1. *Frequency of examinations*

22. It is important to determine with the greatest accuracy the frequency of those examinations which can be judged to make the greatest contribution to the population dose. The frequency of such examinations may be low. For example, in the 1957-1958 British survey (26), obstetrical abdomen examinations contributed 24 per cent of the GSD though their frequency was only 0.6 per cent of the total yearly examinations. The main problem in comparing frequencies from one country with those from another is that the actual procedures may be considerably different for examinations similarly defined.

23. Two basic approaches have been used. The vast majority of the surveys have entailed the collection of the over-all numbers of examinations in age classes from all, or a known fraction of, hospitals, clinics and private practices over a given period of time. This period has varied from a few days to 18 months. Typical values of the percentage of the total year's work in these samples are 40 per cent in the Netherlands (14), 8 per cent in Finland (67), 6.4 per cent in Czechoslovakia (80), 3.5 per cent in New Zealand (156), 2.5 per cent in the United Kingdom (26) 1957-1958, and 2 per cent in Sweden (82). The numbers of persons undergoing examination in the radiological departments included in these surveys have been very large and typical values are 254,000 in Czechoslovakia (80), 143,000 in Finland (67) and 40,000 in New Zealand (156).

24. The second method which was utilized in the United States 1964 survey (106), depends on the selection of householders by a multistage design that permits a continuous sampling of the civilian population. After house-to-house interviews of some 31,000 people, about 3,600 of the 4,500 people who had been radiographed in the past three months were traced. Forty per cent of these, however, had been radiographed for dental examinations. About 2,200 people, therefore, provided the data on the frequency of examinations in radiological department, representing some 0.002 per cent of the radiology carried out in the United States in one year. In 1970, the United States repeated the national survey using the same methodology that was employed in the 1964 survey except that they doubled the sample size so that over 67,000 persons were interviewed in the household interview survey (21).

25. The consumption of x-ray film per year is not in itself a reliable method for estimating GSDs, because for a given film size used at a particular site, the gonad dose will depend on whether good or bad practice is followed. However, within any one institution, film consumption will follow seasonal variations in the frequency of examination as long as changes in techniques, such as the replacement of conventional radiography by photofluorographic methods, do not take place. The consumption of film by month or quarter has been used in a number of surveys (26, 80), in relation to the number of examinations carried out during a sample period of the year, to obtain the yearly number of examinations.

2. *Selection of patients or centres*

26. The hospitals and clinics at which the measurements of gonad doses or the collection of exposure data are to be carried out are usually selected on the basis of their size and geographical location. In some surveys, however, only one or a few centres were utilized and this obviously is likely to have biased the results since the particular hospitals selected were usually the largest or leading ones in the area surveyed and hence can be expected to have a higher standard of radiological practice and of patient's protection than is common in the area. In a number of surveys no measurements were carried out and values of gonad doses published in the literature were utilized. In the United States in both the 1964 and 1970 surveys (21, 106), the centres themselves supplied exposure data on the patients selected in the frequency survey.

3. *Gonad-dose measurements*

27. The need to establish reliably the mean gonad dose per examination is obvious. However, for any one type of examination, the effort should be proportional to the contribution of the examination to the total dose. The difficulty, as far as sample surveys are concerned, is that, by altering the position of the edge of the beam by a few centimetres, the gonads of the patient may be just in or just out of the beam. This can change the gonad dose by a factor of ten or a hundred (100). Similarly, the use of gonad shields greatly reduces the gonad dose when the gonads are in the direct beam.

28. The determination of gonad doses may be direct or indirect. Direct measurements of male gonad doses with the dosemeter in contact with the scrotum have been made in a large number of surveys. A few surveys (119, 132) have made measurements of female gonad doses by placing dosemeters in the vagina or rectum but most surveys have relied on an abdominal skin measurement during an examination of female patients and converted it by phantom measurements to an ovary dose. In one survey (69) a multiple regression method was utilized for the conversion. In the indirect method of gonad-dose determination used in the United States for both the 1964 and the 1970 surveys (21, 106), the radiological centre returned the exposure factors together with an exposed film providing the appropriate field size and radiation quality. The data were then used in phantom experiments to derive the gonad dose.

29. The objection to the direct method is that the presence of the observer may tend to make staff use optimal operational discipline and be more aware of whether the gonads are in the beam or not. The indirect method, on the other hand, is retrospective by at least three months, and staff cannot state accurately the exact field size or precisely where the film was applied.

30. Typical numbers of actual gonad dose measurements made in the large surveys are 10,000 in Czechoslovakia (80), 3,800 in New Zealand (156),

2,200 in Yugoslavia (94) and 1,700 in Bavaria (132). Measurements of the gonad doses during examinations of children are of particular interest as there are only a few surveys which have taken these into account. When careful techniques are used, the gonad doses are smaller than those for adults. Children's gonad doses are given in a number of reports (26, 58, 134). The measurements reported in Thailand (119) are of interest since they not only reflect the result of good radiography but also show how the smaller size of the patients requires reduced exposure factors resulting in lower skin, and therefore lower gonad, doses, as long as all other factors remain constant. Several hundred measurements for a single type of examination usually give reliable distributions of doses per examination. In the Czechoslovak survey (80) the geometric mean rather than the arithmetic mean was used to correct for the small size of some samples.

31. A completely different method of dosimetry has been used in the Johns Hopkins survey (97) in the United States. The dosemeter used consisted of a transmission ionization chamber fitted close to the x-ray tube portal in the primary beam. The reading of such a chamber was, for any exposure, proportional to the integral of the area of the beam at the x-ray tube diaphragm multiplied by the exposure in roentgens, and was therefore proportional to the radiation energy projected onto the patient. This measurement was made for a large number of patients. To derive the gonad dose from such a reading of projected radiation energy, the fraction of the radiation energy falling on to the abdomen was determined for each examination type. There are difficulties and inaccuracies in translating these measurements into actual gonad doses.

4. *Child expectancy*

32. In the calculation of the GSD it is required to know (see appendix) (*a*) the child expectancy by sex and age of the patients that undergo each particular type of examination and (*b*) the child expectancy of the general population, also by age and sex. Data of the first type are practically unobtainable except for a few examinations on which details are given in paragraphs 35-38. In the absence of such data, most surveys have had to assume that the child expectancy of the patient of a given age and sex is equal to the child expectancy of the average person in the population of the same age and sex. These latter child expectancies are obtained from national statistics and representative examples of them are given in table 1 for Czechoslovakia (80), Thailand (119), and New Zealand (118).

33. The values for all European countries and Japan are similar to those from Czechoslovakia; the Thailand values are probably representative of South East Asia, and the United States values are similar to those from New Zealand. The New Zealand data in table 1 are given for four periods and indicate that child expectancy is changing with time. Such changes in absolute values of child expectancy do not make as much difference in the GSD as at first might be anticipated because the same value of the indices appears in both the numerator and denominator of the formulæ for the calculation of the GSD of each irradiated person. The exception to this is in the irradiation of the fœtus. In this case the indices in the numerator will apply to the fœtus and those in the denominator to the mother. Hence any absolute change in child expectancy will be reflected in the contribution from the fœtal exposure to the GSD due to the particular examination.

34. In the New Zealand survey (118) the child expectancy in various age groups has been expressed as a percentage of the remaining child expectancy at various ages. The probit plot of figure I shows that this percentage follows a log-normal distribution and that the values derived from Norway and Sweden lie on the same line as those from New Zealand. This may not be so, however, for countries with very different demographic structures.

35. Several surveys have utilized specific data for the child expectancy of patients undergoing hysterosalpingography and for pregnancy examinations. A sur-

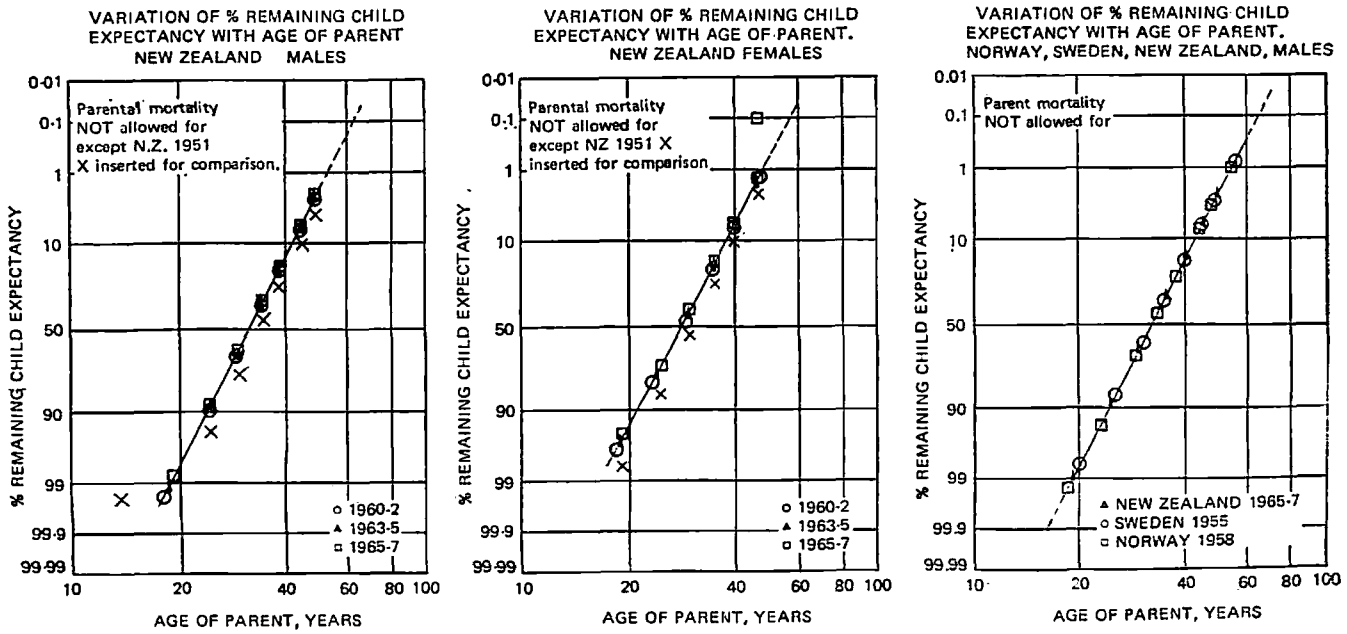


Figure I. Variation in child expectancy with age of parent (118)

vey in Brno, Czechoslovakia (80), followed up 700 women who had had hysterosalpingography examinations and showed that 25 per cent of them gave birth to live children after the examinations. This factor of 0.25 was applied to the average population statistics for the particular age class. Other surveys used different factors—0.5 in the Netherlands (14), Sweden (82), and Texas (27), and 0.1 in the United Kingdom (26).

36. For examinations connected with pregnancy, several surveys have utilized as the expected number of offspring the average population statistics for the particular age class concerned less 1 (or less 0.99) in recognition of the fact that the fœtus must be considclass was derived which also resulted in a considerable ered separately with its own child expectancy. In the Dutch survey (14) a more detailed relationship by age reduction in child expectancy. It is doubtful whether this type of correction is appropriate, for it may be argued that a woman in a particular age class who is currently pregnant is more likely, rather than less likely, to have more children than the average woman in the population of that age class. This was confirmed in a survey based on the 1951 British census (98) which showed the following expectations in the different age classes:

Age class (years)	*Child expectancy*	
	Now pregnant	*Average in population*
15-19	2.78	2.207
20-24	2.23	1.733
25-29	1.84	1.017
30-34	1.60	0.462
35-39	1.47	0.157
40-44	1.38	0.030

37. A correction (9 per cent) for multiple pregnancies, twins, etc. was included in the British survey (26), as multiple pregnancy is one of the clinical indications for x-ray examination. The correction increased the number of offspring per pregnancy x-ray examination by 9 per cent.

38. The contribution from fœtal irradiation during examinations not apparently connected with pregnancy, or before the pregnancy was determined, was assessed in some surveys on the basis of the number of women in the population that are pregnant at any given time. This was estimated to be 6 per cent in Finland (67) and 9 and 3 per cent in the 15-29 and 30-49 age groups, respectively, in the United Kingdom (26). In New Zealand (156) the same contribution varied with age as follows:

Age group (years)	*Percentage pregnant at any one time*
15-19	3.59
20-24	19.70
25-29	20.22
30-34	11.95
35-37	5.84
40-44	1.72
45-49	0.12

In the Netherlands (14), however, a further correction factor of ⅔ was applied to take into account the reluctance of clinicians to request x-ray examinations of pregnant women.

C. Genetically-significant dose

1. *Description of surveys*

39. The 1962 report gave detailed information on surveys carried out in 12 countries or districts. The resulting GSD due to diagnostic radiology ranged from 7 to 56 millirads. These surveys were carried out during the period 1950-1961 but most of them during the last five years of that period. A summary of the results is given in table 2 which is abstracted from the 1962 report of the Committee (annex G, tables I, XVII, XXI).

40. Since 1962, a considerable number of investigations in other countries and large districts have been reported. The results of these surveys are given in table 3 and the details of each study in paragraphs 47 to 59. The GSDs range from 5 to 75 millirads and are therefore similar in magnitude to those reported in the previous decade.

41. The frequencies of radiographic examinations per year excluding mass surveys of the chest, given in tables 2 and 3 are plotted in figure II against the year of survey. This figure gives an over-all impression of the variation in the numbers of radiographs carried out in different areas of the world but attention must be drawn to the fact that different diseases and radiological techniques will alter the relative contribution of any one procedure to the over-all frequency of examinations. However, comparisons within any one country or region will be a reasonably valid indication of the growth of radiological services. Examples of this are given by the curves for New Zealand (156) and the United Kingdom (99) in figure II.

42. The frequency of radiological examinations in some industrialized countries is about one examination per person per year. From the GSDs reported in tables 2 and 3 and the annual frequency of radiological examinations in figure II a projection of the GSD has been made for each country or region assuming that the practice has increased to a frequency of one examination per person per year. These projections are shown in figure III against the year in which the original survey was conducted. This shows the variation in the GSDs arising from differences in the prevalent types of examinations in different countries, in radiological procedures and in the standards of patient protection. The main uncertainty in the value of the normalized GSDs lies in the total number of examinations reported.

43. The increase in the number of examinations need not necessarily lead to higher GSDs if the increase is accompanied by procedural improvements. Of the surveys reported in table 3, the regional survey (89) that was carried out in the United Kingdom seven years after the national survey showed a drop in the GSD from 14.1 to 8.6 millirads. The 1969 New Zealand survey (118) yielded a value not significantly higher (5 per cent) than that obtained by the 1963 survey despite an 11 per cent increase in the frequency of examinations.

44. The Dutch survey of 1967 (14) included a useful study of the dependence of the GSD on the particular values of the parameters used in the calculation. The parameters studied were the gonad dose and the frequency of the examinations. The values of gonad doses per examination used in this study were those determined in four surveys carried out in Leiden (13),

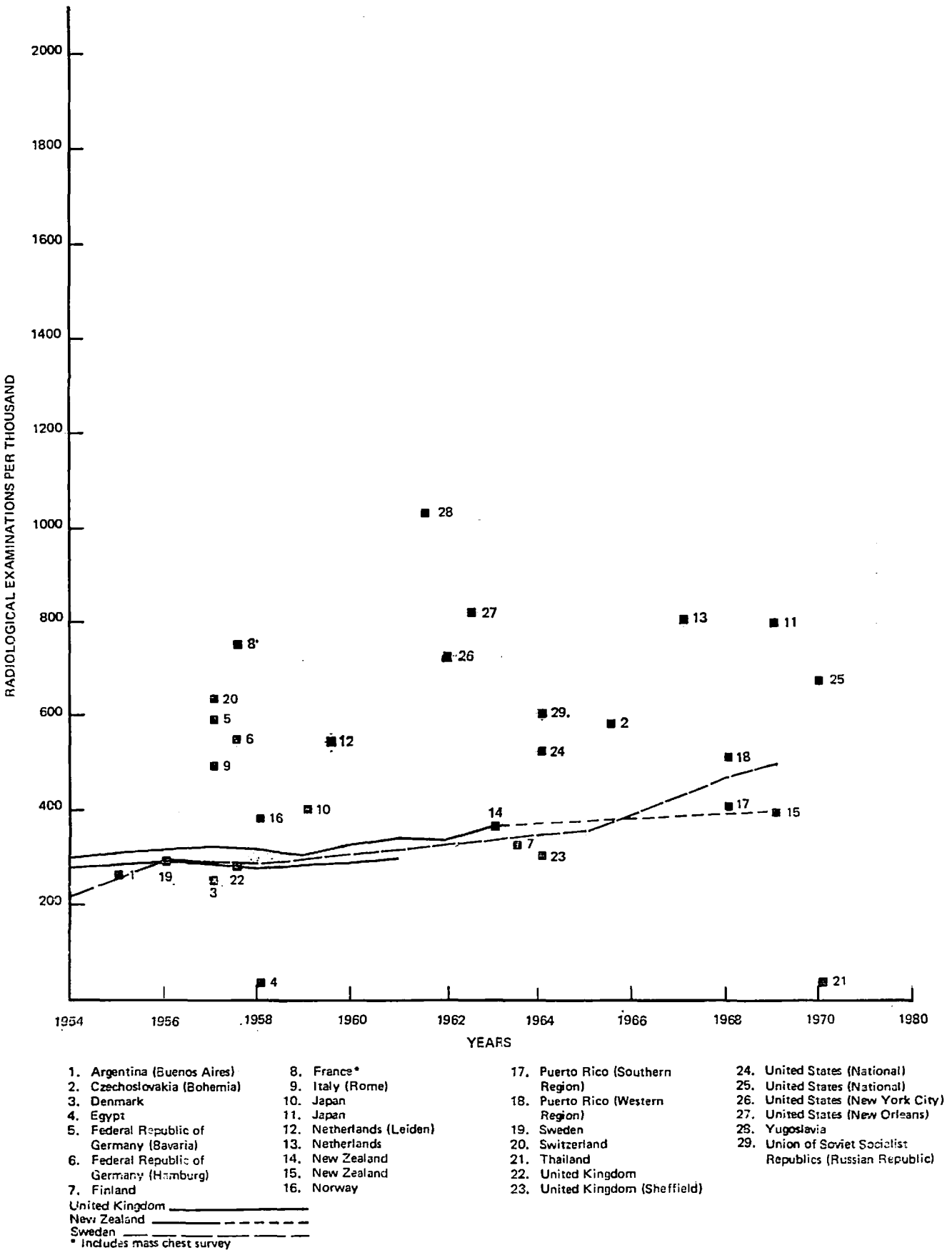
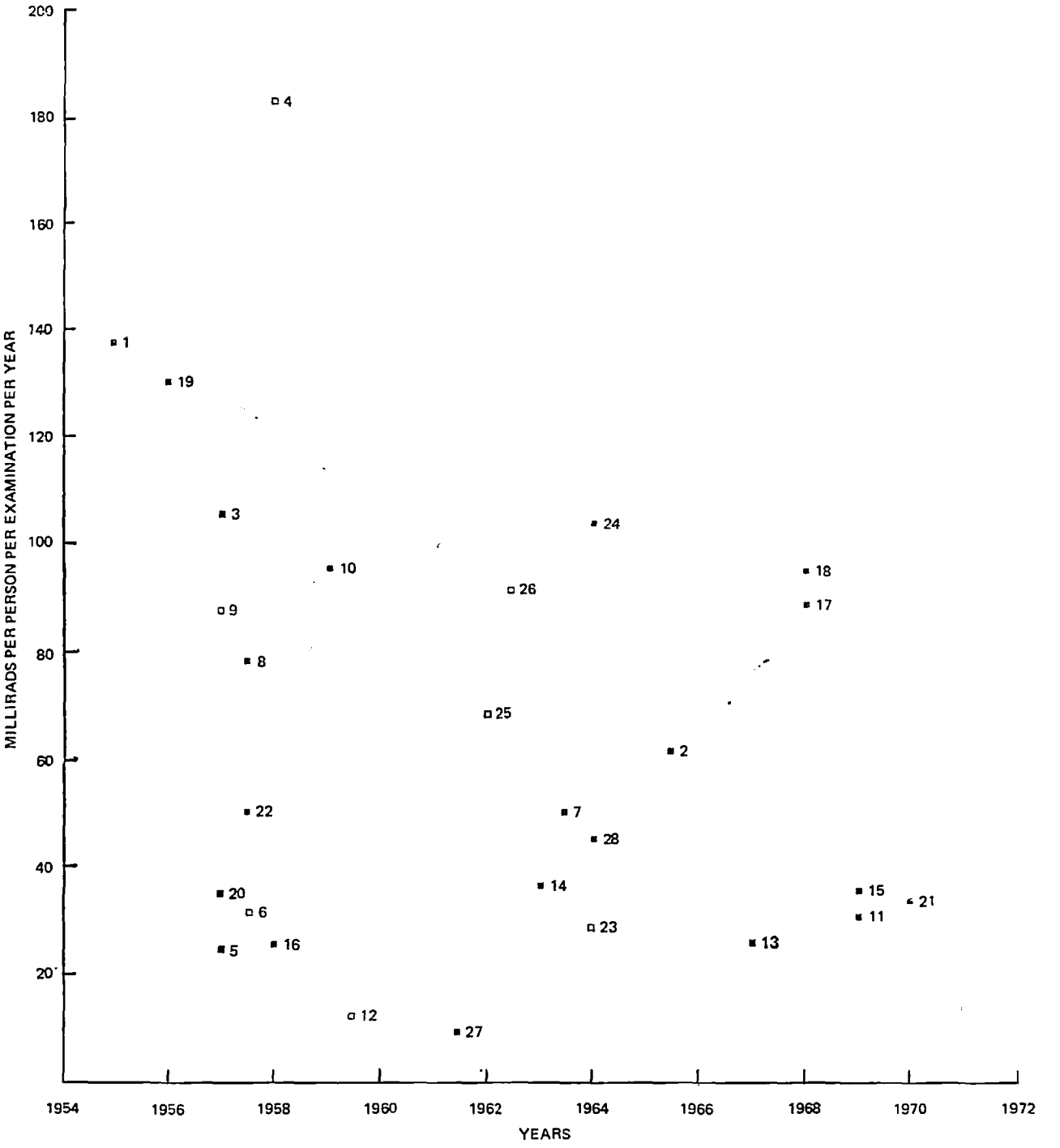


Figure II. Annual frequency of radiological examinations in the population excluding mass chest surveys



1. Argentina (Buenos Aires)
2. Czechoslovakia (Bohemia)
3. Denmark
4. Egypt
5. Federal Republic of Germany (Bavaria)
6. Federal Republic of Germany (Hamburg)
7. Finland
8. France*
9. Italy (Rome)
10. Japan
11. Japan
12. Netherlands (Leiden)
13. Netherlands
14. New Zealand
15. New Zealand
16. Norway
17. Puerto Rico (Southern Region)
18. Puerto Rico (Western Region)
19. Sweden
20. Switzerland
21. Thailand
22. United Kingdom
23. United Kingdom (Sheffield)
24. United States (National)
25. United States (New York City)
26. United States (New Orleans)
27. Yugoslavia
28. Union of Soviet Socialist Republics (Russian Republic)

* Includes mass chest survey

■ National surveys

□ Local surveys

Figure III. Normalized GSD for population receiving one examination per person per year

in Denmark (53) and in Texas (27) by the same physicist (14) and in the United States national survey of 1964 (15). These were combined with one of two sets of examination frequencies obtained in the Netherlands on 1 million people (survey A) and on 5 million people (survey B), respectively (see paragraph 50). Six values of the GSD were determined using the following selections from the above data:

Selection 1 using Leiden gonad dose data and survey A
Selection 2 using Texas gonad dose data and survey A
Selection 3 using Leiden gonad dose data and survey B
Selection 4 using Texas gonad dose data and survey B
Selection 5 using Denmark gonad dose data and survey B
Selection 6 using U.S.A. gonad dose data and survey B

45. The six estimates of the GSD together with their male and female components were as follows:

Selection	*Male*	*Female*	*GSD*
1	7.8	10	17.8
2	5.6	7.8	13.4
3	7.6	9.1	16.7
4	5.4	7.4	12.8
5	9.4	7.6	17.0
6	30.6	8.9	39.5
		Mean	19.5

Comparison of 1 with 3 and 2 with 4 shows that there was little difference between the two sample populations. Comparison of 3, 4, 5 and 6 shows the difference produced by using different sets of gonad doses per examination. The four female contributions to the total were similar, but one of the male contributions was far higher than the others as a result of examinations, included in the United States national survey (106), in which the testes were exposed in the direct beam.

46. The main details of the actual surveys referred to in table 3 are presented in the following paragraphs. The results of most of the surveys are given in tables 4-17. In each of these tables the 10 examinations making the greatest contribution to the GSD are presented, with the exception that pelvimetry and obstetrical abdomen are included even though they might not rank among the top ten. In these cases they replace the ninth and tenth types of examination. The frequency of these examinations and the gonad doses are also given for each examination.

47. *Czechoslovakia, Bohemia, 1965-1966 (table 4) (80).* The survey covered three (population 4,341,000 or 30.5 per cent of the country total) out of the 11 regions of the Czechoslovak Socialist Republic. The number of examinations carried out in all radiological and fluoroscopic units over a one-year period were collected, together with those carried out during a three-month period in all mass chest survey units and during two one-week periods in 219 out of 570 dental x-ray departments. A breakdown of the examinations by age was obtained for 253,853 examinations, i.e. for 6.4 per cent of the annual number of examinations (2.2 million radiographic and fluoroscopic; 1.4 million mass chest; 0.4 million dental). Central-axis skin-dose and gonad-dose measurements were carried out on 5,602 patients in 70 departments at 28 industrial and agricultural localities. To obtain the ovary dose, phantom measurements were carried out on each machine immediately following each exposure. The national average child expectancy in the population was used in the calculation of the GSD (table 1) except for hysterosalpingography (paragraph 35). It should be noted that pelvimetry examinations are practically never carried out in Czechoslovakia.

48. *Finland, 1963-1964 (table 5) (67).* All medical institutions, hospitals and private physicians in Finland were asked to supply details of all radiological examinations carried out during four weeks in 1963, together with the total number, or estimated total number, of x-ray examinations during 1963. A second survey was instituted to complete the required information. The frequency of dental examinations was estimated from film consumption. Total examinations for 1963 were 2.7 million plus 80,000 dental examinations. 143,000 examinations were recorded in the study period. Gonad dose measurements were obtained by using 1960 fluoroglass dosemeters sent to 124 hospitals. In the case of males, fluoroglass rods were in contact with the testes; in females the dosemeter was placed on the back, near the ovaries. The ovary dose was obtained by phantom measurements using a calibration factor dependent on the type of x-ray unit used. National child-expectancy figures were used in the calculation of the GSD. Six per cent of the women examined were assumed to be pregnant and a fœtal dose equal to the female gonad dose was assumed.

49. *Federal Republic of Germany, Bavaria, 1956-1958 (table 6) (130-132, 134).* Statistical data regarding the admission of patients to hospitals in Bavaria were obtained in 1956. The classification by type of examination, age and sex was obtained for a population of 0.75 million. Gonad-dose measurements were made on 1,759 patients in 10 different types of hospitals and private practices. Some 705 measurements on children and 700 on adults were also carried out at the University of Munich. The gonad doses of adult females were measured in the vagina and for female children in the rectum. The comparison of gonad doses in various clinics and hospitals and for various ages showed a wide variation depending on the procedures observed. The national child-expectancy figures were used in the calculation of the GSD.

50. *Netherlands, 1967 (table 7) (14, 107).* The radiological examinations carried out in one year on 4.9 million people covered by 53 insurance companies were used to derive the annual total number of examinations. A subsample of nine companies which covered 1 million people was used to obtain the breakdown by age and sex. Both samples were geographically scattered. The two samples were cross-checked and found to be in reasonable agreement. The gonad-dose measurements were those obtained in a previous survey in Leiden (13) on patients and on a phantom, but other gonad-dose measurements (some by the same authors working in Texas) were used to compute various estimates of the GSD (see paragraph 44). National child-expectancy figures were used, except for the examinations of pregnant women (paragraph 35). An increase in the GSD has been reported (154) on the basis of further gonad-dose measurements at two hospitals in 1971 and on the 7 per cent per annum increase in the frequency of examination.

51. *Japan, 1969 (table 8) (57).* The frequencies of examinations were obtained during 30 consecutive days from a number of hospitals of various sizes (number of beds) and from 1,000 physicians. Answers giving the numbers of examinations and the physical conditions used were received from 60 per cent of the hospitals approached. Gonad doses were measured

on four phantoms using x-ray units from different manufacturers operating at the particular conditions used for each examination type in the various hospitals included in the survey. The phantoms represented 8-month, 5-year and 10-year-old children and the adult. The output of some 54 x-ray generators was surveyed to obtain a mean output per unit. The child expectancies were derived from national statistics.

52. *New Zealand, 1963 and 1969 (table 9) (118, 156).* Annual figures from the Department of Health showed an increase of over-all frequencies of 21.6 per cent during the years 1963-1970. During the same time the population of New Zealand increased from 2.5 to 2.8 million. A survey in which details of 40,000 examinations were collected and analysed, sampled 3.5 per cent of the annual number of examinations. A field survey was conducted in which the gonad or skin doses were measured in 1,400 examinations and 2,460 technique forms were used to derive the gonad dose. The male measurements were carried out directly and the ovary dose was calculated from the data used in the British national survey of 1957. Child expectancies were derived from national statistics (table 1 and figure I). The 1970 survey utilized the same gonad-dose measurements and the distribution of examinations by age and sex as in the earlier survey but current data on the total frequency of examinations and child expectancy were used. The most notable changes in the frequency of examinations that took place during the 1957-1963 period regarded pelvimetry examinations, which dropped to 40 per cent of the 1957 frequency, and obstetrical abdomen examinations, which dropped to 60 per cent of that frequency.

53. *Thailand, 1970 (table 10) (4, 119).* The total number of patients radiographed in all centres was requested for the month of January 1970 and the 56 per cent return obtained represented some 45 per cent of the estimated number of examinations carried out. A very low total frequency of 30 examinations per year per 1,000 persons was reported. Gonad-dose measurements were made in one hospital during fluoroscopic procedures using thermoluminescent dosemeters placed on the scrotum of male patients and in the vagina of female patients. Phantom measurements were undertaken in five hospitals utilizing the exposure data of patients. The lower gonad dose due to the smaller size of the patients is to be noted (paragraph 30). As data were insufficient to make possible an accurate estimate of the GSD, a "most probable" value was derived. As this value seems exceptionally low, an upper limit has been estimated, referred to as "the maximum" GSD based on the "maximum" average gonad dose. The female child-expectancy data derived in 1966 by the Ministry of Public Health was used and the male fertility was deduced from it, using as a basis the relationships observed in New Zealand (figure I). It was considered that the pattern for females might be changing since the median age of the mother at childbirth had dropped from 27 years in 1966 to 25 years in 1970.

54. *United Kingdom, Sheffield, 1964 (table 11) (89).* The frequencies of the examinations in the Sheffield area (population 4.5 million) were collected in all the x-ray departments during a one-week period. This showed an increase in the frequency of radiography of 33 per cent compared to that reported in the 1957 survey. The population increase was 6.2 per cent, showing a 26 per cent increase in the frequency of radiography *per caput*. Fluoroscopic examinations had decreased by 36 per cent *per caput* and mass chest surveys increased by 42 per cent. Gonad doses were measured using ionization chambers placed at the scrotum in males and at the level of the iliac crest in females. Over 2,000 measurements on 800 patients in 30 hospitals were made. The ovary dose was calculated using the conversion data measured on a phantom in the 1957 British survey (26, 38, 39). For changes indicated by analyses of the two surveys, see paragraph 61. The same child expectancies, based on national statistics, that were used in the earlier survey (26) were utilized in the later one.

55. *United States, 1964 national survey (table 12) (21, 51, 104, 106, 108).* The national survey was conducted on the basis of interviews of 9,653 complete households in 1964 and 21,667 in 1970, selected by a multistage sampling programme used for sampling the civilian population of the United States. The first division consisted of 357 geographically-defined primary sampling units. Within each, the ultimate subdivisions, called segments, consisted of a cluster of nine neighbouring households. Each week a random sample of approximately 90 segments (800 households) was drawn from the whole country. Interviews of these selected households over a three-month period covered just over 31,000 people of whom 4,525 had had an x-ray examination during the previous three months. (For details see paragraph 24.) The follow-up consisted of an approach to each clinic or hospital at which a selected person had had an x-ray examination, with requests for details on the examination together with a film from which the x-ray quality and the field size could be determined. The gonad doses were determined on the basis of these exposure factors by processing the results of comprehensive scatter measurements made on a phantom. These were checked by *in vivo* thermoluminescent dosemeters applied to 360 patients undergoing a variety of examinations. The mean "system-calculated" male-gonad doses ranged for particular examinations from +170 to −71 per cent of the mean dosimetric measurements. For examinations with the ovary expected to be in the direct field, the "system-calculated" values ranged from +57 to −30 per cent of the dosimetric measurements. For data regarding field size variation, see paragraph 61. Child expectancy figures were derived from national statistics.

56. *United States, Puerto Rico, southern and western regions, 1968 (table 13) (44, 45).* The average number of patients radiographed per week over the year 1968 was presented from all hospitals in the two regions of Puerto Rico. These statistics were broken down into types of examinations. An earlier investigation had been carried out in the western region in 1967 (44). The majority of the dosimetric work was carried out on one unit. Thermoluminescent dosemeters and ionization chambers were used for a limited number of *in vivo* dose measurements at one centre and agreed reasonably with phantom measurements. The average gonad doses were derived from the returns from the 47 facilities with one or more x-ray units in the southern region and from 65 facilities in the western region. The regions had a total of 83 and 75 x-ray units, respectively. In the southern region the number of x-ray units excluding dental units was 13 in 1940, 28 in 1950, 57 in 1960 and 83 in 1968, indicating a doubling period of about 10 years. The difference in the GSD estimates in the two regions may be accounted for by technically sounder practices in the southern

region. For instance, 60 per cent of the 83 units in the southern region had variable collimators compared with 22 per cent in the western region. The child-expectancy figures were derived by the Department of Health but not published.

57. *United States, other local surveys.* Four surveys have been completed in local areas of the United States since the 1962 report, in New York City in 1962 (102), in New Orleans in 1962-1963 (69), at the Johns Hopkins Hospitals in 1965 (97) and in Texas in 1963 (27). Each of these surveys have had to depend on the national child-expectancy figures. The results at the Johns Hopkins Hospitals and the survey in Texas were expressed in terms of the national frequency rate in 1960 of 8.9 10^7 examinations per year. The detailed results of the surveys in New York City, New Orleans and Texas are given in tables 14-16, respectively. In the New York City survey 68 out of 234 institutions took part and each reported the annual number of x-ray examinations and a breakdown by age and type for a period of a few days. Physicians' offices reported over a four-week period. In New Orleans 262 x-ray units and 144 physicians' offices, 73 per cent of those in the area, reported data for a six-month period and the details of the exposure of 8,000 patients comprising 9,000 examinations and 18,000 projections were collected and used to derive the gonad doses using relevant phantom data (41). The Johns Hopkins survey was based on the radiographic examinations of 100,000 patients and the details of the determination of the GSD is given in paragraph 31. The 220,000 examinations at the hospitals of the University of Texas over a 30-month period were used together with gonad and skin dose measurements to derive the GSD.

58. *Union of Soviet Socialist Republics, Russian Republic (1964) (75).* The results of surveys at the Moscow X-ray Radiology Research Institute concluded that 65 million x-ray examinations were carried out annually on the 82 million people in the Russian Republic (14 million radiographies, 36 million fluoroscopies and 15 million chest photo-fluorographies). The total number of fluoroscopic examinations included 10 and 22 million examinations of thoracic organs for prophylactic and clinical reasons, respectively, and 3.6 million for gastro-intestinal tract examinations. Radiography included 2.1 million investigations of thoracic organs, 0.8 million gastro-intestinal tract and 10 million examinations of knee and joint systems. Measurements of the skin dose, gonad dose and the integral dose were made for a number of x-ray examinations. The total exposure to the gonads received each year in these examinations was 220 10^4 man-roentgens. The *per caput* gonad exposure was calculated to be 27 milliroentgens per year of which 10 per cent was due to prophylactic examinations and the remainder to clinical examinations. The total integral dose was 845 10^6 kilogramme-rads of which 91 per cent was from fluoroscopy, 6 per cent from photofluorography and 3 per cent from radiography. The *per caput* annual integral dose was 10.3 kilogramme-rads which was 1.5 times natural background (150 millirads).

59. *Yugoslavia, Slovenia, 1960-1963 (table 17) (94).* During 1960, the total number of radiographic and fluoroscopic examinations was determined for all the institutions in Slovenia. Information on a 25 per cent sample of these examinations was obtained in terms of age, sex and type of examination. The gonad-dose survey was biased towards those examinations which contribute most to the GSD. The centres to be visited were deduced on the basis of the 1960 workload. Some 2,000 gonad-dose measurements were made. The gonad dose was measured at the scrotum for male patients and at the iliac crest for female patients. The data from the British survey and some additional data were used to convert iliac crest doses to ovary doses. The child-expectancy figures were derived from national statistics. For examinations unconnected with pregnancy, the fœtal contribution was taken into account, by assuming the proportion of pregnant women of a particular age group in the population and reducing this by a factor of 0.75 to take into account the reluctance of staff to subject women known to be pregnant to x-ray examination.

2. *Gonad dose*

60. The gonad doses received in a variety of examinations were reported in tables XVIII, XIX and XX of annex G of the 1962 report. The gonad doses reported in more recent surveys are summarized here in table 18 which shows the median of the national mean values and the range of the mean gonad doses per examination. The examinations have been classified in three categories, according to whether they involve high, medium or low gonad doses. It will be noted that, although the mean gonad doses from the same examinations tend to be lower than those reported in 1962, their range is still wide. The range of the gonad doses reported for a particular examination reflects to some extent the difference in practice in different countries, e.g. the number of radiographs that are usually taken and the physical factors used for a particular examination type. However, improvements of practice such as those recommended by Ardran (8) will ensure that the mean value for an examination approaches the lower end of the reported range.

61. The importance of strict field-size limitation, of the use of gonad shields and of filtration of the incident beam in the reduction of the gonad dose have been illustrated by the analyses presented in some of the surveys. The excess of field area over film area shown in figure IV was taken from the United States

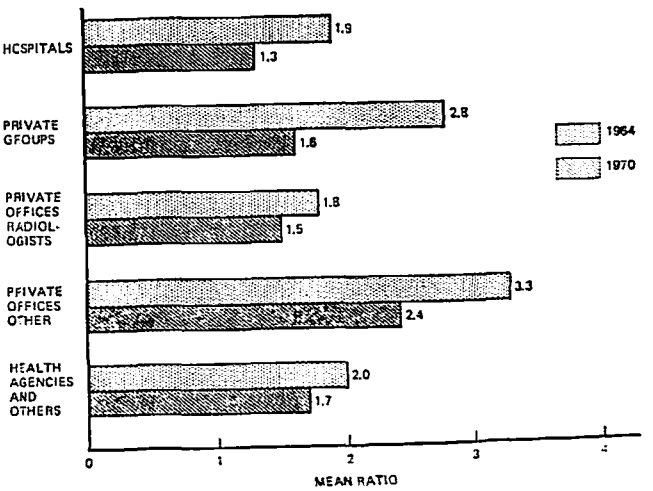


Figure IV. Estimated mean ratio of beam area to film area for radiographic examinations by type of facility, United States, 1964 and 1970 (21, 106) showing the reduction taking place during that period

national surveys (106). The 1964 survey indicated that if the field area had been equal to the film area, then the GSD would have been reduced from 55 to 19 millirads. Similarly, in the United Kingdom survey at Sheffield (89) in 1964, 67 per cent of the examinations had field sizes larger than film sizes and 8 per cent had field sizes larger than twice the film sizes. For examinations of the chest in 1957 (26) 10 per cent of males and 51 per cent of females had gonads in the direct beam but in 1964 this had been reduced to 4 and 10 per cent, respectively. In New Orleans (69), 12 per cent of the examinations were taken with units with no beam-limiting device and 30 per cent had only one large cone available. The British surveys (26, 89) indicate that gonad shields were used in examinations of 11 per cent of the male patients and 4 per cent of the female patients in 1957 but in 28 and 12 per cent, respectively, seven years later. In 1957, 24 per cent of the units had no added filtration but this was so in only 0.8 per cent of the units in 1964.

62. The radiation dose to the fœtus has been studied in several surveys. In Poland an extensive survey has been carried out by Jankowski and Liniecki (70) in the city of Łodz. Reekie, Davison and Davidson (116) have also reported the doses to the fœtus resulting from x-ray investigations. These surveys indicate doses to the centre of the fœtus in the range of 0.1-6 rads.

63. The estimated accumulated mean gonad doses *per caput* from diagnostic medical radiology in the United States (106), assuming that examinations and dose rates were to remain constant for 30 years at the 1964 rate, would, at 15 years of age, be 160 and 50 millirads for males and females, respectively; 2,770 and 490 millirads at 30 years and 6,600 and 1,490 millirads at 45 years.

3. *Genetically-significant dose by examination type*

64. The contribution of the various examinations to the GSD was reported in table XXI of annex G of the 1962 report and the values reported since are contained in table 19 of the present annex in terms of their percentage contributions to the GSD. The examinations contributing most are those that involve irradiation of the pelvis and abdomen, namely, urography, lumbar spine, lumbo-sacral spine, hip and pelvis, barium meal and barium enema. The age groups contributing most to the GSDs are considered in paragraphs 66-68. The practices that are recommended to ensure that the minimum dose is received, consistent with good radiology, are referred to in paragraphs 61 and 89.

65. Particularly significant is the small contribution from examination carried out during pregnancy in some countries, e.g., in Czechoslovakia (80). In connexion with the reduction of doses by the evolution of improved techniques it is noted that in France fluoroscopic examination of the chest for mass surveys is not now allowed and that therefore radiography or photofluorography must be used for the chest examinations of pregnant women. In the United Kingdom (89) the number of examinations of pregnant women has greatly decreased since the 1957 survey and similarly in New Zealand (118) (paragraph 52). However, a high contribution of examinations during pregnancy is still shown by the local surveys made in the United States. Thus, the survey by Brown and Nelson in 1963 (19) indicated that 9 per cent of all pregnancies had either a pelvimetry or obstetric abdomen examination. These examinations provided 58 per cent of the female contribution to the genetically-significant dose at New Orleans (69) in 1962-1963 and 24 per cent in New York (102) in 1962. This contribution from examinations during pregnancy is not apparent in the nationwide survey carried out in the United States (104, 106) in 1964.

4. *Genetically-significant dose by sex and by age at examination*

66. The contributions of examinations of males and females and of fœtuses to the GSD as shown by the recent surveys are given in table 20. The fœtal contribution has not always been assessed for examinations not connected with pregnancy, and sometimes that contribution is included in the female contribution. In general, the male and female contributions are about equal but in the United States 1964 survey (106) a very high male contribution, due principally to the examinations of the lumbo-sacral and lumbar spine, was recorded, 25 per cent of the male gonad doses from these examinations being in excess of five rads. The corresponding contribution to the GSD would have been reduced from 22 to 1.3 millirads, had the field sizes been reduced to the size of the films.

67. The contributions of the various age groups to the total GSD is illustrated in figure V. The fact that the examinations of the 20-30 years age group contribute about 50 per cent of the total GSD is important when considering the age group for which both gonad-dose reduction and reduction in the frequency of examinations is particularly desirable.

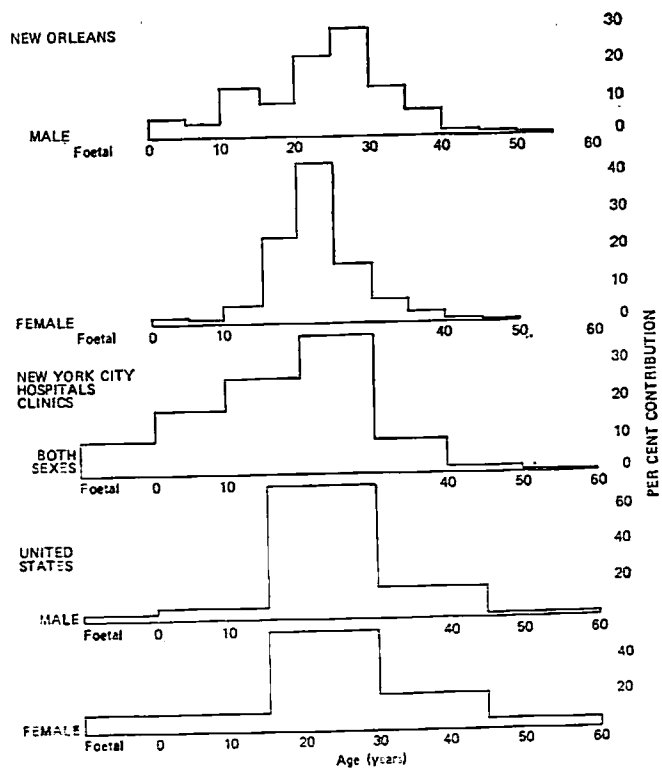


Figure V. Contribution of age groups to the genetically-significant dose

68. *Children.* The importance of reducing the gonad dose when examining children has been emphasized in several reports (26, 28, 74, 80) which have shown that such radiography needs to be carried out using careful techniques to ensure that doses smaller than those for adults are received (see paragraph 30). Otherwise gonad doses several times greater than the adult gonad doses will be received particularly from examinations of the hip, femur and of the abdomen.

5. *Other investigations*

69. Estimates of the GSD have now been made over a period of two decades and it is important to consider the contributions that further studies might make. Probably the most important contribution made in any country or region by the conduct of a survey is educational. Increased awareness of the need to protect the patient develops among the staff and many country-wide and regional surveys have been undertaken for this reason. Surveys have the additional advantage of bringing to light the specific practices which may be important contributors to the GSD. However, the repetition of such investigations should aim more at determining the order of magnitude of any changes in the GSD that may have taken place over, say, a 10-year period than at obtaining highly precise estimates of the GSD.

70. In countries where resources of both trained staff and finances are limited, the determination of the GSD should not rank high in the order of priorities but effort should be placed on the improvement of the facilities and on training of staff. Estimates of the GSD can be made on the basis of the studies in other countries and of data on the frequency of examination which do not require highly skilled staff for their collection.

71. As medical radiological practices change and new techniques are introduced estimates should be made of the doses to the gonads, to the skin and to other organs in the direct field. From the frequency of these investigations in a few broad age groups it should be possible to determine the importance of these practices to the GSD. Such estimates should be included in the description of the techniques in the scientific literature.

72. A number of investigations are known to be in progress, e.g., in Australia (138). In particular, a prospective survey of 20,000 patients is being undertaken in Canada (34) in which ill effects in progeny are being recorded together with radiation-dose estimates. A survey of dental radiology in the United States (30) has shown that the GSD from dental radiology is less than 0.01 millirad per year. Investigations on the doses to the body in mammography examinations (50, 101) have shown the vaginal dose per examination to be less than one millirad.

D. Bone-marrow dose

73. In paragraphs 10-13 of the introduction the basic criteria have been stated for the study of the dose to the bone marrow. However, paragraph 11 emphasizes particularly the deficiencies in our present knowledge of the role of radiation in the induction of leukæmia. Only further study will elucidate whether the bone marrow is the most important organ to study or whether the reticulo-endothelial system, the lymphocytes or the immune response of the body or some other factor may each have to be considered. It is important that, in considering the detailed information that is available on the dose to the bone marrow, these other factors should not be ignored. Further investigations of the bone-marrow dose delivered during particularly extensive examinations are required both as to the range of individual mean marrow doses and to their frequency throughout a population. The results of these investigations will not only help draw attention to the need to use the minimum dose consistent with good radiology but will also indicate groups of patients who may provide epidemiological information.

74. When the 1962 report was assembled, measurements of bone-marrow doses from only a few diagnostic x-ray examinations had been made. Since then the results of three comprehensive surveys have become available. Weber (153) published data for the Leiden district in the Netherlands giving a *per caput* mean marrow dose (CMD) of 30 millirads, in the United Kingdom (25) the result of the national survey for diagnostic radiology gives a figure of 32 millirads, and in Japan (58) a national survey has reported a CMD of 189 millirads. Estimates of the CMD in Czechoslovakia (81) amounted to 68 and 184 millirads, depending on which of two different approaches based on the British results were used. Other measurements were made in Japan (6, 7, 56, 127) utilizing some published data (37, 41).

75. The basic data on bone-marrow distribution which have been used in most of the surveys are very limited and are mostly derived from the figures established by Mechanik (91) in 1926 on 13 cadavers and subsequently modified by Ellis (37) to give the active bone-marrow distribution in a 40-year-old adult. This modification utilized the measurements made by Custer (29) on the distribution of the active bone marrow in the adult and its change with age. Hashimoto *et al.* (54, 58, 95) have investigated the marrow distribution in 10 Japanese cadavers by weighing each bone before and after the chemical removal of the marrow. The percentage cellularity at each site and the resultant active bone-marrow distribution were determined. Table 21 shows the percentage distribution of active bone marrow obtained by Ellis and by Hashimoto *et al.* The distribution of active marrow in children was derived by Hashimoto *et al.* from the adult distribution by taking into account the presence of active marrow in the extremities of children. The amounts of active marrow in Japanese were 765 grammes in the adult, 583 grammes in children at 8-14 years of age, 329 grammes at 3-7 years, and 162 grammes at 0-2 (derived on a body-weight basis). The corresponding adult active bone-marrow derived from the Mechanik data was 1,046 grammes. Further studies on the variation of the distribution of the active bone marrow with age are needed, and determinations of the quantitative distribution of the active bone marrow by means of radio-active tracer studies would provide a useful check of the values being currently used.

76. The use in the Japanese report (58) of a weighting factor to give a leukæmia-significant dose (paragraph 14) takes into account the shape of the time-incidence curve of radiation-induced leukæmia, and also the survival statistics for the different age groups in the population. When applied to the CMD, these factors give a "leukæmia-significant" dose of 169 millirads, about 10 per cent lower than the uncorrected CMD (table 22).

1. *Variation with type of examination*

77. The bone-marrow doses from the various examinations as obtained in the Netherlands (153), the United Kingdom (25) and Japan (58) are given in table 23. The examinations giving the highest doses are those involving irradiation of the trunk and particularly those, such as barium meals and barium enemas, that require long fluoroscopic exposures.

78. The active bone marrow is widely distributed in the body and therefore the factors which mainly determine the magnitude of individual mean marrow dose are the extent of the examination in terms of field area and the incident skin dose (25, 65). The latter is increased by high screening currents and long screening times during fluoroscopic examinations and by the number of radiographic exposures made. The radiation quality used has only a minor effect on the mean marrow doses received. A study of these factors and their effect on the mean marrow dose was undertaken in the British survey (25). The variation in the individual mean marrow doses for particular examinations is shown in figure VI. The variation in the fœtal marrow dose during obstetric abdomen and pelvimetry is shown in figure VII. Fœtal dose studies have also been reported by Jankowski and Liniecki (70).

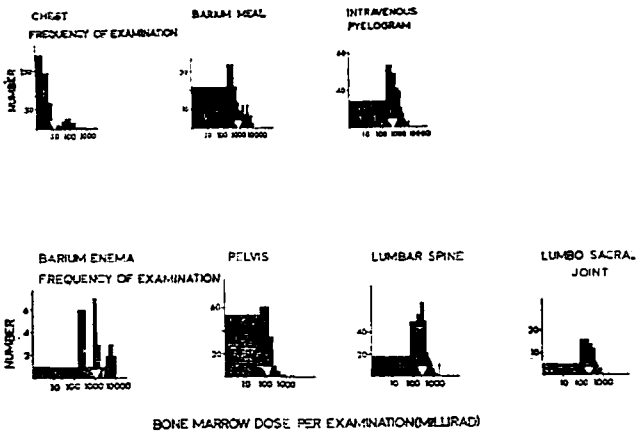


Figure VI. Histograms showing variation in bone-marrow dose with various types of x-ray examinations (male) (25) (the white triangle denotes the mean value)

2. *Determination of mean bone-marrow dose*

79. The values of the bone-marrow dose for particular investigations have been determined by extensive phantom measurements. In the British survey (25), the percentage of the radiation at the skin was measured with a very small ionization chamber at 12 bone-marrow sites in a specially constructed phantom containing a human skeleton impregnated with wax under vacuum. For each site the doses were measured for seven radiation qualities with different focal skin distances and field areas, and for the anterior, posterior and lateral projections of the incident beam.

80. The calculation of the bone-marrow doses was based on the size of the skin field. The active bone marrow was subdivided into elements by means of a grid superimposed over the body in anterior, posterior and lateral projections. For each element so obtained, the dose contribution to the marrow arising from the particular exposure conditions was calculated at each site within the element, using the results of the physical measurements and the proportion of the total active bone marrow present at that site. The doses to each element were then totalled to give the mean marrow dose. The computer programme used for these computations is available on decks of Fortran IV cards (40). A similar aproach was followed in the Japanese survey (124).

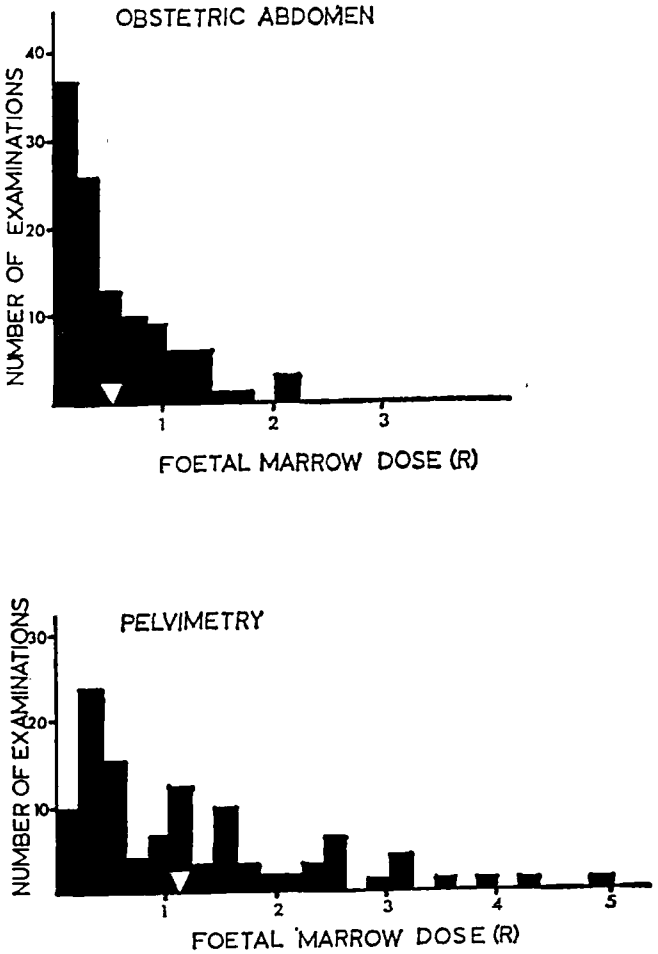


Figure VII. Variation in the fœtal bone-marrow dose due to two types of examinations (25)

3. Per caput *mean marrow dose by examination type*

81. Table 24 indicates the contribution of the various examinations to the CMD in the Netherlands (Leiden) (153) and the United Kingdom (25). Table 22 provides the information for Japan (58). The contribution of the various radiological techniques to the CMD and the leukæmia-significant dose in the Japanese survey (58) are given in table 25.

82. According to the British survey (25), the examinations contributing most to the population dose were mass surveys of the chest (24 per cent), barium meals (18 per cent) and barium enemas (10 per cent). The examinations that were the greatest contributors in the Dutch survey (153) were fluoroscopy of the chest, mass surveys of the chest and descending urography (27.0, 12.8 and 12.3 per cent, respectively). In Japan fluoroscopic examinations of the stomach contribute 55 per cent to the CMD. Their high frequency is due to the mass surveys carried out because of the high

incidence of stomach cancer in that country (58). These results are good examples of the contribution that bone-marrow dose surveys can make in identifying those groups of patients of importance for the epidemiological studies recommended by the ICRP/ICRU reports (42, 43) and by the UN/WHO seminar (144).

4. *Dental radiography*

83. Few data are available on the individual mean marrow dose from dental radiography. This dose was estimated in 1959 to be 1.8 millirads in the United Kingdom which, with an annual examination rate of 2 million dental examinations in a population of 50 million, corresponds to a CMD from dental radiography of 0.1 millirad (25, 26). However the practice in some countries is tending towards the use of wider fields and more frequent dental x-ray examinations so that the CMD from dental radiography is likely to increase. When radiographs of the whole mouth are required the use of intra-oral x-ray tubes may reduce the doses received.

E. Dose to the skin and other organs

84. The dose to the skin in the primary beam and the area of the beam are two important parameters that determine the total dose to important organs such as the bone marrow. Significant radiation may also be received by other organs and tissues of particular groups of patients. For example, young children with orthopædic conditions may receive many radiographs of particular bones over a number of years. Such groups of people may lend themselves to epidemiological studies and the ICRP/ICRU reports (42, 43) have drawn attention to the necessity to ensure accurate dose estimates for these groups of patients.

85. Variations in the skin dose from radiographic examinations reflect the type of film and screen used and the amount of initial filtration inserted in the primary beam. For most examinations the fastest film-screen combination may be used, but where fine detail is required, as in bone radiography, fine-grain screens or no screens are often used. Table 26 gives for a number of examination types the median and the range of the average skin doses in the primary beam reported in seven surveys (8, 25, 63, 80, 123, 126, 156). Ardran (8) has drawn attention to the need to reduce the off-focus radiation and thus reduce the incident skin and gonad doses. The skin dose due to any particular examination may be much less or much more than the average values reported in table 26, depending on the number of exposures and on the exposure factors used. For example, in the British survey (25) the mean value of skin dose was 2.1 rads for pelvic examinations, but values up to 33.4 rads were recorded. In the investigations on the skin doses received during mammography examinations, local doses up to 35 rads were measured (50).

86. The doses to the skin, thyroid, hypothalamus and the lens of the eye from dental radiography are not negligible. The doses delivered to the lens will be considerably reduced by the use of protective diaphragms and centring techniques. When radiographs of the whole mouth are required the use of intra-oral x-ray tubes, if correctly applied, will reduce the irradiation of the patient.

F. Trends with extensive examinations

87. The main trends in diagnostic radiology have been identified in paragraph 17. The doses received during the use of image intensification and cine procedures have received attention. The incident skin-dose rate during non-intensified fluoroscopic examinations may be about 4-10 rad min^{-1}. The ICRP (114) recommends that it should not exceed 5 rad min^{-1}. When the conditions under which image intensification is carried out are optimised, for example by dark adaptation of the operators, and technical problems are overcome, the dose rate may be reduced to about 0.5-1 rad min^{-1}. However, reports indicate that when the image-intensifier tube deteriorates, the higher screening current necessary to obtain a good image may increase the skin-dose rate above that for non-intensified fluoroscopy. With cine-fluorography, very much higher skin-dose rates are used, rates of 50-100 rad min^{-1} being delivered on thick patients. Gough, Davis and Stacey (52) report the following doses delivered during cardiac catheterization of 85 patients in the United Kingdom:

	Mean dose		*Maximum dose*	
	rad	*mrad*	*rad*	*mrad*
Skin	47		140	
Marrow	1.4		3.9	
Male gonads		25		80
Female gonads		39		100

Ardran (9) reported similar doses in another series of patients in the United Kingdom. Even higher radiation doses were reported by Gough, Davis and Stacey (52) as being delivered during pacemaker insertion—an emergency procedure. An average skin dose of 132 rads per patient was received in a group of six patients. Other surveys of the doses received during fluoroscopy have been published by Seyss (135) on 5,000 cases, and by Schoen (128).

88. The irradiation of children both for cardiac catheterization and for such examinations as voiding urethrocystography may lead to high gonad doses. Typical measurements by Kaude, Lorenz and Reed (74) give average male gonad doses of 105 millirads and ovary doses of 270 millirads, with maximum values of 570 and 690 millirads, respectively.

G. Recommendations for the protection of the patient in diagnostic radiology

89. Because of the increasing use of diagnostic radiology (for example, an estimate in the United States (24) indicates that 50 per cent of all diagnoses are made or confirmed by diagnostic radiology), the ICRP (65, 114) and other international and national bodies have made recommendations for achieving the minimum patient dose consistent with good radiology. Similar recommendations regarding special aspects of radiology have also been published (93, 155), for example, for the examination of children (47) and for dental examinations (35).

II. Diagnostic use of radio-pharmaceuticals

90. In many countries the increase in the diagnostic use of radio-pharmaceuticals has been extremely rapid during the 1960s. The procurement of radio-pharmaceuticals has been relatively easy and their dispatch by air freight has enabled many clinics and laboratories to use radio-pharmaceuticals manufactured in a few centres. Both the number of patients investigated by

such well-established tests as the use of radio-active iodine for the study of the thyroid function and the number of radio-pharmaceuticals available for use have been increasing. This has been particularly noticeable since the column generators of short-lived radio-nuclides have been available. In industrialized countries, the introduction of large numbers of scanners into departments has also stimulated the use of radio-pharmaceuticals. The use of radio-pharmaceuticals in the developing countries is increasing and is likely to expand at a fast rate during the next decade.

91. The increase has to be judged from data that have been reported differently in various countries, e.g., comprehensive estimates of radio-nuclides distributed, but not necessarily all administered, number of orders for radio-pharmaceuticals or, better from a population-exposure viewpoint, number of patients to whom the various diagnostic radio-pharmaceuticals have been administered. Typical data are available in the reports from Australia (5), Denmark (15, 79), France (96), Japan (36, 73, 146), New Zealand (90), the United Kingdom (117) and the United States (142, 143). The basic trend observed from these data indicates a doubling of the number of investigations every three years or so. A typical growth pattern is shown by West Berlin (population 2.2 million) with a 100 per cent increase from 1963-1968 (10) and is shown in figure VIII for various radio-pharmaceuticals.

92. The information currently available on the total number of each type of investigation carried out per year is summarized in table 27. Data on the use of three main radio-pharmaceuticals in West Berlin (61) are also included in table 28. General reports from India (68) and Argentina (12) are available.

93. Even though a three- or four-fold increase in the frequency of persons exposed to diagnostic radio-pharmaceuticals has taken place since 1958, the GSD from this source is unlikely yet to approach one millirad per year. This conclusion is based on the assumption that the average gonad dose per investigation has not radically changed. Even though increased activities of short-lived radio-nuclides have been used, those have generally replaced investigations utilizing lower activities of nuclides with longer half-lives so that the two effects on the total gonad dose have tended to cancel out.

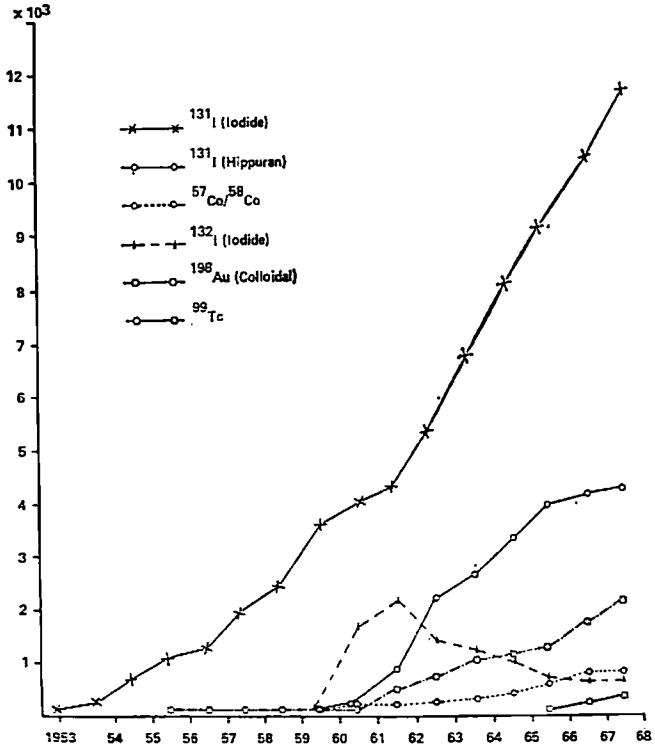


Figure VIII. Number of patients in West Berlin investigated using radio-pharmaceuticals (10)

1. *Organ dose from radio-pharmaceuticals*

94. A knowledge of the radiation dose to particular organs following the administration of a radio-pharmaceutical is necessary to judge the activity that may be administered to any particular patient. Useful publications giving this type of information are the booklet of the Swedish National Institute of Radiation Protection (49), Publication 17 of the ICRP (64), the series of reports produced by the Medical Internal Radiation Dose Committee (16, 20, 31, 32, 84) and other reports (78, 92, 115). These publications emphasize the fact that the dose delivered by a radio-nuclide is dependent on the metabolism of the chemical compound in which it is incorporated and that the estimates of dose per unit activity administered that they provide are mostly those for normal individuals. Variations in the doses may be caused by the particular disease of which a patient is suffering.

2. *Genetically-significant dose*

95. Tables XXXII and XXXIII of the 1962 report gave details on the GSD from radio-pharmaceuticals used in medical diagnosis. The GSDs varied from 0.01 to 0.03 millirad per year for Canada (72), the Federal Republic of Germany (Hamburg) (62), the United Kingdom (26) and the United States (22) in the years 1956-1958.

96. Estimates of the GSD that were made subsequently gave a value of 0.015 millirad for New Zealand in 1966 (90), 0.05 millirad for Japan (2) in 1965, 0.13 millirad for West Berlin (10) in 1968 and 0.4 millirad for Sweden (49) in 1968. The mean annual gonad dose in the Swedish survey (49) was 70 millirads. This latter dose is the average gonad dose to the population regardless of child expectancy. It is large compared with the GSD because most of the patients are in older age groups with small child expectancies. Reports from the United States (143) and the Soviet Union (103) indicate that assessments of the level of exposure of patients and of the activities administered have been made.

97. Data from New Zealand and West Berlin provide a useful breakdown of the contribution of each type of investigation. The New Zealand data (90) are given in table 29. Where more than one radio-pharmaceutical was used for a particular investigation, a mean gonad dose was derived on the basis of the frequency of use of each individual radio-pharmaceutical. The percentage contribution to the total GSD, including therapy with ^{131}I, in West Berlin (10) is given in table 30.

III. X- and gamma-ray treatments

98. In the treatment of neoplastic disease, large doses of radiation may need to be given over a period of weeks to a limited volume of the patient. The aim

of the treatment is, of course, to restore the health of the patient yet it is also necessary to consider the small probability of causing, during the lifetime of the patient, some deleterious effect due to the radiation, either to the individual or to any subsequent offspring. For the treatment of non-neoplastic disease alternative forms of therapy not involving radiation have been recommended for some disorders (26) so as to reduce the incidence of somatic effects over the long subsequent life expectancy of these patients.

99. In many industrialized countries about one-half of the new cancer cases arising each year are treated with radio-therapy. This proportion has not changed appreciably even though the use of chemotherapy has been increasing. Technological developments in the form of linear accelerators, betatrons and telecurie units and 14-MeV neutron therapy units are likely to maintain the current régimes of radio-therapy in the industrialized countries. 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 in living conditions and the availability of medical care.

1. *Genetically-significant dose*

100. Tables XXV to XXVIII of annex G of the 1962 report showed the average gonad doses received by patients during treatment for non-neoplastic diseases, together with the GSDs arising from these treatments.

101. These were 2.2 millirads in the Federal Republic of Germany (62), 3.1 millirads in France (110), 3.1-12.1 millirads in the Netherlands (129) and 4.47 millirads in the United Kingdom (26) with additional contributions from the treatment of neoplastic disease of 0, 2.5, 1.0 and 0.52 millirads, respectively.

102. In Japan (95) in 1962 the GSD from therapeutic irradiation was estimated to be 0.9 millirad. A further survey in 1971 (59) has been carried out and utilizes a range of child-expectancy factors for patients by age and disease. A value of GSD of 0.97 millirad was obtained. From unpublished reports in the United Kingdom it appears that the frequency of treatments of non-neoplastic diseases has tended to decrease and that the use of x-rays of lower kilovoltage for the treatment of many skin diseases has tended to reduce the GSD.

2. *Bone-marrow dose*

103. The results of the British survey (25) on bone-marrow doses from the treatment of non-neoplastic diseases and on the subsequent contribution to the population dose in terms of man-rads were issued in 1966. The method of calculation of the bone-marrow dose was based on that described in paragraphs 79 and 80.

104. Table 31 gives the mean marrow dose per treatment course in those patients who were treated on the head and trunk only, and also the average for all patients treated for a particular condition, including those that were treated on the limbs and whose bone marrow was therefore not exposed since no active marrow is present in the adult limbs. The first set of data can then be used for calculating marrow doses to individuals or populations known to have been treated on the head and trunk, the second set to obtain population doses in groups of patients treated for a particular condition, assuming that the distribution of treatment sites is the same in the study population as in the British survey (25).

105. Table 32 gives the total annual radiation load in man-rads from radio-therapy of non-neoplastic disease. This is 617,000 man-rads per year in the United Kingdom (25). The authors of the original report considered that this radiation load to the population could not justifiably be expressed as a *per caput* mean marrow dose (CMD) since only 1.2 persons per thousand in the population receive such treatment in any one year. However, expressed as CMD, it would amount to 11 millirads.

106. The three procedures making the greatest contributions to the total radiation load are the treatment of skin conditions (41 per cent), that of ankylosing spondylitis (25 per cent) and the induction of artificial menopause (20 per cent). The contribution from the treatment of skin conditions arises from a large number of irradiated patients receiving each year mean marrow doses of about 3.3 rads. On the other hand, the treatment of ankylosing spondylitis and the induction of artificial menopause are carried out on relatively small populations, each receiving mean marrow doses of 50-100 rads.

107. The marrow doses resulting from the treatment of neoplastic disease were also considered in the British survey (25). Estimates per treatment course for the main conditions are given in table 33. The estimates were made for treatments carried out at 250 kVp (2mm Cu HVT). No estimates seem to have been made of the bone-marrow dose received from treatments by supervoltage equipment. It is estimated, however, that such treatments will not appreciably increase the bone-marrow doses since similar integral doses are received from 250 kVp therapy and supervoltage therapy for the 100-400 cm^2 fields that are used in the treatment of neoplasms 6 to 9 centimetres deep.

108. An extensive survey of the bone-marrow dose from the radio-therapy of neoplastic disease has been carried out in Japan in 1971 (59). The CMD for the population amounted to 206 millirads. Utilizing a weighting factor to give a "leukæmia-significant" dose (paragraphs 14 and 76) a value of 37 millirads was obtained.

3. *Doses to other organs*

109. The radiation dose received by the skin, or, in the case of supervoltage radiation, by the tissues lying just beneath the skin surface, will be of the same order as the doses to the main treatment volume. By increasing the number of fields the superficial doses can be reduced. Nevertheless, significant radiation may be received by organs such as the lung, the kidney and the tissues of the nervous system and the gastro-intestinal tract which are in a direct beam. The radiation doses received by stomach, pancreas and œsophagus during the treatment of ankylosing spondylitis are currently being estimated in the United Kingdom as part of a study of the cancers occurring in these organs, which are heavily irradiated during the treatment of the spine.

IV. Therapeutic use of radio-pharmaceuticals

110. The two most important radio-nuclides administered to patients for therapy are ^{131}I for thyroid

treatment and ^{32}P for polycythæmia vera. ^{198}Au and ^{90}Y are used in the local treatment of effusions and ^{131}I-lipidiol for endolymphatic therapy.

111. GSDs due to the therapeutic use of radiopharmaceuticals were presented in table XXXII of annex G of the 1962 report. The annual doses were 0.40 millirad in Canada (72), 0.18 millirad in the Federal Republic of Germany (Hamburg) (62), 0.15 millirad in the United Kingdom (26) and 0.24 millirad in the United States (22). The only further information available is from New Zealand (90) where the dose in 1966 was estimated to be 0.047 millirad, from West Berlin (10) where the use of ^{131}I for therapy contributed 0.014 millirad in 1968, and from Japan (2) where ^{131}I was estimated to contribute 0.047 millirad in 1965.

112. Typical values of the gonad doses per millicurie administered for therapy are 0.45-0.6 rad for ^{131}I (17) and 2.6-7.0 rads for ^{32}P (90). The bone-marrow doses per millicurie in the treatment of thyroid cancer has been estimated as 1.7 rads (83) and for intravenously administered ^{32}P the bone-marrow dose is 30 rads per millicurie (64). The use of colloidal gold in malignant diseases and rheumatoid arthritis leads to local doses at the site of injection but to insignificant gonad and bone-marrow doses as long as there is no transport away from the injection site. Endolymphatic therapy is a relatively infrequent form of treatment and the dose to the lung per millicurie administered is about 10 rads (64).

113. Sealed sources of radio-nuclides are also used in the treatment of patients. These sources emit either beta rays, as with ^{90}Sr surface applicators, or gamma rays as with ^{137}Cs tubes and needles inserted into the patient. The gonad and bone-marrow doses received will depend on the distance of the gonads or the bone marrow from the area under treatment, the radionuclide used and the total dose delivered. For a typical treatment of cancer of the cervix using sealed gamma-ray emitters the gonad dose will be 1,800 rads and the individual mean marrow dose about 260 rads (25).

V. Conclusions

114. The aim of medical radiology being to provide maximum benefit to the population served, any increase in frequency of radiological examinations must be justified, particularly in the developing countries. The Committee has examined data on the frequency of diagnostic radiological examinations and noted that in the 10 years since its last review of the subject (148) there has been an increase by a few per cent per year in this frequency in a number of technically advanced countries and that considerably larger increases may have occurred in developing countries. The Committee has also reviewed information on the attendant doses and concluded that an increase in the frequency of x-ray examinations need not be accompanied by a proportionate rise of the population dose.

115. The results of surveys carried out in the various countries are sufficiently in agreement to make it possible to assess within an order of magnitude the average doses resulting from particular examinations. It therefore appears to be questionable whether emphasis should continue to be placed on the need to carry out dose surveys alone or whether more attention should not be given to other means of achieving the minimum practicable dose to the patient commensurate with the needs of diagnostic radiology.

116. Three basic approaches can contribute variously to this improvement depending, in any particular case, on the availability of funds and trained staff —educational programmes, surveys of the frequency of examination and of the doses received, and administrative control measures. Educational programmes can be aimed at (*a*) the radiation staff in the conduct of their day-to-day work; (*b*) the clinical staff that prescribe investigations involving radiation; (*c*) the development in the general public of an awareness of the need for radiation protection. The provision of educational training programmes and the establishment of some administrative control may be much more important than dose surveys, particularly where resources are limited.

APPENDIX [a]

1. A general definition of genetically significant dose has been given in paragraph 9 above.[b] Approximations must be made to calculate this dose, the most obvious being consideration of groups rather than individuals. It is convenient to start with the approximate definition*

$$D = \frac{\sum_j \sum_k \left(N^{(F)}_{jk}\, w^{(F)}_{jk}\, d^{(F)}_{jk} + N^{(M)}_{jk}\, w^{(M)}_{jk}\, d^{(M)}_{jk} \right)}{\sum_k \left(N^{(F)}_{k}\, w^{(F)}_{k} + N^{(M)}_{k}\, w^{(M)}_{k} \right)} \qquad (1)$$

where

D = (annual) genetically significant dose,

N_{jk} = (annual) number of individuals of age-class k, subjected to class j exposure,

N_k = total number of individuals of age-class k,

w_{jk} = future number of children expected by an exposed individual of age-class k subsequent to a class j exposure,

w_k = future number of children expected by an average individual of age-class k,

d_{jk} = gonad dose per class j exposure of an individual of age-class k,

(F) and (M) denote "female" and "male" respectively.

2. For the practical work, formula 1 can be simplified considerably, the first step being to replace the denominator by $w \cdot N$, where

$$w = \frac{N^{(F)}}{N} \cdot w^{(F)} + \frac{N^{(M)}}{N} \cdot w^{(M)} \qquad (2)$$

and

$$w^* = \frac{1}{N^*} \sum_k w^*_k N^*_k \qquad (3)$$

In the last expression, * denotes the sex. N is the total number of individuals of the population. It should be noticed that $w \cdot N$ is about twice the future number of children expected by the present population even though the value of w may be as low as 0.8.

[a] Reprinted from annex G of the 1962 report of the Committee (148).

[b] This definition is reproduced in paragraph 7 of the present annex B.

* The degree of approximation involved in the use of formula 1 depends on the definition of classes j. In theory, there need be no approximation since the classes may be made so restrictive as to include only one individual per class.

3. As formula 1 has w^* in both the numerator and denominator, the numerical value of w has no direct relevance, and all terms can be expressed by help of the ratio w_{jk}/w. For understanding of the demographic background, however, it is valuable to realize that w must be calculated from the sum of the age-group products $\underset{k}{w^*}\ \underset{k}{N^*}$ for a population, which means that an assumption has to be made regarding the expected *future* number of children ($\underset{k}{w^*}$) of an individual in any specified age-group.

4. The assumption could be that the average individual will have a future annual child-expectancy expressed by the present specific annual birth rate. This makes it possible to calculate, by summation, the total future expected number of children of an individual of any age, and hence also the mean for any age-group. If significantly less than unity, the probability of an individual of age a to reach age t should also be considered. This gives

$$\underset{a}{w^*} = \sum_{t=a}^{\infty} \underset{t}{c^*} \cdot \Delta t \cdot \underset{a}{P^*}\ (t) \tag{4}$$

where

$\underset{a}{w^*}$ = expected future number of children of an individual of age a. With knowledge of the function $\underset{a}{w^*}$ of age, the average $\underset{k}{w^*}$ for any age-group k can be calculated,

$\underset{t}{c^*}$ = age-specific annual birth rate, i.e., annual expected number of children of an individual of age-group t,

Δt = number of years included in age-group t,

$\underset{a}{P^*}\ (t)$ = probability of an individual of age a to reach age (group) t.

5. It must be noted that $\underset{t}{c^*}$ may have a tendency to change considerably before an average individual of a specified age has reached the age-group in question. As it is, however, difficult to predict the values for the future, $\underset{t}{c^*}$ has been assumed not to vary with time.

6. $W^* = \underset{a\to 0}{w^*}$ is the number of children expected by the average individual during his whole life. The range of w^* is normally 0.8-2, and the range of W^* is 2-4 for most developed countries. The ratio W/w ranges from 1.5 to 3.

7. The female and male contribution to the genetically significant dose can both be written

$$D^* = \frac{1}{wN} \sum_j \sum_k \underset{jk}{N^*}\ \underset{jk}{w^*}\ \underset{jk}{d^*} \tag{5}$$

8. If the gonad dose due to an examination of type j is nearly uniform for all age-classes k, then

$$\underset{jk}{d^*} = \underset{j}{d^*} \tag{6}$$

approximately for all k, and formula 5 reduces to

$$D^* = \frac{1}{wN} \sum_j \underset{j}{d^*} \sum_k \underset{jk}{N^*}\ \underset{jk}{w^*} \tag{7}$$

or

$$\underset{j}{D^*} = \underset{j}{d^*} \cdot \frac{1}{wN} \sum_k \underset{jk}{N^*}\ \underset{jk}{w^*}$$

where $\underset{j}{D^*}$ is the contribution from type j examination of the specified sex to the genetically significant dose. This again can be written as

$$\underset{j}{D^*} = \underset{j}{d^*} \cdot \frac{\underset{j}{N^*}}{N} \cdot \frac{\underset{j}{w^*}}{w} \tag{8}$$

which is the expression for numerical calculations.

9. The necessary information to make it possible to calculate $\underset{j}{D^*}$ by help of formula 8 is:

(a) $\underset{j}{d^*}$ = the mean gonad dose per individual undergoing class j examination;

(b) $\underset{j}{N^*/N}$ = the relative frequency of class j examination, i.e., the number of examinations *per caput*, per year;

(c) $\underset{j}{w^*/w}$ = the relative child-expectancy of the average individual undergoing class j examination.

The formula is applicable also to fœtal exposure ($w_j = W$) which must not be overlooked.

10. Often d_j varies considerably from hospital to hospital. Most of the uncertainty in estimates of D_j is probably due to the difficulty of estimating a reliable average of d_j for a population.

11. If there are no data on the child-expectancy of the patients, an approximate estimate of $\underset{j}{D^*}$ may be made, under the assumption that the child-expectancy is not influenced by the nature of the condition for which the patient is examined. $\underset{j}{w^*}$ can then be calculated from the age-distribution of the patients and the normal child-expectancy for each age-group,

$$\underset{j}{w^*} = \frac{\sum_k \underset{jk}{w^*}\ \underset{jk}{N^*}}{\underset{j}{N^*}} \approx \frac{\sum_k \underset{k}{w^*}\ \underset{jk}{N^*}}{\underset{j}{N^*}} \tag{9}$$

where w^* can be taken from formula 4. If $\underset{j}{w^*/w}$ is not given in the primary material, it may be recalculated from $\underset{j}{N^*/N}$, d^* and this approximation of $\underset{j}{D^*}$, but will in that case reflect only variations in the age-distribution of the patients examined and not indicate any dependence of child expectation on type of examination.

12. In the case where the age-distribution in an examination class is not known, a yet more simplified assumption may be used, namely

$\underset{k}{w^*} = W^*$ for all persons below mean age of child-bearing,

$\underset{k}{w^*} = 0$ for all persons above mean age of child-bearing.

If n is the total number in the population below the mean age of child-bearing, it follows from formula 3 that

$$w^* = \frac{n^*}{N^*} \cdot W^* \tag{10}$$

which is also, indirectly, a definition of the "mean age of child-bearing". Formula 8 reduces approximately to

$$\underset{j}{D^*} = \frac{\underset{j}{n^*}}{n} \cdot \underset{j}{d^*} = \frac{N}{n} \cdot \frac{\underset{j}{n^*}}{N} \cdot \underset{j}{d^*} \tag{11}$$

TABLE 1. CHILD EXPECTANCY IN THE POPULATION BY AGE AND SEX

New Zealand (118)

Age group	1951 Male	1951 Female	1960-1962 Male	1960-1962 Female	1963-1965 Male	1963-1965 Female	1965-1967 Male	1965-1967 Female
Fœtus	—		3.897		3.598		3.271	
0-14	3.171	3.396	3.710	4.084	3.420	3.776	3.109	3.432
15-19	3.185	3.332	3.686	3.967	3.391	3.631	3.075	3.272
20-24	3.010	2.785	3.385	3.213	3.077	2.880	2.773	2.557
25-29	2.364	1.767	2.487	1.913	2.229	1.696	1.978	1.473
30-34	1.457	0.863	1.390	0.871	1.248	0.786	1.077	0.662
35-39	0.744	0.314	0.652	0.303	0.588	0.282	0.493	0.237
40-44	0.325	0.068	0.270	0.062	0.239	0.060	0.194	0.052
45-49	0.128	0.005	0.101	0.004	0.089	0.004	0.068	0.004
50+	0.02	—	0.013	—	0.012	—	0.004	—

Czechoslovakia 1965 (80)

Age group	Male	Female
0-1	2.37	2.32
1-5	2.41	2.34
5-10	2.42	2.35
10-15	2.43	2.35
15-20	2.43	2.35
20-25	2.42	2.14
25-30	1.85	1.17
30-35	0.98	0.50
35-40	0.43	0.17
40-45	0.16	0.04
45-50	0.06	0.002
50-55	0.02	—
55-60	0.004	—
60-65	$9.6\ 10^{-4}$	—
65-70	$1.4\ 10^{-4}$	—

Thailand 1966 (119)

Age group	Male	Female
0-14	4.58	4.93
15-19	4.53	4.65
20-24	4.18	3.73
25-29	3.34	2.61
30-34	2.29	1.55
35-39	1.42	0.61
40-44	0.76	0.15
45-49	0.30	0.0
50+	0.03	—

Male values estimated on basis of female values

TABLE 2. ANNUAL FREQUENCIES OF X-RAY EXAMINATIONS

(Surveys reviewed in the 1962 report)

Country or area	Year	Population (millions)	Annual number of x-ray examinations per 1,000 of total population: Diagnostic: Radiography	Diagnostic: Fluoroscopy	Mass surveys: Radiography	Mass surveys: Fluoroscopy	Genetically-significant dose in millirads: Diagnostic examinations	Mass surveys	Reference
Argentina									
Buenos Aires	1950-1959	6	270		80		37.0	1.90	105
Denmark	1956-1958	4.5	260		140		27.5	0.05	53
Egypt									
Alexandria	1956-1960	1.4	36		4		7.0	0.09	86
Cairo	1955-1961	2.6	40		5		7.0	0.07	87
Federal Republic of Germany									
Hamburg	1957-1958	1.8	560		130		17.7	0.05	62
France	1957-1958	42	150		40	570	58.2[a]	0.02[b]	111–113
Italy									
Rome	1957	1.9	500		80		43.4	0.93	18
Japan	1958-1960	90	410		320		39.0	0.08	121
Netherlands									
Leiden	1959-1960	0.1	350	200	130		6.8	0.02	13
Norway	1958	3.5	390		210		10.0	0.08	48
Sweden	1955-1957	7.3	290		140		37.8	0.40	82
Switzerland	1957	5.2	310	330	130	60	22.3	0.12	158
United Kingdom	1957-1958	50	280		95		14.1	0.01	26

[a] From radiographic mass survey.
[b] Includes fluoroscopic mass survey.

TABLE 3. ANNUAL FREQUENCIES OF X-RAY EXAMINATIONS AND GENETICALLY-SIGNIFICANT DOSE

(Recent surveys)

Country or area	Year	Population (millions)	Annual number of x-ray examinations per 1,000 of total population: Diagnostic: Radiography	Diagnostic: Fluoroscopy	Mass surveys: Radiography	Mass surveys: Fluoroscopy	Genetically-significant dose millirads per caput y: Diagnostic examinations	Mass surveys	Reference
Czechoslovakia									
Bohemia	1965-1966	4.3	517	79	331		37.0	0.44	80
Federal Republic of Germany									132, 134
Bavaria	1956-1958	9.6	601[a]		267		13.7 (15.1)[b]	0.05	130, 131
Finland	1963-1964	4.5	334		266		16.8		66, 67
Japan	1969	105	610	191	628		25.7	0.8	57
Netherlands	1967	12.6	810				20.0		14, 107
New Zealand	1963	2.5	366		113		13.1		156
	1969	2.8	400		113		13.7		118
Puerto Rico									
Southern region	1968	0.5	414				36.4		45
Western region	1968	0.4	512				48.6		44
Thailand	1970	34.7	39				5.2-1.3		4, 119
United Kingdom									
Sheffield	1964	4.5	310				8.6		89
United States									
National surveys	1964	187	475	56	87		55.0		51, 104, 106, 108
	1970	200	580	65	45				21
Local surveys									
New York City	1962	8	630	100			50.0		102
New Orleans	1962-1963	0.9	825				75.3		69
Johns Hopkins	1965						20.3		97
Texas	1963						16.0		27
Union of Soviet Socialist Republics									
Russian Republic	1964	82	171	439	183		27.0[c]		75
Yugoslavia									
Slovenia	1960-1963	1.5	594	436			9.1		94

[a] One examination in this case = one radiograph.
[b] Later figure to include special children's clinics.
[c] Mean gonad dose per year rather than GSD.

TABLE 4. GENETICALLY-SIGNIFICANT DOSES IN CZECHOSLOVAKIA, 1958-1966 (80)

Type of examination	Frequency (N_j^*/N) 1,000: Male	Frequency (N_j^*/N) 1,000: Female	Gonad dose (d_j^*) mrad: Male	Gonad dose (d_j^*) mrad: Female	GSD (D_j^*) mrad: Male	GSD (D_j^*) mrad: Female	GSD (D_j^*) mrad: Fœtal	Total GSD (D_j) mrad: Total	Total GSD (D_j) mrad: Percentage
Hip	13	17	430	200	4.24	2.46		6.70	18.3
Lumbosacral spine	9	8	490	1,580	2.63	3.80		6.43	17.6
Femur	2	1	2,430	930	4.55	0.43		4.98	13.6
Upper gastro-intestinal tract	15	10	18	670	0.29	3.43		3.72	10.2
Urography (descending)	4	4	380	1,110	2.14	1.52		3.66	10.0
Pelvis	2	2	1,770	700	2.01	0.58		2.59	7.1
Abdomen	5	5	130	540	0.64	0.88		1.52	4.2
Cholecystography	3	8	100	380	0.72	0.80		1.52	4.2
Thorax	11	6	35	65	0.51	0.40		0.91	2.5
Obstetrical abdomen		1		330		0.06		0.06	0.2
Other examinations	424	371						3.04	8.3
Fœtal contribution							1.39	1.39	3.8
	488	432							
TOTAL	920				18.74	16.39	1.39	36.52	100

TABLE 5. GENETICALLY-SIGNIFICANT DOSES IN FINLAND, 1963 (67)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Male	Female	Fœtal	Total	Percentage
Abdomen	8	8	44	790	0.13	1.62	0.72	2.47	14.7
Lower gastro-intestinal tract	3	4	100	1,140	0.27	1.20	0.45	1.92	11.4
Lumbar spine	5	5	200	730	0.40	1.08	0.36	1.84	11.0
Pelvimetry		1		520		0.60	1.03	1.63	9.7
Chest	56	54	13	20	0.52	0.53	0.12	1.17	7.0
Fluoroscopy	17	15	18	93	0.17	0.67	0.15	0.99	5.9
Urography (descending)	2	3	320	270	0.23	0.53	0.08	0.84	5.0
Obstetrical abdomen		2		113		0.22	0.40	0.62	3.7
Lower leg and foot	17	14	29	13	0.41	0.18	0.02	0.61	3.6
Dorsal spine	5	5	150	110	0.30	0.18	0.07	0.55	3.3
Other examinations								4.16	24.7
	302	299							
TOTAL	601				4.23	8.69	3.88	16.80	100

TABLE 6. GENETICALLY-SIGNIFICANT DOSES IN THE FEDERAL REPUBLIC OF GERMANY (BAVARIA), 1957 (130-132, 134)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Male	Female	Fœtal	Total	Percentage
Pelvis	12		1.020	710	2.88	1.65		4.53	33.1
Urography (descending and ascending)	7		740	470	1.07	0.91		1.98	14.4
Hip and upper half of the femur	10		1,100	350	1.76	0.14		1.90	13.9
Middle and lower half of the femur			1	1					
Stomach and small intestine	54		16	120	0.31	1.23		1.54	11.2
Sacrum lumbo sacral spine Dorsal spine	39		65	73	0.69	0.54		1.23	9.0
Large intestine	6		550	1,200	0.44	0.79		1.23	9.0
Abdomen	8		480	57	0.92	0.11		1.03	7.5
Obstetric						0.01	0.02	0.03	0.2
Other examinations	498				0.13	0.10		0.23	1.7
TOTAL	634				8.20	5.48	0.02	13.70	100

TABLE 7. GENETICALLY-SIGNIFICANT DOSES IN THE NETHERLANDS, 1967 (14, 107)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Male	Female	Fœtal	Total	Percentage
Hip, upper femur	5	6	1,200	180	4.06	0.14		4.20	21.0
Urography (descending)	13	11	290	600	1.90	2.10		4.00	20.0
Lumbo sacral spine	19	15	240	560	1.05	2.15		3.20	16.0
Lower gastro-intestinal tract	11	13	230	750	0.48	2.33		2.81	14.0
Pelvis	12	14	190	110	0.71	0.54		1.25	6.2
Stomach and duodenum	31	21	88	180	0.57	0.54		1.11	5.6
Urethrocystography	<1	1	330	1,390	0.14	0.74		0.88	4.4
Lumbar spine	8	6	250	230	0.47	0.30		0.77	3.9
Obstetrical abdomen		1		370		0.40		0.40	2.0
Pelvimetry		<1		700		0.03		0.03	0.2
Other examinations	345	278			0.62	0.73		1.35	6.7
	444	366							
TOTAL	810				10.0	10.0		20.0	100

TABLE 8. GENETICALLY-SIGNIFICANT DOSES IN JAPAN, 1969 (57)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad		Total GSD (D_j^*) mrad	
	Male	Female	Male	Female	Male	Female	Total	Percentage
Intestine	10	8	800	400	3.9	2.7	6.6	24.9
Stomach	157	96	11	130	0.96	5.5	6.46	24.4
Hip joint	7	7	460	120	2.0	0.32	2.32	8.7
Lumbo sacral spine	5	3	530	180	2.0	0.26	2.26	8.5
Lumbar spine	19	10	70	220	0.84	0.88	1.72	6.5
Bladder	3	2	990	160	1.2	0.12	1.32	5.0
Pelvis	2	2	830	200	1.1	0.20	1.30	4.9
Chest	484	408	0.2	0.6	0.73	0.43	1.16	4.4
Obstetrical abdomen		2		250		0.67	0.67	2.5
Pelvimetry		1		460		0.25	0.25	0.9
Other examinations	127	76			1.38	1.10	2.48	9.3
	814	615						
TOTAL	1,429				14.1	12.4	26.5	100

TABLE 9. GENETICALLY-SIGNIFICANT DOSES IN NEW ZEALAND, 1963 (156), 1969 (118)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad						Total GSD (D_j^*) mrad		
					Male		Female		Fœtus				
	Male	Female	Male	Female	1963	1969	1963	1969	1963	1969	Total 1963	Total 1969	Percentage 1969
Pelvis Lumbar spine Lumbo sacral spine	16	32	220	280	1.70	1.78	1.16	1.20	0.13	0.11	2.99	3.09	22.5
Obstetrical abdomen		2		390			0.67	0.69	1.11	1.33	1.78	2.02	14.7
Urography (descending)	4	8	140	380	1.11	1.14	0.62	0.65	0.06	0.05	1.79	1.84	13.4
Abdomen	7	15	380	130	0.75[a]	0.78	0.32	0.33	0.03	0.03	1.10	1.14	8.3
Barium enema	2	6	310	1,260	0.13	0.14	0.83	0.85	0.11	0.09	1.07	1.08	7.9
Pelvimetry		1		590			0.33	0.34	0.39	0.56	0.72	0.90	6.6
Hip, upper femur	2	5	630	110	0.40	0.42	0.06	0.06			0.46	0.48	3.5
Barium meal	10	18	19	252	0.05	0.05	0.35	0.36	0.04	0.03	0.44	0.44	3.2
Other examinations	165	107			0.52	0.55	0.13	0.14	0.02	0.01	0.67	0.70	5.1
	206	194											
TOTAL	400				4.66	4.86	4.47	4.62	1.89	2.21	11.02	11.69	85.2
Chiropractics											1.92	1.92[b]	14.0
Dental radiography											0.10	0.10[b]	0.7
Mass miniature radiography											0.02	0.02	0.1
										GRAND TOTAL	13.06	13.73	100

[a] Corrected 1963 figure.
[b] Upper limits.

TABLE 10. GENETICALLY-SIGNIFICANT DOSES IN THAILAND, 1970 (4, 119)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD maximum (D_j^*) mrad				GSD most probable (D_j^*) mrad			
	Male	Female	Male	Female	Male	Female	Total	Percentage	Male	Female	Total	Percentage
Plain urological	1.4	0.8	300	300	0.86	0.37	1.23	23.8	0.26	0.11	0.37	29.6
Pelvis Lumbar spine Lumbo sacral spine	0.5	0.4	300	420	0.64	0.27	0.91	17.6	0.10	0.08	0.18	14.4
Urography (descending)	0.3	0.2	400	900	0.56	0.19	0.75	14.5	0.06	0.09	0.15	12.0
Abdomen	0.6	0.6	100	200	0.16	0.40	0.56	10.8	0.04	0.08	0.12	9.6
Hip, upper femur	0.4	0.2	700	200	0.40	0.08	0.48	9.3	0.28	0.03	0.31	24.8
Upper gastro-intestinal tract	0.5	0.3	30	60	0.23	0.13	0.36	7.0	0.01	0.01	0.02	1.6
Pelvimetry		<0.1		600		0.14	0.14	2.7		0.02	0.02	1.6
Obstetric abdomen		0.1		300		0.08	0.08	1.5		0.01	0.01	0.8
Other examinations	17.9	14.6			0.39	0.27	0.66	12.8	0.03	0.04	0.07	5.6
	21.6	17.2										
TOTAL	38.8				3.24	1.93	5.17	100	0.78	0.47	1.25	100

TABLE 11. GENETICALLY-SIGNIFICANT DOSES IN THE UNITED KINGDOM (SHEFFIELD), 1964 (89)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad			GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Fœtus	Male	Female	Fœtal	Total	Percentage
Hip, upper femur	3	3	1,220	250	250	2.04	0.29	0.08	2.41	28
Pelvis, lumbo sacral joint, lumbar spine	6	6	150	470	470	0.58	1.22	0.27	2.07	24
Abdomen obstetrical		1		230	200		0.30	0.62	0.92	11
Urography (descending)	3	2	460	310	310	0.53	0.29	0.05	0.87	10
Pelvimetry		0.2		440	710		0.16	0.40	0.56	7
Abdomen	3	3	31	180	180	0.06	0.27	0.05	0.38	4
Barium enema	1	1	95	690	690	0.03	0.20	0.12	0.35	4
Barium meal	3	2	5	200	200	0.01	0.12	0.07	0.20	3
Urography (retrograde)	0.1	0.20	730	390	390	0.13	0.03		0.16	2
Others	173					0.33	0.34	0.03	0.70	7
TOTAL	310					3.71	3.22	1.69	8.62	100

TABLE 12. GENETICALLY-SIGNIFICANT DOSES IN THE UNITED STATES OF AMERICA, 1964 (51, 104, 106, 108)

Type of examination	Frequency[a] (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad			GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Fœtus	Male	Female	Fœtal	Total	Percentage
Lumbar spine Lumbo sacral spine	15		2,550	420	240	21.4	0.6		22.0	40.3
Barium enema	23		1,585	810	810	6.5	2.9		9.4	17.2
Urography (retrograde descending)	24		2,090	410	450	5.1	1.4	0.1	6.6	12.1
Pelvis	No data		720	40	80	3.8		0.2	4.0	7.3
Abdomen	21		250	290	290	2.0	0.4	0.5	2.9	5.3
Lower extremities	54		96			2.6			2.6	4.8
Upper gastro-intestinal tract	30		140	560	540	1.0	1.4		2.4	4.4
Pelvimetry	No data			No data						
Obstetric abdomen	No data			No data						
Other examinations	364					3.0	1.6	0.1	4.7	8.6
TOTAL	531					45.4	8.3	0.9	54.6	100

[a]Deduced by Committee.

TABLE 13. GENETICALLY-SIGNIFICANT DOSES IN PUERTO RICO, 1968 (44, 45)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		Southern region GSD (D_j^*) mrad				Western region GSD (D_j^*) mrad			
	Male	Female	Male	Female	Male	Female	Total	Percentage	Male	Female	Total	Percentage
Lumbar spine	13	7	160	1,190	2.0	7.5	9.5	26.3	0.8	7.9	8.7	17.9
Gastro-intestinal tract	7	9	180	690	1.1	5.7	6.8	18.8	0.5	7.4	7.9	16.9
Urography (descending)	6	6	1,150	760	2.1	4.5	6.6	18.7	3.1	7.6	10.7	22.0
Abdomen	11	16	360	530	1.7	3.0	4.7	13.0	1.3	2.5	3.8	7.8
Barium enema	1	2	1,240	880	1.4	1.5	2.9	8.0	7.6	2.3	9.9	20.4
Pelvimetry		1		1,030		1.1	1.1	3.0		<0.1	<0.1	
Hip	2	2	780	280	1.5	0.4	1.9	5.3	1.6	1.0	2.6	5.4
Pelvis	3	4	760	64	1.4	0.2	1.6	4.4	3.3	0.5	3.8	7.8
Cholecystography	3	7	9	190		0.9	0.9	2.5	0.1	1.0	1.0	2.1
Chest	104	109	1	1	0.1	0.1	0.2	0.5	0.1	0.1	0.2	0.4
Other examinations	64	64										
	214	227										
TOTAL	441				11.2	25.0	36.2	100	18.3	30.3	48.6	100

TABLE 14. GENETICALLY-SIGNIFICANT DOSES IN NEW YORK, 1962 (102)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Male	Female	Fœtal	Total	Percentage
Hip	1	1	1,330	580	13.7	1.6		15.3	30.6
Lumbo sacral spine	2	2	2,020	1,780	9.1	3.1		12.2	24.4
Pelvis	1	1	890	350	9.6	1.0		10.6	21.2
Lumbar spine	No data		190	930	1.1	1.1		2.2	4.4
Upper gastro-intestinal tract	7	7	65	830	0.3	1.7		2.0	4.0
Barium enema	3	4	350	1,110	0.4	1.3		1.7	3.4
Urography (descending)	No data		17	690	0.4	1.3		1.7	3.4
Pelvimetry / Obstetrical abdomen	No data			1,010		3.6		3.6	7.2
Other examinations	701				0.3	0.4		0.7	1.4
TOTAL	730				34.9	15.1		50.0	100

TABLE 15. GENETICALLY-SIGNIFICANT DOSES IN NEW ORLEANS, 1963 (69)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Male	Female	Fœtal	Total	Percentage
Pelvimetry / Obstetrical abdomen		6		1,600		23.3		23.3	31.0
Urography descending, retrograde, cystography	25	25	750	580	5.97	9.00		14.97	19.9
Lower spine			580	660	11.36	3.58		14.94	19.8
Pelvis	35	25							
Hip	480			400	10.76	1.39		12.15	16.1
Barium enema	13	10	380	670	1.70	2.74		4.44	5.9
Upper gastro-intestinal tract	18	19	90	230	0.59	1.63		2.22	3.0
Chest, including mass miniature radiography	240	182	3	9	0.72	1.26		1.98	2.6
Other examinations	124	103			0.40	0.90		1.30	1.7
	455	370							
TOTAL	825				31.5	43.8		75.3	100

TABLE 16. GENETICALLY-SIGNIFICANT DOSES IN TEXAS, 1963 (27)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Male	Female	Fœtal	Total	Percentage
Region									
Lower abdomen					5.5	6.8		12.3	68.0
e.g., Lumbar spine	7	7	230	—					
Pelvis	4	4	260	180					
Urography	12	13	260	340					
Abdomen	8	8	260	300					
Barium enema	11	11	120	850					
Pelvimetry		1		630					
Hysterosalpingography		1		2,700					
Upper abdomen					1.7	2.3		4.0	22.0
Upper gastro-intestinal tract	14	12	55	170					
Chest	113	113	1	2	0.3	0.9		1.2	7.0
Extremities, hip	6	5	520	360	0.4	0.1		0.5	3.0
Other examinations	75	75							
	250[a]	250[a]							
TOTAL	500				7.9	10.1		18.0	100

[a] Assumed equal.

TABLE 17. GENETICALLY-SIGNIFICANT DOSES IN YUGOSLAVIA (SLOVENIA), 1960-1963 (94)

Type of examination	Frequency (N_j^*/N) 1,000		Gonad dose (d_j^*) mrad		GSD (D_j^*) mrad			Total GSD (D_j) mrad	
	Male	Female	Male	Female	Male	Female	Fœtal	Total	Percentage
Pelvis Lumbo sacral spine }	17	19	200	200	3.27	2.37	—	5.64	62
Urography, descending retrograde	5	5	220	290	0.60	0.88		1.48	16
Femur	4	2	230	30	0.48	0.05		0.53	6
Chest (not mass miniature radiography)	227	188	1.4	2.7	0.12	0.28		0.40	4
Hand and wrist	38	18	6	2	0.14	0.01		0.15	2
Cystography	1	1	520	61	0.07	0.06		0.13	1
Hysterosalpingography		2	—	150	—	0.13		0.13	1
Pelvimetry		1	—	500	—	0.01		0.01	1
Other examinations	267	237			0.34	0.32		0.66	8
	558	472							
TOTAL	1,030				5.02	4.11		9.13	100

TABLE 18. MEAN GONAD DOSE PER EXAMINATION IN RECENT SURVEYS

	Male		Female	
	Median value mrad	Range of mean values mrad	Median value mrad	Range of mean values mrad
High gonad dose group				
Barium meal	30	5-230	340	60-830
Urography (descending)	430	15-2,090	590	270-1,160
Retrograde urography ..	580	150-2,090	520	85-1,390
Abdomen	250	12-480	210	57-790
Colon, barium enema ..	300	95-1,590	870	460-1,750
Pelvis	300	100-1,020	230	40-710
Lumbar spine	210	26-2,270	410	230-1,190
Lumbo sacral spine	300	65-2,019	340	73-1,780
Upper femur	920	230-1,710	240	58-680
Obstetrical abdomen ...			300	110-1,600
Pelvimetry			620	230-1,600
Hysterosalpingography ..			1,270	275-2,700
Medium gonad dose group				
Cholecystography	8	1.3-39	120	14-380
Femur lower two thirds	92	1.1-290	1	1-13
Low gonad dose group				
Mass survey chest	0.4	0.2-1.3	3	0.9-11
Chest, heart, lung	0.7	0.1-13	2	0.2-8
Head	Less than 10[a]		Less than 10[a]	
Dental	0.6	0.5-0.7	0.06	0.03-0.1
Extremities	Less than 10[a]		Less than 10[a]	
Mammography			Less than 10[b]	

[a] Reference 65.
[b] Reference 50.

TABLE 19. PERCENTAGE CONTRIBUTIONS TO THE GENETICALLY-SIGNIFICANT DOSE

	Mass survey chest	*Chest, heart, lung*	*Cholecystography*	*Stomach barium meal*	*Urography (descending)*	*Retrograde Pyelography*	*Abdomen*	*Obstetrical abdomen*	*Pelvimetry*	*Colon barium enema*	*Pelvis*	*Lumbar spine*	*Lumbo sacral spine*	*Upper femur, hip*	*Femur*	*Tomography chest*	*Hysterosalpingography*	*Chiropractics*	*Fatal*	*Dental*	*Others*	*Total percentage*	*Total mrad*
Czechoslovakia	1.2	0.4	4.2	10.2	10.0	0.4	4.2	0.2		2.7	7.1		17.6	18.3	13.6	1.0	0.3		3.8	0.3	5.5	100	36.52
Finland	0.9	7.0	2.7	0.6	5.0	1.0	14.7	3.7	9.7	11.4	2.8	11.0	2.2	3.1	0.6		3.0		(23.1)	0.01	21.6	100	16.8
Federal Republic of Germany, Bavaria				11.2	—14.4—		7.5	0.2		9.0	33.1	— 9.0 —		—13.9—							1.7	100	13.7
Netherlands				5.6	20.0	4.4		2.0	0.2	14.0	6.2	3.9	16.0	21.0							6.7	100	20.0
Japan	3.0	1.4		24.4	— 6.6 —		2.6	2.5	0.9	24.9	4.9	6.5	8.5	8.8	1.4						3.6	100	26.5
New Zealand (1969)	0.1			3.2	13.4		8.3	14.7	6.6	7.9	———	22.5	———	3.5				14.0		0.7	5.1	100	13.73
Puerto Rico																							
Southern region ..		0.5	2.5	18.8	18.2		13.0		3.0	8.0	4.4	26.3		5.3								100	36.2
Western region ..		0.4	2.1	16.2	22.0		7.8			20.4	7.8	17.9		5.4								100	48.6
Thailand				1.6	12.0	29.6[a]	9.6	0.8	1.6		———	14.4	———	24.8							5.6	100	1.25
United Kingdom Sheffield				3	10	2	4	11	7	4	———	24	———	28					(5.1)		7	100	8.6
United States				4.4	—12.1—		5.3			17.2	7.3	—40.3—							(0.9)		13.4	100	54.6
New York City ..				4.0	3.4			— 7.2 —		3.4	21.2	4.4	24.4	30.6							1.4	100	50.0
New Orleans	—2.6—			3.0	—19.9—			—31.0—		5.9	16.1	—19.8—									1.7	100	75.3
Texas		7.0		22.0	———				68.0	———				3.0								100	18.0
Yugoslavia, Slovenia	1	4.0			—16.0—						———	62	———		6						11	100	9.1

[a] Plain urological examinations.

TABLE 20. GENETICALLY-SIGNIFICANT DOSES BY COUNTRIES AND SEX CONTRIBUTIONS

	GSD mrad				*GSD percentage*			
	Male	*Female*	*Fœtal*	*Total*	*Male*	*Female*	*Fœtal*	*Total*
Czechoslovakia, Bohemia	18.74	16.39	1.39	36.52	51	45	4	100
Finland	4.23	8.69	3.88	16.80	25	52	23	100
Federal Republic of Germany, Bavaria	8.20	5.48	0.02	13.70	60	40	1	100
Netherlands	10.0	10.0	—	20.0	50	50		100
Japan	14.1	12.4	—	26.5	53	47		100
New Zealand (1969)	4.86	4.62	2.21	13.73[a]	42	39	19	100
Puerto Rico								
Southern region	11.2	25.0		36.2	31	69		100
Western region	18.3	30.3		48.6	38	62		100
Thailand	3.24	1.93		5.17	63	37		100
United Kingdom, Sheffield	3.7	3.2	1.7	8.6	43	37		100
United States	45.4	8.3	0.9	54.6	83	15	2	100
New York City	34.9	15.1		50.0	70	30		100
New Orleans	31.5	43.8		75.3	42	58		100
Johns Hopkins	11.9	11.2		23.1	52	48		100
Texas	7.9	10.1		18.0	44	56		100
Yugoslavia, Slovenia	5.02	4.11		9.13	54	46		100

[a] Includes 2.04 mrad not allocated.

TABLE 21. PERCENTAGE DISTRIBUTION OF ACTIVE BONE MARROW

	Adult, 40 years (37)	*Adult (57)*	*Child, 3-7 years (57)*
Head	13	7	7
Upper limb girdle	8	7	6
Sternum	2	3	3
Ribs	8	14	13
Cervical vertebræ	4	3	3
Thoracic vertebræ	14	13	12
Lumbar vertebræ	11	11	10
Sacrum	14	9	8
Lower limb girdle	26	33	31
Extremities			7
TOTAL	100	100	100

TABLE 22. *Per caput* MEAN BONE-MARROW DOSE (JAPAN) (58)

(mrad per person per year)

		Mean bone-marrow dose				*Leukæmia-significant dose*			
		Male	*Female*	*Total*	*Percentage*	*Male*	*Female*	*Total*	*Percentage*
Skull		0.49	0.25	0.74	0.4	0.42	0.24	0.64	0.4
Cervical spine		0.55	0.28	0.83	0.4	0.50	0.26	0.76	0.5
Shoulder	R	0.38	0.17	0.55	0.3	0.35	0.16	0.51	0.3
	F	0.30	0.19	0.48	0.2	0.39	0.18	0.57	0.3
Thorax	R	0.22	0.16	0.38	0.2	0.20	0.15	0.35	0.2
	F	0.44	0.24	0.68	0.4	0.43	0.24	0.67	0.4
Chest	R	1.6	0.90	2.5	1.3	1.4	0.82	2.22	1.3
	F	5.4	2.2	7.6	4.0	4.4	2.0	6.4	3.8
	PF	10.2	10.0	20.2	10.7	9.4	9.5	18.9	11.2
Œsophagus		0.68	0.49	1.7	0.9	0.57	0.4	1.0	0.6
Stomach	R	11.4	6.1	17.5	0.3	10.2	5.5	15.7	9.3
	F	60.0	40.6	100.6	53.2	53.2	36.5	89.7	53.0
		3.6	3.0	6.6	3.5	3.0	2.7	5.7	3.4
Cholecystography	R	0.59	0.5	1.1	0.6	0.52	0.42	0.9	0.5
	F	3.8	2.2	6.0	3.1	3.5	2.1	5.6	3.3
Abdomen		0.41	0.34	0.75	0.4	0.35	0.30	0.65	0.3
Barium enema	R	0.66	0.58	1.24	0.7	0.59	0.53	1.1	0.7
	F	4.7	4.4	9.1	4.8	4.05	4.00	8.05	4.7
Dorsal spine		0.50	0.46	0.96	0.5	0.45	0.41	0.86	0.5
Lumbar spine		2.9	1.5	4.4	2.3	2.5	1.4	3.9	2.3
Lumbo-sacral spine		0.49	0.32	0.81	0.4	0.43	0.28	0.71	0.4
Pelvis		0.16	0.15	0.31	0.2	0.14	0.13	0.27	0.1
Urography	R	0.44	0.33	0.77	0.4	0.39	0.31	0.70	0.4
	F	0.34	0.12	0.46	0.2	0.30	0.10	0.40	0.2
Bladder		0.12	0.057	0.13	0.1	0.10	0.05	0.15	0.1
Pelvimetry		—	0.13	0.13	0.1	—	0.10	0.10	0.1
Hysterosalpingography	R	—	0.042	0.042	—	—	—	—	—
	F	—	0.37	0.37	0.1	—	0.36	0.36	0.2
Obstetrical abdomen		—	0.17	0.17	0.1	—	0.16	0.16	0.1
Hip		0.22	0.21	0.43	0.2	0.20	0.19	0.39	0.2
Femur		0.013	0.007	0.02	—	0.01	—	0.01	—
Lower leg		0.008	0.005	0.013	—	0.01	—	0.01	—
Other examinations		1.40	0.73	2.13	1.1	1.0	0.76	1.7	1.2
TOTAL		112	77	189	100	99	70	169	100

R = radiography.
F = fluoroscopy.
PF = photofluorography.

TABLE 23. BONE-MARROW DOSE (mrad) PER EXAMINATION

	Japan (58)	Netherlands (153)	United Kingdom (25)		Epp (37, 41)	
			Male	Female	Antero-posterior projection	Lateral projection
Head	29	90	32	39		
Cervical spine	43	8	54	49	10	3
Barium swallow	140	50	1.300	590		
Arm and hand						
Clavicle and shoulder	18		38	81		
Dorsal spine	140	105	200	220	30	90
Whole chest	9	R 10 F 40	12	13	1.3[d]	4.5
Thorax (ribs and sternum)	34	6	180	37		
Barium meal	210	80	510	800		
Cholecystography	73	36	150	150		
Abdomen	59	93	120	130		
Abdomen (obstetric)	72	56		210[a]		
Descending urography	110	433	580	450		
Retrograde urography		257	440	330		
Salpingography	50	282		210		
Placentography						
Pelvimetry	170			280[b]		
Cystography	37	168	170	940		
Barium enema	210	359	530	1,060		
Pelvis	70	138	130	140	70	180
Lumbar spine	150	140	270	270	50	180
Lumbo-sacral joint	92	651	290	220		
Hip and upper femur (upper ⅓)	43	47	57	60	35	
Rest of femur	8					
Leg and foot						
Dental			1.8	1.8		
Angiography (head)			130	130[c]		
Angiography (abdomen)			380[c]	380		
Tomography (chest)			360	390		
Cardiac catheterization			190[c]	190		
Bronchogram			31	31		
Mass survey chest	35	47	61	101		
Mass survey stomach	60					

[a] Fœtal contribution 500 mrad.
[b] Fœtal contribution 1.100 mrad.
[c] Assuming equal frequencies of male and female examinations.
[d] Postero-anterior projection.
R = radiography.
F = fluoroscopy.

TABLE 24. *Per caput* MEAN BONE-MARROW DOSE CONTRIBUTION FROM EXAMINATION TYPE
(mrad per person per year)

	Netherlands (153)		*United Kingdom (25)*			
	Total male and female (mrad)	*Percentage*[a]	*Male (mrad)*	*Female (mrad)*	*Total (mrad)*	*Percentage*[b]
Head	1.14	3.8	0.275	0.258	0.533	
Cervical spine	0.06	0.2	0.155	0.089	0.244	
Barium swallow	0.12	0.4	0.752	0.450	1.202	3.7
Arm and hand						
Clavicle and shoulder			0.097	0.153	0.250	
Dorsal spine	0.3	1.0	0.250	0.342	0.592	
Whole chest: (*a*) Fluoroscopy	8.1	27.0				
(*b*) Radiography	1.11	3.7	1.010	0.827	1.837	5.7
Thorax (ribs and sternum)	0.03	0.1	0.329	0.046	0.375	
Barium meal	2.52	8.4	2.394	3.580	5.974	18.5
Cholecystography	0.48	1.6	0.192	0.326	0.518	
Abdomen	0.57	1.9	0.375	0.395	0.770	
Abdomen (obstetric)	n[c]	n[c]	0.400[d]	0.729	1.129	3.5
Descending urography	3.69	12.3	1.375	0.915	2.290	7.1
Retrograde urography	0.27	0.9	0.143	0.133	0.276	
Salpingography	0.09	0.3		0.043	0.043	
Placentography						
Pelvimetry			0.210[d]	0.315	0.525	
Cystography	0.24	0.8	0.021	0.067	0.088	
Barium enema	3.12	10.4	0.569	1.590	2.159	6.7
Pelvis	0.9	3.0	0.214	0.057	0.271	
Lumbar spine	1.05	3.5	0.999	0.046	1.465	4.5
Lumbo-sacral joint	2.19	7.3	0.645	0.080	0.725	
Hip and upper femur (upper ⅓)	0.18	0.6	0.107	0.172	0.279	
Other examinations			0.593	0.445	1.038	
General diagnostic radiology			11.105	11.478	22.583	
Other hospitals					1.9	
Mass miniature radiography	3.84	12.8			7.8	24.2
TOTAL	30	100			32.3	100

[a] Mean value of HVL and kV determination.
[b] Contributions greater than 3 per cent.
[c] Negligible.
[d] Fœtal contribution.

TABLE 25. *Per caput* MEAN BONE-MARROW DOSE (mrad y^{-1}) IN JAPAN (58)

	Radiography	*Photofluorography*	*Fluoroscopy*	*TV-fluoroscopy*	*Total*
Male	23	14	56	19	112
Female	14	13	35	15	77
TOTAL	37	27	91	34	189

Leukæmia-significant dose (mrad y^{-1} per person)

	Radiography	*Photofluorography*	*Fluoroscopy*	*TV-fluoroscopy*	*Total*
Male	20	13	49	17	99
Female	13	12	32	13	70
TOTAL	33	25	81	30	169

TABLE 26. AVERAGE SKIN DOSE (rad) IN PRIMARY BEAM

	Per exposure		Per examination	
	Median value	Range of average values	Median value	Range of average values
High skin dose group				
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			15	10–22
Pelvimetry	2	0.8–3.8	8	6–10
Lumbo sacral 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 group				
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 group				
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

[a] R min^{-1}.
R = radiography.
F = fluoroscopy.

TABLE 27. ANNUAL NUMBER OF INVESTIGATIONS WITH RADIO-PHARMACEUTICALS PER 1,000 PERSONS

Country	Year	Investigations per thousand	Reference
Australia	1967–1968	5.6	5
	1966–1967	3.3	5
Denmark	1968	7.1	79
	1967	5.7	79
Japan	1968	1.7	73
New Zealand	1966	2.4	90
Sweden	1968	6.1	49
	1970	7.2	152
United States	1966	9.2	22, 142, 143
West Berlin	1960	1.9	10, 11, 60
	1968	10.1	10, 11, 60

TABLE 28. ANNUAL NUMBER OF DIAGNOSTIC INVESTIGATIONS WITH RADIO-PHARMACEUTICALS BY AGE AND SEX IN WEST BERLIN (60)

Age group (years)	Percentage total population		Number of investigations per 1,000 persons					
			^{131}I Thyroid[a]		^{131}I Hippuran[b]		^{198}Au Colloid[c]	
	Male	Female	Male	Female	Male	Female	Male	Female
0-6	3.6	3.4	0.09	0.10	0.09			
7-14	3.5	3.2	0.10	0.49	0.27	0.88		
15-20	3.0	2.9	0.64	7.05	0.53	1.35	0.11	
21-25	4.0	3.5	2.68	12.0	1.22	1.30	0.08	
26-30	4.5	4.1	2.92	15.1	1.07	2.15	0.28	0.08
31-35	3.1	3.0	1.46	13.7	1.16	1.93	0.94	0.11
36-40	2.5	2.7	2.56	15.7	2.18	2.36	0.26	0.47
41-45	2.0	3.2	3.38	14.4	2.08	2.03	0.97	1.12
46-50	1.9	3.3	3.99	12.2	1.83	2.51	1.00	1.07
50	15.4	27.4	2.71	5.96	3.01	2.56	2.24	1.59
TOTAL	43.0	57.0	2.28	7.90	1.77	2.11	1.04	0.95
GRAND TOTAL	100		5.5		1.96		0.99	

[a] Thyroid function test.
[b] Kidney function test.
[c] Liver function test.

TABLE 29. ANNUAL GENETICALLY-SIGNIFICANT DOSE (microrad) DUE TO DIAGNOSTIC USE OF RADIO-PHARMACEUTICALS IN NEW ZEALAND (90)

Test	Male	Female	Fœtus	Total	Percentage
Thyroid uptake and scan	2.4	1.8	0.16	4.4	29.0
Brain scan	3.3	1.4	0.22	4.9	32.2
Liver scan	0.23	0.76	0.04	1.03	6.8
Kidney scan	0.04	0.056		0.096	0.7
Schilling test	0.024	0.044	0.004	0.072	0.5
Renogram	0.003	0.88	0.25	1.13	7.5
Blood volume	0.012	1.7	1.2	2.9	19.0
Red cell survival	0.032			0.032	0.2
Bone scan		0.052		0.052	0.3
Lung scan	0.008	0.024		0.032	0.2
Exchangeable sodium	0.012	0.028		0.040	0.2
Miscellaneous	0.044	0.45	0.024	0.52	3.4
TOTAL	6.1	7.2	1.9	15.2	100

TABLE 30. GENETICALLY-SIGNIFICANT DOSE DUE TO RADIO-PHARMACEUTICALS IN WEST BERLIN 1968 (10)

Product	Percentage
^{131}I therapy	10.0
^{131}I diagnostic	23.5
^{75}Se methionine	23.2
^{198}Au colloid	11.6
^{131}I macro-aggregate of human serum albumin	9.9
^{57}Co ^{58}Co B-12 vitamin	5.3
^{197}Hg ^{203}Hg neohydrin	4.6
^{131}I Hippuran	4.0
^{99m}Tc	2.7
^{51}Cr	2.5
^{59}Fe	2.4
^{132}I	0.3
GSD=0.14 mrad	100

TABLE 31. RADIO-THERAPY OF NON-NEOPLASTIC DISEASE: MEAN MARROW DOSE PER TREATMENT COURSE[a] (25)

Condition treated	*Head and trunk only*								*All cases*							
	Children				*Adults*				*Children*				*Adults*			
	Males		*Females*		*Males*		*Females*		*Males*		*Females*		*Males*		*Females*	
	No.	*Mean dose rad*	*No.*	*Mean dose rad*	*No.*	*Mean dose rad*	*No.*	*Mean dose rad*	*No.*	*Mean dose rad*	*No.*	*Mean dose rad*	*No.*	*Mean dose rad*	*No.*	*Mean dose rad*
1. Skin conditions																
Growths	27	14.6	21	10.0	52	4.8	80	7.6	91	4.3	125	1.7	110	2.3	185	3.3
Allergic and inflammatory	10	10.8	13	23.3	201	10.4	230	7.9	26	4.2	18	16.8	600	3.5	578	3.2
Ringworm	5	92.0	1	62.5	2	36.0	—	—	6	76.0	2	31.3	4	18.0	3	18.0[b]
Others	1	49.0	1	5.6	38	6.9	38	4.3	1	49.0	1	5.6	65	4.0	115	1.4
2. Glandular enlargements	—	—	2	6.2	7	5.5	1	5.9	—	—	2	6.2	7	5.5	1	5.9
3. Ankylosing spondylitis	—	—	—	—	70	83.6	14	59.5	—	—	—	—	70	83.6	14	59.5
4. Arthritic and rheumatic	—	—	—	—	23	27.1	29	22.0	—	—	—	—	33	18.9	42	15.1
5. Artificial menopause	—	—	—	—	—	—	74	51.5	—	—	—	—	—	—	74	51.5
6. Deafness	5	9.4	2	8.6	7	3.5	10	3.7	5	9.4	2	8.6	7	3.5	10	3.7
7. Other non-malignant	1	2.6	2	282.0	15	20.9	35	27.6	1	2.6	2	282.0	23	13.6	37	26.2

[a] The computer programme was adapted to make an approximate estimate of the bone-marrow dose from small treatment areas which receive high doses.
[b] Assumed male value in absence of data.

TABLE 32. RADIO-THERAPY OF NON-NEOPLASTIC DISEASE: TOTAL PATIENT-RADS EXPOSURE PER YEAR (25)[a]

X-ray treatments	Patient rads per year ($\times 10^3$)					
	Contribution					
	Male		Female		Total	Percentage
	Children	Adults	Children	Adults		
1. Skin conditions						
(a) Growths, etc.	9.8	5.5	6.1	12.2	33.6	5.4
(b) Allergic and inflammatory etc.	4.3	72.6	14.6	80.5	172	27.8
(c) Ringworm	20.8	1.8	1.2	3.7	27.5	4.5
(d) Others	4.3	8.5	1.2	3.7	17.7	2.9
2. Glandular enlargements etc.	n[b]	n	n	n	n	n
3. Ankylosing spondylitis	—	133	—	22	155	25.1
4. Arthritic and rheumatic, etc.	n	16.5	n	17.1	33.6	5.5
5. Artificial menopause	—	—	—	126	126	20.4
6. Deafness	2.4	n	1.8	n	4.2	0.7
7. Any other non-malignant conditions	n	9.8	12 8	25	47.6	7.7
					617.2	100

[a] This total exposure in patient-rads per year is obtained by multiplying the mean marrow dose per treatment course with the number of patients treated per year.
[b] n=less than 10^3 patient-rads.

TABLE 33. RADIO-THERAPY OF NEOPLASTIC CONDITIONS: MEAN MARROW DOSE PER TREATMENT COURSE (25)

Malignant conditions	Marrow dose (rad)	
Buccal cavity and pharynx	114	
Œsophagus	320	
Stomach	157	
Small intestine	77	
Large intestine	70	
Rectum	31	
Other digestive	106	
Nose, etc.	47	
Larynx	40	
Trachea, etc.	399	
Other respiratory	392	
Breast: male	10	
female	19	
Cervix[a]	Radium 260 / X rays 208	468
Other uterus	276	
Ovary	198	
Prostate	94	
Testis	476	
Kidney	79	
Bladder	223	
Eye	13	
Brain	109	
Thyroid	62	

[a] For the treatment of the cervix uteri a standard Manchester technique irradiation of 9100 mghrs has been assumed in addition to two supplementary fields to the parametrium. The marrow dose from the radium treatment was deduced from Holodny *et al.* (61a).

REFERENCES

1. Andrews, P. S. Radiation induced basal cell squamous carcinoma. M.D. thesis, London University, 1958.
2. Anno, Y., A. Takeshita and M. Iwamoto. Medical use of radio-isotopes in Japan, especially for treating hyperthyroidism and evaluation of the consequent radiation risk. Gann Monograph 9: 241-253 (1970).
3. Annual Report for the year 1968. R.P.S. AR.2. Ministry of Public Health, Bangkok, Thailand, 1968.
4. Annual Report for the year 1969. R.P.S. AR.3. Ministry of Public Health, Bangkok, Thailand, 1969.
5. Annual Report of the National X-ray and Radium Laboratory, Melbourne, 1968.
6. Antoku, S. and R. C. Milton. Dose to bone marrow and gonads from chest examinations. Atomic Bomb Casualty Commission, Technical Report 4/67 (1967).
7. Antoku, S., H. Yoshinaga and W. J. Russell. Bone marrow and gonadal dose in roentgenography excluding posteroanterior chest examinations. Atomic Bomb Casualty Commission, Technical Report 5/68 (1968).
8. Ardran, G. M. and H. E. Crooks. A comparison of radiographic techniques with special reference to dosage. Brit. J. Radiol. 26: 352 (1953).
9. Ardran, G. M., J. Hamill, E. Emrys-Roberts *et al.* Radiation dose to the patient in cardiac radiology. Brit. J. Radiol. 43: 391-94 (1970).
10. Aurand, K. and G. Hinz. Erhebungen über die Entwicklung der Anwendung offener Radionuklide in Diagnostik und Therapie. Bundesgesundheitsblatt 13: 30-33 (1970).
11. Aurand, K. and G. Hinz. Paper presented at the 7th Congress of the Intern. Society for Nuclear Medicine, Zurich, 25-27 Sept. 1969.
12. Baro. G. B., J. G. Flegenheimer. Survey of Radioisotope applications in Latin America. Isotop. Radiat. Technol. 7: 465-468 (1970).
13. Beekman, Z. M. Genetically significant dose from diagnostic roentgenology (A study concerning a defined population in the Netherlands). Leiden, Neder. Inst. v. Praevent. Geneesk. 53 (1962).
14. Beentjes, L. B. An estimate of G.S.D. in the Netherlands (1967). Thesis. Utrecht. 1969.
15. Beretning om Laboratoriets Virksomhed for tiden 1 April 1966-31 Marts 1970. Radiation Hygiene Laboratory, Copenhagen (1970).
16. Berger, M. J. Energy deposition in water by photons from point isotropic sources. Medical Internal Radiation Dose (MIRD) Committee. Pamphlet No. 2. Journal of Nuclear Medicine (1968).
17. Berman, M., D. V. Becker and R. S. Benna. The use of I^{133} in the treatment of Graves' disease. J. Clin. Endoc. 17: 1222-1228 (1957).
18. Biagini, C., M. Barilla, A. Montanara. Zur genetischen Strahlenbelastung der Bevölkerung Roms durch die Röntgendiagnostik. Strahlentherapie 113: 100-109 (1960).
19. Brown, M. L. and A. B. Nelson. Medical x-ray visits and examinations during pregnancy, U.S. Department of Health. Education and Welfare, National Center for Health Statistics Series 22 Number 5.
20. Brownell, G. L., W. H. Ellett and A. R. Reddy. Absorbed fractions for photon dosimetry. Medical Internal Radiation Dose (MIRD) Committee. Pamphlet No. 3. Journal of Nuclear Medicine (1968).
21. Bureau of Radiological Health, Department of Health, Education and Welfare. Information provided by J. C. Villforth.
22. Chamberlain, R. H. Gonadal radiation in the genetically significant portion of the population derived from radioactive isotope procedures in medicine, p. 885-888 *in* The nature of radioactive fallout and its effects on man. Hearings, 85th Session, U.S. Congr. Jt Cttee. Atomic Energy, Spec. Subcttee Rad. (May 1957), vol. 1.
23. Cocco, A. E. and A. I. Mendeloff. Effects of gastric irradiation in duodenal ulcer patients: gastric secretory response to maximal histamine stimulation during a three-year period. Johns Hopkins Med. J. 126, 2, p. 61-68 (1970).
24. Coll, W. S. The judicious use of diagnostic radiation in the healing arts. Amer. J. Public Health 59: 1199-1203 (1969).
25. Committee on Radiological Hazards to Patients. Final report of the Committee. London. H.M. S.O. (1966).
26. Committee on the Radiological Hazards to Patients. Second report of the Committee. London. H.M.S.O. (1960).
27. Cooley, R. N. and L. B. Beentjes. Weighted gonadal diagnostic roentgen ray doses in a teaching hospital with comments on x-ray dosages to the general population of the United States. Am. J. Roentgenol. 92: 404-417 (1964).
28. Cox. D. W. An investigation of possible genetic damage in the offspring of women receiving multiple diagnostic pelvic x rays. Am. J. Human Genet. 16: 214-230 (1964).
29. Custer. R. P. Atlas of Blood and Bone Marrow. p. 29. W. B. Saunders Co., New York (1949).
30. Diagnostic dental x-rays and the patient—an overview. Bureau of Radiological Health. Rad. Health Data. Jan. 1970.

31. Dillman, L. T. Radionuclide decay schemes and nuclear parameters for use in radiation-dose estimation. Medical Internal Radiation Dose (MIRD) Committee. Pamphlet No. 4 (1969).

32. Dillman, L. T. Radionuclide decay schemes and nuclear parameters for use in radiation-dose estimation. Part 2. Medical Internal Radiation Dose (MIRD) Committee. Pamphlet No. 6. (1970).

33. Doll, R. and P. G. Smith. The long-term effects of x-irradiation in patients treated for metropathia haemorrhagica. Brit. J. Radiol. 41: 362-368 (1968).

34. Duggan, H. E. and G. L. Olde. Radiation dose to the skin and to the gonads from diagnostic x-ray procedures. Canad. Med. Assoc. J. 89: 1144-7 (1963).

35. Eleven recommendations of radiographic examination in oral diagnosis. N. Y. J. Dent. 38: 101 (1968).

36. Eleventh annual report 1966-1967, p. 59-60. Atomic Energy Commission, Japan.

37. Ellis, R. E. The distribution of active bone marrow in the adult. Phys. Med. Biol. 5: 255-258 (1961).

38. Ellis, R. E. The estimation of ovary dose received during diagnostic x-ray examinations from measurements of the iliac crest dose and skin dose. Adrian Committee Internal Report, 9/5/60/S (1960).

39. Ellis, R. E. The use of a computer to carry out the computation of ovary dose in the Adrian Committee Survey. Adrian Committee Internal Report, 10/5/60/S (1960).

40. Ellis, R. E. and M. Healey. Unpublished.

41. Epp, E. R., J. M. Heslin, J. S. Laughlin *et al.* Measurement of bone marrow and gonadal dose from x-ray examinations of the pelvis, hip and spine as a function of field size, tube kilovoltage and added filtration. Brit. J. Radiol. 36: 247-265 (1963).

42. Exposure of man to ionizing radiation arising from medical procedures. Report of the ICRP and ICRU. Phys. Med. Biol. 2: 107-151 (1957).

43. Exposure of man to ionizing radiation arising from medical procedures with special reference to radiation induced diseases. Report of the ICRP and ICRU Phys. Med. Biol. 6: 199-258 (1961).

44. Evaluation of health hazards due to unintentional irradiation of the gonads during routine abdominal x-ray examinations of male and female patients in Puerto Rico. Report No. 1. Western Region. Nuclear Center Department of Health, Commonwealth of Puerto Rico (1969).

45. Evaluation of health hazards due to unintentional irradiation of the gonads during routine abdominal x-ray examinations of male and female patients in Puerto Rico. Report No. 2. Southern Region. Nuclear Center Department of Health, Puerto Rico (1970).

46. Faber, M. A follow-up of 1,000 thorotrast cases in Denmark, Proc. 1st Intern. Congress of Radiation Protection, 1966, p. 1521-1524, Pergamon Press, 1968.

47. Fendel, H. Radiation problems in roentgen examinations of the chest. Prog. Pediat. Radiol. 1: 18-32 (1967).

48. Flatby, J. Genetically significant dose in x-ray diagnosis in Norway. In press.

49. Garby, L., B. Nosslin and S. Löfveberg. Data on dose to organs/μCi administered and statistical data. Swedish Institute of Radiation Protection, 1969.

50. Gilbertson, J. D., M. G. Randall and A. G. Fingerhut. Evaluation of roentgen exposure in mammography. Radiology 95: 383-394 (1970).

51. Gitlin, J. N. and P. S. Lawrence. Population exposure to x-rays, U.S. 1964. A report of the Public Health Service X-ray Exposure Study. United States Department of Health, Education and Welfare. PHS Publication No. 1519 (1966).

52. Gough, J. H., R. Davis and A. J. Stacey. Radiation doses delivered to the skin, bone marrow and gonads of patients during cardiac catheterisation and angiocardiography. Brit. J. Radiol. 41: 508-518 (1968).

53. Hammer Jacobsen, E. Genetically significant radiation doses in diagnostic radiology. Acta Radiologica, Suppl. 222 (1963).

54. Hashimoto, M., K. Yamada *et al.* Distribution of red marrow and its weight. (Estimation of population dose due to diagnostic x rays in Japan.) Annual Reports of Scientific Research Grants 1963 (1964).

55. Hashizume, M. Reduction of patient dose. Proc. 17th Japanese Med. Congress V: 801-839 (1967).

56. Hashizume, T. and Y. Kato. Bone marrow dose in photofluorography in Japan. Nippon Acta Radiolog. 25: 991-7 (1965).

57. Hashizume, T., Y. Kato, T. Maruyama *et al.* Genetically significant dose for diagnostic medical x-ray examinations in Japan, 1969; United Nations document A/AC.82/G/L.1388.

58. Hashizume, T., Y. Kato, T. Maruyama *et al.* Population mean marrow dose and leukæmia significant dose from diagnostic medical x-ray examinations in Japan 1969; United Nations documents A/AC.82/G/L.1389 and A/AC.82/G/L.1389/Corr.1.

59. Hashizume, T., Y. Kato, H. Yamaguchi *et al.* Population doses from teleradiotherapy in Japan 1971: United Nations document A/AC.82/G/L.1396.

60. Hemphill, F. M., F. B. Locke and R. D. Hesselgren. Diagnostic radiation utilization in selected short-term general hospitals. U.S. Department of Health, Education and Welfare, BRH/DBE 70-8 (1970).

61. Hinz, G. Unpublished.

61a. Holodny, E., H. Lechtman and J. S. Laughlin. Bone-marrow dose produced by radioactive isotopes. Radiol. 77:1-11 (1961).

62. Holthusen, H., H. H.-K. Leetz, W. Leppin. Die genetische Belastung der Bevölkerung einer Grosstadt (Hamburg) durch medizinische Strahlenanwendung, Schriftenreihe des Bundesministers für Atomkernenergie und Wasserwirtschaft. Strahlenschutz, Heft 21 (1961).

63. Hunt, A. B. *et al.* Cancer cervix in 3rd trimester of pregnancy. Clin. Obstet. Gyn. 6: 964-974 (1963)
64. International Commission on Radiological Protection. Protection of patient in radio-nuclide investigations. ICRP Publication 17, Pergamon Press (1971).
65. International Commission on Radiological Protection. Protection of the patient in x-ray diagnosis. ICRP Publication 16. Pergamon Press (1970).
66. Isola, A. On the extent of X-ray examinations in Finland. Proc. 1st Intern. Cong. of Radiation Protection. 1966, p. 1321-1324, Pergamon Press. 1968.
67. Isola, A. and O. Ojala. The genetically significant dose from roentgen examination in Finland in 1963. Acta Radiologica, 254: 120-130.
68. Iya, V. K., R. G. Deshpande. Radioisotope program in India. Isotop. Radiat. Technol. 7: 452-457 (1970).
69. Izenstark, J. L. and W. Lafferty. Medical radiological practice in New Orleans: estimates and characteristics of visits, examinations and genetically significant dose. Radiol. 90: 229-242 (1968).
70. Jankowski, J. and J. Liniecki. The frequency of radiography of the pelvic region in pregnant women in the city of Lodz and the province of Lodz and the exposure of the fœtus to x rays connected with it. Zdrowie Pub. 8: 707-716 (1970).
71. Jayerwardene, R. P. Unpublished.
72. Johns, H. E., R. M. Taylor. Gonadal dose in Canada arising from the clinical use of unsealed radioactive isotopes. J. Can. Assn. Radiologists 9: 55-58 (1958).
73. Kakehi, H. Nuclear medicine in Japan, past, present and future. XII Intern. Cong. Radiol., Tokyo, 1969.
74. Kaude, J. V., E. Lorenz and J. M. Reed. Gonad dose to children in voiding urethrocystography performed with 70-mm image-intensifier fluorography. Radiol. 92: 771-774 (1969).
75. Konganz, A. N., L. N. Gorelova and V. Ya. Gotlib. Radiation doses to patients and criterion for maximum permissible dose. Med. Radiol. 11.8: 77-84 (1966).
76. Koren, C. and S. Mandal. Genetically significant dose following radio-therapy. Abstract 305. 11th Intern. Cong. Radiology. Excerpta Medica International Congress Series No. 89, p. 166 (1965).
77. Krishnamoorthy, P. N. Radiological protection problems in the developing countries, Health Phys. 21: 163-171 (1971).
78. Kriss, J. P., R. Barrall, R. Greenberg *et al.* Guidelines and criteria for a Committee authorizing the use of radioactive isotopes in humans. J. Nucl. Med. 8: 70-73 (1967).
79. Kristensen, K. Nuclear medicine in Danish hospitals, 1969.
80. Kunz, E. and V. Michal. Exposure of the population of the CSSR to ionizing radiation in x-ray diagnostics; United Nations document A/AC.82/G/L.1322.
81. Kunz, E. Unpublished.
82. Larsson, L.-E. Radiation doses to the gonads of patients in Swedish roentgen diagnostics: studies on magnitude and variation of the gonad doses together with dose reducing measures. Acta Radiol., Suppl. 157: 7-127 (1958).
83. Lewallen, C. G. Some observations on radiation dose to bone marrow during I^{131} therapy of thyroid cancer. Am. J. Roentgen. 89: 618-623 (1963).
84. Loevinger, R., M. Berman. Schema for absorbed-dose calculations for biologically-distributed radionuclides. Medical Internal Radiation Dose (MIRD) Committee. Pamphlet No. 1. Journal of Nuclear Medicine (1968).
85. Mackenzie, I. Breast cancer following multiple fluoroscopies. Brit. J. Cancer 19: 1-8 (1965).
86. Mahmoud, K. A., M. M. Mahfouz, I. R. Atiyah *et al.* Report on genetically significant dose from diagnostic radiology in Cairo and Alexandria. U.A.R. Scientific Committee on the Effects of Atomic Radiation on Man, Vol. 4-2 (1962).
87. Mahmoud, K. A., M. M. Mahfouz, M. E. Mahmoud *et al.* Gonadal and bone marrow dose in medical diagnostic radiology. U.A.R. Scientific Committee on the Effects of Atomic Radiation on Man, Vol. 3-1 (1961).
88. Marinelli, L. D. Dosimetry in relation to epidemiology: its implications in radiogenic leukemias and bronchial carcinoma (thorotrast). Annual report July 1966-June 1967, Radiological Physics Div., Argonne Nat. Laboratory, ANL-7360, 37-44 (1967).
89. Matthews, J. C. and H. Miller. Radiation hazards from diagnostic radiology. A repeat survey over a small area. Brit. J. Radiol. 42: 814-817 (1969).
90. McEwan, A. C. Unsealed radioisotopes in medical practice in New Zealand. Publication NRL/PDS/1967.
91. Mechanik, N. Untersuchungen über das Gewicht des Knochenmarkes des Menschen. Zeitschrift für die Gesamte Anatomie 79 (Abt.1): 58-90 (1926).
92. Medical radionuclides: radiation dose and effects. (Cloutier, R. J., C. L. Edwards and W. S. Snyder, eds.). United States Atomic Energy Commission. Div. Technical Information. AEC Symposium Series 20 (1970).
93. Memorandum on implementation of the second report of the Adrian Committee on radiological hazards to patients. Brit. J. Radiol. 37: 559-561 (1964).
94. Milhailović, M., M. Pavlic, M. V. Milhailović *et al.* Radiation doses to the gonads of patients from diagnostic radiology in Yugoslavia. Proc. XI. International Cong. Radiol. Excerpta Med. ICS No. 105: 1547-1561 (1967).
95. Miyakawa, T. Population dose from medical exposures in Japan (bone marrow dose and genetically significant dose). Proc. XI Intern. Cong. Radiol. Excerpta Med. ICS No. 105: 1574-1579 (1967).
96. Moroni, J. P. and M. L. Remy. Doses délivrées lors des examens médicaux mettant en cause des radioéléments ostéotropes. Rapport SCPRI No. 131 (1971).

97. Morgan, R. H. and J. C. Gehret. The radiant energy received by patients in diagnostic x-ray practice. Am. J. Roentgenol. 97: 793-810 (1966).

98. Osborn, S. B. A study of radiation hazards to large populations with special reference to diagnostic radiology. Ph. D. Thesis. University of London, 1960.

99. Osborn, S. B. The implication of the reports of the Committee on radiological hazards to patients (Adrian Committee). I. Variations in the radiation dose received by the patient in diagnostic radiology. Brit. J. Radiol. 36: 230-234 (1963).

100. Osborn, S. B. and R. E. Ellis. Protection from ionizing radiation. Chapter 29. The science of ionizing radiation (Etter, L. E., C. Thomas, eds.), Illinois, USA, 1965.

101. Palmer, R. C., R. L. Egan and B. J. Barrett. Preliminary evaluation of absorbed dose in mammography. Radiology 95: 395-397 (1970).

102. Pasternack, B. S. and M. B. Heller. Genetically significant dose to the population of New York City from diagnostic medical radiology. Radiology 90: 217-228 (1968).

103. Pavlov, A. S. The principles of regulation and of reducing the levels of irradiation of patients examined with the use of radioactive preparations with diagnostic aims. Paper to WHO group, 1969.

104. Penfil, R. L. and M. L. Brown. Genetically significant dose to the United States population from diagnostic medical roentgenology, 1964. Radiology 90: 209-216 (1968).

105. Placer, A. E. Dosis genéticamente significativa debida al radio-diagnóstico médico. República Argentina, Comisión Nacional de Energía Atómica, Informe No. 49, Buenos Aires, 1961.

106. Population dose from x rays, U.S. 1964. Estimates of gonad dose and genetically significant dose from the Public Health Service X-ray Exposure Study. United States Department of Health, Education and Welfare. PHS Publication No. 2001 (1969).

107. Puylaert, C. B. A. J. De Expansie van de Röntgendiagnostick. Medisch Contract, 1969/24/685. Medicamundi 14, 3, 137-149 (1969).

108. Radiation bio-effects. Summary report Jan-Dec. 1969. United States Department of Health, Education and Welfare. PHS Publication No. BRH/DBE 70-1 (1970).

109. Radiological hazards to patients. Lancet 2: 1325-1326 (1964).

110. Reboul, J., G. Delorme, Y. Meilhan *et al.* Doses gonades résultant de l'utilisation des radiations ionisantes en France. 3. Radiothérapie. Ann. Radiol. 3: 293-304 (1960).

111. Reboul, J., G. Delorme, J. Tavernier *et al.* Doses gonades résultant de l'utilisation des radiations ionisantes en France. II. Radioscopie. Ann. Radiol. 3: 89-99 (1960).

112. Reboul. J., J. Tavernier, G. Delorme *et al.* Doses gonades résultant de l'utilisation des radiations ionisantes en France. I. Radiodiagnostic (suite et fin). Ann. Radiol. 2: 571-584 (1959).

113. Reboul, J., J. Tavernier, Y. Istin *et al.* Doses gonades résultant de l'utilisation des radiations ionisantes en France. I. Radiodiagnostic Ann. Radiol. 2: 179-196 (1959).

114. Recommendations of the International Commission on Radiological Protection. Protection against ionizing radiations from external sources. ICRP. Publication 15, Pergamon Press (1970).

115. Reduction of radiation exposure in nuclear medicine. United States Department of Health, Education and Welfare. PHS Environmental Health Series. Radiological Health. Publication No. 99-RH-30, 1967.

116. Reekie, D., M. Davison and J. K. Davidson. The radiation hazard in radiography of the female abdomen. Brit. J. Radiol. 40: 849-854 (1967).

117. Report of the Working Party on the Organization of Radioactive Isotope Services, London, H.M.S.O., 1970.

118. Report on radiation control and population dose in New Zealand. National Radiation Laboratory, Christchurch, NRL UN/2 (1970).

119. Report on some aspects of radiation protection and population exposure in Thailand. Ministry of Public Health, Thailand, Radiation Protection Service, Department of Medical Sciences, 1970.

120. Report to the Surgeon General. U.S. PHS. Protecting and improving health through the radiological sciences. National Advisory Committee on Radiation. United States Department of Health, Education and Welfare. Public Health Service. Washington D.C., 1966.

121. Research Group on the Genetically Significant Dose by the Medical Use of X-ray in Japan. The genetically significant dose by the x-ray diagnostic examination in Japan (March 1961).

122. Resolution of the 24th World Health Assembly WHA 24.31 sixteenth plenary meeting A24/VR/16, 18 May 1971.

123. Rogers, R. T. Radiation dose to the skin in diagnostic radiography. Brit. J. Radiol. 42: 511-518 (1969).

124. Russell, W. J., H. Yoshinaga *et al.* Active bone marrow distribution in the adult. Brit. J. Radiol. 39: 735-739 (1966).

125. Sagerman, R. H., J. R. Cassady, P. Tretter *et al.* Radiation induced neoplasia following external beam therapy for children with retinoblastoma. Am. J. Roentgenol. 105: 529-535 (1969).

126. Sanders, A. P., K. Sharpe, K. Cahoon *et al.* Radiation dose to the skin in diagnostic procedures. Am. J. Roentgenol. 84: 359-368 (1960).

127. Sawada, S., T. Wakabayashi and W. J. Russell, Photofluorography techniques in hospitals and clinics. Atomic Bomb Casualty Commission, Technical Report 3/68 (1968).

128. Schoen, D. On the dependence of radiation exposure on the experience of the examiner and on the characteristics of the patient. Strahlenschutz Forsch. und Prax., 7: 31-48 (1967).

129. Scholte, P. J. L., A. van Vianen, J. W. E. Vos *et al.* Genetically significant dose from radiotherapy in the Netherlands, 1942-1951. Brit. J. Radiol. 36: 622-623 (1963).

130. Seelentag, W. Die gegenwartige Exposition der Bevölkerung durch die medizinische Strahlenanwendung und ihre Bedeutung. Strahlentherapie 52: 326-333 (1963).

131. Seelentag, W., D. V. Arnim, E. Klotz *et al.* Zur Frage der genetischen Belastung der Bevölkerung durch die Anwendung ionisierender Strahlen in der Medizin, II. Teil: Messungen über die bei röntgendiagnostischen Untersuchungen an die Gonaden gelangenden Dosen. Strahlentherapie 105: 169-195 (1958).

132. Seelentag, W., E. Seelentag-Lupp and E. Klotz. Zur Frage der genetischen Belastung der Bevölkerung durch die Anwendung ionisierender Strahlen in der Medizin, V. Teil: Werte und Schwankungsbreiten von Untersuchungsfrequenzen und gemessenen Dosen in 10 grossen und kleinen Krankenhäusern und in der freien röntgenologischen Praxis. Strahlentherapie 111: 435-467 (1960).

133. Seelentag, W. On the importance of the radiation burden of a population with special reference to the genetically significant dose from application of radiation in medicine. Progress in Nucl. Energy. Series XII. Health Physics, Vol. 2, Part I: 125-155 (1969).

134. Seelentag, W., T. Numberger, D. Knorr *et al.* Zur Frage der genetischen Belastung der Bevölkerung durch die Anwendung ionisierender Strahlen in der Medizin, IV. Teil: Die Strahlenbelastung durch die Röntgendiagnostik in Kinderkliniken. Strahlentherapie 107: 537-555 (1958).

135. Seyss, R. Radiation exposure in radiography of the gastrointestinal tract. Radiol. Aust. 17: 135-142 (1967).

136. Sobels, F. H. Estimation of the genetic risk resulting from the treatment of women with ^{131}Iodine. Strahlentherapie 138: 172-177 (1969).

137. Stanford, R. W., K. Twinn and C. B. Allsopp. Some problems encountered in the investigation of gonad doses received by patients undergoing dental x-ray examinations. Brit. J. Radiol. 35: 366-371 (1962).

138. Stevens, D. J. and D. W. Keam. Unpublished.

139. Stewart, A., G. W. Kneale. Radiation dose effects in relation to obstetric x-rays and childhood cancers. Lancet 1: 1185-1188 (1970).

140. Stewart, A. M., G. W. Kneale. Age distribution of cancers caused by obstetric x-rays and their relevance to cancer latent periods. Lancet 2: 4-8 (1970).

141. Stewart, A., R. Barber. Epidemiological importance of childhood cancers. British Medical Bulletin 27, 1: 64-70 (1971).

142. Survey of the uses of radio-nuclides in medicine. Preliminary report. United States Department of Health, Education and Welfare. PHS publication MORP 68-10, 1968.

143. Survey of the uses of radio-nuclides in medicine. United States Department of Health. Education and Welfare. PHS publication BRH/DMRE, 70-1, 1970.

144. The use of vital and health statistics for genetic and radiation studies. Seminar UN and WHO, Geneva 1960. UN publication A/AC.82/Seminar (1962).

145. Thompson, P. L. and I. R. Mackay. Radiation nephritis after gastric irradiation for peptic ulcer. In press (1969).

146. Twelfth annual report 1967-1968, p. 83-85. Atomic Energy Commission, Japan.

147. United Nations. General Assembly. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. 1958. (A/3838: G.A. Official records, 13th sess. Suppl. No. 17.)

148. United Nations. General Assembly. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. 1962. (A/5216: G.A. Official records, 17th sess. Suppl. No. 16.)

149. United Nations. General Assembly. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. 1964. (A/5814: G.A. Official records, 19th sess. Suppl. No. 14.)

150. United Nations. General Assembly. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. 1966. (A/6314: G.A. Official records, 21st session. Suppl. No. 14.)

151. United Nations. General Assembly. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. 1969. (A/7613: G.A. Official records, 24th sess. Suppl. No. 13.)

152. Verksamheten 1970. Statens Stralskyddsinstitut Stockholm (1971).

153. Weber, J. Beenmergdosis tengevolge van de röntgendiagnostiek. Thesis. Leiden (1964).

154. Weber, J. Unpublished.

155. Williamson, B. D. P. A simple patient dose calculator for radiographic exposures. National Radiation Laboratory, Christchurch, New Zealand, Publication T/26—undated.

156. Williamson, B. D. P. and A. C. McEwan. The genetically significant radiation dose to the population of New Zealand from diagnostic radiology. NRL/PDS/1965.

157. World Health Organization. The medical uses of ionizing radiation and radio-isotopes. Report of a joint IAEA/WHO Expert Committee (Geneva, 26 October-1 November 1971). Technical Report Series No. 492 (1972).

158. Zuppinger, A., W. Minder, R. Sarasin *et al.* Die Strahlenbelastung der schweizerischen Bevölkerung durch röntgendiagnostische Massnahmen. Radiol. Clinica 30: 1-27 (1961).

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