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NOTE

Throughout this report and its annexes cross-references are denoted by a letter followed by a number: the letter refers to the relevant technical annex (see Table of Contents) and the number is that of the relevant paragraph. Within each technical annex, references are made to its individual scientific bibliography by a number without any preceding letter.

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ANNEXES

Annex C

MAN-MADE SOURCES

(Other than environmental contamination)

TABLE OF CONTENTS

I. Introduction

1. The various estimates of genetically significant dose which have been available to the Committee are discussed in this annex, and some preliminary estimates of mean marrow doses are also given. The presentation follows, as far as possible, the scheme given in chapter III.

II. Medical uses of X-rays and radioactive materials

2. Medical uses of X-rays and radioactive materials are responsible for the largest man-made exposures of many populations at the present time, the doses possibly ranging up to more than 100 per cent of the dose due to natural sources in some of the countries for which estimates have been made.

3. The medical exposure is mainly an exposure of patients undergoing diagnostic examinations or radiation therapy. It is also an occupational exposure, from which, however, the dose to the population as a whole is comparatively very small. This occupational exposure is treated separately in paragraphs 72-83.

4. In view of the importance of the medical exposure, the Committee invited the International Commission on Radiological Protection (ICRP) and the International Commission on Radiological Units and Measurements (ICRU)

"(*a*) To consider and discuss the question of how to arrive at reliable data indicating the doses to different parts of the body (particularly the gonads) received by individuals and, in the aggregate, by large population groups due to medical uses of ionizing radiations and

"(*b*) To examine what recording system, if any, is at present feasible for the determination of the relevant dose values."

The two Commissions formed a joint study group to consider and prepare a report[1] for the Committee on these problems.* The following is the summary of their report.**

"*1. Preliminary considerations*

"(*a*) The principal objective has been to recommend methods for the evaluation of the genetically significant annual gonad dose, G_m, which arises from medical uses of ionizing radiation.

"(*b*) It is assumed that the magnitude of the significant gonad dose due to natural background may be taken as a standard of reference and that 25 per cent of this dose is the greatest absolute accuracy which need be aimed at for an initial determination.

"(*c*) While not always yielding values strictly in terms of G_m as defined in paragraph 4 (of the ICRP/U Study Group report), the preliminary surveys which have already been conducted have yielded values of G_m of the order of 100 mrad (probable value) and 50 mrad (minimum value) for the U.S.A. and of the order of 20-40 mrad (minimum values) for Denmark, Sweden and the United Kingdom (England and Wales).

"(*d*) These surveys show at present that diagnosis makes a much larger contribution than therapy, and that some 85 per cent of the diagnostic dose arises from 6 or 7 types of examination, constituting only about 10 per cent of all examinations of the types listed.†

"(*e*) It follows that, as regards dosimetry, those 6 or 7 types call for special consideration in future surveys.

"*2. Recommendations*

"(*a*) It is recommended that the basic studies be continued and extended, making use of suitable ionization dosemeters in order to obtain data that may be used in the preparation of standard tables which give the average gonad dose in mrad corresponding to each type of diagnostic and therapeutic use of ionizing radiation. Special attention should be paid to the six or seven types of diagnostic examinations which account for 85 per cent of the gonad dose.

"(*b*) It is recommended that in all countries the analysis of film records, together with the results of 2 (a) above, be used as a first approximation to G_m. If the dose so calculated exceeds a few per cent of natural background, a detailed analysis is recommended.

"(*c*) It is recommended that where required, the more detailed analysis should be obtained by means of a sampling programme, operated through personal contact between trained surveyors and both medical institutions and radiation practitioners, and that data obtained from this sampling programme should be used for the determination of G_m.

"(*d*) It is recommended that prior to initiating the main sampling programme (referred to in 2 (c) above), a number of presurveys should be conducted in order to obtain information useful in planning and conducting the programme.

"(*e*) It is recommended that in preparation for the main sampling programme, careful planning and instructional programmes should be initiated by a properly selected group of medical physicists, health physicists, radiologists, statisticians, biometricians, and surveyors. Appropriate dosemeters should be made available to the surveyors who should be instructed in their use.

"(*f*) It is suggested that surveys will result in improved practices with a consequent reduction in exposure. This is likely to be a most important consequence of all surveys, and specific suggestions are made for the reduction of gonad dose due to diagnostic procedures.

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** The references to pages in the Joint Study Group report have been omitted here.

† The list referred to here excludes dental examinations and mass miniature radiography.

"3. Not recommended

"The systematic recording and registration of the radiation received by every member of the population is not recommended."

5. The ICRP/ICRU Joint Study Group was mainly concerned with how the genetically significant dose should be assessed. This problem is discussed in further detail in this report. As the scheme of computation is common for all types of exposure, it is presented separately, before the various classes of exposure are discussed.

The genetically significant dose

Calculations

6. A general definition of genetically significant dose has been given in chapter II. 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.

7. For the practical work, Equation (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 tota 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.

8. As equation (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.

9. 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.

10. 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.

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

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

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

13. 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 Equation (5) reduces to

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

or

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

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

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

which is the expression that has been used for presentation of the data in most of appendices I–X.

14. The necessary information to make it possible to calculate D_j^* by help of Equation (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,

* The degree of approximation involved in the use of equation (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.

(*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.

15. 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.

16. 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 Equation (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.

17. In the case where the age-distribution in an examination class is not known, a yet more simplified assumption must 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 Equation (3) that

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

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

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

Statistical data

18. The scheme of calculation presented in paragraphs 6-17 is the one that has been followed by the Committee in evaluating reported data on gonad exposure. The difficulty of applying any standardized method of calculation to a large amount of heterogeneous information from various countries confirms the importance of carefully planning any survey of exposure levels which is to yield a statistically useful result.

19. Appropriate measures should be taken to determine more accurately the frequency of each type of examination or treatment. The data available at the present time are particularly scarce or unreliable with regard to the following:

(*a*) Diagnostic examinations by non-radiologists (by radiographic and fluoroscopic methods but particularly by the latter) in countries where these constitute an appreciable part of the total radiological practice.

(*b*) X-ray treatment.

(*c*) Diagnostic and therapeutic uses of internally-administered radioisotopes.

In collecting these data, examinations and treatments should be classified by

(i) radiological type;

(ii) anatomical part;

(iii) age and sex of patient;

(iv) disease (for therapy and radioisotopes, at least).

For (i), (ii) and (iii), the classifications recommended by the ICRP/ICRU Study Group[1] should be used.

20. The classification of examinations suggested by the ICRP/ICRU Joint Study Group[1] has been slightly rearranged, for the purposes of this report, to comprise

1. Hip and femur (upper third)
2. Femur (middle and lower third)
3. Pelvic region
4. Lumbosacral
5. Lumbar spine
6. Dorsal spine
7. Urography (descending [intravenous] pyelography)
8. Retrograde (ascending) pyelography
9. Urethrocystography (bladder examinations, cystography, urethrography)
10. Pelvimetry
11. Hysterosalpingography
12. Obstetrical abdomen
13. Abdomen (pancreas, spleen, liver, pneumoperitoneum, general examinations of the urinary tract)
14. Lower gastrointestinal tract (small intestine, appendix, colon, "barium enema")
15. Upper gastrointestinal tract (pharynx, oesophagus, stomach, "barium swallow and meal")
16. Gall bladder (cholecystography)
17. Chest (heart, cardiac angiography, aorta, respiratory system, lungs)
18. Thorax (sternum, ribs, shoulder, clavicle)
19. Upper limb (hand, forearm, upper arm)
20. Lower leg and foot
21. Head (skull, cervical spine)
22. Dental
23. Mass miniature radiography (photofluoroscopy)

21. For countries where a large part of the radiological work is done in private offices, much of it perhaps by non-radiologists, it is very difficult to determine the total number of examinations per year, and still more difficult to establish the number of examinations of each type or the age and sex distribution of the patients examined. Film consumption provides some check on total volume of radiography, but none at all on fluoroscopy. Under these circumstances it appears that a rather carefully organized survey along the lines suggested by the ICRP/ICRU Study Group is required to obtain the necessary data. It is important to specify whether a total number of examinations, or a figure for film consumption in a country, in fact includes all practices. Special care should be given the presentation of dental and mass chest examinations.

22. For countries where the major part of the diagnostic radiology is controlled by governmental institutions and a high percentage of the examinations is carried out in hospitals, it is probable that the total number of procedures is known fairly accurately and

that sampling of representative hospitals is satisfactory for determining the number of examinations of each type carried out.

23. All information on the number of films, views taken, size of fields and radiographic factors used for an "average" examination are helpful for calculation of dose in the absence of measurements, or as a check on measured values. Measurements performed by specialists give, however, more reliable results than any calculations.

24. The gonad dose per examination should be determined more carefully for those exposure classes in which the doses are expected to have the greatest genetic significance. The dose should be investigated in a manner that permits the assessments of an average for a whole population. The doses received by children require particular attention since few data are available. In any estimates of genetically significant doses, at least children and adults should be treated separately and, when the inaccuracy in other factors has been reduced sufficiently, it may be desirable to classify adults on the basis of size as well.

25. Foetal exposure has a special genetic significance because of the comparatively high relative child-expectancy, which in the case of the foetus becomes W/w (stillborns neglected).

26. The difference between the mean child-expectancy of each class of patients and the mean child-expectancy of the same age and sex group in the population should be determined with regard to its correlation with:

(*a*) type of diagnostic examination;

(*b*) disease treated and type of treatment.

The correlation with type of diagnostic examination may prove to be small but there is at present no evidence. In therapy, the dependence on disease treated is obvious but must be determined quantitatively to permit accurate estimation of the genetically significant dose.

Exposure of the bone marrow

27. According to one hypothesis, the possible radiation induction of leukemia is a linear function of dose. The same dose to different individuals will probably entail different degrees of risk for the subsequent occurrence of the disease, depending upon the age at the time of exposure and other unknown factors. As the appropriate weighting procedure is not known, the various contributions to marrow exposure must, at present, be compared without weighting, and the *per capita* dose in a population is taken as approximately determining the total number of cases of leukemia to be expected during the years following a certain exposure.

28. For the linear dose-effect relationship the relevant dose is assumed to be the mean marrow dose, averaged over the whole mass of active marrow (ca. 1,500 g in an adult). The active marrow is taken to be distributed approximately as follows:

Spinal column	40 per cent
Ribs and sternum	25 " "
Pelvis	15 " "
Skull	10 " "
Other (e.g. in extremities, etc.)	10 " "

Infants and children have a wide distribution of active marrow throughout the skeleton, making estimates of the mean dose difficult, especially as the distribution is dependent on age.

29. According to another hypothesis, there is a threshold dose for the induction of leukemia; in this case a *per capita* marrow dose has no relevance but the individual marrow doses become the determining factors. As the relevant dose may then well be the maximum dose to the marrow, wherever it occurs, the mean dose will not give a measure of the possible risk.

30. As the evaluation of the significance of a marrow exposure may involve the number of "years-at-risk", the mean life-expectancy of each class of patients should be studied.

31. More extensive measurements of the marrow dose resulting from diagnostic and therapeutic procedures should be made.

32. The weight and distribution of active marrow at different ages should be determined.

Diagnostic uses of X-rays

33. It has been estimated that 75 to 90 per cent of the total dose from medical uses of ionizing radiations results from the diagnostic uses of X-rays.[1]

Estimates of the genetically significant dose

34. It should be noticed that almost all estimates of the genetically significant dose from diagnostic exposure have been made under the assumption that the child-expectancy of the patients is not influenced by the nature of the condition for which they were examined. This assumption has not yet been supported by any evidence.

35. The Committee has considered data on gonad exposure from diagnostic X-ray procedures in Australia,[2] Austria,[3] Denmark,[4] England and Wales,[5] France,[6] Japan,[7] Norway,[8] Sweden[9] and U.S.A.[10] Some authors have reported all data needed for an estimate of the genetically significant dose (with the exception stated in paragraph 34), while others have given less complete information. Because of the different procedures of estimates and because of the difference in diagnostic practice, the data are not strictly comparable. However, as far as practicable the material is presented in this report according to the same uniform scheme, following the procedure given in paragraphs 6-26.

36. The material from the various countries is presented separately in appendices 1-10, as it has been found difficult to make a step by step comparison of the data. So far as possible the anatomical classification of examinations recommended by the ICRP/ICRU Study Group[1] has been used. When the original report differs from this classification, the authors' own terms have been used, within quotation marks, following the number of the most closely related standard class. For uniformity of presentation, the data are recorded in terms of equation (8).

37. The procedure by which D_j was estimated for each country is indicated in the introduction to each set of tables. Values of d_j for some of the more important examinations are collected in appendix XI.

38. The most obvious feature of the detailed results has already been pointed out by the ICRP/ICRU Study Group[1] and by others, namely that about 85 per cent of the genetically significant dose results from six or seven anatomical types of examinations (those in the region of the lower abdomen and pelvis), during which the gonads are usually in the primary beam, although these constitute less than 10 per cent of the total number of examinations.

39. Data from countries for which it has been possible to calculate both the *per capita* gonad dose and the genetically significant dose indicate that, at present, these doses are almost the same. This is, of course, a mere coincidence and is true only for the *total* of all contributions. The *relative* contribution from the various exposure classes is quite different in the two cases. For example, while both the annual *per capita* gonad dose and the annual genetically significant dose in the British minimum estimate (see appendix IV) are 23 mrem, the corresponding contributions for an examination of a group with a low child-expectancy such as "female bladder", are 0.26 and 0.08 mrem, and the contributions from a high child-expectancy group such as "foetal exposure in pelvimetry" are 1.4 and 3.4 mrem respectively.

40. Some of the available data have been collected in table I, which gives a comparison of the frequency of examinations and the level of exposure in various countries. The *per capita* number of radiographic examinations reported by Martin in Australia is unusually high and is the main source for the high estimate of the genetically significant dose in this country.

TABLE I. DATA ON GONAD EXPOSURE FROM DIAGNOSTIC X-RAY PROCEDURES IN VARIOUS COUNTRIES

Country	Year of study	Population at time of study (N)	Population under mean age of child bearing (n)	Mean child expectancy (w)	Expected number of children after birth (W)	Relative child expectancy after birth (W/w)	Annual number of examinations per capita of total population: •R Radiography (except dental & mass survey)	•F Fluoroscopy	•M Mass surveys	•D Dental	Consumption of X-ray films—Annual number per capita (f)	Annual genetically significant dose (D_i) (mrem)	$\frac{D_i}{(\bullet R+\bullet F)}$ (mrem)	D_i/f (mrem)	Per capita dose (mrem)
Australia	1955–1957	9,500,000					0.48	—[a]	0.19	no data		160 (28[d])	330 (58[d])		150 (28[d])
Austria	1955–1957	6,974,000	3,095,000			2.25	0.067	0.31	0.0075	no data					16–24
Denmark	1956–1957	4,450,000	(1,610,000)	0.92	2.54	2.76	0.23	—[a]	0.23	no data	1.0	17[d]	75[d]	17[d]	25[d]
England & Wales	1955	44,440,000	(18,700,000)	0.93	2.20	2.36	0.30	—[a]	0.076	0.021		23[d]	75[d]		23[d]
France	1957	42,000,000	19,000,000			2.21	0.15	0.62[c]	0.50[c]	no data	0.86	57[d]	75[d]	65[d]	57[d]
Japan	1956	90,000,000	58,000,000			1.55	0.28	0.04	0.26	no data					10–30
New Zealand	1957	2,221,000	(1,160,000)	1.71	3.28	1.92	0.34	—[a]	0.09	0.24					
Norway	1956	3,400,000							0.15		1.1				
Sweden	1955	7,178,000	(2,980,000)	0.91	2.19	2.41	0.31	—[a]	0.14	(0.3[b])	1.0	38	115	36	
U.S.A.	1955–1956	162,000,000	81,700,000			1.98	0.25	0.08	0.13	0.4 (1.2[b])	0.68	141 (50[d])	430 (150[d])	210 (75[d])	170

[a] Fluoroscopy is generally performed only in connexion with radiography.

[b] Number of films.

[c] 26,000,000 fluoroscopic examinations per year in France include 19,000,000 mass surveys on the population under age 30. In addition, 2,000,000 photofluoroscopic examinations are performed annually, so the total number of mass survey examinations is likely to exceed 21,000,000 per year.

[d] Minimum estimate.

Estimates of bone marrow dose

41. The reports on the dose resulting from the treatment of *Ankylosing Spondylitis* provide the best basis at present for evaluation of a possible risk for radiation-induced leukemia.[11] A discussion on the interpretation of this material is given in chapter V. It should be noticed that some references to marrow dose in literature refer to the mean *spinal* marrow dose instead of the average over the whole mass of active marrow. The latter dose is only about 40 per cent of the mean dose in the spine marrow if other marrow than the spinal has not been exposed.

42. Few measurements of the dose resulting from *diagnostic* X-ray exposure of the bone marrow have been published. The annual mean marrow dose from diagnostic X-ray exposure in Australia has been estimated to be about 100 mrem *per capita*.[12] An attempt has been made here to make another estimate based upon a good current practice and an average frequency of examinations in the same countries which have reported data on gonad exposure.

43. A representative number of examinations of each type N_j, has accordingly been taken from the data on the genetically significant dose, and the mean marrow dose, averaged over the whole active marrow dose, has been calculated from available information on number of films per examination, size of films, skin dose per film, percentage depth dose, etc. Since the estimate at best is only a very preliminary one, it has been considered justifiable to make several simplifying assumptions.

44. All estimates have been based on "standard man" as defined by the ICRP.[13] It has been assumed that the total weight of active marrow is 1,500 grams and that it is distributed as follows: spinal column, 40 per cent; ribs and sternum, 25 per cent; pelvis, 15 per cent; skull, 10 per cent; other, 10 per cent. No estimates for children have been attempted; this would be more difficult because of the wide distribution of active marrow throughout the skeleton of a child and the dependence of this distribution on age.

45. The number of films per examination have been determined from manuals of radiology[14,15] and from published reports on radiographic techniques. The number of films assumed per examination range from one to five (including spot films), depending on the anatomical part; the average is 2.6 as compared with an average of 3 assumed by Laughlin and Pullman.[10] In most cases, Webster and Merrill's[16] values of skin dose have been used. These are considerably lower than many of the published values (e.g. Ritter, Warren and Pendergrass[17]) but are not as low as those of Ardran and Crooks.[18] They are probably fairly representative of the best present-day radiological practice but may be appreciably lower than the skin doses in average practice.

46. The half-value layer of the incident radiation has been assumed to be 3.0 mm of aluminium in all cases, corresponding to an effective voltage of 33.6 kV. The position of the marrow for each view has been determined from "A Cross-Section Anatomy" by Eyclesymer and Schoemaker[19] and the amount of marrow included in the field estimated from reproductions of typical radiographs as found in manuals of radiographic

techniques.[15,16] The percentage depth dose at the level of the marrow has been determined in each case from depth dose tables published by Johns, Epp and Fedoruk,[20] their values being corrected for differences in focus-skin distance and for shielding of marrow by the surrounding bone. The absorption coefficient assumed for bone is not too important since, for the quality of radiation used, the reduction in dose due to bone shielding is probably less than 20 per cent in every case. No correction has been made for the fact that the marrow is located in a trabecular bone structure since it has been estimated[21] that the increase in marrow dose due to proximity of bone is not more than 5 to 15 per cent for radiation of diagnostic quality.

47. The product of the skin dose, the corrected percentage depth dose and the fraction of active marrow assumed to be in the field gives the contribution to the mean marrow dose for each location of marrow. Calculation of dose by this method gives values somewhat lower than measurements of marrow dose reported by Jones and Ellis[21] but are not in serious disagreement. The calulated doses are in good agreement with some preliminary measurements by Laughlin *et al.*[22] of the dose received by the marrow of the vertebral column during a photofluorographic chest examination.

48. The estimates of mean marrow dose from fluoroscopic procedures are much more uncertain than those from radiography. Skin dose rates of 5 r per minute and 10 r per minute have been assumed for radiologists and non-radiologists respectively, and the total time of fluoroscopy taken to be two to five minutes depending on examination. For a country, such as the United States, where the number of examinations by non-radiologists is high, the annual contribution from these examinations to the *per capita* mean marrow dose can be estimated to be between 10 and 20 mrem. In the examinations made by radiologists the fluoroscopic contribution to the *per capita* mean marrow dose is less important although the individual dose from this practice in extreme cases may be very high.

49. From the mean marrow dose, calculated under the simplified assumptions specified above, a *per capita* marrow dose from each type of examination has been estimated, assuming an average frequency of each examination fairly representative for countries such as the United Kingdom, the United States and Sweden. The breakdown of the total by type of examination is given in table II.

50. It is apparent from the table that the highest contribution to the *per capita* mean marrow dose comes from examinations of the gastro-intestinal tract and that mass chest X-ray surveys are of relatively much greater importance here than they are in the case of genetically significant dose. The sum of the contributions in the table is approximately 45 mrem/year and after allowance for the contribution from fluoroscopy, the *per capita* mean marrow dose might be of the order of 50-100 mrem per year, somewhat lower than the Australian estimate[12] and current British estimates[63].

51. The mean marrow dose per examination in mass chest X-ray procedures has been measured by several investigators, who report doses between 70 and 120 mrem

TABLE II. ANNUAL PER CAPITA MEAN MARROW DOSE FROM DIAGNOSTIC X-RAY EXPOSURE (EXCLUDING FLUOROSCOPY)

(Figures based upon an assumed average practice, cf. text)

No.	Examination	Views	*Mean marrow dose (mrem)*	*No. exam. per 1,000 of total pop.*	*Annual per capita marrow dose (mrem)*
1.	Lower femur	1 AP + 1 LAT	5	5	0.025
2.	Hip and femur	1 AP + 1 LAT	30	5	0.15
3.	Pelvis	1 AP	20	5	0.1
4.	Lumbo-sacral	1 AP + 1 LAT + 2 OBL	300	5	1.5
5.	Lumbar spine	1 AP + 2 LAT	400	5	2.0
6.	Dorsal spine	1 AP + 1 LAT + 1 OBL	400	5	2.0
7.	Intrav. pyelography	5 AP	200	5	1.0
8.	Retrog. pyelography	2 AP	100	2	0.2
9.	Urethrocystography	1 AP + 1 LAT + 2 OBL	300	1	0.3
10.	Pelvimetry	1 AP + 1 outlet + 2 LAT	800	0.5	0.4
11.	Salpingography	3 AP	100	0.2	0.02
12.	Abdomen (obstetrical)	1 AP	100	0.5	0.05
13.	Abdomen	1 AP	50	5	0.25
14.	Lower G.I.	2 AP + 3 PA	700	10	7.0
15.	Upper G.I.	1 AP + 2 PA + 1 LAT	500	20	10
16.	Cholecystography	4 PA	400	5	2.0
17.	Chest	1 PA + 1 LAT	40	80	3.2
18.	(*a*) Ribs and sternum.	1 PA + 1 LAT	200	2	0.4
	(*b*) Shoulder	1 PA + 1 LAT	20	5	0.1
19.	Arm	1	2	30	0.06
20.	Foot	1	2	30	0.06
21.	(*a*) Skull	1 AP + 1 PA + 2 LAT	50	30	1.5
	(*b*) Cervical spine	1 AP + 1 PA + 2 LAT	50	5	0.25
22.	Dental	1	20	100	2.0[a]
23.	Mass min.[b]	1 PA	100	100	10

[a] American practice including about 400 examinations per year per 1,000 of total population gives a mean marrow dose of 8 mrem *per capita* and year. British practice involves only 20 examinations per year per 1,000 of total population, which corresponds to less than 0.4 mrem *per capita* and year. The assumptions on location of active marrow make estimates for skull exposure very uncertain.

[b] See discussion in text, paragraphs 51–52.

for good practice, with examinations involving only a postero-anterior view.[12,22,23,63] In some countries lateral views are taken in addition to the postero-anterior view.[23] Although the doses reported per examination might be considered as low estimates for the current practice, there are indications that it may be possible to reduce this exposure considerably in the future.

52. The relatively high *per capita* mean marrow dose from mass chest X-ray examinations is due to the high frequency of this examination. Assuming 10 per cent of the population examined each year the annual *per capita* mean marrow dose from this type of examination would be 10 mrem; however, certain regions report as high frequency as one examination *per capita* per year which would result in the ten-fold *per capita* dose.

53. In countries where fluoroscopy has not been replaced by photofluoroscopy for mass surveys,[6] the annual *per capita* mean marrow dose probably results to a high degree from these surveys and may considerably exceed 100 mrem.

Accuracy of estimates

54. The Committee is in agreement with the suggestion of the ICRP/ICRU Study Group[1] that since the accuracy in estimating the annual genetically significant dose to a "normal" population due to natural sources is about ± 25 mrem, the same absolute accuracy is satisfactory for a first estimate, at least, of the genetically significant dose due to medical sources. This means an accuracy of ± 25 per cent for e.g. the United States and about ± 100 per cent for countries such as Denmark and Sweden. It is stated by Osborn and Smith[5] that the estimate for the United Kingdom may be out by a factor of 2 to 10 and there is a factor of nearly 3 between the minimum and probable doses estimated for the United States.[10] It is evident that the accuracy desired for even a first estimate has not yet been obtained: the eventual objective should be to reduce the absolute uncertainty of the estimate well below that of the background dose.

55. It is convenient to discuss the inaccuracies in the estimates which have been made of the genetically significant dose in terms of equation (8). As pointed out in paragraphs 21-22, the total number of examinations is not very accurately known in countries where a large part of the radiological work is done in private offices and even by non-radiologists.

56. Estimation of the factor w_j/w in equation (8) depends, as has already been said, on two considerations: (*a*) the age and sex distribution of patients receiving each type of examination and (*b*) the difference between the child-bearing expectancies of class jk and class k as a whole. There does not appear to be any evidence on the latter point. However, for most types of diagnostic examination w_{jk} may not differ greatly from w_k. Further, it is only for the six or seven examinations which make the largest contributions that a difference between w_{jk} and w_k can affect appreciably the estimate of genetically significant dose.

57. The determination of the distribution of the total number of examinations on various exposure classes and on age and sex groups must be made by sampling procedures. This is difficult to carry out satisfactorily unless a high percentage of the examinations are made out at a relatively small number of hospitals.

58. The same difficulty is related to the estimate of a representative average gonad dose per examination. As the gonad dose per examination varies from hospital to hospital it is very difficult to give an average with a good accuracy. This is probably the main source of uncertainty to the calculated genetically significant dose and the *per capita* mean marrow dose. Values of the gonad dose per examination as measured in various countries are collected by type of examination in appendix XI.

59. Another source of uncertainty in the *per capita* mean marrow dose is the scant information on the distribution of active marrow.

Reduction of gonadal dose

60. From an international point of view, the most serious criticism is the fact that to date, estimates are available for only six or seven countries. Fortunately, the have been made for some of the countries in which medical exposures may be expected to be highest.

61. It has been demonstrated[1,9,13,16,18,22,24-36,61] that gonad doses can be reduced very decidedly by improved techniques (e.g., by a factor of 50 to 100) for some examinations of males. The greatest attention must be paid, of course, to the six or seven examinations which contribute the largest significant doses. Methods have been pointed out by the ICRP.[1,13]

62. The following is quoted from the report of the ICRP/ICRU Joint Study Group:[1]

"1. *Current Recommendations*

"*Equipment for fluoroscopy*

"The fixed total filter equivalent value should be at least 2 mm aluminium, and should be based on the value obtained at the highest voltage of the X-ray apparatus.

"The use of a timer to measure the fluoroscopy time is recommended.

"*Procedure for fluoroscopy*

"Before a fluoroscopic examination is begun, the eyes must be sufficiently dark-adapted. In order to work with the lowest possible dose-rate, the adaptation period should be at least 10 minutes. A smaller time may be used if there has been preliminary adaptation using red goggles.

"*Equipment for radiography*

"A total filter of at least 2 mm aluminium should be used.

"An automatic switch should be incorporated.

"*Other types of diagnostic work*

"*Dental radiography*

"Fluoroscopy is strongly deprecated.

"*Mobile diagnostic equipment*

"All transportable equipment should be provided with cones or with other restricting devices so that the smallest anode skin distance is normally at least 30 cm (12 in.).

"It should be noted that damage has occurred to workers and patients from contact radiography.

"At least 1.5 mm aluminium equivalent should be provided as a fixed total filter.

"Fluoroscopy should be used only if the equipment meets the requirements recommended for fluoroscopic equipment.

"*Protection of patients*

"*General rules*

"By X-ray protection of the patient it is meant that the radiation exposure of the patient should be reduced as much as is compatible with successful diag-

nostic investigation or therapeutic treatment. In the case of non-malignant diseases, therapeutic treatment shall be employed with caution. In all therapeutic and diagnostic exposures, the integral dose should be kept as low as possible in order to protect the patient as much as possible from the radiation. Moreover, for this purpose, the tube-current, or the mAs value, and the number of examinations should be kept to a minimum. An automatic timer should indicate the length of the diagnostic or therapeutic exposure. In all diagnostic investigations, the beam that strikes the patient should have a cross-section no larger than is essential for the investigation. This is of particular importance in fluoroscopy. In all irradiations the gonads should be protected as much as possible by collimation of the beam or by protective screens. In the case of children, it is important, in view of the little known action of radiation on growing tissues, to be cautious about repeating diagnostic examinations and to avoid too frequent systematic examinations of the whole of the body.

"*Exposure in diagnostic examinations*

"For ease and clarity in the consideration of exposures received in diagnostic work, it is recommended that tables be set up giving doses for radiography and fluoroscopy of lung, stomach, intestines, etc. Integral dose should also be taken into account as it gives a much clearer picture of the true exposure. Special attention should be given to the possible hazards to pneumothorax patients who, as a result of the many screenings after each inflation, may receive large doses. The screenings should be replaced in part by radiographs.

"*Radiation certificate*

"In view of the continually increasing medical and technical use of ionizing radiation, it is desirable to accumulate information regarding the doses received both by individuals and by the population as a whole. As far as the individual is concerned, the information could be obtained by the introduction of a certificate in which are recorded details of all radiation exposure (medical and occupational) received through life. Probably it is impracticable to introduce such a certificate at present, but it is recommended that all radiologists and dentists keep records of the doses given, and the field sizes and radiation qualities used, in all diagnostic procedures. (It is presumed that such records are already available in the case of therapeutic procedures.)

"2. *Recommendations regarding the following items are under consideration*

"(*a*) The provision of specially designed protective devices for the gonads of patients.

"(*b*) Additional recommendations regarding minimum film-focus distances.

"(*c*) Increasing the protective requirements for diagnostic and therapeutic tube housings.

"(*d*) Improvements in beam collimation.

"(*e*) The provision of permanent filters of at least 2 mm Al equivalent on all diagnostic X-ray tubes.

"(*f*) The advantages of using high voltage techniques for diagnostic work.

"(*g*) The provision of exposure counters on all diagnostic equipment.

"(*h*) The use of image intensifiers to reduce the dose to the patient, and consequently to the operator, rather than as a means of permitting more extensive and prolonged fluoroscopy than hitherto."

63. It is improbable that there will be great improvement in accuracy of estimation of gonad doses until the range of actual doses is reduced appreciably by conscientious adherence to procedures as have been recommended by the ICRP. In this connexion it is probable that the "feedback" suggested by the ICRP/ICRU Study Group is already operating, i.e., the attention to estimation of the genetically significant dose is already reducing the dose.

64. Reduction of gonad dose may also be obtained in the future by means of improved radiological equipment and supplies, e.g., faster films, faster screens, etc. The advantage to be gained by increased use of image amplifiers has already been pointed out by the ICRP/ICRU.[1]

65. Finally, reduction in gonad dose can be achieved by a reconsideration by the medical profession of the circumstances under which X-ray diagnosis is appropriate. This could be facilitated by statistical information on the significance of each examination class for the reduction of any specified morbidity. When medical decision has been taken, administrative co-ordination should be improved between authorities who require that certain examinations be made in the routine health surveillance of whole populations or special groups such as school-children, students, employees, immigrants.

66. The tables in appendix XI point to the possibility of carrying out some examinations at much lower gonad exposure levels than are likely to be obtained in the average case at present. The annual genetically significant dose that may be achievable without detriment to diagnostic information has been estimated to be less than 30 mrem for Australia[2] and 15 mrem for Sweden.[9]

Radiotherapy

Genetically significant dose

67. S. H. Clark[37] has estimated the genetically significant dose due to radiotherapy in the United States as about 10 mrem per year. This figure, quoted by Laughlin and Pullman,[10] is based on the assumption that treatment of malignant conditions are not genetically significant. It may hence be an under-estimate. For Australia, Martin[2,36] reports an estimate of the contribution to the genetically significant dose from radiotherapy as 28 mrem per year, assuming a normal child-expectancy of all surviving patients that were not assumed to be sterilized by the irradiation. Survey by Purser and Quist[38] yields an estimate of 1 mrem *per capita* gonad dose per year in Denmark. In the Danish survey it was found that 22 per cent of the genetically significant dose resulted from treatment of malignant conditions, assuming that the patients treated for malignancies have one-fifth the child-expectancy of normal individuals.

Bone marrow dose

68. It does not appear possible to estimate with any certainty even the order of magnitude of the *per capita* mean marrow dose, due to radiotherapy, from the data at present available to the Committee.

Internally administered radioisotopes

69. The principal contributions to the population dose from the medical use of radioisotopes arise from the use of I^{131} and P^{32} which are most widely employed. While considerable quantities of Au^{198} are used, the biological significance of exposure from this course is negligible

since Au^{198} is generally limited to palliative treatment of incurable conditions. Other radioisotopes are used in very small quantities and almost entirely for diagnostic purposes.

70. Estimates of the *per capita* gonad dose resulting from the use of I^{131} and P^{32} can be based upon information about either treatments or radioisotope shipments, the first approach being more accurate and preferable.[37,39,40] From the report of the ICRP/ICRU Joint Study Group[1] and other information available to the Committee,[39,40] it seems likely that the genetically significant dose is lower than 1 mrem per year, even in the countries for which the highest figures can be expected.

71. Some experience on the effects of ingesting radioactive substances relates to the early period when the hazard was not realized. The work with radioactive luminous materials was early recognized as hazardous if not properly conducted,[41] but radioactive contrast media such as Thorotrast were being used occasionally in X-ray diagnostic work until a few years ago. The high retention of the radioactive material in the liver and the spleen resulted in rather high exposure, with dose-rates of the order of 0.3 rem per day during periods of years.[42,43]

III. Industrial and research uses of X-rays and radioactive materials

Occupational exposure

72. The exposure from industrial and research uses of X-rays and radioactive materials is mainly an occupational one. The extent to which non-occupationally exposed individuals are exposed depends upon the degree of environmental contamination. The latter problem is treated in annex D.

Medical workers

73. The countries reporting on the number of persons in medical radiological work[3,7,10,44–46] have presented figures ranging from 0.17—0.69 per 1,000 of the total population. However, in many cases it is not clear what has been meant by "medical worker".

74. The following table shows the extent of X-ray work in New Zealand[45] and Sweden[47] and gives an idea of the relative number of various installations in countries with extensive medical facilities.

Table III. Number of X-ray installations

Type of installation	New Zealand, 1957: Number of plants per 1,000 of total population	Sweden, 1955: Number of plants per 1,000 of total population	Sweden, 1955: Number of exposed workers per 1,000 of total population
Diagnostic	0.14	0.15	0.46
Therapy	0.02	0.01	0.03
Dental	0.24	0.40	0.93
Chiropractors and naturopathic	0.02	—	—
TOTAL MEDICAL	0.42	0.56	1.42
Shoefitting	0.03	—	—
Veterinary	0.01	0.004	0.01
Industrial	0.003	0.02	0.06
Research and educational	0.01	0.03	0.02

75. The age-distribution of the workers is usually such that about 50 per cent are under the mean age of child-bearing.[3,7,46] Hence, the genetically significant dose is approximately equal to the *per capita* dose. Average annual doses ranging from 500 - 5,000 mrem have been reported to the Committee as resulting from occupational medical exposure,[3,7,44–46] but this exposure does not refer to all installations shown in table III. For example, the exposure of dentists or their assistants is usually very small,[47] and most radiotherapy with X-rays can be carried out under conditions ensuring good protection of the personnel.[48] Annual average doses of up to 5,000 mrem refer to less than 0.2 persons per 1,000 of the total population and result therefore in a *per capita* dose of less than 1 mrem per year, mostly from X-ray diagnostic work.[48,49]

76. Medical radioisotope work is usually performed with little exposure of the personnel.[48] An important exception is the work with implantation of radium applicators and needles where the personnel may at present be exposed to considerably more than 100 mrem per week.[50,66,67] This exposure, however, involves only a very small group of people.

Atomic energy workers

77. More complete and more accurate data are available for this group than for any other occupationally exposed group, since in countries in which atomic energy establishments are operated, monitoring procedures have been set up to cover exposed personnel.

78. The contribution from exposure of atomic energy workers to the genetically significant dose to the population is about 0.1 mrem per year or less in countries for which it has been estimated.[44,46,51,52] However, since the number of atomic energy workers is expected to increase in the near future, this figure may increase in proportion.

79. The figures in table IV have been taken from a report of the United States Atomic Energy Commission.[51]

Table IV. Exposure of atomic energy personnel in the United States of America

(a) *Exposure of A.E.C. contractor personnel to penetrating radiation (1955)*

Annual dose (mrem)	Number of workers	Percentage
0– 1,000	56,708	94.2
1,000– 5,000	3,157	5.2
5,000–10,000	285	0.5
10,000–15,000	41	<0.1
>15,000	3	<0.01
	60,194	100.0

(b) *Highest accumulated yearly doses to individual A.E.C. contractor employees during routine operations (accidents excluded)*

Year	Highest dose (rem)	Average of 10 highest doses (rem)
1947	23.5	5.2
1948	20.3	4.2
1949	13.6	2.6
1950	9.0	2.2
1951	7.1	1.8
1952	15.7	2.9
1953	12.9	3.4
1954	27.8	3.9
1955	17.9	4.1

Industrial and research workers

80. The information on exposure of industrial and research workers is less complete than the information on exposure of the other occupational groups.[3,44–46,48,53] As is evident from the relation between the number of persons and number of plants in table III, the concept "research worker" is not well defined. If the exposure is assumed to be equal to that in the group of medical workers, the contribution to the population dose is lower, because of the smaller number of workers. Industrial γ-radiography is one of the main sources of exposure of this group.[48]

81. A special occupational problem is the exposure of workers in mining and milling radioactive materials such as uranium.[48,54] If not properly conducted, this work may involve considerable hazard to the workers.

Summary

82. From the information surveyed above, it appears that the contribution from occupational exposure to the genetically significant dose is less than 2 mrem per year for most countries. Despite the fact that this contribution is relatively small and the corresponding contribution to doses significant for somatic injury is also small, the exposure of radiation workers merits special attention for two reasons: (*a*) there will be a considerable increase in the near future in the number of atomic energy employees in many countries, and (*b*) individual exposures may be high even though the contribution to the mean dose of the population is small.

83. Methods for reducing the occupational exposure have been pointed out by ICRP[13] and ILO.[55]

IV. Other man-made sources of radiation

84. Watches and clocks with radioactive luminous dials give an annual genetically significant dose of about 1 mrem.[46,56] X-rays from television receivers contribute less than 1 mrem.[46] X-rays from shoe-fitting fluoroscopes contribute still less, as they normally expose a relatively small number of individuals.[45,46,57] (However, they might be an important hazard to the exposed individuals, see reference 64.)

Appendices

DATA FOR EVALUATION OF THE GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

Appendix I

AUSTRALIA

The data on gonad exposure in Australia have been taken from papers by Martin[2,36]. The author has rearranged his material for the purpose of this report. Martin's estimate of the annual genetically significant dose is unusually high. This is mainly due to the high *per capita* number of examinations, which the author has assumed to be 60 per cent higher than the number for England and Wales (cf. paragraph 40).

(*See Appendix I. Table I on page 71.*)

Data for evaluation of the genetically significant dose from diagnostic X-ray exposure

Appendix I. Table I. Australia

No.	Examination	Females <30 d_j^* (mrem)	Females <30 1,000 N_{jk}^*/N	Females <30 w_{jk}^*/w	Females <30 D_{jk}^* (mrem)	Females 30–44 1,000 N_{jk}^*/N	Females 30–44 w_{jk}^*/w	Females 30–44 D_{jk}^* (mrem)	Females >44 1,000 N_{jk}^*/N	Females >44 w_{jk}^*/w	Females >44 D_{jk}^* (mrem)	Males <30 d_j^* (mrem)	Males <30 1,000 N_{jk}^*/N	Males <30 w_{jk}^*/w	Males <30 D_{jk}^* (mrem)	Males 30–44 1,000 N_{jk}^*/N	Males 30–44 w_{jk}^*/w	Males 30–44 D_{jk}^* (mrem)	Males 44> 1,000 N_{jk}^*/N	Males 44> w_{jk}^*/w	Males 44> D_{jk}^* (mrem)	TOTAL D_j (mrem)	TOTAL Per cent
1.	"Hips"	440	1.94	3.05	2.61	1.34	0.25	0.15	3.48	0.003	0.0046	880	1.97	2.76	4.8	1.24	0.58	0.63	2.42	0.003	0.0061	8.2	10.8
2.																							
3.	"Pelvis"	800	1.7	"	4.15	1.17	"	0.235	3.04	"	0.0007	1,080	1.9	"	5.66	1.19	"	0.749	2.34	"	0.007	10.8	14.2
4.	"L. S. J."	1,025	2.06	"	6.45	1.42	"	0.364	3.68	"	0.0113	81	3.28	"	0.734	2.06	"	0.097	4.03	"	0.001	7.7	10.1
5.																							
6.	"D. Vert"	124	1.27	"	4.82	0.87	"	0.27	2.27	"	0.0084	17.2	1.75	"	0.083	1.1	"	0.011	2.15	"	0.0001	5.2	6.8
7.	"I. V. P."	1,360	1.4	"	5.83	0.96	"	0.328	2.5	"	0.0102	590	1.68	"	2.73	1.05	"	0.36	2.06	"	0.0037	9.3	12.2
8.	"Ret. Pyel."	800	0.3	"	0.73	0.21	"	0.042	0.54	"	0.0013	700	0.29	"	0.56	0.18	"	0.073	0.35	"	0.0007	1.4	1.8
9.	"Bladder"	210	0.18	"	0.115	0.12	"	0.0063	0.32	"	0.0002	240	0.44	"	0.29	0.28	"	0.0383	0.54	"	0.0004	0.45	0.6
10.																							
11.	"Salpine"	25,000	0.12	"	9.15	0.08	"	0.5	0.21	"	0.016	—	—	—	—	—	—	—	—	—	—	9.7	12.7
12.																							
13.	"Ur. tract"	203	2.9	"	1.795	2	"	0.101	5.19	"	0.00315	110	4.01	2.76	1.22	2 52	0.58	0.161	4.93	0.003	0.0016		
	"Kidney"	60	0.12	"	0.0021	0.08	"	0.0001	0.21	"	—	3.7	0.15	"	0.0014	0.09	"	0.0002	0.18	"	—		
	"Liver"	20	0.06	"	0.0037	0.4	"	0.0002	0.11	"	—	2.0	0.07	"	0.0003	0.04	"	0.0001	0.09	"	—	3.3	4.3
14.	"Intest. Tract"	520	1.45	"	2.3	1	"	0.13	2.6	"	0.0041	130	1.82	"	0.651	1.14	"	0.086	2.24	"	0.0009	3.2	4.2
15.	"Stomach"	360	3.27	"	3.59	2.26	"	0.203	5.85	"	0.0063	470	6.05	"	7.84	3.8	"	1.04	7.43	"	0.010	12.7	16.7
16.	"Gall Bladder"	70	2.78	"	0.591	1.92	"	0.0335	4.97	"	0.001	2.7	1.39	"	0.0105	0.87	"	0.0014	1.71	"	—	4.0	5.2
	"Cholecyst."	378	2.76	"	3.17	1.9	"	0.179	4.94	"	0.0056	13.5	1.01	"	0.0375	0.64	"	0.005	1.24	"	—		
17.	"Chest"	2.4	17.6	"	0.1285	12.1	"	0.0073	31.4	"	0.0023	0.4	15.2	"	0.0168	9.55	"	0.0022	18.7	"	—	0.2	0.2
18.	"Ribs"	3.8	0.49	"	0.0055	0.34	"	0.0003	0.88	"	—	0.7	0.37	"	0.0008	0.23	"	0.0001	0.45	"	—		
	"Shoulder"	3.4	0.91	"	0.0095	0.63	"	0.0005	1.63	"	—	0.7	1.75	"	0.0033	1.1	"	0.0005	2.15	"	—	0.02	0.03
19.	"Extrem."	1.0	10.6	"	0.0324	7.3	"	0.0018	19	"	—	2.1	19.6	"	0.113	12.3	"	0.015	24.1	"	0.0002	0.2	0.2
20.																							
21.	"Skulls, etc."	1.0	7.5	"	0.0229	5.4	"	0.0013	13.4	"	0.0004	0.2	9.2	"	0.005	5.77	"	0.007	11.3	"	0.0001	0.05	0.06
	"C. Vert."	1.2	1.03	"	0.0037	0.71	"	0.0002	1.84	"	—	1.5	1.09	"	0.0044	0.68	"	0.0006	1.34	"	—		
22.																							
23.																							

			100
Sub-total:	Adult examinations	76	47
	Children	46	28.4
	Foetus	22.6	14.0
	Fluoroscopy	17	10.5
	Mass surveys	0.2	0.1
	Total	162	100.0

APPENDIX II
AUSTRIA

The data submitted by Austria[3] do not permit a presentation according to Equation (8). The following information is given:

Type of examination	1,000 N_j/N	d_j (mrem) Females	d_j (mrem) Males
(A) *Radiography:*			
Pelvis, hips, lumbar spine	6	40–240 (AP) 20–80 (Lat)	6–24 (AP) 8–30 (Lat)
Abdomen, colon, genito-urinary	7.5	6,000	12,000
Pelvimetry, obstetrics	0.75	200 (AP) 1,000 (Lat)	—
Other classic techniques	52	60	40
Tomography	0.15	2	2
Other special techniques	0.75	—	—
Dental	not known	10–100	10–100
Mass surveys	7.5	2	1
(B) *Fluoroscopy:*			
Mass surveys	negligible	—	—
Other examinations	310	not known	not known

From the above data, the *per capita* gonad dose from diagnostic X-ray exposure is estimated to be 16-25 mrem per year.

APPENDIX III
DENMARK

The primary material

1. The following estimate of the genetically significant dose from diagnostic X-ray procedures in Denmark is based upon data published by Hammer-Jacobsen.[4] The author assumes the annual number of examinations in Denmark to be 1,000,000 plus 1,000,000 mass chest photofluoroscopies. The data are assumed to be representative for 1956 (the dose-measurements were made during September 1956-February 1957).

2. The examinations cover the total practice with radiography and fluoroscopy combined. However, the distribution of examinations with respect to type and sex is as observed in one hospital in which about 5 per cent of the total number of examinations are performed.

3. The author estimates a *per capita* dose of 26 mrem from the above data, but considers that this may be a minimum estimate.

4. No data on foetal exposure are given. The author estimates the foetal contribution to the total *per capita* dose in proportion to the relation foetal/female contribution given by Osborn and Smith.[5]

Presentation of the material for this report

5. The Danish data include values for N_j and d_j in all cases needed for an estimate of D_j.

6. No values for w_j/w are given. The values for w_j/w presented in the table for England and Wales have been used as substitutes in the first approximation. This gives female and male contributions of 5 and 8 mrem to the genetically significant dose, as compared to the author's *per capita* doses of 7 and 15 mrem respectively.

7. If the foetal contribution is taken in proportion to the female contribution and the ratio 72.2 per cent from the British report is used, the foetal value will be 4 mrem. This seems, however, to be a low value, as a back calculation by help of the known value of w_j/w for the foetus, implies a foetal dose of, e.g., less than 500 mrem per examination from pelvimetry, whereas other countries report values ranging from 2,500-4,500 mrem.

DATA FOR EVALUATION OF THE GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

APPENDIX III. TABLE I. DENMARK

No.	Type of examination	Females 1,000 N_j/N	Females d_j mrem	Females w_j/w	Females D_j mrem	Males 1,000 N_j/N	Males d_j mrem	Males w_j/w	Males D_j mrem	Totals D_j mrem	Totals D_j per cent
1.	Hip and femur	2.5	54	0.7	0.09	2.2	911	1.1	2.20	2.29	13.4
2.	"Knee and crus"	4.7	0.6	0.7	0.00	4.3	3.25	1.1	0.02	0.02	0.1
3.	Pelvic region	0.7	195	0.9	0.13	2.5	527	0.6	0.79	0.92	5.4
4.–5.	Lumbar spine	3.4	206	0.6	0.42	4.3	97	0.8	0.33	0.75	4.4
6.	Dorsal spine	1.1	14	0.7	0.01	2.2	20	0.8	0.04	0.05	0.3
7.	Intraven. pyelography	4.3	525	0.8	1.81	4.3	948	0.5	2.04	3.85	22.5
8.	Retrograde pyelography	0.4	1,060	0.8	0.34	0.9	2,400	0.5	1.08	1.42	8.3
9.	"Urethrocystography"	0.0	430	—	0.00	0.4	3,450[a]	0.5	0.69	0.69	4.0
	"Cystogr. dur. micturition"	0.4	406	0.3	0.04	0.4	4,720	0.23	0.43	0.45	2.6
10.	Pelvimetry	2.2	764	0.9	1.51	—	—	—	—	1.51	8.8
11.	Hysterosalpingography	0.9	183	1.1	0.18	—	—	—	—	0.18	1.1
12.	Obstetrical abdomen	2.0	177	1.8	0.64	—	—	—	—	0.64	3.7
13.	"Abdomen, A. P., urin."	0.4	79	0.6	0.02	0.4	567	0.6	0.14	0.16	0.9
14.	"Barium enema"	4.3	19	0.2	0.02	4.3	37	0.4	0.06	0.08	0.5
15.	"Barium swallow and meal"	7.2	8.4	0.4	0.02	7.4	19	0.04	0.06	0.08	0.5
16.	"Gall bladder"	4.0	14.5	0.2	0.01	2.0	1.7	0.3	0.00	0.01	0.1
17.	"Chest"	36.0	0.07	1.3	0.00	34.6	0.33	1.3	0.01	0.01	0.1
	"Chest, special"	3.8	5.0	0.5	0.01	4.5	34	0.8	0.12	0.13	0.8
18.	"Shoulder"	2.0	0.03	0.7	0.00	2.2	0.20	0.9	0.00	0.00	0.0
	"Ribs and sternum"	0.2	0.15	0.4	0.00	0.4	0.45	0.7	0.00	0.00	0.0
19.	"Arm and hand"	5.8	0.05	1.1	0.00	9.4	0.24	1.5	0.00	0.00	0.0
20.	"Foot"	2.9	0.6	1.0	0.00	4.7	3.25	1.2	0.02	0.02	0.1
21.	"Head"	14.8	0.2	1.5	0.00	17.5	0.8	1.6	0.02	0.02	0.1
	"Teeth"	1.3	0.8	1.0	0.00	1.8	4.4	0.9	0.01	0.01	0.1
	"Cervical spine"	4.0	0.17	0.5	0.00	3.8	1.6	1.1	0.01	0.01	0.1
22.	Dental	—	—	0.5	0.00	—	—	0.4	—	0.00	0.0
23.	Mass min. radiography	110	0.15	1.3	0.02	110	0.25	0.9	0.02	0.04	0.2
	SUB-TOTALS	—	—	—	5.25	—	—	—	8.09	13.3	—
	Allowance for foetal exposure, assumed to be 72.2% of female contribution									3.8	22.4
									TOTAL	17	100

[a] The dose 3,450 mrem for males in item 9 is an average of dose measurements from 7 male adults urethrography + 1 boy urethrography + 2 male adults cystography.

APPENDIX IV

ENGLAND AND WALES

The primary material

1. The Committee has not received material upon which it can base an estimate of the probable genetically significant dose for England and Wales. It is, however, possible to give a lower limit under certain assumptions. The primary figures (for radiography and fluoroscopy combined) have been taken from a report by Osborn and Smith (1956).[5] These authors have used values for the gonad dose per examination published by Stanford and Vance (1956).[58] They computed the product $N_j^* w_j^* d_j^*$ using the following statistics:

(*a*) The total number of diagnostic examinations per year based on official figures.

(*b*) The distribution of examination with respect to type, age and sex in what was believed to be a representative sample of hospitals.

(*c*) The child-expectancy derived from official statistics and assumed not to be influenced by the nature of the condition for which the patient was examined (except in the case of hysterosalpingography).

2. An extensive British survey of the diagnostic exposure in the United Kingdom is at present being made,[59] but no data are available for this report.

*Presentation of the material for this report**

3. After division by wN the values reported by Osborn and Smith may be taken as approximate lower limits of the contributions to the genetically significant dose for England and Wales. The values of w_j/w for each examination class have been calculated from the known values of N_j/N, d_j and the approximation of D_j, and should depend only upon the age-distribution within the class following the assumption under 1. (*c*) above.

* These calculations are based on available figures which in some cases have been "rounded off" in publication. The results are therefore approximate and, although adequate for the present purpose, are less accurate than could be derived from calculations based on the original data.

NUMBER OF EXAMINATIONS PER 1,000 OF TOTAL POPULATION
(1000 N_j^*/N)

APPENDIX IV. TABLE I. ENGLAND AND WALES

Exam. No.	*Females (all ages)*	*Males (all ages)*	*Foetal gonads*
1.			
2. "Hip and femur"	5.6	5.6	0.03
3. Pelvis	2.8	2.8	0.09
4.			
5. "Lumbar spine"	5.6	5.6	0.10
6. "Thoracic spine"	2.4	2.0	0.04
7.			
8. "Pyelography"	2.4	2.8	0.07
9. "Bladder"	0.4	0.4	0.014
10. Pelvimetry	0.58	—	0.58
11. Salpingography	0.14	—	—
12.			
13. "Abdomen with obstetric"	4.4[a]	2.4	2.15[b]
14. "Barium enema"	2.8	2.0	0.02
15. "Barium swallow and meal"	6.4	10.4	0.11
16. Cholecystography	1.6	0.8	0.02
17. Chest	50[c] + 3.2[d]	47[c] + 1.6[d]	1.2[c] + 0.24[d]
18. "Ribs and sternum + shoulder"	0.4 + 2.4	1.6 + 3.2	0.00 + 0.00
19. Arm	17.1	19.1	0.20
20. Lower leg	15.6	20.0	0.17
21. "Head + cervical spine"	13.6 + 2.8	15.4 + 1.6	0.25 + 0.00
22. Dental	11.9 + 1.2[e]	7.2 + 0.8[e]	0.14
23. Mass surveys	30.2	46	
24. Others	0.8	16.3	

[a] Including 1.94 obstetrical.
[b] Including allowance for possible pregnancy in non-obstetric abdominal examinations.
[c] Large film.
[d] Special film.
[e] Teeth exam. at hospitals.

Relative child expectancy
(w_j^*/w)

Appendix IV. Table II. England and Wales

Exam. No.	Females (all ages)	Males (all ages)	Foetal gonads
1.			
2. "Hip and femur"	0.75	1.13	2.36
3. Pelvis	0.93	0.56	"
4.			
5. "Lumbar spine"	0.63	0.83	"
6. "Thoracic spine"	0.67	0.80	"
7.			
8. "Pyelography"	0.81	0.53	"
9. "Bladder"	0.30	0.23	"
10. Pelvimetry	0.94	—	"
11. Salpingography	1.07	—	—
12.			
13. "Abdomen with obstetric"	1.08	1.54	2.36
14. "Barium enema"	0.22	0.58	"
15. "Barium swallow and meal"	0.40	0.43	"
16. Cholecystography	0.16	0.28	"
17. Chest	1.3/0.50	1.3/0.85	"
18. "Ribs and sternum + shoulder"	0.38/0.67	0.74/0.88	"
19. Arm	1.1	1.5	"
20. Lower Leg	0.98	1.2	"
21. "Head + cervical spine"	1.5/0.52	1.6/1.1	"
22. Dental	0.53/1.0	0.37/0.87	"
23. Mass surveys	1.32	0.88	"
24. Others			

(See footnotes to table I).

Gonad dose per examination
(d_j^* in mrad or mrem)

Appendix IV. Table III. England and Wales

Exam. No.	Females (all ages)	Males (all ages)	Foetal gonads
1.			
2. "Hip and femur"	195	660	744
3. Pelvis	195	1,020	744
4.			
5. "Lumbar spine"	663	120	663
6. "Thoracic spine"	14	20	14
7.			
8. "Pyelography"	1,200	452	2,990
9. "Bladder"	642	260	2,430
10. Pelvimetry	1,190	—	2,490
11. Salpingography	1,580	—	—
12.			
13. "Abdomen with obstetric"	186	64	539
14. "Barium enema"	18.6	37	18.6
15. "Barium swallow and meal"	8.4	18.6	8.4
16. Cholecystography	14.5	1.7	14.5
17. Chest	0.065/5.0	0.33/34	0.065/5.0
18. "Ribs and sternum + shoulder"	0.15 /0.03	0.45/ 0.20	0.15 /0.03
19. Arm	0.05	0.24	0.05
20. Lower leg	0.56	3.3	0.56
21. "Head + cervical spine"	0.2 /0.17	0.74/ 1.6	0.2 /0.17
22. Dental	0.74	4.4	0.74
23. Mass surveys	0.14	0.23	0.14
24. Others			

(See footnotes to table I).

ANNUAL GENETICALLY SIGNIFICANT DOSE
(D_j in mrem)

APPENDIX IV. TABLE IV. ENGLAND AND WALES

Exam. No.	*Females (all ages)*	*Males (all ages)*	*Foetal*	*Total*	*Per cent of total*
1.					
2. "Hip and femur"	0.82	4.18	0.05	5.05	21.8
3. Pelvis	0.51	1.60	0.16	2.27	9.8
4.					
5. "Lumbar spine"	2.34	0.56	0.16	3.06	13.2
6. "Thoracic spine"	0.02	0.03	0.00	0.05	0.2
7.					
8. "Pyelography"	2.33	0.67	0.49	3.49	15.0
9. "Bladder"	0.08	0.02	0.08	0.18	0.8
10. Pelvimetry	0.65	—	3.47	4.06	17.5
11. Salpingography	0.24	—	—	0.24	1.0
12.					
13. "Abdomen with obstetric"	0.88	0.24	2.73	3.85	16.6
14. "Barium enema"	0.01	0.04	0.00	0.05	0.2
15. "Barium swallow and meal"	0.02	0.08	0.00	0.10	0.4
16. Cholecystography	0.00	0.00	0.00	0.00	0.0
17. Chest	0.01	0.07	0.00	0.08	0.3
18. "Ribs and sternum – shoulder"	0.00	0.00	0.00	0.00	0.0
19. Arm	0.00	0.07	0.00	0.07	0.3
20. Lower leg	0.01	0.08	0.00	0.09	0.4
21. "Head + cervical spine"	0.01	0.02	0.00	0.03	0.1
22. Dental	0.00	0.01	0.00	0.01	0.0
23. Mass surveys	0.01	0.01	0.00	0.02	0.1
24. Others	0.01	0.44	0.00	0.45	1.9
TOTAL	8.0	8.1	7.1	23.2	100

APPENDIX V

FRANCE

The primary material

1. The estimate presented here is based upon data submitted by Reboul and Istin.[6] The authors assume the annual number of *radiographic* examinations in France to be 5,000,000 plus 1,300,000 examinations of employees and militaries. The distribution on various types of examinations is studied on 18.889 cases. The data are assumed to be representative for 1957.

2. The authors point out that the foetal exposure due to pelvimetry and obstetrical examinations is lower in France than in other countries, due to the low frequency of these examinations.

3. 28,000,000 *fluoroscopies* are performed annually, 19,000,000 of which are examinations of patients under age 30, mostly in mass chest examinations. There are only 2,000,000 *photofluoroscopies* per year. The gonad dose from photofluoroscopy has been estimated by Turpin, Dupire, Jammet and Lejeune.[60]

4. The authors consider their values to be minimum estimates.

Presentation of the material for this report

5. The French data include values of N_j for the whole material, and the corresponding values of d_j in most cases. Where the dose is not reported, an average dose, likely to be representative, has been used. These values are indicated with an asterisk in the table.

6. Values for the relative child expectancy (w_j/w) cannot be derived from the French data. However, an approximate figure can be calculated from the information on the fraction of patients under age 30, for each type of examination. The approximate figures differ little from the values of w_j/w presented in the table for England and Wales. Therefore, the British values may be regarded as fairly representative also for the French material, and they have accordingly been used in the calculations.

7. The contribution from radiography, 27 mrem, is most likely a very low estimate. An interesting feature of the French material is the remarkably high contribution of *fluoroscopy used in mass survey examinations.* Because of the uncertainty with regard to average viewing time and other factors determining the dose per examination, the total value 57 mrem must be considered uncertain by at least a factor of two.

DATA FOR EVALUATION OF THE GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

A. ANNUAL CONTRIBUTION FROM 5,000,000 RADIOGRAPHIC EXAMINATIONS

(foetal exposure excluded)

APPENDIX V. TABLE I. FRANCE

No.	Examinations involving radiography	Females				Males				Total	
		1000 N_i/N	d_i mrem	w_i/w	$D_i^{(F)}$ mrem	1000 N_i/N	d_i mrem	w_i/w	$D_i^{(M)}$ mrem	D_i mrem	Per cent
1.											
2.	"Membres inf. 1/3 sup."	1.59	150	0.7	0.17	2.18	1,200	1.1	2.88	3.05	11.3
3.	"Bassin" (items 10 and 12 excluded)	3.30	1,200	0.9	3.56	3.13	1,500	0.6	2.82	6.38	23.7
4.	"Colonnes lombaires"	2.43	750	0.6	1.09	2.79	130	0.8	0.29	1.38	5.1
5.											
6.	"Colonnes dorsales"	1.70	20	0.7	0.02	2.13	6	0.8	0.01	0.03	0.1
7.	"Urographies"	1.38	2,100	0.5	1.45	1.54	380	0.4	0.23	1.68	6.2
8.	"Urètho-Cysto" (not incl. item 11)	0.25	1,200	0.5	0.15	0.30	2,000	0.4	0.24	0.39	1.4
9.											
10.	"Pelvimetries"	0.038	1,200*	0.9	0.04	—	—	—	—	0.04	0.1
11.	"Hysterographies"	0.46	1,700*	1.1	0.86	—	—	—	—	0.86	3.2
12.	"Grossesses"	0.26	1,600*	1.8	0.75	—	—	—	—	0.75	2.8
13.	"Pneumo et retropneumoperitoines"	0.043	300	0.6	0.01	0.074	160	0.6	0.01	0.02	0.1
	"Splenoportographies"	0.046	70		0.00	0.111	32		0.00	0.00	0.0
14.	"Grèle"	0.28	250*	0.2	0.01	0.21	75*	0.4	0.01	0.02	0.1
	"Lavement"	2.28	220		0.10	1.65	140		0.09	0.19	0.7
15.	"Oesophages"	0.51	6*	0.4	0.00	0.87	6*	0.4	0.00	0.00	0.0
	"Estomacs"	3.17	190		0.24	4.95	60		0.12	0.36	1.3
16.	"Vesicules"	1.97	40	0.2	0.02	1.20	28	0.3	0.10	0.12	0.4
17.	"Poumons"	20.7	9	1.3	0.24	28.9	13	1.3	0.49	0.73	2.7
	"Lipiodols"	0.042	250*	0.5	0.01	0.13	320	0.8	0.03	0.04	0.1
	"Arteriographie"	0.12	250*	0.5	0.02	0.24	320*	0.8	0.06	0.08	0.3
	"Tomographies"	1.07	1,900	0.5	1.02	2.93	1,500	0.8	3.52	4.54	16.9
18.	"Membres sup. 1/2 sup."	1.50	0.9*	0.7	0.00	1.85	0.4*	0.9	0.00	0.00	0.0
19/20.	"Membres sup./inf. 1/2 inf."	1.93	0.4*	1.1	0.00	3.74	0.4*	1.5	0.00	0.00	0.0
	"Extrémites osseuses"	2.41	0.3*	1.0	0.00	3.79	0.3*	1.2	0.00	0.00	0.0
21.	"Crânes"	2.57	4	1.5	0.02	4.37	4	1.6	0.03	0.05	0.2
	"Col. cervicales"	0.94	15	0.5	0.01	0.95	15	1.1	0.02	0.03	0.1
22.	—				0.00				0.00	0.00	0.0
23.	"Radiophotographies"	240	0.3	1.3	0.09	240	0.3	0.9	0.06	0.15	0.6
	TOTALS				10.32				10.74	20.9	77.4

B. ADDITIONAL CONTRIBUTION FROM 1,300,000 RADIOGRAPHIC EXAMINATIONS OF EMPLOYEES AND MILITARIES

Contribution estimated in proportion to number of examinations, photofluoroscopy excluded	5.2	19.3

C. ALLOWANCE FOR FOETAL EXPOSURE

Estimate from British values in proportion to the frequency of examinations

		U.K.: D_i (mrem)	U.K.: 1000 N_i/N	France: 1000 N_i/N		
10.	"Pelvimetries"	3.47	0.58	0.038	0.2	0.7
12.	"Grossesses"	2.73	1.94	0.26	0.4	1.5
				TOTAL RADIOGRAPHY:	27	100

D. CONTRIBUTION FROM FLUOROSCOPY

19,000,000 examinations under age 30, with an average gonad dose of 30 mrem per exam. (mostly mass surveys)

		1000 N_i/N	d_i (mrem)	w_i/w	
23.	"Examens systématiques"	452	30	2.21	30
				TOTAL DIAGNOSTIC:	57

APPENDIX VI

JAPAN

The data submitted by Japan[7] do not permit a presentation according to Equation (8). The following information is given:

Type of examination	*1000 N_j/N*	*d_j (mrem)*
(A) *Radiography:*		
Chest, large film	109	0.06–0.5
Chest, tomography	57	1–3
Abdomen	68	100
Mass surveys	260	0.05–0.4
Others	46	1
(B) *Fluoroscopy:*		
Chest	18	1.6–12.7
Abdomen	22	200–1000

From the above data, the *per capita* gonad dose from diagnostic X-ray exposure is estimated to be 10 - 30 mrem per year.

APPENDIX VII

NEW ZEALAND

1. No exposure data have been submitted from New Zealand, but it has been reported that an extensive survey of diagnostic exposure has been initiated. New Zealand has full records of all diagnostic X-ray plants in the country and a system of medical services that permits a quantitative assessment of virtually all diagnostic X-ray work done.

2. Data on the number of examinations have been reported[45] to the Committee and are presented in table I in the main text of annex C. A characteristic feature is the high annual number of dental examinations (0.24 *per capita*). 95 per cent of these are made on school children between the ages of 12 and 16.

3. The frequency of mass miniature chest examination (with an annual number of 0.09 *per capita*) is reported together with the information that 23 per cent of all notified cases of pulmonary tuberculosis are discovered by mass X-ray surveys, with a case yield of about 1.8 per 1,000 examinations.

APPENDIX VIII

NORWAY

The data submitted by Norway[8] do not permit any estimate of the genetically significant dose. Gonad doses have been measured by Koren and Maudal;[65] their annual consumption of X-ray films is 1.1 *per capita*, the values are included in the tables in appendix XI. As the contribution from diagnostic X-ray procedures to the genetically significant dose is likely to be high enough to warrant more detailed analysis, which is reported to be planned.

APPENDIX IX

SWEDEN

The primary material

1. The estimate of the genetically significant dose from diagnostic X-ray procedures in Sweden is based upon a report by Larsson.[9] The data are representative for 1955.

2. Dose measurements were performed on 1,957 patients in 17 X-ray departments. Of the patients, 394 were children. The age-distribution in the various types of examinations is based upon a material of 39,315 examinations.

3. The total number of examinations for 1955 was found to be 1,910,000. The annual increase during the period 1945-1954 was 15.5 per cent. The number of mass miniature radiographs during 1955 was estimated at 1,000,000.

4. In addition to the actually occurring doses, the author presents "possible" values found after simple measures to reduce the gonad exposure. If the indications for pelvimetry and obstetric examinations are made more restrictive, the achievable annual genetically significant dose that would result is estimated to be 15 mrem instead of the value of 38 mrem found for 1955.

Presentation of the material for this report

5. In the original paper the genetically significant dose was calculated for each sex as an average dose per productive gamete. The sum of these doses was taken to express the radiation burden to the zygote. The figures in the following table have been recalculated by the author to conform with the presentation in this report.

APPENDIX X

UNITED STATES OF AMERICA

The primary material

1. The estimate of the genetically significant dose for the United States of America is based upon a survey of literature up to about the middle of 1956, reported by Laughlin and Pullman[10]. In the report, which is only preliminary, the authors have computed the *probable* annual gonad dose per person up to age 30 years. They also give a *minimum* estimate.

2. The most characteristic feature of these data is that the surveyors have listed radiography and fluoroscopy separately and, in the case of fluoroscopy, also separated radiologists' examinations from those of non-radiologists.

3. The primary material of the Laughlin-Pullman report is shown in the tables I to VI, with regard to the estimate of the *probable* dose. The probable *per capita* gonad dose up to age 30 is found to be about 140 ± 100 mrem. The minimum estimate is 50 ± 30 mrem.

Presentation of the material for this report

4. As nothing is known about the actual child-expectancy of patients undergoing X-ray examinations, the first approximation has been to assume that it is not influenced by the nature of the condition for which the patient was examined. The value of w_j/w for each examination class would then depend only upon the age-distribution within the class. With this assumption, the annual gonad dose per person up to age 30 years may be taken as an approximate figure for the annual genetically significant dose. w_j/w has been calculated from the known values of N_j/N, d_j and this approximation of D_j. It has been necessary to assume that the dose per examination is the same for the two age-groups "12-29 years" and "over 12". Tables VII to XVI give the final presentation of the material.

DATA FOR EVALUATION OF THE GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC X-RAY EXPOSURE

APPENDIX IX. TABLE I. SWEDEN

No.	Type of examination	Female adults 1,000 N^*_j/N	Female adults w^*_j/w	Female adults d^*_j (mrem)	Female adults D^*_j (mrem)	Female children 1,000 N^*_j/N	Female children w^*_j/w	Female children d^*_j (mrem)	Female children D^*_j (mrem)	Male adults 1,000 N^*_j/N	Male adults w^*_j/w	Male adults d^*_j (mrem)	Male adults D^*_j (mrem)	Male children 1,000 N^*_j/N	Male children w^*_j/w	Male children d^*_j (mrem)	Male children D^*_j (mrem)	Foetus 1,000 N^*_j/N	Foetus w^*_j/w	Foetus d^*_j (mrem)	Foetus D^*_j (mrem)	Subtotal (mrem) $D_j^{(F)}$ (mrem)	Subtotal (mrem) $D_j^{(M)}$ (mrem)	Subtotal (mrem) $D_j^{(Fet)}$ (mrem)	Total D_j (mrem)	Total Per cent
1.	"Hip"	4.3	0.10	260	0.11	0.12	2.47	400	0.14	2.5	0.08	1000	1.85	0.091	2.35	1600	0.34	c	2.41	260	0.01	0.25	2.19	0.01	2.45	6.5
2.	"Femur"	0.84	0.71	35	0.021	0.040	"	6.1	0.0006	1.7	0.89	830	1.25	0.066	"	960	0.15	c	"	35	0.006	0.022	1.40	0.006	1.43	3.8
3.	Pelvic region	3.8	0.25	200	0.19	0.30	"	280	0.21	3.6	0.41	870	1.29	0.45	"	1330	1.41	c	"	200	0.03	0.40	2.70	0.03	3.13	8.3
4. 5.	"Lumbar and sacral spine"	6.8	0.31	490	1.05	0.22	"	580	0.31	8.7	0.49	940	4.00	0.43	"	2270	2.30	c	"	490	0.14	1.36	6.30	0.14	7.80	20.6
6.	"Thoracic spine"	2.6	0.28	0.2	0.0046	0.026	"			3.2	0.03	3.3	0.01	<0.0082	"			c	"	0.2	<0.001	0.0046	0.01	<0.001	0.015	<0.1
7. 8.	"Intravenous urography"	3.6	0.42	925	1.40	0.22	"	445 (910)[d]	0.37	5.2	0.45	1240	2.91	0.10	"	930 (3880)[d]	0.57	c	"	925	0.16	1.77	3.48	0.10	5.41	14.3
9.	Urethrocystography	0.20	0.28	1940	0.11	0.011	"	1240	0.034	0.93	0.30	3700	1.05	0.035	"	6370	0.52	c	"	1940	0.016	0.14	1.57	0.016	1.73	4.6
10.	Pelvimetry	0.59	0.44[a]	1080	0.28	<0.0006	"			—	—	—	—	—	—	—	—	0.59	"	4500	6.4	0.28	—	6.4	6.68	17.6
11.	Hysterosalpingography	1.2	0.36[b]	2600	1.12	0.0036	"			—	—	—	—	—	—	—	—	—	—	—	—	1.12	—	—	1.12	3.0
12.	Obstetrical abdomen	0.59	0.44[a]	265	0.064	<0.0006	"			—	—	—	—	—	—	—	—	0.59	2.41	910	1.2	0.064	—	1.2	1.26	3.3
13.	"Abdomen survey"	2.4	0.30	1150	0.84	0.030	"		0.085	2.5	0.49	1360	1.65	0.040	2.35		0.13	c	"	1150	0.11	0.93	1.78	0.11	2.82	7.4
14.	"Colon"	4.8	0.20	1520	1.43	0.16	"		0.60	3.9	0.27	310	0.32	0.17	"	600	0.24	c	"	1520	0.21	2.03	0.56	0.21	2.80	7.4
15.	"Stomach"	17.1	0.27	29	0.13	0.17	"	105	0.044	12.8	0.48	14	0.086	0.065	"	75	0.011	c	"	29	0.02	0.17	0.097	0.02	0.29	0.8
16.	Cholecystography	8.5	0.35	16.8	0.050	0.017	"		0.0007	3.5	0.50	6.3	0.011	<0.0035	"		<0.0001	c	"	16.8	0.007	0.051	0.011	0.007	0.07	0.2
17. 18.	"Chest"	41.6	0.37	4.1	0.063	2.2	"	2.4	0.013	33.8	0.61	1.8	0.037	1.8	"	1.0	0.0042	c	"	4.1	0.005	0.076	0.041	0.005	0.12	0.3
19. 20. 21.	"Lower leg, skull, fore and upper arm, hand, foot"	39.6	0.41	0.5	0.008	4.4	"	<0.5	<0.0054	52.8	0.53	1	0.028	5.9	"	<1	<0.014	c	"	0.5	0.0015	<0.013	<0.042	0.0015	0.06	0.2
22.	Dental	128	0.41	≪1	≪0.052	27	"	≪1	≪0.067	124	0.53	<1	<0.066	28	"	<1	<0.066	c	"	≪1	≪0.10	≪0.12	<0.13	≪0.10	0.35	0.9
23.	Mass miniature (photofluoroscopy)	58.2	0.44	1.8	0.046	12.1	"	3.6	0.11	56.1	0.59	0.76	0.025	12.6	"	1.6	0.046	c	"	1.8	0.093	0.16	0.071	0.093	0.32	0.8
	TOTALS				7.0				2.0				14.6				5.8				8.5	9.0	20.4	8.5	37.9	100

[a] A correction of the normal age-specific child-expectancy has been made here.

[b] Every three women are expected to have a child subsequently.

[c] In all cases of foetal exposure except pelvimetry and obstetrical abdomen, the foetal contribution has been derived from the assumption that 5.6 per cent of the women in fertile ages were pregnant.

[d] Including two radiographs over the trigone.

Number of female examinations under age 30 per 1000 of total population
($1000n_j^{(F)}/N$)

Appendix X. Table I. USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists 12–29	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists 12–29	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists 12–29
1.	"Skeleton—pelvic region"	2.54[a]	2.81[c]			0.35[h]	0.50[i]
2.							
3.							
4.							
5.		0.40[b]					
6.							
7.	"Pyelography"		1.11	0.043[f]	0.90[f]	0.30[f]	0.28[f]
8.							
9.	"Urinary tract"		0.71				
10.	Pelvimetry	—	2.26				
11.	Salpingography	—	0.08				
12.	Abdomen (obstetrical)	—	0.62				
13.	"Abdomen and colon"	(1.0)	3.26	0.86	1.80	0.38	0.48
14.							
15.	Stomach and upper G.I.	(1.0)	3.53	1.04	2.16	0.25	0.60
16.	"Gall bladder"		0.81				
17.	Chest (lungs, heart, oesophagus)	(3.6)	9.5	0.22[g]	0.45[g]	(0.60)	1.44
18.							
19.	"Skeleton—extremities and chest"	(2.8)	3.26			(0.20)	0.48
20.							
21.	Head	(2.0)	2.17			(0.13)	0.24
22.	Dental	35[d,e]	275[d]				
23.	Mass surveys	(all ages (0–29):	20.4				

[a] Pelvis and hips.
[b] Lumbar spine.
[c] Including 0.09 from chiropractors.
[d] Each film counted as one examination.
[e] Children under 10 years.
[f] Genito-urinary region.
[g] Heart.
[h] Including 1/3 of all examinations of age-group under 2 years.
[i] Including 0.10 from chiropractors.

(Figures in brackets have been derived by an arbitrary split of a figure for a larger group of examination-classes.)

Female gonad dose per examination
($d_j^{(F)}$ in mrem)

Appendix X. Table II. USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists 12–29	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists 12–29	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists 12–29
1.	"Skeleton—pelvic region"	500[a]	1,000[b]			1,000[a]	3,000[b]
2.							
3.							
4.							
5.		1,300[a]					
6.							
7.	"Pyelography"		1,200	1,000[a]	3,000[a]	1,000[a]	3,000[a]
8.							
9.	"Urinary tract"		1,000				
10.	Pelvimetry	—	2,500				
11.	Salpingography	—	10,000				
12.	Abdomen (obstetrical)	—	260				
13.	"Abdomen and colon"	(550)	500	1,500	1,500	1,000	1,500
14.							
15.	Stomach and upper G.I.	(350)	300	750	750	500	350
16.	"Gall bladder"		200				
17.	Chest (lungs, heart, oesophagus)	(60)	0.3	15[a]	15[a]	(30)	10
18.							
19.	"Skeleton—extremities and chest"	(60)	0.5			(30)	5
20.							
21.	Head	(60)	0.2			(30)	5
22.	Dental	4[a]	2[a]				
23.	Mass surveys	(all ages 0–29):	3				

[a] See footnotes to table I.
[b] The dose from chiropractors has been assumed to be 1000 mrem/exam.

Annual female gonad dose per person under age 30

$$(1.98 \times \frac{n^{(F)}}{N} \times d_j^{(F)} \text{ in mrem})$$

Appendix X. Table III. USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists 12–29	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists 12–29	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists 12–29
1.							
2.		2.5[a]					
3.							
4.	"Skeleton—pelvic region"		5.6[b]			0.7[a]	2.6[b]
5.		1.0					
6.							
7.							
8.	"Pyelography"		2.6	0.1[a]	0.5[a]	0.6[a]	1.7[a]
9.	"Urinary tract"		1.4				
10.	Pelvimetry	—	11.2				
11.	Salpingography	—	1.6				
12.	Abdomen (obstetrical)	—	0.3				
13.							
14.	"Abdomen and colon"	(1.1)	3.2	2.6	5.3	0.8	1.4
15.	Stomach and upper G.I.	(0.7)	2.1	1.5	3.2	0.2	0.4
16.	"Gall bladder"		0.3				
17.	Chest (lungs, heart, oesophagus)	(0.4)	0.01	0.01[a]	0.01[a]	(0.04)	0.03
18.							
19.	"Skeleton—extremities and chest"	(0.03)	0.00			(0.01)	0.00
20.							
21.	Head	(0.02)	0.00			(0.01)	0.00
22.	Dental	0.3[a]	1.1[a]				
23.	Mass surveys	(all ages 0–29):	0.1				
	Total	6.5	29.5	4	9	2.5	6

[a] See footnotes to table I.

[b] Including 0.2 from chiropractors.

Number of male examinations under age 30, per 1,000 of total population

$$(1{,}000\ n_j^M/N)$$

Appendix X. Table IV USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists 12–29	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists 12–29	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists 12–29
1.							
2.		2.85[a]					
3.							
4.	"Skeleton—pelvic region"		3.11[c]			0.40[b]	0.55[i]
5.		0.45[b]					
6.							
7.							
8.	"Pyelography"		1.24	0.05[f]	0.10[f]	0.34[f]	0.31[f]
9.	"Urinary tract"		0.79				
10.	Pelvimetry	—	—				
11.	Salpingography	—	—				
12.	Abdomen (obstetrical)	—	—				
13.							
14.	"Abdomen and colon"	(1.1)	3.63	0.99	2.02	0.44	0.53
15.	Stomach and upper G.I.	(1.1)	3.93	1.19	2.43	0.29	0.67
16.	"Gall bladder"		0.91				
17.	Chest (lungs, heart, oesophagus)	(4.1)	10.6	0.25[g]	0.51[g]	(0.69)	1.60
18.							
19.	"Skeleton—extremities and chest"	(3.2)	3.63			(0.23)	0.53
20.							
21.	Head	(2.2)	2.42			(0.15)	0.36
22.	Dental	33[d,e]	172[d]				
23.	Mass surveys	(all ages 0–29):	16.7				

[a] Pelvis and hips.
[b] Lumbar spine.
[c] Including 0.09 from chiropractors.
[d] Each film counted as one exam.
[e] Children under 10 years.
[f] Genito-urinary region.
[g] Heart.
[h] Including 1/3 of all exams. of age-group under 2 years.
[i] Including 0.11 from chiropractors.

(Figures in brackets have been derived by an arbitrary split of a figure for a larger group of examination classes.)

MALE GONAD DOSE PER EXAMINATION
(d_j in mrem)

APPENDIX X. TABLE V — USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists 12–29	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists 12–29	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists 12–29
1.							
2.		1,100[a]					
3.	"Skeleton—pelvic region"		2,000[b]			2,000[a]	6,000[a]
4.							
5.		2,000[a]					
6.							
7.							
8.	"Pyelography"		2,000	2,000[a]	6,000[a]	2,000[a]	6,000[a]
9.	"Urinary tract"		300				
10.	Pelvimetry	—	—				
11.	Salpingography	—	—				
12.	Abdomen (obstetrical)	—	—				
13.							
14.	"Abdomen and colon"	(750)	200	750	750	2,000	750
15.	Stomach and upper G.I.	(750)	200	500	500	600	500
16.	"Gall bladder"		10				
17.	Chest (lungs, heart, oesophagus)	(120)	1.2	20[a]	20[a]	(40)	10
18.							
19.	"Skeleton—extremities and chest"	(120)	1.0			(40)	5
20.							
21.	Head	(120)	0.6			(40)	5
22.	Dental	12[a]	8[a]				
23.	Mass surveys	(all ages 0–29):	1				

[a] See footnotes to table I.

[b] The dose from chiropractors has been assumed to be 2,000 mrem/exam.

ANNUAL MALE GONAD DOSE PER PERSON UNDER AGE 30
$$(1.98 \times \frac{n_j^{(M)}}{N} \times d_j^M \text{ in mrem})$$

APPENDIX X. TABLE VI. — USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists 12–29	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists 12–29	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists 12–29
1.							
2.		6.2[a]					
3.	"Skeleton—pelvic region"		12[b]			1.6[a]	5.7[b]
4.							
5.		1.8					
6.							
7.							
8.	"Pyelography"		4.9	0.2[a]	1.2[a]	1.3[a]	3.7[b]
9.	"Urinary tract"		0.5				
10.	Pelvimetry	—	—				
11.	Salpingography	—	—				
12.	Abdomen (obstetrical)	—	—				
13.							
14.	"Abdomen and colon"	(1.6)	1.4	1.5	3.0	1.7	0.8
15.	Stomach and upper G.I.	(1.6)	1.6	1.2	2.4	0.3	0.7
16.	"Gall bladder"		0.02				
17.	Chest (lungs, heart, oesophagus)	(1.0)	0.03	0.01[a]	0.02[a]	(0.05)	0.03
18.							
19.	"Skeleton—extremities and chest"	(0.8)	0.01			(0.02)	0.00
20.							
21.	Head	(0.5)	0.003			(0.01)	0.00
22.	Dental	0.8[a]	2.7[a]				
23.	Mass surveys	(all ages 0–29):	0.03				
	TOTAL	14.5	23	3	6.5	5	11

[a] See footnotes to table I.

[b] Including 0.4 from chiropractors.

Number of female examinations per 1000 of total population
($1{,}000.N_j^{(F)}/N$)

Appendix X. Table VII. USA

Exam. No.		Radiography		Fluoroscopy			
		Radiologists and non-radiologists		Radiologists		Non-radiologists	
		0–11	Over 12	0–11	Over 12	0–11	Over 12
1. 2. 3. 4. 5. 6.	"Skeleton—pelvic region"	2.54 / 0.40	9.7			0.35	1.69
7. 8.	"Pyelography"		4.6	0.043	0.28	0.30	1.13
9.	"Urinary tract"		2.9				
10.	Pelvimetry	—	2.26				
11.	Salpingography	—	0.16				
12.	Abdomen (obstetrical)	—	0.75				
13. 14.	"Abdomen and colon"	(1.0)	12.4	0.86	6.1	0.38	2.47
15.	Stomach and upper G.I.	(1.0)	13.1	1.04	7.3	0.25	2.80
16.	"Gall bladder"		2.9				
17.	Chest (lungs, heart, oesophagus)	(3.6)	35.9	0.22	1.5	(0.60)	6.8
18. 19. 20.	"Skeleton—extremities and chest"	(2.8)	6.3			(0.20)	1.83
21.	Head	(2.0)	9.1			(0.13)	1.50
22.	Dental	35	515				
23.	Mass surveys	(All ages)	61				

Female gonad dose per examination
($d_j^{(F)}$ in mrem)

Appendix X. Table VIII. USA

Exam. No.		Radiography		Fluoroscopy			
		Radiologists and non-radiologists		Radiologists		Non-radiologists	
		0–11	Over 12[a]	0–11	Over 12[a]	0–11	Over 12[a]
1. 2. 3. 4. 5. 6.	"Skeleton—pelvic region"	500 / 1,300	1,000			1,000	2,600[b]
7. 8.	"Pyelography"	—	1,200	1,000	3,000	1,000	3,000
9.	"Urinary tract"	—	1,000				
10.	Pelvimetry	—	2,500				
11.	Salpingography	—	10,000				
12.	Abdomen (obstetrical)	—	260				
13. 14.	"Abdomen and colon"	(550)	500	1,500	1,500	1,000	1,500
15.	Stomach and upper G. I.	(350)	300	750	750	500	350
16.	"Gall bladder"		200				
17.	Chest (lungs, heart, oesophagus)	(60)	0.3	15	15	(30)	10
18. 19. 20.	"Skeleton—extremities and chest"	(60)	0.5			(30)	5
21.	Head	(60)	0.2			(30)	5
22.	Dental	4	2				
23.	Mass surveys	(All ages)	3				

[a] It has been assumed that the dose in the age-group over 12 years is the same as in the age-group 12–29.

[b] Weighted average including chiropractors' contribution.

Relative female child expectancy
$(w_j^{(F)}/w)$[a]

Appendix X. Table IX. USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists Over 12	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists Over 12	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists Over 12
1.							
2.		1.98					
3.							
4.	"Skeleton—pelvic region"		0.58			1.98	0.59
5.		1.98					
6.							
7.							
8.	"Pyelography"		0.48	1.98	0.64	1.98	0.49
9.	"Urinary tract"		0.48				
10.	Pelvimetry	—	2.0				
11.	Salpingography	—	1.0				
12.	Abdomen (obstetrical)	—	1.69				
13.							
14.	"Abdomen and colon"	1.98	0.52	1.98	0.58	1.98	0.38
15.	Stomach and upper G. I.	1.98	0.53	1.98	0.59	1.98	0.43
16.	"Gall bladder"		0.55				
17.	Chest (lungs, heart, oesophagus)	1.98	0.6	1.98	0.6	1.98	0.5
18.							
19.	"Skeleton—extremities and chest"	1.98	0.6			1.98	0.5
20.							
21.	Head	1.98	0.6			1.98	0.5
22.	Dental	1.98	1.1				
23.	Mass surveys	(All ages):	0.7				

[a] Figures back-calculated from tables II, III and VII.

Female contribution to the annual genetically significant dose
$(D_j^{(F)}$ in mrem)[a]

Appendix X. Table X. USA

Exam. No.		Radiography: Radiologists and non-radiologists 0–11	Radiography: Radiologists and non-radiologists Over 12	Fluoroscopy: Radiologists 0–11	Fluoroscopy: Radiologists Over 12	Fluoroscopy: Non-radiologists 0–11	Fluoroscopy: Non-radiologists Over 12
1.							
2.		2.5					
3.							
4.	"Skeleton—pelvic region"		5.6			0.7	2.6
5.		1.0					
6.							
7.							
8.	"Pyelography"		2.6	0.1	0.5	0.6	1.7
9.	"Urinary tract"		1.4				
10.	Pelvimetry	—	11.2				
11.	Salpingography	—	1.6				
12.	Abdomen (obstetrical)	—	0.3				
13.							
14.	"Abdomen and colon"	(1.1)	3.2	2.6	5.3	0.8	1.4
15.	Stomach and upper G. I.	(0.7)	2.1	1.5	3.2	0.2	0.4
16.	"Gall bladder"		0.3				
17.	Chest (lungs, heart, oesophagus)	(0.4)	0.01	0.01	0.01	(0.04)	0.03
18.							
19.	"Skeleton—extremities and chest"	(0.3)	0.00			(0.01)	0.00
20.							
21.	Head	(0.2)	0.00			(0.01)	0.00
22.	Dental	0.3	1.1				
23.	Mass surveys	(All ages):	0.1				
	Total	6.5	29.5	4	9	2.5	6

[a] Figures identical with those in table III.

NUMBER OF MALE EXAMINATIONS PER 1000 OF TOTAL POPULATION
$(1{,}000.N_j^{(M)}/N)$

APPENDIX X. TABLE XI. USA

Exam. No.		Radiography		Fluoroscopy			
		Radiologists and non-radiologists		Radiologists		Non-radiologists	
		0–11	Over 12	0–11	Over 12	0–11	Over 12
1.							
2.							
3.	"Skeleton—pelvic region"	2.85					
4.			11.0			0.40	1.91
5.							
6.		0.45					
7.							
8.	"Pyelography"		5.2	0.05	0.32	0.34	1.27
9.	"Urinary tract"		3.2				
10.	Pelvimetry	—	—				
11.	Salpingography	—	—				
12.	Abdomen (obstetrical)	—	—				
13.							
14.	"Abdomen and colon"	(1.1)	13.9	0.99	6.9	0.44	2.79
15.	Stomach and upper G. I.	(1.1)	14.7	1.19	8.2	0.29	3.17
16.	"Gall bladder"		3.2				
17.	Chest (lungs, heart, oesophagus)	(4.1)	40.5	0.25	1.7	(0.69)	7.6
18.							
19.	"Skeleton—extremities and chest"	(3.2)	7.0			(0.23)	2.1
20.							
21.	Head	(2.2)	10.3			(0.15)	1.7
22.	Dental	33	580				
23.	Mass surveys	(All ages):	69				

MALE GONAD DOSE PER EXAMINATION
$(d_j^{(M)}$ in mrem)

APPENDIX X. TABLE XII. USA

Exam. No.		Radiography		Fluoroscopy			
		Radiologists and non-radiologists		Radiologists		Non-radiologists	
		0–11	Over 12[a]	0–11	Over 12[a]	0–11	Over 12[a]
1.							
2.							
3.	"Skeleton—pelvic region"	1,100					
4.			2,000			2,000	5,200[b]
5.							
6.		2,000					
7.							
8.	"Pyelography"		2,000	2,000	6,000	2,000	6,000
9.	"Urinary tract"		300				
10.	Pelvimetry	—	—				
11.	Salpingography	—	—				
12.	Abdomen (obstetrical)	—	—				
13.							
14.	"Abdomen and colon"	(750)	200	750	750	2,000	750
15.	Stomach and upper G. I.	(750)	200	500	500	600	500
16.	"Gall bladder"		10				
17.	Chest (lungs, heart, oesophagus)	(120)	1.2	20	20	(40)	10
18.							
19.	"Skeleton—extremities and chest"	(120)	1.0			(40)	5
20.							
21.	Head	(120)	0.6			(40)	5
22.	Dental	12	8				
23.	Mass surveys	(All ages):	1				

[a] It has been assumed that the dose in the age-group over 12 years is the same as in the age-group 12–29.

[b] Weighted average including chiropractors' contributions.

Relative male child expectancy
$(w_1^{(M)}/w)$[a]

Appendix X. Table XIII. USA

Exam. No.		Radiography		Fluoroscopy			
		Radiologists and non-radiologists		Radiologists		Non-radiologists	
		0–11	Over 12	0–11	Over 12	0–11	Over 12
1. 2. 3. 4. 5. 6.	"Skeleton—pelvic region"	1.98 1.98	0.55			1.98	0.57
7. 8.	"Pyelography"		0.47	1.98	0.62	1.98	0.48
9.	"Urinary tract"		0.5				
10.	Pelvimetry	—	—				
11.	Salpingography	—	—				
12.	Abdomen (obstetrical)	—	—				
13. 14.	"Abdomen and colon"	1.98	0.50	1.98	0.58	1.98	0.4
15.	Stomach and upper G. I.	1.98	0.54	1.98	0.59	1.98	0.4
16.	"Gall bladder"		0.6				
17.	Chest (lungs, heart, oesophagus)	1.98	0.6	1.98	0.6	1.98	0.4
18. 19. 20.	"Skeleton—extremities and chest"	1.98	1			1.98	0.4
21.	Head	1.98	0.6			1.98	0.4
22.	Dental	1.98	0.6				
23.	Mass surveys	(All ages)	0.7				

[a] Figures back-calculated from tables V, VI and XI.

Male contribution to the annual genetically significant dose
$(D_1^{(M)}$ in mrem)[a]

Appendix X. Table XIV. USA

Exam. No.		Radiography		Fluoroscopy			
		Radiologists and non-radiologists		Radiologists		Non-radiologists	
		0–11	Over 12	0–11	Over 12	0–11	Over 12
1. 2. 3. 4. 5. 6.	"Skeleton—pelvic region"	6.2 1.8	12			1.6	5.7
7. 8.	"Pyelography"		4.9	0.2	1.2	1.3	3.7
9.	"Urinary tract"		0.5				
10.	Pelvimetry	—	—				
11.	Salpingography	—	—				
12.	Abdomen (obstetrical)	—	—				
13. 14.	"Abdomen and colon"	(1.6)	1.4	1.5	3.0	1.7	0.8
15.	Stomach and upper G. I.	(1.6)	1.6	1.2	2.4	0.3	0.7
16.	"Gall bladder"		0.02				
17.	Chest (lungs, heart, oesophagus)	(1.0)	0.03	0.01	0.02	(0.05)	0.03
18. 19. 20.	"Skeleton—extremities and chest"	(0.8)	0.01			(0.02)	0.01
21.	Head	(0.5)	0.00			(0.01)	0.00
22.	Dental	0.8	2.7				
23.	Mass surveys	(All ages)	0.03				
	Total	14.5	23	3	6.5	5	11

[a] Figures identical with those in table VI.

APPENDIX X. TABLE XV. USA

Exam. No.		d_j mrem	$n_j/N = N_j/N$ x1,000	w_j/w (back-calculated)	D_j mrem[a]
1.	"Skeleton—pelvic region"				
2.					
3.					
4.					
5.					
6.					
7.	"Pyelography"				
8.					
9.	"Urinary tract"				
10.	Pelvimetry	4,000	2.53	1.98	20.0
11.	Salpingography				
12.	Abdomen (obstetrical)	400	0.88	1.98	0.7
13.	"Abdomen and colon"				
14.					
15.	Stomach and upper G.I.				
16.	"Gall bladder"				
17.	Chest (lungs, heart, oesophagus)	0.3	10.5	1.98	0.01
18.					
19.	"Skeleton—extremities and chest"				
20.					
21.	Head				
22.	Dental				
23.	Mass surveys				
24.	Others				
	TOTAL				20.7

[a] 1/0.67 of the figures given by Laughlin and Pullman.

GENETICALLY SIGNIFICANT DOSE (D_j IN MREM); SUMMARY TABLE

APPENDIX X. TABLE XVI. USA

Exam. No.		*Children*	*Female adults*	*Male adults*	*Foetal*	*Total*	*Per cent*
1.	"Skeleton—pelvic region"	13.8	8.2	17.7		39.7	28
2.							
3.							
4.							
5.							
6.							
7.	"Pyelography"	2.2	4.8	9.8		16.8	12
8.							
9.	"Urinary tract"		1.4	0.5		1.9	1.3
10.	Pelvimetry	—	11.2	—	20.0	31.2	22
11.	Salpingography	—	1.6	—		1.6	1.1
12.	Abdomen (obstetrical)	—	0.3	—		0.3	0.2
13.	"Abdomen and colon"	9.3	9.9	5.2	0.7	25.1	18
14.							
15.	Stomach and upper G.I.	5.5	5.7	4.7		15.9	11
16.	"Gall bladder"		0.3	0.0		0.3	0.2
17.	Chest (lungs, heart, oesophagus)	1.5	0.1	0.1	0.0	1.7	1.2
18.							
19.	"Skeleton—extremities and chest"	1.1	0.0	0.0		1.1	0.8
20.							
21.	Head	0.7	0.0	0.0		0.7	0.5
22.	Dental	1.1	1.1	2.7		4.9	3.5
23.	Mass surveys	[a]	0.1	0.0		0.1	0.1
	TOTAL	35.2	44.7	40.7	20.7	141	100

[a] Included in adult figures.

DATA ON DIAGNOSTIC X-RAY EXPOSURE: GONAD DOSE PER EXAMINATION FOR THE MOST IMPORTANT EXPOSURE CLASSES

APPENDIX XI

The tables I to XIV have been taken from the report of the ICRP/ICRU Joint Study Group. They show estimates of various authors of the gonad doses due to given types of examinations. The wide variations probably result from different techniques rather than from uncertainty in measurements. Hence the lower values indicate what levels may be achieved with good practice. Further details and references are given in the ICRP/ICRU Study Group report.

TABLE I. HIPS

Reference	*Technical data*	*Measurements made on*	*Remarks*	*Gonad dose per examination (mrad)*	
				Male	*Female*
Hammer-Jacobsen (1957) Denmark[4]	62–64 kv, 400–450 mAs FFD = 100 cm 2 films per examination	Patients: 12 male 9 female		567 (20–3600)	53 (30–100)
Larsson Sweden[9]	60–70 kv, 200–500 mAs 3 films per examination	Patients: 19 male 18 female		1150 (100–2600)	205 (75–450)
Laughlin and Pullman (1957) U.S.A.[10]			Years: 0– 2 2– 7 7–12 12–30	480 840 2100 650–2000	270 420 900 600–1000
Stanford and Vance (1955) U.S.A.[58]	68 kv, 200 mAs FFD = 90 cm	Patients		710	210

TABLE II. FEMUR

Reference	*Technical data*	*Measurements made on*	*Remarks*	*Gonad dose per examination (mrad)*	
				Male	*Female*
Hammer-Jacobsen (1957) Denmark[4]	58–60 kv, 250 mAs FFD = 100 cm 2 films per examination	Patients: 7 male 4 female		1393 (50–3500)	63 (20–100)
Koren and Maudal Norway[65]	62 kv, 250 mAs FFD = 100 cm 2 films per examination	Phantom		73	9·6
Larsson Sweden[9]	50–78 kv, 80 mAs	Patients: 6 male 2 female		65–650	50
Laughlin and Pullman (1957) U.S.A.[10]			Years: 12–30	1650	300

TABLE III. PELVIS

Reference	Technical data	Measurements made on	Remarks	Gonad dose per film (mrad)		Gonad dose per examination (mrad)	
				Male	Female	Male	Female
Hammer-Jacobsen (1957) Denmark[4]	60–63 kv, 200–360 mAs FFD = 100 cm 1–2 films per examination	Patients: 7 male 1 female				567 (50–2500)	70
Koren and Maudal Norway[65]	70 kv. 250 mAs FFD = 100 cm	Phantom		3580	96	3580	96
Larsson Sweden[9]	59–64 kv, 500 mAs FFD = 100 cm 1 film per examination	Patients: 16 male 20 female				1010 (50–2800)	190 (100–300)
Laughlin and Pullman (1957) U.S.A.[10]			Years: 0– 2 2– 7 7–12 12–30			480 840 2100 1650–2000	270 420 900 600–1000
Stanford and Vance (1955) U.K.[58]	65 kv, 100 mAs FFD = 90 cm	Patients	AP	1100	210	1100	210
Ardran and Crooks (1957) U.K.[25]	65 kv, 100 mAs FFD = 90 cm, no extra filter		Normal technique	2000			
	65 kv, 100 mAs FFD = 90 cm, 3mm Al-filter			670			
	75 kv, 80 mAs FFD = 110 cm, 3 mm Al-filter.		'AERE'† technique	480	80*		
	The same, but testes covered with lead			20			

* Measurement made on phantom.
† Atomic Energy Research Establishment.

TABLE IV. LUMBAR SPINE

Reference	*Technical data*	*Measurements made on*	*Remarks*	*Gonad dose per film (mrad)*		*Gonad dose per examination (mrad)*	
				Male	*Female*	*Male*	*Female*
Hammer-Jacobsen (1957) Denmark[4]	65–84 kv, 1250 mAs FFD = 100 cm 3 films per examination	Patients: 22 male 22 female				104 (10-400)	222 (20–600)
Koren and Maudal Norway[65]	68kv, 310 mAs FFD = 100 cm	Phantom	AP	4.5	60	4.5	60
	75 kv, 500 mAs FFD = 90 cm		Lat.	6	91	6	91
Larsson Sweden[9]	65–70 kv, 500 mAs FFD = 90–100 cm 4 films per examination	Patients: 12 male 7 female	Lumbar spine and lumbo-sacral region			375 (68–1180)	680 (490–860)
Laughlin and Pullman (1957) U.S.A.[10]			Years: 0– 2 2– 7 7–12			2700 2400 900	900 1050 2190
Stanford and Vance (1955) U.K.[58]	68 kv, 200 mAs FFD = 90 cm	Patients	AP	24	227	24	227
	72 kv, 500 mAs FFD = 90 cm		Lat.	26·6	86	26·6	86
	120 kv, 20 mAs FFD = 90 cm		AP	6	40	6	40
	120 kv, 60 mAs FFD = 90 cm		Lat.	7	16	7	16
Ardran and Crooks (1957) UK[25]	68 kv, 200 mAs FFD = 90 cm, no extra filter		Normal technique	24			
	68 kv, 200 mAs FFD = 90 cm, 3 mm Al-filter			6·0			
	75 kv, 80 mAs FFD = 110 cm 3 mm Al-filter		'AERE'† technique	1·0	95*		
	The same, but testes covered with lead			0·5			

* Measurement made on phantom.
† Atomic Energy Research Establishment.

TABLE V. INTRAVENOUS PYELOGRAPHY

Reference	Technical data	Measurements made on	Remarks	Gonad dose per film (mrad)		Gonad dose per examination (mrad)	
				Male	Female	Male	Female
Hammer-Jacobsen (1957) Denmark[4]	61–65 kv, 3300–4300 mAs FFD = 130–143 cm 6 films per examination	Patients: 50 male 50 female	Adults Adults			1383 (100–4000) †	424 (50–4000)
	65–73 kv, 650–1700 mAs FFD = 130–143 cm 6 films per examination	Patients: 14 male 8 female	Childen under 15 years			654 (100–1600)	706 (100–3800)
LeFebvre and Serra (1957) France	10 films 12 films 16 films	Patients	Children: 3 months 3 years 6 years	50 84 95	30 56 87	500 1008 1520	300 678 1384
Larsson Sweden[9]	66–120 kv, 95 mAs 12–26 films per examination	Patients: 25 male 17 female	Hospital 1			790 (141–2160)	1820 (935–2680)
	55 kv, 250–270 mAs 5–11 films per examination	Patients: 10 male	Hospital 2			1300 (22*–2500)	
Laughlin and Pullman (1957) U.S.A.[10]			12–30 years Pyelography			100–2000	200–1200
Stanford and Vance (1955) U.K.[58]	72 kv, 100 mAs FFD = 90 cm 6 films per examination	Patients				486	1290
Ardran and Crooks (1957) U.K.[25]	75 kv, 80 mAs FFD = 110 cm 3 mm Al added	Male: patients Female: phantom		0·5*	95		

* With lead rubber over the scrotum.
† Doses reduced to 1–3% by shielding of scrotum.

TABLE VI. RETROGRADE PYELOGRAPHY

Reference	Technical data	Measurements made on	Remarks	Gonad dose per examination (mrad)	
				Male	Female
Hammer-Jacobsen (1957) Denmark[4]	63–67 kv, 4000 mAs FFD = 130—143 cm 7 films per examination	Patients: 8 male 9 female		2580 (700–3800)	1136 (200–4000)
Laughlin and Pullman (1957) U.S.A.[10]			12–30 years Pyelography	100–2000	200–1200

TABLE VII. URETHROCYSTOGRAPHY

Reference	Technical data	Measurements made on	Remarks	Gonad dose per examination (mrad)	
				Male	Female
Hammer-Jacobsen (1957) Denmark[4]	71 kv, 3285 mAs FFD = 137 cm 6 films per examination	Patients: 7 male	Urethrography	4209 (2700–8400)	
	63–87 kv, 2000–2850 mAs FFD = 100–130 cm 5 films per examination	Patients: 2 male 2 female	Cystography	5261 (3500–7000)	460 (350–560)
	102–109 kv, 357–476 mAs FFD = 90 cm 9 films per examination	Patients: 9 male 9 female	Urethrocystography during micturition Adults	7841 (2400–17200)	669 (200–1500)
	79–86 kv, 256–341 mAs FFD = 90 cm 8 films per examination	Patients: 6 male 5 female	Under 15	2314 (200–4700)	205 (120–330)
Koren and Maudal Norway[65]	75 kv, 200 mAs 100 kv, 500 mAs FFD = 60 cm 1+4 films per examination	Phantom	AP Lat.		210 104 314
Larsson Sweden[9]	80–100 kv	Patients: 26 male 16 female	Hospital 1	4100 (1000–11000)	1000 (550–1650)
	100–200 mAs 5–15 films per examination	Patients: 5 male	Hospital 2	760 (320–1240)	
Laughlin and Pullman (1957) U.S.A.[10]	Radiography		Years: 12–30	100–300	200–1000
	Fluoroscopy		Years: 0–12 12–30	500–2000 500–6000	500–1000 500–3000

TABLE VIII. PELVIMETRY

Reference	*Technical data*	*Measurements made on*	*Remarks*	*Gonad dose per film (mrad)*	*Gonad dose per examination (mrad)*
				female	*female*
Hammer-Jacobsen (1957) Denmark[4]	81–85 kv, 1354 mAs FFD = 100 cm 2–3 films per examination	15 patients	AP+Lat.		738 (400–1400)
	84–92 kv, 1250 mAs FFD = 97 cm 3–4 films per examination	4 patients	Stereoscopic AP+Lat.		906 (650–1300)
Koren and Maudal Norway[65]	78 kv, 310 mAs FFD = 100 cm	Phantom	AP	86	86
	85 kv, 500 mAs FFD = 90 cm		Lat.	76	76
Larsson Sweden[9]	2 films: 90 kv 640 mAs 1 film: 90 kv 95 mAs FFD = 90–100 cm	12 patients	3 different projections		1500 (760–2500)
Laughlin and Pullman (1957) U.S.A.[10]					700–2500
Stanford and Vance (1955) U.K.[58]	120 kv, 100 mAs 120 kv, 50 mAs FFD = 90 cm	Patients	AP Lat.	240 840	

TABLE IX. SALPINGOGRAPHY

Reference	*Technical data*	*Measurements made on*	*Remarks*	*Gonad dose per examination (mrad)*
				Female
Hammer-Jacobsen (1957) Denmark[4]	69 kv, 1259 mAs FFD = 100 cm 2–7 films per examination	7 patients		197 (140–270)
Larsson Sweden[9]	65–90 kv, 120–150 mAs 6–11 films per examination	32 patients		2650 (1100–6700)
Laughlin and Pullman (1957) U.S.A.[10]				600–1000

TABLE X. ABDOMEN

Reference	Technical data	Measurements made on	Remarks	Gonad dose per examination (mrad)	
				Male	Female
Hammer-Jacobsen (1957) Denmark[4]	63–70 kv, 600 mAs FFD = 100–143 cm 1 film per examination	Patients: 5 male 4 female	AP	610 (40–1800)	85 (40–100)
	71 kv, 750 mAs FFD = 100 cm 1–2 films per examination	Patients: 21 female	Obstetric		90 (60–600)
Koren and Maudal Norway[65]	80 kv, 180 mAs FFD = 100 cm 3 films per examination	Phantom		7·8	120
Larsson Sweden[9]	Female 4–13 films per examination. Male 3–7 films per examination. Sometimes fluoroscopy, 1·5–2 min.	Patients: 7 male 7 female		450–2725	18–1280
Laughlin and Pullman 1957) U.S.A.[10]	Abdomen and colon radiography		Years: 0– 2 2– 7 7–12 12–30	450 930 750 10–200	240 390 720 460–500
Stanford and Vance (1955) U.K.[58]	72 kv, 100 mAs FFD = 90 cm	Patients	AP	69	200
	80 kv, 150 mAs FFD = 90 cm		Obstetric		200
Ardran and Crooks (1957) U.K.[25]	75 kv, 60 mAs FFD = 110 cm 3 mm Al-filter added	Male: patients Female: phantom	AP	0·5*	75

* With lead rubber protection.

TABLE XI. BARIUM ENEMA

Reference	Technical data	Measurements made on	Remarks	Gonad dose per examination (mrad)	
				Male	Female
LeFebvre and Serra (1957) France	15 films 7 films 9 films	Patients	Children: 3 months 3 years 6 years	450 700 900	400 455 800
Larsson Sweden[9]	About 10 films: mean fluoroscopy time 7 min.	Patients: 31 male 15 female		255 (52–485)	2065 (1075–2920)
Laughlin and Pullman (1957) U.S.A.[10]	Radiography		Abdomen & colon 12–30 years	140–200	420–500
	Fluoroscopy		Lower G.I.T. 12–30 years	0–750	420–1500
	Fluoroscopy		Lower G.I.T. Children	420–750	420–1500
Stanford and Vance (1955) U.K.[58]	Fluoroscopy: 70 kv, 2 mA 3 min.	Patients		40	20

TABLE XII. BARIUM SWALLOW AND MEAL

Reference	Technical data	Measurements made on	Remarks	Gonad dose per examination (mrad)	
				Male	Female
			Children:		
LeFebvre and Serra (1957) France	20 films		3 months	220	
	16 films	Patients	3 years	496	
	20 films		6 years	220	
Koren and Maudal Norway[65]	75 kv, 60mAs FFD = 60 cm 12 films per examination	Phantom		2·9	144
	Fluoroscopy: 70 kv, 3 mA, 3 min. FSD = 40 cm	Phantom		1·2	45
Larsson Sweden[9]	80–110 kv 40–80 mAs 10–15 films	Patients: 25 male 25 female	Hospital 1	12·5 (2·7–29)	33 (8·5–55)
	Mean fluoroscopy time 7 min.	Patients: 25 male 25 female	Hospital 2	4·3 (2·1–13·6)	31 (7·8–78)
Laughlin and Pullman (1957) U.S.A.[10]	Radiography		Stomach & upper G.I.T. 12–30 years	60–200	200–300
			Upper G.I.T. 12–30 years	0–500	200–750
	Fluoroscopy		Upper G.I.T. Children	200–500	200–750
Stanford and Vance (1955) U.K.[58]	Fluoroscopy 70 kv, 2 mA 3 min.	Patients		20	9
Ardran and Crooks (1957) U.K.[25]	Fluoroscopy with image intensifier 75 kv, 0·5 mA 5 min. 5 mm Al-filter added	Male: patients Female: phantom		5	5

TABLE XIII. CHOLECYSTOGRAPHY

Reference	Technical data	Measurements made on	Remarks	Gonad dose per examination (mrad)	
				Male	Female
Koren and Maudal Norway[65]	80 kv, 125 mAs FFD = 100 cm 5 films per examination	Phantom		6·7	260
Larsson Sweden[9]	60–80 kv 35–200 mAs 4–6 films per examination.	Patients: 26 male 25 female	Hospital 1	3·1 (1·3–6·5)	19 (10–41)
	Fluoroscopy 80 kv, 3 mA, 1·2–2·5 min.	Patients: 16 male	Hospital 2	7·1 (4·3–11)	
Laughlin and Pullman (1957) U.S.A.[10]	Radiography		12–30 years	0–10	75–200
Stanford and Vance (1955) U.K.[58]	70 kv, 150 mAs FFD = 90 cm 3 films per examination	Patients		1·8	15·6

TABLE XIV. CHEST

Reference	Technical data	Measurements made on	Remarks	Gonad dose per film (mrad)		Gonad dose per examination (mrad)	
				Male	Female	Male	Female
LeFebvre and Serra (1957) France		Patients	Children: 3 months	5			
Koren and Maudal Norway[65]	80 kv, 27 mAs FFD = 150 cm	Phantom	PA	<1	1·0	<1	1·0
	95 kv, 60 mAs FFD = 150 cm		Lat.	<1	1·5	<1	1·5
Larsson Sweden[9]	3–5 films per examination & fluoroscopy 70–80 kv, 2–2·5 mA 1–3 min	Patients: 78 male 22 female				1·6 (0·9–2·7)	4·6 (2·6–10·8)
Laughlin and Pullman (1957) U.S.A.[10]	Radiography		Years: 0– 2			0–450	0–240
			2–12			0–5	0–5
			12–30			0–1·2	0–0·3
	Fluoroscopy					0–40	0–30
Sanford and Vance (1955) U.K.[58]	68 kv	Patients	PA	0·36	0·07	0·36	0·07
Ardran and Crooks (1957) U.K.[25]	Radiography FFD = 180 cm 3 mm Al-filter added.	Male: patients Female: phantom	PA	0·01	0·02	0·01	0·02
	Fluoroscopy with image intensifier 75 kv, 0·5 mA 3 min., 5 mm Al-filter added	Male: patients Female: phantom				3·0	3·0

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Appendix

LIST OF SCIENTIFIC EXPERTS

The scientific experts who have taken part in the preparation of the report while attending Committee sessions as members of national delegations are listed below. The Committee must also express its appreciation to the many individual scientists not directly connected with national delegations whose voluntary co-operation and good will contributed in no small measure to the preparation of the report.

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