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NOTE

Throughout the present report and the annexes thereto, references to the annexes are indicated by a letter followed by a number: the letter denotes the relevant annex and the number the paragraph therein. Within each annex, references to its scientific bibliography are indicated by numbers.

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates a reference to a United Nations document.

ANNEX G

MEDICAL, OCCUPATIONAL AND OTHER EXPOSURES

CONTENTS

I. Introduction

1. This annex deals mainly with information and data on radiation doses to individuals and populations as a result of exposure to ionizing radiation of:

(*a*) Patients undergoing medical radiological procedures—medical exposure;

(*b*) Workers as a consequence of their work—occupational exposure;

(*c*) Persons from miscellaneous man-made sources and abnormal exposure to natural radiation, when the exposures do not belong to (*a*) or (*b*)—other exposures.

2. The term "medical exposure" is taken to apply to all types of exposure (except occupational) resulting from radiation administered by radiologists, general practitioners, dentists, obstetricians, osteopaths, chiropractors, etc.

3. The term "occupational exposure" is, in the present annex, taken to apply to all activities involving exposure of workers to ionizing radiation in the course of their work, regardless of whether the workers are directly engaged in radiation work or not.[1,2]

4. Data concerning radiation doses to specific organs and tissues, and to the whole body may be used for the purpose of:

(*a*) Risk estimates; this implies adequate knowledge of the dose-effect relationship;

(*b*) Education, which, by presenting comparative data, might result in improved standards of operation and a reduction of doses;

(*c*) Guiding epidemiological studies.

5. The concept of significant dose for the evaluation of a specific biological risk was considered by the Com-

mittee in its 1958 report (chapter II, para. 26)[3] in the following way:

"Any specific biological effect of irradiation must be evaluated from physical factors such as the distribution of tissue dose (expressed in rem) in space and time and from biological factors such as radiosensitivity, latent period, recovery and repair. The simplest situation is that in which a dose-effect relation for a biological effect is known, making it possible for the probability or degree of this effect to be calculated. Whether the effect eventually may manifest itself in the form of deleterious consequences, however, depends on individual circumstances such as expectation of life, or, in the case of genetic injury, expectation of children. For this reason, the potential effect indicated by a direct application of an assumed dose-effect relation must be weighted according to these individual circumstances."

As has been pointed out earlier in the present report, quantitative risk estimates presuppose assumptions regarding the dose-effect relationship. As long as the true mode of dose-effect relationship is not known, any use of the presented dose data for risk estimates must be made with the recognition of the necessary assumptions and the awareness of the uncertainty of the result. In any circumstances only comparative risk estimates may be made on the basis of the presented data and they should be limited to considerations of exposures to the same organs or tissues.

6. The present annex deals with the following types of radiation dose:

(*a*) Genetically significant dose;

(*b*) Mean dose to the active bone-marrow;

(*c*) Doses to organs and tissues of special interest.

Data on radiation exposure to the gonads are presented using the accepted definition of the genetically significant dose (para. 9) with the intention that they may be used for comparative risk estimates of the radiation-induced genetic effect, following the procedures outlined in the 1958 report. However, in the cases of radiation exposures to the bone-marrow and to other organs and tissues of special interest the data are not given with the intention that they be used for risk estimates but for educational purposes and as a guide for epidemiological studies as mentioned in paragraph 4 above. Medical exposure is dealt with in paragraphs 7-99, occupational exposure in paragraphs 100-116 and other exposures in paragraphs 117-126.

II. Medical uses of ionizing radiation

7. Medical exposure arises from the following types of procedures:

(*a*) X-ray diagnosis;

(*b*) Radio-therapy by X-rays and sealed radio-active sources;

(*c*) Administration of unsealed radio-isotopes for diagnostic, therapeutic and research purposes; radiation exposures also result from the use of contrast media containing radio-active materials, e.g. thorium dioxide.

8. Data on the frequencies of radiological procedures in various countries and areas are presented in tables I, II and III. The frequency figures are obtained as the annual number of procedures per 1,000 individuals of the population under study:

(*a*) Table I deals with X-ray diagnosis. Although the frequencies are based on sample studies, nine of the twelve countries which had carried out comprehensive surveys had similar amounts of radiography and fluoroscopy (excluding mass surveys and dental exposures). Their annual frequencies range between 260 and 410 examinations per 1,000 individuals. The frequency figures in the cities tend to be higher than those based on the whole country, not only because cities usually have more X-ray facilities, but also because many patients are examined there without being residents of the city itself or the surrounding suburban area.

(*b*) Table II, which sets out the frequencies of cases treated with X-rays and sealed radio-active sources, shows large differences between the various countries and areas.

(*c*) Table III gives the frequency of the administration of radio-active isotopes to cases for either diagnostic or therapeutic reasons. The number of patients undergoing diagnostic procedures is four to ten times higher than the number undergoing therapeutic procedures. The table also gives the annual consumption for medical use of I^{131}, P^{32} and Au^{198}. The contribution to the amounts of radio-active isotopes from the diagnostic use may be disregarded, as compared to the amounts used for therapeutic purposes. The information usually originates from the distributors. The figures given for the amounts should be regarded as maximum estimates in view of the disintegration of the radio-active isotopes in transit and because the total amount of requested isotopes may not have actually been used for medical purposes.

The genetically significant dose

Definitions and calculations

9. In the 1958 report the genetically significant dose was defined (chapter II, para. 27) as

". . . 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 definition was based upon the following assumptions and considerations:

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

(*b*) The dose-effect relation is linear, without a threshold;

(*c*) The individual gonad dose is weighted with a factor which takes into account the future number of children expected of the irradiated individual compared with an average member of the population (in this connexion the foetus is treated as such an irradiated individual and not as a child to be expected).

10. Evidence has lately been obtained that although the dose-effect relation for the production of most genetic damage might be linear at any given dose-rate, it has a lower slope for low dose-rates than for high ones. (C, 84-87) There are also indications that the genetic damage to future generations at any given dose or dose-rate may differ with sex and with the cell-stage of a gamete, depending on a difference in the radio-sensitivity of the male and female gametes and on a difference in the possibility of transferring the damage to future generations. This means that the weighting of the individual gonad dose should, in addition to the factor for future number of children, include weighting factors for the dose-rates to the gonads and for the difference both be-

tween the sexes and the cell-stages. Since these new weighting factors are not yet known, it is not possible to incorporate them in the calculation of the genetically significant dose.

11. It is still justifiable to use the formulas for the calculation of the genetically significant dose as they were presented in the previous report. The derivations of these formulas are therefore repeated in the appendix.*

12. Available information on genetically significant dose and its parameters is given under the heading "Data", with the following subdivisions: X-ray diagnosis; radio-therapy by X-rays and sealed radio-active sources; administration of radio-active isotopes.

Data

13. During the last few years many investigations have been performed to determine the genetically significant dose arising from medical exposure. Though most of these were performed along the lines presented in the appendix, using either formula 8 or 11 for the calculations, the sampling techniques and the modes of measurement or estimation of the gonad doses vary. Because of this, short explanatory statements of the investigations presented are given below in paragraphs 17 to 30.

X-ray diagnosis

(a) *National surveys*

14. Tables XVIII and XIX present the average gonad dose for each of the ten most significant examinations for each of the countries submitting information, with the reservations of paragraph 15. Table XVIII gives the values for examinations of male patients and table XIX the information for female patients. Table XX presents the values for the foetal gonad dose during examinations of the obstetric abdomen and pelvimetry. Only the Federal Republic of Germany (Hamburg) and the United Kingdom presented separate values of foetal gonad doses for the other examinations. Some countries assumed that the foetal gonad dose was the same as the female gonad dose for these other examinations. The variation in the values shown in these tables demonstrate that for any one examination a wide range of gonad doses may be obtained. This is due to varying techniques, for example the amount of fluoroscopy carried out as part of an examination and the size of the incident skin fields. Reductions in both of these will greatly reduce gonad dose in an examination. Table XXI presents the total genetic dose contribution for each examination for each of the countries submitting information. Similarly, table XXII gives the same information but presented as the percentage of the total genetic dose of each country, whilst the totals are summarized in table XXIII.

15. Further details of the genetic dose computations and data for each country may be obtained by reference to the national tables presented as tables IV-XVI. In these tables the ten types of examination which contribute most to the genetically significant dose originating from X-ray diagnosis are set out in descending order of their contribution. All other types of examination are presented as a whole. As an exception to this principle, the two types of obstetrical examination, e.g., pelvimetry and obstetric abdomen, are always individually presented, although their contribution to the genetically significant dose does not always justify this. They are then placed at the bottom of the table, replacing the ninth and tenth types of examination. It should be mentioned that although the genetically significant dose is referred to as the "annual" dose, the validity of the figures is limited to the year or years to which the surveys relate.

16. The doses to the gonads and the annual genetically significant doses are presented in mrem. The dose-rates being the dose averaged over the exposure time are presented in mrem per sec and for the purposes of this annex it is assumed that for X-, β- and γ-radiation 1 r corresponds to 1 rad and to 1 rem.

17. *Argentina (Buenos Aires)*. Table IV is based on a report by Placer.[4] His investigation is limited to radiography. Studies on the numbers of different types of radiographs and their distribution by sex of the patients radiographed were undertaken in a total of eighty-six hospitals and medical centres. The dose measurements were made with ionization chambers and film badges attached to the skin of the patients. Depth dose data were used for computing the gonad doses. The genetically significant dose was calculated from formula 11. The mean age of child-bearing was set as thirty. It should be emphasized that Placer's report deals with numbers of radiographs and not examinations. An estimate of the contribution to the genetically significant dose caused by radiography in private clinics and practices has been made, assuming the distribution of the radiographs in various types of examination to be the same as in the hospitals.

18. *Denmark*. The figures presented in table V are taken from the investigation published by Hammer-Jacobsen.[5] The figures on the numbers of various types of examination are based upon a sample inquiry. Information on sex and age distribution of the patients was obtained from a special study on 139,000 examinations. Measurements on the doses to the gonads were made with ionization chambers on 2,475 patients during the actual course of examination. Data on doses to the foetus were obtained by measurements in a phantom. The genetically significant dose was calculated by means of formula 8 in the appendix. The fertility factors used were calculated from the official vital statistics of the population.

19. *Federal Republic of Germany (Hamburg)*. The data in table VI are taken from the investigation published by Holthusen, Leetz and Leppin.[6] The genetically significant dose was calculated by means of formula 8. Information on the number of examinations of various types, subdivided by sex and age of the patients, was collected by means of questionnaires, compiling all examinations during the period from November 1957 to October 1958. Measurements were made on the gonad doses to adults in the course of examinations belonging to the types which were expected to give the highest contribution to the genetically significant dose. In addition, gonad doses to children and to adults were taken from an investigation made by Seelentag.[7] The figures for d; in table VI are, according to the original paper, mean figures including all age groups. They were obtained by means of formula 8 after the detailed calculation of the annual genetically significant dose had been made. The fertility factors were computed from the official vital statistics of the population. For comparative purposes figures are presented for the annual genetically significant dose using formula 11 and a figure for the annual per capita dose for the whole population, disregarding fertility factors.

* Although, for editorial reasons, the pertinent paragraphs are not directly quoted, they are substantially a quotation from the Committee's 1958 report, annex C, para. 6-17.

20. *France.* Table VII is based upon data published by Reboul *et al.*[8-10] The sample study of the number of different types of examinations and their subdivision with regard to sex and age of the patients, was performed in Bordeaux during 1957, and comprised 36,000 examinations. By means of the records of the Sécurité sociale the results obtained from the sample study were extrapolated to cover the whole of France. Measurements of the gonad doses were made during the examinations. For the female patients, the ionization chambers were placed on the skin at the level of the ovaries. The factors for the ratio of ovary dose to skin dose were determined by measurements in cadavers and phantoms. The genetically significant dose was computed with the use of formula 11.

21. *Italy (Rome).* Table VIII is based on an investigation published by Biagini, Barillà and Montanara.[11] The numbers of examinations of various types, subdivided by sex and age of the patients, are based upon a year-long study of the number of examinations performed in certain selected hospitals and clinics. A special correction was made, to exclude the examinations on patients who were not residents of Rome. Using ionization chambers the authors arrived at gonad doses through measurements in a phantom and in patients during the examinations. In order to account for the variations in the gonad doses as a consequence of differences in technique and physical parameter, figures on gonad doses were obtained as mean figures from pertinent data presented by ten authors. The genetically significant dose was calculated from formula 8. The fertility factors were computed from official vital statistics of the population.

22. *Japan.* Table IX is based upon data from a Japanese report.[12] This investigation is based upon two sample studies, the first covered seven districts comprising around 80,000 examinations and the second was representative of the whole of Japan, in which details of 66,000 examinations were obtained. The sample studies for the collection of numbers of examinations lasted for one week each. During this period, information was also obtained on the sex and age distribution of the patients. The gonad doses to adults and children were obtained by measurements with ionization chambers in body-shaped phantoms. The influence on the gonad doses as a consequence of variations in physical parameters was investigated. No measurements were made of doses to the foetal gonads. Fertility factors were determined from official statistics. The genetically significant dose was calculated according to the principles set out in formula 8. The contribution to the genetically significant dose from the exposure of foetal gonads was computed only for obstetrical examinations.

23. *Netherlands (Leiden).* Table X presents data obtained from Beekman and Weber.[13] The numbers of roentgen examinations of various types are based upon a study of the records from 30,000 examinations. Information on sex and age distribution in different types of examination was also collected. The gonad doses were obtained from measurements with ionization chambers in a body-shaped phantom. The influence on the gonad doses was studied in relation to variations in examination techniques and physical dose parameters. The figures presented for gonad doses are averaged with regard to the existing ranges of techniques and parameters. The annual genetically significant dose was calculated by means of formula 8. For comparative purposes, formula 11 was used, under the assumption that the mean age of child-bearing was thirty years. In addition, a per capita annual gonad dose was calculated without regard to the fertility factors. The fertility factors were obtained from the official vital statistics of Leiden.

24. *Norway.* The data set out in table XI are extracted from an investigation performed by Flatby.[14] Information on the numbers of examinations of various types was obtained during 1957 and 1958 from all the establishments in Norway where X-ray diagnosis was performed. The subdivision of the number of examinations by sex and age of the patients was based on a study comprising four diagnostic departments (40,000 examinations). The gonad doses were measured directly with ionization chambers during the examination. In addition, doses to the ovaries were also assessed by measurements in a body-shaped phantom. The dose measurements comprised around 1,300 patient and 100 phantom measurements. The fertility factors were determined from the official vital statistics of the population. The genetically significant dose was calculated by means of formula 8.

25. *Sweden.* Table XII summarizes the data on genetically significant dose presented in the Committee's previous report. The data are based on the investigation published by Larsson.[15] Information on the numbers of examinations of various types, subdivided by sex and age of the patients, was collected from a sample of hospital records (40,000 examinations) and corrected by an estimate of the numbers of examinations performed by private practitioners. Only around 5 per cent of the total number of examinations were carried out by these practitioners. These were mainly chest and small bone examinations. Around 1,900 measurements of the doses to the male and female gonads were performed with ionization chambers during the actual course of examination. Only the doses to foetal gonads were obtained by measurements in a phantom. The fertility factors were computed from the official vital statistics of the population. The genetically significant dose was calculated from formula 8.

26. *Switzerland.* Table XIII is based on an investigation performed by Zuppinger, Minder, Sarasin and Schaer.[16] Through a sample study, lasting for three weeks in 1957 and comprising around 65,000 examinations, information was gained regarding the numbers of examinations of various types, subdivided by sex and age of the patients. The doses to the gonads were obtained partly from the authors' own measurements with ionization chambers in patients and a body-shaped phantom, and partly, when appropriate, from dose data published in other countries. Since the Swiss investigation started with the original intention of computing the genetic dose to individuals below the age of forty but later changed to a determination of the genetically significant dose according to formula 8, the calculations were not made directly with the use of this formula, although the principles were the same. The fertility factors were determined from official statistics.

27. *United Arab Republic.*[17,18] Investigations carried out in Alexandria and Cairo during the years 1955-1961 are presented in tables XIV and XV. They are representative of the whole of Alexandria and the area west and south-west of Cairo. Phantom measurements were carried out on a selection of units used in these cities. The calculations were made on the basis of formulae 8 and 11 and the results presented as a weighted mean. The survey showed that some 17 per cent of the annual examinations were for investigations of the urinary tract. This is due to the investigation of the endemic disease, schistosomiasis.

28. *United Kingdom.* The material presented in table XVI has been taken from the report of the Adrian Committee.[19] The comprehensive survey covered all medical radiology carried out in the United Kingdom, except Northern Ireland. The numbers of examinations of various types and their distribution by sex and age of the patients are based on two nation-wide sample studies in 1957, each one lasting for one week, and together comprising around 310,000 examinations. The whole country was divided into nineteen regions and in each measurements were carried out in a sample of six hospitals. The gonad doses were obtained for 5,400 examinations by measurements with ionization chambers. The methods used for making these measurements were:

(i) Male patients: by a direct dose measurement made with the chamber in contact with the scrotum during the examination;

(ii) Female patients: by an indirect method, using the dose to the skin at the level of the iliac crest, measured during the course of examination, and the ratio of the corresponding skin dose and the ovary dose, as obtained from dose measurements in body-shaped phantoms;

(iii) Foetus: by calculations based upon dose data derived from body-shaped phantoms.

The fertility factors were computed from official statistics. A separate statistical investigation was made to determine the average number of future children to be born to a pregnant woman. While the accuracy of this estimation is low, the general indication is that the fertility factor for a pregnant woman is higher than that for a woman in the population at large. These higher fertility factors, although admittedly approximate, have been used solely in computations on examinations made in connexion with a pregnancy, viz. pelvimetry and obstetric abdomen examinations. The genetically significant dose was calculated by the use of formula 8.

(b) *Other investigations*

29. *United States of America.* Most of the national surveys are performed in countries with small populations. In countries with large populations, a small-scale study may not truly reflect the situation, especially when there are great variations within the country in the parameters that determine the genetically significant dose. For the United States, Laughlin and Pullman[20] made an estimate of the annual genetically significant dose, on the basis of those data in the literature up to 1955, using formula 11. They arrived at a figure of 50 ± 25 mrem as a minimum estimate and a more probable estimate of 140 ± 100 mrem. With the same formula, Norwood *et al.*[21] calculated the annual genetically significant dose caused by X-ray diagnosis for the inhabitants of a small American town to be 45 mrem. Another United States investigation[22] covers the employees of the Oak Ridge National Laboratory who were regarded as patients. The annual genetically significant dose from X-ray diagnosis was found to be 50 mrem (13 mrem caused by exposure of male patients and 35 mrem by exposure of female patients). The results of the two later investigations are within the range of the minimum estimate obtained by Laughlin and Pullman.

30. *USSR.* In the USSR no calculations of the genetically significant dose arising from medical X-ray diagnosis have yet been published. However, Pobedinsky[23] has published data on the doses to the gonads during diagnostic X-ray examinations, e.g. chest, stomach (barium meal), kidneys, gall bladder, pelvic region, lumbar spine and lumbosacral region. The data, which are based upon dose measurements in a body-shaped phantom, are within the ranges of the individual gonad doses presented in tables XVIII and XIX. Data have also been published by Vikturina.[24] Provided there are not significant differences in the age distribution of the patients and in the numbers of examinations of various types, it is reasonable to believe that the annual genetically significant dose from X-ray diagnosis in the USSR is of the same order of magnitude as the doses presented in the summary table, XXIII.

(c) *Mass survey examinations of the chest*

31. Since mass survey examinations of the chest are frequently performed in many countries, current interest has been devoted to the doses associated with this type of examination. In table XVII data have been collected from various countries and areas for gonad exposure in this type of survey examination. In most countries these examinations are performed as mass miniature radiography (photo-fluorography). The table shows that these radiographic examinations, in spite of their high numbers, give a very low genetically significant dose. In some countries, however, survey examinations are performed by means of fluoroscopy. These examinations give individual gonad doses which are up to 100 times higher than those given by mass miniature radiography. Even if the doses to the gonads are much lower than in many other types of examination, the high number of these fluoroscopic examinations among individuals in the prefertile and fertile ages may cause a considerable contribution to the genetically significant dose. Therefore, in order to reduce the dose, mass miniature radiography should be used when practicable rather than mass survey fluoroscopy.

(d) *Comments*

32. Certain types of examination, mainly those of the pelvic region, together contribute 85-95 per cent of the genetically significant dose. This is shown in table XXII. However, in terms of numbers of examinations, these examinations represent only about 15 per cent of the total in those countries where the contributions from chest and mass survey examinations are small.

33. The following points from the national tables require further explanation:

(i) In table VI, relating to Hamburg, the colon examinations are responsible for a third of the total genetically significant dose. Holthusen *et al.*[6] have explained this as being the result of a special technique used in Hamburg for colon examinations, involving extensive fluoroscopy.

(ii) In Japan[12] stomach and colon examinations cause 50 per cent of the genetically significant dose. Table IX shows high gonad doses for the fluoroscopy in these two types of examination, which form 23 per cent of the total number of Japanese examinations.

(iii) In the Netherlands (Leiden) (table X),[13] pelvimetric examinations are never performed and the number of obstetrical abdomen examinations is very low. Although the investigation reflects only Leiden, this statement is valid for the whole of the Netherlands.

(iv) Table XII, relating to Sweden,[15] shows a high contribution to the genetically significant dose caused by foetal exposure during pelvimetry. Since the investigation was made, the examination technique for pelvimetry has been changed in Sweden with the result that the dose to the foetal gonads has been decreased to a small fraction of the previous dose.[25]

(v) Table XVI (United Kingdom) shows that obstetrical abdomen examinations form nearly 70 per cent of the genetically significant dose caused by foetal exposure.[19]

34. In table XXIII, the annual genetically significant doses arising from X-ray diagnostic procedures in various countries and areas are brought together. The contributions to the genetically significant dose caused by diagnostic exposures of males, females and foetuses are given separately. For some countries and areas, estimates are also given of the uncertainty in the determination of the genetically significant dose.

35. Table XXIII gives information covering populations that together comprise over 200,000,000 individuals (6-7 per cent of the total population of the world).

36. Some estimates of the genetically significant dose arising from X-ray diagnosis do not include the contribution from dental radiography. However, available data show that this contribution is very small with values ranging from 0.01 to 0.15 mrem/y.

37. In the investigations from the Federal Republic of Germany (Hamburg)[6] and from the Netherlands (Leiden)[13] comparisons were made between the genetically significant dose computed according to formulas 8 and 11 in the appendix. The figures are set out in table XXIII. There is good agreement between the figures derived by the use of formula 8, which accounts for the relative child expectancy of the average individual for each type of examination, and by the simplified formula 11, which considers only the examinations performed on patients below the mean age of childbearing (usually thirty years). The per capital dose was also computed for Leiden and Hamburg. In these two cities the per capita dose is much higher than the genetically significant dose, which means that the relative child expectancy factor (w_j/w) is considerably less than unity for most of those types of examination that contribute most to the genetically significant dose. In other countries the per capita gonad dose may be of the same magnitude as the genetically significant dose as indicated in the last report. This depends upon the age distribution of the patients within the various types of examination and the future number of children expected to be conceived after the exposure.

(e) *Consideration of the dose-rate effect*

38. As was pointed out in paragraph 10, there is now experimental evidence with mice and insects that the genetic effect caused by irradiation is governed not only by the magnitude of the dose but also by the rate at which the dose is delivered. Table XXIV presents probable dose-rates to the gonads during some types of examination and during fluoroscopy and radiography. Because of the difference in the sites of the testes and the ovaries, the dose-rate to the ovaries is lower than to the testes when the gonads are in the primary beam. Since examinations usually consist of several radiographs of various sites and in different projections, and sometimes of both radiography and fluoroscopy, the dose-rate may vary considerably during an examination, by a factor of 1,000 and even more. Although table XXIV presents only probable dose-rates, these range from 0.005 mrem/sec to 2,000 mrem/sec, which is a difference of a factor 10^6. The lowest dose-rate presented in the table is still 1,000 times higher than the dose-rate by which the natural radiation is delivered. The range of dose-rates used by Russell in his experiments are quoted in table XXIV. These dose-rates, which were used in obtaining experimental evidence for dose-rate dependence, are within the range of dose-rates which occur in X-ray diagnosis.

39. Except for examinations consisting of only one radiograph, or continuous fluoroscopy, the dose to the patient strictly must be regarded as fractionated, even though for most examinations the duration is short compared with the time cycle of cells. An exception is the general film series taken over the alimentary tract. This type of examination may be conducted over a period of twenty-four hours, during which radiographs are taken at intervals of minutes or hours. The rate of delivery of the dose may either be represented by the actual dose-rate for each exposure, which usually does not last more than ten seconds, or by the average dose-rate over the total time for the examinations, e.g. twenty-four hours. The computed rate will thus differ by a factor of 10^4, depending upon the criterion used.

40. Since Russell's experiments were carried out on mice with continuous irradiation, with a constant rate of dose delivery at doses of 100-1,000 rem, it is not possible to use his results for a quantitative determination of weighting factors for the dose-rate dependence in the calculation of the genetically significant dose arising from X-ray diagnosis. Neither is there information sufficient to take into account the variation in the sensitivity with the cell stage of the gamete.

(f) *Reduction of the genetically significant dose*

41. It is obvious that efforts to reduce the genetically significant dose should be devoted to the types of examination which give the highest dose contribution. Since the genetically significant dose (formula 8) caused by a type j examination (D_j) is the product of the frequency of conducting the examination (N_j/N), the relative child expectancy of the individuals examined (w_j/w) and the gonad dose (d_j), a decrease in the genetically significant dose may be achieved by a reduction in N_j, w_j or d_j:

(i) N_j may be decreased by lowering the number of type-j examinations, which means more rigorous indications for the examinations;

(ii) w_j may be lowered by a reduction of the number of examinations of young patients;

(iii) In general, however, the greatest effect in the reduction of the genetically significant dose can be obtained by lowering the dose to the gonads, d_j.

42. The ways of reducing the gonad dose are well known and are recommended in most of the papers on which the tables are based and they are summarized as follows:[26]

(i) To reduce the number of radiographs per patient;

(ii) To reduce the length of time and the intensity of exposure;

(iii) To avoid, as much as possible, pre-set schemes of radiological examinations;

(iv) When fluoroscopy is not essential, to take radiographs only;

(v) To use the appropriate physical parameters, with special emphasis to the use of the smallest field size;

(vi) To avoid the inclusion of gonads within the primary beam;

(vii) To protect the testicles by adequate shielding of scrotum during male pelvic radiologic examinations; and

(viii) To train properly the staff engaged in X-ray diagnostic examinations.

43. The Adrian Committee[19] states that the result of bringing the techniques in the 10 per cent of hospitals showing the highest doses up to the standard of the average technique of all the other hospitals would in total reduce the genetically significant dose to 70 per cent of the present one. If the techniques used by the 25 per cent of the hospitals in the survey showing the lowest doses were used by all hospitals it would mean a reduction of the genetically significant dose to less than 20 per cent of the present value. For Sweden, Larsson[15] estimates that an increased use of already existing examination techniques, which give low gonad doses, would mean a reduction of the genetically significant dose to 40 per cent of its existing value. Such reduction may be achieved without detriment to the diagnostic information to be obtained from the examinations.

External radio-therapy by X-rays and sealed radio-active sources

44. As compared to those for X-ray diagnosis, there are few data for gonad doses and genetically significant dose caused by exposure of patients undergoing external radio-therapy. One of the reasons for this is that the first investigations showed that the contribution from external radio-therapy to the genetically significant dose was less than the contribution from X-ray diagnosis. However, detailed data on gonad doses and genetically significant dose arising from external radio-therapy have recently been obtained from the Federal Republic of Germany (Hamburg), France and the United Kingdom. To make estimates of the average gonad dose received during the treatment of any one disease is more difficult than for one diagnostic examination since a disease such as eczema may affect any area of the body and the details of the actual treatment are not always available. Therefore details of the treatment of a large number of patients are required to get a representative distribution of the sites affected by a particular disease.

45. Radio-therapy is used in the treatment of non-malignant and malignant conditions. It is necessary to consider in any calculation of genetically significant dose from radio-therapy the effect of the disease itself and the irradiation on the relative child expectancy. It may be assumed that neither the non-malignant conditions nor the radiation doses, with the possible exception of those in the regions of the gonads, affect the fertility of the patients. However, for patients suffering from malignant conditions the life expectancy is usually shorter than in the general population and in each age group of such patients a lesser number of children will be conceived as compared to the statistics for the whole population. The irradiation itself may cause decreased fertility, which would also reflect upon the number of children to be expected.

(a) *National surveys*

46. *Federal Republic of Germany (Hamburg):* The investigation performed by Holthusen, Leetz and Leppin[6] also covers radio-therapy. The number of patients treated for various conditions, subdivided by sex and age, and the individual gonad doses were arrived at by the same methods as were used for X-ray examinations (para. 19). In their calculations Holthusen *et al.* have taken the fertility factors to be zero for patients who have been irradiated for malignant diseases, and presume that the genetically significant dose caused by external radio-therapy arises only from irradiation for non-malignant conditions. The annual genetically significant dose is presented in tables XXV and XXIX in which the genetically significant dose is subdivided by various locations of treatment. The individual gonad doses and the numbers of patients treated are also set out. The genetically significant dose was calculated from formula 8. For comparative purposes, Holthusen *et al.* also calculated the genetically significant dose, using formula 11, and the per capita dose for the whole population (para. 19).

47. *France.* The figures for France in tables XXVI and XXIX are based upon an investigation by Reboul *et al.*[27] who determined the number of patients who underwent external radio-therapy for various conditions in a large hospital. By means of information from the Sécurité sociale, these numbers, subdivided by sex and age, were extrapolated to cover the whole of France. The doses to the gonads in various types of treatment were measured with ionization chambers in the same way as has been described in paragraph 20. The genetically significant dose was calculated according to formula 11. In the cases of non-malignant conditions, only around 7 per cent of the dose, expressed by $\Sigma N_j \cdot d_j$, was estimated to have been given to patients below the age of thirty. When the contribution to the genetically significant dose from the treatment of malignant conditions was calculated, the cases with the most severe prognoses were disregarded. Also, the cases where the irradiation was expected to have caused sterility were disregarded. From the remaining cases, the numbers of patients below thirty years of age were estimated by means of their hospital records. These patients together form around 6 per cent of all those treated for malignant conditions.

48. *Netherlands.* The data presented in tables XXVII and XXIX are from an investigation by Scholte *et al.*[28] for the period 1942-1951 based on radio-therapy treatments in three large hospitals in The Hague, Leiden and Rotterdam. The survey does not include any contribution from dermatology. The calculations were made according to formula 8 and it was possible to use the actual number of children born to the patients up to 1960. The number of children conceived by the patients who received high gonad doses from pelvic region irradiation were only 53 per cent of those which would be expected from the number of legitimate live births in the period 1955-1959 in the Netherlands. Even though these statistics are not strictly comparable they emphasize the effect of the diseases and the irradiation itself on the relative child expectancy compared with that based on average values of the population.

49. *United Kingdom.* The data presented in tables XXVIII and XXIX have been taken from the report of the Adrian Committee[19] which covers the United Kingdom except Northern Ireland. The numbers of patients treated for various conditions, subdivided by sex and age, were calculated from a sample study during three months in 1957 of all treatments carried out in United Kingdom hospitals and comprising around 30,000 patients. The doses to the gonads were calculated from information on the dose parameters used in various hospitals and private clinics and the results of dose measurements in a phantom under various conditions. The genetically significant dose was calculated according to the principles set out in formula 8. In the calculations of the contribution from radio-therapy of non-malignant conditions, it was assumed that the child expectancy was zero for all patients in whom an artificial menopause was

induced. For all other non-malignant conditions the fertility factors obtained from population statistics were used. In the calculation of the genetically significant dose caused by external radio-therapy of malignant conditions, due attention was paid to the changes in the fertility factors, as determined from official statistics, that are caused by the shortening of the patients' life expectancy and by the reduction in fertility, due to the radiation received by the gonads.

(b) *Other investigations*

50. In the United States, Clark[29] estimated the annual per capita dose of the total population due to external radio-therapy to be 12 mrem. He assumed that the gonad doses arising from irradiation for malignant conditions were of no genetic significance. A survey of the individual gonad doses received has also been carried out by Bailey.[30]

51. A survey by Purser and Qvist[31] yields an estimate of the annual genetically significant dose in Denmark (Copenhagen) of 1 mrem. In the Danish estimate, reduced fertility as a consequence of the severity of the prognosis of the disease and of the actual irradiation was allowed for by subdividing the patients into three groups, with the fertility factor being zero, one-fifth of normal, and normal, respectively. Twenty-two per cent of the genetically significant dose was assumed to arise from treatments of malignant disease.

52. For Australia, Martin[32, 33] estimated the annual genetically significant dose from external radio-therapy to be 28 mrem. The estimate was made using the appropriate survival rates from the Central Cancer Registry. It was assumed that the prospects of parenthood were not impaired by the treatment, except for those patients receiving doses which would cause sterilization.

53. In the United Arab Republic (Cairo) a survey has been carried out in 1959-1960 of the frequency of treatments by X-rays.[34, 35]

(c) *Comments*

54. Compared to the genetically significant dose originating from X-ray diagnosis (table XXIII) the genetically significant dose from external radio-therapy (table XXIX) is small. However, the individual gonad doses received from external radio-therapy are larger than from an X-ray diagnosis examination.

55. It is the practice in some countries to use radiation for so termed ovarian stimulation in cases of subfertility. Little data are available regarding the numbers of such treatments but a report[36] shows that, in 33 institutions surveyed in Buenos Aires, 222 cases were treated in 1960 representing some 2 per cent of the total number of patients treated by radio-therapy for non-malignant and malignant conditions. The radiation used was generated at 200-250 kV and the average dose to the ovary was 60 rem with a range of doses from 35-110 rem.

56. In the German investigation[6] the annual genetically significant dose was calculated according to both formula 8 and formula 11. The per capita dose for the whole population was also calculated. On the basis of the data from investigations in France[27] and the United Kingdom[19] the per capita dose to the population arising from the treatment of non-malignant conditions in each of the two countries has been estimated. The figures are set out in table XXX. As expected, the per capita doses are higher than the genetically significant doses. Clark's figures for the United States of America,[29] 12 mrem, should be compared with the figures in the last column of table XXX, which are 6.5, 21 and 9 mrem in the Federal Republic of Germany (Hamburg), France and the United Kingdom respectively. The explanation for the difference between the figures for per capita dose and genetically significant dose is the same as was given in paragraph 37.

57. Both in the Federal Republic of Germany (Hamburg) (table XXV) and the United Kingdom (table XXVIII) the major part of the genetically significant dose caused by external radio-therapy for non-malignant conditions originates from treatments of the skin (around 55 and 75 per cent respectively). In France (table XXVI) the bulk of the corresponding genetically significant dose arises from treatment to the lumbar spine and the hips.

(d) *Consideration of the dose-rate effect*

58. For the reasons indicated in paragraphs 10 and 38 the probable dose-rates to the gonads during external radio-therapy of certain treatment areas, are given in table XXXI. The dose-rates have been calculated assuming a maximum dose-rate at the treatment site of 50 rem per minute. Since high doses to the gonads may cause sterility or reduced fertility, treatment sites have not been included in this table when the dose to the gonads during a complete treatment is estimated to exceed 200 rem. The dose-rates range between 0.002 mrem/sec and 50 mrem/sec, which means that the highest dose-rate is around 10^4 times greater than the lowest one. This range of dose-rates covers the lower portion of the range used by Russell in his experiments.

59. In most instances external radio-therapy is administered in fractionated doses. In external therapy for non-malignant conditions a total dose seldom exceeds 3,000 rem given over a period of two to three weeks, while for malignant conditions doses to the treated volume of up to 7,000 rem may be given. The period of treatment is varied, dependent on the total dose, up to about seven weeks. If the gonad dose-rates are calculated as mean dose-rates over these periods, the figures in table XXXI should be divided by a factor of around 10^3. The lowest dose-rates would then be of the same magnitude as the delivery rate of natural radiation (3.10^{-6} rem/sec).

60. In radio-therapy, as in X-ray diagnosis (para. 40), it does not seem possible to use Russell's results for a quantitative determination of weighting factors for the dose-rate dependence in the calculation of the genetically significant dose. Neither is there information sufficient to take into account the variation in the sensitivity with the cell-stage of the gamete.

(e) *Reduction of the genetically significant dose*

61. In contra-distinction to X-ray diagnosis, where the radiation is a means for producing an image on a screen or a film, the dose in radio-therapy to be delivered to an actual part of the body is determined with regard to the effect that is sought by the treatment. With reference to paragraph 41, N_j, w_j and d_j govern the genetically significant dose. Regarding malignant conditions, where there are strong indications for treatment, N_j and w_j cannot be expected to undergo changes in favour of reduced genetically significant dose. For non-malignant conditions, it might be possible to reduce N_j and w_j by using stricter criteria for the treatment of non-malignant

conditions, especially among young patients. Reductions in the individual gonad doses, d_j, when the gonads are not the sites of the irradiation, may be obtained as follows:

(i) By the use of strictly appropriate physical conditions of exposure, placing emphasis on the smallest possible radiation field and, for instance, the use of low energy radiation and beta-emitting sources in skin therapy;

(ii) By satisfactory shielding against leakage radiation;

(iii) By the use of scrotum protection;

(iv) By adequate positioning of the patients during treatment so that the gonads are as far away as possible from the primary beam.

Administration of radio-isotopes

62. Only a few national surveys exist on the contribution from the medical use of unsealed radio-isotopes to the genetically significant dose. It is assumed that this contribution is even less than the contribution from external radio-therapy. The number of cases to whom the isotopes were administered and the total quantities of isotopes are given in table III.

63. Since unsealed radio-isotopes are used for both malignant and non-malignant conditions, the same allowance described in paragraph 45 has to be made for possible changes in the fertility factors among patients. This means, for instance, that Au^{198}, although used in considerable quantities for treatment (table III) has been considered to be of no genetical significance.

(a) *National surveys*

64. In the present annex, national surveys and estimates of genetically significant dose are presented from Canada, the Federal Republic of Germany (Hamburg), the United Kingdom and the United States of America (table XXXII).

65. *Canada.* The figures in table XXXII are taken from an investigation published by Johns and Taylor.[37] They considered patients below thirty years of age (formula 11) but did not make any correction with regard to severe prognoses for malignant conditions. I^{131} formed 75 per cent and P^{32} 25 per cent of the genetically significant dose from the administration of radio-active isotopes.

66. *Federal Republic of Germany (Hamburg).* Holthusen *et al.*[6] have studied the genetically significant dose from I^{131} (table XXXII). The dose was calculated according to formula 8 but the malignant conditions were disregarded (cf. para. 46).

67. *United Kingdom.* The Adrian Committee's results[19] are presented in table XXXIII. The genetically significant dose was calculated from formula 8 and the normal fertility factors were modified for some of the malignant conditions. In table XXXIII the annual genetically significant dose is subdivided into the diagnostic use of radio-isotopes and their use for the treatment of malignant and non-malignant conditions. I^{131} delivers 60 per cent and P^{32} 40 per cent of the genetically significant dose from the administration of radio-active isotopes.

68. *United States of America.* Chamberlain[38] has estimated the annual genetically significant dose from the medical use of unsealed radio-isotopes. His results are presented in table XXXII. The dose was calculated according to the principles of formula 11 and the genetical significance of treatment for conditions with severe prognoses was considered. It was estimated that only the use of I^{131} gave a dose of genetical significance.

69. In the national surveys presented above (paras. 65-68), calculation of the gonad doses was based on existing information regarding deposition in various organs and tissues and the effective half-lives of the radio-isotopes in question. In table XXXIV, some results are presented for gonad doses arising from the administration of 1 mc I^{131} or P^{32}.[37,39-41] Weijer *et al.*[39] obtained their results from measurements on patients with different diseases, thus allowing for disturbances in the normal distribution of I^{131} in the body. Regarding I^{131}, Johns and Taylor[37] found that the beta and gamma components formed 50 per cent each of the gonad dose. The figures in table XXXIV, or results from other investigations, can be used for estimating the genetically significant dose arising from the medical use of unsealed radio-isotopes in various countries.

(b) *Comments*

70. The contribution from the administration of radio-isotopes to the genetically significant dose is small (table XXXII) as compared to X-ray diagnosis (table XXIII) and external radio-therapy (table XXIX). Between 5 and 15 per cent of the genetically significant dose caused by the administration of radio-isotopes originates from their use for diagnostic purposes. The individual gonad doses are estimated to range between 25 mrem and 200 rem.

(c) *Consideration of the dose-rate effect*

71. The dose to the gonads from a deposited radio-isotope is received through continuous irradiation, with a decreasing rate of delivery as a consequence of the excretion and the decay of the radio-isotope. The initial dose-rate to the gonads per millicurie administered I^{131} or P^{32} is of the order of 10^{-3} mrem/sec. This estimate does not allow for differences in dose-rates as a consequence of various distances from the gonads to the deposits of activity in the body. Since the administered amounts of radio-isotopes usually range between around 5 μc in diagnosis and 200 mc in therapy, dose-rates may range between 5.10^{-6} mrem/sec to 0.2 mrem/sec.

72. Although these dose-rates should be regarded as rough estimates, they are lower than the ones used by Russell in his experiments. It is not possible at the present time to take into account variations of dose-rate or of the cell-stage of the gamete.

(d) *Reduction of the genetically significant dose*

73. Since the administration of radio-isotopes contributes only 1 or 2 per cent to the genetically significant dose caused by medical exposure, there is no urgent need for improvements aimed at lowering this contribution. The amounts of radio-isotopes used can be decreased in diagnostic investigation by further improvement of the sensitivity of the measuring instruments and by the use of *in vitro* rather than *in vivo* tests. Particular care is necessary when labelled substances are used which are incorporated into the chromosomes, such as thymidine, for these may result in high radiation doses to the genetic material. In therapy, deposits of radio-isotopes in organs and tissues which are not objects of treatment, can sometimes be reduced by special measures. For instance, high fluid intake following I^{131} administration induces fre-

quent micturition, thus reducing the residual time in the bladder of the excreted radio-isotope.[39] This causes a decrease in the dose to the gonads.

Summary

74. The annual genetically significant dose from medical exposure has been shown to be in the range 6-58 mrem from diagnostic radiology for those countries given in table XXIII. The contribution from radio-therapy and the use of radio-active isotopes has been shown in tables XXIX and XXXII to be in the ranges 2-13 mrem and 0.18-0.42 mrem respectively. Due to the many national and international reports on the subject which have been issued in the last seven years there is a greater awareness of the desirability of reducing the genetically significant dose. This has resulted in many countries in a downward trend in the levels estimated. For the purposes of making comparisons of risk in annex H, it has been accepted according to table XXIII that a representative value of the genetically significant dose would be 30 mrem/y from diagnostic exposure and 5 mrem/y from radio-therapy.

Exposure of the bone-marrow

75. This section of the annex summarizes the data regarding the doses received by the active bone-marrow of patients undergoing radiological examinations or treatments. This tissue is regarded as the significant one in respect to the induction of leukaemia by radiation (D, 254-271, 485-489). It has been suggested (H, 8) that the mean dose to a tissue should be used, in the light of present knowledge, for the assessment of the effects of radiation at these dose levels. The term "mean marrow dose" is defined as the dose received by any portion of the active marrow averaged over the whole mass of active marrow. The mean marrow dose can either be given for an irradiated individual or as a per capita dose for a population.

Determination of the mean marrow dose

76. The marrow doses presented below are given as individual mean marrow doses for various types of radiological procedure. Mean marrow doses are usually obtained from dose measurements with small ionization chambers placed either on the skin in the radiation field or at the actual site of the primary irradiated bone-marrow. In the latter case, the measurements are made in phantoms which undergo the irradiation procedures. The phantoms should represent as closely as possible, in size, shape and material, the radiation conditions *in vivo*. Since measurements with ionization chambers express exposure doses in roentgens under given conditions, the absorbed doses have to be calculated with the application of appropriate conversion factors. When calculations are based on exposure doses to the skin, the dose figures have to be multiplied by the percentage depth dose at the location of the bone-marrow in question, corrected for the shielding effect of the bone surrounding the bone-marrow.

77. In soft tissues adjacent to bone, the absorbed dose is increased by secondary electrons, which are generated in the bone. This should be allowed for in the calculation of the absorbed dose to the bone-marrow. A discussion of this effect is included in the report of the ICRU.[42] A typical example from this report shows that within a marrow cavity of size 400 μ, irradiated by radiation of photon energy 50 keV, there is a 13 per cent increase in the dose received by soft tissue remote from bone.

Distribution of active bone-marrow

78. The calculation of the mean marrow dose presupposes knowledge of the distribution in the body of the active bone-marrow. A comprehensive study was carried out by Mechanik[43] of the quantitative distribution of the total bone-marrow in adults. A summary of his data has been published by Woodard and Holodny.[44] These studies do not, however, give any information on the distribution of the active marrow. Studies on the distribution of the active marrow have shown that before birth the liver and spleen are the major erythropoietic organs, the activity of the liver being equal to that of the bone-marrow at 7½ months. At birth all bones which contain marrow have active red marrow; however with increasing age this is gradually replaced in some bones by inactive yellow marrow. By the age of eighteen to twenty years little red bone-marrow exists in the limb bones, except for the proximal epiphysis of femur and humerus.[45] A gradual replacement also takes place in all adult bones with increasing age and measurements of this effect have been given by Custer[46] for the ribs, sternum and vertebrae. Ellis[47] has calculated from the data of Mechanik and Custer the distribution of total and active marrow in the adult (table XXXV). This table also gives the set of distribution figures that was presented in the Committee's 1958 report.

79. Further research on the distribution of the bone-marrow is needed, for it is well known that the distribution of active marrow varies very much between adult individuals. Also diseases or other conditions which impose a stress on the haematopoietic system cause the red marrow to reappear in the limb bones. Large radiation doses to local volumes of active marrow may also cause variations in the active bone-marrow distribution.[48]

Dose data

80. There are few available data on mean marrow doses from medical exposure.

X-ray diagnosis

81. In its 1958 report the Committee presented mean marrow doses calculated on the basis of assumed average practice and available information for various types of examination—number of radiographs, skin doses and depth dose data. Several of these dose figures are set out in table XXXVI, together with the results from a Danish investigation performed by Buhl,[49] and from measurements by Epp *et al.*[50,51] A national survey has been conducted in the United Kingdom (para. 28) and extensive phantom measurements at eleven marrow sites are being used to derive a per capita mean marrow dose.

82. Even though the investigations presented in table XXXVI show differences between the dose figures in each of several types of examination, the order of the types of examination with regard to the size of the dose is nearly the same in the investigations. These types are examinations of the upper and lower gastro-intestinal tract (barium meal and barium enema), the gall bladder, dorsal and lumbar spine, and the lumbosacral region. Pelvimetry also belongs to those types of examination giving among the highest mean marrow doses. The differences in the dose figures reported for any one examination are due to the variations in the assumed extent and techniques of the particular examination and the values of percentage depth doses used.

83. It is obvious that the mean marrow dose will depend upon the field size and the incident skin dose. Another parameter that influences the magnitude of the mean marrow dose is the quality of the radiation used. For radiography of the chest, Epp, Weiss and Laughlin[50] showed that a low kilovoltage technique (60 keV, 1-2 mm Al filter) gives 50 per cent greater mean marrow dose than kilovoltages between 80 and 120 (2-3 mm Al filter), for which the mean marrow dose is nearly constant. Weber[52] has reported similar results for radiography of the stomach (barium meal) and abdomen. He found 50 per cent higher mean marrow doses at 70 keV (2 mm Al filter) than at 90 keV (3 mm Al filter).

84. In paragraph 31 it was pointed out that in some countries mass survey examinations of the chest are performed by means of either fluoroscopy or radiography (table XVII). Skin doses to patients from fluoroscopy may amount to more than 100 times the skin dose when radiography is used.[53] While reported mean marrow doses for mass survey examinations of the chest using radiography range between 50 and 100 mrem, it has been calculated that mass survey fluoroscopy in Austria, France and Spain gives mean marrow doses averaging 1,900, 1,200 and 1,300 mrem respectively.[53] For Belgium and Switzerland, the corresponding doses were reported to be 380 and 230 mrem respectively. The doses are set out in table XXXVII. Owing to differences between apparatuses and the duration of the fluoroscopy, the individual mean marrow doses range from around 200 mrem up to around 4,000 mrem. Since many of the examinations in France[10] are made on young people (40 per cent on individuals below the age of twenty) the figures for the mean marrow doses, calculated by means of distribution figures for the active marrow in adults, may be rather uncertain (para. 78). It is obvious from this table that in order to reduce the dose, mass miniature radiography should be used rather than mass survey fluoroscopy (cf. para. 31).

85. In the 1958 report of the Committee (annex C, para. 50) an estimate of the population per capita bone-marrow dose was made and it was suggested that it might be of the order of 50-100 mrem/y. The Committee has no reason to alter this estimate, as little information has been obtained since the last report.

External radio-therapy by X-rays and sealed radioactive sources

86. Few data on bone-marrow doses are available at present for patients who have undergone radio-therapy. Comprehensive measurements of the radiation doses to the spinal marrow in a phantom were carried out by Jones and Ellis[54] as part of the survey by Court Brown and Doll[54] on patients irradiated for ankylosing spondylitis. Maudal[55] has also made measurements of doses to organs and tissues for several sites of treatment. The latter investigation also gives data regarding the dose received by sites outside the primary beam. Further measurements have also been conducted in the United Kingdom as part of the national survey. All these measurements give the dose at the particular site in terms of 100 rem incident at the skin. Table XXXVIII gives representative values of the mean marrow dose received during such treatment.

87. Holodny, Lechtman and Laughlin[56] have reported mean marrow doses arising from the treatment of cervix carcinoma with radium applicators. Their results, presented in table XXXVIII, are based on measurements of the doses in a body-shaped phantom at different sites of the bone-marrow. They calculated the mean marrow doses by means of Ellis's distribution figures for active marrow.

88. Mean marrow doses to children below two years of age who were treated with radium skin applicators for haemangioma have been reported by Nordberg.[57] Dose measurements were made in a phantom which, in shape and size, corresponded to a child below the age of two. It was assumed that the active bone-marrow is distributed throughout the skeleton. The mean marrow doses were calculated by means of the data on the distribution of marrow space given by Woodard and Holodny[44] assuming that the distribution of marrow space in children is the same as in adults. The results are given in table XXXVIII and the distribution figures used are presented in a footnote to the table.

Administration of radio-isotopes

89. The data at present available to the Committee on relevant parameters for I^{131}, P^{32} and Au^{198} do not suffice for estimating the individual mean marrow doses with any certainty. The estimates of the total dose to the blood following administration of these isotopes give a first approximation of the mean marrow dose.[37, 39]

Comments

90. The mean marrow doses caused by external radiotherapy are, of course, much higher than the ones caused through X-ray diagnosis. A diagnostic examination of the lumbar spine results in a mean marrow dose of 100-400 mrem, but the treatment of this site for non-malignant conditions may give a mean marrow dose that is 100 times greater. In certain types of radio-therapy for malignant conditions, the mean marrow doses may be even higher.

Dose to other organs and tissues of special interest

General remarks

91. The organs and tissues which, in addition to the gonads and the bone-marrow, are usually considered of special interest with regard to radiation doses are the foetal tissue, the lenses of the eyes, the thyroid, skin, and the liver. Information regarding the effects caused by the irradiation of these organs are given in annex D together with analyses of the radiation doses which have caused them. Other information is given in the report of the meeting, held at the Committee's invitation, of the ICRP/ICRU Study Group in 1960.[58]

Data

92. Table XXXIX gives a few examples of the radiation doses which may be received by these selected tissues as a consequence of various radiological procedures. The doses must not be considered as being the results of extreme circumstances but as figures obtained from radiological procedures at present or recently used in various countries. Particular points regarding each tissue are given in the following paragraphs.

Foetal tissue

93. During the first two months after conception, it may happen, because of unawareness of pregnancy, that women undergo various kinds of radiological procedures which would not have been performed if the pregnancy had been known. Because of the small dimensions of the

foetus at this stage, the foetal dose can be regarded as the same as the dose to the maternal gonads. Data regarding the incidence of malignancies following irradiation *in utero* are given in annex D, paragraphs 277-285, and table VII.

Lens of the eye

94. Full mouth examination and encephalography are two X-ray diagnostic procedures which may give substantial doses to the lens of the eye. Similarly, treatment of lesions of the eye, or in the region of the eye, may also contribute high doses. Data regarding the formation of cataract or lens opacity is given in annex D, paragraphs 91-93, 289-307 and 443-445.

Thyroid

95. Tests of thyroid functions are frequently performed in most countries. The dose to the normal adult thyroid is about 1.5 rem per μc administered I^{131}. Barium swallow and examination of the cervical spine are assumed to be the two types of commonly performed X-ray diagnostic procedure which give the highest dose to the thyroid. The treatment of hyperthyroid conditions and heart conditions with I^{131} gives doses of the order of 10,000 rem to the thyroid (see para. 96 below) (D, 286, 402-404).

Thymus

96. In some countries enlarged thymus glands have been treated by radiation with doses of the order of 200 rem. In annex D, paragraphs 263-272, 485 and table VI, data are given regarding surveys carried out on the incidence of leukaemia and thyroid cancer in these patients.

Liver

97. The use of thorotrast as a contrast medium in diagnostic radiology has been curtailed since its possible deleterious effects have been recognized. The effects observed are sequelae at the site of injection and the induction of liver malignancies. Reports of surveys of patients injected with thorotrast have been given by Hursh *et al.*,[59] Baserga,[60] Looney[61] and Blomberg *et al.*[62] Studies of the radiation doses received have been carried out by Rotblat and Ward[63] and Rundo.[64, 65] A comparison of the doses to various body tissues over twenty years from an injection of 20 ml thorotrast is given in table XL from Marinelli.[66]

Reduction of doses to various organs and tissues including the bone-marrow

98. Earlier in this annex (paragraphs 41, 42, 61) the Committee has considered ways of reducing the doses to the gonads. Most of these measures are also applicable for the reduction of doses to other organs and tissues and can be summarized as follows:

(*a*) Improved methods of radiological procedure;

(*b*) The use of strictly appropriate physical conditions of exposure, including the smallest possible radiation field and good collimation of the beam;

(*c*) The reduction of the incident skin dose, e.g. by reducing fluoroscopy time;

(*d*) Satisfactory shielding against leakage radiation;

(*e*) The use of radio-active isotopes in diagnostic investigations utilizing *in vitro* rather than *in vivo* tests and the use of the nuclide with the shortest half life consistent with the requirements of the investigation; for example, I^{132} may be used rather than I^{131} for some thyroid investigations.

(*f*) Well-trained staff of all categories for the performance of the procedures.

FIELDS OF RESEARCH

99. The present state of knowledge requires that consideration should be given to the following items and that research in these fields should be encouraged:

(*a*) The promotion of statistical studies concerning the number of people medically exposed;

(*b*) Follow-up studies on the offspring of pregnant patients having radiological examinations or treatments of the pelvic region;

(*c*) Follow-up studies of patients having had (i) radio-therapy for non-malignant conditions such as ankylosing spondylitis and enlarged thymus; (ii) I^{131} treatment, or (iii) diagnostic examinations using thorotrast as a contrast medium;

(*d*) Investigations aimed at defining good practices in diagnostic radiology so that minimum gonad doses are received;

(*e*) Investigations of the effect of dose-rate on the production of mutation;

(*f*) More quantitative information on the distribution of active marrow and how it varies with age;

(*g*) Investigations of the dose received by the bone-marrow during radiological procedures.

III. Occupational exposure

100. In the introduction to the present annex (para. 3) the Committee considered the term "occupational exposure" as being applicable to all activities involving exposure of individuals to ionizing radiation in the course of their work, regardless of whether they are directly engaged in radiation work or not.

NUMBER OF INSTALLATIONS AND RADIATION WORKERS

101. Work with ionizing radiation is usually subdivided with regard to the purpose of the work as follows: medical (diagnosis and therapy), dental, veterinary, industrial, research and educational, and atomic energy. Table XLI gives the range of the number of X-ray installations* per thousand of total population for these purposes in the Netherlands,[67] New Zealand,[68] Norway,[69] Sweden,[70] Switzerland,[16] and two areas of the United States of America, New York City[71] and California.[72] Most of the installations for medical and dental purposes have X-ray apparatus only. The number of X-ray installations used for veterinary, industrial, and research and educational purposes, is at present very small compared with those used for medical purposes.

102. Only a few data exist on the number of installations where radio-isotopes are used. In California, work with radio-isotopes is performed in 6 per cent of the total number of installations and most of this work is done where X-ray work also is performed.[72] Even if work with radio-isotopes is carried out in the majority of hospitals and of industrial and research installations, the large number of private medical and dental practi-

* "Installation" covers any department or private practice. If a hospital has a central X-ray department as well as X-ray facilities in various other sections of the hospital, each one is counted as an installation.

tioners using X-ray apparatuses exclusively, keeps the figure low as compared to X-ray installations. It does not seem likely that in any country the number of installations where radio-isotopes are used would surmount 10-20 per cent of the total number of installations.

103. Table XLI also gives the ranges of the numbers of individuals per 1,000 of the population directly occupied in radiation work in the countries listed in paragraph 101.

Recommendations on the conditions of work

104. Recommendations regarding the exposure of workers to ionizing radiation have been made by the ICRP.[1] The doses to which their suggested limits apply do not include the contributions from natural sources of radiation, or from the exposure of the workers for medical reasons. The maximum permissible levels of exposure are kept under constant surveillance and the present recommendations state that for the dose "accumulated in the gonads, the blood forming organs and the lenses of the eyes, at any age over 18, shall be governed by the relation $D = 5\ (N-18)$ rem where D is tissue dose in rem and N is age in years". The ICRP goes on: "To the extent the formula permits, an occupationally exposed person may accumulate the maximum permissible dose at a rate not in excess of 3 rem during any period of 13 consecutive weeks". Exposure limited to certain parts of the body, such as the extremities, or to single organs, as in the case of internal exposure, is subject to special recommendations allowing somewhat higher doses. Based on these recommendations many national and international organizations have produced their own rules and recommendations.

Dose information from individual monitoring

105. Table XLII sets out average figures for the annual occupational exposure to individuals from external X- and γ-ray sources in various kinds of radiation work in Argentina,[36] Canada,[73] the Netherlands,[67] Norway,[74] and the United Kingdom.[75] In Norway and the United Kingdom, for which doses are given separately for diagnosis and therapy, the annual doses in therapeutic work are higher than in diagnosis. This may be explained by the fact that therapeutic work involves the handling of radium applicators. It is necessary that there be a continuous improvement of protection devices, especially for work with radium applicators.

106. Even though the average values received by workers are of interest, the distribution of doses and the number of personnel exceeding the recommended annual level is of more importance. A comprehensive analysis of the doses received by the 12,000 workers in the Federal Republic of Germany has been given by Wachsmann[76] and shows for the years 1952 to 1959 the gradual reduction in the number of persons exceeding the recommended level. In 1952, 23 per cent exceeded 0.4 rem/mo while in 1958 only 4 per cent were observed. The division of these into medicine, industry and research showed that 31 per cent, 12 per cent, and 14 per cent respectively of the personnel working in these fields exceeded 5 rem/y. It is known that there has been over the last decade a great improvement in the doses received by workers so that reports[67,75,77] show that only 0.1-0.5 per cent of the dose measurements show doses of such a magnitude that the individual, if these doses continued to be recorded, would exceed the maximum permissible annual or quarterly levels.

107. For atomic energy work, detailed results have been published on the extensive monitoring of individuals for occupational exposure. Table XLIII gives data on occupational exposure from penetrating radiation at Oak Ridge National Laboratory, United States,[78] the establishments of the United Kingdom Atomic Energy Authority,[75] Argentina,[36] Canada[79] and the United Arab Republic.[80]

Internal contamination

108. As far as occupational exposure caused by internal contamination of the body by radio-isotopes is concerned, surveys are frequently made on the radioactivity in the air and water and by whole body counting and urine surveys the inhaled or otherwise absorbed radio-isotopes may be estimated. During usual working conditions the surveys have given concentrations far below the highest permissible concentrations, corrected to allow for occupational exposure by external radiation. At Oak Ridge National Laboratory[78] the level of air contamination in the laboratories during 1959 was only 0.4 per cent of the assumed maximum permissible concentration (10^{-9} μc/cm^3 of air). Regarding surveys of body burdens of radio-isotopes, practically no concentrations beyond the maximum permissible ones have been detected for radio-isotopes other than uranium.[75,81]

Mining: industrial processing of uranium and thorium

109. High concentrations of radon and thoron and daughters exist in mines. In areas of poor ventilation where high-grade uranium ores or radium enriched residues are stored, the radon concentrates may be as high as 10^{-4} to 10^{-5} μc/cm^3 of air.[82] Experience has shown, however, that the concentrations of radon daughter products can be greatly reduced by forced ventilation.[83] During the industrial processing of uranium and thorium, fine dusts are often produced and precautions must be taken to prevent inhalation of them.[84,85] Consideration of these hazards is given in the report of the United States National Academy of Science on the effects of inhaled radio-active particles,[83] which also gives data regarding the radon concentration in seventy-five uranium mines surveyed in Utah. Information is also available for the Argentinian,[36] Canadian,[86] French,[87] and South African[88] uranium mines, and the phosphate mines in the United Arab Republic.[89] Since uranium is excreted very rapidly from the body, concentrations of the isotope can easily be detected in man. In the workers in Argentinian[36] mines mean levels of uranium in the urine vary from 2-29 micrograms excreted per 24 hours.

Luminizing industry

110. Total body burdens of 273 persons employed in the luminizing industry have been measured in the United Kingdom.[75] Ten of these were found to have body burdens in excess of 0.1 μc radium, the highest being 0.6 μc. Twenty-nine persons had burdens between 0.05 μc and 0.1 μc and 234 had burdens less than 0.05 μc. All those persons having burdens above 0.05 μc were employed before the introduction, in 1942, of the first regulations. An incident involving the occupational contamination from Sr^{90} used in the luminizing industry has been reported from Czechoslovakia.[90]

Estimates of occupational exposure in high altitude aircraft

111. Cosmic radiation increases with altitude. Commercial jet aircraft fly at an altitude of 8-12 km (25,000-

40,000 feet), while military jet aircraft may reach an altitude of 16 km (50,000 feet). According to estimates in the United Kingdom[75] and in the United States,[91] the annual radiation dose to a crew at 16 km amounts to 400-500 mrem. At an altitude of 12 km, the corresponding dose is around 300-350 mrem. Dose figures relate to a northern latitude of around 40°, assuming 80 hours' flying time per month.

112. It is anticipated that supersonic transport aircraft, if and when they become commercially available, may fly at altitudes of up to 26 km (85,000 ft). Aircraft crews might be expected to fly a maximum of 40 hours per month at these altitudes. It has recently been calculated by Foelsche[92] that at a latitude of N 50° a crew, under these assumptions, would be exposed to an annual dose of approximately 1,500 mrem. However, during intense solar flares a few hours' supersonic flight at an altitude of 24 km may cause a dose of 8,000 mrem. If these solar flares can be predicted in advance, aircraft flying at very high altitudes would be able to descend to lower altitudes before the peak activity is reached.

113. The contribution to the dose from contamination of an aircraft by surrounding radio-active particles can be disregarded, although the exposure of maintenance staff has received some consideration.[91,93]

114. Consideration[94] has been given to the computation of the radiation likely to be received by space crews and also to the problem of determining the dose due to protons in solar flares.[95,96]

Genetically significant dose

115. By the use of dose information obtained from individual monitoring, the genetically significant dose from occupational exposure has been reported from a number of countries. Allowance has been made for the age distribution of the workers. The estimated annual genetically significant doses calculated from formula 11 (see appendix) give the following results:

	Dose mrem	*Year of Estimation*
Austria[119]	0.2	1955
Netherlands[67]	0.3	1960
United Kingdom[75]	0.4	1959

In the United Kingdom, the contribution to the genetically significant dose from atomic energy establishments has been calculated to be 0.15 mrem. There is no reason at present to assume that the genetically significant dose from occupational exposure in other countries would considerably exceed the figures listed above.

Mean marrow dose

116. No data are available on the actual mean marrow dose from occupational exposure. However, the values given in table XLII may be regarded as the dose at the skin and therefore the bone marrow doses will be considerably smaller.

IV. Other exposures

117. In addition to the doses received by individuals, either as patients undergoing medical radiological procedures or by radiation workers during working hours, irradiation may come from other man-made sources.* These comprise such sources as X-ray fluoroscopy for shoe fitting, luminous markings in clocks and watches and other luminous devices, and television sets. The public living in the vicinity of radiological installations and passengers in aircraft may also receive additional radiation. Some of the more important sources are considered in the following paragraphs.

Radiological installations

118. Members of the general public living near or having access to these installations may receive small doses mainly from scattered radiation. The Committee notes that the ICRP[1] has made recommendations that such people should not receive from such exposure more than 500 mrem per year in the gonads, the blood forming organs and the lenses of the eyes.

X-ray fluoroscopy for shoe fitting

119. A survey by Seelentag and Peck[97] has comprehensively reviewed the literature regarding the doses received from these machines. They also report measurements on ten different units. The average annual genetic dose to the population of the Federal Republic of Germany was estimated as 4-7 microrem per year. The Medical Research Council of the United Kingdom[75] estimated in 1956 that the annual genetic dose in that country from this source was not more than 0.1 per cent of that received from natural background and that after the full implementation of present legislation (by 1963) the dose would be reduced to some 0.01 per cent. In several countries fluoroscopy for shoe fitting has been prohibited since it is regarded as causing unnecessary radiation exposure.

Luminous markings in clocks and watches

120. Reports of the activities of watches and clocks have been made in Germany,[98] Norway,[99] Sweden,[100] Switzerland[101] and the United Kingdom.[75] These show that there is a wide variation in activities of watches and clocks up to about 0.5 microgram of radium with a mean value of about 0.1 microgram. Estimates of the annual genetically significant dose from this source are 2.6 mrem,[98] 1-3 mrem,[100] 8 ± 3 mrem,[101] and 0.5 mrem.[75] The annual dose to the sales staff has been estimated as 90 mrem.[98]

Television sets

121. The ICRP[1] has recommended that the dose-rate at any accessible point 5 cm from the surface of any set used in the home or place where the public is likely to be shall not exceed 0.5 mrem/hr under normal operating conditions. Braestrup and Wycoff[102] have shown that at 15 kV, the normal operating voltage of home television sets, the dose-rate at the surface of the screen is about 1 mr/hr. However, most sets are provided with a further plastic or glass sheet which reduces the dose-rate, but when these sets are operated above normal voltages, for testing purposes for example, then the dose-rate may be increased greatly. Operation at 24 kV increased the dose-rate by a factor of 1,000. It has been pointed out that colour television tubes operate at about this voltage so that further shielding is required to conform to the ICRP recommendation.

122. The dose-rates received by the operators of projection TV units working at 80 kV may be of the order of 10 mrem/hr, but high dose-rates of the order of 1 r/hr have been measured close to the tubes. However, these are not in the direction of the audience.[102]

* Environmental contamination is dealt with in Annex F.

123. Braestrup[103] has estimated that the average gonad dose from home television is much less than 1 mrem/yr.

Passengers in aircraft

124. The enhanced cosmic radiation experienced in aircraft makes a negligible contribution to the total dose received by the population at the present time.

Use of nuclear power in ships

125. Information has been given of the predicted radiation levels to the workers and public from the use of nuclear propulsion in ships.[104, 105] The doses received by occupationally exposed workers were on the average about 0.5 rem/y and were up to a maximum of 1-2 rem/y.[130] The activities discharged as waste from these vessels are unlikely at the present time to make any contribution to the dose received by the general public.

Genetically significant dose

126. The use of these miscellaneous sources is likely to contribute about 2 mrem/y, mainly from the use of luminizing of clocks and watches. However, with the increasing uses of miscellaneous sources of radiation, none of which individually contribute an appreciable dose, the total genetically significant dose may be expected to increase slightly.

Appendix

1. A general definition of genetically significant dose has been given in paragraph 9 above. 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*

$$D = \frac{\sum_j \sum_k (N_{jk}^{(F)}\, w_{jk}^{(F)}\, d_{jk}^{(F)} + N_{jk}^{(M)}\, w_{jk}^{(M)}\, d_{jk}^{(M)})}{\sum_k (N_k^{(F)}\, w_k^{(F)} + N_k^{(M)}\, w_k^{(M)})} \qquad (1)$$

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.

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 $w_k^* \cdot N_k^*$ for a population, which means that an assumption has to be made regarding the expected *future* number of children (w_k^*) 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

$$w_a^* = \sum_{t=a}^{\infty} c_t^* \cdot \Delta t \cdot P_a^*(t) \qquad (4)$$

where

w_a^* = expected future number of children of an individual of age a. With knowledge of the function w_a^* of age, the average w_k^* for any age-group k can be calculated,

c_t^* = 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,

$P_a^*(t)$ = probability of an individual of age a to reach age (group) t.

5. It must be noted that c_t^* 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, c_t^* has been assumed not to vary with time.

6. $W^* = w_{a \to 0}^*$ 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

$$D^* = \frac{1}{wN} \sum_j \sum_k N_{jk}^*\, w_{jk}^*\, d_{jk}^* \qquad (5)$$

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

$$d_{jk}^* = d_j^* \qquad (6)$$

approximately for all k, and formula 5 reduces to

$$D^* = \frac{1}{wN} \sum_j d_j^* \sum_k N_{jk}^*\, w_{jk}^* \qquad (7)$$

or

$$D_j^* = d_j^* \cdot \frac{1}{wN} \sum_k N_{jk}^*\, w_{jk}^*$$

* 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.

where D_j^* is the contribution from type j examination of the specified sex to the genetically significant dose. This again can be written as

$$D_j^* = d_j^* \cdot \frac{N_j^*}{N} \cdot \frac{w_j^*}{w} \qquad (8)$$

which is the expression for numerical calculations.

9. The necessary information to make it possible to calculate D_j^* by help of formula 8 is:

(*a*) d_j^* = the mean gonad dose per individual undergoing class j examination;

(*b*) N_j^*/N = the relative frequency of class j examination, i.e., the number of examinations per capita, per year;

(*c*) w_j^*/w = the relative child-expectancy of the average individual undergoing class j examination.

The formula is applicable also to foetal 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 D_j^* 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. w_j^* can then be calculated from the age-distribution of the patients and the normal child-expectancy for each age-group,

$$w_j^* = \frac{\sum_k w_{jk}^* N_{jk}^*}{N_j^*} \approx \frac{\sum_k w_k^* N_{jk}^*}{N_j^*} \qquad (9)$$

where w^* can be taken from formula 4. If w_j^*/w is not given in the primary material, it may be recalculated from N_j^*/N, d^* and this approximation of D_j^*, 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

$w_k^* = W^*$ for all persons below mean age of child-bearing,

$w_k^* = 0$ 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

$$w^* = \frac{n}{N^*} \cdot W^* \qquad (10)$$

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

$$D_j^* = \frac{n_j^*}{n} \cdot d_j^* = \frac{N}{n} \cdot \frac{n_j^*}{N} \cdot d_j^* \qquad (11)$$

TABLE I. ANNUAL FREQUENCIES OF X-RAY EXAMINATIONS

Country or area	Year of study	Population at time of study	Annual number of x-ray examinations per 1,000 of total population: Examinations, except mass surveys and dental — Radiography	Examinations, except mass surveys and dental — Fluoroscopy	Mass surveys — Radiography	Mass surveys — Fluoroscopy	Dental	Reference
Argentina (Buenos Aires)	1950–1959	6,000,000[a]	270[b]	No data	80[b]	Not applicable	No data	4
Australia	1955–1957	9,500,000	480[c]	—[d]	190[c]	Not applicable	No data	32, 33
Austria	1955–1958	6,974,000	67[c]	310[c]	25	25	No data	53;119
Belgium	1958	8,924,000	No data	No data	130	21	No data	53
Canada	1958	17,048,000	220[c]	30[c]	90	Not applicable	No data	106, 107
Denmark	1956	4,466,000	260	—[d]	140	Not applicable	40	5
Federal Republic of Germany (Hamburg)	1957–1958	1,755,000	560	—[d]	130	Not applicable	80	6
France	1957–1958	42,000,000	150	—[d]	40	570	No data	8-10
Israel	1959	2,062,000	300	110	170	Not applicable	20	108
Italy (Rome)	1957	1,875,000	500	—[d]	80	Not applicable	No data	11
Japan	1958–1960	90,000,000	410	—[d]	320	Not applicable	10[b]	12, 53
Netherlands (Leiden)	1959	110,000	350	200[f]	130	Not applicable	40[b]	13
New Zealand	1957	2,221,000	340[c]	—[d]	90[c]	Not applicable	240[c]	68
Norway	1958	3,525,000	390	—[d]	210	Not applicable	100	14
Sweden	1958	7,300,000	290	—[d]	140	Not applicable	No data	15
Switzerland	1957	5,160,000	310	330	130	60	140	16
United Arab Republic:								
Alexandria	1959–1960	1,361,700[e]	36	—[d]	4	Not applicable	0.3	17
Cairo	1955–1961	2,640,000[e]	40	—[d]	5	Not applicable	2	18
United Kingdom (except Northern Ireland)	1957–1958	50,000,000	280	—[d]	95	Not applicable	40	19
United States of America	1955–1956	162,000,000	250[c]	80[c]	135[c]	Not applicable	400[c]	20

[a] Including commutors.
[b] Figures relate to films and not to examinations.
[c] Data are taken from the 1958 report of the United Nations Scientific Committee on the Effects of Atomic Radiation.[3]
[d] Fluoroscopy is generally performed only in connexion with radiography.
[e] Figures relate to hospitals only.
[f] Fluoroscopy of the chest not connected with radiography but not mass surveys.
[g] Population served by hospitals surveyed.

TABLE II. ANNUAL FREQUENCIES OF CASES TREATED BY X-RAYS AND SEALED RADIO-ACTIVE SOURCES

Country or area	Year of study	Population at time of study	Annual number of cases per 1,000 of total population			Reference
			Malignant	Non-malignant	Total	
Austria	1955–1957	6,974,000	4	10	14	119
Canada	1958	17,048,000	No data	No data	1.9[a]	106
Czechoslovakia (Prague)	1958	990,000	No data	7.7	—	109
Federal Republic of Germany (Hamburg)	1957–1958	1,755,000	4.0	8.3	12.3	6
France	1957	42,000,000	3.7	2.2	5.9	27
Israel	1959	2,062,000	0.6[a,b]	3.5[a,b]	4.1[a,b]	108
Italy (Rome)	1957	1,875,000	No data	1.3	—	110
Lebanon	1956–1960	1,500,000	0.2	0.1	0.3	111
United Arab Republic:						
Alexandria	1956–1961	1,361,700	0.25	0.21	0.46	18
Cairo	1959–1960	2,640,000	0.6	0.7	1.3	34, 35
United Kingdom (except Northern Ireland)	1957	50,000,000	1.2	1.2	2.4	19

[a] Figures relate to hospitals only.
[b] For non-malignant conditions around 70 per cent of all cases. For malignant conditions around 80-85 per cent of all cases.

TABLE III. ANNUAL FREQUENCIES OF ADMINISTRATIONS OF RADIO-ACTIVE ISOTOPES FOR MEDICAL REASONS AND THE ANNUAL AMOUNT OF I^{131}, P^{32} AND Au^{198} FOR MEDICAL USE

Country or area	Year of study	Population at time of study	Annual number of cases per 1,000 of total population		Annual amounts of radio-active isotopes for medical use (curies)[c]			Reference
			Diagnosis	Therapy	I^{131}	P^{32}	Au^{198}	
Argentina	1960	20,956,000	0.30	0.03	6.0[c]	0.8[c]	No data	36
Australia	1959–1960	9,800,000	0.65[b]	0.09[b]	8.2	2.1	4.4	112
Canada	1958–1960	17,048,000	No data	0.04[c]	55.0	5.1	23.8	106, 113
Federal Republic of Germany (Hamburg)	1957–1958	1,755,000	1.1[d]	0.20[d]	No data	No data	No data	6
Israel	1959	2,062,000	1.7	0.16	2.5	0.3	3.4	108
Lebanon	1956–1960	1,500,000	0.1	0.01	0.3	<0.1	No data	11
Norway	1960	3,500,000	No data	No data	2.1	0.5	5.7	69
United Arab Republic: Cairo	1961	2,640,000	0.33	0.42	1.3	0.07	1.1	18
United Kingdom (except Northern Ireland)	1957	50,000,000	0.5	0.08	50[c]	4.2[c]	88[c]	20
United States of America	1959	180,000,000	1.2	0.3	No data	No data	No data	114

[a] See paragraph 8 (*c*) above.
[b] Minimum estimate.
[c] Figures refer to hospitals only.
[d] Figures refer to the use of I^{131} only.
[e] Figures refer to the quantities actually administered.

TABLE IV. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1950-1959 — *Argentina (Buenos Aires)*[4]

Type of examination	$\frac{N^*_j}{N} \times 1{,}000$[a]		d^*_j (mrem)[a]			D^*_j (mrem)			D^*_j	
	Male	Female	Male adults	Female adults	Foetus	Male	Female	Foetus	mrem	Percentage
A. HOSPITALS AND CITY CENTRES (RADIOGRAPHY)										
Urography (descending pyelography)	2.7	2.2	700	900	No data	1.9	2.0	No data	3.9	16
Hip, upper femur	2.8	3.0	600	600	No data	1.7	1.8	No data	3.5	14
Colon (barium enema) lower GI	2.7	2.7	300	450	No data	0.8	1.2	No data	2.0	8
Lumbar spine	2.4	3.7	200	400	No data	0.5	1.5	No data	2.0	8
Mass miniature radiography	58	18[c]	10	15	No data	1.3	0.6	No data	1.9	7
Pelvis	1.1	1.6	600	700	No data	0.7	1.1	No data	1.8	7
Obstetrical abdomen	—	1.0[e]	—	800	No data	—	1.8	No data	1.8	7
Lumbosacral region	1.2	2.3	230	600	No data	0.3	1.4	No data	1.7	7
Pelvimetry	—	0.6[e]	—	900	No data	—	1.2	No data	1.2	5
Retrograde (ascending) pyelography	1.0	0.6	600	800	No data	0.6	0.5	No data	1.1	4
SUB-TOTAL	72	36				7.8	13.1		20.9	83
Other types of examination[b]	67	56				1.7	2.7		4.4	17
SUB-TOTAL	139	92				9.5	15.8		25.3	100
B. PRIVATE CLINICS AND PRACTICES (RADIOGRAPHY)[d]						4.5[d]	7.5[d]		12[d]	
TOTAL						14	23		37	100

[a] Figures are related to radiographs and not to examinations.
[b] Does not include dental radiography.
[c] Does not include contribution from foetal exposure.
[d] Estimated figures (see para. 17).
[e] Below mean reproductive age, i.e., (n^*_j/n).

TABLE V. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1956-1958 — *Denmark*[5]

Type of examination	$\frac{N^*_j}{N} \times 1{,}000$		d^*_j (mrem)			D^*_j (mrem)			D_j	
	Male	Female	Male adults	Female adults	Foetus	Male	Female	Foetus	mrem	Percentage
Intravenous pyelography	4.3	4.3	1,019	565		4.3	2.4		6.7	24
Retrograde pyelography	0.9	0.4	2,580	1,136		2.3	0.5		2.8	10
Cystography	0.4	0.4	5,078	437		2.3	0.2		2.5	9
Hip and femur	2.2	2.5	980	58		2.2	0.1		2.3	8
Pelvimetry	—	2.2	—	822		—	1.8		1.8	7
Urethrography	0.4	—	3,709	—		1.7	—		1.7	6
Pelvis	2.5	0.7	567	210		1.4	0.1		1.5	5
Spine lumbar	4.3	3.4	104	222		0.4	0.7		1.1	4
Abdomen obstetric	—	2.0	—	190		—	0.4		0.4	2
Abdomen A.P.	0.4	0.4	610	85		0.3	0.1		0.4	2
SUB-TOTAL	15.4	16.3				14.9	6.3		21.2	77
Foetal contribution								5.0	5.0	18
Other types of examination	244					0.7	0.6		1.3	5
TOTAL	260					15.6	6.9	5.0	27.5	100

TABLE VI. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1957-1958 — *Federal Republic of Germany (Hamburg)*[6]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$ Male	$\frac{N_j^*}{N} \times 1{,}000$ Female	d_j^* (mrem) Male adults[a]	d_j^* (mrem) Female adults[a]	d_j^* (mrem) Foetus	D_j^* (mrem) Male	D_j^* (mrem) Female	D_j^* (mrem) Foetus	D_j mrem	D_j Percentage
Colon (barium enema) lower GI	3.7	4.0	890	2,530	2,740	1.87	4.03	0.19	6.09	34
Hip, upper femur	2.6	3.2	1,520	214	255	3.15	0.17	0.01	3.33	19
Urography (descending pyelography)	5.1	3.6	241	439	476	0.70	0.71	0.04	1.45	8
Lumbar spine	11.2	10.2	63	183	178	0.52	0.72	0.04	1.28	7
Pelvis	3.8	3.7	275	94	166	0.90	0.24	0.01	1.15	7
Obstetrical abdomen	—	0.32	—	680	677	—	0.22	0.54	0.76	4
Stomach (barium meal) upper GI	23.9	16.9	65	67	63	0.11	0.47	0.02	0.60	3
Retrograde (ascending pyelography)	1.2	1.1	311	657	720	0.21	0.27	0.02	0.50	3
Abdomen	4.6	2.9	88	128	167	0.27	0.20	0.01	0.48	3
Pelvimetry	—	0.05	—	600	2,900	—	0.03	0.37	0.40	2
SUB-TOTAL	56	46				7.73	7.06	1.25	16.04	90
Other types of examination	369	299				1.07	0.61	0.02	1.70	10
TOTAL	425	345				8.80	7.67	1.27	17.74	100

[a] Denotes mean figures of gonad dose. After detailed calculation of D_j^* formula 8 was used for obtaining d_j^*.

TABLE VII. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1957-1958 — *France*[8-10]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$ Male	$\frac{N_j^*}{N} \times 1{,}000$ Female	d_j^* (mrem) Male adults	d_j^* (mrem) Female adults	d_j^* (mrem) Foetus	D_j^* (mrem) Male	D_j^* (mrem) Female	D_j^* (mrem) Foetus	D_j^* mrem	D_j^* Percentage
Chest (heart, lung)	340	230	30[b]		No data	38[c]		No data	38	65
Abdomen	3.7	4.4	1,500	1,300	No data	5.58	4.62	No data	10.20	18
Hip, upper femur	2.1	1.7	1,200	180	No data	2.61	0.23	No data	2.84	5
Urography	2.1	1.8	390	4,500	No data	0.32	2.30	No data	2.62	4
Lumbar spine	3.0	2.4	250	700	No data	0.48	0.80	No data	1.28	2
Obstetrical abdomen	—	0.2	—	1,600	No data	—	0.80	No data	0.80	1
Urethrocystography	0.7	0.5	1,900	1,800	No data	0.24	0.23	No data	0.47	1
Stomach (barium meal) upper GI	5.9	3.8	90	300	No data	0.14	0.29	No data	0.43	1
Colon (barium enema) lower GI	2.0	2.5	134	264	No data	0.14	0.23	No data	0.37	1
Pelvimetry	—	0.02	—	1,200	No data	—	0.02	No data	0.02	0
SUB-TOTAL	360	247				9.51	9.52		57.03	98
						38[c]				
Other types of examination[d]	84	65				0.22	0.96		1.18	2
TOTAL	444	312				9.73	10.48		58.21	100
						38[c]				

[a] Does not include contribution from foetal exposure.
[b] Mean value for the dose to testes and ovaries.
[c] Since d_j is given only as mean figure for the gonads the dose figure cannot be split into male and female dose.
[d] Does not include dental radiography.

TABLE VIII. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1957 — *Italy (Rome)*[11]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$ Male	$\frac{N_j^*}{N} \times 1{,}000$ Female	d_j^* (mrem) Male adults	d_j^* (mrem) Female adults	d_j^* (mrem) Foetus	D_j^* (mrem) Male	D_j^* (mrem) Female	D_j^* (mrem) Foetus[a]	D_j mrem[b]	D_j Percentage
Digestive tract	27.8	14.2	123	411	No data	3.08	5.25		8.33	19
Hip, femur	6.1	7.0	586	223	No data	3.93	1.09		5.02	12
Urography (descending pyelography)	5.2	3.4	940	1,060	No data	2.44	2.52		4.96	11
Pelvis	5.0	4.7	1,130	330	No data	3.38	1.40		4.78	11
Lumbar spine	7.9	4.8	234	570	No data	2.03	2.19		4.22	10
Barium enema	4.7	2.4	239	1,050	No data	1.01	2.27		3.28	8
Cholecystography	9.1	11.6	12	156	No data	0.12	1.27		1.39	3
Abdomen	5.2	3.4	141	210	No data	0.66	0.64		1.30	3
Obstetrical abdomen	—	0.8	—	399	No data	—	0.59		0.59	1
Pelvimetry	—	0.1	—	1,250	No data	—	0.23		0.23	1
SUB-TOTAL	71	52				16.65	17.45		34.10	79
Foetal contribution[a]								2.59	2.59	6
Other types of examination[c]	276	174				4.15	2.57		6.72	15
TOTAL	347	226				20.80	20.02	2.59	43.41	100

[a] No figures subdivided into various types of examination are available.

[b] The figures for D_j are the sum of the male and female contributions.

[c] Does not include dental radiography.

TABLE IX. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1958-1960 — *Japan*[12]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$ Male	$\frac{N_j^*}{N} \times 1{,}000$ Female	d_j^* (mrem) Male adults	d_j^* (mrem) Female adults	d_j^* (mrem) Foetus	D_j^* (mrem) Male	D_j^* (mrem) Female	D_j^* (mrem) Foetus	D_j mrem	D_j Percentage
Stomach (barium meal) upper GI	53	33	4.3[a] (28)	74[a] (2,660)	No data	0.69	10.92	No data	11.61	30
Colon (barium enema) lower GI	5.0	4.5	220[a] (2,390)	81[a] (4,320)	No data	4.01	4.28	No data	8.29	21
Lumbar spine	7.6	3.6	767	121	No data	4.36	0.19	No data	4.55	12
Lumbosacral region	3.7	1.6	1,700	116	No data	4.44	0.06	No data	4.50	12
Hip, upper femur	4.7	6.0	691	30.5	No data	1.93	0.46	No data	2.39	6
Pelvis	1.6	1.5	1,490	80	No data	1.58	0.08	No data	1.66	4
Chest (heart, lung)	103	65	1.0[a] (0.6)	8.0[a] (78)	No data	0.41	1.07	No data	1.48	4
Urography (descending pyelography)	3.6	2.6	631	92	No data	1.27	0.13	No data	1.40	4
Obstetrical abdomen	—	1.1	—	162	162[b]	—	0.12	0.30	0.42	1
Pelvimetry	—	0.15	—	322	322[b]	—	0.03	0.09	0.12	0.3
SUB-TOTAL	182	119				18.69	17.34	0.39[d]	36.42[d]	96
Other types of examination[c]	74	37				1.82	0.79	No data	2.61	4
TOTAL	256	156				20.51	18.1	0.39[d]	39.0[d]	100

[a] Dose figures relate only to the radiographical part of the examination. In around 8 per cent of chest, 38 per cent of stomach and 50 per cent of colon examinations, fluoroscopy is performed. The figure within brackets denote the gonad doses arising from fluoroscopy. The values of D_j^* refer to the total from both radiography and fluoroscopy.

[b] The dose is assumed to be the same as to the maternal ovaries.

[c] Does not include mass miniature and dental radiography.

[d] The figure implies contribution from foetal exposure only from obstetrical examination.

TABLE X. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1959-1960 — *Netherlands (Leiden)*[13]

Type of examination	$\frac{N^*_j}{N} \times 1{,}000$		d^*_j (mrem)			D^*_j (mrem)			D_i	
	Male	Female	Male adults	Female adults	Foetus[a]	Male	Female	Foetus	mrem	Percentage
Urography (descending pyelography)	5.6	3.0	512	604	604	1.16	0.62	0.08	1.86	27
Hip, upper femur	1.6	2.1	3,323	140	140	1.48	0.04	n	1.52	22
Colon (barium enema) lower GI	3.7	2.6	25	613	613	0.03	0.50	0.08	0.61	9
Lumbosacral region	1.9	1.5	60	790	790	0.07	0.46	0.07	0.60	9
Pelvis	3.4	3.4	157	142	142	0.35	0.19	0.01	0.55	8
Urethrocystography	1.1	0.3	423	1,608	1,608	0.11	0.30	0.03	0.44	6
Abdomen	3.7	2.6	92	132	132	0.18	0.16	0.01	0.35	5
Lumbar spine	4.5	3.3	16	47	47	0.03	0.06	0.01	0.10	2
Obstetrical abdomen[b]	—	0.1	—	100	100	—	0.01	0.02	0.03	<1
Pelvimetry	—	0	—	—	—	—	0	0	0	0
SUB-TOTAL	26	19				3.41	2.34	0.31	6.06	89
Other types of examination[c]	282	222				0.32	0.36	0.05	0.73	11
TOTAL	308	241				3.73	2.70	0.36	6.79	100

[a] Doses are the same as for female.
[b] The position is not justified by the magnitude of the dose.
[c] Does not include mass miniature radiography and dental radiography.
n = negligible.

TABLE XI. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1958 — *Norway*[14]

Type of examination	$\frac{N^*_j}{N} \times 1{,}000$		d^*_j (mrem)			D^*_j (mrem)			D_i	
	Male	Female	Male adults	Female adults	Foetus[a]	Male	Female	Foetus	mrem	Percentage
Lumbosacral region Lumbar spine	11.9	9.2	130	592	592	0.78	1.81	0.12	2.71	27
Colon (barium enema) lower GI	3.0	3.4	185	2,050	2,050	0.16	1.19	0.09	1.44	15
Pelvis	5.7	5.9	376	135	135	0.92	0.29	0.01	1.22	12
Urography (descending pyelography)	3.8	3.5	217	403	403	0.37	0.51	0.03	0.91	9
Hip	3.4	6.0	384	159	159	0.61	0.20	n	0.81	8
Pelvimetry	—	0.3	—	800[b]	900[b]	—	0.19	0.50	0.69	7
Femur	1.4	1.4	407	10	10	0.58	0.01	n	0.59	6
Obstetrical abdomen	—	0.3	—	400[b]	600[b]	—	0.10	0.34	0.44	4
Abdomen	3.3	3.0	65	178	178	0.12	0.27	0.01	0.40	4
Stomach (barium meal) upper GI	14.4	11.2	2.8	17.5	17.5	0.05	0.07	n	0.12	1
SUB-TOTAL	47	44				3.59	4.64	1.10	9.33	93
Other types of examination	320	294				0.30	0.32	0.02	0.64	7
TOTAL	367	338				3.89	4.96	1.12	9.97	100

[a] Except for obstetrical examinations, the doses are the same as for female.
[b] Estimate and calculation based on exposure data.
n = negligible.

TABLE XII. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1955-1957 — *Sweden*[15]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$		d_j^* (mrem)			D_j^* (mrem)			D_j	
	Male	Female	Male adults	Female adults	Foetus[a]	Male	Female	Foetus	mrem	Percentage
Lumbosacral region / Lumbar spine	9.1	7.0	940	490	490	6.30	1.36	0.14	7.80	21
Pelvimetry	—	0.6	—	1,080	4,500	—	0.28	6.40	6.68	18
Urography	5.3	3.8	1,240	925	925	3.48	1.77	0.16	5.41	15
Pelvis	4.1	4.2	870	200	200	2.70	0.40	0.03	3.13	8
Abdomen	2.5	2.4	1,360	1,150	1,150	1.78	0.93	0.11	2.82	7
Colon	4.1	5.0	310	1,520	1,520	0.56	2.03	0.21	2.80	7
Hip	2.6	4.4	1,090	260	260	2.19	0.25	0.01	2.45	6
Urethrocystography	1.0	0.2	3,700	1,940	1,940	1.57	0.14	0.02	1.73	5
Femur	1.8	0.9	830	35	35	1.40	0.02	0.01	1.43	4
Obstetrical abdomen	—	0.6	—	265	910	—	0.06	1.20	1.26	3
SUB-TOTAL	31	29				20.0	7.2	8.3	35.5	94
Other types of examination[b]	186	188				0.3	1.8	0.2	2.3	6
TOTAL	217	217				20.3	9.0	8.5	37.8	100

[a] Except for obstetrical examinations the doses are the same as for female.

[b] Does not include dental radiography.

TABLE XIII. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1957 — *Switzerland*[16]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$		d_j^* (mrem)			D^* (mrem)			D_j	
	Male	Female	Male adults	Female adults	Foetus	Male	Female	Foetus	mrem	Percentage
Urography (descending pyelography)	3.7	4.0	1,000	1,000		1.93	2.14		4.07	18
Obstetrical abdomen	—	1.1	—	700	800	—	1.73	1.96	3.69	17
Pelvis	2.8	2.4	1,200	300		2.55	0.55		3.10	14
Lumbar spine	7.4	7.4	150	500		0.48	1.62		2.10	9
Colon (barium enema), lower GI	6.9	6.9	150	200		0.90	1.20		2.10	9
Retrograde (ascending pyelography)	0.8	1.2	1,000	1,000		0.42	0.62		1.04	5
Chest	190.0	188.0	2	1		0.69	0.35		1.04	5
Hip, upper femur	4.1	3.5	100	300		0.27	0.70		0.97	4
Stomach (barium meal), upper GI	31.1	26.5	20	50		0.31	0.65		0.96	4
Pelvimetry	—	0.24	—	700	800	—	0.34	0.38	0.72	3
SUB-TOTAL	247	241				7.55	9.90	2.34	19.8	88
Other types of examination	290	194				1.78	0.73		2.5	12
TOTAL	537	435				9.33	10.63	2.34	22.3	100

TABLE XIV. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1956-1960 — *United Arab Republic (Alexandria)*[17]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$		d_j^* (*mrem*)			D_j^* (*mrem*)			D_1	
	Male	*Female*	*Male adults*	*Female adults*	*Foetus*[a]	*Male*	*Female*	*Foetus*[a]	*mrem*	*Percentage*
Urinary tract	3.7	4.6	500	320	—	1.85	1.47	—	3.32	47
Lumbosacral spine	3.2	3.1	255	270	—	0.82	0.84	—	1.66	24
Lower GI tract	2.3	2.2	100	600	—	0.2	1.3	—	1.5	21
Upper GI tract	0.7	0.8	70	470	—	0.05	0.36	—	0.41	6
Mass radiography	7.2	10.7	5	5	—	0.04	0.05	—	0.09	1
Chest	3.6	7.4	5	5	—	0.02	0.04	—	0.06	1
Cervical spine	2.4	2.4	—	1	—	—	0.002	—	0.002	<1
Skull	1.1	1.2	—	1	—	—	0.001	—	0.001	<1
Obstetrical abdomen[a]	—	—	—	—	—	—	—	—	—	—
Pelvimetry[a]	—	—	—	—	—	—	—	—	—	—
SUB-TOTAL	24	32				2.98	4.06	—	7.04	100
Other types of examination	—[a]	—[a]				—[a]	—[a]		—[a]	—[a]
TOTAL	36					2.98	4.06		7.04	100

[a] No data.

TABLE XV. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1955-1961 — *United Arab Republic (west and south-west of Cairo)*[18]

Type of examination	$\frac{N_j^*}{N} \times 1{,}000$		d_j^* (*mrem*)			D_j^* (*mrem*)			D_1	
	Male	*Female*	*Male adults*	*Female adults*	*Foetus*[a]	*Male*	*Female*	*Foetus*[a]	*mrem*	*Percentage*
Urinary tract	4.1	5.1	500	320	—	2.08	1.9	—	3.98	57
Lower GI tract	1.5	1.8	100	600	—	0.13	1.10	—	1.23	17
Upper GI tract	1.0	1.1	70	470	—	0.05	1.13	—	1.18	17
Lumbosacral spine	0.9	0.9	255	270	—	0.23	0.23	—	0.46	7
Mass radiography	5.7	8.4	5	5	—	0.02	0.04	—	0.06	1
Chest	5.0	10.0	5	5	—	0.02	0.05	—	0.07	1
Cervical spine	0.9	0.9	—	1	—	—	0.001	—	0.001	<1
Skull	2.6	2.9	—	1	—	—	0.003	—	0.003	<1
Obstetrical abdomen[a]	—	—	—	—	—	—	—	—	—	—
Pelvimetry[a]	—	—	—	—	—	—	—	—	—	—
SUB-TOTAL	22	31				2.53	4.45		6.98	100
Other types of examination	22	4				—[a]	—[a]		—[a]	
TOTAL	44	35				2.53	4.45		6.98	100

[a] No data.

TABLE XVI. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Survey, 1957-1958 — *United Kingdom (except Northern Ireland)*[19]

Type of examination	$\frac{N^*_j}{N} \times 1{,}000$		d^*_j (*mrem*)			D^*_j (*mrem*)			D_j	
	Male	*Female*	*Male adults*	*Female adults*	*Foetus*	*Male*	*Female*	*Foetus*	*mrem*	*Percentage*
A. NATIONAL HEALTH SERVICE HOSPITALS										
Obstetrical abdomen	—	1.5	—	367	723	—	1.12	2.27	3.39	24
Pelvis	1.8	2.0								
Lumbosacral region	2.2	2.3	370	392	536	1.72	1.17	0.22	3.11	22
Lumbar spine	3.5	3.1								
Urography (descending pyelography)	2.3	2.0	765	585	843	0.96	0.69	0.09	1.74	12
Retrograde (ascending pyelography)	0.3	0.4								
Hip, upper femur	2.0	2.9	740	102	154	1.33	0.14	0.01	1.48	11
Pelvimetry	—	0.4	—	745	885	—	0.55	0.60	1.15	8
Abdomen	3.0	3.0	105	183	281	0.22	0.32	0.06	0.60	4
Stomach (barium meal), upper GI	6.0	4.3	44	333	448	0.11	0.36	0.04	0.51	4
Chest (heart, lung) (excluding mass miniature radiography)	63	61	2.75	5.4	5.5	0.14	0.29	0.05	0.48	3
SUB-TOTAL	84	83				4.48	4.64	3.34	12.46	88
Other types of examination	52	40				0.35	0.39	0.04	0.78	6
TOTAL	136	123				4.83	5.03	3.38	13.24	94
B. DIAGNOSTIC X-RAY EXPOSURE OUTSIDE NATIONAL HEALTH SERVICE HOSPITALS										
General diagnostic examinations	22						No data		0.83	6
Mass miniature radiography	95		0.09	0.09	0.09		No data		0.01	
Dental radiography	40		0.3	0.3	0.3		No data		0.01	
TOTAL genetically significant dose									14.1	100

TABLE XVII. DATA FROM VARIOUS COUNTRIES AND AREAS ON GONAD EXPOSURE FROM MASS SURVEY EXAMINATIONS OF THE CHEST

Country or area	Population at time of study		Number of examinations per 1,000 of total population		Number of examinations per 1,000 of population below age 30		Gonad dose adults (mrem)		Genetically significant dose (mrem)			Reference
	Total	Below age 30	Radiography	Fluoroscopy	Radiography	Fluoroscopy	Male	Female	Male	Female	Total	
Argentina (Buenos Aires)	6,000,000	2,770,000	76	—[a]	166	—[a]	10	15	1.3	0.6	1.9[b]	4
Australia	9,500,000	—	190	—[a]	No data	—[a]	No data	No data	No data	No data	0.2[b]	3, 33
Austria	6,984,000	2,990,000	25	25	37	28	R 0.3 F 7	0.8 18	No data	No data	0.02[b] 0.36[b]	53
Belgium	8,924,000	3,797,000	128	26	226	48	R 0.2 F 5	0.6 13	No data	No data	0.09[b] 0.45[b]	53
Canada	17,048,000	9,300,000	90	—[a]	86	—[a]	0.7	12	0.03	0.5	0.53[b]	107, 115
Denmark	4,466,000	2,080,000	140	—[a]	120	—[a]	0.25	0.15	0.03	0.02	0.05	5
Federal Republic of Germany (Hamburg)	1,755,000	—	130	—[a]	No data	—[a]	0.16	0.32	0.02	0.03	0.05	6
France	43,600,000	20,000,000	40		71		R 0.25	0.6	No data	No data	0.02[b]	3, 10
Italy (Rome)	1,875,000	—	77	—[a]	No data	—[a]	5.5	11	0.33	0.60	0.93	11
Japan	90,000,000	—	322	—[a]	No data	—[a]	0.05	0.4	No data	No data	0.08[b]	53
Netherlands (Leiden)	110,000	58,400	80	—[a]	53	—[a]	0.4	0.4	0.01	0.01	0.02	13
Norway	3,525,000	—	211	—[a]	No data	—[a]	0.13	1.0	0.02	0.06	0.08	14
Spain	29,000,000	16,000,000	2	5	4	6	R 0.3 F 12	0.8 31	No data	No data	0.002[b] 0.13[b]	53
Sweden	7,300,000	—	140	—[a]	No data	—[a]	0.8	1.6	0.1	0.3	0.4	15
Switzerland	5,160,000	2,300,000	130	60	155	70	R 0.2 F 0.6	0.5 1.5	No data	No data	0.05 0.07[b]	16, 53
United Arab Republic:												
Alexandria	1,361,700	787,000	4	—[a]	7	—[a]	5	7	0.04	0.05	0.09	17
Cairo	2,640,000	1,527,000	5	—[a]	6	—[a]	5	7	0.03	0.04	0.07	18
United Kingdom (except Northern Ireland)	50,000,000	—	95	—[a]	No data	—[a]	0.09	0.09	No data	No data	0.01	19
United States of America	162,000,000	82,000,000	135	—[a]	90	—[a]	1	3	0.05	0.13	0.18[b]	20

R = Radiography.
F = Fluoroscopy.

[a] Not applicable.
[b] Genetically significant dose calculated according to formula 11, e.g. assuming the mean age of child-bearing to be 30.

TABLE XVIII. GONAD DOSES AS SUBMITTED BY COUNTRIES AND EXAMINATIONS (MALES)

(*mrem*)

	Mass survey, chest	*Chest, heart, lung*	*Cholecystography*	*Stomach, barium meal*	*Urography descending*	*Retrograde pyelography*[c]	*Abdomen*	*Colon, barium enema*	*Pelvis*	*Lumbar spine*	*Lumbosacral*	*Hip, upper femur*	*Femur*
Argentina (Buenos Aires)[a]	10	5	60	60	700	600	150	300	600	200	230	600	
Denmark	0.3	0.4	2	20	1,019	2,580	610	40	567	104		980	
Federal Republic of Germany (Hamburg)	0.2	0.5	4	65	241	311	88	890	275	63	555	1,520	
France		30[d]	45	90	390	1,900	250	134	1,500	250		1,200	
Italy	6	0.5	12	123	940		141	239	1,130	234		—586—	
Japan	0.1	1	2	13	631		220	1,310	1,490	767	1,700	691	
Netherlands (Leiden)	0.4	2	3	4	512	423	92	25	157	16	60	3,233	
Norway	0.1	1	3	3	15	217	65	185	376	—130[b]—		384	407
Sweden[c]	0.8	2	6	14	1,240	3,700	1,360	310	870	—940[b]—		1,090	830
Switzerland	0.4	10	—	20	1,000	1,000	—	150	1,200	150		100	
United Arab Republic	5	5		70	500			100			255		
United Kingdom	0.1	3	8	44	—765—		105	146	———	370	———	740	

[a] Radiographs, not examinations.
[b] In these countries the two types of examinations are combined.
[c] Hip only; femur only.
[d] Estimate from contribution due to fluoroscopic examinations in private practice.
[e] Including urethrocystography.

TABLE XIX. GONAD DOSES AS SUBMITTED BY COUNTRIES AND EXAMINATIONS (FEMALES)

(*mrem*)

	Mass survey, chest	*Chest, heart, lung*	*Cholecystography*	*Stomach, barium meal*	*Urography descending*	*Retrograde pyelography*[e]	*Abdomen*	*Obstetrical abdomen*	*Pelvimetry*	*Colon, barium enema*	*Pelvis*	*Lumbar spine*	*Lumbosacral*	*Hip, upper femur*	*Femur*
Argentina (Buenos Aires)[a]	15	10	90	90	900	800	200	800	900	450	700	400	600	600	
Denmark	0.2	0.1	16	9	565	1,136	85	190	822	20	210	222		58	
Federal Republic of Germany (Hamburg)	0.3	0.7	35	67	439	657	128	680	600	2,530	94	183	402	214	
France		30[d]	105	300	4,500	1,800	375	1,600	1,200	264	1,300	700		180	
Italy	11	1.0	156	411	1,060		210	399	1,250	1,050	330	570		—223—	
Japan	0.4	13	80	1,108	92		49	162	322	2,200	80	121	116	31	
Netherlands (Leiden)	0.4	2	4	6	604	1,608	132	100		613	142	47	790	140	
Norway	1	2	8	18	125	403	178	400	800	2,050	135	—592[b]—		159	10
Sweden[c]	1.6	4	17	29	925	1,940	1,150	265	1,080	1,520	200	—490[b]—		260	35
Switzerland	1.0	5		50	1,000	1,000		1,500	1,500	200	300	500		300	
United Arab Republic	5	5		470	320					600			270		
United Kingdom	0.1	5	299	333	—585—		183	367	745	464	———	392	———	102	

[a] Radiographs, not examinations.
[b] In these countries the two types of examinations are combined.
[c] Hip only; femur only.
[d] Estimate from contribution due to fluoroscopic examinations in private practice.
[e] Including urethrocystography.

TABLE XX. FOETAL GONOD DOSES AS SUBMITTED BY COUNTRIES FOR OBSTETRICAL EXAMINATIONS

(*mrem*)

	Obstetrical abdomen	*Pelvimetry*		*Obstetrical abdomen*	*Pelvimetry*
Federal Republic of Germany (Hamburg)	677	2,900	Sweden	910	4,500
Netherlands (Leiden)	100	—	Switzerland	800	—
Norway	600	900	United Kingdom	723	835

TABLE XXI. TOTAL ANNUAL GENETICALLY SIGNIFICANT DOSE FROM X-RAY DIAGNOSIS SUBMITTED BY COUNTRIES AND EXAMINATIONS

(*mrem*)

	Mass survey, chest	*Chest, heart, lung*	*Cholecystography*	*Stomach, barium meal*	*Urography descending*	*Retrograde pyelography*[c]	*Abdomen*	*Obstetrical abdomen*	*Pelvimetry*	*Colon, barium enema*	*Pelvis*	*Lumbar spine*	*Lumbosacral*	*Hip, upper femur*	*Femur*	*Others*	*Total*[a]
Argentina[d] (Buenos Aires)	2.8	0.3	0.3	1.2	5.7	1.6	1.3	2.6	1.8	2.9	2.6	2.9	2.5	5.1		3.4	37
Denmark					6.7	7.0	0.4	0.4	1.8		1.5	1.1		2.3		6.3	27.5
Federal Republic of Germany (Hamburg)				0.60	1.45	0.50	0.48	0.76	0.40	6.09	1.15	1.28		3.33		1.70	17.7
France		38[e]		0.43	2.62	0.47	10.2	0.80	0.02	0.37		1.28		2.84		1.18	58.2
Italy			1.39	8.33	4.96		1.30	0.59	0.23	3.28	4.78	4.22		5.02		6.72	43.4
Japan		1.48		11.61		1.40		0.42	0.12	8.29	1.66	4.55	4.5	2.39		2.61	39.0
Netherlands (Leiden)					1.86	0.44	0.35	0.03		0.61	0.55	0.10	0.60	1.52		0.73	6.8
Norway				0.12	0.91		0.40	0.44	0.69	1.44	1.22	—2.71[b]—		0.81	0.59	0.64	10.0
Sweden					5.41	1.73	2.82	1.26	6.68	2.80	3.13	—7.8 [b]—		2.45	1.43	2.3	37.8
Switzerland		1.04		0.96	4.07	1.04		3.69	0.72	2.1	3.1	2.1		0.97		2.5	22.3
United Arab Republic:																	
Alexandria	0.09	0.06		0.41	3.32					1.5			1.66				7.0
Cairo	0.06	0.07		1.18	3.98					1.23			0.46				7.0
United Kingdom		0.48		0.51	1.53	0.21	0.60	3.39	1.15			—3.11—		1.48		1.63	14.1

[a] Rounded-off total from national figures.
[b] In these countries the two types of examinations are combined.
[c] Includes contribution from fluoroscopic examinations in private practice.
[d] These values include the contribution from private clinics and practices.
[e] Includes urethrocystography.

TABLE XXII. COMPARISON OF PERCENTAGE TOTAL GENETIC DOSE FROM DIAGNOSTIC RADIOLOGY BY COUNTRIES AND EXAMINATIONS

	Mass survey, chest	*Chest, heart, lung*	*Cholecystography*	*Stomach, barium meal*	*Urography descending*	*Retrograde pyelography* [b]	*Abdomen*	*Obstetrical abdomen*	*Pelvimetry*	*Colon, barium enema*	*Pelvis*	*Lumbar spine*	*Lumbosacral*	*Hip, upper femur*	*Femur*	*Subtotal*	*Others*	*Total*
Argentina (Buenos Aires)	8	1	1	3	15	4	4	7	5	8	7	8	7	14		92	8	100
Denmark					24	25	2	2	7		5	4		8		77	23	100
Federal Republic of Germany (Hamburg)				3	8	3	3	4	2	34	6	7		19		89	11	100
France		65[a]		1	4	1	18	1		1		2		5		98	2	100
Italy			3	19	11		3	1	1	8	11	10		—12—		79	21	100
Japan				30	4		4	1	0.3	21	4	12	12	6		96	4	100
Netherlands (Leiden)					27	6	5	1		9	8	2	9	22		89	11	100
Norway				1	9		4	4	7	15	12	—27—		8	6	93	7	100
Sweden					15	5	7	3	18	7	8		21	6	4	94	6	100
Switzerland		5		4	18	5		17	3	9	14	9		4		88	12	100
United Arab Republic:																		
Alexandria	1	1		6	47					21			24					100
Cairo	1	1		17	57					17			7					100
United Kingdom		3		4	12	1	4	24	8		———	—22—	———	10		87	13	100

[a] Includes contribution from fluoroscopic examination in private practice.

[b] Includes urethrocystography.

TABLE XXIII. COMPARISON OF THE ANNUAL GENETICALLY SIGNIFICANT DOSE ARISING FROM X-RAY DIAGNOSTIC EXPOSURE IN VARIOUS COUNTRIES AND AREAS

Country or area	Genetically significant dose (mrem)								Reference table
	Male		Female		Foetus	Total			
	A	B	A	B		A	B	C	
Argentina (Buenos Aires)		14[a]		23[a]	No data		37[a]		IV
Austria	No data		No data		No data			16–25	
Denmark						28[c]			V
Federal Republic of Germany (Hamburg)	8.8		7.7		1.3	18	17	29	VI
France		10[b]		10[b]	No data		58		VII
Italy (Rome)	21		20		2.6	43 ± 35			VIII
Japan	21		18		0.4	39[c, d]			IX
Netherlands (Leiden)	3.7		2.7		0.4	6.8[c]	5.7[c]	18.7[c]	X
Norway	3.9		5.0		1.1	10 ± 3			XI
Sweden	20		9		8.5	38 ± 10			XII
Switzerland	10[d]		12[d]		No data	22[d]			XIII
United Arab Republic:									
Alxandria	3		4			7			XIV
Cairo	2.5		4.5			7			XV
United Kingdom (except Northern Ireland)	5.1[a]		5.3[a]		3.6[a]	14 ±1			XVI

A is computed according to the formula $D = \Sigma \frac{N_j}{N} \cdot \frac{w_j}{w} \cdot d_j$

B is computed according to the formula $D = \Sigma \frac{n_j}{n} \cdot d_j$

C is computed according to the formula $D = \Sigma \frac{N_j}{N} \cdot d_j$

[a] Arising from radiography only.

[b] Except for chest examinations in private practice which give a contribution of 38 mrem to the genetically significant dose and which cannot be split into male and female figures.

[c] Does not include mass miniature radiography.

[d] Includes a contribution from foetal exposure arising from obstetrical examinations.

[c] 0.85 mrem, arising from examinations outside the National Health Service hospitals, are distributed among male, female and foetus.

TABLE XXIV. PROBABLE DOSE-RATES TO THE GONADS DURING VARIOUS TYPES OF X-RAY EXAMINATIONS

Type of examination	Dose rate (mrem/sec)	
	Testes	Ovaries
Fluoroscopy		
Chest	0.005–0.02	0.01–0.04
Stomach (barium meal)	0.05 –0.2	0.1 –0.3
Colon (barium enema)	1–100[a]	3– 20
Radiography		
Chest	10–30	30– 50
Stomach	4–8	10– 50
Colon	30–2,000[a, c]	40–200
Lumbar spine, Lumbosacral joint, Pelvic region — AP	40–500[a, d]	20– 80
Lumbar spine, Lumbosacral joint, Pelvic region — Lateral	50–100	30–100
Urinary bladder	100–1,500[a, c]	100–400
Natural radiation		3.10^{-6}

Note: Russell's experiments cover the following dose-rate range 0.014–1400 mrem/sec.[b]

[a] The testes in the primary beam.

[b] See annex C, table X.

[c] With scrotum protection ~ 10 mrem/sec.

[d] With scrotum protection 2–3 mrem/sec.

TABLE XXV. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM EXTERNAL RADIO-THERAPY FOR NON-MALIGNANT CONDITIONS

Survey, 1957-1958 — *Federal Republic of Germany (Hamburg)*[6]

Location	Number of patients treated per 1,000 of total population		Gonad dose (mrem) Average figures		Annual genetically significant dose (mrem)			
	Male	Female	Male	Female and foetus	Male	Female	Foetus	Total
Skin (various conditions)....	1.52	1.63	0.1–[a] 390	3–[a] 6,900	0.05	1.40	0.01	1.46
Spine.....	0.46	0.72	800 40–[a]	6,000 70–[a]	0.05	0.25	0.02	0.32
Other sites.....	1.48	2.43	3,000	10,000	0.18	0.22	n	0.40
TOTAL	3.5	4.8			0.28	1.87	0.03	2.2

[a] The dose ranges are due to various conditions and different sites treated.

n denotes less than 0.005 mrem.

TABLE XXVI. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM EXTERNAL RADIO-THERAPY FOR NON-MALIGNANT CONDITIONS

Survey, 1957 — *France*[27]

Location	Number of patients treated per 1,000 of total population		Gonad dose (mrem) Average figures		Annual genetically significant dose (mrem)[a]			
	Male	Female	Male	Female	Male	Female	Foetus	Total
Skin (various conditions).....	0.31	0.38	5–[b] 100	20–[b] 200	n	n	No Data	n
Spine:								
Cervical.....	0.16	0.22	900	1,500	0.02	0.04	No Data	0.06
Dorsal.....	0.04	0.07	2,800	4,500	0.01	0.04	No Data	0.05
Lumbar.....	0.25	0.16	14,200	49,600	0.5	1.0	No Data	1.5
Hip.....	0.04	0.04	91,500 100–[b]	99,500 20–[b]	0.5	0.5	No Data	1.0
Other sites.....	0.26	0.29	17,000	8,000	0.2	0.3	No Data	0.5
TOTAL	1.1	1.2			1.2	1.9		3.1

[a] Reboul has calculated that 6.8 per cent of $\Sigma N_i d_i$ originates from patients below age 30. The subdivision into locations is made under the assumption that this percentage is valid for all locations.

[b] The dose ranges are due to various conditions and different sites treated.

n denotes less than 0.01 mrem.

TABLE XXVII. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM EXTERNAL RADIO-THERAPY FOR NON-MALIGNANT CONDITIONS

Survey, 1942-1951 — *Netherlands*[28]

Condition treated	Number of patients treated per 1,000 of total population		Gonad dose (mrem) Average figures		Annual genetically significant dose (mrem)		
	Male	Female	Male	Female	Male	Female	Total
High gonad doses.....	0.65	0.33	70	110	1.16–5.03[a] (2.57–8.02)[b]	1.63 (3.76)[b]	2.79–6.66[a] (6.33–11.78)[b]
Low gonad doses.....	1.4	(1.4)[c]	1	(1)[c]	0.17	(0.17)	0.34
TOTAL	2.1	1.7					3.1–12.1

[a] Based on actual number of children born to patients.

[b] Based on total expected number of children averaged throughout population.

[c] Female assumed equal to male.

TABLE XXVIII. DATA ON THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM EXTERNAL RADIO-THERAPY FOR NON-MALIGNANT CONDITIONS

Survey, 1957-1958 — *United Kingdom (except Northern Ireland)*[19]

Condition treated	Number of patients treated per 1,000 of total population		Gonad dose (mrem) Average figures		Annual genetically significant dose (mrem)			
	Male	Female	Male	Female and foetus	Male	Female	Foetus	Total
Skin conditions.....	0.46	0.57	150–32,000[a]	300–6,000[a]	1.55	0.93	0.03	2.52
Ankylosing spondylitis..	0.03	0.01	50,000	20,000	1.07	0.08	n	1.15
Arthritic and rheumatic conditions.....	0.02	0.02	23,000	160,000	0.04	0.18	0.05	0.27
Other non-malignant conditions.....	0.02	0.07	40–6,000[a]	20–50,000[a]	0.04	0.49	n	0.53
TOTAL	0.5	0.7			2.70	1.69	0.08	4.47

[a] The dose ranges are due to various conditions and different sites treated.

n denotes less than 0.005 mrem.

TABLE XXIX. COMPARISON OF THE ANNUAL GENETICALLY SIGNIFICANT DOSE ARISING FROM EXTERNAL RADIO-THERAPY IN VARIOUS COUNTRIES AND AREAS

Country or area	Annual genetically significant dose (mrem)								Total	Reference
	Non-malignant conditions				Malignant conditions					
	Male	Female	Foetus	Sub-total	Male	Female	Foetus	Sub-total		
Federal Republic of Germany (Hamburg).	0.28	1.87	0.03	2.2	0[a]	0[a]	0[a]	0	2.2	6
France[b].....	1.2	1.9	No data	3.1	—2.5[c]—		No data	2.5	5.6	27
Netherlands.....	1.33–8.19	1.8–3.93	No data	3.1–12.1	0.5	(0.5)[d]	No data	1.0	4.1–13.1	28
United Kingdom except Northern Ireland....	2.70	1.69	0.08	4.47	0.41	0.11	0	0.52	5.0	19

[a] Fertility factors regarded as zero.
[b] Genetically significant dose calculated according to formula 11.
[c] Not subdivided into sexes.
[d] Female assumed equal to male.

TABLE XXX. COMPARISON OF GENETICALLY SIGNIFICANT DOSE AND PER CAPITA DOSE CAUSED BY EXTERNAL RADIO-THERAPY FOR NON-MALIGNANT CONDITIONS

Country or area	Mode of calculation (doses in mrem)		
	$\Sigma \frac{N_j}{N} \cdot \frac{w_j}{w} \cdot d_j$	$\Sigma \frac{n_j}{n} \cdot d_j$	$\Sigma \frac{N_j}{N} \cdot d_j$
Federal Republic of Germany (Hamburg).....	2.0	2.0	6.5
France.....	—	3.1	21
United Kingdom (except Northern Ireland)....	4.5	—	9

TABLE XXXI.[a] ESTIMATED DOSE-RATES TO THE GONADS FROM EXTERNAL RADIO-THERAPY FOR NON-MALIGNANT AND MALIGNANT CONDITIONS[b]

Location	Dose rate (mrem/sec)	
	Testes	Ovaries
Head.....	0.01–0.05	0.01–0.05
Thorax.....	0.5–3	2–5
Abdomen and pelvic region.....	5–15	20–50
Skin (various sites).....	0.002–0.5	0.008–1
Natural radiation.....		3.10^{-6}

[a] Russell's experiments cover the following dose-rate range—0.014–1400 mrem/sec.
[b] Estimated on the assumption of 50 rad/min at the treatment site.

TABLE XXXII. COMPARISON OF THE ANNUAL GENETICALLY SIGNIFICANT DOSE FROM THE ADMINISTRATION OF RADIO-ACTIVE ISOTOPES IN VARIOUS COUNTRIES AND AREAS

Country or area	Year of study	Genetically significant dose (mrem)		Source	Reference
		Diagnosis	Therapy		
Canada	1956	0.02[a]	0.40[a]	I^{131}, P^{32}	37
Federal Republic of Germany (Hamburg)	1957–1958	0.01	0.18	I^{131}	6
United Kingdom (except Northern Ireland)	1957	0.03	0.15	I^{131}, P^{32}	19
United States of America	—	0.01[b]	0.24[b]	I^{131}[c]	38

[a] Computed according to formula 11. No allowance made for the influence on fertility from the severity of the disease.
[b] Computed according to formula 11.
[c] Other radio-isotopes considered to be of no significance.

TABLE XXXIII. ANNUAL GENETICALLY SIGNIFICANT DOSE FROM THE ADMINISTRATION OF RADIO-ISOTOPES

Survey, 1957 — *United Kingdom (except Northern Ireland)*[19]

Use	Radio-isotope	Genetically significant dose	
		mrem	Percentage
Diagnosis			
Test doses	I^{131}	0.016	9
	P^{32}	0.012	6
Therapy			
Non-malignant conditions	I^{131}	0.049	27
	P^{32}	0.059	33
Malignant diseases	I^{131}	0.045	25
TOTAL		0.18±0.18	

Note. The contribution from other radio-isotopes is negligible.

TABLE XXXIV. GONAD DOSES IN MREM PER ADMINISTERED MILLICURIE OF I^{131} OR P^{32}

Radio-isotope	Gonad dose (mrem)	Remarks	Reference
I^{131}	450	Normal physiological conditions	37
	450 (130–1,170)	20 patients: 10 thyroid cancer, 7 hyperthyroidism, 3 others	39
	600±300	Normal physiological conditions	40
P^{32}	2,600	Normal physiological conditions	37
	7,000	Normal physiological conditions	41

TABLE XXXV. MARROW DISTRIBUTION IN THE ADULT

Site	Bones	Total marrow in g[a]	Fraction active marrow[b]	Total active marrow in g[c]	Active marrow per cent: Ellis[45]	Active marrow per cent: 1958 report of the committee[3]
Head	Cranium, mandible	182	0.75	140	13	10
Upper limb girdle	Scapulae, clavicles, head and neck of humeri	116	0.75	85	8	5[d]
Thorax	Sternum	39	0.6	25	2.5	25
	Ribs 1 to 12	207	0.4	85	8	
Spine	Cervical vertebrae	47	0.75	35	3.5	
	Dorsal vertebrae	197	0.75	150	14	40
	Lumbar vertebrae	152	0.75	115	11	
	Sacrum	194	0.75	150	14	
Lower limb girdle	Pelvic bones, coccyx, head and neck of femora	364	0.75	270	26	20[e]

[a] Mechanik[43], and Woodard and Holodny.[44]
[b] Custer[46] for ribs, sternum and vertebra at age 40. Other values assumed in study.
[c] Ellis.[47]
[d] Half the contribution of 10 per cent from "other" (e.g. in extremities, etc.) in the 1958 report of the Committee (annex C, para. 44).
[e] The contribution from pelvis and half the contribution of 10 per cent from "other" (e.g. in extremities, etc.) in the 1958 report of the Committee (annex C, para. 44).

TABLE XXXVI. MEAN MARROW DOSES FROM DIAGNOSTIC X-RAY EXPOSURE (EXCLUDING MASS SURVEYS OF THE CHEST)

Examination	Mean marrow dose (mrem): 1958 Report of the Committee[a]	Mean marrow dose (mrem): Buhl[49] Denmark[b]	Epp et al. U.S.A.[c 50]: AP	Epp et al. U.S.A.[c 50]: Lat.
Head	50	—	—	—
Spine				
Cervical	50	—	10	3
Dorsal	400	200	30	90
Lumbar	400	100	50	180
Lumbosacral region	300	—	—	—
Pelvis	20	30	70	180
Hip, incl. upper femur	30	20	35	—
Arm and hand	2	0.2	—	—
Thorax (ribs and sternum)	200	150	—	—
Chest (regular)	40	20	PA 1.3	4.5
Gall bladder	400	150	—	—
Stomach (barium meal), upper GI	500	200	—	—
Colon (barium enema), lower GI	700	200	—	—
Abdomen	50	30	—	—
Urography	200	80	—	—
Retrograde pyelography	100	30	—	—
Urethrocystography	300	—	—	—
Pelvimetry	800	—	—	—
Obstetrical abdomen	100	—	—	—
Hysterosalpingography	100	25	—	—
Dental	20	—	—	—

[a] Radiography only.
[b] In Buhl's investigation the dose calculations are based upon the figures for the distribution of active marrow presented by the Committee[3].
[c] The technical factors used are those of the Memorial Hospital, New York. The doses are those that arise from well collimated and aligned fields. The dose due to the scatter outside the direct beam has been included but not the effect due to the photo-electrons from the bone.

TABLE XXXVII. INDIVIDUAL AND PER CAPITA MEAN MARROW DOSES IN SOME COUNTRIES ARISING FROM MASS SURVEY FLUOROSCOPY OF THE CHEST AND COMPARISON WITH CALCULATED PER CAPITA DOSES FROM RADIOGRAPHY

Country	Number of examinations per 1,000 of total population[a]	Mean marrow dose (mrem): Individual	Mean marrow dose (mrem): Per capita in total population	Mean marrow dose (mrem): Per capita dose if radiography is used instead of fluoroscopy[b]
Austria	25	2,000	50	2.5
Belgium	26	380	10	2.6
France	570	1,200	680	57
Spain	5	1,300	8	0.5
Switzerland	60	230	14	6

[a] Figures taken from table XVII.
[b] Mean marrow dose per examination assumed to be 100 mrem.

TABLE XXXVIII. EXAMPLES OF MEAN MARROW DOSES IN EXTERNAL RADIO-THERAPY[a]

Site or condition	Type of radiation	Mean marrow dose (rem)		Reference
		Per 100 r skin dose	Total treatment	
Cervical spine, 10 × 15 cm	X-rays (170 keV, filter 0.5 mm Cu)	2.6	—[b]	
Lumbar spine, 10 × 15 cm	X-rays (170 keV, filter 0.5 mm Cu)	5.5	—[b]	54, 55
Hip, one side, 10 × 15 cm	X-rays (170 keV, filter 0.5 mm Cu)	2.5	—[b]	
Carcinoma of cervix	Radium (applicators containing 50, 75 or 87.5 mg Ra)	—	60–100	56
Haemangioma[c]	Radium (applicators containing Ra ranging between 80–130 mg)	—	0.5–25[d]	57

[a] With the exception of those for haemangioma Ellis's figures for the distribution of active bone-marrow have been used (table XXXV).

[b] The values of total skin doses used in references 54 and 55 range from 300 rem to several thousand rem delivered over more than one course of treatment.

[c] Children below two years age. According to paragraph 78, it is assumed that only red bone-marrow exists. The distribution of the active marrow is taken from Woodard and Holodny[49] under the assumption that the distribution of marrow space in children and adults is the same. The following distribution figures were used: upper limbs 12%, lower limbs 39%, ribs 7%, head 7%, spine 15%, scapulae 2%, clavicles 1%, sternum 1%, pelvis 16% of total marrow space.

[d] The range covers various sites of the haemangioma. The highest figures are received when the haemangioma are situated on the skin of the abodomen and the thigh.

TABLE XXXIX. EXAMPLES OF RADIATION DOSES IN VARIOUS KINDS OF RADIOLOGICAL PROCEDURE TO ORGANS AND TISSUES OF SPECIAL INTEREST

Tissue	Diagnosis		Radio-therapy			
	Examination	Dose rem	Non-malignant condition	Dose rem	Malignant condition	Dose rem
Foetal tissue						
(*a*) age < 2 months	See tables in this annex—assume foetal dose is same as maternal gonad dose					
(*b*) age > 7 months	Pelvimetry	1–3				
	Obstetric Abdomen	~0.5				
Lens of the eye	Dental (full mouth)	5–25			Retinoblastoma (dose to unaffected eye)	~200
	Encephalography	5–20			Head lesions	100–1,500
Thyroid	Uptake from 25 μc I^{131}	40	Cervical spine	400–1,200		
	Ba Swallow	2–10	Tonsillitis	150		
			Thyrotoxicosis I^{131}	10,000		
Thymus			Enlarged gland	~200		
Liver	20 cc Thorotrast	2,100–5,400 (over 20 years)				

TABLE XL. ESTIMATES OF RADIATION DOSES IN THOROTRAST PATIENTS
(20 ml injection)

Estimates of Th^{232} activity[117]: 0.0217 μc/ml (German), 0.0244 μc/ml (U.S.A.)

Tissue	Radio-active source	Average dose-rate rad/y	Accumulated rem[a] (20 years)	Reference
Skeleton	Th^{232} + d	1.4–3.0	600	116
Marrow	Th^{232} + d	1.2–2.9	580	59
Bronchi	Thoron + daughter	12–19	3,800	117
Lungs	Thoron + daughter	0.8–1.9	380	117
Liver	Th^{232} + d	27	5,400	118
Spleen		71	14,000	118

[a] The RBE value used in this report for α particles is 10, but Marinelli[65] suggested that the range of RBE values in this case may be between 4–10.

TABLE XLI. RANGE OF NUMBERS OF INSTALLATIONS AND OCCUPATIONALLY EXPOSED PERSONS PER 1,000 OF THE POPULATION

	Number of installations per 1,000 of total population	*Number of workers directly engaged in radiation work (per 1,000 of total population)*	*Contribution to the annual genetically significant dose (mrem)*
Medical:			
Diagnosis	0.1–0.7	0.3–0.5	
Therapy	0.02–0.1		
Dental	0.1–0.8	≈ 0.9	0.1–0.3
Veterinary	0.004–0.03		
Industrial	0.003–0.02	0.05–0.06	
Research and educational	0.01–0.03	≈ 0.02	
Atomic energy	—	0.1–0.3	0.1–0.2

TABLE XLII. MEAN ANNUAL DOSES (IN MREM) OF EXTERNAL X- AND γ-RADIATION TO VARIOUS GROUPS OF OCCUPATIONALLY EXPOSED PERSONS

Type of work	*Argentina[36] (1959–1960)*	*Canada[73] (1959)*	*Netherlands[47] (1960)*	*Norway[74] (1960)*	*United Kingdom[75] (1959)*	
					Male	*Female*
Medical:						
Diagnosis		150–225[a]	300–1,400[b]	50–380	440	500
Therapy				2,000	1,900	1,600
Dental		70		170		
Veterinary				400		
Industrial		640	400–1,000[b]	110 (1,900)[d]	1,100[c]	380
Research and educational		180	100–800[b]		40	27
Atomic energy	430				420	

[a] The lower figure concerns private practitioners; the higher, hospitals.
[b] The range of observed values is given.
[c] Both X-ray and gamma-radiography.
[d] The dose within brackets concerns gamma-radiography only.

TABLE XLIII. RESULTS FROM MONITORING RADIATION WORKERS AT THE OAK RIDGE NATIONAL LABORATORY, USA, THE ESTABLISHMENTS OF THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY, ARGENTINA, CANADA AND THE UAR
(Penetrating radiation)

	Oak Ridge National Laboratory[78] (1959)		*United Kingdom Atomic Energy Authority[75] (1959)*		*Argentina[36] (1959–1960)*		*Canada[73] (1959)*		*UAR[10] (1961)*	
	No. of persons	*Per cent*	*No. of persons*	*Per cent*	*No. of persons*	*Per cent*	*No. of persons*	*Per cent*	*No. of persons*	*Per cent*
Total wearing dose meters or films	4,695	100	16,374	100	579	100	423	100	600	100
Annual dose (rem)										
> 1	441	9.4	1,492[a]	9.1		12.4	9	2	4	1
> 2	179	3.8				4.5	6[c]	1		
> 3	74	1.6	417	2.6		2.0				
> 4	35	0.75	133	0.81		0.6				
> 5	10	0.21	43	0.26						
> 6	8	0.15	22	0.13						
> 7	2	0.04	6	0.04						
> 8	1	0.02	3	0.02						
> 9	0	0	3[b]	0.02						

[a] Annual dose > 1.5 rem.
[b] Three individuals received annual doses of 17.2, 10.3 and 10.7 rem.
[c] In range 2.0–4.9 rem.

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