MINISTRY OF HEALTH
DEPARTMENT OF HEALTH FOR SCOTLAND

RADIOLOGICAL HAZARDS TO PATIENTS

Second Report of the Committee

LONDON
HER MAJESTY'S STATIONERY OFFICE
1960
SIX SHILLINGS NET

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A

TABLE OF CONTENTS

COMMITTEE ON RADIOLOGICAL HAZARDS TO PATIENTS

SECOND REPORT

PART I. INTRODUCTION

Constitution and Terms of Reference

1. The Committee was appointed by the Secretary of State for Scotland and the Minister of Health at the end of 1956, with terms of reference " To review the present practice in diagnostic radiology and the use of radiotherapy in non-malignant conditions, having regard to the report of the Committee on the Hazards to Man of Nuclear and Allied Radiations,* and to make recommendations ". A list of members is given on page 49. The Committee first met on 10th January, 1957, and has held twenty-two meetings.

Present State of Knowledge

2. In our interim report† we outlined in brief the state of knowledge concerning the effect of ionizing radiation on human beings and, for the convenience of the reader, the substance of this outline is repeated here.

3. It has long been known that living cells may be damaged by ionizing radiations and that excessive exposure may cause serious injury to man. In recent years attention has been drawn to two less obvious hazards which may perhaps be produced by relatively low levels of radiation dosage. Firstly, there is the possibility of a genetic risk to future generations. Experimental work has shown that ionizing radiations can induce mutations in reproductive cells, and so cause genetic damage to future generations in the species studied. In mankind such damage could lead to a variety of inherited defects, although most of these would not manifest themselves for several generations. Secondly, there is the somatic hazard to the individual. It has been shown that there may be a risk of delayed effects, the one about which most is known being leukaemia arising from heavy exposure to ionizing radiations. It is not, however, known whether these delayed effects are ever caused by slight exposure.

4. The Report of the Medical Research Council on the Hazards to Man of Nuclear and Allied Radiations, and the Report of the United Nations Scientific Committee on the Effects of Atomic Radiation** discuss the present evidence on the genetic and somatic effects. This evidence suggests that any genetic effects which are produced by ionizing radiations will be on the whole harmful and

* Medical Research Council, 1956. *The Hazards to Man of Nuclear and Allied Radiations.* H.M.S.O.

† Published in May, 1959.

** Report: *General Assembly Official Records: Thirteenth Session Supplement No.* 17 (*A*/3838). 1958.

that perceptible damage would certainly arise if the radiation dose to the whole population was high enough to increase the mutation rate (which occurs " naturally " in any population) to twice the present level. This so-called doubling dose has been estimated to be probably greater than 10 rad and less than 100 rad per generation†† and 30 rad has been regarded as a reasonable figure for practical purposes.** All people receive a small radiation dose which arises naturally from the environment. This background dose is due to external radiation from cosmic rays and from radioactive materials in the earth's crust and to internal radiation from the traces of radioactive potassium and carbon in the body tissues. The background dose varies considerably from locality to locality and from country to country. Its average magnitude in Great Britain has been estimated at about 3 rad per generation of 30 years. On the evidence available the Medical Research Council report for 1956 suggested that the maximum amount of additional radiation which may be received by a population as a whole, without giving rise to concern, is unlikely to be more than twice the natural background dose, or approximately 6 rad per generation. A similar conclusion was reached by the International Commission on Radiological Protection.‡ It should be emphasised that this maximum permissible dose level is the dose per person averaged over the whole population and that the genetic effects of the dose can only manifest themselves fully after many generations. Any possible effects of a dose of 6 r received by the gonads of a single individual could only be extremely small and the chance of any abnormality appearing in the next generation additional to that arising from " natural " heredity must be insignificant. The Medical Research Council, in their 1956 report, concluded that " doses up to, and somewhat beyond, the ' doubling dose ' need cause no undue concern to the individual as regards his own offspring " and that " an individual could reasonably accept a total dose to the gonads of not more than 50 r from conception to the age of 30 years, in addition to that received from the natural background ". The considerations that have given rise to this enquiry are, therefore, those concerning the long-term genetic hazard to the population as a whole, arising from the average radiation dose received by the population in excess of that from natural sources.

5. The reports mentioned above described the sources of ionizing radiations to which the human race is subjected and assessed the contribution made by each source to the total radiation received by the population. In countries with extensive medical facilities where its magnitude has been estimated it was concluded that medical radiology makes the largest man-made contribution to the irradiation of the population.

Work of the Committee

6. The great benefits of medical radiology are recognised, but the above short review of the possible hazards of radiations shows that it is essential to ensure

†† The *roentgen* (r) is a commonly used unit of dose which is defined in terms of the electrical charge set free by radiation in a prescribed mass of air; it is equivalent to an absorption of radiation energy by soft tissues of between 88 and 97 ergs per gram, depending on the quality of the radiation. The *rad* is defined simply as a unit of absorbed dose equal to 100 ergs per gram.

** Report: *General Assembly Official Records: Thirteenth Session Supplement No.* 17 (*A*/3838). 1958.

‡ *Recommendations of the International Commission for Radiological Protection*, 1959. London, Pergamon Press.

that any unnecessary exposure from this source is prevented. The Committee therefore set itself the task of measuring in detail the present extent of medical and dental radiology over the whole of Great Britain, of assessing the level of radiation dosage thus produced, and finally of recommending ways and means of reducing this dosage without detriment to the needs of the patient or the health of the population. In this present report we have limited our study to the genetic dose. Estimation of the somatic dose (the possible hazard to the individual during his lifetime) is a more complicated procedure, to which we are giving further study.

7. During a week in 1957 a survey was made of the numbers and types of all X-ray examinations carried out, of the number of films used, and of the apparatus available in all National Health Service hospitals and chest clinics, in dental surgeries and in a few other institutions in Great Britain. A second survey, at a different time of the year, was made on a random selection of a quarter of the National Health Service hospitals and chest clinics. Physical measurements were then carried out of the radiation dose received by patients undergoing different types of radiological procedures in a representative sample of 130 hospitals and chest clinics.

8. These investigations were designed to survey radiological practice in all types of hospitals with widely differing standards of technique. This should be borne in mind when comparison is made later in this report with the earlier figures of the report of the Medical Research Council (1956) which was based unavoidably on a restricted sample of 5 hospitals. Moreover the present survey analyses radiological practice which had already begun to be influenced by the findings of the Medical Research Council's report, emphasising the possibility of future genetic damage from cumulative small doses to the gonads.

9. A separate investigation, including a three months' survey, was carried out to estimate the dose contribution from radiotherapeutic procedures.

10. Ten specialist panels have examined the results of these surveys, have studied the radiological practices and needs of their speciality, and have made recommendations.

11. *We now have sufficient evidence to recommend ways and means by which the genetic dose may be reduced. In short, as the result of a comprehensive national survey we have found that the total annual genetic dose from medical radiology in* 1957 (*both diagnostic and therapeutic*) *was* 19·3 *milliroentgens* (*mr*) *per person and that if greater consideration were given to improvements in technique, this dose would be reduced to* 6 *mr, or even less. This figure of* 19·3 *mr is less than that estimated by the Medical Research Council in* 1955 *for medical diagnostic radiology alone. We do not believe that the levels indicated show any need for major restrictions in radiological practice and we are convinced that the number and type of examinations or treatments must be dictated by the clinical needs of the patients. The dose to the gonads from any X-ray examination is small in comparison with that considered by the Medical Research Council to be acceptable to the individual without causing any undue concern on behalf of himself or his offspring. The dose will be reduced still further by the adoption of our recommendations.*

PART II.

DETERMINATION OF THE GENETIC DOSE TO THE POPULATION

A. General diagnostic radiology

General plan of survey

12. If the mutational effect of radiation is proportional to the dose received by the germ cells and is irreversible, the importance of a given dose will depend upon age. The potential effect of the dose on future generations will be greatest in a young person having a high expectancy of future parenthood, less in an older person and nil at an age when child expectancy has ceased. A genetic dose to the individual is therefore defined as the dose to the gonads, adjusted to allow for the child expectancy of that individual. The genetic dose to the population is then defined as the gonad dose which, if given to every member of that population, would have the same effect as the sum of the individual doses actually received.*

13. The determination of the genetic dose to the population from diagnostic radiology is based on three sets of information, (*a*) statistical data of the number and types of radiological examinations carried out per year, in relation to the sex and ages of persons examined, (*b*) physical information on the average dose to the gonads for each type of examination which is representative of radiological practice throughout the country, and (*c*) fertility factors giving the average child expectancy, i.e. the average number of children to be expected subsequent to any given age. The required statistical data were obtained by means of questionnaires issued in May and December, 1957. The collection of the physical data was undertaken on a large scale by hospital physicists in all the hospital regions, some 13,800 measurements being made in 130 hospitals selected to give a representative cross-section of radiological practice in hospitals and chest clinics. The fertility data have been calculated from the 1951 census for England and Wales corrected to apply to 1956.

14. The dose to the male gonads has been measured directly and that to the female gonads has been derived either from a measurement of the dose received at a point on the abdomen or from the measured skin dose at the centre of the

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* The annual genetic dose, G, to the population is defined as the summation over all groups of the product of the average annual gonad dose D_i received by each person in age group i, multiplied by the average child expectancy P_i of the group, multiplied by the number of individuals N_i in the group and divided by the expected number of offspring in the population:—

$$G = \frac{\Sigma D_i P_i N_i}{\Sigma P_i N_i}$$

This is the same as the summation carried out for the *exposed* persons in each group, numbering N_{ix} and receiving average gonad dose D_{ix}, divided by the expected number of offspring in the whole population:—

$$G = \frac{\Sigma D_{ix} P_i N_{ix}}{\Sigma P_i N_i}$$

Both expressions assume the child expectancy P_i for the whole group applies equally to the exposed fraction of the group.

X-ray beam. This derivation of the female gonad dose from the survey data has been based on extensive investigations, made on a specially constructed model, to relate the ovary dose to the surface dose. The results of these investigations have a general validity which will enable them to be used in other dose-surveys either in this country or elsewhere.

15. All dose measurements have been made with a common type of dosemeter, developed specially for the purpose of measuring a wide range of doses under conditions which interfered as little as possible with the diagnostic X-ray procedures under investigation. The dosemeter consisted of an ionization chamber coupled to a battery-operated amplifier with a system of range-switching which largely prevented a measurement being inadequately recorded or lost because the dose proved to be either too small, or too large, for the range set on the instrument.

16. A general account of the survey follows, with a summary of the results and of the salient features of their analysis. The data and analysis are presented more fully in the appendices. Further scientific data and more detailed information on the survey will be published later.

Questionnaires on Diagnostic Radiology

17. The first questionnaire was designed to ascertain the amount of radiology carried out in hospitals and dental units in the week beginning 29th April, 1957. Information was requested on the amount and type of X-ray equipment, the numbers of films used and the numbers of patients examined in each of 32 types of examination and in each of four age groups. In fluoroscopic examinations, numbers of patients and average screening times were required for the same four age groups and in 11 types of examination. Separate entries were asked for where it was known that patients were pregnant.

18. The second questionnaire was sent to a sample of hospitals and chest clinics (approximately one in four) selected at random from the National Health Service hospitals known to have X-ray equipment. Returns were required for the week beginning 2nd December, 1957, and were received from 343 out of the 376 hospitals chosen in England, Wales and Scotland (91 per cent) so that the final sample was 1 in 4·36. In this survey the categories of examination types were slightly modified, to conform more closely to proposals made by the International Commissions on Radiological Protection and Radiological Units (1957)* and 11 age groups were used in place of the 4 in the first questionnaire to enable the calculation of the genetic dose to be made more accurately.

19. During the week of the first survey the total number of radiological examinations (including fluoroscopy) carried out in all National Health Service hospitals and chest clinics was 259,447. The results of the second survey, when multiplied by the sampling factor, gave a total for the week in December of 220,260. The difference between the numbers in the May and December surveys accords with a variation which can be gauged, for example, from the monthly supplies of X-ray film. The amount of X-ray film supplied in May, 1957 was 9·2 per cent, and in December, 1957, 7·3 per cent, of the year's total. Using these monthly proportions, the number of examinations made in 1957 can be estimated

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* *Physics in Medicine and Biology*, 1957, **2**, 107.

as 12·5 million on the basis of the May survey and 13·3 million on the December survey. In the light of these values 13·0 million examinations may be taken as a reasonably accurate estimate for 1957.

20. The detailed replies, made by each hospital to the first questionnaire, were used to plan the physical dose survey so that the maximum statistical accuracy could be obtained with the resources available for the work. The results of both questionnaires were used for the calculation of the final genetic dose.

The Physical Dose Survey

21. In making sample measurements to determine the gonad dose for different types of X-ray examination, most weight must be given to those types of examinations which contribute most to the population dose. Likewise, other things being equal, more measurements must be made in those hospital regions and classes of hospital which perform the majority of the X-ray work. The maximum accuracy will be attained if the number of measurements for any given type of examination in a given class of hospital is proportional to the contribution expected to be made thereby to the population dose. The measurements were therefore distributed among the selected hospitals and among the types of examination as closely as possible in accordance with this principle.

22. All hospitals where X-ray work was done were divided into three broad categories. Hospitals of 300 beds or more (excluding special hospitals such as sanatoria and mental hospitals) comprised Class A; hospitals having between 100 and 300 beds and the special hospitals were put in Class B; the Class C hospitals were those with less than 100 beds. Two A hospitals, three B hospitals, one C hospital and where possible one chest clinic were selected in each of the 19 hospital regions in England, Wales and Scotland, including the four Metropolitan regions, and also in the London Teaching Hospitals, regarded as one group, making in all 20 hospital regions or groups. Three regions, because of their size, had an additional hospital selected in Class C, and one small region had only one A hospital and two B hospitals. The sampling fractions were not exactly the same for each region, nor for the three classes of hospital, but these differences were taken into account in estimating the division of effort.

23. In planning the distribution of measurements between the various hospitals and types of examination, earlier data, given in the Medical Research Council report (1956), were combined with the statistical information of the May, 1957 questionnaire to obtain approximate estimates of the genetic doses to be expected. A theoretically ideal distribution of measurements was then calculated and in each category of examination in each hospital a provisional number of measurements, conforming as nearly as possible to the theoretical figure, was chosen in the light of the actual returns of work in the May, 1957 survey. These numbers varied from about 115 for the smallest regions to 560 for the largest with about 350 as the average allocation (Table 7, App. I(2)). The earlier work of Osborn and Smith (1956) had shown that the major fraction of the genetic dose is contributed by only a few types of examination. The following categories of examination were used for the allocation of the measurements: (1) abdomen (including obstetric cases), (2) pyelography, (3) pelvis (including hip, upper femur, lumbar spine), (4) pelvimetry and (5) the remainder as a single

category. In addition observations were made of barium meal examinations and examinations in the chest clinics.

24. In all, measurements in 7,101 examinations were aimed at and finally reports on 5,414 examinations, involving 13,800 individual measurements, were completed. A total of 139 hospitals and chest clinics were selected for the survey and data were obtained from 130. Of the remainder, four hospitals had delegated their small amount of radiological work to other hospitals and five were in regions where it proved impossible for the available staff to carry out all the work allocated.

25. The total returns thus amounted to approximately 80 per cent of the number provisionally set but the allocations were not uniformly covered. Some regions were able to complete their work, most achieved more than 80 per cent of their allocation and only two less than 50 per cent. More chest examinations were returned than were allocated, whereas some examinations were more difficult to observe in the required numbers. Pelvimetry yielded only 32 per cent of the allocation, mainly because it was undertaken less frequently than was anticipated from the returns to the first questionnaire.

26. A form was devised to give, alongside the physical dose measurement, detailed information on the patient's age, sex, height and weight with full details of the examination type, radiographic technique, quality, size and location of the radiation beam and the measured doses. In this way it has been possible to relate dose to technique and reveal factors which in practice lead either to low or to high gonad exposure.

27. The male gonad doses per examination could be directly ascertained and analysed. The female gonad doses, however, required a calculation in terms of the conversion factors relating ovary dose to the measured surface dose. Conversion factors covering the necessary range of operating conditions were measured by a central team working with the specially designed model (Appendix I(3), Fig. 4). The model consisted of a plastic shell constructed around a human skeleton and filled with a granular material which absorbed and scattered X-rays to the same extent as soft tissues of the body. Measurements of the dose in the model at the site of an ovary were then compared with dose measurements at the point on the surface of the abdomen which had been selected for the hospitals survey. The relationship was investigated for various radiation qualities, sizes of area irradiated, distance of the X-ray tube from the patient's skin and distance of the surface point from the nearest edge of the X-ray beam. The required ovary doses were then calculated with the aid of an electronic computor.

Results

28. In the following paragraphs the results of the physical dose survey are considered and the estimated genetic dose is analysed in relation to the broad categories of X-ray examination which contribute most significantly to it. A detailed analysis of the results is presented in Appendix I.

29. The present estimate of 13,000,000 examinations in National Health Service hospitals in 1957 is not very different from the corresponding figure of 12,200,000 used in the Medical Research Council's report of 1956. There are certain differences, however, in the distribution of examinations among different age groups. Broadly the national surveys of radiological practice made in

1957 showed fewer examinations in children than was estimated in the 1956 Report from the limited data then available. In particular only 13·5 per cent of examinations were made in the age group 0–14 years compared with the estimate of 31·9 per cent on which the calculations of the 1956 Report were based. As a consequence a greater fraction of the examinations is distributed among the older age groups, the greatest difference being shown by the over-50 age group which accounts for 34·3 per cent, instead of 25·9 per cent, of the total examinations. There are also some differences in the distribution of examinations among the various types, the important change being that chest examinations are about one-third more frequent than was formerly estimated. The effect of this difference, however, upon the final level of the genetic dose is small.

30. The averages of the measured doses to the male, female and foetal gonads are given in Table I for the 8 groups of examination which together contribute more than 90 per cent of the total genetic dose. In many of the examinations the averages found in the present survey are reasonably near in magnitude to those used in the Medical Research Council's report. Larger differences, where they occur, reflect the variability to be expected in the measured doses in a survey on a national scale. The doses per examination given in the Medical Research Council's report were based on measurements made largely at one hospital. In the present survey, however, the doses were measured under the varied conditions of X-ray examination in a large number of different hospitals. If bad practice occurs in only a few instances, for example if the gonads are unnecessarily included in the X-ray beam, the average gonad dose can be greatly increased.

TABLE I

General Diagnostic Radiology: National Survey, 1957/8
Mean Gonad Dose per Examination in Milliroentgens

Type of Examination	Male	Female	Foetus
1. Chest, heart, lung (excluding mass miniature radiography)	2·75	5·4	5·5
2. Barium meal	44	333	448
3. Abdomen	105	183	281
4. Abdomen obstetric	—	367	723
5. Intravenous Pyelography	765	585	843
6. Pelvimetry	—	745	885
7. Pelvis, lumbar spine, lumbo-sacral joint	370	392	536
8. Hip, upper femur	740	102	154

31. Fertility factors giving the average number of live-born children to be expected subsequent to a given age are presented in detail in Appendix I. For males the factors are approximately 2·2 up to age 20, falling to rather less than 1·0 by age 30 and to less than 0·1 beyond age 45. For females the factors are slightly higher in the early years than those for males but they diminish to

approximately 1·0 by age 25 years and are almost zero by age 45. Rather higher factors have been used for X-ray examinations of the obstetric abdomen and for pelvimetry—examinations which are made in connection with pregnancy.

32. Genetic doses calculated from the survey data are given in Table II. Contributions to the total genetic dose are given for each of the 8 examination groups of Table I and for all other examinations grouped together. These contributions are given separately for the male, female and foetus and totalled in column 5. It is evident that 5 examinations—numbers 4 to 8—together provide over 80 per cent of the total genetic dose, viz., obstetric abdomen 26, pyelography 13, pelvimetry 8, pelvis, lumbar spine and lumbo-sacral joint 23 and hip and upper femur 11 per cent respectively. Examinations of the chest, heart and lung together with barium meal contribute about 8 per cent and all other examinations together contribute only 11 per cent.

TABLE II

General Diagnostic Radiology: National Survey, 1957/8

Annual Genetic Dose in Milliroentgens per Person

Examination	Male	Female	Foetus	Total	Percentage
1. Chest, heart, lung	0·14	0·29	0·05	0·48	4
2. Barium meal	0·11	0·36	0·04	0·51	4
3. Abdomen	0·22	0·32	0·06	0·60	5
4. Obstetric abdomen	—	1·12	2·27	3·39	26
5. Pyelography	0·96	0·69	0·09	1·74	13
6. Pelvimetry	—	0·55	0·60	1·15	8
7. Pelvis, lumbar spine, lumbo-sacral joint	1·72	1·17	0·22	3·11	23
8. Hip, upper femur	1·33	0·14	0·01	1·48	11
9. All other examinations ..	0·35	0·39	0·04	0·78	6
Total	4·83	5·03	3·38	13·24	100
Percentage	36	38	26	100	

33. The annual genetic dose from general diagnostic radiology in National Health Service hospitals amounts to 13·2 mr to which a small increment, estimated at 0·9 mr, has been added to take into account general diagnostic radiology performed outside the National Health Service. *The total annual genetic dose of 14·1 mr per person from general diagnostic radiology is therefore less than the earlier estimate of 22 mr per head per year shown by the Medical Research Council's report of 1956.**

* The estimated genetic dose from general diagnostic radiology is, in fact, given in the report of the Medical Research Council not as an absolute figure, but as 22 per cent of that received from natural sources in this country. Since, however, the figure for natural sources has been estimated at about 100 mr per year, the 22 per cent is equal to 22 mr.

34. This reduction can be attributed partly to the altered distribution of examinations with age, and partly to a reduction in gonad dose in some of the more important examinations. The increased number of chest examinations makes only a small change in the estimate of the total genetic dose.

35. The use of techniques employing higher kilovoltage and increased filtration has been advocated in recent years for certain radiographic examinations. It has been possible in this survey to assess the effect of these techniques on the gonad dose. Analysis of the measurements made (Appendix I(4)) shows that with the increasing penetration of the beam the gonad dose at first decreases and then increases. In most measurements the minimum gonad dose occurs with X-rays generated at 70 kVp with a total filtration of about 1 mm of aluminium. A similar variation is shown in the measurements of the skin dose, but the minimum occurs in this case for 70 kVp radiation filtered by a total of about 2 mm of aluminium. These findings do not support the contention that higher kilovoltage and extra filtration necessarily reduce the gonad dose.

B. Mass Miniature Radiography of the Chest

36. A report on the gonad and somatic dose from mass miniature radiography was included in the interim report (May, 1959). A brief account of the measurement survey is given here so that the results may be included in the calculation of the total genetic dose from all diagnostic X-ray procedures.

37. The Medical Research Council's report in 1956 gave figures for the gonad dose from mass miniature radiography which amounted to a contribution of less than 0·1 per cent of the total genetic dose received by the population from general diagnostic radiology.

38. A new assessment of the gonad dose has been made by means of a survey in which more than 600 measurements were carried out on four different types of mass radiography equipment representative of those used throughout the country. Further research to estimate the ovary dose was undertaken by experimental irradiation of a specially constructed model. An account of this work is given in Appendix II, in which the results of the survey are compared with those contained in the earlier survey used in the Medical Research Council report.

39. A study of the measurements shows that the male gonad dose from a single examination is appreciably less than was reported for the same type of unit in the Medical Research Council's report for 1956. For females the present figures approximate those previously published. The new experimental work on the model has shown, however, that the earlier figures must be adjusted and, if this is done, the doses found in the present survey are in all cases lower than those previously reported.

40. The mean gonad dose per examination given by the present measurements is 0·090 mr for males and 0·092 for females. The average foetal gonad dose is assumed to be the same as that for the ovary. *The genetic dose per person is then* 0·01 *mr per year. The contribution from mass miniature radiography to the genetic dose from diagnostic radiology as a whole is, therefore, extremely small.*

C. Survey of Dental Radiography

41. In the Medical Research Council's report of 1956 it was estimated that dental X-ray examinations contributed less than 0·2 per cent of the total genetic

dose from general diagnostic radiology. This estimate was, however, based upon a comparatively small number of measurements made in one dental hospital. Although there was no reason to anticipate that dental radiology could make more than some such small contribution, the Committee thought it nevertheless desirable to obtain a more widely based estimate from measurements taken both in hospitals and in general dental practice. It was impracticable to include dental work in the general survey carried out by the physicists (as described in Section A of this Part) and a method of recording X-ray doses on a photographic film was therefore devised. By this means, and under the direction of a small central team, the total doses over a period of time were recorded in 154 dental surgeries and hospitals (both civil and military).

Annual number of radiographic examinations

42. The first statistical inquiry into the frequency of diagnostic radiology included all hospitals and dental surgeons in the country. The replies received from hospitals indicated that only a small fraction of them (13 per cent) undertook dental radiology. On the other hand of the 16,000 questionnaires sent to dental practitioners only 43 per cent were returned. There is no means of telling whether the figures given by this proportion is representative of the total. It might well be that dental surgeons not using X-rays at all tended not to reply and that the sample is thereby appreciably biassed. Data on technique, however, might be much less liable to bias and from the returns received an average of two films per dental examination was calculated. This figure can be combined with information on the annual dental film consumption (estimated from other sources to be about 3,500,000 in hospitals and general dental practice) to give an estimate that approximately 1,750,000 dental X-ray examinations were made in 1957. Dental radiography in the armed forces will increase this figure slightly and it will be sufficient for the present purpose if it be raised to 2 millions.

Physical dose measurements

43. The apparatus used consisted of a piece of very sensitive photographic film enclosed between fluorescent intensifying screens in a specially designed cassette. The cassette was fixed to one side of a plastic foam prism which could be firmly strapped across the seat of a dental chair so that the film was at an angle of 45 degrees to the seat and facing the body of a patient sitting in the chair. One apparatus was sent to each dentist taking part in the survey with the request that it be kept in position on the chair until 100 exposures had been recorded or until a given date. On the average 70 exposures were in fact recorded in the measurements made in each of 12 National Health Service hospitals, 12 dental departments serving the armed forces and 130 private dental surgeries. (These 130 formed part of a larger sample randomly drawn from the dental register. They should be amply sufficient in number to give a good indication of the very small dose involved but in view of the non-responses cannot be regarded as a true cross-section.)

44. The films thus exposed were returned to the central team for processing under carefully controlled conditions and the amount of radiation received by each film could be deduced by measuring the film blackening. It was necessary to carry out investigations with a model to relate the blackening of the film to the dose that would be received by the ovaries and the male gonads.

45. The mean gonad dose per examination derived from these measurements is 0·27 mr for each sex and *the annual genetic dose per person calculated on the basis of 2 million examinations per year is 0·01 mr.*

D. Radiotherapy of Non-malignant and Malignant Disease

46. Estimates have been made of the annual genetic dose from the radiotherapy of non-malignant and malignant disease. One panel has investigated the use of external sources of ionizing radiation in therapy and another panel the use of unsealed radioactive isotopes for both diagnostic and therapeutic purposes.

47. Although it was not considered necessary or practicable to carry out measurements in selected hospitals, as was done in the survey of diagnostic radiology, the basic procedure was essentially similar. Statistical data on the numbers and types of treatment were obtained by questionnaires sent to National Health Service hospitals and to private dermatologists. The average gonad dose for each type of treatment was determined by the measurements of simulated treatments on the model (Appendix IV). The average gonad dose was then derived by calculation from a sufficient number of case histories. Normal fertility factors were used (Appendix I(5)) where appropriate but in the radiotherapy of malignant disease, the factors were reduced to take into account the limited survival time of these patients. In addition, if the gonads were heavily irradiated, further allowance was made for the consequent impairment of fertility. In the case of internal radioisotopes the gonad dose per millicurie administered was derived by calculation. The genetic dose was then calculated from statistical data on the numbers of patients treated in each age group together with the average amount of each radioisotope used per patient.

External radiotherapy of non-malignant disease

48. Questionnaires were sent to all National Health Service hospitals and to dermatologists in private practice who used therapeutic radiation. The total numbers of cases reported for the three months from 29th April to 28th July, 1957 were 13,950 in hospitals and 1,015 in private practice. It was estimated that these figures represented respectively 90 per cent of the total number of treatments carried out in hospitals and about one-third of those in private practice. Details are given in Appendix IV.

49. To determine the gonad dose for various types of treatment, detailed information for 2,262 treatments was collected and classified into categories as in Table III. Measurements were made on the model to obtain the male and female gonad doses for various sizes and qualities of X-ray beam directed to 16 regions of the body from the head to the foot. The results of these appropriate measurements together with the treatment data gave the gonad dose for each treatment and the average dose for each treatment category. The annual genetic dose per person was calculated by combining these figures with the numbers of treatments per year and the normal fertility factors.

50. The annual genetic dose per person is given for the male, female and foetus in Table III from which it is evident that the male dose is nearly twice the female dose and that the foetal dose is very small. *In total the annual genetic dose from non-malignant radiotherapy is 4·5 mr per person*, of which the treatment

TABLE III

External Radiotherapy of Non-malignant Disease; National Survey, 1957/8
Annual Genetic Dose in Milliroentgens per Person

Diagnosis	Male	Female	Foetus	Total	Percentage
1. Skin condition:—					
(*a*) Benign growths etc. ..	0·02	0·07	n	0·09	2
(*b*) allergic etc.	0·34	0·59	0·03	0·96	21
(*c*) ringworm	n	0·01	n	0·01	n
(*d*) others	1·19	0·27	—	1·46	33
2. Glandular enlargements ..	n	n	n	n	n
3. Ankylosing spondylitis ..	1·07	0·08	n	1·15	26
4. Arthritis, Rheumatism ..	0·04	0·18	0·05	0·27	6
5. Artificial menopause.. ..	—	—	—	—	—
6. Deafness	n	n	n	n	n
7. Any other non-malignant condition	0·04	0·49	n	0·53	12
Total	2·70	1·69	0·08	4·47	100

n —used to denote less than 0·005 mr or less than 0·5%.

of skin conditions contributes about one half and radiotherapy of ankylosing spondylitis about one quarter.

External radiotherapy of malignant disease

51. The questionnaire sent to all radiotherapy departments in April, 1957, provided information on the total numbers of patients treated, classified by sex, age and type of disease. The full details of the returns are given in Appendix IV.

52. The gonad doses were measured on the model for a treatment regarded as typical for each disease, (with the exception that a heavy dose given to the pelvic region was deemed to produce permanent sterility in a woman and no calculation of genetic dose was therefore required). Treatments were assumed to be carried out by standard methods with X-rays generated at 220 kV. In cancer of the breast, bladder and mouth an additional allowance was made for those cases in which radium was used.

53. The normal fertility factors have been modified to allow for the reduced expectation of life of persons suffering from different forms of malignant disease and a rough allowance has been made for the loss of fertility caused by the treatment (Appendix IV.)

54. The genetic doses from those types of treatment which make significant contributions are listed in Table IV. *The annual genetic dose per person from the radiotherapy of malignant disease amounts to 0·5 mr*. It is small relative to other radiation doses we have considered, and the unavoidable uncertainties in its

estimation do not lead, therefore, to serious error in the total genetic dose from medical radiology. In particular, calculations show that the substitution of higher energy radiation in the range 1–10 MeV would not materially alter the result.

TABLE IV

External Radiotherapy of Malignant Disease; National Survey, 1957
Annual Genetic Dose in Milliroentgens per Person

Site of Disease	Male	Female	Total	Percentage
Male genitalia	0·22	—	0·22	42
Bladder	0·04	n	0·04	8
Bone	0·03	0·04	0·07	13
Connective tissue	0·02	n	0·02	4
Lymphatic and haemopoietic tissue ..	0·03	0·02	0·05	10
Skin	0·05	0·04	0·09	17
Others	0·02	0·01	0·03	6
Total	0·41	0·11	0·52	100

n—used to denote less than 0·005 mr.

Internal administration of radioactive isotopes

55. In recent years radioactive isotopes have been increasingly used in diagnosis and in the treatment of non-malignant and malignant disease. The numbers of patients investigated and treated by unsealed radioactive isotopes are given for the three-month survey period of 1957 in Appendix IV, together with the total amounts of the different isotopes used.

56. From the information available on the radioactive isotopes in clinical use the gonad dose from each had been estimated for an amount of 1 mc administered. These doses have been combined with the numbers of patients treated and with the appropriate fertility factors to give an estimate of the genetic dose. As in the case of the external radiotherapy of malignant disease modification of the normal fertility factors has been made in the calculations for some of the types of treatment.

57. Table V shows those radioisotopes and types of examination and treatment which lead to a significant genetic dose. In calculating these figures it may be noted that a range of values of the gonad dose per millicurie administered has been reported. The higher figures have been taken so that our estimate is likely to be a maximum. *In total the annual genetic dose per person from all the present uses of radioisotopes in medicine amounts to only 0·18 mr per person* of which 85 per cent arises from therapy.

TABLE V

Internal Administration of Radioactive Isotopes; National Survey, 1957
Annual Genetic Dose in Milliroentgens per Person

Use	Isotope	Dose	Percentage
Diagnosis:—test doses			
Thyroid function	Iodine 131	0·011	6
Carcinoma of thyroid	Iodine 131	0·005	3
Other investigations	Phosphorus 32	0·012	6
Therapy			
Non-malignant conditions:—			
Thyrotoxicosis and other non-malignant conditions of thyroid	Iodine 131	0·049	27
Polycythaemia	Phosphorus 32	0·059	33
Malignant diseases:—			
Carcinoma of thyroid	Iodine 131	0·045	25
Total		0·181	100

PART III. SUMMATION OF THE RESULTS OF THE RADIOLOGICAL SURVEYS

58. The results of the radiological surveys made by the Committee are collected together in Table VI where the annual genetic doses are given in milliroentgens per head of population. The accuracy is indicated by an estimated error in the same units. The annual genetic dose from general diagnostic radiology (14·1 mr) is less than was estimated in the Medical Research Council's report of 1956, but still contributes the major fraction of the total genetic dose from the medical use of ionizing radiations. The genetic dose from the uses of radiotherapy, excluding radioactive isotopes, in non-malignant conditions (4·5 mr) stands next in order of magnitude, followed by the contribution from the radiotherapy of malignant disease, excluding radioactive isotopes (0·5 mr). The use of radioactive isotopes (0·18 mr), mass miniature radiography (0·01 mr) and dental radiography (0·01 mr) make almost negligible contributions on the total genetic dose. *The final total, which is now estimated to be 19·3 mr per person per year, is smaller than that attributed to diagnostic radiology alone in the Medical Research Council's report (22 mr). This national survey of radiological practice therefore shows the genetic dose in this country to be of the same order of magnitude as that previously deduced and not several times greater as was at one time thought to be possible.*

TABLE VI

All Medical Uses of Ionizing Radiation, National Survey, 1957/8
Summation of Annual Genetic Doses in Milliroentgens per Person

Medical Use	Dose	Estimated Error
General diagnostic radiology	14·07	1·0
Mass miniature radiography	0·01	0·01
Dental radiography	0·01	0·01
Radiotherapy:—		
External—non-malignant disease	4·47	1·2
malignant disease	0·52	0·25
Internal—non-malignant	0·13	0·13
malignant disease	0·05	0·05
Total annual genetic dose	19·3	1·6

59. Detailed calculations of the accuracy of the estimate of the genetic dose from general diagnostic radiology have been possible and are outlined in Appendix I (5). Errors arising from the following causes have been assessed and are included in the error in Table VI.

(*a*) variability of the doses reported for each type of examination;
(*b*) the differences between the numbers of measurements made in the survey and the numbers theoretically required to be made on the basis

of a strict proportionality to the numbers of examinations undertaken in each region, type of hospital and category of examination;

(*c*) the statistical uncertainty in the numbers of each type of examination and in each age group reported in the two questionnaires, especially where the numbers are small;

(*d*) uncertainty as to what fraction of the year's radiological work is represented by the examinations reported in the questionnaires;

(*e*) errors inherent in the derivation of ovary doses and foetal gonad doses from skin dose measurements;

(*f*) instrumental errors.

No assessment of the accuracy of the fertility factors has been possible; it is assumed that these are correct at the present time and it is implied in the calculation that they will remain unchanged during the generation now considered. The accuracy in the estimated genetic dose from the other medical uses of ionizing radiation could not be assessed in the same detail and in respect of these the standard errors given in Table VI are regarded as estimates of upper limits.

60. The estimated error in the total annual genetic dose of 19·3 mr per person is 1·6 mr, but this does not fully allow for errors introduced in the derivation of ovary doses and foetal gonad doses in diagnostic radiology. If these derivations had been based on the dose delivered to the skin at the centre of the X-ray beam (instead of by the method described in paragraph 27), the dose would have been somewhat higher. We conclude therefore that the genetic dose from the medical use of ionizing radiation in this country is unlikely to have been higher than 25 mr or lower than 15 mr for the year of the survey. This accuracy is well within the limits recommended as desirable by the International Commissions on Radiological Protection and on Radiological Units and Measurements (1957).

61. Detailed study of the variation in the gonad dose per examination shows that in any given type of X-ray examination the average is strongly influenced by the proportion of high doses occurring in the sample of measurements. This is most marked in those examinations where the gonads should be normally outside the beam but are sometimes included in it by use of unnecessarily large beams. For example, in chest, heart and lung examinations in males, the average gonad dose per examination is 1·34 mr for the 503 examinations measured in 104 hospitals; the exclusion of 8 hospitals in which very high doses were observed reduces the average to 0·35 mr for the remaining 469 measurements; selecting only 34 hospitals giving low doses leads to an average dose of only 0·03 mr for the 136 measurements in this class. Similarly, selecting only those hospitals which produce low doses in abdominal examinations of males reduces the gonad dose from 105 mr averaged over all 204 measurements to 4·7 mr averaged over the selected 51 measurements. It should be emphasised that these reductions are not calculated by simply taking the lowest doses for all hospitals. They represent the average of all the measurements in a given type of examination in those hospitals which produce a low average dose for the examination in question. It has been calculated from the survey results that, for each type of examination separately, bringing the techniques in the 10 per cent of hospitals showing the highest doses up to the standard of the average technique of all the other hospitals would in total reduce the genetic dose to about 70 per cent of

that now estimated. If all techniques were raised to the standard shown by the 25 per cent of hospitals showing the lowest doses, the annual genetic dose would be lowered to somewhere in the region of 2 mr per person.

62. Although it is not possible to give the same precision to estimations of the effect of technique on the genetic dose from radiotherapy, substantial reduction should be possible in the genetic dose from the radiotherapy of non-malignant conditions. *An over-all reduction of the total genetic dose from medical radiology to an annual figure of about 6 mr per person would appear to be attainable if more consideration were given to the techniques employed.*

PART IV. REPORTS OF THE CLINICAL PANELS

63. The present practice of radiology in different specialties together with the results of the surveys described in Part II was studied by nine panels. These panels made recommendations on how the dose to the gonads might be reduced in diagnostic and therapeutic radiological practice without detriment to the value of these procedures.

64. The reports of the clinical panels are reproduced in full in this part, with the exception of those on mass miniature radiography and on internal radiotherapy. A summary of the findings on mass miniature radiography is given, based on the Committee's interim report.

65. The full report of the panel on internal radiotherapy dealt with wider problems than those we are discussing in this present report (e.g., the dose to various organs) and a summary is therefore given of that part which concerns the genetic dose.

66. In the course of the physical dose survey observations on current radiological practice were made by the panel of physicists carrying out the work, and these are given at the conclusion of this Part.

(A) Mass Miniature Radiography*

67. Mass miniature radiography was dealt with in detail in the Committee's interim report and the importance of maintaining this procedure on a wide scale was illustrated by the national figures available for 1957. Those for 1958 now show that 4,278,108 mass miniature radiography examinations were made in Great Britain in that year and led to the discovery of 17,569 cases of pulmonary tuberculosis requiring supervision and 3,503 cases of lung cancer, 10,161 cardiac abnormalities and 3,741 cases of pneumoconiosis. It is clear that any possible hazard has to be balanced against these findings.

68. The Committee was enabled to strike this balance by means of new and extensive data specially collected for them. They concluded that such examinations are a relatively unimportant source of gonad radiation exposure.

69. On the principle, however, that all unnecessary exposure should be prevented the Committee advised certain modifications of mass miniature radiography units and these have already been carried out. They recommended that the procedure should not be used for case-finding amongst children or pregnant women and that for these groups full size films with strict limitation of field size are required. The Committee has given further consideration to this recommendation and now advises that either technique may be used for children or adults of small stature.

(B) Dental

70. As it was recognised that a large number of patients were radiographed in this country by dental surgeons it was felt that the situation should receive the attention of a special panel. In addition when the Committee's first survey was held in May, 1957, it was decided to include in it all dental practitioners.

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* Summary only: see paragraph 64.

71. Unfortunately a proportion of the survey forms were not completed so it is not possible to give an accurate figure for the total number of dental patients radiographed annually. However, information from other sources as to the quantity of dental X-ray film used, together with information resulting from the survey has enabled the number of dental radiographic examinations made in 1957 to be estimated at not more than 2 million. From the completed forms that were returned it was calculated that dental practitioners took an average of 1·7 films per patient examined and hospital dental clinics 3·5 films per patient, or an overall average of 2 films per examination. The dental dose measurement survey indicated that the mean gonad dose for both male and female patients was 0·27 mr for each examination of 2 films producing an annual genetic dose to the population of 0·01 mr per person.

72. These various figures support the impression formed after discussions with members of the profession that in this country dental radiography is used mainly as a diagnostic aid, a state of affairs which has contributed to the small genetic dose from dental radiography. On the other hand it was disturbing to find from the survey that intra-oral fluoroscopy is still being used occasionally in spite of its potential dangers.

73. Consideration was given to the use of radiography in relation to current clinical practice and a statement concerning this is given below.

74. In dental radiography films may be placed either inside or outside the mouth. Intra-oral radiographs may be taken of the whole length of the tooth and its surrounding bone as periapical radiographs, of the crowns of both upper and lower teeth together as bite-wing radiographs or they may be taken with a film held between the upper and lower jaws as occlusal radiographs. Extra-oral radiography includes views of the mandible, temporo-mandibular joints, facial bones and nasal sinuses. Tomograms of both flat and curved sections (pantomograms) are occasionally used and radiography after the injection of a contrast medium may be carried out to investigate pathological cavities, sinuses, fistulae and diseases of the salivary glands.

75. Cephalometric radiographs are used by the orthodontist and occasionally by other dental specialists. These are films taken of the skull and soft tissues of the face with the aid of a precision positioning device, the cephalostat. Measurements are taken from such films and comparison can be made between serial radiographs of a patient taken in this manner over a period of time.

76. Broadly speaking, four groups of patients are radiographed, namely:—(*a*) the casual patient, usually requiring the relief of pain, (*b*) the orthodontic patient, (*c*) those attending for regular routine treatment and (*d*) the patient seeking the advice of a specialist or consultant on some difficult problem or serious disease.

(*a*) The cause of the casual patient's trouble is frequently obvious after a brief clinical examination. When radiographs are required usually only one or two are needed.

(*b*) With few exceptions orthodontic patients are children between the ages of 8 and 14 years. Courses of treatment rarely last longer than three years and the number of films usually taken is not very large.

Radiographs are taken to determine the presence and position of the permanent canines and premolars and less often the second and third molars. When the eruption of teeth is delayed, radiographs may be taken to identify the cause. If a supernumerary tooth or some other abnormality requiring surgical removal is present, further views may be required before surgery can be safely undertaken. The presence and position of the permanent canines and premolars can be determined by periapical films and this is probably the usual practice of the general practitioner. Some orthodontists prefer oblique lateral jaw views, believing that they more accurately display the positions of these teeth, but such films require expert radiography if they are to be taken with minimum distortion.

(*c*) The use of bite-wing radiography as a routine examination for children is still a matter on which there is a difference of opinion. Some feel that a child attending an experienced practitioner regularly at three-monthly intervals is unlikely to lose a deciduous tooth other than by misadventure. Practitioners holding this view reserve the use of bite-wing radiographs for those children whose visits are irregular to ensure that early caries is disclosed and treated. Others feel that the regular bite-wing examination plays an important part in the management of the child's dentition. It is now generally recognised that even a careful clinical examination may not reveal all the interproximal caries present in the adult dentition. Bite-wing radiographs taken of the posterior teeth show both their approximal surfaces and also the crests of the interdental septa. During the teens and early twenties the rapid development of interproximal cavities may require a six-monthly examination. In later life the incidence of fresh caries in this situation tends to decline, but bite-wing films are still valuable as a means of detecting cavities, especially where the teeth are already heavily filled. In older patients the interval between examinations can often be increased depending on the practitioner's knowledge of the individual patient's caries incidence. Where root canal therapy is undertaken a number of periapical films, usually about three, are taken to control the treatment and filling of the root canal. Follow up films are also taken at intervals to ensure that treatment has been successful. The amount of radiography required to supplement the clinical examination in periodontal disease varies from case to case. Some patients may require three or four films of suspected areas only, others needing more extensive treatment will require a full mouth examination. Repeat examinations are made at intervals to survey the results of treatment and can often be limited to selected areas.

(*d*) Patients seeking advice on difficult problems or serious disease may require a great many radiographs before a proper opinion can be given.

Observations on Methods of Reducing Radiation Dosage

77. Methods of reducing the dosage of radiations to the patient are, with minor variations, the same, irrespective of the type of diagnostic radiography being carried out. The application of these methods to dental radiography however, needs some special consideration since the design of dental X-ray

equipment has to meet the particular requirements of dental practice. Methods of reducing dosage in dental radiography will be considered under the following headings:—(*a*) the diameter of the primary beam, (*b*) kilovoltage peak and filtration, (*c*) the focus-skin distance, (*d*) speed of film, (*e*) gonad shields, (*f*) age of machine and (*g*) training of operators.

(*a*) *The diameter of the primary beam*

The diameter of the primary beam can have the greatest single effect on the gonad dose and should be just large enough to cover the part to be radiographed. This is of particular importance in dental radiography where many overlapping fields may occur. The use of larger diameter beams will mean the irradiation of an unnecessary area of skin and volume of tissue, producing a higher gonad dose. While narrower beams may be satisfactory in expert hands, a beam 2½ inches in diameter at the tip of the cone, at 8 inches from the anode, is most suitable for radiographers of average skill. Particular attention should be given to beam size in occlusal radiography of the maxilla and also in cephalometric radiography where an anode-film distance of 6 feet is used. Rectangular diaphragms have only a limited application in dentistry and with small areas not much is gained by changing from a circle to a rectangle.

(*b*) *Kilovoltage peak and filtration*

The penetrating power of an X-ray beam is increased by either increasing the kilovoltage applied to the tube or by placing aluminium filters in the beam. To estimate the effect on the gonad dose by increasing this penetration necessitates taking into account two self balancing factors. On the one hand, the ratio of gonad dose to skin dose always increases with an increase of penetrating power for both males and females. For example, this ratio increases by a factor of about two from 50 kV to 90 kV with no added filtration. On the other hand a balancing factor is the reduction of skin dose which occurs when taking a radiograph at higher kilovoltage or with added filtration. These effects vary according to the view, the type of film and the acceptable density of the radiograph. The available evidence would indicate that the gonad dose in dental radiography may be slightly increased by the use of higher penetrating powers.

(*c*) *The focus-skin distance*

In dental radiography the focus-skin distance is regulated by using a pointer cone, two systems of technique being employed; the short cone technique using, according to the output of the machine, distances of 4 to 8 inches and the long cone technique using 16 to 36 inches. Both methods of projection have practical advantages and disadvantages. Apart from the type of periapical projection preferred, both the output of the machine and the range of movement of the tube head limit the choice of focus-skin distance.

The effect of increasing the focus-skin distance is to decrease the skin dose for a given film dose thereby reducing the gonad dose. These differences however are not great. For example, for a film exposed at a depth of 3 cm, the skin dose is only 10 per cent greater at 4 inches focus-skin distance than at 8 inches. If a distance of 16 inches is used the skin dose is reduced by a further 10 per cent.

(*d*) *Speed of film*

The selection of a fast film reduces irradiation to all parts of the patient's body. Methods of increasing film speed include increasing grain size and emulsion thickness. The use of intensifying screens also materially reduces exposure times. Unfortunately all these methods result in some loss of resolution of the image. Movements of the patient present a particular problem in dental radiography. The number of retakes may be minimised by using fast films and short exposure times. Efforts should be made to improve the timers fitted to dental X-ray machines so that shorter exposures are possible. The fastest film should be chosen which will adequately record the fine details required for the diagnosis of dental conditions.

(*e*) *Gonad shields*

The dose of radiation to the gonads has been shown to be very small during dental radiography, provided due care is taken in the radiographic technique. Nevertheless the dose can be reduced still further by the use of a lead rubber shield. Such a shield is appropriate where much radiography is to be done, especially for young children and pregnant women and certainly if there is a chance that the gonads or foetus may lie in the primary beam. A small apron of lead rubber or lead loaded plastic, equivalent in absorbing power to not less than 0·25 mm of lead is advised by various authorities.

(*f*) *Age of machine*

Modern X-ray machines are more likely than older ones to comply with the necessary standards of safety, both from a radiation and an electrical point of view. Dentists are recommended to see that their machines conform to the " Code of Practice for Protection of Persons Exposed to Ionizing Radiations ".

(*g*) *Training of operators*

A high degree of skill is required to produce good dental radiographs without retakes and every effort should be made to improve the training of dental students and radiographers in techniques of dental radiography. Emphasis should be laid on careful instruction in the methods of reducing radiation dosage.

(C) Orthopaedic

78. The reduction of the irradiation dose delivered in X-ray examinations made for orthopaedic purposes is important for the following reasons:—

(*a*) The proportion of patients in the child-bearing period is high and the relative proportion of children to adults is also very high.

(*b*) A number of radiological examinations may have to be carried out over a period of months, years or even a whole lifetime.

(*c*) There are a number of orthopaedic conditions which occur round the lower part of the trunk and hip joints, e.g., congenital dislocation of the hip (a condition which is commoner in females than males). These conditions sometimes require repeated examinations which may cause excessive exposure to the gonads.

(*d*) In scoliosis of the spine and generalised bone conditions large areas of the body may have to be irradiated.

(*e*) Assessment of the results of treatment of certain fractures often demands a large series of X-rays.

(*f*) X-rays are very frequently made " to exclude fracture ", as a defence against possible action at law for negligence.

Current practice

79. There is a general and new awareness of most of the points mentioned in paragraph 78 and efforts are obviously being made to reduce the number of unnecessary exposures.

Recommendations

80. (*a*) The close liaison between orthopaedists and radiologists which already exists must be maintained if dosage is to be kept down.

(*b*) Precautionary X-rays should not be requested in the absence of a definite indication. Radiographic examinations should be undertaken only if the findings are likely to affect the management of the patient.

(*c*) The gonad dose should be diminished by stricter control of requests for progress reports in conditions such as congenital disease of the hip. Gonad shields should be employed whenever possible.

(*d*) Transfer of films from one hospital or department to another should be facilitated.

(*e*) The request for radiological examination in all cases should indicate the precise portion of the skeleton to be examined together with the information required.

(*f*) Progress films on the treatment of fractures and other radiological examinations for following up orthopaedic cases should generally be based on definite clinical indications rather than be taken as a routine before clinical examination.

(*g*) " The Code of Practice for the Protection of Persons Exposed to Ionizing Radiations " should be strictly complied with in all centres.

(*h*) Field size should be restricted by efficiently designed light-beam collimators or cones. Lead rubber should be used to shield the body appropriately.

(*j*) At the sacrifice of some detail, exposures can be considerably reduced by more general use of fast film and the new improved fast screens.

(*k*) The use of restrictive devices when examining young children is recommended to avoid the necessity of repeat examinations due to movement.

(D) Urological

81. The risk of high gonad dosage is great in the radiological examination of the urinary tract. A large proportion of these examinations are carried out in relatively young people, in the 20–30 year age group, in their active reproductive years. When good technique is employed the reduction in dose can be remarkable and the great importance of this is obvious.

82. The technical faults responsible for the largest amount of unnecessary gonad dosage are:—

(1) The field size is too large. Too often the bladder area is included unnecessarily.

(2) Failure to use a gonad shield in the male.

General considerations applicable to all X-ray work

83. (*a*) Definite indications should be present for every radiological investigation.

(*b*) Close liaison between clinician and radiologist is essential if X-ray dosage is to be reduced.

(*c*) When a patient is transferred from one hospital or department to another, any relevant radiographs should accompany him.

(*d*) Every possible reduction in the frequency of examinations consistent with clinical efficacy is desirable, particularly in the young. The necessity for " progress " examinations is recognised but the frequency of such examinations should depend on the demands of the individual case. Junior hospital medical staff, who may unwittingly offend in this respect, should receive guidance and instruction on the matter from their seniors.

(*e*) The form of request for X-ray examinations can be improved in some hospitals. A "box " for " points for special investigation " should be included and the clinician should indicate as precisely as possible the nature of the assistance which he hopes to get from the examination.

(*f*) The radiologist should refer back to the clinician when he considers that the information given is inadequate. He should also do so where the patient's previous dosage has been excessive.

Technical factors applicable to all X-ray work

84. (*a*) Attention is drawn to the need for adequate filtration.

(*b*) Field size should be reduced to the minimum necessary in every case; light collimation with a light-beam diaphragm of good design giving a rectangular field is of the greatest assistance in restricting the size of the beam and is recommended for general use.

(*c*) Consideration should be given to the more frequent use of fast film and fast screens for certain types of work at the discretion of the radiologist. This would substantially reduce the radiation dosage, though at the sacrifice of some detail.

Specific factors applicable in urological work

85. (*a*) In view of the danger of excessive X-ray dosage, requests for X-ray examinations in urology should come from the consultant concerned.

(*b*) In males of all ages a gonad screen or shield should be used in these examinations except when it would be impracticable, e.g., in urethrograms.

(*c*) The great increase in gonad dosage which is caused by making films of the bladder area, as distinct from those made for the kidneys, is very important. Films of the bladder area should therefore be reduced to the minimum essential number and the field size must be restricted.

(*d*) During intravenous pyelography the inclusion of the whole urinary tract in each film is often unnecessary. In those stages where pictures of the kidney area only are required the pelvis should be protected by a shield.

(*e*) Fluoroscopy is to be avoided in routine diagnostic X-ray work in urology and should only be considered for exceptional cases. If fluoroscopy is ever used it is recommended that timing clocks should be incorporated in the circuit and that the use of image intensification should be considered. The recommendation in " The Code of Practice " (p. 8), that dark adaptation for 10 minutes before fluoroscopy is necessary, must be strongly emphasised.

Special Radiographic Procedures

Intravenous Pyelograms

86. (*a*) The problem of how frequently intravenous pyelograms need to be repeated, whether complete sets of films are needed each time and whether the field could be restricted if the radiologist had more information from the clinician, needs careful consideration. When an examination has to be repeated only the X-rays actually necessary should be taken.

The common current practice of making a full series of films as a routine in all cases is condemned.

(*b*) A radiologist should view the initial films, so as to determine the timing and numbers of subsequent films.

(*c*) In many cases, e.g., when an X-ray is being done to exclude the remote possibility of renal tract abnormality, the series can be cut short when normal form and function have once been demonstrated in both kidneys.

(*d*) If the blood urea is 100 mgm per ml or more, intravenous pyelography is likely to fail. Avoidable exposure to X-rays may be prevented by a prior test of renal function in appropriate cases.

(*e*) When bowel shadows obscure the kidneys in the control film, tomograms localised to both kidney areas may be helpful and save a further examination.

(*f*) In general three films of the upper urinary tract and two of the bladder area should be adequate though in individual cases more films might be necessary.

Retrograde Pyelograms

87. The use of a good technique with particular attention to restriction of field size is indicated and it would seem that fast films and fast screens will often be adequate. Collimation by a light-beam diaphragm is essential here, both for the protection of the patient and of the surgeon. Particular attention must be paid to the shielding of the gonads in taking bladder films.

88. *Cysto-urethrograms* carry an unavoidably large X-ray dose to the gonads and these examinations should only be undertaken after due consideration.

89. *Nephrograms* are often carried out on a rapid serial changer, sometimes using image intensification. Shielding of the gonads is indicated.

Perirenal Insufflation

90. Gonad shielding is indicated; the procedure may sometimes be combined with intravenous pyelography.

Other factors

Pregnancy

91. Only in very exceptional circumstances should it be necessary to make X-ray urological examinations in pregnant women.

Age

92. All the precautions discussed are of particular importance in persons under the age of 40 in whom the risk of genetic damage is most significant. In childhood there is the risk of whole trunk radiation because of the difficulty in restraining the patient and because there is a temptation to use a generous field size. The field size must be restricted. The necessity for repeat examinations is a matter for the greatest consideration.

(E) Gastro-intestinal

93. The Panel has reviewed current practice in the radiological investigation of the gastro-intestinal tract and has given special consideration to some of the procedures most frequently used.

General Considerations

94. The clinical indications for radiological investigation and the techniques to be employed need to be considered in relation to the sex and age of the patient and the history of previous radiological investigation. It is desirable, whenever radiological investigation of a patient is contemplated, to have available a record of past radiological examinations and their dates. Further study is needed of administrative arrangements for obtaining this information, especially after transfer of a patient from hospital to hospital or from region to region.

Brief Commentary on Specific Radiological Examinations

95. (*a*) *Plain Radiograph*

In this type of examination the radiation dosage is small. Plain radiography is indicated in infancy and childhood in the investigation of such conditions as imperforate anus, suspected intussusception, megacolon, intestinal obstruction, perforation of a hollow viscus and renal stone. Because of the inherent difficulties in radiography of infants and children, it is essential that protective equipment should be used so that the field size is restricted and the gonads adequately protected.

(*b*) *Barium Meal in the Investigation of Peptic Ulcer*

The initial barium meal examination of a patient suspected of peptic ulcer is both necessary and beneficial. The indications for repeating the barium meal examination vary with the circumstances. When the initial examination has revealed the presence of an ulcer, repeat X-ray examinations should be minimal and the field of examination restricted to the site of the ulcer.

(*c*) *Gastric Ulcers*

(i) *Lesser Curve Gastric Ulcers above the angulus*

It is advisable to take fresh X-rays at intervals until complete healing has occurred. The intervals between X-rays should not normally be less than four weeks. Once the ulcer has healed it is not necessary to re-X-ray unless new symptoms develop.

(ii) *Juxta-pyloric Ulcers and Antral Ulcers*

Unlike ulcers on the vertical part of the lesser curve, ulcers at or distal to the angulus involve an appreciable risk of malignancy and it may be necessary to re-X-ray more frequently at the discretion of the doctor in charge of the patient.

(*d*) *Duodenal Ulcers and Pyloric Canal Ulcers*

The progress of the healing of these ulcers should be decided on clinical grounds and, unless there are any unusual features of size or position or associated stenosis or associated gastric ulcer, further X-rays should not be necessary after the diagnosis has been established.

(*e*) *Stomal Ulcers*

Radiological evidence of ultimate complete healing is often difficult to obtain and clinical evidence is often adequate.

(*f*) *Patients with a Peptic Ulcer History with Negative Barium Meal Findings*

It is not uncommon for patients to have a negative barium meal after investigation for dyspepsia or haemorrhage. In the case of haemorrhage, although most of these bleeds are due to acute peptic ulcers, there is a small risk of neoplastic change or chronic ulceration and gastroscopy can be helpful in excluding these. It is advisable to arrange clinical re-assessment after three to six months.

(*g*) *Small Intestine*

Small intestine meals should involve little or no screening.

(*h*) *Appendix*

There would appear to be little justification for the use of the appendix meal.

(*j*) *Large Intestine*

Change in bowel habit after middle age, persistent diarrhoea and continued unexplained rectal bleeding when no extra-colonic cause is found are justifiable indications for barium enema examinations. The majority of lesions of the large intestine affect the recto-sigmoid and sigmoid colon. About 75 per cent of the carcinomas and pre-malignant adenomatous polypi are situated in these regions and are within reach of the sigmoidoscope. Therefore it is absolutely essential that digital rectal examination, bimanual pelvic examination, proctoscopy and sigmoidoscopy should be performed before a barium enema is requested. An all too common cause of repeated X-ray examination is failure of adequate preparation. The importance of careful and thorough pre-X-ray preparation is stressed. Repeated barium enema X-ray examinations are justifiable when blood is repeatedly found arising above the reach of the sigmoidoscope. A barium meal is not an essential initial examination for patients with suspected colon disease and, indeed, may be dangerous in the presence of partial obstruction. A follow-through meal may sometimes be necessary to reveal a small lesion, often inflammatory, in the right side of the colon. This is complementary to the barium enema and the field of examination should be restricted to the ileo-caecal region. In ulcerative colitis, as in duodenal ulcer, clinical assessment of progress is often of the greatest value and repeated barium enemas are seldom necessary. They may indeed even precipitate a relapse. In general, X-ray within 12 months is seldom advisable. In diverticulitis, repeated X-rays should not as a rule be necessary unless symptoms persist or become gradually worse. When it is associated with bleeding, or when there is definite evidence of changes in the bowel, repeated X-ray examinations are seldom informative and resection is indicated.

(*k*) *Extra-gastro-intestinal abdominal tumours*

Barium enema may be needed, occasionally, to localise abdominal tumours outside the gastro-intestinal tract.

Radiological Considerations

96. The published figures on dosage in gastro-intestinal examinations show wide variations not only in different countries and different hospitals but even between different individuals in the same hospital. In the light of the figures found in the national survey (Appendix I(4)) we consider that every encouragement should be given to the production and supply of devices for reducing this dosage. We advise that no new experimental techniques such as cine-radiography should be embarked on without due regard to the dosage to the individual. Although the present image intensifiers are cumbersome and expensive, we think that they should be given a more extensive trial for gastro-intestinal examinations.

(F) Thoracic and Cardiac

General Considerations

97. (*a*) It has been established already that the gonad dose with properly

conducted routine chest X-ray examinations is small; nevertheless in view of the possible cumulative effect of doses, any reduction in the frequency of the examination that can be made without detriment to the patient is desirable.

(*b*) The importance of repeat chest X-rays is recognised but the frequency of such examinations should depend upon the particular demands of each individual case and extra views, which result in a higher dose than from a single postero anterior view, should be asked for only when clinically necessary and not as a matter of routine. Junior hospital medical staff are frequently unwitting offenders in this matter of ordering routine repeat X-rays and they should be suitably instructed by their seniors. It would be beneficial to bring this point to the notice of hospital committees so that they may review their instructions to junior medical staff.

(*c*) When a patient, having been subjected to radiological examination at one centre, is transferred or attends elsewhere, the previous films should also be transferred. The mechanism whereby this transfer of films is effected is at present arbitrary and inefficient and requires immediate administrative action.

(*d*) If a patient attending a small hospital with limited X-ray facilities is found to have a chest lesion requiring extensive radiological investigations, it is desirable that the whole of the radiological examination should be carried out at a major centre to which the patient should be referred.

(*e*) It is desirable that the skills of a radiologist should be available to all chest clinics, to advise on the type of apparatus, to control techniques and technicians and to avoid the perpetration of unrecognised errors—this type of control can rarely be given by the chest physician untrained in radiology. We have seen in chest clinics mistakes where qualified technicians were giving whole body radiation to children. The chest physician would retain the function of interpreting films but the radiologist would be available for consultation.

(*f*) The working of radiological units in Cottage hospitals should be closely controlled by radiologists.

Specific factors which could result in a general reduction of exposure to radiation in thoracic work

98. (*a*) The Panel is in accord with the recommendations in the " Code of Practice for the Protection of Persons Exposed to Ionizing Radiations ".

(*b*) It is emphasised that it is important that field size must be reduced to the absolute minimum necessary in every case, preferably by the use of multiple leaf diaphragms. Diaphragms providing a square or oblong field and light collimators should be available in chest radiography.

(*c*) *Protective shields*

In addition to limiting field size it is essential that the abdomen should be protected in all chest radiography by the use of a lead rubber shield or other protective device. Particular attention should be paid to this point when dealing with infants.

(*d*) *Photo-electric timers or similar devices*

There is value in the use of such devices in that it ensures correct exposure thereby reducing the need for repeat examinations due to bad technique.

Fluoroscopy in Lung Disease

99. (*a*) Special consideration has been given to fluoroscopy, a procedure of limited value and involving higher skin and gonad dosage than is generally suspected. There is a lack of awareness in the medical profession that fluoroscopy results in a much greater dosage than filming; for example, the average skin dose in a fluoroscopic examination of the chest is some 2,000 mr compared with only 150 mr for a chest film.

(*b*) In chest radiology, fluoroscopy is only necessary when further information is required as to the nature of lesions seen on straight films.

(*c*) The importance of adequate dark adaptation of the operator conducting fluoroscopic examination is stressed.

(*d*) It is advocated that clocks should be incorporated in each unit used for fluoroscopy and should be used invariably in this examination. The clocks should be of a type to cut off the exposure when a certain time has elapsed, e.g., when a certain skin dose has been received by the patient. Re-setting allows fluoroscopy to be resumed, involving a further dose of X-ray, at the discretion of the operator. The clocks now in use in cardiac catheterisation are quite suitable for general use.

(*e*) Methods of intensifying the screen image are desirable and should be used as they become available. In the event of it becoming possible for screen luminosity to be markedly increased, without after glow, many of the problems of fluoroscopy would be resolved and such a development would be of value in reducing the radiation hazard.

Special procedures in lung and chest radiography

100. (*a*) *Tomography*

It is the opinion of the Panel that this procedure which always involves a high dosage is often carried out unnecessarily and frequently with inadequate supervision. It always involves a high dosage particularly when lateral films are taken. All tomographic procedures should be made under the control of the radiologist. Only standard tomographic apparatus should be used and " home-made " equipment should not be used unless certified as safe by a competent person. Preliminary and efficient localisation of the lesion with good postero-anterior and lateral films allows the individual tomographic procedure to be reduced. Particular attention should be paid to field size. In view of the high dosage occasioned by the lateral examination it is desirable that, if there is a strong case for lateral examination on any occasion, multi-section tomography should be used. Simultaneous multi-section tomography, in which all the pictures are taken with one exposure, is a satisfactory process provided that the screens used are specifically designed for this purpose. It is recommended that the dosage for each tomographic unit should be assessed. It is felt to be desirable that units for tomography should be centralised but it is agreed that the present strain on all radiological departments renders this impossible.

(*b*) *Bronchography*

When bronchography is performed under fluoroscopic control, the patient is likely to receive a high skin dose. In hospitals where bronchography is a daily routine, skilled personnel are able to outline the whole of the bronchial tree without fluoroscopy. The Panel considers that this technique should be used as much as possible and that fluoroscopy should seldom if ever be required for bronchography.

Special procedures in cardiac radiography

101. (*a*) *Fluoroscopy in cardiac disease*

Fluoroscopy was for a long period of the greatest value in cardiography, but radiography which gives much more information and provides a permanent record is rapidly replacing it. There is, however, still a place for fluoroscopy of the heart since it is the quickest and most convenient method of assessing heart size. Cardiologists should not be deprived of this valuable tool, but they should always conduct a fluoroscopic examination with due regard to the possible radiation hazard.

(*b*) *Angiocardiography*

Little concern need be felt on account of this procedure as long as it is restricted to certain centres. The radiological dose is generally assessed for the type of machine used and there are other circumstances which make it unlikely that an excessive dose would be given; this is not a procedure likely to be repeated often in an individual case. Attention must be paid to field size and to gonad protection, which is easy with this procedure.

(*c*) *Cardiac catheterisation*

The exposure time must always be checked by a clock. The catheter can be visualised even when using a very low intensity. The dosage involved can be substantially reduced by image intensification; this has other advantages and its use in all centres is recommended.

Mobile equipment

102. The Panel recommends that three protective aprons and two pairs of hand guards should accompany every ward mobile unit, that cones should be used, and that such mobile units should be of adequate capacity and efficiency. A number of existing portable units are of low power and are clearly inferior to high power units. It is desirable that, in order to obtain satisfactory results with diminished or reduced dosage, all mobile machines should be high power units (300 mA and 100 kVp) and that, as opportunity presents itself in the future, electrical wiring capable of supplying such units should be provided in hospitals.

Chest radiography in children

103. This is a subject of the greatest importance. Any X-ray of an infant or young child's chest is liable to result in whole trunk radiation and a very high

gonad dose. This is due to the relatively large size of the field involved and the mobility of the subject. Careful use of a protective device is essential to protect the gonads from the direct beam. This danger is also present but to a lesser extent in the case of older children unless a careful radiographic technique is adopted. Since the tissues of infants and children are believed to be particularly susceptible to radiation damage, the necessity for repeat examination requires particular consideration.

Chest radiography in pregnancy

104. Experience shows that there is value in ante-natal X-ray examination of the chest and the Panel recommends that this should be carried out in all cases as long as there exists a significant incidence of tuberculosis. Apart from this the necessity for each chest X-ray in pregnancy must be carefully considered. This examination should be carried out as infrequently as possible and particular care must be taken over the protection of the whole abdomen.

Follow-up examination of contact cases

105. Although the gonad dose using small film technique (75 or 100 mm) is very small indeed, the skin dose is appreciably greater than that with large film examinations. If 3-monthly examinations of contacts were carried out by photo-fluorography the skin dose would be the equivalent to that given by fortnightly large film examinations. It is considered that photo-fluorographic units should only be used for cases not examined more frequently than once a year.

Fast films and fast screens

106. These are desirable when they can be used without detriment to the photographic result. They are not yet suitable for chest radiography where the finest detail is necessary.

(G) Obstetric and Gynaecological

Obstetrics

107. While diagnostic radiology in obstetrics has undoubtedly contributed to the saving of lives of many mothers and babies, in general all radiological examinations should be kept to a minimum during pregnancy. In particular, radiological examinations of the urinary and alimentary tracts should whenever possible be avoided during pregnancy. Those of the sacro-iliac joints and lumbar spine should whenever possible be deferred until after confinement.

108. The time when radiation is most likely to cause foetal damage is during the first few weeks. Therefore hysterosalpingography for the diagnosis of early pregnancy is quite unjustified, and even straight X-ray examination should be employed only in exceptional circumstances. Radiological examination for the estimation of foetal maturity should be undertaken only when there is clear need. Multiple pregnancy or breech presentation may properly be established by X-ray examination when the clinical diagnosis is in any doubt. Other mal-presentations and suspected foetal abnormality fully justify X-ray examination, as does suspicion of placenta praevia when accurate clinical diagnosis is not immediately feasible.

109. Pregnant women should be submitted to pelvimetry only after thorough clinical examination by an experienced obstetrician. The full radiological exam-nation is necessary for only a small proportion of primigravidae and a very few

multigravidae, but once decided upon the examination should be thorough. Of the four radiographic projections in common use—erect lateral, antero-posterior, subpubic arch and outlet, and supero-inferior or inlet—the last named presents by far the highest dosage to both maternal ovaries and foetal gonads and should be omitted whenever possible. (Table VII).

110. In view of the relative magnitude of the maternal and foetal gonad doses delivered in obstetric X-ray procedures, especially pelvimetry, most careful radiographic technique and expert supervision is always desirable. In particular

TABLE VII

Average Gonad Doses in Milliroentgens per Exposure to Foetal Gonads and Maternal Ovaries in Pelvimetry

Projection	Dose to Maternal Ovary	Dose to Foetal Gonads
1. Antero-posterior	460	630
2. Lateral	577	535
3. Sub-pubic arch and pelvic outlet	670	140
4. Supero-inferior, pelvic inlet or Thom's	992	2,242

the beam size should be restricted to the smallest dimensions practicable in every instance.

111. At the present time routine chest X-ray examination may be expected to reveal one active and hitherto unsuspected case of pulmonary tuberculosis for every 500 pregnant women X-rayed and is therefore on this basis worthwhile. To reduce to the minimum the already small genetic hazard involved, full sized films should be used with full precautions and then preferably not after the twenty-fourth week of pregnancy.

112. In general medical and surgical practice, the possibility of pregnancy should be considered and inquiry made concerning the recent menstrual history of any woman of child-bearing age before any abdominal radiological investigations or the use of radiocative isotopes are instituted.

Gynaecology

113. Hysterosalpingography is a procedure that demands special co-operation between clinician and radiologist to restrict the number of films and the amount of fluoroscopy. The Panel considers that image intensification should be employed in this procedure whenever feasible. To reduce the exposure in fluoroscopy, full dark adaptation should be achieved before it is performed. Hysterosalpingography should not be carried out after the presumed day of ovulation.

114. In urinary stress incontinence clinical diagnostic methods are efficacious and cysto-urethrography is required only in quite exceptional circumstances.

115. Irradiation therapy is undesirable in leukoplakia vulvae and should not be pursued in pruritus vulvae et ani unless an early beneficial response is apparent. For the treatment of pelvic tuberculosis the modern anti-tuberculous drugs and surgery are the methods of choice.

116. The induction of a temporary menopause by means of irradiation of the ovaries or attempts in infertile women to stimulate the ovaries by direct irradiation cannot be justified.

(H) External Radiotherapy

General principles to be observed in radiotherapy of non-malignant disease

117. The Panel feel it would be helpful to enunciate certain general principles and, although many may appear elementary, and most are applicable to general medical radiology, their repetition may serve to emphasise their importance.

118. Radiotherapy is the treatment of choice in a number of non-malignant conditions but it is sometimes used where there exists a suitable treatment no- involving any of the possible hazards of radiation; therefore, before radiot therapy is decided upon the question of an alternative form of treatment should be considered. This applies particularly to patients of child-bearing age.

119. Close attention should be paid to the selection of a quality of rays appropriate to the depth and thickness of the lesion. For most skin affections the radiation qualities obtainable from a beryllium-window tube energized by kilovoltages from 10 to 50, with added filters where necessary, are usually hard enough. The gonads must be shielded whenever there is a danger of their being in the beam; special attention is required during treatment to the hands when the patient is in the sitting position.

120. The possibility of previous irradiation for a chronic or recurring condition demands routine investigation and must be taken into account when planning further treatment. Permanent records with full details of the technique of radiotherapy should be kept in each case and these records should be readily available and transferable to other centres if required.

Radiotherapy of non-malignant disease

Skin and allied conditions

121. Having studied conditions treated by radiations as reported in the Committee's survey (Table VIII) the Panel consider that there is little, if any, justification for the use of any form of ionizing radiations in any of the following conditions:—

Pityriasis capitis
Erythema multiforme
Sebaceous cyst
Impetigo
Pigmented mole

In some other conditions radiotherapy has a limited application and the Panel have selected the following for special comment:—

(*a*) *Acne vulgaris*

This condition tends to be self-healing and good results may be obtained from other remedies. X-rays may be indicated for the indurated type. The risk of damage from a summation of X-rays and sunlight especially in blondes must be borne in mind. It is a good rule not to treat acne vulgaris patients under the age of 17 years by X-rays. The survey recorded instances of excessively high doses being given.

(*b*) *Dermatitis, including allergic, contact and infective*

The use of X-rays is best reserved for intractable residual patches especially if fissured. If the groins are treated gonad shielding is essential.

(*c*) *Epidermophytosis*

Radiation is useless as a curative agent but may be of value in inflammatory phases resistant to other methods of therapy.

(*d*) *Furunculosis*

Generally radiotherapy is not required, but in relapsing boils in the axillae and in chronic folliculitis of the beard and of the back of the neck the use of X-rays may hasten resolution considerably. For facial furuncle X-ray treatment may be life saving.

(*e*) *Hyperhidrosis*

Some cases respond to appropriate drugs. The use of X-rays should be limited to the treatment of severe axillary sweating. The effective dose for palmar or plantar sweating is dangerously high and X-rays are best avoided.

(*f*) *Ichthyosis*

The use of X-rays is not recommended.

(*g*) *Keratosis including senile keratoma*

In senile keratoma other methods should be tried but very soft (low voltage) rays can give excellent results.

(*h*) *Lichen planus*

The use of X-rays should be restricted to the hypertrophic or verrucous forms.

(*j*) *Lichen simplex*

The introduction of effective antipruritics has reduced the need for the use of radiations.

(*k*) *Naevus, including haemangioma and lymphangioma*

Most angiomata are best treated by other methods.

(*l*) *Onychia including onycholysis*

Dystrophies and fungous infections of the nail plates are uninfluenced by ionizing rays.

(*m*) *Pruritus ani et vulvae*

Great care must be taken in the use of X-rays in this condition as the anogenital and particularly the anal region is a calamitous one in which to produce radio-dermatitis and the genetic risk is high.

(*n*) *Psoriasis*

Psoriasis frequently involves large areas of the body. Due to this and its relapsing tendency X-rays must be used with the greatest reserve.

(*o*) *Ringworm of the scalp*

It is hoped that the newer antibiotics will render X-ray epilation unnecessary.

(*p*) *Rosacea, including rhinophyma*

In general, rosacea is easily irritated by irradiations and the tendency to telangiectasia may be aggravated by X-rays: therefore X-rays should be used with caution and in small doses. Advanced rhinophyma is more effectively treated by means other than irradiation.

(*q*) *Warts*

A dose of X-rays high enough to destroy a wart with certainty would cause severe permanent radio-atrophy and, although a proportion of warts will disappear after moderate doses, other methods of treatment are preferable. X-rays should seldom be given for warts on the finger tips; usually their use for warts should be restricted to the plantar variety. Excessively high dosage and the use of unnecessarily high voltages were recorded during the survey.

TABLE VIII

External Radiotherapy for Non-malignant Disease
Skin conditions reported treated by Radiations in Hospitals and Private Practice

1	Acne vulgaris
2	Alopecia, cicatrisata
3	Blepharitis
4	Cellulitis
5	Cheilitis and angular stomatitis: rhagades
6	Darier's disease
7	Dermatitis, including allergic, contact and infective
8	Eczemas
9	Epidermophytosis
10	Erythema multiforme
11	Furunculosis (boils, sycosis barbae et nuchae, folliculitis)
12	Granuloma, including sarcoid
13	Herpes simplex, recurrent
14	Hidradenitis of axillae
15	Hyperhidrosis
16	Ichthyosis
17	Intertrigo
18	Keloid
19	Keratoses, including senile keratoma
20	Lichen planus
21	Lichen simplex, prurigo Besnier, neurodermatitis
22	Lymphocytoma
23	Molluscum sebaceum (keratoacanthoma)

24	Naevus, including haemangioma, lymphangioma, pigmented mole
25	Onychia, including onycholysis
26	Papilloma
27	Paronychia
28	Pilonidal sinus
29	Pityriasis capitis
30	Pompholyx, dyshidrosis
31	Pruritus ani et vulvae
32	Psoriasis
33	Pustular pompholyx (bacteride, pustular psoriasis)
34	Pyoderma, including impetigo
35	Reiter's disease
36	Ringworm of scalp
37	Rosacea, including rhinophyma
38	Sebaceous cyst
39	Ulcer of leg
40	Warts. (Verrucae is the Latin synonym but is often used specifically for plantar warts.)
41	Zoster

Ankylosing spondylitis

122. In the 3-month period of the Committee's survey, 437 cases, 355 males and 82 females, were given radiotherapy for this condition; 76 per cent of these were under 50 years of age and the treatment of this disease accounted for approximately one-quarter of the total genetic dose attributable to non-malignant radiotherapy. Nevertheless the benefits of radiotherapy for this serious and disabling disease are great and far outweigh any radiological hazards both genetic and somatic. On the other hand, heavy doses are seldom necessary. Special precautions are required to safeguard the ovaries when irradiating the sacro-iliac joints of women of child-bearing age. In the male, gonad shielding should be practised.

Lymphoid hyperplasia

123. Most cases of deafness from this cause were children under 15 years of age. Even though the results of these treatments are usually good in selected cases, excessive and repeated doses are to be avoided.

Radiation menopause

124. When permanent menopause is intended there is obviously no genetic risk. The Panel consider that radiations should not be used to effect a temporary menopause.

Radiotherapy of malignant disease

125. In the treatment of malignant disease the seriousness of the condition outweighs any genetic risk. The importance, however, of adequate gonad shielding, where relevant, should always be borne in mind. In females any irradiation of the pelvis for malignancy is tantamount to sterilization, and so no genetic hazard arises in such cases.

126. Owing to the danger of hormonal stimulation, women treated for cancer of the breast are usually advised to avoid future pregnancy and in many instances ovarian activity is permanently suppressed by surgery or irradiation.

(J) Internal Radiotherapy†

127. The Panel has considered the genetic hazards to patients from radioactive materials administered internally for diagnostic and therapeutic purposes for both malignant and non-malignant diseases. The statistical data from the national surveys (Appendix IV), the clinical experience of the Panel, and a study of the recent literature have been used to assess the total genetic dose. It is clear, however, that there are aspects of the subject about which there is still insufficient knowledge.

128. The only important gonad doses from the medical use of isotopes administered internally arise from the use of Iodine 131 and Phosphorus 32. The total genetically effective dose from their use is estimated at 0·18 mr per person per year. Of this, 15 per cent arises from diagnostic use and 85 per cent from therapeutic use. Of the latter, comparable contributions come from the three main uses—treatment of thyrotoxicosis and other non-malignant conditions of the thyroid by Iodine 131, of polycythaemia vera by Phosphorus 32, and of thyroid cancer by Iodine 131.

129. Thorotrast used as a contrast medium is discussed. Caution is advised in the administration of diagnostic isotopes to children, pregnant women and nursing mothers. Further research on the genetic effects of internally administered isotopes is needed.

(K) Assessment of Techniques by Physicists

130. During the survey carried out by the Committee, nearly 14,000 measurements were made of the dose received by patients undergoing radiological examinations in over 100 hospitals throughout Great Britain. Thus the physicists making these measurements were able to observe the variety of techniques that prevail in the present practice of diagnostic radiology in this country and to suggest means of improving them.

131. The predominant comment is that field sizes are often excessive and it would appear that the greatest scope for reduction of the dose to the patient lies in a reduction of field size. The use of efficient light beam collimators is of particular importance and in general, especially with large fields, the use of rectangular rather than circular fields is much to be commended. The hallmark of sound radiographic technique should be for all the edges of the beam of radiation to show on the margin of the film. This will often enable the gonads to be kept outside the main beam and ensures that the bone-marrow exposed is a minimum.

132. The fitting of filters to X-ray tubes is proceeding throughout the country. A specified amount of filtration should be fitted to all new tubes by their manufacturers and the users should be made fully aware of its importance and of not removing it. In addition, mobile X-ray equipment should be fitted with a device which only allows exposure for some pre-determined period, e.g., 10 seconds continuously.

† Summary only.

133. Higher speed films or screens could sometimes be used with no sacrifice of clarity. The use of a grid increases the dose to the patient, but may, on the other hand, be justified by the great improvement in the film. The use of high ratio grids in conventional techniques, however, merely gives an unnecessarily high dose to the patient.

134. Obsolete and erratic equipment should be replaced. Such faulty equipment must lead to unnecessary repeat examinations. To reduce repeat examinations there is also a great need for immobilising devices to hold patients undergoing examinations (in particular children and orthopaedic patients).

135. Extra radiation is often received when films need to be repeated because of the inexperience or lack of supervision of junior radiographers, or because of undue haste in staff working short-handed. In small hospitals making only a few examinations the X-ray technique may be poor and excessive doses may result. Every radiological department should have a sufficient and adequately trained staff.

136. In some hospitals the physicists working in this survey have been able to co-operate with radiologists in methods of reducing the dose to the patient. Such co-operation should be encouraged.

PART V. SUMMARY

Introduction

137. The existing state of knowledge concerning the effect of ionizing radiations on human beings is reviewed. (Paras. 2 to 3)

138. Reference is made to the various sources of ionizing radiations to which the human race is subjected. In countries with extensive medical facilities, medical radiology provides the largest man-made contribution. (Paras. 4 to 5)

139. Two nation-wide surveys were organised by the Committee. They were supplemented by physical measurements carried out in a representative sample of hospitals and chest clinics, and by a separate investigation of radiotherapeutic procedures. The results were assessed by ten specialist panels, which have made recommendations. (Paras. 6 to 10)

140. The total annual genetic dose from all medical radiology in 1957 has been calculated to be 19·3 mr per person. This is less than that estimated by the Medical Research Council in 1955 for medical diagnostic radiology alone, and the gonad dose is small in comparison with that considered by the Medical Research Council to be acceptable to the individual without causing undue concern on behalf of himself or his offspring. The dose will be reduced further by adoption of our recommendations. (Paragraph 11)

Determination of the Genetic Dose to the Population

141. The methods and results of the radiological surveys are described and assessed under four headings: (Paras. 12 to 57)

General diagnostic radiology

142. The genetic doses to the individual and to the population are defined, and the methods of calculation described. The following surveys were conducted:—

(i) A questionnaire designed to ascertain the total amount of medical and dental radiology carried out in the week beginning 29th April, 1957;

(ii) another questionnaire sent to a random sample (approximately one in four) of National Health Service hospitals, covering the week beginning 2nd December, 1957;

(iii) physical measurements to determine the gonad dose from different types of X-ray examination at 130 hospitals selected at random. (Paras. 12 to 27.)

143. The reports of the measurements were accompanied by details enabling the dose to be related to the technique. The results are considered and the genetic dose analysed, the details being presented in Appendix I. The total annual genetic dose from diagnostic radiology is estimated at 14·1 mr per person. This is less than the estimate of the Medical Research Council in 1956. Higher kilovoltage and extra filtration do not necessarily reduce the gonad dose. (Paras. 28 to 35)

Mass miniature radiography

144. The Committee issued an interim report in May, 1959. A survey on four typical mass miniature equipments showed that the gonad doses were less than those given in the Medical Research Council's report of 1956, and that the

contribution to the total genetic dose received by the population from this source—estimated at 0·01 mr per person per year—was also less than that in the 1956 report, even allowing for the increased numbers examined in recent years. (Paras. 36 to 40.)

Dental radiography

145. A survey of the gonad doses received by patients was conducted in 154 dental surgeries and hospitals, using a special film technique. Replies to a questionnaire were inconclusive but an estimate was made of the total amount of dental radiology. The calculation of the results indicated an annual contribution of 0·01 mr per person, which is again less than that in the 1956 Report. (Paras. 41 to 45.)

Radiotherapy

146. The numbers and types of non-malignant and malignant diseases treated were derived from a three months national survey. The methods of calculating the gonad doses from measurements on a model are described. The annual genetic dose from radiotherapy of non-malignant conditions was found to be 4·5 mr per person, from radiotherapy of malignant conditions 0·5 mr, and from the use internally of radioactive isotopes 0·18 mr. (Paras. 46 to 57.)

Summation of the Results of the Radiological Surveys

147. A summation of the results of the radiological surveys is presented in terms of milliroentgens (mr) per head of population. The annual genetic dose from general diagnostic radiology (14·1 mr) is less than was estimated in the report of the Medical Research Council in 1956, but it still contributes the major fraction of the total genetic dose from the medical use of ionizing radiations. This is followed by radiotherapy for non-malignant conditions (4·5 mr) and radiotherapy for malignant conditions (0·5 mr). The contributions from mass miniature radiography, dental radiography and radioactive isotopes amount to 0·2 mr. The total annual genetic dose, estimated at 19·3 mr per person, is smaller than that attributed to diagnostic radiology alone in the 1956 report. Detailed calculations were made of the accuracy of the result for general diagnostic radiology, but it was not possible to make a similar assessment of the accuracy of the fertility factors. The accuracy is well within the recommended limits. (Paras. 58 to 60.)

148. Poor techniques in a proportion of diagnostic examinations strongly influenced the average gonad dose. It has been calculated from the survey results that for each type of examination separately, bringing the techniques in the 10 per cent of hospitals showing the highest doses up to the standard of the average technique of all the other hospitals would in total reduce the genetic dose to about 70 per cent of that now estimated. If all techniques were raised to the standard shown by the 25 per cent of hospitals showing the lowest doses, the annual genetic dose would be lowered to somewhere in the region of 2 mr per person. An overall reduction to about 6 mr for medical radiology as a whole appears to be attainable. (Paras. 61 to 62.)

Reports of the Clinical Panels

149. The results of the surveys were studied in their clinical aspects by nine specialist panels and by a panel of physicists. These panels made recommenda-

tions on how the dose to the gonads might be reduced in diagnostic and therapeutic radiological practice, without detriment to the value of these procedures. Observations on current radiological practice were made by a panel of physicists. (Paras. 63 and 66.)

(*A*) *Mass miniature radiography*

150. The figures in the Committee's interim report, 1959, are supplemented by statistics for 1958. It was concluded that mass miniature radiography examinations conferred many benefits and were a relatively unimportant source of gonad radiation exposure. The Committee recomended, however, that the procedure should not be used for case-finding among children or pregnant women. (Paras. 67 to 69.)

(*B*) *Dental*

151. The procedure is considered in relation to patients in pain, to orthodontic patients (mainly children), to those receiving regular routine treatment and those with gross infection or suspected tumour. Recommendations are made for reducing the genetic dose still further. (Paras. 70 to 77.)

(*C*) *Orthopaedic*

152. Special care is needed since so many patients are children or of child-bearing age. Close liaison is needed between orthopaedists and radiologists. Possible improvements in technique are described. (Paras. 78 to 80.)

(*D*) *Urological*

153. The risk from X-ray examinations is necessarily high, and every possible reduction in the frequency of examinations is desirable. Some radiographic procedures call for very particular attention and care. The use of the best techniques is again stressed. (Paras. 81 to 92).

(*E*) *Gastro-intestinal*

154. Much information and benefit derives from these procedures, but their use must be closely considered in relation to the age and sex of the patient and previous X-ray history. In certain conditions, clinical assessment of progress is sufficient and further radiography can be avoided. Barium enemas should only be requested when considered absolutely essential. Techniques for reducing the dosage in all examinations are again emphasised. (Paras. 93 to 96.)

(*F*) *Thoracic and cardiac*

155. Clear-cut indications should exist for every radiological examination of the chest. Repeat examinations should never be asked for as a matter of routine. Fluoroscopy is not necessary in pulmonary radiography unless to determine the nature of lesions already revealed by straight films. Tomography and other special procedures require specialised control. Mobile units in wards and theatres must have appropriate protection. Techniques for reducing dosage are recommended. (Paras. 97 to 106.)

(*G*) *Obstetric and gynaecological*

156. Whilst the great value of radiology in obstetrics is recognised so also is the need to reduce radiological examinations during pregnancy to a minimum. The Panel outlines conditions in which radiology is justifiable and when it should not be used. Thorough clinical examination should precede any request for

pelvimetry and then the radiographic projections giving the highest dose should be omitted whenever possible. The need for the most careful techniques and expert supervision is emphasised. Radiological procedures in gynaecology usually entail large gonad doses and demand special co-operation between clinician and radiologist and the employment of every means to reduce radiation dosage. The induction of a temporary menopause by irradiation of the ovaries is considered undesirable. (Paras. 107 to 116.)

(*H*) *External radiotherapy*

157. Over half of the total genetic dose from non-malignant radiotherapy comes from the treatment of skin conditions. The precautions needed in treating these are emphasised and recommendations concerning treatment of individual conditions given. In the treatment of ankylosing spondylitis, the benefits of irradiation outweigh any genetic risk. In malignant disease the genetic risk rarely requires consideration. (Paras. 117 to 126.)

(*J*) *Internal radiotherapy*

158. The only internally administered radioactive isotopes which give rise to any appreciable gonad dose are Iodine 131 and Phosphorus 32 and this occurs during treatment of thyrotoxicosis, and of thyroid cancer, and of polycythaemia vera in roughly equal proportions. (Paras. 127 to 129.)

(*K*) *Assessment of techniques by physicists*

159. The variety of techniques used during the practice of radiology, observed by the physicists in the course of their survey, is commented on. Field sizes were often found to be excessive. Measures to remedy this are outlined. The use of adequate tube filtration, of higher speed films or screens, and of timing devices, is advocated. Every radiological department should have sufficient and adequately trained staff. Co-operation between radiologists and physicists in their efforts to reduce radiation exposure should be encouraged. (Paras. 130 to 136.)

CONCLUSIONS

160. Our survey shows that all medical radiology in 1957/8, both diagnostic and therapeutic, resulted in a genetic dose of 19·3 mr per person per year. The main contributions to this total genetic dose are derived from diagnostic radiology (14·1 mr), radiotherapy of non-malignant conditions (4·5 mr), radiotherapy of malignant conditions (0·5 mr), whilst minor contributions are made by the medical uses of radioactive isotopes (0·18 mr), mass miniature radiography (0·01 mr) and dental radiography (0·01 mr).

161. The figure of 14·1 mr for diagnostic radiology in 1957/8, obtained from a nation-wide survey after radiological practice had begun to be influenced by the Medical Research Council's report, is less than that given (22 mr) by the Council for the year 1955. It is also less than the level that has been calculated in other countries with comparable radiological facilities.

162. No figure for the contributions from radiotherapy to the genetic dose to the population has so far been available in this country, but the national surveys which we have conducted have now provided a firm basis for the calculation of a figure of 5·2 mr.

163. We do not believe that the levels indicated show any need for major restrictions in radiological practice and we are convinced that the number and type of examinations or treatments must be dictated by the clinical needs of the patient.

164. In view, however, of the increasing use of ionizing radiations in the many activities of our present daily life and the greater opportunities for exposure of the population, it is necessary to reduce the gonad dose wherever possible.

165. We are convinced that in many instances of diagnostic and therapeutic procedures this dose could be substantially reduced without any detriment to the efficiency of the examination or treatment.

166. If the recommendations which we have set out below are carried out we are satisfied that the total annual genetic dose to the population from all forms of medical radiology can be reduced to a figure of 6 mr or less.

167. Our survey has also shown that in the present circumstances the dose to the gonads from any X-ray examination is small in comparison with that considered by the Medical Research Council to be acceptable to the individual without causing any undue concern on behalf of himself or his offspring. The dose will be reduced still further by the adoption of our recommendations.

168. We would emphasise that any possible genetic risk from these doses must be weighed against the undoubted benefits which are conferred upon the individual and the population by diagnostic and therapeutic radiology. We confirm the opinion expressed in our interim report that " much individual suffering would follow any unnecessary curtailment of those services ".

RECOMMENDATIONS

I. GENERAL

(*a*) There should be clear-cut clinical indications before any X-ray examination is undertaken, and it should be ascertained whether there has been any previous radiological examination which would make further examination unnecessary. For this purpose the case sheet should have a section labelled " previous X-rays ".

(*b*) To reduce unnecessary examinations, arrangements should be made for the ready availability of previous films and for the routine transfer of films from one hospital to another.

(*c*) All requests for examinations should state precisely the clinical indications and the information required.

(*d*) There should be consultation between clinician and radiologist before extensive or repeated radiological examinations of young individuals are undertaken. It must be realised that radiological exposure is just as much the responsibility of the clinician as of the radiologist.

(*e*) To reduce the necessity for repeat investigation strict attention should be paid to adequate preparation of the patient before abdominal investigation.

(*f*) Special precautions should be adopted in the radiography of pregnant women. Only essential examinations should be carried out during pregnancy and particular care should be taken to avoid irradiation of the foetus whenever possible. In all women of child-bearing age the clinician requesting the examination should never overlook the possibility of early pregnancy.

(*g*) Any previous history of radiotherapy should be ascertained before a new course of treatment is undertaken. Permanent records of all radiotherapy should be maintained and be readily available for transfer from one hospital to another.

(*h*) Consideration should always be given to alternative methods of treatment before radiotherapy for non-malignant conditions is undertaken.

II. TECHNIQUES

In every radiological examination, care should be taken to reduce to a minimum the irradiation of the gonads. The steps necessary to this end are discussed throughout the Report. In particular, strict attention should be paid to the following:—

1. General to all forms of radiology

(*a*) *Limitation of field size*

Strict limitation of field size to the area necessary for the particular examination or treatment should be routinely practised. In diagnostic radiology, this should be done by fitting light beam diaphragms rather than circular cones, particularly when a large field size is used.

(*b*) *Beam direction*

Whenever possible, the beam should not be directed towards the gonads and this should be borne in mind particularly in examinations or treatments of the limbs, especially of the hands with the patient in the sitting position.

(*c*) *Gonad shields*

Adequate gonad shields should invariably be used in examinations or treatments which are likely to give a high gonad dose, unless they interfere with the proposed examination or treatment.

(*d*) *Immobilizing devices*

In the examination or treatment of children or patients who need support, mechanical devices to ensure immobilization should be used.

2. **Particular to radiography**

(*a*) *High speed films and screens*

The use of the fastest films and screens consistent with satisfactory diagnostic value is strongly recommended.

(*b*) *Automatic timing devices*

Repeat exposures should be kept to a minimum by the use of photo-electric timers or similar devices. Where these are not practicable, accurately pre-set timing devices should be readily available.

3. **Particular to fluoroscopy**

(*a*) *Limitation of use*

Fluoroscopy should not be undertaken if the same information can be obtained by radiography. It should not be used for locating metallic foreign bodies at operations as electronic metal-locating equipment is now available.

(*b*) *Dark adaptation*

No fluoroscopic examination should be undertaken without adequate dark adaptation on the part of the clinician undertaking the examination (at least 10 minutes).

(*c*) *Automatic switches*

All fluoroscopy machines should be fitted with a clock, or other timing device, which automatically cuts off the beam after a certain time or a certain dose.

(*d*) *Image intensification*

More general use should be made of image intensification in such examinations as cardiac catheterisation. There is urgent need for more research into the problems of image intensification for medical purposes.

4. **Particular to mass miniature radiography**

In accordance with the recommendations of our Interim Report, chest examinations of pregnant women should not be carried out with mass miniature techniques, but by full size films with strict limitation of field size. For the chest radiography of children and adults of short stature either technique may be used, so long as adequate steps can be taken to exclude the gonads from the X-ray beam; otherwise large films should be used.

5. **Particular to radiotherapy**

(*a*) In the treatment of skin conditions, use should always be made of the softest quality of radiation consistent with adequate irradiation of the tissues to be treated.

(*b*) Radiation should not be applied to the ovaries for the production of a temporary artificial menopause, or for the treatment of infertility.

III. EQUIPMENT

1. Checks should be made regularly to ensure that all radiological equipment is maintained to the standard laid down in the Code of Practice for the Protection of Persons Exposed to Ionizing Radiations. Obsolete and erratic equipment should be replaced immediately.
2. The development of automatic devices, and particularly those which reduce the risks of human error, should be actively encouraged.

IV. STAFF AND TRAINING

1. Attention should be given to the provision at all times of adequate medical and technical staff in radiological departments.
2. In sparsely populated areas where radiologists or radiographers are not available, training in the safe use of equipment should be given to the general practitioners or nurses who have to carry out any minor X-ray examinations.
3. Adequate instruction should be given in the medical and dental undergraduate curricula on the uses and hazards of ionizing radiations.

V. SURVEILLANCE

The genetic dose to the population from diagnostic and therapeutic radiology should be kept under effective review by the Health Departments.

Signed on behalf of the Committee,

Adrian. (Chairman)

November, 1960.

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* Appointed August, 1957.
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APPENDIX I

GENERAL DIAGNOSTIC RADIOLOGY

(1) STATISTICAL SURVEYS

First statistical survey for the week beginning 29th April, 1957

The questionnaire sent to all hospitals in the National Health Service asked for the following information relating to diagnostic radiology:—

(*a*) A list of X-ray equipment and a record of the total number of films used during the week under review.

(*b*) The numbers of patients examined and the numbers of films used in each of 32 types of examination divided into sex and age groups 0–14, 15–29, 30–49 and 50 +.

(*c*) The numbers of patients examined by fluoroscopy and the screening times in each of 11 types of examination classified by sex and by the same four age groups.

Almost all hospitals completed the questionnaire and the few which did not were small hospitals which could be reasonably assumed to have no X-ray equipment. The number of X-ray examinations recorded was therefore taken to be the total for all National Health Service hospitals in the week of the survey.

In age groups 15–29 and 30–49 the numbers of examinations of females ascertained to be pregnant were also requested. Returns however, showed that it was not possible to obtain enough information to be of use in determining the number of foetuses irradiated.

Second statistical survey for the week beginning 2nd December, 1957

The second statistical survey was designed to give information on radiological practice at a different time of the year to take account of seasonal variations in the frequency of X-ray examinations. It was considered sufficient for this purpose to send a questionnaire to a sample of hospitals and chest clinics—approximately one in four—selected at random from the National Health Service hospitals known to have X-ray equipment. Returns were made by 91 per cent of the hospitals and chest clinics selected and the final sampling fraction was calculated to be 1 in 4·36. The information required was similar to that in the first questionnaire but the categories of examination types were modified slightly to conform more closely to proposals made by the International Commissions on Radiological Protection and Radiological Units and Measurements (1957) and 11 age groups were used. No further requests were made for information on the numbers of women ascertained to be pregnant.

Tabulation of the survey data

The results of the first questionnaire excluding military hospitals were tabulated by region and type of hospital for the purpose of planning the numbers and distribution of measurements in the physical dose survey. It is impossible to present it in such detail here and Tables 1 to 5 relating to the two surveys are therefore restricted to:—

(*a*) the numbers of each type of radiological examination in each age group;

(*b*) the numbers of films used for each type of examination at all ages;

(*c*) the numbers of each type of fluoroscopic examination in each age group;

(*d*) the average fluoroscopic exposure for examinations of each category at all ages.

TABLE I

First Questionnaire—Week beginning 29th April, 1957

Numbers of Radiographic Examinations

Examination	Males					Females					Total
	Age Group					Age Group					
	0–14	15–29	30–49	50+	Total Males	0–14	15–29	30–49	50+	Total Females	
1 Dental	193	271	261	137	862	181	361	260	173	975	1,837
2 Head	2,594	1,813	2,134	1,859	8,400	1,612	1,235	1,666	1,703	6,216	14,616
3 Neck, Cervical, spine	192	268	741	842	2,043	116	271	886	1,000	2,273	4,316
4 Trachea, Thoracic Inlet	80	71	135	180	466	57	136	222	200	615	1,081
5 Chest, Ribs	8,502	12,141	19,047	21,904	61,594	7,671	19,378	18,795	14,485	60,329	121,923
6a Abdomen (Excl. Gonads)	170	235	528	735	1,668	152	257	513	715	1,637	3,305
6b Abdomen (Incl. Gonads)	451	297	647	1,027	2,422	398	572	781	1,155	2,906	5,328
7 Pelvis	850	1,078	2,123	2,670	6,721	831	976	2,107	3,935	7,849	14,570
8 Shoulder	524	655	611	832	2,622	349	235	450	996	2,030	4,652
9 Arm, Elbow	1,928	845	832	543	4,148	1,220	368	489	717	2,794	6,942
10 Hand, Finger, Wrist	2,966	3,637	3,007	1,743	11,353	1,756	1,151	1,476	2,873	7,256	18,609
11 Femur	347	317	265	359	1,288	197	86	133	656	1,072	2,360
12 Knee	590	960	1,014	894	3,458	389	380	550	1,442	2,761	6,219
13 Tibia, Fibula, Foot & Ankle	2,370	3,370	2,928	2,091	10,759	1,700	1,508	1,789	2,435	7,432	18,191
14 Bronchogram	36	74	113	118	341	38	75	78	21	212	553
15 Barium Swallow	68	55	183	273	579	46	66	207	307	626	1,205
16 Barium Meal	112	676	2,136	2,584	5,508	87	387	1,411	2,167	4,052	9,560
17 Barium Enema	40	60	301	699	1,100	27	87	352	997	1,463	2,563

TABLE 1—*continued*

Examination	Males					Females					Total
	Age Group					Age Group					
	0–14	15–29	30–49	50+	Total Males	0–14	15–29	30–49	50+	Total Females	
18 Pyelogram	150	325	770	1,121	2,366	154	410	791	781	2,136	4,502
19 Cholecystogram	3	42	274	420	739	9	133	650	1,124	1,916	2,655
20 Cystogram	14	5	23	73	115	12	13	27	47	99	214
21 Hysterosalpingography ..	—	—	—	—	—	—	120	100	1	221	221
22 Pelvimetry	—	—	—	—	—	—	428	148	—	576	576
23 Pregnancy	—	—	—	—	—	—	1,104	686	—	1,790	1,790
24 Neurological Exam.	21	30	51	62	164	15	25	30	41	111	275
25a Angiography, Head	6	15	45	57	123	4	2	39	42	87	210
25b Angiography, Chest	5	22	33	27	87	12	20	20	9	61	148
25c Angiography, Abdomen ..	—	1	14	19	34	1	5	3	11	20	54
26a Tomography, Head	—	8	12	22	42	2	14	12	7	35	77
26b Tomography, Chest	15	214	439	348	1,016	16	258	260	84	618	1,634
26c Tomography, Abdomen ..	4	8	5	7	24	2	7	11	10	30	54
27 Others	99	442	788	474	1,803	79	465	301	237	1,082	2,885
Totals	22,330	27,935	39,460	42,120	131,845	17,133	30,533	35,243	38,371	121,280	253,125

TABLE 2

First Questionnaire—Week beginning 29th April, 1957
Numbers of Fluoroscopic Examinations

Type of Examination	Age Group				Total Patients	Average Exposure in Minutes
	0–14	15–29	30–49	50+		
MALES						
1. Chest and Heart	520	1,832	2,704	1,589	6,645	1·12
2. Bronchogram	13	18	25	24	80	2·13
3. Barium Swallows	61	73	226	337	697	2·98
4. Barium Meals	104	643	2,064	2,468	5,279	5·72
5. Barium Enemas	36	55	299	653	1,043	4·99
6. Pyelography	11	9	10	20	50	2·68
7. Cystography	2	—	1	8	11	2·32
8. Cholecystography	—	6	27	28	61	2·12
9. Hysterosalpingography	—	—	—	—	—	—
10. Cardiac Catheterization	6	6	6	5	23	14·30
11. Others	18	26	75	57	176	3·00
Total	771	2,668	5,437	5,189	14,065	
FEMALES						
1. Chest and Heart	397	2,266	2,162	964	5,789	1·20
2. Bronchogram	13	8	19	6	46	1·80
3. Barium Swallows	44	69	217	314	644	2·66
4. Barium Meals	85	374	1,353	2,032	3,844	6·09
5. Barium Enemas	25	72	319	943	1,359	5·17
6. Pyelography	4	8	13	11	36	3·99
7. Cystography	1	1	1	4	7	2·68
8. Cholecystography	2	16	58	91	167	2·63
9. Hysterosalpingography	1	69	64	2	136	2·15
10. Cardiac Catheterization	4	11	10	4	29	11·09
11. Others	16	43	52	48	159	3·29
Total	592	2,937	4,268	4,419	12,216	

Total number of examinations in 1957

Radiographic and fluoroscopic examinations were reported separately so that examinations consisting of both were reported twice. The number of radiological examinations has been derived by adding to the number of radiographic examinations only those fluoroscopic examinations thought unlikely to be associated with radiography, i.e. all cardiac catheterizations and one half of the chest and heart fluoroscopic examinations.

The total number of examinations thus obtained for the week of the first survey was 259,477 and that derived by multiplying the results of the second survey by the sampling factor 220,260. The difference between these two figures is in reasonable accord with the Ministry of Health figures for the monthly supply of X-ray film in the months of May and December, 1957. Calculations of the annual number of examinations, (*a*) by multiplying up to one year and (*b*) by making a further allowance for a monthly variation based on film consumption, are set out below.

Survey Week	No. of Examinations	Sampling Fraction	Fraction of Year's Film Consumption	No. of Examinations in 1957 in millions	
				(*a*)	(*b*)
April/May	259,477	1·000	0·0922	13·53	12·46
December	50,501	4·3615	0·0735	11·48	13·27

In the light of these results the number of X-ray examinations has been taken as 13·0 million for 1957.

TABLE 3

Second Questionnaire—Week beginning 2nd December, 1957

Numbers of Radiographic Examinations of Males

Type of Examination	Age Group											Total Patients	Total Films
	Under 2	2–4	5–9	10–14	15–19	20–24	25–29	30–39	40–49	50–59	60+		
1. Hip and Femur (Upper Third) ..	7	17	34	22	29	22	18	35	36	51	111	382	787
2. Femur (Middle and Lower Third)..	—	12	16	18	30	51	22	39	51	43	56	338	719
3. Pelvis	10	10	23	10	16	17	28	45	48	45	95	347	456
4. Pelvimetry	—	—	—	—	—	—	—	—	—	—	—	—	—
5. Lumbo-Sacral	1	1	5	6	13	31	41	77	87	91	70	423	1,075
6. Lumbar Spine	—	5	6	15	26	43	59	116	164	139	112	685	1,801
7. Intravenous Pyelogram	3	5	10	9	10	17	30	54	89	95	126	448	2,738
8. Retrograde Pyelography	—	—	1	1	1	4	2	14	9	10	20	62	236
9. Barium Swallow	1	—	—	2	—	5	4	16	20	30	33	111	315
10. Barium Meal													
(*a*) Stomach and Duodenum ..	1	2	1	4	8	46	77	129	180	228	214	890	3,755
(*b*) Complete and Follow through	—	—	5	3	1	18	21	47	43	82	51	271	1,344
11. Barium Enema	1	—	—	—	2	3	8	19	28	53	88	202	882
12. Abdomen (Obstetrical)	—	—	—	—	—	—	—	—	—	—	—	—	—
13. Abdomen (Others)	22	15	31	25	12	29	33	67	79	96	181	590	1,008
14. Salpingography	—	—	—	—	—	—	—	—	—	—	—	—	—
15. Cystogram	—	—	1	1	—	—	—	1	1	5	13	22	107
16. Cholecystography	—	—	—	—	2	6	14	23	52	59	89	245	760
17. Chest (Lung, Heart)	295	235	532	649	557	793	760	1,614	1,848	2,264	2,261	11,808	14,664
18. Head (including Cervical Spine) ..	43	75	163	136	154	178	147	271	271	268	243	1,949	5,658

TABLE 3—*continued*

Type of Examination	Age Group											Total Patients	Total Films
	Under 2	2–4	5–9	10–14	15–19	20–24	25–29	30–39	40–49	50–59	60+		
19. Bony Thorax (Ribs, Sternum, Clavicle)	4	3	5	14	21	27	30	53	82	71	57	367	693
20. Dorsal Spine	3	3	3	5	15	19	23	42	50	46	39	248	537
21. Shoulder Girdle	4	5	16	42	42	48	36	87	63	84	101	528	811
22. Arm (including Forearm and Hand)	28	63	170	371	325	277	239	430	328	280	200	2,711	3,758
23. Leg and Foot	22	54	115	221	273	296	206	363	364	274	242	2,430	4,306
24. Dental	—	4	20	35	26	41	31	54	23	23	10	267	722
25. Neurological (Examination by contrast media only)	—	2	1	—	3	1	1	5	6	9	3	31	331
26. Angiography (Head)	—	—	—	—	2	1	1	5	8	20	7	44	378
27. Angiography (Chest)	—	—	—	—	—	—	—	—	—	—	1	1	5
28. Angiography (Abdomen)	—	—	—	—	1	—	—	—	2	3	7	13	75
29. Tomography (Head)	—	—	—	—	—	—	—	—	3	4	3	10	69
30. Tomography (Chest)	—	—	1	1	3	20	24	37	55	49	36	226	1,483
31. Tomography (Abdomen)	—	—	—	—	—	1	2	1	1	—	1	6	37
32. Bronchogram	—	—	3	1	4	2	7	12	17	18	7	71	269
33. Others	—	3	2	3	5	10	20	28	33	19	21	144	383
Total	445	514	1,164	1,594	1,581	2,006	1,884	3,684	4,041	4,459	4,498	25,870	50,162

c

TABLE 4

Second Questionnaire—Week beginning 2nd December, 1957

Numbers of Radiographic Examinations of Females

Type of Examination	Age Group											Total Patients	Total Films
	Under 2	2–4	5–9	10–14	15–19	20–24	25–29	30–39	40–49	50–59	60+		
1. Hip and Femur (Upper Third) ..	23	15	14	28	21	6	5	30	29	76	318	565	1,256
2. Femur (Middle and Lower Third)..	3	4	3	16	15	8	1	18	21	30	88	207	427
3. Pelvis	6	4	8	16	13	18	17	40	80	65	124	391	504
4. Pelvimetry	—	—	—	—	7	25	21	14	2	1	—	70	137
5. Lumbo-Sacral	—	—	4	6	17	22	31	88	100	97	83	448	1,111
6. Lumbar Spine	3	3	7	16	21	33	35	87	149	122	141	617	1,621
7. Intravenous Pyelogram	3	4	8	10	19	29	31	70	83	71	64	392	2,353
8. Retrograde Pyelography	—	—	1	1	2	4	9	11	13	19	16	76	289
9. Barium Swallow	3	3	4	3	2	1	11	30	21	32	45	155	454
10. Barium Meal													
(*a*) Stomach and Duodenum ..	2	—	—	3	16	26	23	78	115	157	209	629	2,586
(*b*) Complete and Follow through	1	1	1	2	5	8	14	34	28	40	80	214	1,111
11. Barium Enema	—	1	2	3	3	5	8	18	48	74	120	282	1,297
12. Abdomen (Obstetrical)	—	—	—	—	20	99	79	89	10	3	—	300	404
13. Abdomen (Others)	18	21	23	19	15	29	36	73	78	97	187	596	872
14. Salpingography	—	—	—	—	—	3	15	15	1	2	1	37	89
15. Cystogram	—	1	1	—	—	—	1	1	1	8	3	16	60
16. Cholecystography	—	—	1	—	2	11	21	54	82	115	124	410	1,341
17. Chest (Lung, Heart)	195	220	458	595	950	1,367	1,190	1,910	1,613	1,321	1,535	11,354	13,854
18. Head (including Cervical Spine) ..	27	43	110	114	99	109	98	201	250	261	309	1,621	4,482

TABLE 4—*continued*

Type of Examination	Age Group											Total Patients	Total Films
	Under 2	2–4	5–9	10–14	15–19	20–24	25–29	30–39	40–49	50–59	60+		
19. Bony Thorax (Ribs, Sternum Clavicle)	5	5	6	9	9	14	7	21	41	49	70	236	416
20. Dorsal Spine	2	5	6	16	12	9	15	35	59	55	91	305	661
21. Shoulder Girdle	8	8	11	16	20	16	12	31	56	74	126	378	563
22. Arm (including Forearm and Hand)	26	47	144	259	161	89	85	159	228	356	457	2,011	2,857
23. Leg and Foot	15	25	73	179	104	80	88	161	255	302	361	1,643	2,905
24. Dental	—	4	30	48	28	55	51	56	31	29	17	349	962
25. Neurological (Examination by contrast media only)	1	1	1	1	3	2	2	2	6	4	2	25	219
26. Angiography (Head)	—	1	—	1	2	1	—	1	8	12	3	29	270
27. Angiography (Chest)	—	—	—	—	—	—	—	—	—	—	—	—	—
28. Angiography (Abdomen)	—	—	—	—	—	—	—	—	—	2	—	2	6
29. Tomography (Head)	—	—	—	—	—	1	—	1	2	2	2	8	49
30. Tomography (Chest)	—	1	1	1	10	24	22	43	19	15	8	144	918
31. Tomography (Abdomen)	—	—	—	—	—	—	—	1	—	1	—	2	11
32. Bronchogram	—	—	2	5	5	4	4	16	10	6	—	52	215
33. Others	1	2	4	10	11	17	18	22	32	33	40	190	517
Total	342	419	923	1,377	1,592	2,115	1,950	3,410	3,471	3,531	4,624	23,754	44,817

TABLE 5

Second Questionnaire—Week beginning 2nd December, 1957

Numbers of Fluoroscopic Examinations

Type of Examination	Age Group											Total Patients	Average Exposure in mins.
	Under 2	2–4	5–9	10–14	15–19	20–24	25–29	30–39	40–49	50–59	60+		
MALES													
1. Chest and Heart	2	6	19	29	31	101	118	191	181	159	117	954	0·75
2. Bronchogram	—	—	—	—	—	—	6	1	1	1	—	9	3·33
3. Barium Swallow	4	1	—	1	2	7	5	16	21	37	34	128	1·79
4. Barium Meal													
(*a*) Stomach and Duodenum ..	1	—	—	2	5	39	42	106	162	161	173	691	3·73
(*b*) Complete (including Follow through)	—	1	5	3	1	18	24	33	31	75	42	233	3·64
(*c*) Not defined	1	2	—	2	3	15	25	32	42	72	63	257	3·35
5. Barium Enema	—	—	1	—	4	3	9	27	30	63	105	242	3·48
6. Pyelography	—	—	—	—	—	—	1	1	4	2	1	9	1·69
7. Cystography	—	—	—	—	—	—	—	—	—	—	—	—	—
8. Cholecystography	—	—	—	—	—	—	2	3	5	5	5	20	3·08
9. Cardiac Catheterization	—	—	1	—	—	—	—	—	—	1	—	2	15·00
10. Others	—	—	—	—	2	4	5	3	8	6	6	34	4·75
Total	8	10	26	37	48	187	237	413	485	582	546	2,579	

TABLE 5—*continued*

Type of Examination	Age Group											Total Patients	Average Exposure in mins.
	Under 2	2–4	5–9	10–14	15–19	20–24	25–29	30–39	40–49	50–59	60+		
FEMALES													
1. Chest and Heart	3	12	27	23	39	120	114	166	119	73	67	763	0·82
2. Bronchogram	—	—	—	—	1	1	2	1	3	1	2	11	1·95
3. Barium Swallow	2	2	1	—	2	1	9	24	18	27	40	126	2·16
4. Barium Meal													
(*a*) Stomach and Duodenum ..	2	1	—	2	11	23	18	51	104	116	161	489	3·46
(*b*) Complete (including Follow Through)	1	—	1	1	8	8	15	34	35	52	87	242	3·63
(*c*) Not defined	—	—	—	3	3	6	6	26	23	47	60	174	3·54
5. Barium Enema	—	1	2	2	4	4	7	17	53	71	127	288	3·47
6. Pyelography	—	—	—	—	—	—	—	—	2	—	2	4	1·66
7. Cystography	—	—	—	—	—	—	—	—	—	—	—	—	—
8. Cholecystography	—	—	—	—	1	1	2	4	7	13	18	46	3·55
9. Hysterosalpingography	—	—	—	—	—	2	10	7	—	1	—	20	1·73
10. Cardiac Catheterization	—	—	1	—	—	—	2	—	2	1	—	6	11·38
11. Others	—	—	—	—	2	5	2	2	3	4	4	22	5·19
Total	8	16	32	31	71	171	187	332	369	406	568	2,191	

(2) ORGANISATION OF PHYSICAL DOSE SURVEY

The physical dose survey was organised on a Regional basis. A certain number of hospitals was selected in each Region, and the Senior Hospital Physicist in the Region was asked to undertake the measurements in them. In London, the situation was complicated by the many teaching hospitals, and eased by the greater number of physicists available. A complete list of the 130 hospitals from which measurements were reported is given on Pages 111–113. The division of these hospitals by region and by type of hospital, is discussed in paragraph 22 of the report.

It was decided that measurements should be made on at least 5,000 examinations, if the required statistical accuracy was to be achieved; measurements on 7,101 were therefore requested, so that even if some unexpected difficulties were encountered at least 5,000 could be expected. It was realised that those types of examination contributing most to the genetic dose needed to be known with the greatest accuracy; in fact, the number of measurements required for each type of examination was made proportional to the anticipated contribution by that type of examination to the total genetic dose. Using the statistical information of the first questionnaire, and taking other data from the Medical Research Council (1956) Report, these anticipated contributions were assessed, with the result shown in Table 6.

TABLE 6

Allocation of Effort in Diagnostic Survey

Type of Examination	Proportion of Examinations	
	Theoretical value	Value actually used
	%	%
Abdomen	12	15
Pyelography	22	14
Pelvis	52	31
Pelvimetry	9	5
Barium Meal	—	8
Chest	—	16
Others	5	11
Total	100	100

These proportions, although theoretically ideal, were modified in practice for four reasons; (i) it was necessary to include a substantial number of barium meal examinations in view of their contribution to the somatic dose; (ii) since more than 50 per cent of all radiological examinations are of the chest, it was necessary to make a sufficient number of measurements to give the mean gonad dose per examination accurately, whatever its magnitude; (iii) it was impossible to obtain as many measurements in pelvimetry as was theoretically desirable; (iv) the number of measurements for the class of " other types of examination " was insufficient to obtain satisfactory estimates of dosage per examination of all these types. The final allocation between the types of examination is also shown in Table 6. The total number of examinations allocated to each region was similarly determined by estimating the probable contribution to be made to the total genetic dose by that region, and an effort was made to balance the different types of examination within each region according to the proportions of Table 6. For each hospital, allocations were fixed by

TABLE 7

Diagnostic Survey

Numbers of examinations allocated, and numbers returned

	Number Allocated	Number Returned and Analysed	%
A. By Regions			
Newcastle	395	340	86
Leeds	365	369	101
Sheffield	380	354	93
East Anglia	271	235	87
N.W. Metropolitan	393	353	90
N.E. Metropolitan	367	341	93
S.E. Metropolitan	503	384	76
S.W. Metropolitan*	463	398	86
Oxford	254	259	102
South Western	283	152	54
Wales	355	218	61
Birmingham	390	343	88
Manchester	560	307	55
Liverpool	398	138	35
London Teaching Hospitals	448	262	59
Scotland: Northern	115	85	74
Scotland: North-eastern	218	203	93
Scotland: Eastern	240	70	29
Scotland: South-eastern	253	164	64
Scotland: Western	450	439	97
	7,101	5,414	76·2
B. By Type of Hospital			
Large General Hospitals	3,478	2,685	77
Medium-sized Hospitals	2,617	1,816	69
Small Hospitals	646	515	80
Chest Clinics	360	398	110
	7,101	5,414	76·2
C. By Type of Examination			
Barium Meal	552	377	68
Chest	1,111	1,346	121
Abdomen	1,052	691	65
Pyelography	1,018	664	65
Pelvis	2,174	1,459	67
Pelvimetry	347	110	32
Others	847	765	90
	7,101	5,414	76·2

* Including what is now the Wessex Region.

comparing the number of examinations of each type required from the region as a whole with the number of each type reported by each of the selected hospitals for the week of the first questionnaire. The numbers allocated were then adjusted so as to be as close as possible to the theoretically correct total for the region, without being inequitable as between the hospitals. The allocations are shown in Table 7 analysed in various ways, and in each case compared with the numbers of examinations actually measured, reported, and analysed. Table 8 shows, as an example, the allocations in some detail for one region.

TABLE 8

Allocation of cases of different types in a typical region

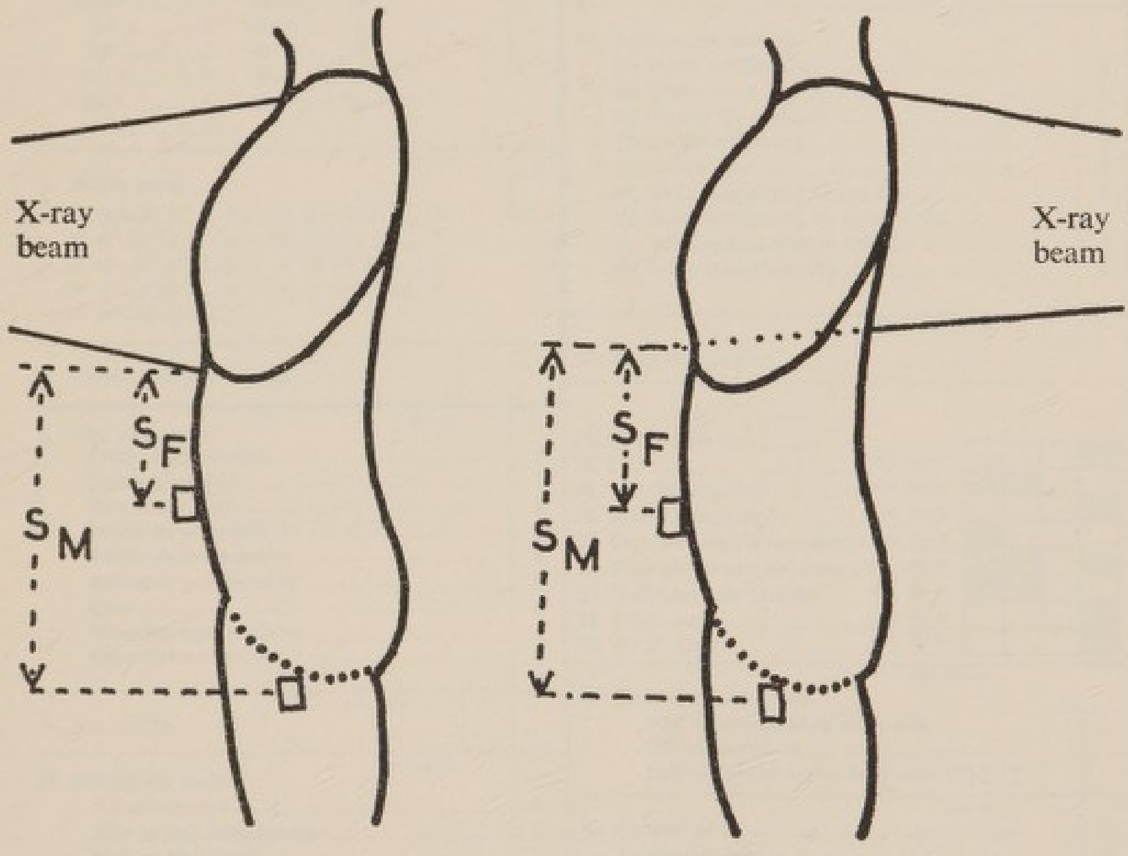
Regional allocation—560 examinations

Hospital No.	1	2	3	4	5	6	7	8	Regional Total
Type of Examinations									
ABDOMEN									
Cases/week	14	18	3	—	11	—	15	—	61
Allocation	20	25	7	—	25	—	20	—	97
PYELOGRAPHY									
Cases/week	12	25	1	—	4	—	2	—	44
Allocation	25	45	3	—	10	—	6	—	89
PELVIS, ETC.									
Cases/week	6	98	6	2	22	—	—	—	134
Allocation	15	70	20	7	50	—	(2)	—	164
PELVIMETRY									
Cases/week	3	—	2	—	—	—	1	—	6
Allocation	8	(2)	5	—	(2)	—	3	—	20
CHEST									
Cases/week	134	483	23	317	203	14	64	75	1,313
Allocation	5	10	5	10	10	5	5	20	70
BARIUM MEAL									
Cases/week	9	70	3	—	15	—	5	—	102
Allocation	5	30	5	—	10	—	5	—	55
THE REST									
Cases/week	46	380	71	8	115	—	85	—	705
Allocation	5	20	10	5	15	—	10	—	65
TOTALS									
Cases/week	224	1,074	109	327	370	14	172	75	2,365
Allocation	83	202	55	22	122	5	51	20	560

Where no cases are reported in the first questionnaire for a particular type of examination, although examinations may be undertaken occasionally at that hospital, an allocation figure appears in brackets. This is intended to indicate that this number should be reported if possible.

For male patients, the measurements presented little difficulty, since the ionization chamber could be placed alongside the scrotum during the examination. For female patients an indirect method had to be used, since a direct measurement of ovary dose is impossible. The method of putting an ionization chamber into the rectum at the approximate level of the ovary (Larsson, 1958 and Hammer-Jacobsen, 1957) was discarded in favour of the indirect method used by Stanford, Osborn and Howard (1952) and Stanford and Vance (1955). The ionization chamber is placed externally on the abdominal surface at the level of the iliac crest, and the ovary dose is deduced from this measurement by means of a series of subsidiary measurements (Appendix 1 (3)). The various sites of measurement are shown in Fig. 1; SM and SF indicate the " scatter distance " for males and females respectively in the examples. In lateral projections for female subjects the chamber is placed at the same level, but on the side of the patient facing the X-ray tube.

Figure 1.
Diagram to show the positions of the ionization chamber for gonad dose measurements.



Antero-posterior projection. Postero-anterior projection.

Suitable apparatus for measuring doses of X-rays over the required range of quality, dose and dose-rate was not available commercially, and this had to be designed and produced (Stuart and Osborn, 1959). A specially constructed ionization chamber (Osborn and Burrows, 1958) was cable-connected to the battery-operated portable electrometer (Fig. 2). The chamber was about 45 cc in air volume, its outer wall being a shell of polystyrene 0·01 inch thick giving a response uniform to about ± 2 per cent over the quality range of diagnostic X-rays. The design was such as to maintain satisfactory saturation up to dose-rates of at least 2,000 r/min. The electrometer, by means of two switches, could record full-scale deflexion for doses from 0·45 mr to 150 r, and for dose-rates from 0·045 mr/sec. to 15 r/sec. One switch could be used to alter the sensitivity after an exposure had been made but without affecting the charge stored in the input capacitor, thus enabling some doses to be recorded which were higher or lower than had been expected.

Measurements were reported on the form shown in Fig. 3. It was designed to record the radiographic technique as completely as possible, and also the relevant physical data and the measured doses, in such a way as to facilitate the transference of the data to punch cards. The detailed instructions and codes relating to the completion of the report form are too long for inclusion here, but will be published later. The divisions of age-groups, of types of examination, and of methods of examination, follow closely the recommendations of the International Commissions on Radiological Protection and on Radiological Units and Measurements (1957).

Figure 3.

Committee on the radiological hazards to patients

Survey of doses in diagnostic radiology

Col. 1—3
1. Hospital code number

2. Date of measurement ....../....../......

3. Hospital No. of patient........................

Col. 3
4. Sex: male X
female Y

Col. 4
5. Age group:

Under 2.........0	25-29.........6
2-4 1	30-39.........7
5-9 2	40-49.........8
10-14...........3	50-59.........9
15-19...........4	60 & over X
20-24...........5	

Col. 5
6. Height group:

Up to 2′ 5″......1	4′ 6″—4′ 11″......6
2′ 6″—2′ 11″......2	5′ 0″—5′ 5″......7
3′ 0″—3′ 5″......3	5′ 6″—5′ 11″......8
3′ 6″—3′ 11″......4	6′ 0″ and over...9
4′ 0″—4′ 5″......5	

Col. 6
7. Weight (completed stones)

Col. 7
8. Film type used:
- Screen type—normal 0
- Screen type—fast 1
- Non-screen type 2
- Miniature green sensitive 3
- Miniature blue sensitive 4
- Miniature panchromatic 5
- Cine 6
- Industrial type emulsion 7
- Other (please specify) 8

Cols. 8—9
9. Size of film

Col. 10
10. Intensifying screens
- No screens used 0
- Slow or high definition type 1
- Fast or high speed 2
- Other (please specify) 3

Col. 11
11. Cone type:
- Fixed 1
- Adjustable 2
- None 3

Col. 12
12. Grid type:
- Stationary 1
- Moving 2
- No grid used 3

Col. 13
13. Grid transmission factor ....

Cols. 14—15
14. Examination type ....

Cols. 16—18
15. Serial number ....

Cols. 19—20
16. Exposure order ....

Cols. 21—22
17. No. of radiographic exposures reported on this form ....

Col. 23
18. Nature of exposure: Routine 1
Repeat 2

Col. 24
19. Examination method:
- (a) Direct radiography 0
- (b) Fluoroscopy 1
- (c) (a) and (b) combined 2
- (d) Photofluorography 3
- (e) Tomography 4
- (f) Serial radiography on one film 5
- (g) Serial radiography on separate film 6
- (h) Serial radiography on roll film 7
- (j) Other (please specify) 8

Col. 25
20. Projection number ....

21. X-Ray tube used
22. kVp .... Cols. 26—28
23. mA (Fluoroscopy) .... Cols. 29—30
24. mAs (Radiography) .... Cols. 31—33
25. Exp. time (min.) (Fluoroscopy) Cols. 34—36
26. Filter add. to tube wall (mm Al) Col. 37
27. Half value layer (mm Al) .... Cols. 38—39
28. F.S.D. (cm) .... Cols. 40—42
29. F.F.D. (cm) .... Cols. 43—45

Cols. 46—47
30. Field size on skin (cm)
Half dimension along body axis
OR radius of field ....
Half dimension across body axis Cols. 48—49

Col. 50
31. Circular field 1
Rectangular field 2

Col. 51
32. Gonads in beam: Yes 1
No 2

Col. 52
33. Gonads shielded: Yes 1
No 2

Cols. 53—54
34. Scatter distance (cm) ....

Cols. 55—59
35. Central skin dose (r) ....

Cols. 60—66
36. Dose to scrotum (mr) ... (male)

Cols. 67—69
37. Dose to iliac crest (mr) ... (female) 7 6 5 4 3 2 1

FOR OFFICE USE ONLY

Cols. 70—75
38. Calculated marrow dose ......

(3) DERIVATION OF OVARY AND FOETAL GONAD DOSE

In order to estimate the ovary dose a measurement was made with an ionization chamber in the midline on the anterior surface of the patient and with its superior end at the level of the iliac crests for all views except lateral ones. In these lateral cases the chamber was placed on the side facing the tube and at the same level.

To obtain the actual ovary dose in each of these measurements it was necessary to multiply the measured dose by a conversion ratio. To determine this factor (conversion ratio) the ovary dose and iliac crest dose have been measured on a phantom for a large range of values of the parameters of field size and shape, focal skin distance, half value layer and scatter distance. Table 9 shows the range of values for which conversion ratios were measured. At the same time measurements of incident skin dose and the male gonad dose have also been made. Ratios of ovary to skin dose and male gonad to skin dose have thus been obtained.

The phantom used for these measurements was manufactured by utilising a complete dried human skeleton, impregnated with wax under vacuum so as to fill the bones with soft tissue equivalent material. The skeleton was mounted inside a polythene skin formed from plaster casts taken of a human subject. This phantom was filled with soft tissue equivalent material. Lung spaces were reproduced by utilising compressed polythene foam. Perspex tubes were inserted into the side of the phantom so that ionization chambers might be introduced to the ovary, rectum and 10 marrow sites in the body. The final phantom was constructed in two halves and is shown in Fig. 4.

Measurements were made with dose rate meters designed for the diagnostic survey. Ionization chambers of the type used in the survey were employed for measuring the iliac crest dose and male gonad dose. A Baldwin Farmer ionization chamber was used for the ovary dose measurements and a small ionization chamber for the incident skin dose.

The conversion ratios having been obtained for the large number of variables in Table 9 it was necessary to determine the appropriate one for each of the 7,000 measurements carried out in the hospital survey. These measurements had been entered on punch cards and an electronic computor was programmed so that the calculation of ovary dose might be interpolated from the data measured on the phantom. This necessitated the sorting of the cards into the groups shown in Table 9, and then subsequently into rectangles and circles. Each of these sub groups was then computed using the appropriate programme. The basis of the method was to use the conversion ratio of the square field of the same dimension across the body axis as the one measured in the survey and to multiply this conversion ratio by either an elongation factor or a circular equivalence factor. These two factors were multiplied by the measured iliac crest dose. The computations required 16 interpolations in order to deduce the appropriate factors.

When the iliac crest chamber was partly in the beam, the skin dose measurement and the appropriate ovary/skin ratio was used. This method was also used for estimating the maternal ovary dose in obstetric examinations.

To estimate the ovary dose in children when the ovary was in the beam the measurements on the phantom were corrected on a logarithmic basis for the reduction in depth of the ovary. The depth was assumed to be half and three-quarters of the adult depth for the age groups 0–2, 3–14 years respectively.

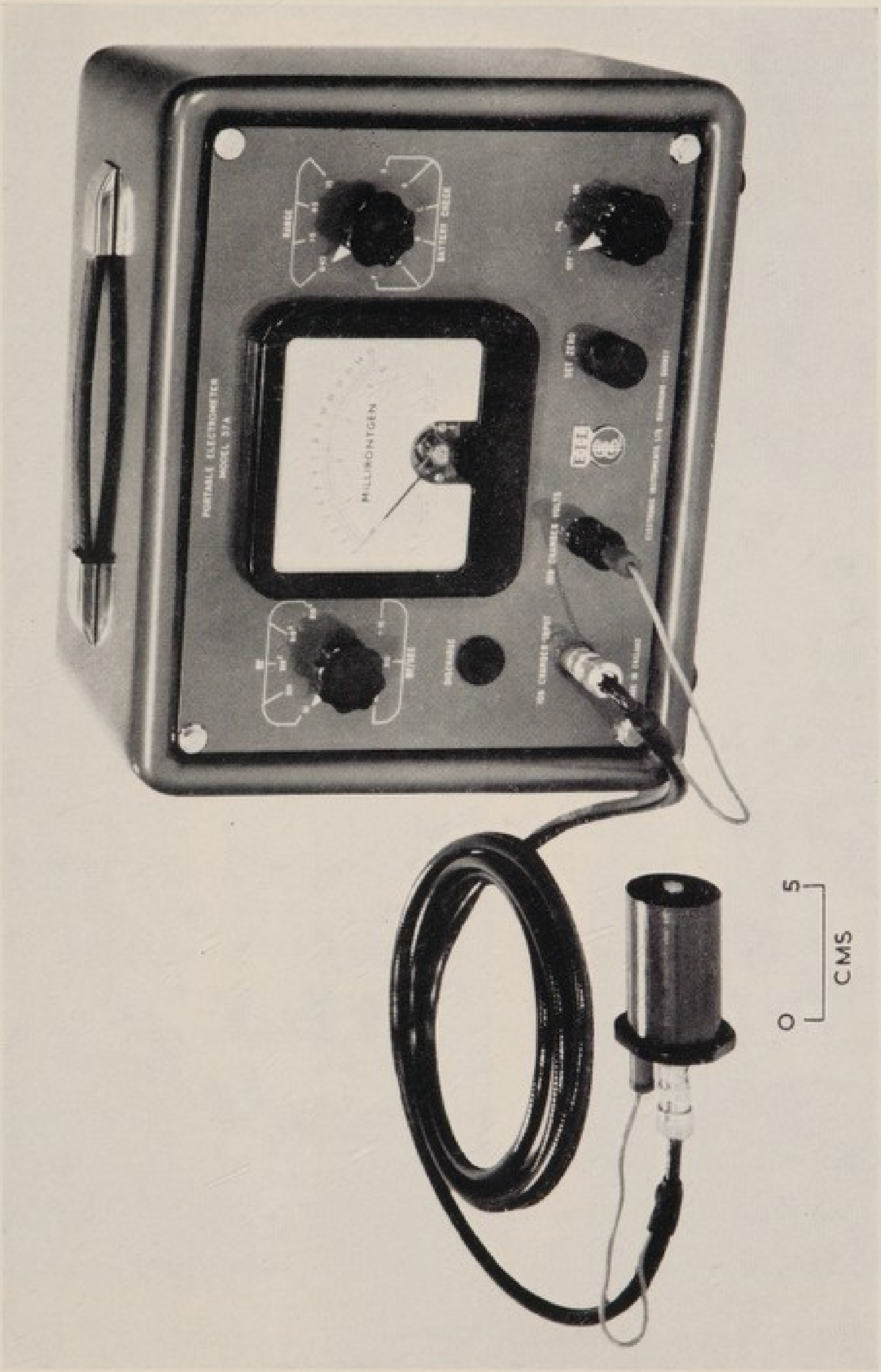


Figure 2.
Photograph of dosemeter used

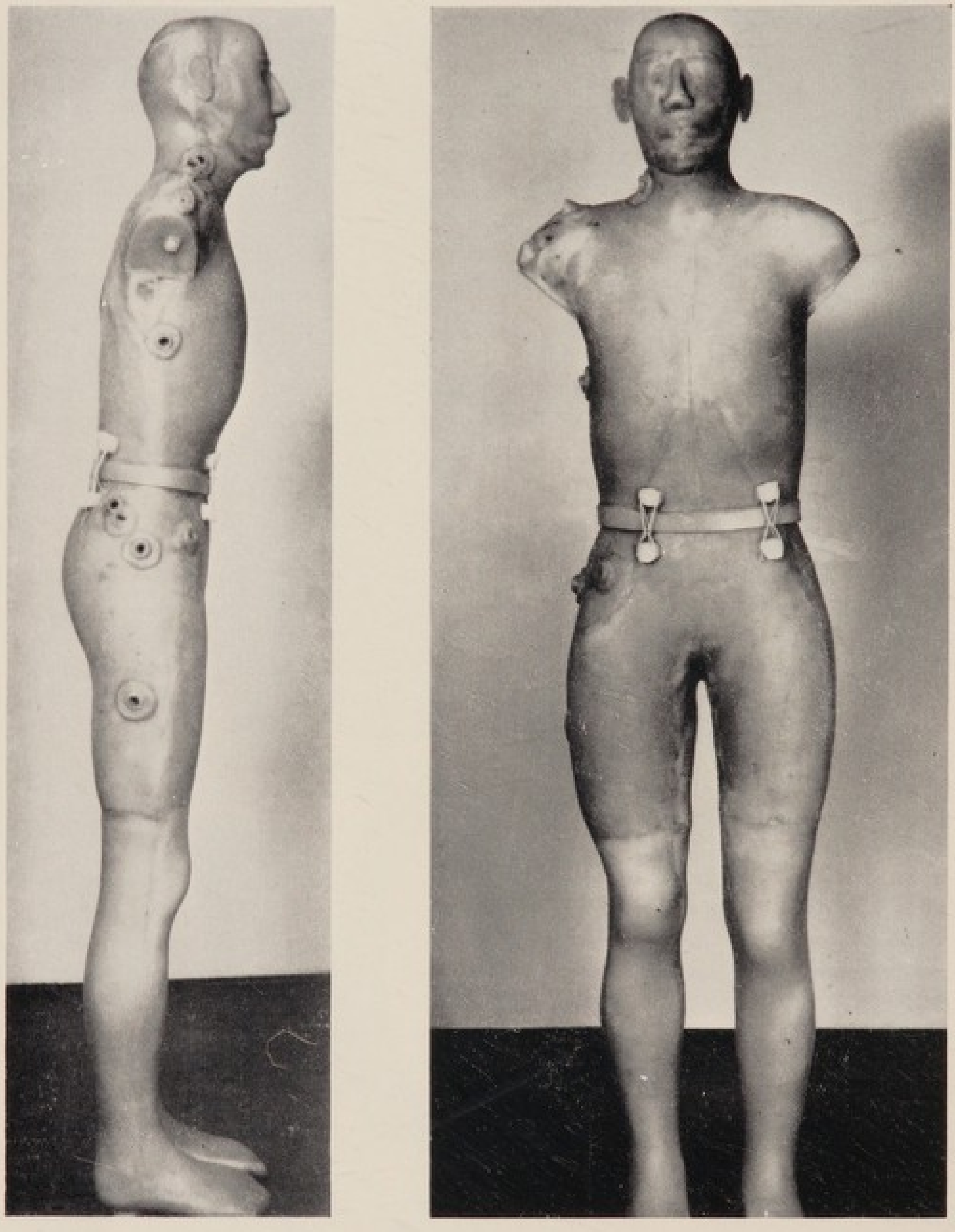


Figure 4.
Phantom used for dose measurements

The derivation of foetal gonad doses in obstetric examinations was based on the original data of Bewley, Laws and Myddleton (1957) and Clayton, Farmer and Warrick (1957), supplemented by further measurements to extend the data to meet the requirements of the survey.

TABLE 9

Measurement of Iliac Crest Dose Conversion Ratios

FIELD POSITION	RADIATION CONDITIONS
1. *Iliac crest chamber IN BEAM* Radiation (*a*) Anterior (*b*) Posterior (*c*) Lateral 2. *Iliac crest chamber NOT IN BEAM* Radiation (*a*) Anterior Superior (*b*) Anterior Inferior (*c*) Posterior Superior (*d*) Posterior Inferior (*e*) Lateral Superior (*f*) Lateral Inferior 3. *Iliac crest chamber PARTLY IN BEAM* Radiation (*a*) Anterior (*b*) Posterior (*c*) Lateral	Square fields 10 cm, 20 cm, 30 cm at F.S.D. 40 cm, 60 cm, 80 cm Elongated fields 0·3 to 2·0 times the square field size at F.S.D. 60 cm Circular fields: Equivalent area of field used. 9 Radiation Qualities from 1·0 mm Al H.V.L. 50 kVp to 6·5 mm Al H.V.L. 130 kVp Scatter Distances −6, −3, 0, 3, 5, 8, 13, 23, 43 cm
4. *Obstetric Examinations*	Measurements using iliac crest chamber on phantoms used at Hammersmith Hospital and Royal Victoria Infirmary, Newcastle (see Text).

(4) RESULTS OF THE DOSE SURVEY

The measured values of average gonad dose per examination, for the different types of examination, are given in Table 10. Male gonad doses were measured directly at the scrotum, while female gonad doses have been deduced from measurements made at the level of the iliac crest (see Appendix 1 (3)). For each sex, those measurements made on children under 15 years of age are separated from those on adults. In types of examination where no measurements were made, an approximate dose has been deduced from measurements made on examinations of the nearest similar type, and the resulting value is entered in brackets. The methods used are as follows:—

(*a*) Where a dose is reported for adults but not for children of the same sex, the dose for adults is taken as that for children and vice-versa.

(*b*) Of those examinations merely stated to be neurological, 90 per cent were assumed to be limited to the head and neck and 10 per cent to be examinations of the whole spinal column; estimates of gonad dose were made accordingly.

(*c*) Angiography of the head was taken as equivalent to an ordinary examination of the head and neck.

(*d*) Angiography of the abdomen was taken as equivalent to an intravenous pyelography examination.

(*e*) Tomography of the head was taken as equivalent to two examinations of the head and neck.

(*f*) Tomography of the abdomen was taken as equivalent to two intravenous pyelography examinations.

(*g*) A single measurement was reported of cardiac catheterization of an adult, a female. For males the scrotum dose was taken as being the same as the iliac crest dose for this female.

(*h*) A bronchogram was regarded as equivalent to three examinations of the chest, heart, lung.

Where more than one measurement has been reported, a standard error has been calculated to indicate the statistical accuracy; inaccuracy arises not only from the spread of measurements averaged, but also (for females) from the calculation of ovary dose from the reported data. For each sex and type of examination, the dose used for the calculations in the 1956 Medical Research Council report is also given. In a footnote to this table, calculated foetal gonad doses are also given for X-ray examinations directly related to pregnancy. In calculating genetic doses received by the foetus when a pregnant woman is subjected to examinations of other types, the foetal gonad dose was taken to be the same as the dose to the ovary of an adult female, except for one third of the examinations of the abdomen and pelvic region. These were assumed to be in late pregnancy, and the foetal gonad dose was derived by multiplying the ovary dose for each of these examinations, by the ratio of foetal gonad dose to ovary dose obtained from obstetric abdomen examinations, i.e., 1·97. These approximations can only cause a small error, as the genetic dose involved is in any case not large.

The doses used in the Medical Research Council report of 1956 were based on the 1955 paper by Stanford and Vance whose measurements were confined to a single large London teaching hospital. It is therefore not surprising to find differences between the Medical Research Council's values and those of the 1957/8 National Survey.

TABLE 10

Mean gonad doses in mr per examination

Type of Examination	MALES							FEMALES						
	Children			Adults				Children			Adults			
	No. of Exam.	mr/ Exam.	Standard Error	No. of Exam.	mr/ Exam.	Standard Error	M.R.C. (1956) Values	No. of Exam.	mr/ Exam.	Standard Error	No. of Exam.	mr/ Exam.	Standard Error	M.R.C. (1956) Values
Head, Neck	29	0·42	0·14	95	0·32	0·14	1·27	25	10·1	4·6	133	1·91	0·52	0·19
Dental	—	(1·0)	—	5	1·0	0·90	4·75	2	22·2	22·2	4	4·4	4·2	0·8
Barium Swallow	—	(12·8)	—	2	12·8	8·9	20	4	2·0	1·7	10	12·8	4·6	9
Arm, Hand	23	2·4	1·2	48	4·7	3·7	0·26	18	1·66	0·89	52	2·16	0·63	0·05
Shoulder	1	1·15	—	12	0·21	0·10	0·22	4	1·71	1·47	19	0·31	0·17	0·03
Dorsal Spine	3	60·5	42·4	33	6·1	4·0	22	5	66	46	41	11·7	6·0	15
Chest, Heart, Lung	77	12·0	2·8	503	1·34	0·29	0·36	81	4·78	1·07	470	5·53	0·87	0·07
Bony Thorax	1	0·05	—	34	2·7	1·2	0·48	3	8·4	3·6	26	14·8	6·4	0·16
Barium meal	10	58·8	23·1	206	43·5	31·4	20	4	114	46	157	339	49	9
Cholecystogram	—	(7·5)	—	40	7·5	4·0	1·8	—	(299)	—	99	299	45	15·6
Abdomen	33	113	40	171	103	21	69	44	55	10	187	212	15	200
Obstetric Abdomen §	—	—	—	—	—	—	—	—	—	—	127	367	26	200
Intravenous Pyelogram	28	327	66	321	804	72	486	34	207	39	247	637	27	1,290
Retrograde Pyelogram	1	49	—	15	1,040	670	486	1	162	—	17	399	56	1,290
Salpingography	—	—	—	—	—	—	—	—	—	—	26	313	40	1,700
Pelvimetry §	—	—	—	—	—	—	—	—	—	—	110	745	66	1,280
Cystography	2	846	89	6	964	420	279	2	45	29	8	1,285	525	690
Barium Enema	2	362	176	33	146	61	40	1	875	—	35	464	76	20

TABLE 10—*continued*

Type of Examinations	MALES							FEMALES						
	Children			Adults				Children			Adults			
	No. of Exam.	mr/ Exam.	Standard Error	No. of Exam.	mr/ Exam.	Standard Error	M.R.C. (1956) Values	No. of Exam.	mr/ Exam.	Standard Error	No. of Exam.	mr/ Exam.	Standard Error	M.R.C. Values (1956)
Pelvis, Lumbar Spine, Lumbo-sacral Joint	46	181	33	511	387	52	417	38	210	44	532	405	18	381
Hip, Upper Femur	60	275	52	74	1,120	170	710	36	60·4	18·0	106	117	11	210
Lower two-thirds of Femur ..	10	24·8	10·7	19	118	48	710	7	4·91	2·80	14	7·3	3·9	210
Leg, Foot	32	2·1	0·8	65	3·2	1·1	3·5	18	3·56	1·61	78	3·59	1·15	0·6
Neurological	—	(45)	—	—	(45)	—	—	—	(36)	—	—	(56)	—	—
Angiography—Head	—	(0·06)	—	1	0·06	—	0·8	—	(10·1)	—	—	(1·9)	—	0·19
—Chest	1	15	—	—	(15)	—	37	—	(8·7)	—	—	(8·7)	—	5·4
—Abdomen ..	—	(327)	—	—	(804)	—	69	—	(247)	—	3	310	45	200
Tomography—Head	—	(0·68)	—	—	(0·68)	—	0·8	—	(20·3)	—	—	(3·8)	—	0·19
—Chest	—	(1·32)	—	14	1·32	0·74	37	—	(1·12)	—	9	1·12	0·53	5·4
Abdomen	—	(50)	—	2	50	35	69	—	(495)	—	—	(1,275)	—	200
Cardiac Catheterization ..	—	(30)	—	—	(30)	—	37	3	18·9	17·6	1	8·72	—	5·4
Bronchogram	—	(5·0)	—	4	(5·0)	1·5	37	—	(14·3)	—	—	(16·6)	—	5·4

(—) Bracketed values are estimated as described in the text.

§ Foetal gonad doses—obstetric abdomen—723 mr/examination. Standard error 63 (M.R.C. 1956 value—580),
pelvimetry 885 mr/examination. Standard error 111 (M.R.C. 1956 value—2,680).

TABLE 11

Number of films and average fluoroscopy time per examination

Type of Examination	MALES Average number of Exposures	MALES Average time of Fluoroscopy mins.	FEMALES Average number of Exposures	FEMALES Average time of Fluoroscopy mins.
Head, Neck	2·6	—	2·6	—
Dental	2·2	—	3·7	—
Barium Swallow	3·5	4·4	2·9	2·8
Arm, Hand	2·3	—	1·9	—
Shoulder	1·5	—	1·3	0·8
Dorsal Spine	1·9	—	2·2	—
Chest, Heart, Lung ..	1·2	0·5	1·1	0·5
Bony Thorax	1·6	1·8	1·4	—
Barium Meal	5·7	2·7	5·1	2·8
Cholecystography ..	3·3	—	3·4	1·5
Abdomen	1·3	2·2	1·4	1·3
Abdomen, Obstetric ..	—	—	1·2	—
Intravenous Pyelography ..	6·3	—	5·9	—
Retrograde Pyelography ..	3·3	—	3·2	0·7
Salpingography	—	—	2·1	1·3
Pelvimetry	—	—	1·7	—
Cystography..	3·2	—	3·7	—
Barium Enema	4·2	1·8	3·9	3·3
Pelvis, Lumbar Spine ..	2·2	2·8	2·3	—
Hip, Upper Femur ..	1·5	—	1·6	—
Lower Femur	2·0	—	2·1	—
Leg, Foot	2·1	—	2·2	—
Angiography—Head ..	7·0	—	—	—
—Chest ..	20·0	—	—	—
—Abdomen ..	—	—	3·3	1·4
Tomography—Chest ..	7·3	—	7·0	—
Cardiac Catheterization ..	—	—	1·0	12·5
Bronchogram	4·0	—	—	—

N.B.—Fluoroscopy times are averaged only over the examinations in which fluoroscopy was actually used.

The average time of fluoroscopy given here is as measured by the physicists in the survey, and may therefore differ from the estimates of fluoroscopy time given in Tables 2 and 5.

Table 11 gives the average number of radiographs taken per examination, and also the average fluoroscopy time for examinations in which fluoroscopy was performed. Table 12 gives an analysis of the types of examination reported. Many further analyses of technique are being carried out for subsequent publication, and one or two points of interest from them may be noted here.

The Dependence of the Gonad Dose on Radiation Quality

The use of techniques employing higher kilovoltage and increased filtration has been advocated for certain radiographic examinations. Even though these techniques lead to a reduction of the incident skin dose, demonstration of their effect on the gonad dose has been inconclusive.

It has been possible to analyse data in the survey to provide information on the dependence of the gonad dose on the quality of radiation used in a number of types of examination. In the most commonly-used projections in five examinations the average gonad doses and skin doses were classified into the following categories of radiation qualities:—below 1·0, 1·0–1·4, 1·5–1·9, 2·0–2·4, 2·5–2·9, 3·0–3·4 and

TABLE 12

Numbers of Radiological Examinations Measured, Reported and Analysed

Type of Examination	MALES			FEMALES			TOTAL
	Radiography only	Fluoroscopy only	Radiography and Fluoroscopy	Radiography only	Fluoroscopy only	Radiography and Fluoroscopy	
Head, Neck	124	—	—	158	—	—	282
Dental	5	—	—	6	—	—	11
Barium Swallow	—	—	2	2	—	12	16
Arm, Hand	71	—	—	70	—	—	141
Shoulder	13	—	—	22	1	—	36
Dorsal Spine	36	—	—	46	—	—	82
Chest, Heart, Lung	557	12	11	521	18	12	1,131
Bony Thorax	34	1	—	29	—	—	64
Barium Meal	—	6	210	—	5	156	377
Cholecystogram	40	—	—	98	—	1	139
Abdomen	201	—	3	228	1	2	435
Abdomen (Obstetric)	—	—	—	127	—	—	127
Intravenous Pyelogram	349	—	—	281	—	—	630
Retrograde Pyelogram	16	—	—	17	—	1	34
Salpingography	—	—	—	17	—	9	26
Pelvimetry	—	—	—	110	—	—	110
Cystography	8	—	—	10	—	—	18
Barium Enema	1	2	32	1	—	35	71
Pelvis, Lumbar Spine and Lumbo-sacral Joint	556	—	1	570	—	—	1,127
Hip, Upper Femur	134	—	—	142	—	—	276
Lower Femur	28	—	—	21	—	—	49
Leg, Foot	98	—	—	96	—	—	194
Angiography—Head	1	—	—	—	—	—	1
—Chest	1	—	—	—	—	—	1
—Abdomen	2	—	—	1	—	2	5
Tomography—Chest	14	—	—	9	—	—	23
Cardiac Catheterization	—	—	—	3	1	—	4
Bronchogram	4	—	—	—	—	—	4
Total	2,293	21	259	2,585	26	230	5,414

3·5–3·9 mm Al. H.V.L. The measurements were also subdivided into two categories:—(*a*) examinations with gonads in the beam and (*b*) examinations with gonads out of the beam for various scatter distances.

For each projection in each examination it was possible to compare the average gonad and skin doses, obtained at the different qualities, with those obtained for the quality range 1·0–1·4 mm Al. H.V.L. In view of the wide differences in techniques sampled in the survey for any particular projection, mean gonad doses and mean skin doses were taken irrespective of scatter distance. Table 13 gives the normalised mean gonad doses for examinations where the gonads were out of the beam and the normalised mean ovary doses where the ovaries were in the beam. It is evident that the gonad dose increases in most examinations as the H.V.L. of the radiation increases beyond the range 1·0–1·4 mm Al. (e.g. radiation generated at 70 kVp with about 1 mm Al. filter). The only exceptions to this are the lateral lumbar spine in males where the gonad dose decreases with increasing H.V.L. and the postero-anterior chest, with fields so large that the ovaries are included, where the gonad dose increases only at the highest radiation quality listed.

In these analyses the skin dose decreased with increasing quality to a broad minimum which occurred at about 2·2 mm Al. H.V.L. (e.g. radiation generated at 70 kVp with about 2 mm Al. filter). At higher values of the H.V.L. the skin dose, in some instances, then increased.

These observations represent findings in radiological practice as sampled in the measurement survey. Similar conclusions were reached in laboratory investigations with the model where gonad doses were compared for large films, taken at different radiation qualities but otherwise under the same conditions of technique, with the exposure adjusted to give identical radiographic density. The results of both investigations are in accord with the physical findings that with increasing H.V.L., in the quality range considered, both the amount and penetration of the scattered radiation increases and the sensitivity of the film decreases, and that in most cases the effect of these factors on the gonad dose outweigh the effect of a reduced skin dose.

The Code of Practice for the Protection of Persons Exposed to Ionizing Radiations (Ministry of Health, 1957) drew attention to the importance of additional filtration to all diagnostic X-ray equipment. In our measurement survey of 1958 it was noted that in 24 per cent of a total of over 14,200 radiographic exposures analysed, no additional filter was fitted.

TABLE 13

Mean gonad dose at each quality expressed as a ratio to the mean dose at quality 1·0–1·4 mm Al. H.V.L.

Gonads out of the Beam

	Male H.V.L. mm Al.				*Female* H.V.L. mm Al.			
	below 1·0	1·0–1·4	2	3	below 1·0	1·0–1·4	2	3
Head antero-posterior	—	1	1·85	2·95	0·4	1	1·15	1·35
Chest postero-anterior	1·68	1	1·80	2·80	1·5	1	3·45	6·55
Abdomen antero-posterior	2·95	1	2·4	4·12	0·6	1	2·55	4·55
Pelvis postero-anterior	—	1	1·8	2·80				
Lumbar Spine antero-posterior	1·83	1	2·2	3·80				
Lumbar Spine lateral	1·06	1	0·75	0·65				
Average	1·88	1	1·8	2·85	0·8	1	2·41	4·2

Gonads in the Beam

	Female H.V.L. mm Al.			
	below 1·0	1·0–1·4	2	3
Chest postero-anterior	7·5	1	0·4	6+
Abdomen antero-posterior	0·7	1	1·9	3·0
Pelvis antero-posterior; Lumbar Spine antero-posterior and lateral	0·3	1	1·3	1·7

Gonads in the beam unnecessarily

Shielding of the gonads was used infrequently, in only 11 per cent of the exposures on males and 4 per cent of those on females. It was noticeable that shielding was more frequently used in large hospitals and in chest clinics. In spite of this, in all chest exposures reported 10 per cent of the exposures on males included the gonads in the X-ray beam, and 51 per cent of those on females, which underlines the fact that a little more care in technique could reduce gonad doses substantially.

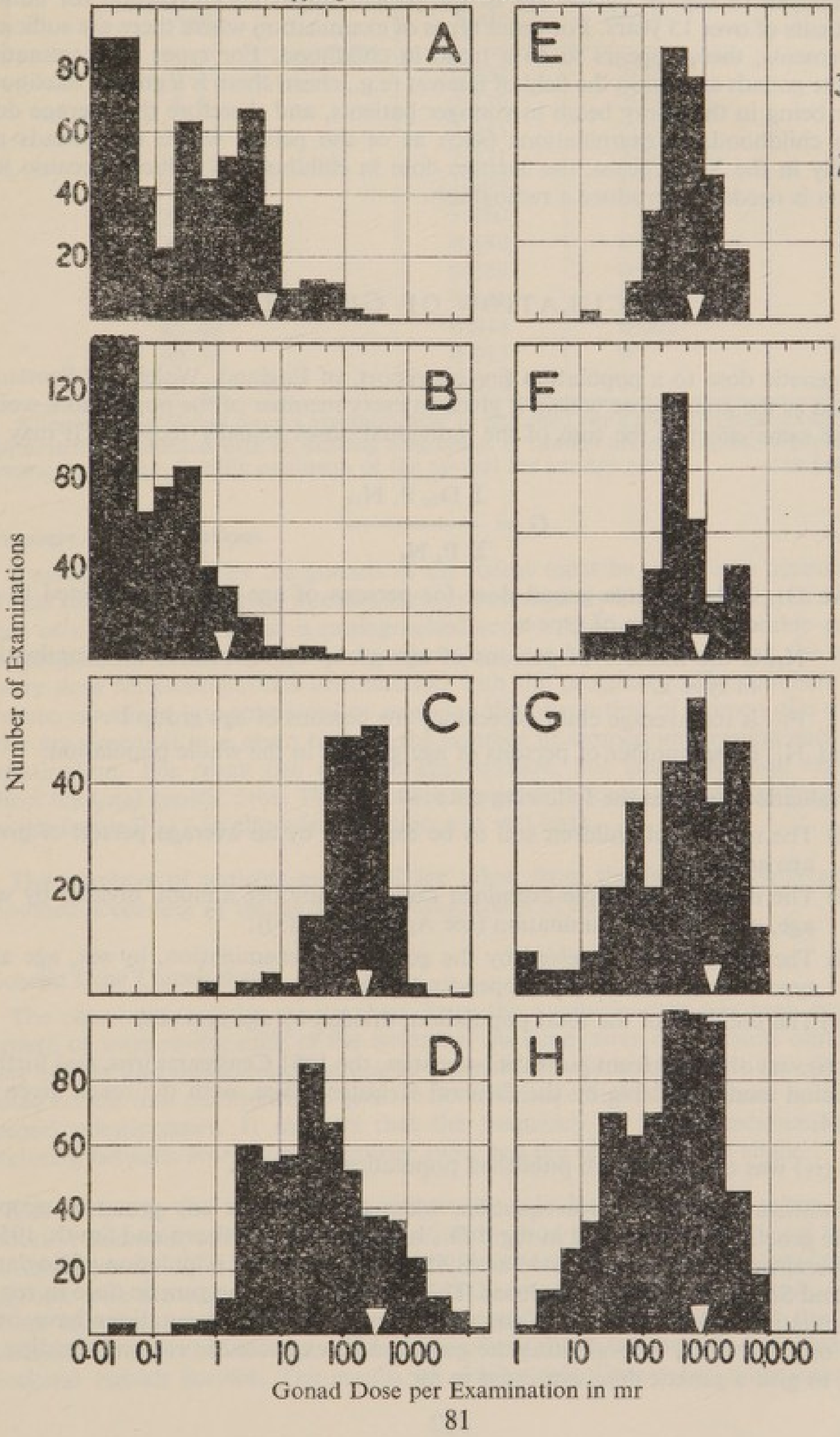
Excessive beam area

Of over 6,000 radiographic exposures reported for females, 23 per cent used a beam of area at least twice that of the film; 11 per cent of at least three times the area and 0·5 per cent of at least 10 times the area of the film. In many such cases the gonads are in the beam quite unnecessarily.

Figure 5.

Histograms showing distribution of measured gonad doses for different types of examination.

A. Chest, heart and lung examinations of adult females.
B. Chest, heart and lung examinations of adult males.
C. Abdomen examinations of adult females.
D. Pelvis, lumbar spine, lumbo-sacral joint examinations of adult males.
E. Pelvimetry examinations—maternal ovary doses.
F. Pelvimetry examinations—foetal gonad doses.
G. Hip and upper femur examinations of adult males.
H. Intravenous pyelogram examinations of adult males.



This point is illustrated in Fig. 5, each diagram of which gives some idea of the variations found in gonad dose for essentially the same type of examination. A logarithmic scale for dosage has been used, and in each case the arrow indicates the arithmetic mean (see Table 10). In each case, a few high dose examinations affect the average disproportionately.

An analysis of dosage by the age of the patient shows no correlation for adults, i.e., patients of over 15 years. For those types of examination where there are sufficient measurements, there appears to be a trend in childhood. For types of examination where the gonads are not in the field of interest (e.g., chest) there is a greater likelihood of their being in the X-ray beam in younger patients, and therefore the average dose rises in childhood. In examinations (such as of the pelvis) where the gonads are inevitably in the X-ray beam, the average dose in childhood is reduced because less radiation is needed to produce a radiograph.

(5) CALCULATION OF GENETIC DOSE

General

The genetic dose to a population (in this report, of England, Wales and Scotland) is defined as the gonad dose which, if given to every member of the population, would have the same effect as the sum of the individual doses actually received. It may be expressed as:—

$$G = \frac{\Sigma D_{ix} P_i N_{ix}}{\Sigma P_i N_i}$$

Where D_{ix} is the average gonad dose for persons of age group i subjected to an examination of type x.

N_{ix} is the number of persons of age group i subjected to an examination of type x.

P_i is the average child expectancy for persons of age group i

and N_i is the number of persons of age group i in the whole population.

Its evaluation requires the following data:—

(i) The number of children still to be expected by an average person of given age and sex;

(ii) The number of people examined radiologically per annum, divided by sex, age, and type of examination (see Appendix 1 (1));

(iii) The average dose received by the gonads per examination, by sex, age and type of examination (see Appendix 1 (4));

(iv) The numbers of the total population, divided by age and sex.

Item (i) was obtained from published statistics, the 1951 Census returns, and further information made available by the General Register Office, with the result given in Table 14.

Item (iv) was obtained from published population statistics.

The numerator of the above equation, when evaluated for any group of people, gives the genetic dose expressed in reg if D_{ix} is in roentgens (Osborn and Smith, 1956). The denominator has been estimated as 48,650,000 for the 1957 population of England, Wales and Scotland, including foetuses. This would also be the genetic dose in reg to this population if each received a gonad dose of 1 r. The computations have been carried out, therefore, by evaluating the genetic dose expressed in reg and dividing by 48,650, to give a genetic dose expressed in mr.

TABLE 14

Fertility Factors

The probable number of live-born children still to be expected by the average person in each age group at current fertility rates

Age	Male	Female*
0–4	2·229	2·323
5–9	2·239	2·331
10–14	2·245	2·325
15–19	2·221	2·207
20–24	1·999	1·733
25–29	1·460	1·017
30–34	0·840	0·462
35–39	0·389	0·157
40–44	0·141	0·030
45–49	0·044	0·002
50–54	0·013	0
55 + ...	0·002	0

* Somewhat different figures are applicable to and used for a woman undergoing an X-ray examination connected with an existing pregnancy. A woman undergoing salpingography was assumed to have a fertility one-tenth of the normal for her age group.

Numbers of Examinations

Radiation received by the gonads of the foetus must be taken into account. Most of this radiation is received in examinations connected with pregnancy, but when any part of a pregnant woman is radiographed some radiation will inevitably reach the foetal gonads. The foetal gonad dose has therefore been deduced from the maternal ovary dose for examinations unconnected with the pregnancy. The numbers of such women examined was calculated by applying the proportion of women of a given age who are pregnant at a given time to the number of women undergoing each type of examination. The result can only be approximate, but inaccuracy will not greatly affect the total genetic dose. The radiation received by foetal gonads has been reduced by the factor 0·917 to allow for abortion and still-birth.

The numbers of patients examined are taken from the tables of Appendix I (1), modified according to the method of paragraph 4 of that Appendix.

Genetic Dose Calculations

The calculation of the genetic dose from the available data has been made in a variety of ways, using each of the statistical questionnaires. The results obtained are very similar and the totals are given in Table 15. It will be seen that the calculations based on the first questionnaire give results which are higher than those based on the second questionnaire. It may be that the frequency of certain examinations was declining between April and December 1957, but the differences are slight.

The first entry for the second questionnaire calculations has been taken as representative and analysed in detail. Table 16 shows how this figure is made up by contributions from the different types of examination and also from male and female patients, together with the contribution arising from the irradiation of foetal gonads. Standard errors are also presented and (so far as possible) a comparison with the Medical Research Council (1956) values. This table relates solely to hospitals and clinics of the National Health Service. The results of similar calculations for other branches of medical diagnostic radiology are given in Table 17, which shows that the total genetic dose amounts to about 14 mr per annum per person. Comparable values are given from the Medical Research Council (1956) report, calculated from additional information made available for the purpose. Differences for individual types of examinations are due partly to differences in mean gonad dose, and partly to differences between the assumed age distributions.

TABLE 15

Genetic Dose from General Diagnostic Radiology

Questionnaire	Method (see footnotes)	mr per Person	Standard Error
1.	1	13·10	0·36
	2	12·30	0·34
	4	12·28	0·34
	5	12·72	—
	6	13·43	—
2.	1	13·24	0·44
	2	12·67	0·43
	3	12·69	0·41
	4	12·63	0·42

1. Gonad dose averaged over all age groups.

2. One mean gonad dose used for all subjects of over 15 years, and another for all those under 15.

3. As method 2 except that for chest, intravenous pyelogram, pelvis and hip and upper femur examinations the gonad doses for children are divided into those measured in the four separate age-groups.

(N.B.—This method can only be used with the second statistical questionnaire, as only this has the numbers of patients divided into these age-groups.)

4. The gonad dose averaged over all age-groups except for chest, intravenous pyelograms , pelvis and hip and upper femur examinations, where separate averages are used for adults and for children under 15.

5. The genetic dose evaluated for each Hospital region separately and summated.

6. The genetic dose evaluated for each of the four hospital types separately, and summated.

Errors

Errors in this computation may arise from any or all of the sources listed in paragraph 59 of this Report. These have been calculated following accepted statistical methods as far as possible. For National Health Service hospitals, the standard errors for the different types of examination are given in Table 16. The effort made to reduce the error in those types of examination which contribute most to the total genetic dose has resulted in an overall standard error of less than 5 per cent.

It has been found possible to separate the data between the different hospital regions; the genetic dose can then be calculated for each region separately, and hence (by addition) for the country as a whole. Similarly, the dose can be calculated separately for the different types of hospital, and by adding these together yet another estimate obtained for the country as a whole. All these are in reasonably good agreement, and indicate that the method of sampling has been effective.

TABLE 16

Genetic Doses (in mr per person) from General Diagnostic Radiology

Type of Examination	Male	Female	Foetal	Total	Standard Error	M.R.C. (1956) Values*
Head, Neck	0·01	0·02	—	0·03	0·01	0·03
Dental	—	0·02	—	0·02	0·02	—
Barium Swallow	—	—	—	—	—	—*a*
Arm, Hand	0·07	0·02	—	0·09	0·04	0·01
Shoulder	—	—	—	—	—	—
Dorsal Spine	0·01	0·01	—	0·02	0·01	0·06
Chest, Heart, Lung	0·14	0·29	0·05	0·48	0·05	0·02
Bony Thorax	—	0·01	—	0·01	0·01	—
Barium Meal	0·11	0·36	0·04	0·51	0·09	0·10 *a*
Cholecystogram	—	0·11	0·02	0·13	0·02	0·01
Abdomen	0·22	0·32	0·06	0·60	0·06	2·42 *b*
Obstetric Abdomen	—	1·12	2·27	3·39	0·20	— *b*
Intravenous Pyelogram.. ..	0·82	0·63	0·08	1·53	0·11	3·37 *c*
Retrograde Pyelogram	0·14	0·06	0·01	0·21	0·09	— *c*
Salpingography	—	—	—	—	—	0·23
Pelvimetry	—	0·55	0·60	1·15	0·09	3·91
Cystography	0·03	0·03	—	0·06	0·03	0·18
Barium Enema	0·03	0·11	0·02	0·16	0·03	0·06
Pelvis, Lumbar Spine, Lumbo-sacral Joint	1·72	1·18	0·22	3·12	0·26	5·15
Hip, Upper Femur	1·33	0·14	0·01	1·48	0·19	4·84
Lower Femur	0·15	0·01	—	0·16	0·06	— *d*
Leg, Foot	0·04	0·02	—	0·06	0·01	0·09
Neurological Examinations ..	—	0·01	—	0·01	0·01	—
Angiography—Head	—	—	—	—	—	—
—Chest	—	—	—	—	—	0·06 *e*
—Abdomen ..	0·01	—	—	0·01	0·01	—
Tomography—Head	—	—	—	—	—	—
—Chest	—	—	—	—	—	— *e*
—Abdomen ..	—	—	—	—	—	—
Cardiac Catheterization ..	—	—	—	—	—	— *e*
Bronchogram	—	0·01	—	0·01	0·01	— *e*
Total	4·83	5·03	3·38	13·24	0·44	20·54
Standard error	0·34	0·16	0·23	0·44		

NOTES: (*a*) Barium meal and swallow examinations grouped together.

(*b*) Obstetric abdomen examinations included with abdomen.

(*c*) Both kinds of pyelography taken together.

(*d*) Lower femur examinations grouped with those of the upper femur and hip.

(*e*) " Special chest " examinations taken together.

* These values do not appear in this form in the Medical Research Council's report, but additional information has enabled them to be calculated.

The figure for the genetic dose arising outside the National Health Service hospitals is inevitably less accurate (Table 17). Some sources (e.g., the Armed Forces) can be calculated almost as accurately as can the National Health Service hospitals, whereas for others the number of examinations is uncertain, or can only be estimated, while the distribution of the examinations between the different types, and the ages and sex of the patients, can only be estimated very approximately. It is assumed in these cases that the resulting genetic dose is subject to a standard error of 100 per cent. The standard error in the estimate of the genetic dose from general diagnostic radiology as a whole is still less than 5 per cent.

TABLE 17

Summary of Medical Diagnostic Radiology

Source	Estimated number of Examinations in a Year	Genetic Dose (mr)	Standard Error	M.R.C. (1956) Values (a)
The Armed Forces	411,692	0·41	0·03	0·45
Hospitals not in the National Health Service	286,000	0·24	0·24	0·62
Industrial Medical Sources	114,736	0·09	0·09	—
Private Medical Radiology	100,000	0·08	0·08	0·17
Dental Radiography (b)..	2,000,000	0·01	0·01	0·02
Mass Miniature Radiology (c)	4,770,927	0·01	0·01	0·02
Commercial Medical Radiological Services	22,200	0·01	0·01	—
Medical Research Council, Pneumoconiosis Research Unit	3,066	—	—	—
Atomic Energy Research Establishment	6,995	—	—	—
Red Cross and St. John	554	—	—	—
National Coal Board	100,000	—	—	—
Ministry of Pensions and National Insurance	40,000	—	—	—
Total	7,856,170	0·85	0·27	1·3
Add National Health Service Hospitals (Table 16)	13,000,000	13·24	0·44	20·5
Total for Diagnostic Radiology	20,856,170	14·09	0·52	21·8

NOTES: (*a*) These values do not appear in this form in the Medical Research Council's report, but additional information has enabled them to be calculated.

(*b*) Totals carried from Appendix III.

(*c*) Totals carried from Appendix II.

To this statistical estimate of error must be added errors associated with the calibration and use of the dosemeter, and with the evaluation of ovary and foetal gonad doses from the experimental data. Under the conditions of the measurements survey, the dosemeter error was unlikely to be more than 5 per cent. Some errors would also have been introduced by making the measurement at an incorrect point, but such errors are likely to cancel out in a survey of nearly 14,000 measurements. The accuracy of determination of ovary dose was tested by calculating, for examinations contributing some 77 per cent of the genetic dose for females, from the central skin dose rather than from the dose at the level of the iliac crest. This gave a result some 20 per cent higher than that obtained previously, or about 6 per cent higher for the total genetic dose from general diagnostic radiology.

The estimated value of the genetic dose from general diagnostic radiology is therefore 14·1 mr with an estimated total error of ± 1·0 mr (Table VI).

Effect of Technique

In view of the wide variation in reported gonad dose for essentially the same examination, calculations were made to demonstrate the effect on the genetic dose of improvements in technique. For each type of examination the reported measurements were divided into three categories:—

(*a*) Those from hospitals where the technique was worst, giving high average gonad doses and including about 10 per cent of the measurements for this type of examination.

(*b*) From hospitals with intermediate techniques, including about 65 per cent of the measurements.

(*c*) From hospitals using the best techniques giving low gonad doses and including about 25 per cent of the measurements.

The result of excluding category (*a*) is to suppose that these hospitals so improved their technique that the gonad doses were reduced to the average of the remaining hospitals. The result of basing the calculations on category (*c*) is to suppose that all hospitals are improved to the standard of the best 25 per cent at present. From the results in Table 18 it is clear that excluding the worst techniques reduces the genetic dose to about 70 per cent whereas if only the best techniques are included the genetic dose is reduced to less than 20 per cent of the present value.

TABLE 18

Effect of Improvement of Technique on Genetic Dose

Type of Examination	Total	Excluding Worst Techniques	Including Best Techniques only
Head, Neck ..	0·03	0·01	—
Dental	0·03	0·03	—
Barium Swallow	—	—	—
Arm, Hand ..	0·09	0·03	—
Shoulder	—	—	—
Dorsal Spine..	0·02	0·01	—
Chest, Heart, Lung	0·48	0·28	0·01
Bony Thorax	0·01	0·01	—
Barium Meal	0·51	0·29	0·05
Cholecystogram	0·13	0·11	0·01
Abdomen	0·60	0·45	0·16
Obstetric Abdomen	3·39	3·07	0·61
Intravenous Pyelogram	1·53	1·23	0·31
Retrograde Pyelogram	0·21	0·11	0·03
Salpingography	—	—	—
Pelvimetry ..	1·15	0·85	0·28
Cystography	0·06	0·02	—
Barium Enema	0·16	0·13	0·05
Pelvis, Lumbar Spine, Lumbo-sacral Joint	3·11	2·10	0·64
Hip, Upper Femur ..	1·48	1·02	0·20
Lower Femur	0·16	0·08	0·01
Leg, Foot ..	0·06	0·04	—
Neurological	0·01	0·01	0·01
Angiography—Head	—	—	—
—Chest	—	—	—
—Abdomen ..	0·01	0·01	—
Tomography—Head	—	—	—
—Chest	—	—	—
—Abdomen ..	—	—	—
Cardiac Catheterization	—	—	—
Bronchogram	0·01	—	—
Total	13·24	9·89	2·37
Per cent of dose	100·0	74·70	17·90
No. of exams. analysed	5,414	4,985	1,488
Per cent of examinations ..	100·0	92·08	27·48

The symbol — indicates an insignificant contribution.

APPENDIX II

MASS MINIATURE RADIOGRAPHY OF THE CHEST

The genetic dose from mass miniature radiography was estimated by the Medical Research Council in 1956 to be less than 0·1 per cent of the total from diagnostic radiology as a whole. Because this conclusion was based on measurements made mainly on one particular mass miniature radiography unit (Stanford and Vance, 1955) it was decided to carry out a more extended investigation in which measurements were made under conditions of normal practice on a number of different units, details of which are given in Table 19. This work was described fully in Appendix II of the Interim Report of 1959; it is summarized briefly in this appendix and the annual genetic dose per head of population is calculated. As in the survey of diagnostic radiology, the male gonad dose was measured directly, the female gonad dose was deduced from the dose measured at a point on the anterior surface of the abdomen and additionally the dose to the skin at the centre of the field was measured.

Gonad Dose per Examination

The technique and apparatus used were as described by Stanford and Vance (1955). It was thought desirable, however, to check for a number of radiation qualities, the ratio of the ovary dose to the dose measured at a point on the surface of the abdomen anterior to the ovary. This ratio was originally stated to be 0·10 for chest radiography. Measurements in a water-filled Neoprene phantom of the shape of a female figure gave factors varying from 0·10 at 60 kV to 0·26 at 90 and 100 kV, for a 17 × 17 inch field at 36 inches. For the calculations of the ovary doses given in Table 19 the ratio used was 0·10 at 61 and 63 kV and 0·18 for 74, 75 and 76 kV.

Table 19 shows the gonad doses received per examination and also for comparison the values published by Stanford and Vance (1955) which were subsequently used in the Medical Research Council's report (1956). It should be noted that, in the light of the recent phantom measurements, their value of 0·15 mr for the female gonad dose should be amended to 0·35 mr. In all cases the recently measured values are substantially below those obtained earlier.

The weighted mean doses per examination (one film) obtained from the measurements listed in Table 19 are:—

Males: mean gonad dose per examination: 0·090 mr

Females: „ „ „ „ „ : 0·092 mr

Although the 70 mm unit delivers a dose to women that is about twice that from the standard 35 mm unit, it is unlikely, having regard to the comparatively small number of 70 mm units in present use, that these units could appreciably increase the mean gonad dose.

Skin Dose at Centre of the Field

Measurements of the dose at the skin where the X-ray beam enters the body were made on 347 patients in 13 centres in England and Scotland. The numbers and types of X-ray apparatus investigated were:—

35 mm mass radiographic units	9
70 mm „ „ „	1
100 mm „ „ „	2
Static unit with 35 mm camera	1

All these units, with the exception of one 100 mm unit and one 35 mm unit, had no external filtration.

TABLE 19

Gonad Doses derived from Mass Miniature Radiography

Type of Unit	Female							Male					
	Mean kV	Exposure mAs	Age Range	No. of Observa-tions	Surface Dose Range mr	Mean Surface Dose mr	Mean Ovary Dose mr	Mean kV	Exposure mAs	Age Range	No. of Observa-tions	Gonad Dose Range mr	Mean Gonad Dose mr
70 mm ..	76	17	24–66	12	0·55–3·5	1·26	0·23	80	18	23–58	24	0·01–0·33	0·07
100 mm ..	74	27	18–70	53	0·24–2·4	0·83	0·15	74	28	17–75	22	0·08–0·20	0·16
35 mm Trailer 1	75	24	18–47	66	0·10–2·7	0·65	0·12	75	21	16–36	15	0·03–0·11	0·07
35 mm Trailer 2	63	29	15–63	101	0·04–0·36	0·20	0·02	65	27	22–64	118	0·02–0·72	0·05
35 mm Static ..	61	42	15–60	93	0·16–2·8	0·98	0·10	69	40	17–70	98	0·02–0·48	0·13
35 mm Trailer*	83	24					0·35	83	24				0·25

* Values from Stanford and Vance (1955). See interim report of the Committee (1959), Appendix II, para. 6.

Observations were made by placing the survey ionization chamber (see Appendix I (2)), over the patient's clothing at the centre of the field. The presence of the clothing and the size of the ionization chamber locate the point of measurement at a small distance away from the skin; the chamber then receives more primary radiation but less scattered radiation than the skin and because these effects partly compensate, it is unlikely that the measured skin dose is in error by more than 5 per cent.

The results of the survey are given in Table 20. It is evident that the use of an external filter significantly reduces the skin dose compared with the unfiltered beams.

TABLE 20

Mass Miniature Radiography

Skin Dose Measurements

	Female				Male			
Type of Apparatus and Place	kV Mean and Range	mAs Mean and Range	Mean Skin Dose r	No. of Observa-tions	kV Mean and Range	mAs Mean and Range	Mean Skin Dose r	No. of Observa-tions
35 mm								
Aberdeen .. P.A.	70 65–72·5	20 18–24	0·47	5	73 70–77	22 20–24	0·62	10
Aberdeen .. A.P.	70 65–72·5	20 18–24	0·49	4	74 70–79	20 18–24	0·50	9
Bradford	65 · 61–77	24 20–30	1·00	13	69 65–75	20 19–22	0·79	11
Cambridge ..	65 61–72	22 21–26	0·61	21	—	—	—	—
Hull	60 52–66	24 16–48	0·47	32	65 52–70	30 18–58	0·47	45
Leeds†	60 52–66	32·5 12–74	0·70	40	—	—	—	—
London† (Guys) ..	79 69–88	23 16–40	0·47	17	—	—	—	—
Maidstone ..	79 75–84	34 22–40	1·10	14	80 73–86	34 22–40	1·00	8
Manchester* ..	74 64–81	24 20–34	0·35	16	78 75–81	21 20–25	0·26	13
Sheffield .. P.A.	60 58–61	30 20–40	0·57	12	66 61–73	20 16–38	0·59	20
Sheffield .. A.P.	64 61–73	30 22–42	0·76	7	—	—	—	—
Southampton ..	76 70–85	25	0·94	9	84	25	1·06	1
70 mm								
Southampton ..	65 61–69	—	0·59	2	69 65–77	—	0·74	8
100 mm								
London* (Middlesex) ..	74 70–78	21 17–29	0·23	13	78 75–86	30 19–44	0·48	7
Southampton ..	72 59–85	25 20–33	0·90	7	66–80	17–24	0·64	3

† Figures refer to males and females.

* Unit fitted with 1 mm aluminium filter.

The mean skin dose per examination derived from Table 20 is 0·60 r and the mean kilovoltage used is 70 kV.

Calculation of the Genetic Dose

The number of mass miniature radiographic examinations in 1957 in England, Scotland and Wales totalled 4,770,927. Taking the age distribution of examinations from the report of the Ministry of Health for 1958, Part II, Table XXII and mean gonad doses per examination of 0·090 mr for males and 0·092 for females and the foetus the annual genetic dose is 0·01 mr.

Alternatively, assuming in the case of females a central skin dose of 0·60 r and using conversion factors based on measurements with the model described in Appendix I (3), a female gonad dose is obtained which could amount to 0·5 mr. The resulting genetic dose could then be as high as 0·03 mr. The annual genetic dose will be taken, therefore, as 0·01 mr and this may carry an error as high as 0·01 mr. The contribution made by mass miniature radiography to the genetic dose from medical radiology is so small, however, that this degree of uncertainty does not appreciably affect the estimate of the total dose.

APPENDIX III

DENTAL RADIOGRAPHY

Introduction

A survey was planned to investigate the genetic dose to the population due to dental radiography by estimating the gonad doses received by patients attending a sample of dental practitioners and hospitals. A random selection of 400 dentists was made from the Dental Register and they were asked to take part in the survey. From some 252 replies, 150 were willing to participate. A random selection of 20 hospitals was made and of these 12 were found to do dental radiography. A further 12 establishments of the Armed Forces were selected by the Ministry of Health. Finally, 154 dental practices or departments were covered by the survey.

In order to estimate the levels of radiation, each dentist was issued with a special film in a cassette mounted on a wedge of plastic foam. This was placed across the seat of the dental chair so that the film was in the midline of the chair in front of the patient's buttocks (Figure 6). Each dentist was requested to return the film when 100 exposures had been made or, if that number had not been reached, at the end of two months with details of the number of patients examined and exposures made during the period.

Measurement Survey

A film method of estimating these doses was used as ionization chamber methods were considered unsuitable for readings over a protracted time and might have caused inconvenience to the dentist and to the patient. The dose measured on the film after 100 exposures was expected to be about 2 mr. Several combinations of film and intensifying screen were tested, and that producing the greatest film blackening for such a dose was Gevaert Curix Rapid Film used with Gevaert Special Express intensifying screen. These were mounted in a modified Kodak Intra-oral cassette (Figure 7), which allowed estimation to be made separately of the backscattered radiation, the forwardscattered radiation, the chemical fog level and whether the film had received scattered or direct radiation. A film mounted in a metal cassette suffers from a directional effect in which the sensitivity becomes very low when radiation is incident in the plane of the film. Measurements with a phantom showed that the radiation received by the film was greatest in a direction at an angle of 45 degrees to the seat of the chair. In order to obtain the greatest sensitivity, therefore, the cassette was inclined at 45 degrees, facing the back of the chair.

Laboratory Measurements

To make investigations into the film-screen combination used in the survey, an extensive series of measurements was carried out on a model phantom consisting of a neoprene skin, filled with water. The head was made of a dried skull built up with gelatin. This was mounted on a dental chair so designed that film cassettes and ionization chambers could both be easily placed in position simultaneously.

An X-ray unit was used at 70 kVp with no additional filtration, the beam having a half value layer of 0·8 mm of Al. The dose rate at 30 cm from the focus was 12 r/min.

Measurements were made with a 10 ml ionization chamber inside the phantom and one of the Committee's diagnostic survey ionization chambers outside the phantom. These were connected to D.C. amplifiers designed by Wyard (1950) and Stuart and Osborn (1958) respectively.

All laboratory measurements were carried out with the X-ray tube positioned to take a view of the upper central incisors, a preliminary study of the doses received by the film from all the dental X-ray views having shown that this view was representative of the views of the upper jaw and gave the largest gonad doses. The doses from the views of the upper jaw were in all cases greater than those of the lower jaw.

Fig. 6.

Mounting of film on the dental chair

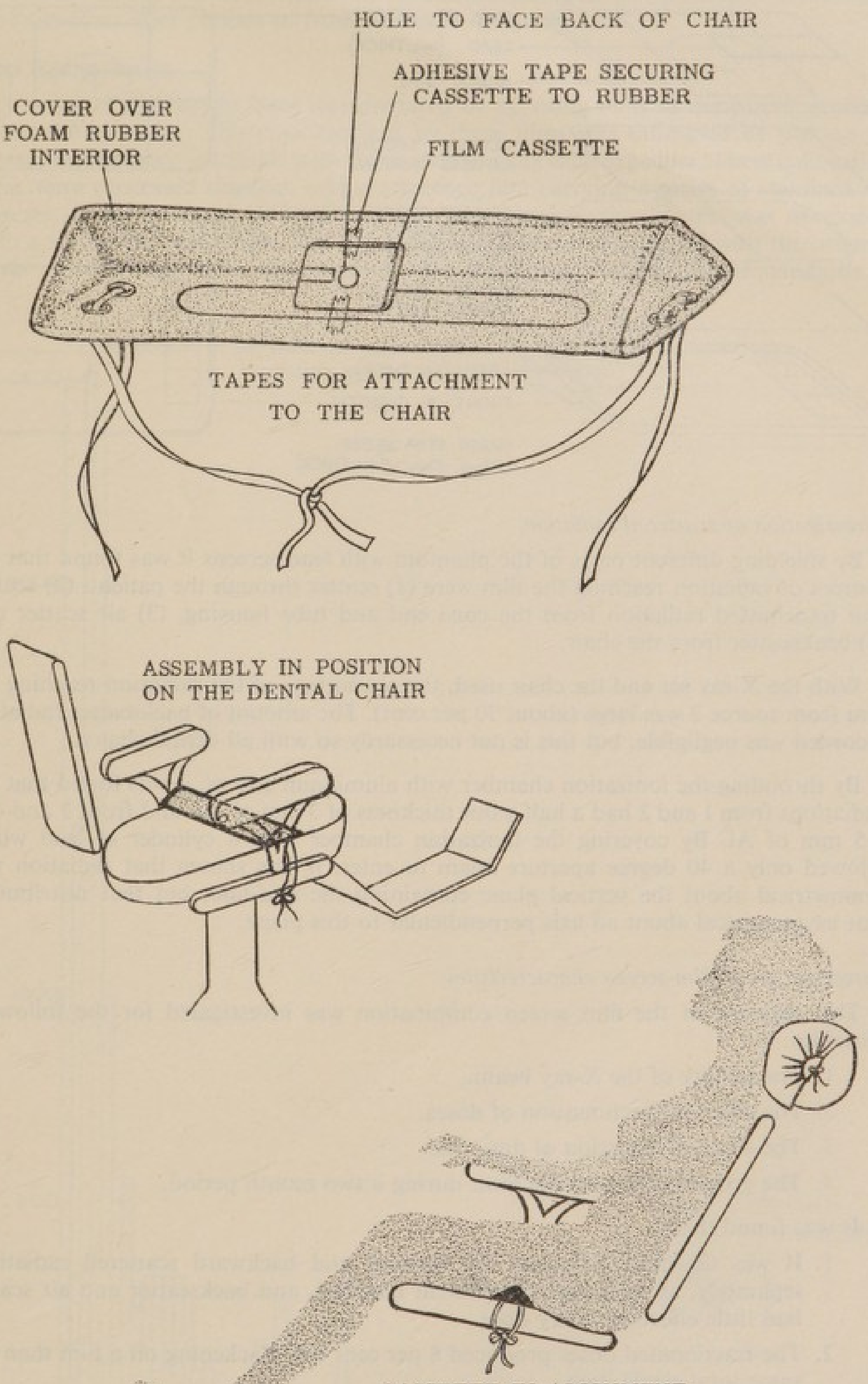
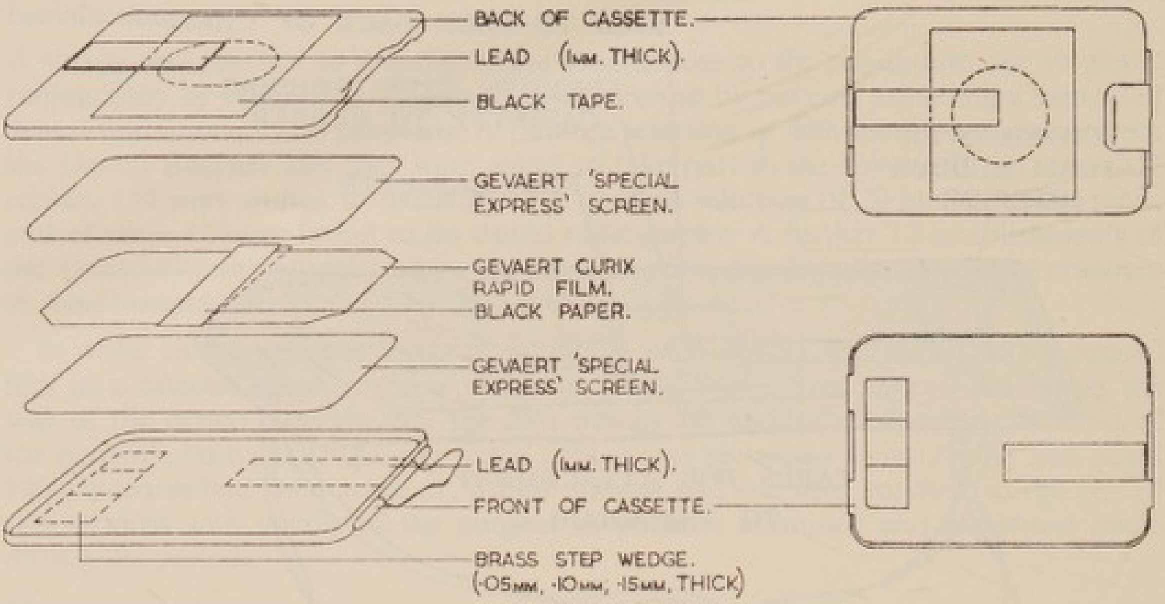


Fig. 7.

Exploded view of the cassette.



Investigation of scattered radiation

By shielding different parts of the phantom with lead screens it was found that the sources of radiation reaching the film were (1) scatter through the patient, (2) scatter and transmitted radiation from the cone end and tube housing, (3) air scatter and (4) backscatter from the chair.

With the X-ray set and the chair used, the proportion of the radiation reaching the film from source 2 was large (about 70 per cent). The amount of backscatter radiation recorded was negligible, but this is not necessarily so with all dental chairs.

By shrouding the ionization chamber with aluminium covers, it was found that the radiations from 1 and 2 had a half-value thickness of 3 mm of Al and from 3 and 4 of 1·5 mm of Al. By covering the ionization chamber with a cylinder of lead which allowed only a 40 degree aperture beam to enter, it was shown that radiation was symmetrical about the vertical plane containing the mid-line; but that distribution was asymmetrical about an axis perpendicular to this plane.

Investigation of film-screen characteristics

The response of the film screen combination was investigated for the following variables:—

1. The quality of the X-ray beam.
2. The effect of fractionation of doses.
3. The effect of variation of dose rate.
4. The growth of fog on the films during a two month period.

It was found that:—

1. It was desirable to assess the forward and backward scattered radiations separately, as they were of different qualities, and backscatter and air scatter had little effect on ovary dose.
2. The fractionated doses produced 8 per cent less blackening on a film than the same total single dose.
3. The increase of film speed for a total dose of 0·9 milliroentgen was 50 per cent in the range of dose rates 0·013 mr/sec to 0·115 mr/sec.

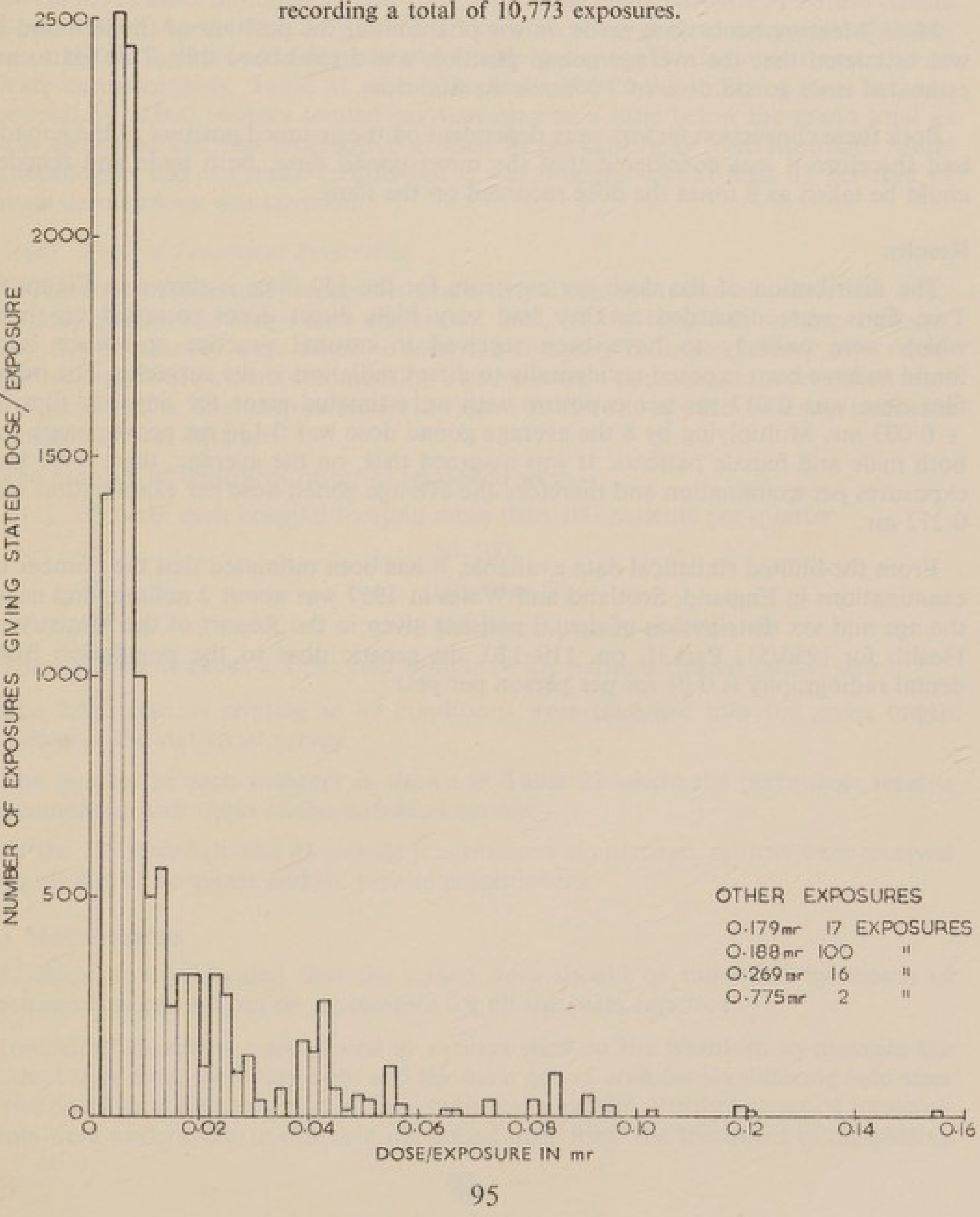
4. Loaded cassettes were placed on dental chairs in a department in which no X-ray exposures were made and similar cassettes were kept in a lead lined box also isolated from any source of radiation. There was no significant difference in fog level on these films after periods of from two days to two months.

Film Interpretation

A series of calibration films was prepared by exposing films in the survey position under the phantom. The dose received by these films was estimated by placing an ionization chamber in contact with the cassette during each exposure. These calibration films were processed together with a reference film carrying a series of standard exposures. Every batch of 10 films returned from participating centres was developed with a similar reference film. The batch of films was then compared with the original series of calibration films, the reference films being used as intermediate standards.

Fig. 8.

Distribution of the dose per exposure for 152 films in the dental survey recording a total of 10,773 exposures.



Development was carried out by mounting the films in a plastic spiral which was rocked continuously through one revolution per second. The developer was pumped in at a rate of one gallon per minute. It was shown that uniformly irradiated films had densities constant to ± 0·02.

Each film was measured at 16 separate points and forward and backscattered radiation could be assessed separately. Each was assessed from several sets of points and the maximum doses recorded were used in the calculations.

Conversion of Film Dose to Gonad Dose

Female. A series of measurements was made with ionization chambers at the site of the film and in a series of positions inside the water phantom corresponding to ovary positions. An average position of the ovary was assumed to be 11·5 cm above the seat of the chair and 9 cm from the anterior surface of the abdomen. On this basis, the ovary dose was estimated to be 8·8 times the dose recorded on the film, this being the extreme upper limit.

Male. Measurements were made on the phantom at the position of the film and it was estimated that the average gonad position was 5 cm above this. This led to an estimated male gonad dose of 7·5 times the film dose.

Both these conversion factors were dependent on the assumed position of the gonads and therefore it was considered that the mean gonad dose, both male and female, could be taken as 8 times the dose recorded on the films.

Results.

The distribution of the dose per exposure for the 152 films is shown in Figure 8. Two films were discarded as they had very high direct doses recorded on them which were unlikely to have been received in normal practice and were later found to have been exposed accidentally to direct radiation in the surgeries. The mean film dose was 0·017 mr per exposure with an estimated error for any one film of ± 0·003 mr. Multiplying by 8 the average gonad dose was 0·136 mr per exposure for both male and female patients. It was assumed that, on the average, there were two exposures per examination and therefore the average gonad dose per examination was 0·272 mr.

From the limited statistical data available, it has been estimated that the number of examinations in England, Scotland and Wales in 1957 was about 2 million, and using the age and sex distribution of dental patients given in the Report of the Ministry of Health for 1950/51, Part II, pp. 119–120, the genetic dose to the population from dental radiography is 0·01 mr per person per year.

APPENDIX IV

RADIOTHERAPY

This appendix describes the surveys, physical measurements and calculations carried out in order to estimate the genetic dose from the use of ionizing radiations in the treatment of (*a*) non-malignant and (*b*) malignant disease by external radiotherapy.

Tables of figures of the three-month survey of the use of unsealed radioactive isotopes referred to in paragraph 55 of the report are included in Tables 28 and 29 at the end of this Appendix.

TREATMENT OF NON-MALIGNANT DISEASE

(1.) National Surveys

(*a*) *Numbers of Patients Treated*

All hospitals in England, Wales and Scotland were requested to complete a return showing the number of patients treated for non-malignant conditions by X-rays during the period 27th April—28th July, 1957. There were seven general categories of conditions and four age groups for male and female patients. The form was sent also to private dermatologists. Table 21 of this appendix shows the totals of these returns. The total of 60,000 patients treated per year may be a little below the grand total as it was estimated that this represented at least 90 per cent reply from hospitals. Many dermatologists did not make returns but it was thought that at least 33 per cent of private dermatology was covered.

(*b*) *Type of Treatment Prescribed*

To ascertain the actual treatments given to patients in terms of prescribed dose, field size, quality of X-ray beam and site of field, all the hospitals making a return, under the first survey were asked to send the complete radiation history of a representative sample of patients commencing treatment for a non-malignant condition after 1st October, 1958. The form is shown in Figure 9. The site of each field was indicated on an anatomical diagram.

The number of treatment histories requested was:—

35 from each hospital treating more than 100 patients per quarter
15 ,, ,, , ,, 50–100 ,, ,, ,,
10 ,, ,, ,, ,, less than 50 ,, ,, ,,
5 ,, ,, ,, ,, from each private practitioner.

These represent about a 4 per cent sample of the patients treated in one year.

The 2,262 returns relating to 87 conditions were classified into the seven broad divisions of the statistical survey.

The number in each category is shown in Table 22 where the percentage returns are compared with those of the statistical survey.

Of the 139 hospitals and 41 private practitioners circularised, returns were received from all but 12 hospitals and six private practitioners.

(2.) Measurements

1. *Basis*. It was decided that the gonad dose should be estimated by means of measurements carried out on a phantom for all the cases reported.

Ionization chambers were placed at various sites on the phantom to measure the incident skin dose, the ovary dose and the male gonad dose for six differing field sizes at two focal skin distances and at four radiation qualities. Further series of measurements were undertaken to estimate the gonad dose from the treatment of ankylosing spondylitis and from ringworm of the scalp. From the anatomical diagram completed by the hospitals the position of the field could be estimated and the gonad dose deduced from a knowledge of the field size, f.s.d., quality and incident skin dose. The results therefore are true for one size of patient having the same scatter distance from the field to the gonad as in the phantom. The exact details of the simplifications used are given in the following sections of this report.

2. *Phantom.* The phantom was constructed from a human skeleton wax-impregnated, and mounted inside a polythene skin filled with a soft tissue equivalent bolus material. A measurement site at the ovary was constructed by means of a perspex tube let into the polythene skin. Further details are given in Appendix I (3).

(3.) Ionization Chambers

The male gonad dose was measured with the ionization chamber and dosemeter used in the diagnostic survey. The skin dose chamber was constructed of perspex and of volume 0·05 cc and also connected to the same type of dosemeter. The ovary dose was measured either with a chamber connected by capacity input to an electrometer or by an ionization chamber of volume 2 cc used in conjunction with an electrometer.

(4.) Radiation Qualities

Measurements were carried out for the main survey at the following qualities:—

	H.V.L. mm Al	*KV.*	*Filter* mm Al
1. ..	0·75	50	Nil
2. ..	1·0	90	Nil
3. ..	2·25	105	1·0
4. ..	5·5	120	5·75

(5.) Field Sizes

In the main survey the following field sizes were used which were provided by conical applicators:—

Field Diameter cm ..	1	2	4	5	12·5	25
F.S.D. cm	15	15	15	25·5	25·5	25·5

(6.) Measurement Organisation

(*a*) The accuracy of the estimation of the gonad dose from the description of a field treated at a hospital depended on the assessment of the scatter distance being the same for the patient and the phantom. It was decided, therefore, that there was little value in trying to assess accurately the gonad dose for the exact field positions remote from the gonads. Therefore the body was divided into regions and measurements made for fields centred at the middle of these regions from the anterior surface. No correction was made for lateral or posterior field directions in treatments of these areas.

Regions considered this way were:—head, upper thorax, lower thorax, abdomen, knee and foot.

(*b*) To assess the gonad doses due to fields close to either gonad, measurements were made on the phantom for all field sizes for scatter distances from the edge of the field to the gonad of 1, 2, 4, 7 and 10 cm. This was carried out on the anterior surface in both superior and inferior directions and for both female and male gonads. For the male gonad in the inferior direction this was carried out on the mid-surface of the thigh.

TABLE 21

RADIOTHERAPY

Survey of all Radiotherapeutic Procedures for Non-malignant Disease other than by Unsealed Radioactive Isotopes
29th April, 1957—28th July, 1957

(a) *139 Hospitals*

Type of Radiation used (see below)	Condition Treated	Age										
		Male				Female						
		0–14	15–29	30–49	50+	0–14	15–29	(P) 15–29	30–49	(P) 30–49	50+	Total
	1. Skin conditions:—											
bf	(*a*) Growths—Keloids, Warts, Haemangiomas, etc. ..	487	203	124	177	777	328	8	207	1	213	2,525
b	(*b*) Allergic and inflammatory—Eczemas, Dermatitis, etc. ..	188	875	1,503	1,383	162	1,248	28	1,658	15	1,545	8,605
b	(*c*) Ringworm	50	5	8	7	16	1	—	7	—	4	98
bc	(*d*) Others	13	144	101	151	17	157	—	88	—	116	787
c	2. Glandular Enlargemen's (e.g. Thymus, T.B. Glands, etc.) ..	—	1	3	4	2	4	—	5	—	2	21
c	3. Ankylosing Spondylitis ..	—	88	182	85	—	15	—	48	—	19	437
c	4. Arthritic and Rheumatic conditions (including Sciatica) ..	1	3	29	163	—	3	—	31	1	214	445
cg	5. Artificial Menopause	—	—	—	—	—	2	—	401	—	144	547
cg	6. Deafness	52	2	3	4	42	8	—	7	—	4	122
abcf	7. Any other non-malignant conditions	8	17	48	95	10	22	—	63	—	100	363
											Total	13,950

(b) *41 Private Practices*

Type of Radiation used	Condition Treated	Male 0–14	Male 15–29	Male 30–49	Male 50+	Female 0–14	Female 15–29	Female (P) 15–29	Female 30–49	Female (P) 30–49	Female 50+	Total
	1. Skin conditions:—											
b	(*a*) Growths—Keloids, Warts, Haemangiomas, etc. ..	5	4	2	3	13	10	—	8	—	8	53
b	(*b*) Allergic and inflammatory—Eczemas, Dermatitis, etc.	19	53	98	191	12	82	7	137	—	229	828
b	(*c*) Ringworm	4	—	2	—	1	—	1	1	—	—	9
b	(*d*) Others	2	9	3	15	8	23	1	30	—	20	111
	2. Glandular Enlargements (e.g. Thymus, T.B. Glands, etc.) ..											
	3. Ankylosing Spondylitis ..											
c	4. Arthritic and Rheumatic conditions (including Sciatica) ..				1							1
c	5. Artificial Menopause							1				1
	6. Deafness											
b	7. Any other non-malignant conditions			1			8				3	12
											Total	1,015

P = pregnant.

Letter	Type of Radiation
a	X-rays excited at 0 to 40 kV.
b	X-rays excited at 41 to 150 kV.
c	X-rays excited at 151 to 500 kV.
e	Telecurie units.
f	Superficial applications by sealed radioactive sources.
g	Intercavitary applications by sealed radioactive sources.
h	Interstitial applications by sealed radioactive sources.

Figure 9.

TREATMENT OF NON-MALIGNANT CONDITIONS BY X-RAYS
RADIATION HISTORY

Patient's Name.......................... Age........ Sex........ Hospital Number........... Hospital............................

	1.	2.	3.	4.	5.
1. Condition treated					
2. Date course started					
Date course ended					
3. Area No.					
4. Position of patient during treatment—prone, or supine or sitting					
5. Skin dose prescription Dose per treatment.................r No. of treatments..............					
6. Skin Field size:— Along body axis in cms Across body axis in cms					
7. Focal Skin Distance in cms					
8. KVp					
9. H.V.L. mm Al or mm Cu					
10. Filtration added (additional to tube wall) mm Al or mm Cu					
11. Gonads in beams? YES or NO					
12. Gonads shielded? YES or NO.					
FOR OFFICE USE					
NOTES					

TABLE 22

Treatment of Non-malignant Disease

Number of Cases reported in Sample Survey

Classification No.	Condition treated	Sample No. of Cases	%	Statistical Survey %
1.	*Skin conditions*			
(*a*)	Growths—Keloids, Warts, Haemangiomas	516	23	17
(*b*)	Allergic and inflammatory—Eczemas, Dermatitis, etc.	1,202	53	64
(*c*)	Ringworm	14	0·4	1·3
(*d*)	Others	176	7·7	5·3
2.	Glandular enlargements	15	0·7	0·1
3.	Ankylosing Spondylitis	84	3·8	2·6
4.	Arthritic and Rheumatic conditions ..	75	3·3	2·7
5.	Artificial menopause	75	3·3	3·8
6.	Deafness	23	1·2	0·8
7.	Any other non-malignant conditions ..	58	2·7	2·3
	No diagnosis	7	0·3	
	Malignant cases discarded	17	0·7	
		2,262	100%	100%

(*c*) In order to correct for fields incident laterally or posteriorly in Section (*b*), measurements were made with 12·5 cm circle 25·5 cm F.S.D. in these directions and the ratio of these measurements to those obtained in the anterior direction deduced. These corrections were applied to all the field sizes.

(*d*) Measurements with the ovary in the direct beam were made for all applicators from anterior, posterior and lateral directions.

(*e*) For treatments of the arms and hands carried out in the sitting position measurements were made on the phantom with the phantom standing and some bolus bags arranged so as to simulate the legs in a sitting position. Measurements were made for all field sizes on bolus bags simulating the hands and arms on a couch in front of the phantom.

(*f*) In order to deduce the gonad dose from rectangular fields for those in which the gonads were in the beam, the circular equivalent tables from Day (1950) were used. For fields in which the gonads were out of the beam the circle of equivalent area was used.

(7.) Special Cases

(a) *Ankylosing Spondylitis*

Measurements of the gonad doses were made with the normal field sizes and the following positions:—cervical spine, upper dorsal, lower dorsal, lumbar, sacro-iliac joints, ischial tuberosities, hip, knee and foot. All measurements were carried out at 220 KV and 50 cm F.S.D. with a Thoraeus filter 0·44 mm Sn + 0·25 mm Cu + 1 mm Al, having a H.V.L. of 2·1 mm Cu. This was the average quality used in the treatments reported.

(b) *Ringworm of the Scalp*

Measurements of the gonad doses were made with a wax head and bolus bags to simulate a 4 year old child. The normal 5 field technique was used at qualities 2 and 3 discussed in paragraph 4 of this appendix.

(8.) **Application of Measurements to Treatment Survey**

For each field reported in the survey it was necessary to decide to which of the anatomical regions listed in paragraph 6 (*a*) the treatment was given or, when the scatter distance was less than 10 cm to the gonads as indicated on the diagram on the report sheet, what exact value of scatter distance to use.

The appropriate ratios of gonad dose to skin dose were deduced from the field size and quality used by interpolation from the graphical data. The rectangular fields were converted to circular fields of equivalent area. The transmitted dose was deduced by multiplying by the total skin dose given to that field and by the correction for lateral or posterior views in cases 6 (*c*) above.

In calculating the gonad dose it was assumed that the sample of over 2,000 radiation histories obtained was representative of non-malignant conditions being treated and of the dose given to them.

These average gonad doses per treatment are given in Table 23.

TABLE 23

Treatment of Non-Malignant Disease

Average Gonad Doses per Patient Treated in Sample Survey

Condition Treated	Male mr		Female mr	
1. Skin conditions:—				
(*a*) Growths—Keloids, Warts, Haemangiomas, etc.		154		304*
(*b*) Allergic and inflammatory—Eczemas, Dermatitis, etc. ..		1,184*		1,912
(*c*) Ringworm	Age 0–14	219	Age 0–14	883
	Age 15+	332	Age 15+	1,704
(*d*) Others		32,419		5,984
2. Glandular enlargements (e.g. Thymus, T.B. Glands, etc.)		76		58
3. Ankylosing spondylitis		49,900	Age 15–29	35,700*
			Age 30–49	5,200*
			Age 50+	0*
4. Arthritic and Rheumatic conditions (including Sciatica)		23,474		160,910
5. Artificial menopause		—		No fertility
6. Deafness		42		23
7. Any other non-malignant conditions ..		6,149		51,152

* Average if age weighting included (see text).

The conditions which made most contribution to the average gonad dose per treatment in the main categories were:—

1(*a*) Keloid
1(*b*) Dermatitis, eczema, intertrigo
1(*d*) Pruritus ani et vulvae
3 Ankylosing spondylitis
4 Arthritis
7 Paget's disease of bone

In 17 cases out of the total of 2,262, clinical judgement was used to apply an age weighting factor to the gonad dose before these averages were taken as it was considered that these patients would not have been treated with certain fields had they been younger. The genetically significant dose for each category of conditions was calculated by multiplying the number of people treated per year (obtained from the statistical survey) by the fertility factor (see Appendix 1 (5)) for the respective age group and again multiplied by the average gonad dose per treatment taken from Table 23.

(9.) **Calculation of Genetic Dose**

The following assumptions were made in the calculation of the genetic dose:—

(*a*) It was assumed that all artificial menopause patients had no fertility after radiation had been given.

(*b*) The treatment of ringworm was sub-divided and it was assumed that all patients under 15 were treated for ringworm of the scalp and those over 15 for epidermophytosis as reported in the sample.

(*c*) In order to deduce the foetal contribution it was assumed that the foetal dose was the same as the maternal ovary dose and that the number of pregnancies reported were those between three months and full term and hence a further number equal to 0·5 times those reported would have been treated during the first three months of pregnancy.

The genetically significant doses obtained from the surveys are tabulated in Table 24.

Therefore, the treatment of non-malignant conditions contribute the same genetic dose as 4·5 millirontgen/year to the gonads of the whole population.

Table 24 shows the contributions to this total from each of the categories, the two main ones being skin treatments amounting to 56 per cent and ankylosing spondylitis to 26 per cent.

TREATMENT OF MALIGNANT DISEASE

In order to obtain an estimate of the population genetic dose from radiotherapy of malignant disease, four items of data were required.

1. The numbers of people treated for a particular condition per year in various age groups.
2. The average gonad dose received in the treatment of a particular condition.
3. The expectation of life and the number of children expected to be born during the period.
4. The reduction in fertility due to the radiation treatment itself.

The following information has been used to make an estimate of the genetic dose corresponding to the above headings.

TABLE 24

Genetic Dose from Radiotherapy of Non-malignant Disease

Condition Treated	Male (mr)		Female (mr)		Foetal (mr)		Total	%
	Hospital	Private Practice	Hospital	Private Practice	Hospital	Private Practice		
1. Skin conditions:—								
(*a*) Growths—Keloids, Warts, Haemangiomas, etc.	0·021	0·001	0·067	0·004	0·001	—	0·094	2·1
(*b*) Allergic and inflammatory—Eczemas, Dermatitis, etc.	0·285	0·053	0·492	0·099	0·026	0·006	0·961	21·5
(*c*) Ringworm (i) 0–14 years	0·002	—	0·003	—	—	—	0·005	0·1
(ii) 15+ years	—	—	0·001	0·002	—	0·001	0·004	0·1
(*d*) Others (Mainly ano-genital)	1·006	0·183	0·170	0·096	—	0·001	1·456	32·6
2. Glandular Enlargements (e.g. Thymus, T.B. Glands, etc.)	—	—	—	—	—	—	—	—
3. Ankylosing Spondylitis	1·065	—	0·084	—	—	—	1·149	25·7
4. Arthritis, Rheumatism, etc.	0·042	—	0·178	—	0·050	—	0·270	6·0
5. Artificial Menopause	—	—	—	—	—	—	—	—
6. Deafness	0·001	—	—	—	—	—	0·001	—
7. Any other non-malignant conditions	0·039	0·001	0·325	0·167	—	—	0·532	11·9
	2·461	0·238	1·320	0·368	0·077	0·008	4·472	100

These figures have been corrected on the basis of a 90 per cent return from National Health Service hospitals, and a 33 per cent return from private practitioners.

TABLE 25

Radiotherapy of Malignant Disease

Survey of all Radiotherapeutic Procedures other than by Unsealed Radioactive Isotopes for the three monthly period of 29th April, 1957, to 28th July, 1957

International Classification Nos.	Malignant Neoplasms	No. of Patients: Males 0–14	Males 15–29	Males 30–49	Males 50+	Males Total	Females 0–14	Females 15–29	p*	Females 30–49	p*	Females 50+	Females Total	Total Patients
140–148	Buccal Cavity and Pharynx	3	3	66	515	587	2	4		38	1	230	275	862
150	Oesophagus			6	68	74		1		6		50	57	131
151	Stomach			5	12	17				1		1	2	19
152	Small Intestine				2	2						1	1	3
153	Large Intestine (not rectum)			2	8	10		1		6		18	25	35
154	Rectum			9	35	44				9		40	49	93
155–159	Other Digestive Organs and Peritoneum	1	3	3	11	18	2	2		4		10	18	36
160	Nose, Middle Ear, Sinuses	1	4	13	78	96	1	3		18		64	86	182
161	Larynx			21	219	240		1		6		22	29	269
162	Trachea Bronchus and Lung—Primary		6	194	1,120	1,320		2		26		131	159	1,479
163–165	Other Respiratory System		2	2	24	28	1	1		6		5	13	41
170	Breast			3	16	19		15		923	2	2,225	3,165	3,184
171	Cervix Uteri							13		357	4	743	1,117	1,117
172–174	Other Uterus							1		43	1	298	343	343
175–176	Ovary and Other Female Genital Organs						1	8		97		314	420	420
177	Prostate			1	25	26								26
178–179	Testis and Other Male Genital Organs	1	36	72	48	157								157
180	Kidney	3	1	17	44	65	8	2		2	1	13	26	91
181	Bladder and Other Urinary Organs	1	1	24	337	363				9		116	125	488
192	Eye	6		7	11	24	5			4		8	17	41
193	Brain and Nervous System	31	18	40	60	149	23	14		33		35	105	254
194	Thyroid		1	3	18	22	1	2		15		48	66	88
a 195	Other Endocrine Glands			1	2	3		1		4		9	14	17
a 196	Bone	7	13	20	68	108	7	3		60		134	204	312
a 197	Connective Tissue	3	3	14	20	40		2		3		18	23	63
a 198	Lymph Nodes (Secondary)		1	5	32	38	1	1		5		48	55	93
a 199	Other Unspecified Sites	2	3	8	17	30	2	1		10		19	32	62
a 200–205 (excl. 204)	Lymphatic and Haematopoietic Tissues	6	30	40	82	158	3	9		27		50	89	247
a 204	Leukaemia and Aleukaemia	1	1	13	31	46	2	3		13	1	28	47	93
a 190–191	Skin	1	1	28	193	223		3		19		166	188	411
b 195	Other Endocrine Glands		1	5	5	11	1	2		5		9	17	28
b 196	Bone	2	5	16	98	121	8	9		21		125	163	284
b 197	Connective Tissue	3	7	20	24	54	2	7		10		18	37	91
b 198	Lymph Nodes (Secondary)	1	6	24	125	156		4		26		121	151	307
b 199	Other Unspecified Sites	2	9	16	38	65		4		9	2	46	61	126
b 200–205 (excl. 204)	Lymphatic and Haematopoietic Tissues	12	12	111	156	291	10	32		63	3	138	246	537
b 204	Leukaemia and Aleukaemia	3	4	23	78	108		2		22	3	42	69	177
b 190–191	Skin		6	154	1,126	1,286	1	10		116	5	995	1,127	2,413
		90	177	986	4,746	5,999	81	163		2,016	23	6,338	8,621	14,620

* Number ascertained to be pregnant at treatment, not included in preceding column.
(*a*) For lesions situated in the area of the lower abdomen, pelvis and upper third thighs.
(*b*) For lesions elsewhere in the body than specified in (*a*).

TABLE 26

Gonad Dose per Treatment of Malignant Disease

Condition	No. of Fields	App. Field Size cm	Skin Dose/per Field r	Gonad Dose per Treatment r Male	Gonad Dose per Treatment r Female
1. Buccal Cavity and Pharynx ..	2 or 3	6 × 8	4,500	0·22	0·25
2. Oesophagus	6	7½ × 15	4,500	3·02	5·94
3. Stomach	3	10 × 12	4,500	9·07	16·94
4. Small Intestine	3	10 × 12	4,500	39·77	—
5. Large Intestine (not rectum) ..	3	10 × 15	4,000	212·09	—
6. Rectum	3	10 × 12	4,000	385·20	—
7. Other Digestive Organs and Peritoneum	2	10 × 12	4,000	5·38	10·04
8. Nose, Middle Ear, Sinuses ..	4	6 × 8	4,500	0·51	0·57
9. Larynx	2 or 3	6 × 10	4,500	0·43	0·94
10. Trachea, Bronchus and Lung—Primary	6	10 × 8	4,500	2·05	5·94
11. Other Respiratory System ..	6	10 × 10	4,500	2·05	5·94
12. Breast (male)	2	10 × 20	4,000	1·58	—
(female)	4	10 × 20	4,000	—	7·79
13. Cervix Uteri	—	5 × 15	—	—	—
14. Other Uterus	—	10 × 12	—	—	—
15. Ovary and Other Female Genital Organs	—	10 × 20	—	—	—
16. Prostate	3	10 × 12	4,500	238·60	—
17. Testis and Other Male Genital Organs	2	30 × 30	3,000–4,000	4,069·0	—
18. Kidney	3	10 × 15	4,500	44·74	—
19. Bladder and Other Urinary Organs	3	10 × 12	4,500	262·59	71·71
20. Eye	2	3 ⊙	3,500	0·20	0·22
21. Brain and Nervous System ..	4	10 × 8	3,500	0·40	0·44
22. Thyroid	3	10 × 8	4,000	0·45	1·00
23. (*a*) Other Endocrine Glands ..	3	6 × 8	4,500	44·74	405·0
(*b*) Other Endocrine Glands ..	5	6 × 8	4,500	0·64	0·71
24. (*a*) Bone	3	10 × 12	4,000	212·09	360·0
(*b*) Bone	3	10 × 12	4,000	1·34	4·61
25. (*a*) Connective Tissue	2	10 × 12	4,000	141·39	240·0
(*b*) Connective Tissue	2	10 × 12	3,000	0·67	2·30
26. (*a*) Lymph Nodes (Secondary) ..	1	10 × 8	5,000	88·37	150·0
(*b*) Lymph Nodes (Secondary) ..	1	10 × 8	5,000	0·39	1·10
27. (*a*) Other Unspecified Sites ..	1	10 × 12	5,000	88·37	150·0
(*b*) Other Unspecified Sites ..	1	10 × 12	5,000	0·56	1·92
28. (*a*) Lymphatic and Haematopoietic Tissues	2	10 × 12	3,500	123·72	210·0
(*b*) Lymphatic and Haematopoietic Tissues	4	10 × 12	3,500	1·57	5·38
29. (*a*) Leukaemia and Aleukaemia ..	2	10 × 12	3,500	123·72	210·0
(*b*) Leukaemia and Aleukaemia ..	4	10 × 12	3,500	1·57	5·38
30. (*a*) Skin	1	10 × 12	5,000	88·37	150·0
(*b*) Skin	1	10 × 12	5,000	0·39	1·10

(*a*) For lesions situated in the area of the lower abdomen, pelvis and upper third thigh.
(*b*) For lesions elsewhere in the body than specified in (*a*).

(1.) National Survey

The Committee's returns for the three months April to July, 1957, (Table 25) give the number of patients treated in the country for 30 conditions in four age groups. In eight of these conditions which are not specific to one site of the body the statistics are given separately for those lesions treated in the area of the lower abdomen, pelvis and upper third of the thighs and those lesions elsewhere in the body.

TABLE 27

Genetic Dose from Radiotherapy of Malignant Disease

Condition	Male		Female	
	reg.	%	reg.	%
1. Buccal Cavity and Pharynx ..	4	—	2	—
2. Oesophagus ..	1	—	2	—
3. Stomach ..	3	—	1	—
4. Small Intestine ..	—	—	—	—
5. Large Intestine (not rectum) ..	16	0·1	—	—
6. Rectum ..	183	1·0	—	—
7. Other Digestive Organs and Peritoneum ..	3	—	3	—
8. Nose, Middle Ear, Sinuses ..	4	—	3	—
9. Larynx ..	14	0·1	1	—
10. Trachea Bronchus and Lung—Primary ..	22	0·1	7	0·1
11. Other Respiratory System ..	1	—	2	—
12. Breast ..	2	—	186	2·9
13. Cervix Uteri ..	—	—	—	—
14. Other Uterus ..	—	—	—	—
15. Ovary and Other Female Genital Organs ..	—	—	—	—
16. Prostate ..	22	0·1	—	—
17. Testis and Other Male Genital Organs ..	10,485	55·6	—	—
18. Kidney ..	123	0·7	—	—
19. Bladder and Other Urinary Organs ..	1,984	10·5	55	0·9
20. Eye ..	1	—	—	—
21. Brain and Nervous System ..	9	—	7	0·1
22. Thyroid ..	2	—	13	0·2
23. (*a*) Other Endocrine Glands ..	6	—	224	3·5
(*b*) Other Endocrine Glands ..	1	—	2	—
24. (*a*) Bone ..	1,169	6·2	2,102	33·1
(*b*) Bone ..	13	0·1	44	0·7
25. (*a*) Connective Tissue ..	842	4·5	163	2·6
(*b*) Connective Tissue ..	7	—	15	0·2
26. (*a*) Lymph Nodes (Secondary) ..	103	0·5	98	1·5
(*b*) Lymph Nodes (Secondary) ..	4	—	8	0·1
27. (*a*) Other Unspecified Sites ..	149	0·8	164	2·6
(*b*) Other Unspecified Sites ..	5	—	8	0·1
28. (*a*) Lymphatic and Haematopoietic Tissues	1,352	7·2	893	14·1
(*b*) Lymphatic and Haematopoietic Tissues	67	0·4	166	2·6
29. (*a*) Leukaemia and Aleukaemia ..	65	0·3	113	1·8
(*b*) Leukaemia and Aleukaemia ..	4	—	10	0·2
30. (*a*) Skin ..	2,072	11·0	1,877	29·6
(*b*) Skin ..	125	0·7	174	2·7
	18,863	100	6,343	100

(*a*) For lesions situated in the area of the lower abdomen, pelvis and upper third thighs.
(*b*) For lesions elsewhere in the body than specified in (*a*).

1 milliroentgen given to the gonads of all the population is equivalent to 48,650 reg. Calculated on this basis, the total genetic dose of 25,206 reg. is then equivalent to 0·52 mr per person per year.

The symbol — indicates an insignificant contribution.

(2.) Measurements

To estimate the gonad doses received whilst patients were undergoing radiotherapy, measurements were made on the phantom previously described using the ionization systems described in the previous section. One quality of radiation, 220 kV 2·1 mm Cu HVL 50 cm F.S.D. was used throughout the measurements and applicators were used in contact with the phantom.

A list of the normal treatments was prepared for the 30 conditions and an estimate then made of the gonad doses for both male and female patients during the treatment. These are tabulated in Table 26. In the case of breast, buccal and bladder cancers, an additional contribution to the dose was estimated for radium treatments and included in these figures. The dose was not estimated in the case of treatments of the female pelvic region as it was assumed that no fertility existed after these treatments.

(3.) Expectation of Life

The supplements on Cancer published by the Registrar General of England and Wales (1952, 1953) give survival data for 5–7 years after the treatment of malignant disease at 14 sites. Using this data and also that of Greenwood (1926) for cancer of the larynx and that of Lea and Abbatt (1957) for leukaemia the logarithmic mean survival time has been calculated. The survival times have been utilised to derive the number of children expected to be born during this period to such patients in each of the separate age groups. It has not been possible to break down the statistics to derive a survival time for each age group separately. The statistics are derived from both treated and untreated cases.

For those sites for which no survival statistics were readily available, the mean survival time of those determined was used, excluding however, cancer of the skin.

On these assumptions and calculations it has been possible to derive the total number of children expected per year from patients suffering from malignant disease at each site.

(4.) The Reduction in Fertility due to the Actual Radiation Received

The literature gives approximate values for sterilising doses for males and females (National Academy of Sciences Report, 1956). The information on humans is insufficient, however, to make any other than crude allowances for the loss of fertility. Such estimates have been made and are as follows:—

(a) Male Patients

Patients treated for malignant neoplasms of the testis and other male genital organs have been assumed to have 2 per cent of normal fertility. For those patients who have had treatment to the pelvic region, 40 per cent has been allowed. All other male patients have been considered to have normal fertility.

(b) Female Patients

All women having treatment of the pelvis have been considered as subsequently having no fertility. This includes all treatments of the bladder, cervix, rectum and kidney. For those conditions listed as being in the pelvic region a mean scatter distance of 5 cms and a fertility of 40 per cent of normal have been assumed.

(5.) Genetic Dose Estimates for External Radiotherapy of Malignant Diseases

The calculation of the genetic dose has been made by combining the four items listed above and the genetic doses are given in Table 27. The combined total is equivalent to 0·52 mr per person per year for the whole population.

TABLE 28

RADIOTHERAPY

Survey of the Use in Man of Unsealed Radioactive Materials for the Three-month Period, 29th April, 1957 to 28th July, 1957

Test Doses

	Males					Females							Total Patients	Total Dose mc
Radio-Isotope ..	0—	15—	30—	50+	Total	0—	15—	p*	30—	p*	50+	Total		
Thyroid Function														
Iodine .. 131 ..	17	74	293	406	790	36	416	3	1,646		1,649	3,750	4,540	150·509
Iodine .. 132 ..	2	74	93	31	200	9	70		134	1	159	373	573	14·259
Carcinoma of Thyroid														
Iodine .. 131 ..				8	8		3		15		26	44	52	129·552
All Other Investigations														
Iodine .. 131 ..	1	2	26	43	72		2	1	23	3	28	57	129	6·098
Iodine .. 132 ..								1		1		2	2	0·004
Chromium.. 51 ..		5	25	42	72		7		30		50	87	159	12·547
Bromine .. 82 ..		10	9	16	35		8		10		13	31	66	1·903
Phosphorus 32 ..	2	1	7	25	35	1	2		35		49	87	122	52·203
Potassium .. 42 ..		11	6	3	20		12	5	22		10	49	69	7·330
Iron .. 59 ..		4	11	27	42		2		18		30	50	92	0·768
Cobalt .. 56 ..		3	8	61	72		2		15		44	61	133	0·090
Cobalt .. 58 ..			2	5	7				3		9	12	19	0·104
Cobalt .. 60 ..			1	4	5				4		11	15	20	0·020
Sodium .. 22 ..		1			1						1	1	2	0·050
Sodium .. 24 ..		20	8	41	69		6	26	14	12	9	67	136	6·445
Yttrium .. 90 ..									1		3	4	4	92·6
Zinc .. 65 ..	2				2								2	0·120
Calcium .. 45 ..											1	1	1	0·050
Carbon .. 14 ..		1	2	6	9				3		2	5	14	0·004
	24	206	491	718	1,439	46	530	36	1,973	17	2,094	4,696	6,135	

p* Patients pregnant at examinations, not included in preceding column.

TABLE 29

Survey of the Use in Man of Unsealed Radioactive Materials for the Three-month Period, 29th April, 1957 to 28th July, 1957

Therapeutic Doses

Radio-Isotope	Condition Treated	Number of Treatments												Total Patients	Total Dose mc
		Male					Female								
		0—	15—	30—	50+	Total	0—	15—	p*	30—	p*	50+	Total		
Iodine 131	Thyroid Disfunctions			35	66	101		5		170		368	543	644	6,505
	Cancer, Thyroid ..	1			10	11				8		24	32	43	5,152
	Cardiac Failure ..			1	4	5				1		5	6	11	327
	Myelomatosis ..			1	3	4								4	443
Gold 198	Malignant Effusions			1	4	5		2		1		13	16	21	1,851
	Pericardial Effusion											1	1	1	40
	Pleural Effusion ..			3	1	4				6		17	23	27	2,385
	Cancer, Breast ..									2		3	5	5	510
	Cancer, Pharynx ..				1	1								1	30
	Cancer, Bronchus ..				1	1						1	1	2	180
	Cancer, Pinna ..											1	1	1	20
	Cancer, Bladder ..			1	1	2						2	2	4	770
	Cancer, Ovary ..								1	10		9	20	20	2,550
	Cancer, Stomach ..			1		1								1	120
	Cancer, Pancreas ..			1		1								1	120
	Carcinomatosis ..							1		2		6	9	9	780
	Ascites			4	1	5		1		14		43	58	63	8,487
	Papillomatosis ..				10	10				1			1	11	2,950
	Anaemia									1			1	1	12
	Glands, Neck ..									1			1	1	20
	Rh. Arthritis ..			1		1				1		1	2	3	3·9
	Secondary Seedings on Lung Wall ..			1		1								1	100
	Bladder Papilloma ..			1		1								1	400
	Peritoneal Effusion							1				4	5	5	650
Phos-phorus 32	Polycythaemia ..	1		12	44	57				7		45	52	109	595
	Recticulosarcoma ..				2	2								2	13·5
	Lymphosarcoma ..									1			1	1	8
	Thrombocythaemia ..									1			1	1	4
	Cancer, Bronchus ..				2	2								2	20
	Cancer, Pancreas ..			1		1								1	15
	Leukaemia			1	7	8						3	3	11	60
	Plasmocytoma ..				1	1								1	5
	Multiple Myeloma ..											1	1	1	5
	Cranial Neoplasm ..	1				1								1	20
	Blood Diseases ..		1		8	9				1		7	8	17	90
	Myelomatosis ..				6	6						6	6	12	66
	Lymphosarcoma ..				2	2								2	10·5
	Reticulosis											2	2	2	13
	Hodgkin's Disease			1		1								1	80
															Units
Thorium X	Naevus	50	1			51	54						54	105	27,500
	Cap. Haemangioma	15				15	36						36	51	2,000
	Psoriasis	1		1	1	3		5		5		3	13	16	16,000
	Alopecia		3	7	1	11	2	4		4		1	11	22	1,500
	Alopecia Areata ..			2		2		1					1	3	?
	Lichen			2	1	3		1		3		1	5	8	1,500
	Eczema			1	1	2		1				3	4	6	1,500
	Vitiligo											1	1	1	1,500
	Defluvium									1		1	2	2	1,500
	Lymphocytomia ..											1	1	1	1,500
	Hirsuties											1	1	1	1,500
	Capillerosis				1	1								1	1,500
	Port Wine Stain ..						1						1	1	1,500
	Pustular Bacteride ..			1		1								1	1,500
	Mycosis Fungoides											1	1	1	1,500
	Capillary Angiomata	1				1	2			1			3	4	?
	Haemangioma ..	2	4			6	6			1			7	13	20,000
															Total Dose
	Psoriasis, etc. ..	1			1	2		4		4		1	9	11	88,000
	Haemangioma, etc.	2	4			6	6			1			7	13	58,000
Radon Ointment	Rodent Ulcer, Cheek			1		1								1	2
		75	13	81	180	349	107	26	1	248		576	958	1,307	

p* Number ascertained to be pregnant at treatment, not included in preceding column.

HOSPITALS AT WHICH DOSE MEASUREMENTS WERE MADE

Newcastle Region:

A—Hexham General and Preston Hospital (North Shields).

B—Chester-le-Street General, West Hartlepool General and Blencathra Hospital (Keswick).

C—Mary Hewetson Cottage Hospital (Keswick).

D—T.B. Clinic, Jarrow-on-Tyne.

Leeds Region:

A—Kingston General (Hull) and St. Luke's (Bradford).

B—Clayton (Wakefield), St. John's (Halifax) and Victoria Hospital for Sick Children (Hull).

C—Bartholomew (Goole).

D—Chest Clinic, Coltman Street, Hull.

Sheffield Region:

A—Leicester General and Sheffield Royal Hospital.

B—Saxondale (Radcliffe-on-Trent), Carlton Hayes (Narborough) and Western (Doncaster).

C—Alexandra (Woodhall Spa).

D—Rotherham Chest Clinic.

East Anglia Region.:

A—Norfolk and Norwich, and Ipswich and East Suffolk (Anglesea Road Wing).

B—Foxhall (Ipswich) and Hartismere (Eye).

C—Saffron Walden General.

D—Saxmundham (Child Guidance and Chest) Clinic.

North West Metropolitan Region:

A—Barnet General and St. Albans City (Mid-Herts Wing).

B—Leavesden, King Edward Memorial (Ealing) and St. Paul's (Hemel Hempstead).

C—Wood Green and Southgate Hospital.

D—Windsor Chest Clinic.

North East Metropolitan Region:

A—Mile End and St. Ann's (Tottenham).

B—Ware Park, Langthorne (Leytonstone) and Tilbury and Riverside General (Orsett Branch).

C—Victoria (Romford) with Strathmore Annexe.

D—Chest Clinic, High Street, Walthamstow.

South East Metropolitan Region:

A—St. Alfege's (Greenwich) and Kent and Sussex (Tunbridge Wells).

B—Bromley, Buckland (Dover) and Victoria, Deal, Walmer and District.

C—Edenbridge and District War Memorial Hospital.

D—Camberwell Chest Clinic.

South West Metropolitan Region:

A—Salisbury General and Southlands (Shoreham-by-Sea).

B—South Western (Stockwell), Sutton and Cheam General and Queen Mary's Hospital for Children (Carshalton).

C—Bridport.

D—Bournemouth West Chest Clinic.

Oxford Region:

A—Royal Berkshire (Reading) and Stoke Mandeville (Aylesbury).

B—Horton General (Banbury), St. Margaret's (Swindon) and Fair Mile (Wallingford).

C—Chipping Norton and District War Memorial.

D—Wellingborough Chest Clinic.

South Western Region:

A—Royal Devon and Exeter and South Devon and East Cornwall (Freedom Fields Section—Plymouth).

B—North Devon Infirmary (Barnstaple) and South Devon and East Cornwall (Greenbank Road Section—Plymouth).

C—Crewkerne.

D—Bridgwater Health Centre.

Wales Region:

A—St. Tydfil's (Merthyr Tydfil) and East Glamorgan (Pontypridd).

B—Pontypool and District and Maelor General (Wrexham).

C—Aberbargoed and District and Meadowslea (Chester).

D—Bala Chest Clinic.

Birmingham Region:

A—Hereford County and Wolverhampton General.

B—Burton-on-Trent General, Warneford General (Leamington Spa) and St. Matthew's (Lichfield).

C—Eye, Ear and Throat for Shropshire and Wales (Shrewsbury).

D—Wolverhampton Chest Clinic.

Manchester Region:

A—Manchester Royal Infirmary and Bolton District General.

B—Altrincham General, Queen Victoria (Morecambe) and Baguley (Wythenshawe).

C—Wilkinson Sanatorium (Bolton) and Victoria Infirmary and Clinic (Northwich).

D—Blackpool Municipal Health Centre and Chest Clinic.

Liverpool Region:

A—Warrington General.

B—St. Helen's, Mill Road Maternity (Liverpool) and Royal Liverpool Children's.

D—Waterloo Chest Clinic, Liverpool.

London Teaching:

A—University College and Charing Cross.

B—Hampstead General and North West London, Royal Free (Lawn Road Branch) and Royal National Throat, Nose and Ear.

C—Belgrave Hospital for Children.

Scotland—Northern:

A—Raigmore (Inverness).

B—Royal Northern Infirmary (Inverness).

C—Bignold Cottage (Wick).

Scotland—North Eastern:

A—Aberdeen Royal Infirmary and Woodend General (Aberdeen).

B—Aberdeen City, Kingseat (Newmachar) and Royal Aberdeen Hospital for Sick Children.

C—Glen O'Dee Sanatorium (Banchory).

D—Aberdeen Chest Radiography Centre.

Scotland—Eastern:

A—Maryfield (Dundee) and Dundee Royal Infirmary.

B—Brechin Infirmary and Perth Royal.

D—Dundee Chest Clinic.

Scotland—South Eastern:

A—Western General (Edinburgh) and Bangour General (Broxburn).

B—Victoria (Kirkcaldy), East Fortune (North Berwick) and Royal Hospital for Sick Children (Edinburgh).

C—Adamson Cottage Hospital, Cupar.

D—Royal Victoria Dispensary for Diseases of the Chest (Edinburgh).

Scotland—Western:

A—Southern General (Glasgow) and Ayrshire Central (Irvine).

B—Victoria Auxiliary Infirmary (Glasgow), Glenafton (New Cumnock) and Royal Hospital for Sick Children (Glasgow).

C—Garrick (Stranraer).

D—New Paisley T.B. Clinic.

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