GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC ROENTGENOLOGY

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GENETICALLY SIGNIFICANT DOSE FROM DIAGNOSTIC ROENTGENOLOGY

(A STUDY CONCERNING A DEFINED POPULATION IN THE NETHERLANDS)

GENETISCHE DOSIS TENGEVOLGE VAN RÖNTGENDIAGNOSTIEK

(EEN ONDERZOEK BETREFFENDE EEN OMSCHREVEN POPULATIE IN NEDERLAND)

MET EEN SAMENVATTING

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE GENEESKUNDE AAN DE RIJKSUNIVERSITEIT TE LEIDEN, OP GEZAG VAN DE RECTOR MAGNIFICUS DR. G. SEVENSTER, HOOGLERAAR IN DE FACULTEIT DER GODGELEERDHEID, TEGEN DE BEDENKINGEN VAN DE FACULTEIT DER GENEESKUNDE TE VERDEDIGEN OP DONDERDAG 5 JULI 1962 TE 16 UUR.

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INTRODUCTION

During the last two decades the scope of radiation protection has been expanded considerably. Formerly the problems of radiation protection had mainly to do with occupational conditions. As a result of the rapid extension of the uses of nuclear reactions after 1940, not only comparatively small groups of radiation workers, but also large groups of the general population may be exposed to ionizing radiation. It is stressed by geneticists that in exposing large population groups to ionizing radiation, the possibility of genetic effects must be considered (HOWARD, 1952; MULLER, 1954a; RUSSELL, 1956; CROW, 1957).

In 1955 the United Nations General Assembly established a scientific committee which was requested, amongst other things, "to receive and to assemble in an appropriate and useful form radiological information furnished by States Members of the United Nations." The first "Report of the United Nations Scientific Committee on the Effects of Atomic Radiation" (U.N.S.C.E.A.R.-REPORT) was issued in 1958. In Annex C ("Man-made sources") of this report it is noted: "Medical uses of X-rays and radioactive materials are responsible for the largest man-made exposures of many populations at the present time, the dose possibly ranging up to more than 100 per cent of the dose due to natural sources in some of the countries for which estimates have been made". In Annex C it is recommended that in all countries analysis of film records, together with studies of the average gonad dose corresponding to each type of diagnostic and therapeutic exposure, be used as an approximation to the genetically significant dose. A detailed analysis is recommended if the dose so calculated exceeds a few per cent of the natural background. Furthermore, it is suggested that surveys of this kind will result in improved practices with a consequent reduction in exposure.

The term "genetically significant radiation dose" was introduced by OSBORN & SMITH in 1956. In the same year the I.C.R.P. (International Commission on Radiological Protection) and the I.C.R.U. (International Commission on Radiological Units) formed a Joint Study Group. In its 1957 report this Study Group described methods for the evaluation of the genetically significant annual gonad dose, due to medical uses of ionizing radiation.

Preliminary estimates of the genetically significant dose due to diagnostic radiology have been made in various countries during the years 1956–1958. The estimate in the U.S.A. (LAUGHLIN & PULLMAN, 1957) has been quoted frequently. According to this estimate the genetically significant

dose resulting from diagnostic radiology in the U.S.A. possibly exceeds the level of the mean gonad dose due to natural background. An estimate made in Australia by MARTIN (1958) yielded a value of the genetically significant dose of the same order. Estimates in other countries, such as England (OSBORN & SMITH, 1956), Denmark (HAMMER-JACOBSEN, 1957) and Sweden (LARSSON, 1958) yielded considerably lower values. In the Netherlands no estimate has been made before.

As a result of the recommendations of the U.N.S.C.E.A.R. and the I.C.R.P./U. JOINT STUDY GROUP, investigations on population doses were intensified in many countries. A special committee was established in England (ADRIAN, 1957). This committee has published two reports (ADRIAN COMMITTEE, 1959, 1960). Also in Hamburg, Germany, a working committee was established (HOLTHUSEN, 1957). Information on surveys in New Zealand (ROTH, 1958), Belgium (MEYERS et al., 1959), France (REBOUL, 1960) and in various other countries demonstrate the increased activity in this field.

Meanwhile interest in the somatic consequences of low level ionizing radiation is increasing. Measurement and calculation of relevant tissue doses, such as doses to the active bone marrow, were carried out. However for somatic risks a "somatically significant dose" seems to be difficult to express.

It is not expected that the genetically significant dose due to medical exposures in the Netherlands will differ widely from doses estimated for comparable countries, such as for instance Denmark. Nevertheless an estimate for the Dutch population can serve various purposes, of which probably the most useful is an educational one.

A detailed survey on an extensive scale can only be carried out by a large working group, such as those established in England and in Hamburg. The survey that will be described here has been executed on a much smaller scale and therefore can carry only relative weight. The roentgen-diagnostic examinations, performed in a defined year on the individuals of a defined population, have been studied as extensively as possible. It was convenient to choose the population of Leiden (including the suburb Oegstgeest), comprising altogether about 110,000 inhabitants.

The investigation consists of three parts:

1. The collection of data on X-ray units, used for medical roentgen-diagnosis in the area surveyed.
2. The collection of data on frequency of roentgendiagnostic examinations performed in 1959 on individuals of the population surveyed, together with data on the distribution of exposures by type of examination and by age and sex of the patients.
3. A dosimetric study of gonad and bone marrow doses as a function of radiation quality and other parameters. This part of the study has been

carried out with the aid of a tissue-equivalent phantom. The results of the measurements of bone marrow doses will not be reported here.

The data thus collected have enabled us to make an estimate of the minimum genetically significant dose to the surveyed population in the year 1959. However it may be emphasized that this estimate cannot be applied directly to the total population of the Netherlands (about 11,000,000 inhabitants in 1959). For a reliable extrapolation to be made detailed data on the practice of diagnostic roentgenology in the Netherlands are needed.

In Chapter I the genetic effects of ionizing radiation are described. Definition and calculation methods of the genetically significant dose are given in Chapter II. Also a more extensive description of the method of investigation is presented. The results of the first part of the investigation are described in Chapter III. In Chapter IV the results of the frequency analysis are presented, mainly in tabular form. Methods and results of gonad dose measurements in the phantom are described in Chapter V. Data from all three parts of the investigation are used in the calculation of the genetically significant dose in Chapter VI. In Chapter VII methods for dose reduction in diagnostic radiology are indicated. Conclusions are presented in a final section.

CHAPTER I

GENETIC EFFECTS OF IONIZING RADIATION

1. The genetic material

Since the publication of Muller's experiments in 1927 it has been known that ionizing radiation can change the genetic material of Drosophila. Other investigations demonstrated genetic effects of radiation in many other species of animals and plants. Knowledge of radiation genetics in mammals has been increased particularly by experiments on mice (Russell and co-workers, Carter and co-workers). As no fundamental differences exist between hereditary mechanisms in mice and man, it must be supposed that radiation also can induce changes in the human hereditary material. Still, it is extremely difficult to assess the effects of radiation on human heredity.

In all higher organisms the genetic material is organised in chromosomes. Chromosomes form an important part of the cell-nucleus. During division of the nucleus the chromosomes are microscopically visible. Germ-cells, or gametes, possess half the number of chromosomes present in somatic cells. Gametes therefore are haploid cells (n chromosomes), somatic cells are called diploids (2 n chromosomes). The chromosomes in diploid cells occur pairwise. Gametes are formed as a result of reduction-division (meiosis), during which one partner of each chromosome pair is passed on to one of the two daughter cells. The first diploid cell of a new organism is formed during fertilization of an ovum by a sperm-cell. A specific pair of chromosomes is that of the sex chromosomes. In females the chromosomes of this pair are similar (XX); in males the sex chromosomes of a pair differ widely (XY). Little genetic material is found on the Y chromosome.

The number of chromosomes in a nucleus is characteristic of the species. Somatic cells of Drosophila, mice and man carry 8, 40 and 46 chromosomes respectively. During recent years a number of human pathological conditions have been found associated with anomalies in the number or configuration of chromosomes. The great majority of cases of mongolism is found to have cells with 47 chromosomes (Lejeune et al., 1959). In some conditions, such as *Klinefelter*'s and *Turner*'s syndrome, there are sex chromosome anomalies (XXY and XO) due to non-disjunction or to loss of chromosomes (Jacobs & Strong, 1959; Van Gelderen & Hustinx, 1961).

The chromosomes of nearly all organisms consist of desoxyribonucleicacids

(D.N.A.) and proteins. D.N.A. is considered to be the actual material which constitutes the genetic information. It is a polymeric complex with a molecular weight of 6×10^6 or more. In D.N.A., nucleotides, which consist of a purine or a pyrimidine, desoxyribose and phosphoric acid, are linked in a specific way, such that a double helical structure is formed.

Characteristic of the chromosomes is their ability of replication. During cell division (mitosis) an exact copy of each chromosome is formed and passed on to the daughter cells.

The hereditary units, or genes, form parts of the chromosomes, on which they are arranged in a linear fashion. A gene consists of several pairs of nucleotides. Chemical structure and configuration of these nucleotides are specific to the gene. Each of the hereditary characteristics of an organism is determined by one or more genes. In man, the total number of genes is estimated at 20,000 to 40,000 (SPUHLER, 1948).

Together with the gene on the same locus of the homologous chromosome, a gene also forms a pair. The genes of a pair are called alleles. An organism is homozygous for a gene if the related alleles are identical. If the alleles are different, the organism is said to be heterozygous for the gene under consideration. Of a heterozygotic pair of genes usually one, the dominant allele, suppresses the action of the other, called the recessive allele. As on Y chromosomes practically no genes are present, recessive genes on X chromosomes in males (XY configuration) are unpaired and act as dominants. As a result sex-linked heredity follows a distinctive pattern.

Genetic experiments can be carried out by directed cross-breedings in plants and laboratory animals. In man, genetic investigations are mainly restricted to genealogical studies and statistically orientated population genetics.

2. MUTATION

The structure of genes is extremely stable and is exactly replicated during many generations. However, "spontaneous" changes, called mutations, do occasionally occur. During the subsequent divisions the gene will be passed on to the daughter cells in its new, mutated form. Reversion to the original gene is only possible by way of a new mutation. Mutations can occur in somatic cells as well as in genetic cells (gametes).

Mutations in somatic cells have been held responsible for aging of organisms and for cancerogenesis (HENSHAW, 1957; FAILLA, 1957). This so-called somatic mutation theory however is very debatable (BURDETTE, 1955; BRUES, 1958). It has been suggested that somatic mutations result from accumulation of products of cell metabolism. Also, it is quite probable that imperfect replication of gene material occurs during the rapid mitosis of cancer cells.

Mutations occuring in gametes can be passed on to the offspring and

thus are inheritable. The moment of manifestation of a mutant in the offspring is mainly determined by the hereditary pattern. Dominant mutants and mutants on the X chromosome can already appear in first generation descendants. However, particularly in man, the manifestation of non sex-linked, recessive mutants can be delayed for many generations. If two identical recessive genes combine in a fertilized egg, the new organism will be homozygous for this gene and the mutant will be manifest.

Gene mutations are no more microscopically visible than genes themselves. It is supposed that local rearrangements or lesions of nucleotides form the fundamental process in mutation.

Mutations occur naturally in all species that have been studied. The natural mutation frequency is dependent on the species and on the gene locus (EVANS, 1949). The mean natural mutation frequency has been estimated at 1×10^{-5} and 0.9×10^{-5} per locus per generation in Drosophila and mice respectively (MULLER, 1950; RUSSELL, RUSSELL & CUPP, 1959). For man values ranging from 1×10^{-5} to 2×10^{-5} have been estimated (MULLER, 1956; CROW, 1957).

Mutations have been induced artificially by some chemicals, by heat and by ultraviolet and ionizing radiation (CATCHESIDE, 1946). Natural radiation can only be held responsible for a small part of the natural mutation frequency (MULLER & MOTT SMITH, 1930). Products of cell metabolism and temperature influences are probably other factors in natural mutagenesis.

Natural mutations offer to the species the possibility of continuous adaptation to a changing environment. The now living species are the achievement of a long period of evolution. Natural mutation must have been of great importance during the evolution. By way of natural selection those combinations of genes are favoured which provide the greatest reproductive fitness and the best adaptation to environment for the species concerned. For instance, in bacteria this process can work quickly and efficiently when a stock develops resistance against an antibiotic compound. In species now living the most favourable combinations will, in general, have been selected, while the less favourable combinations tend to be eliminated. Natural mutation and natural selection thus reach an equilibrium in which a random change nearly always will mean a deleterious change.

The harmfulness of a mutant can be expressed by the reproductive fitness of its carrier, compared to the reproductive fitness of the carrier of the original gene. Dominant lethal mutants, recessive lethal mutants on the X chromosome in males and recessive lethals in homozygous conditions, cause non-viability of the carrier. In experimental animals these mutants become manifest by reduction of litter size or by litters with a deficit of male animals. In man lethal mutants on the X chromosome also can cause a deficit of males in the offspring. Detection of lethal genes

on other chromosomes, causing sterility or subfertility, is extremely difficult in man. Mutants are called semilethal if the viability of its carriers is less than 10 per cent of normal. Subvital mutants, called "detrimentals" by MULLER, cause a 90 to 10 per cent reduction of viability. In animals as well as in man these mutants can only be detected by extensive studies. In man subvital mutants could for instance cause a high perinatal mortality, a decreased resistance against infections or a retarded growth.

In Drosophila detrimentals are about 4 times as frequent as dominant lethals. Dominant lethals and recessive lethals each make up about 16 per cent of the total number of mutants. It follows that the number of recessive and dominant visible mutants can only be about 4 per cent of the total (MULLER, 1951). In Drosophila these ratios are applicable to natural mutations as well as to radiation induced mutations.

MULLER (1950, 1956) estimated a natural occurence of 1 to 2 new detrimentals per 10 gametes per human generation. He also calculated that by accumulation of mutants during preceding generations today's human beings would carry, on an average, 8 heterozygous mutants. According to DOBZHANSKY (1957) mutation frequency and natural selection are fairly well balanced in human populations at present. Any artificial increase of mutation frequency, or decrease of the efficiency of natural selection will temporary disturb the equilibrium. Adjustment of the equilibrium at another, higher level will result amongst other things in a higher frequency of congenital malformations. (HOWARD, 1952, 1956; MULLER, 1954 a,b).

3. RADIATION INDUCED GENETIC CHANGES

Ionizing radiation can induce two types of changes in the genetic material.

Chromosome damage, which is often microscopically visible, is one of the possible effects of radiation. The primary lesion is a chromosome break. Some chromosome breaks may reheal, however sometimes with accompanying loss of gene loci (deficiency). Other possibilities are depletion (loss of chromosome fragments) and supernumary chromosome fragments. Also the sticky fragments can form abnormal bridges with other chromosomes. When different chromosomes break simultanously or within a short period of time, fragments can be exchanged. The result of this process is a translocation. However, multiple break phenomena require comparatively high doses and high dose-rates.

In man, chromosome breaks were supposed to be of little genetic consequence. A fertilized egg-cell, carrying a coarse chromosome abnormality, will probably die during the first few divisions. The resulting early abortus usually cannot be detected. However, it is considered that chromosome aberrations, induced in post-meiotic stages (in spermatozoa) or just after fertilization may constitute risks (SOBELS, 1961). This could

actually be the case in conditions as mongolism and *Klinefelter's* and *Turner's* syndrome. Much further research is needed on this subject.

Radiation induced gene mutations may be of great importance in human heredity. As with natural mutations, radiation induced mutations are random changes and in most cases have a deleterious effect.

In Drosophila spermatozoa the number of mutations induced increases linearly with the X-ray dose. The lowest dose investigated in Drosophila experiments is 5 r (GLASS, 1962). In bacteria, it was possible to demonstrate a linear dose-mutational effect relation down to a dose of 8,5 r (DEMEREC & SAMS, 1960). According to MULLER (1957) a linear dose-effect relation must be assumed down to zero dose. This would imply that each dose, added to the dose of natural radiation, adds artificial mutations to the natural mutation frequency. There would be no threshold, below which doses are genetically ineffective. As moreover no repair of a completed mutational process can occur, all doses would be cumulative.

RUSSELL (1955) demonstrated a linear dose-effect relation for mutation in spermatogonia of mice at X-ray doses of 300 and 600 r. However, after doses of 1000 r, the number of mutations induced was lower than expected on basis of a linear relation (RUSSELL & KELLY, 1958). This discrepancy probably must be explained by cell-selection.

Further experiments (RUSSELL, RUSSELL & CUPP, 1959) with spermatogonia of mice gave very important results. It was established that the number of mutations, induced by Co^{60} radiation, delivered at low dose-rates (90 r/week), is a factor of about four as low as that observed when the same total dose of 250 kV X-rays is delivered at a dose-rate of 90 r/min. Influence of radiation quality could be ruled out. This dose-rate effect could not be further exaggerated by reducing the dose-rate from 90 r/week down to 10 r/week. Analogous dose-rate effects were established for Drosophila oögonia and spermatogonia (OSTER, 1958).

Also, it was demonstrated that various types and stages of germ-cells have different radiation sensitivities. In mice, spermatocytes, spermatids, spermatozoa and oöcytes are more sensitive than spermatogonia or oögonia by a factor of about two. The sensitivity of oöcytes appears to depend on the age of the mouse. Greatest sensitivity was found about two weeks after birth; however, oöcytes of newborn female mice are less sensitive than those of mature females (CARTER, 1958; RUSSELL, RUSSELL & CUPP, 1959). Relative sensitivity differences also were demonstrated for various stages of Drosophila germ-cells (OSTER, 1958).

The interpretation of these discrepancies may be found in the possibility of repair in a pre-mutational stage. This hypothesis is strongly supported by experimental evidence. SOBELS (1960) has demonstrated that, in Drosophila spermatids and spermatocytes, modification of pre-mutational damage is possible. If, after radiation delivered with a high dose-rate nitrogen or cyanide is breathed by the animals the mutagenic effectiveness

of the radiation is enhanced. Pre-treatment with chloramphenicol was shown to decrease the mutagenic effectiveness of the radiation (SOBELS & TATES, 1961). Further evidence suggests that the irreversible fixation of the mutation occurs during the first post-irradiation replication of D.N.A. (KIMBALL, 1959). In rapidly dividing cells, such as spermatids and young oöcytes the repair process can work only during a relatively short period. These cell stages show the highest sensitivity to the mutational effect of radiation. Dose-rate effects may be explained analogously. During radiation, delivered with high dose-rates, the repair process would not have time to work effectively or, alternatively, might be damaged.

If differences in sensitivity of various germ-cell stages also occur in man, this would seriously effect assessments of human genetic effects. In males, spermatogonia are potentially exposed during much longer periods than the possibly more sensitive spermatids and spermatozoa. In the ovary of mature females, the only germ-cells present are oöcytes, which may be twice as sensitive as spermatogonia. Thus a given exposure of females may have more genetic effect than the same exposure of males (RUSSELL, RUSSELL & KELLY, 1960).

In the evaluation of genetic effects of low dose-rate exposure, the use of radiation induced mutation rates, estimated from high dose-rate data, may lead to over-estimates. In future, comparison of human genetic effects due to low dose-rate exposures (for instance from fall-out), with effects of high dose-rate exposures, may be possible only when appropriate weighting factors are used. Dose-rates can be divided into a "low" and a "high" dose-rate group, setting the dividing line more or less arbitrarily at 50 r/hour. Medical exposures that include the gonads in the direct beam probably would fall into the "high dose-rate" group.

The concept of a linear dose-effect relation for induction of mutations is still supposed to hold true. However, within the region of "high" and "low" dose-rates respectively the linear relation would have different slopes. A threshold for dose-rate is supposed not to exist (RUSSELL, RUSSELL & KELLY, 1958).

For 9 recessive, visible mutants in Drosophila, MULLER, VALENCIA & VALENCIA (1950) assessed a mean induced rate of 1.4×10^{-8} mutations per roentgen. The mean rate at 7 specific autosomal loci, obtained from irradiation of spermatogonia in mice to a dose of 600 r at a dose-rate of 90 r/min. is about 2.5×10^{-7} mutations per roentgen (RUSSELL, 1955). The mutation rate obtained at low dose-rates (90 r/week) is a factor of about 4 lower (RUSSELL et al., 1960). Evidently the radiation induced mutation rate is a factor of 15 to 20 higher in mice than in Drosophila. It is conceivable that the D.N.A. content of a cell is linearly related to the mean mutational sensitivity. Mouse cells contain about 20 times the amount of D.N.A. in Drosophila cells. As human cells contain little more D.N.A. than mouse cells (by a factor of about 6/5), it is assumed that

in man radiation induced mutation rates averagely will be of the same order of magnitude as in mice.

Still it is extremely difficult to evaluate the effects of various radiation exposures on the genetical characteristics of a human population. Calculations, based on data obtained from animals exposed at high dose-rates, can only be tentative and carry wide margins of uncertainty. Nevertheless a few examples of calculation, indicating the magnitude of risks, will be given here.

According to MULLER (1955) a dose of about 200 reps *, as received by a number of atomic bomb survivors in Hiroshima and Nagasaki, would in the first generation descendants add, on the average, one deleterious mutant to the existing mean load of 8 mutants. However, it cannot be expected that this additional load will cause a significant increase in the number of visible abnormalities in the relatively small first generation (NEEL et al., 1953) (see § 4).

It has been calculated that, if atomic bomb test explosions continue, the average gonad dose due to fall-out would be in the order of 0.045 to 0.10 rad per human generation (U.N.S.C.E.A.R. REPORT 1958). As a result perhaps some 7000 children, carrying, on the average, an additional load of one deleterious mutant, would be born annually in the U.S.A. About two per cent of these children, or some 150, would exhibit observable anomalies. Of about 4 million children, born yearly in the U.S.A., some 40,000 are defective at birth. So an added number of about 150 defective children will not be statistically evident. Nevertheless, 150 children, which otherwise would have been normal, would be defective as a result of test explosions (STURTEVANT cited by STERN, 1956).

Genetic risk calculations also have been based on the concept of a mutation frequency doubling dose, i.e. that dose of ionizing radiation per human generation, which doubles the natural mutation frequency. It is estimated that 2 to 20 per cent of the natural mutation frequency in man is caused by natural radiation. As, in most world areas, natural radiation gives a dose of about 3 r per generation, the doubling dose for man would lie between 15 and 150 r (MED. RESEARCH COUNCIL REPORT, 1956). For calculation purposes, a "most probable" value of 30 rad has been recommended (U.N.S.C.E.A.R. REPORT, 1958). Some calculations, made by CARTER (1960), are based on a doubling dose of 100 rad and a gonadal exposure due to natural radiation of 3 rad per human generation: Every year about 19,700 children with minor congenital defects, and about 10,000 children with major congenital defects are born in the U.K. Of these malformations 3 per cent would be induced by natural radiation. According to the estimate made for England and Wales in 1956, the genetically

*) Roentgen-equivalent-physical (unit out of date).

In this review, in general, doses are expressed in the same units as used by the authors quoted. See note on p. 17.

significant gonad dose, due to diagnostic radiology, was as much as 22 per cent of that derived from the natural radiation. Thus $0.22 \times 0.03 \times 19{,}700 = 130$ minor, and $0.22 \times 0.03 \times 10{,}000 = 66$ major congenital defects would be induced annually by diagnostic radiology in the U.K. Though these defective children could not be detected even by large scale investigations, nevertheless they represent individual suffering. Any methods of dose reduction in diagnostic radiology, which can be used without curtailment of essential diagnostic information, should be strongly recommended.

However, the concept of doubling dose, and with that calculations based on this concept, must be re-evaluated in the light of new experimental data (MARQUARDT, 1960; RUSSELL, 1960; SOBELS, 1961). Some data invalidating this concept are:

1. Spontaneous and induced mutation frequencies differ quite considerably for various gene loci.
2. Wide variability exists in mutational sensitivity at different cells and cell-stages in gametogenesis.
3. At high doses cell selection may cause deviation of the linear dose-effect relation.
4. At some stages in gametogenesis a radiation dose, delivered with low dose-rate may have less mutational effect than the same total dose, delivered with high dose-rate.

The dose-rate effects would possibly mean an upward revision of the doubling dose as estimated before. The other effects may invalidate the whole concept of doubling dose. At any rate further use of this term only would be acceptable if cell-line and cell-stage of gametogenesis, dose-rate and possibly other variabilities, such as type of radiation, are stated.

It must be concluded that, at present, no reliable estimates of genetic risks can be made in the case of human exposures. At most, the maximum conceivable risks can be indicated.

4. HUMAN DATA

For studies regarding the hereditary effects of radiation in man, the only possible objects are descendants of irradiated parents. Only well-designed, statistically justified studies permit reliable conclusions.

RUBIN (1952) and KAPLAN (1954) stressed that no abnormalities are evident in first and second generation descendants of woman, irradiated for sterility with quite high ovary doses. However, this material is still too small to permit the conclusion that no deleterious mutations are induced.

MACHT & LAWRENCE (1955) studied, by way of questionnaires, the descendants of American radiologists. As controls, children of other medical specialists were used. Significantly more congenital malformations

were reported in children of radiologists. However, as MACHT and LAWRENCE pointed out themselves, the groups were not wholly comparable. Also quite a number of questionnaires were not returned, specially by non-radiologists. In a comparable investigation carried out by CROW (1955) no significant differences were found.

The descendants of atomic bomb survivors in Hiroshima and Nagasaki are studied most intensively. A total of 65431 children, of which one or both parents were irradiated during the bomb explosions, were examined directly after birth. About one third of these children could be examined again at the age of 9 months (NEEL et al., 1953, 1958). The exposure doses to the parents were estimated on the basis of their location with regard to the hypocentre of explosion. Also the birth rank, the age of the parents and, if present, consanguinity of the parents, were noted. Even in children of consanguineous parents, where genetic effects are expected to show first of all, no significant increase was found in fetal and perinatal mortality, nor in congenital malformations (SCHULL & NEEL, 1959).

Sex-ratio shifts may be the most sensitive indicators for genetic effects in man. According to the genetic theory irradiation of mothers would cause a relative deficit of boys in the offspring (decrease of sex-ratio). Irradiation of fathers would have the opposite effect. These shifts can be explained by lethal mutations on the X chromosome. In the first Japanese data there was a suggestion of sex-ratio shifts (NEEL & SCHULL, 1956). Later data (SCHULL & NEEL, 1958) affirmed this suggestion, but the results were said not to be statistically significant. Nevertheless, in a slightly different analysis of the same data, DE BELLEFEUILLE (1961) showed that maternal exposure resulted in a significant sex-ratio shift ($P < 0.02$) and in a significant increase of stillbirths ($P < 0.03$). Exposure of the father alone has resulted in a higher neo-natal death rate ($P < 0.05$).

TURPIN, LEJEUNE & RETHORE (1957) studied the sex-ratio in descendants of therapeutically irradiated parents. Here also the results were suggestive for shifts according to the genetic theory.

Thus the sex-ratio data, collected up to now, probably may be regarded as evidence for mutations on the X chromosome.

An interesting and promising investigation will be carried out in Kerala (India). Due to the high local thorium content of the soil, in this area natural radiation is higher than in most world areas by a factor of about 10 (GOPAL-AYENGAR, 1957). As extensive demographic data must be collected before the actual investigation can start (W.H.O. TECHN. REP. SERIES, no. 166, 1959), the results of this study cannot be expected for several years.

CHAPTER II

GENETICALLY SIGNIFICANT DOSE

1. Definition

Until six years ago little attention has been paid to the possibility of genetic effects in diagnostic roentgenology. Though Zimmer, in 1935, had pointed out that even the relatively small gonad doses in diagnostic roentgenology should be taken into consideration, measurements were mostly restricted to that of skin doses (Martin, 1947; Ardran & Grooks, 1953; Henny, 1955). Only for a few types of roentgendiagnostic examinations, such as hysterosalpingography and colon examination were gonad doses assessed before 1955 (Mac Gregor & Oliver, 1952; Weens et al., 1954).

More extensive gonad dose measurements were carried out by Martin (1955) and Stanford & Vance (1955). Where possible, these measurements were made directly on patients. As direct measurements of ovary doses are not possible, for this ionization chambers were placed in the posterior vaginal fornix or at the skin anterior to the ovary (see Chapter V).

When data became available on gonad doses received by patients during the various types of roentgendiagnostic examinations, several authors have calculated the genetic significance of gonadal exposures.

Osborn & Smith (1956) introduced the term "roentgenequivalent-genetic". They weighted gonad doses to the mean expected future number of children, according to age and sex of the individuals exposed. In the U.S.A. Laughlin & Pullman (1957) calculated the average gonad dose derived from diagnostic roentgenology for the population during a period of thirty years. It was estimated that this period would represent, for the U.S.A. population, the average duration of a generation.

Billings (1957) based a calculation of genetically significant dose on the same assumption regarding the duration of a human generation. Seelentag (1957) argued that actual data on child-expectancy should be taken into due account. He pointed out that, at least for Germany, the end of the reproductive period would lie, on the average, at the age of 40 for men and at the age of 35 for women. Hammer-Jacobsen (1958) presented data on the "risk of subsequent parenthood", calculated on basis of Danish demographic data. Larsson (1958) calculated subsequent child-expectancy data for the Swedish population.

In 1956 an I.C.R.P./I.C.R.U. JOINT STUDY GROUP was established on request of the U.N.S.C.E.A.R., to indicate methods to arrive at reliable data on doses received by large population groups due to medical uses of ionizing radiation. In its report, presented in 1957, special consideration is given to practical methods of assessment of the genetically significant dose due to diagnostic radiology. In this report:

"The genetically significant annual gonad dose G, of a population is defined as the summation of the product of the average annual gonad dose, D_i mrad, received by each person in age group i, multiplied by the average child expectancy P_i of the age group, multiplied by the number of individuals N_i in the age group, divided by the expected number of offspring of the population". This definition has been formulated as:

$$G = \frac{\Sigma D_i P_i N_i}{\Sigma P_i N_i} \text{ mrad} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The method of calculation, used in the U.N.S.C.E.A.R. REPORT (1958) was mainly based on the I.C.R.P./U. JOINT STUDY GROUP recommendations. The genetically significant dose was defined as: "the dose which, if received by every member of the population, would be expected to produce the same genetic injury to the population as do the actual doses, received by the various individuals".

Equation (1) has been considerably expanded, such that the genetically significant dose now was formulated:

$$D = \frac{\sum_j \sum_k \left(N_{jk}^{(F)} w_{jk}^{(F)} d_{jk}^{(F)} + N_{jk}^{(M)} w_{jk}^{(M)} d_{jk}^{(M)}\right)}{\sum_k \left(N_k^{(F)} w_k^{(F)} + N_k^{(M)} w_k^{(M)}\right)} \quad . \quad . \quad . \quad . \quad (2)$$

where:

D = (annual) genetically significant dose,

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

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

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

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

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

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

Calculation according to equation (2) above can only be carried out with the aid of a computor. Without any great loss of accuracy equation (2) can be simplified considerably. For this it is assumed that the gonad dose due to exposure of a given class is nearly uniform for all age-classes.

Furthermore the term $\frac{w_j}{w}$ is introduced, as representing the relative child-expectancy. Thus, after a few simplifications, the following equation may be derived:

$$D_j^* = d_j^* \cdot \frac{N_j^*}{N} \cdot \frac{w_j^*}{w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where:

D_j^* = contribution of type j examination to the (annual) genetically significant dose,

$\left(D^* = \sum_j D_j^* \text{ and } D = \sum_j D_j^{(F)} + \sum_j D_j^{(M)}\right)$,

(in these equations *, F and M denote the sex),

d_j^* = mean gonad dose per individual undergoing class j exposure,

N = total number of individuals in the population under consideration,

$\frac{N_j^*}{N}$ = relative frequency of class j exposure, i.e. the number of examinations per person (per year),

w_j^* = future number of children, expected by the average individual of the specified sex, subjected to class j exposure,

w = number of children, expected by the average individual of the population,

$\frac{w_j^*}{w}$ = relative child expectancy of the average individual of the specified sex, undergoing class j exposure.

Equations (2) and (3) also indicate the data which need to be collected in order to calculate the annual genetically significant dose due to medical exposure of a defined population. In the U.N.S.C.E.A.R. REPORT (1958) data, collected in various countries, were used for calculations according to equation (3). Where no national data on relative child-expectancy were available, the values for $\frac{w_j^*}{w}$ calculated by OSBORN & SMITH for England and Wales were used. The results of these, and other calculations of the genetically significant dose due to diagnostic radiology will be mentioned in the next paragraph.

In the present investigation the population under consideration is that of all inhabitants of Leiden and Oegstgeest. The genetically significant dose due to diagnostic roentgenology will be calculated according to equation (3). As gonad doses have been measured on a phantom representing an adult person only, equation (2) cannot be used.

It is emphasized that the concept of genetically significant dose is valid only if genetic effects are linearly related to doses and if no threshold

exists. Only on the basis of these assumptions summation of individual doses can have a biological meaning.

In the calculations as indicated above dose-rate effects were not taken into account. Also, no weighting factor has been introduced for possible differences in sensitivity of various cell-lines and cell-stages of gametogenesis. In those types of roentgendiagnostic examinations where the gonads usually are in the primary beam, gonad doses ranging from some 50 mr to about 1 r are delivered in a few seconds. So during these examinations the dose-rate will be higher than 50 r/hour and consequently would fall into the "high dose-rate" class (see Ch. I). These examinations also make up the major part of the genetically significant dose. Originally, genetic effects were established for "high" dose-rates, but evidence has recently been presented showing that low dose-rates will have less genetic effect. So weighting factors would only have to be introduced for low dose-rates and consequently would not greatly change the outcome of genetically significant dose calculations for diagnostic roentgenology. Moreover, at present no such weighting factors have been provided by geneticists.

Regarding sensitivity differences of cell-lines and cell-stages in man, no factual knowledge is available at present. If, on the basis of mouse data, it is assumed that human oöcytes are on the average twice as sensitive as spermatogonia, a weighting factor of about 2 would have to be introduced for female exposures. This would change the outcome of genetically significant dose calculations quite considerably. However, at present, no weighting factor has been recommended for this. So for the present calculations no attempt will be made to take these sensitivity differences into account. The presentation of the material will be such that weighting according to sex, if appropiate, can be applied.

2. Estimates in various countries

In England and Wales the genetically significant annual dose due to diagnostic roentgenology was calculated by Osborn & Smith in 1956. For the various types of examinations they used the gonad doses measured by Stanford & Vance (1956). It was estimated that a total of 17,660,000 roentgendiagnostic examinations was made in England and Wales during 1954 (ca. 0.4 per person). The great majority of these examinations was performed in National Health Service hospitals. The age and sex distribution of the examinations was analysed in five typical hospitals. Thus a total number of 21,187 examinations was analysed. This is, as Osborn & Smith indicated, less than 1 in 800 of the annual number of examinations for the whole country. Subsequent child-expectancy data were derived from official sources. A "total genetically significant dose" of 854,000 "rad-equivalent-genetic" was calculated. This would amount to 22 per cent of the dose due to natural radiation (3,908,950 "rad-eg").

The authors indicated that this might be a minimum value, the actual value possibly being several times greater.

At the end of 1956 a Committee was appointed by the Secretary of State for Scotland and the Minister of Health. LORD ADRIAN served as a Chairman for this Committee, which was requested: "to review the present practice in diagnostic radiology and the use of radiotherapy in non-malignant conditions . . ., and to make recommendations". An analysis was made of the number and type of all roentgen examinations carried out in National Health Service hospitals and chest clinics, in dental surgeries and in a few other institutions in Great Britain. This included a complete analysis of 259,447 examinations in some 1,500 hospitals during a week in May 1957, and a sample analysis (50,501 examinations) during a week in December 1957. In a representative sample of 130 hospitals some 13,800 dose-measurements were made by about 60 hospital physicists collaborating with the investigation. An Interim Report of the Committee was issued in 1959 and dealt with the population exposure by mass miniature radiography of the chest. A second report, dealing with the genetically significant dose due to diagnostic and therapeutic radiology, was published in December 1960. The total annual genetically significant dose, due to all medical radiology, was found to be 19.3 mr *. The main contribution to this dose is derived from diagnostic radiology (14.1 mr), minor contributions are made by mass miniature radiography (0.01 mr) and dental radiography (0.01 mr). Examinations of the lumbar spine, the hips and the femora make up 34 per cent of the dose due to diagnostic radiology. A further 26 per cent is derived from obstetrical abdominal examinations. Chest, heart and lung examinations together make up 4 per cent of the total (ADRIAN COMMITTEE, 1959, 1960).

In the U.S.A. LAUGHLIN & PULLMAN (1957) made a detailed estimate of the genetically significant dose derived from all medical radiology. For 1955 they estimated that a total of 54 million roentgen examinations was made in the U.S.A. This figure was partly derived from data collected by DONALDSON (1951). The distribution of examinations by age and sex of the patients was derived from various sources, but mainly from two hospitals and a children's clinic in Los Angeles and from the Trinity Hospital in Little Rock. A total of 1,728 examinations was analysed. It

* The genetically significant dose can be expressed in various units. In older reports, this dose usually was expressed as a percentage of the gonad dose derived from natural radiation. Some authors prefer the use of the "r" as a unit, others the "rad". In the U.N.S.C.E.A.R. REPORT (1958) the genetically significant doses were expressed in "rem". In this review the doses will be expressed in the same units as were used by the authors quoted. However, it should be remarked that gonad doses are measured in r. In soft tissues and for X-ray qualities as used in diagnostic radiology, the r/rad ratio ranges between 0.88 and 0.94, while the rad/rem ratio can be considered to be unity.

was estimated that 37 per cent of the examinations was performed on patients below the age of 30 years. Only these examinations were taken into account. A detailed anatomical distribution of 30,355 examinations, performed at the University of Minnesota Hospitals, was assumed to be generally applicable for adults. For children some data were collected in a children's hospital. There was a complete lack of information of the way non-radiologists use their roentgen equipment. It was estimated that they perform 26 per cent of all radiological examinations. For gonad doses, values reported by various authors in the U.S.A. and in Europe were collected and compared. The lowest values published were used as a minimum estimate. The calculation of the probable genetic dose was based on averages of the collected figures. Finally the genetic dose to the population during a 30 year period was estimated at a minimum of 1.5 r, while the probable dose would be 4.1 r. This would mean that, in the U.S.A., diagnostic radiology adds at least 50 per cent, and probably 140 per cent, to the 30 year dose of 3 r derived from natural background.

Another estimate was made in the U.S.A. by BILLINGS et al. (1957). They used approximately the same statistical data as did LAUGHLIN & PULLMAN. Gonad doses were measured in a simple masonite phantom. In children the mean ovary dose per examination was assessed at 0.29 r, the mean testis dose at 0.49 r. For individuals between the age of 11 and 30 years the mean ovary and testis dose was estimated at 0.23 r and 0.02 r respectively. Finally BILLINGS et al. calculated a 30 year gonad dose, due to diagnostic radiology, of 0.15 r for the average male and 0.3 r for the average female. This estimate yields a considerably lower value than that of LAUGHLIN & PULLMAN. However, it is very seldom quoted in surveys, while the report of LAUGHLIN & PULLMAN drew much attention.

In Denmark a survey was carried out by HAMMER-JACOBSEN (1957). The total number of examinations, made per year in Denmark, was estimated by the Bureau of Medical Statistics at about 2 million. Frequency data on the various types of roentgen examinations, in relation to sex and age of the patients, were available for two hospitals. Additional data were collected by HAMMER-JACOBSEN in the University Hospital in Copenhagen during 15 days in January 1957. A total of 2,473 examinations was analysed. Gonad dose measurements were made during roentgen examinations in 342 patients. Also some measurements were made in a phantom. Additional gonad dose values were derived from figures published by STANFORD & VANCE. Statistical data with regard to subsequent child-expectancy of females were obtained from the Danish Statistical Department, and were based on British data for males. It was calculated that diagnostic radiology in Denmark gives an annual genetically significant dose of about 17 mrem (minimum value).

An extensive study was made in Sweden by LARSSON (1958). Frequency data were obtained from official sources and were applicable to the years

1954/1955. The total number of examinations in Swedish hospitals was found to be about 1,910,000. The types of examinations and the age and sex of the patients were analysed in 5 large roentgen departments. Additional information was submitted by 14 other roentgen departments. A total of 39,315 examinations was analysed. Subsequent child-expectancy data were calculated on the basis of official Swedish statistics. Gonad dose measurements were performed in 1,957 patients in 17 roentgen departments. Originally LARSSON calculated a "genetically significant dose" for each sex, as the average dose per productive gamete. The sum of these doses was taken to express the average exposure during one year to the genes of an individual conceived after that year. Larsson used the child-expectancy data in the same way as did OSBORN & SMITH and HAMMER-JACOBSEN. The genetically significant dose has been recalculated by the author in accordance with the calculation method used in the U.N.S.C.E.A.R. REPORT. Thus a genetically significant dose of 37.9 mrem was calculated. The original value was about twice as high, namely 71.7 mr.

For Australia, gonad dose measurements made by MARTIN (1955) were combined with some frequency data (MARTIN, 1958). An annual genetically significant dose of 162 mrem was calculated on the basis of these data (U.N.S.C.E.A.R. REPORT, 1958). This high value is mainly due to the high number of examinations per year, as estimated by MARTIN.

Data submitted by France (REBOUL & ISTIN, 1958) served as a preliminary estimate of the genetically significant dose, due to diagnostic radiology, of 57 mrem. Since then an extensive survey has been conducted by REBOUL (1960) in the Bordeaux area. In this area 1,787 roentgen diagnostic units were found to be in regular use. Frequency data were collected in Bordeaux hospitals and were obtained from the local Health Insurance Agencies. The number and distribution of examinations in private offices could only be estimated roughly. It was estimated that more than half of the total number of examinations was performed by non-radiologists. Gonad dose measurements were performed in 10 to 30 patients for each examination class. In this part of the investigation three different types of roentgen units were used; the mean results of the measurements were used for calculation. No weighting factor according to age or subsequent child-expectancy was introduced. On the basis of these data an average annual gonad dose, due to diagnostic radiology, of 19 mrad was calculated for the French population below the age of 30 years.

SEELENTAG et al. (1957, 1958 b, c, d, e, 1959) published a series of articles on the genetically significant dose in Western Germany. Methods of collection of data and of gonad dose measurements were discussed in the first two articles. Data on the distribution of examinations according to type, sex and age of the patients in 3 large hospitals and a children's clinic were presented in the third and the fourth article, together with the

results of dose measurements in 656 adults and 705 children. Argon pressure ionization chambers were used for the measurements of low doses. On the basis of these data an annual mean gonad dose could be calculated for patients in hospitals. In the fifth article the genetically significant dose for Western Germany was finally calculated according to the formula recommended by the I.C.R.P./U. JOINT STUDY GROUP, 1957. A minimum value of 5 mr, a "probable value" of 14 mr and a maximum value of 160 mr were calculated.

A research group under the Chairmanship of Professor Holthusen (HOLTHUSEN, 1959) conducted an extensive survey of all radiological work (diagnosis and therapy) performed in a period from November 1957 to November 1958 on inhabitants of the city of Hamburg (population about 1,800,000) (HOLTHUSEN et al., 1961). For this all hospitals, institutes and private offices concerned noted on special forms the date of the performance, sex and age of the patient and type and method of the examination or therapeutic irradiation. For each set of data the office concerned was granted a fee of 0.05 DM. The cooperation to this part of the investigation was quite good. In this way data were collected about some 1.38 million examinations. In this number mass miniature radiography and dental radiography are included. Thus, in this year, the number of examinations per person amounted to 0.77, which is an exceptionally high figure compared with values found in most other surveys.

The gonad dose per type of examination and per age group was usually assessed on the basis of measurements on patients in a large Hamburg hospital. Also a systematic dosimetric study was carried out on a phantom. The results of this study were used to account for different techniques, that were found to be used in other hospitals, institutes and private offices.

The genetically significant dose was calculated according to formula (3) (p. 15) and was found to be 17.7 mr for diagnostic radiology and 2.2 mr for therapeutic radiology.

To a great extent the Hamburg survey is comparable to the Leiden survey, the main difference being the extent of the survey (population involved 1,800,000 and 110,000 respectively). However, the Hamburg survey was carried out by a large working group and presumably at quite high costs.

Small scale surveys have also been carried out in the U.S.A. by NORWOOD (1958, 1959) and by BROWN et al. (1960).

In Rome (BIAGINI et al., 1960) 7 hospitals and 6 radiological clinics served as a sample of the radiological practice in this city. The number of examinations performed by non-radiologists could only be estimated roughly. Dose measurements were carried out on a phantom and on some patients. The genetically significant dose was estimated at "44 $\pm$ 36" mrem

per year. The authors supposed that the dose for the Italian population at large would be lower than this.

In the U.N.S.C.E.A.R. REPORT (1958) calculations for various other countries, such as Austria, Japan, Norway and New-Zealand, were based on still incomplete data submitted by these countries. Meanwhile, in most countries research on this subject has been intensified considerably, such that in due time complete data can be expected.

The above review cannot be regarded as exhaustive. The main aim of this review was to indicate what data have been used for calculations in various countries. Some authors have made extensive surveys, others have collected only a few reliable data. The recent surveys in Great Britain and Hamburg are the most exhaustive and reliable ones made up to now.

3. INVESTIGATION IN THE NETHERLANDS

In the Netherlands no estimate of the genetically significant dose due to medical radiology has been made before. Only a few data were available to be used for such an estimate.

MERKIES (1959) analysed the frequency of roentgendiagnostic performances in 23 medium sized Dutch hospitals. In 1956, the average number of examinations in these hospitals was assessed at 7,800. In 1958 an average of 8,400 examinations per hospital was found. Also the distribution of examinations into 8 classes was presented. These figures give only a rough idea of the radiological practice in medium sized hospitals and cannot be used for an estimate of the genetically significant dose.

No figures are available regarding the total number of roentgendiagnostic examinations in the Netherlands. It was estimated by VAN JOOST that during population and group tuberculosis surveys 0.22 miniature radiographic and 0.08 fluoroscopic examinations of the chest are made per person per year (SICKENGA, 1959).

According to VAN DER WIELEN (1960) general practitioners are seldom in possession of a roentgendiagnostic unit. In his extensive survey of the working methods of 97 general practitioners, he found only 8 roentgendiagnostic units in their offices.

VAN AKEN (1960) measured gonad doses in dental radiography. With careful technique, the gonad dose per exposure ranged from 0.03 to 0.50 mr. However, when no diaphragm was used, the patient's gonads could easily lie in the primary beam and consequently be exposed to a dose as high as 260 mr per film. VAN AKEN also collected data on the consumption of dental films. About 130,000 dental films are used annually in the Netherlands. On the basis of this figure it was estimated that dental radiography would give an annual per capita gonad dose of 0.0065 mr as a minimum and 3.4 mr as a maximum.

The aim of the study, which will be described here, was to collect reliable data in order to estimate the genetically significant dose due to

diagnostic radiology (excluding dental radiography) in the Netherlands. It was realised that no extensive survey of the whole country was possible at the time, so it was decided to survey only a sample of the population at large. The following considerations serve to explain why the method of investigation, to be described in the next section, has been followed in the present study.

Several criteria can serve to judge whether the sample used for this investigation is representative of the population at large. In general, a sample must be clearly defined and the demographic data of a population sample must be comparable to a great extent with that of the population at large. If the inhabitants of a given area serve as a sample, for this investigation the area must be situated such that all radiological examinations performed on the inhabitants can be traced. It was considered that in a country area quite a large number of patients might be sent to a university town for the more extensive medical and radiological examinations. It might not be possible to trace all these examinations. On the other hand, inhabitants of a large city or a university town would not usually be sent to another medical centre for radiological examinations. However, it is conceivable that more radiological examinations are performed on a city population than on a rural population. On this point factual data have never been presented. Partly for the sake of convenience the population of Leiden and Oegstgeest was chosen as a sample. The homogeneity of the demographic data can be checked quite easily. At least to some extent, film consumption data can serve to check whether the sample is representative. Data on the distribution of examinations regarding type, sex and age of the patients can be compared with those collected in hospitals outside the area surveyed. Further data, that would enable checking of the sample are not available. Thus, as the sample has not been checked adequately, it is emphasized that the results of this investigation cannot be strictly applied to the total population of the Netherlands.

The data that have been used for estimates of the genetically significant dose in various countries were reviewed in section 2 of this Chapter. With the exception of the Hamburg survey, frequency data usually could only be collected in hospitals and large institutes. Also, gonad doses were usually measured in large radiological departments. It is likely that the gonadal exposure during examinations performed in small hospitals and in private offices would, on the average, be higher than those measured in large radiological departments. Some surveys made in the U.S.A. indicate that in private practice beam definition is generally poor, and added filtration of the primary beam is rarely used (see Chapter III). Also gonad shielding is used more frequently in large hospitals and chest clinics (ADRIAN COMMITTEE, 1960). For a reliable evaluation of techniques used in diagnostic radiology, it is absolutely necessary to survey the practices in private offices as well as in hospitals and institutes.

It would be desirable to measure gonad doses under the actual conditions in which the roentgendiagnostic examinations are performed (LEJEUNE, 1957). However, in practice, this cannot be carried out without considerable inconvenience to radiology departments and to patients. Moreover, the actual measurements of gonad doses involve considerable technical difficulties. Gonad doses of the order of a few mr and less cannot be measured accurately with conventional ionization chambers. In Belgium, MEYERS et al. (1959) used film dosimeters for this purpose. However, as most films are not sufficiently sensitive as to measure doses of a few mr, for many types of radiological examinations (and certainly for chest examinations), the same film must be used successively on several patients. The ionization chamber specially constructed for the recent English survey is extremely sensitive, but has an air volume of about 45 cc. The large volume of this chamber and the quite heavy recorder make the instrument inconvenient for routine measurements on a large number of patients. So in this study it was decided to define the techniques used in actual practice as accurately as possible, and to use these data, combined with the results of dose measurements on a phantom, to assess probable gonad doses.

Data on the frequency of various examinations, and the distribution by age and sex of the patients, can be collected by two methods. The first method could be called a prospective one. To all persons involved a record card could be assigned on which the details of all diagnostic exposures during a given period are recorded. Apart from the organisational difficulties attached to such a scheme, this would also require the active co-operation of the medical practitioners. A retrospective study involves an analysis of the examination records of a given period in the hospitals, institutes and private offices concerned. This method has been used in nearly all the surveys mentioned in the preceding section.

4. METHOD OF THE PRESENT INVESTIGATION

As was indicated in the introduction, the investigation regarding the genetically significant dose from diagnostic roentgenology in Leiden and Oegstgeest consists of three parts:

1. Survey of roentgendiagnostic units;
2. Analysis of examination records;
3. Dosimetric study.

The results of these three parts will be presented in the next Chapters. Here a general description of the method of investigation is given.

ad 1. *Survey of roentgendiagnostic units*

Because registration of roentgen units is not at present compulsory in the Netherlands, data from official sources on the number and location of

units are incomplete. It was necessary to send a questionnaire to the medical practitioners in the area, asking for information and co-operation. Also permission was asked to survey the units and to collect further data for the investigation.

In the surveyed area 54 roentgendiagnostic units were used for medical purposes in 1959. From these, 37 are located in hospitals, 9 in institutes and 8 in private offices. No further information was received about two units, one located in the office of a general practitioner, and one used by a chest physician. Evidently these physicians were not willing to co-operate in the investigation. Dental radiography, performed by dentists, was excluded from the survey.

During the last three months of 1959 52 roentgendiagnostic units, incorporating 63 roentgen tubes, were surveyed. During the survey special attention was given to the aspects of units and tubes, that may be of importance from the point of view of the patient's exposure. Some general aspects were noted, such as the type of high-voltage rectifier, the protective quality of the tube housing, the functioning of the diaphragm, the target-panel distance, etc. Next, the output of 35 tubes was measured during normal fluoroscopic conditions. The remaining 28 tubes could not be operated continuously and consequently no normal output measurements could be made.

In connection with the output measurements, the radiation quality, expressed as the first half value layer (H.V.L.) in mm Al, was determined in the usual way at various tube voltages and beam filtrations. At the 35 tubes mentioned above, the radiation quality was determined at the tube voltage, tube current and filtration normally used in chest fluoroscopy. With the aid of standard curves showing the relation between radiation quality, total filtration, tube voltage and wave form, the amount of total filtration (inherent tube filtration and added filtration) was assessed for each tube.

ad 2. *Analysis of examination records*

During the second part of the investigation, from April to December 1960, the hospitals, institutes and private offices performing diagnostic roentgenology in the area were revisited. The examination records of inhabitants of Leiden and Oegstgeest, which had been subjected to a roentgendiagnostic examination in 1959, were analysed. Name, initials, sex and age of the patients, month of examination, the unit used and the type of examination performed were noted. The examinations were classified into 42 examination types. For each examination type, a given number of exposures was noted as a "normal examination". Any additional number of exposures was indicated on the record. Complete data of some 30,000 examinations have been collected and recorded on punch cards.

As could be expected, this part of the investigation involved consider-

able difficulties. In general, only the examination records in hospital roentgendepartments contained complete data. In one general hospital access to the patients' records was denied. The total number of examinations, and their distribution by 32 types, was the only information, submitted by this hospital. Though full co-operation was offered in the Dispensary for Tuberculosis Control (Chest Clinic) the administration of the patients' records was such that complete data on radiological examinations during 1959 could only be collected with considerable difficulty. Here a sample was taken, consisting of the examinations performed on 16 days, equally distributed over the months of the year and the working days of a week. Scarcely any data were available on about 12,000 chest fluoroscopies performed in some out-patient departments, during pre-employment examinations, and in the private offices of medical practitioners. Here chest fluoroscopies may not have been recorded at all, or only as a short note on the patient's record, which may subsequently have been sent to other medical authorities. Thus the information on chest fluoroscopies must be considered incomplete.

Furthermore, it is realised that part of the population surveyed may have been examined with roentgendiagnostic units not included in the survey. It was soon found that during the year 1959 the employees of various firms had attended a tuberculosis group survey. For this a mobile mass miniature radiographic unit had been used. Complete data were submitted about these examinations. In the Netherlands, population tuberculosis surveys generally take place once in three years. In Leiden this was done in 1960. These examinations are not included in the present investigation. Members of the armed forces, in active service during the year 1959 will have been examined in military hospitals outside the area surveyed. Still, it is possible, at least to some extent, to estimate the number of individuals involved in this. However, quite a number of inhabitants of Leiden work elsewhere and may have been submitted to industrial health surveys, including chest fluoroscopy or miniature radiography of the chest. No allowance could be made for this omission and there seems to be no method of calculating the extent of the inaccuracy introduced here.

ad 3. *Dosimetric study*

As was indicated before, for practical reasons measurements of gonad doses were not made under the actual conditions in which the roentgendiagnostic examinations are performed. Instead, a systematic dosimetric study was carried out. For each type of roentgendiagnostic examination gonad doses were measured in a specially constructed, tissue-equivalent phantom. A study was made of the gonad dose as a function of radiation quality. For some types of examination the influence of field size and target-film distance has also been assessed. During the survey of roentgen-

diagnostic units, it had been noted what exposure techniques are normally used for the various types of examinations. Knowledge of the total amount of filtration, together with that of the tube voltage used, enabled us to determine the radiation qualities used for a given type of examination. Furthermore, as mAs and target-film distance were known, a probable gonad dose could be assessed for each type of examination performed on an adult patient with a given roentgendiagnostic unit.

Uncertainty still exists regarding the field sizes used in actual practice. It was assumed that the beam had been restricted to the film size in all instances. It is realised that this assumption is an optimistic one. In actual practice, and especially when there is no direct supervision, radiographers do not always work according to the principles of radiation protection. However, in a retrospective study the extent of this cannot be ascertained. Consequently, the estimated gonad doses are to be considered as minimal doses.

For further calculations, data on subsequent child-expectancy were needed. For this, birth records of children born in Leiden during 1954–1959 were analysed.

CHAPTER III

ROENTGENDIAGNOSTIC UNITS

1. Number and location of units

A roentgendiagnostic unit is defined here as a high voltage generator, designed to generate roentgen radiation of qualities generally used in medical diagnostic radiology. Such a unit can incorporate one or several roentgen tubes. Further roentgendiagnostic equipment, such as couches, stands and fluorescent screens, also form part of a roentgendiagnostic unit.

In this survey information on the number and location of roentgendiagnostic units was collected by way of a questionnaire. A total of 94 questionnaires was sent to medical practitioners in the area surveyed. After a few weeks 54 practitioners had answered; the remaining practitioners were asked again to co-operate in the survey. This resulted in a further 29 questionnaires being answered, but the remaining 11 questionnaires were never returned. It could be ascertained that only two of the physicians, not co-operating in the survey, nevertheless were in possession of a roentgendiagnostic unit.

Only 3 of the 44 general practitioners possessed a diagnostic unit. Of the medical specialists two cardiologists, two chest physicians and one orthopaedic surgeon used roentgendiagnostic units in their private offices.

54 Roentgendiagnostic units were located in the area surveyed. As one general practitioner and one chest physician did not co-operate in the survey, 52 roentgendiagnostic units, with a total of 63 roentgen tubes, were surveyed. The location of these units is shown in table I. This survey revealed a small number of roentgendiagnostic units outside hospitals and institutes, which is quite different from the situation found in the U.S.A. There about half of all general practitioners and large numbers of medical specialists, osteopaths and chiropractors perform some diagnostic radiology (Laughlin & Pullman, 1957).

2. General aspects of units and tubes

The alternating voltage, originating from high-voltage transformers, may be rectified in various ways. The type of rectification influences the output of the roentgen tube and the quality of radiation. Small fluoroscopic or mobile units usually have self-rectifying tubes in which the negative

TABLE I

Location of roentgendiagnostic units and tubes surveyed * in Leiden and Oegstgeest, 1959

		Units	Tubes
Hospitals			
University Hospital		28	36
General Hospital I		2	3
General Hospital II		3	4
Orthopaedic Hospital		3	3
Mental Hospital		1	1
	Subtotal	37	47
Institutes			
Dispensary for Tuberculosis Control		5	6
Industrial Health Service		3	3
Municipal Health Department		1	1
	Subtotal	9	10
Private Offices *			
Medical specialists		4	4
General practitioners		2	2
	Subtotal	6	6
	Total	52	63

* The units located in the private offices of two medical practitioners could not be surveyed and are not included in this table.

phase is suppressed and consequently the tube voltage has a half-wave form. The effective voltage is about $\frac{1}{2}\sqrt{2}$ times the peak voltage. In more elaborate units the voltage may be rectified by 4 or 6 valves. In 4-valve units the negative phase is rectified. During high tube currents, as used in radiography, the effective voltage may be $\frac{1}{2}\sqrt{2}$ times the peak voltage. During fluoroscopy with 4-valve units, low tube currents are used and the cables may act as condensers to smooth out the voltage wave. As a result the tube voltage is nearly of constant potential and the effective voltage differs little from the peak voltage. In 6-valve units, the voltage is already rectified with little ripple and in radiography, as well as in fluoroscopy, a virtual constant potential is generated with an effective voltage about 0.95 times the peak voltage. In this survey 27 units with self-rectifying tubes were found, while 4- and 6-valve rectifiers were present in 23 and 2 units respectively.

It is evident that a tube should be provided with a good functioning diaphragm or with a cone, and should have a protective tube housing and insulated cables. However, in a recent survey in Rensselaer County, New York State, a few old tubes without any protective housing were still found in use (LANZILLO, 1960). In the present survey no such obsolete

units were found. All units were provided with a good functioning diaphragm or, occasionally, with a cone.

The effectiveness of the tube housing was measured with the aid of a Geiger-counter type of radiation monitor. The dose-rate was measured with closed shutters or window, at a distance of one meter from the target, with the tube operating at maximum voltage and current. Though occasionally some leakage could be demonstrated between the tube housing and the diaphragm, the leakage measured at a focal distance of 1 meter was always far below 100 mr in 1 hour (see CODE OF PRACTICE, 1957 and I.C.R.P. COMMITTEE III, 1960).

In 12 units the maximum rated tube voltage exceeded 125 kVp, in 22 units the maximum rated voltage was less than 100 kVp.

As the inherent filtration is different in tubes of various manufacturers, it is of some importance to note the make. Of the 52 units surveyed, 25 were manufactured by Philips, 17 by Smit, 5 by Siemens, 4 by Enraf and 1 by Watson. On Siemens tubes a note is attached, indicating the total amount of filtration. The inherent filtration of Philips tubes is usually equivalent to about 1 mm of Al. Some manufacturers provide their tubes with added filtration of 0.5 or 1 mm Al-equivalent.

The recommendation of the Dutch Radiological Society, to fix a filter of 2 mm Al or more on the tube window, was followed in the hospitals where the diagnostic units are supervised by radiologists. Few other physicians were aware of the advantages of some added filtration. The added filter provided by some manufacturers was found to have been removed by the physician or the radiographer in several instances. The number and thickness of added filters found to be in use on the 63 tubes included in the survey are noted in table II.

TABLE II

Number and thickness of added filters on 63 tubes surveyed

Added filter mm Al	Number of tubes
3	10
2	10
1	8
0.5	7
no added filter	28
	63

When during the second part of the investigation the institutes and offices were revisited, it was found that the advice to add some filtration had been followed in 4 instances only. As was reported by SHARP et al. (1961), similar advice given during a survey in Dade County (Florida), also was seldom followed.

During the survey the protection incorporated in couches, stands, fluoroscopic screens, aprons and gloves was inspected, although this is of little importance from the point of view of the patient's exposure. The patient's skin dose however is to a large extent dependent on the target-skin distance. The target-couch, respectively the target-screen distance was measured in 35 roentgen units. No distance was fixed in 17, mostly mobile, units. The results of these measurements are presented in table III.

TABLE III

Fixed distances, as measured in 35 units *

Target-couch distance		Target-screen distance	
cm	number of units	cm	number of units
35	2		
40	2	70	1
45	3	75	6
50	11	85	2
55	1	100	4
60	1	120	2
	20		15

* No distance was fixed in 17, mostly mobile, units.

For each unit a record was made of the techniques normally used for various types of roentgendiagnostic examinations. The target-film distance, the tube voltage, the mAs, the use of a grid and the number and size of the films were noted. These data, together with the results of the output and radiation quality measurements, were used to assess the gonad doses.

3. TUBE OUTPUTS

The tube output is defined here as the dose-rate, in r per minute, as measured in air, at the couch, with the tube operating continuously at the tube voltage and current normally used in chest fluoroscopy. In the absence of a couch, the output was measured at the assumed position of the patient's back, i.e. at 25 cm from the screen. A Philips ionization chamber, type 37482, calibrated for radiation qualities from 0.2 to 10 mm Al (H.V.L.), and connected to a Philips Universal Dosemeter, was used for these measurements. The ionization chamber was placed in the centre of a small primary beam, measuring about 3 by 3 cm at the level of the ionization chamber. The output of 35 tubes was measured. The remaining 28 tubes could not be operated continuously and therefore were excluded from these measurements. The results are listed in table IV.

The outputs measured in this survey are quite low compared with the outputs measured in surveys in the U.S.A. (COWIE & SCHEELE, 1941; BRAESTRUP, 1942; SONNENBLICK et al., 1951; ZAVON, 1957 and GORSSON

et al., 1959). In two instances only was an output of more than 10.0 r/min. recorded. However, as chest fluoroscopy may be performed with an output of less than 4.0 r/min., nevertheless in 12 of the 35 tubes the output is too high. These 12 tubes were not supplied with any additional filtration and were all used by non-radiologists (see also TAYLOR, 1956; KIRSCH, 1959). The chief reason for the favourable overall result is the low tube current generally used. In small fluoroscopes of Dutch manufacture the maximum rated tube current is nominally 3 mA.

On the basis of output measurements it is possible to calculate the output per mA at a given distance (for instance 50 cm) from the target. However the results of these calculations do not yield standard curves showing the output as a function of radiation quality. The comparison of outputs, measured in different roentgendiagnostic equipments, is hindered for the following reasons:

1. The nominal voltage is usually adjusted and read off via the high-tension coil of the transformer. The effective tube voltage however is dependent amongst other things on the wave-form (type of rectification, see section 2); on the gas-content of the tube which increases due to its use; and on the length and isolation of the cables. The virtual peak voltage can only be measured accurately by a method as described by TROUT et al. (1960). This method is based on the detection of characteristic K-radiation, as induced in various elements by roentgen radiation of a given minimum wave-length. A change of 1 per cent in the effective tube voltage can result in a 3.5 per cent change in the output (STANTON, 1960). In units that are not completely stabilized, the effective tube voltage can change considerably due to small voltage changes in the main power line (RITTER et al., 1952).

2. In small fluoroscopic units the tube current is often fixed at a given nominal value and cannot be read off. In more elaborate units the nominal tube current, as recorded by a milliammeter can differ considerably from the actual tube current. For reliable calibrations a miliammeter must be connected to the high voltage circuit near to the tube.

3. The degree of target pitting also influences the output. Target pitting starts during the first calibration tests and gradually increases during the tube's life. Due partly to this, the output of a tube gradually decreases down to 70 per cent of the original value (DE GROOT, 1956; KUNTKE, 1957; BEETLESTONE & THURMER, 1958). Other factors in this decrease of output are the increasing gas-content of the tube and the increasing inherent filtration, due to deposit of tungsten on the tube window (STANTON, 1960).

4. Other variables are due to inavoidable inaccuracies during output measurements. The distance between the ionization chamber and the target cannot be measured with great accuracy, as the position of the

target is generally not exactly indicated on the tube housing. Also the construction of the roentgendiagnostic equipment has some influence on the measurements. The absorption in the couch may not be the same in each unit, while also a different amount of scattered radiation may arise from this couch. Therefore outputs measured in units without a couch cannot be compared directly with outputs measured behind a couch. Also the radiation scattered by the fluorescent screen causes some inaccuracy. According to HALE (1958) the screen must be removed as far as possible during output measurements.

Consequently no tables or curves on the tube output as a function of tube voltage and total filtration are given here. Several authors have presented such tables (RITTER et al., 1952; HENNY, 1955; JAEGER, 1959a; PIZON, 1957, 1959). However in many instances these tables are derived from output measurements in constant potential units and therefore are not strictly applicable to normal diagnostic units. For exact calculations in actual practice tube outputs must be measured and cannot be derived from standard curves (CHANTRAINE & PYCHLAU, 1952; SCHMITZ, 1961).

TABLE IV

Output in r/min., measured in air, at the couch *, with the tube operating continuously at the tube voltage and current as normally used in chest fluoroscopy. — 35 roentgendiagnostic tubes ** —

OUTPUT IN r/min.						
< 1.0	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-9.9	> 10.0
0.7	1.0	2.0	3.2	4.0	5.8	10.3
0.7	1.0	2.1	3.8	4.1	5.8	13.8
0.9	1.0	2.1		4.5	6.0	
	1.2	2.1			6.5	
	1.2	2.2			6.9	
	1.2	2.2			7.0	
	1.5	2.4			8.5	
	1.6	2.9				
	1.8					
	1.8					
Number of tubes: 3	10	8	2	3	7	2 Total: 35 tubes

* In the absence of a couch the output was measured between target and screen at 25 cm from the screen.

** The remaining 28 tubes could not be operated continuously.

4. RADIATION QUALITY AND FILTRATION

The radiation quality, as used in chest fluoroscopy, was determined in 35 units. For this purpose successively thicker filters of Al were placed in the beam and the reduced dose-rates were measured with the ionization

TABLE V

Radiation qualities, in mm Al, as used in chest fluoroscopy — 35 roentgendiagnostic tubes * —

	Radiation quality, expressed as the 1st H.V.L. in mm Al				
	< 1.0	1.0—1.9	2.0—2.9	> 3.0	
	0.6	1.0	2.0	3.1	
	0.6	1.1	2.0	3.6	
	0.7	1.1	2.0	3.7	
	0.7	1.1	2.0	3.8	
	0.9	1.2	2.1	4.0	
	0.9	1.4	2.2		
		1.4	2.6		
		1.4	2.7		
		1.6	2.8		
		1.6	2.8		
		1.7			
		1.8			
		1.8			
		1.9			
Number of tubes	6	14	10	5	Total: 35 tubes

* The remaining 28 tubes could not be operated continuously.

chamber in the same position. The results were plotted as Al-absorption curves on semilogarithmic paper. From this the first H.V.L. in mm Al can be determined graphically. The radiation qualities, determined for 35 tubes, are listed in table V. As is evident from this table, chest fluoroscopy was usually performed with soft radiation qualities. In 20 units the radiation quality used in chest fluoroscopy was less than 2 mm Al. In these cases fluoroscopy was performed with low tube voltage and without added filtration.

In the tubes used for radiography only, the radiation quality was determined at various tube voltages. The results of the quality determinations were used to assess the total amount of filtration. For this standard curves are required showing the relation between radiation quality, total filtration, tube voltage and wave-form. Some tables and curves showing this relation were presented by HENNY (1955), TROUT (1952, 1956), HALE (1958), PIZON (1957, 1959) and WOLFSON & GARRETT (1960). However the most complete data are those presented by REINSMA (1960a). His curves are applicable to roentgen rays generated at constant potential as well as at alternating voltage. This set of curves has been used as follows:

1. 6-valve units: the curves for constant potential were applied;

2. 4-valve units: the curves for constant potential were applied when the radiation quality had been determined during fluoroscopic conditions (low tube current). During fluoroscopic conditions in 4-valve units the tube voltage is nearly of constant potential (see section 2). However, the effective tube voltage is somewhat lower than peak voltage. Due to this, assessment of total filtration in this way yields values which are somewhat too low. To account for this, the assessed values were rounded off upwards.
3. In some 4-valve units the radiation quality was determined at high tube currents, as used in radiography. Here the curves for alternating voltage were applied.
4. Alternating voltage curves were also applied for the assessment of the total filtration in self-rectifying tubes.

In table VI the total amount of filtration, as assessed by the method described above, is listed for the 63 tubes surveyed. The values are rounded off at 0.5 mm Al-equivalent. Table VI can be compared with table II where the thickness of the added filters, as found on the tubes, is shown.

Once the total filtration is known, the standard curves showing the relation between radiation quality, total filtration, tube voltage and waveform can be used to assess the quality of roentgen rays generated at any given voltage. Thus an assessment can be made of the radiation qualities generally used during various types of examinations (see Chapter V and VI).

TABLE VI

Total amount of filtration as assessed on 63 roentgendiagnostic tubes

Total filtration * (mm Al.Eq.)	Number of tubes, connected to units with maximum rated voltage		
	< 100 kVp	100-124 kVp	> 124 kVp
4.0	—	2	8
3.5	—	—	—
3.0	—	5	4
2.5	—	—	2
2.0	1	3	4
1.5	9	2	2
1.0	12	7	2
TOTAL:	22	19	22 (63 tubes)

* Added filters included, see Table II.

In table VII are listed the main data collected in the survey of roentgen-diagnostic units and tubes. The units are indicated by their code-number, as used during the analysis of examination records. In general, the units present in the various hospitals and departments are listed successively. Units 1 to 11, 18, 20, 25, 37, 38 and 40 to 42 are those under the direct supervision of a radiologist. Where more than one tube is connected to a unit, data on output and radiation quality during fluoroscopy are given only for the tube actually used for fluoroscopic procedures.

TABLE VII. Main data collected in the survey of 52 roentgendiagnostic units

code no. of unit	type of rectification	number of tubes	maximum rated voltage (kVp)	added filter (mm Al)	total filter (mm Al)	Fixed distance		Output and quality during chest fluoroscopy *				Type of unit
						target-couch (cm)	target-screen (cm	kVp	mA	1st H.V.L. (mm Al)	output (r/min.)	
1	4-valve	3	128	3.0	4.0	50		90	1.5	4.0	1.2	elaborate universal units
2	6-valve	2	128	3.0	4.0	50		90	1.5	3.8	1.6	
3	4-valve	1	120	3.0	4.0	50		90	2.0	3.7	1.5	
4	4-valve	1	120	3.0	4.0	50		90	2.0	2.8	1.8	
5	4-valve	1	100	2.0	3.0	—	—					tomography and over-couch tube
6	4-valve	2	128	2.0	3.0	—	—					tomography
7	4-valve	2	100	2.0	3.0	—	—					tomogr. and skull unit
8	4-valve	2	100	2.0	3.0	—	—					angiocardiography
9	self-rect.	1	85	0.5	1.5	—	—					mobile unit
10	4-valve	1	130	0	1.0	50		60	2.0	1.2	2.2	universal unit
11	4-valve	1	100	1.0	2.0	50		80	3.0	2.0	3.2	universal unit
12	4-valve	1	100	0	1.0	—	—					urography only
13	4-valve	1	100	2.0	3.0	55		60	2.0	2.0	1.0	universal unit
14	4-valve	1	128	0	1.0	50		90	1.0	1.4	2.1	universal unit
15	self-rect.	1	160	1.0	2.5		100	100	3.0	2.6	2.4	chest examination units
16	self-rect.	1	160	1.0	2.5		120	100	3.0	2.7	0.7	
17	self-rect.	1	85	0	1.0	—	—					mobile unit
18	4-valve	3	125	3.0	4.0	50		90	3.0	3.6	2.9	elaborate universal unit and skull unit
19	self-rect.	1	85	0	1.5	45		85	2.5	1.9	5.8	fluoroscopic stand
20	4-valve	1	120	2.0	3.0	45		80	2.0	2.8	1.0	elaborate universal unit
21	self-rect.	1	53	0	1.0		75	53	3.0	0.6	6.0	fluoroscopic stands
22	self-rect.	1	53	0.5	1.5		75	53	3.0	1.1	4.1	
23	self-rect.	1	160	0	1.5		100	160	1.0	3.1	1.2	fluorosc. stand and miniature radiography
24	self-rect.	1	85	0.5	1.5	—	—					mobile unit
25	4-valve	1	100	0	1.0	60		85	3.0	1.4	5.8	universal unit
26	self-rect.	1	85	0.5	1.5	—	—					mobile unit
27	4-valve	1	80	1.0	2.0	35		60	3.0	1.7	8.5	chest examin. units
28	4-valve	1	100	1.0	2.0	45		70	3.0	2.0	4.0	
							75	53	3.0	0.7	7.0	fluoroscopic stand

							100	50	2.5	1.0	1.8	
31	self-rect.	1	80	0	1.5		100	80	2.5	1.6	2.1	fluoroscopic stands
32	self-rect.	1	80	0	1.0		75	80	3.0	0.9	13.8	
33	self-rect.	1	120	0	1.5		85	90	2.0	1.8	1.0	
34	4-valve	2	100	1.0	2.0	50		85	2.0	2.2	2.0	elaborate universal unit
35	self-rect.	1	160	0	1.5		120	100	1.0	1.8	0.7	chest examination unit
36	self-rect.	1	85	0	1.0	—	—					mobile unit
37	4-valve	2	125	1.0	2.0	50		75	3.0	2.0	1.2	elaborate univers. unit
38	self-rect.	1	85	0.5	1.5	—	—					mobile unit
39	self-rect.	1	85	0	1.0	—	—					mobile unit
40	6-valve	2	125	0	2.0	40		70	3.0	2.1	4.5	elaborate univers. unit
41	4-valve	1	120	0	1.0	40		80	1.5	1.1	3.8	universal unit
42	self-rect.	1	50	0	1.0	—	—					mobile unit
43	self-rect.	1	53	0	1.0		75	53	3.0	0.6	10.3	fluoroscopic stand
44	self-rect.	1	80	0	1.0		85	80	2.5	1.1	6.5	chest examinat. unit
45	self-rect.	1	53	0	1.0		75	53	3.0	0.7	6.9	fluoroscopic stands
46	self-rect.	1	53	0.5	1.5		70	53	3.0	0.9	2.2	
47	4-valve	1	110	0.5	1.5	35		70	1.0	1.4	2.1	chest examination unit
48	4-valve	1	110	0	1.0	—	—					over-couch tube
49	4-valve	1	108	0	1.0	50		85	1.0	1.6	0.9	universal unit
50	self-rect.	1	80	0	1.0	—	—					mobile unit
51	self-rect.	1	90	0	1.0	—	—					mobile unit
52	self-rect.	1	85	0	1.0	—	—					mobile unit

* Only the tubes that can be used for fluoroscopy are mentioned here.

CHAPTER IV

FREQUENCY OF ROENTGENDIAGNOSTIC EXAMINATIONS

1. Collection of data

As was described in Chapter II frequency data were collected by analysis of the examination records in hospitals, institutes and private offices in the area of Leiden and Oegstgeest. Only the examinations performed in 1959 on inhabitants of Leiden and Oegstgeest were taken into account. A complete analysis included name, initials, sex and age of the patient, month of the examination, the roentgendiagnostic unit used and the type of examination performed. A complete analysis was possible of 26765 examinations. Of 2955 chest examinations the name of the patient was not available, but full information regarding the sex and age distribution of these patients was submitted by the institutes concerned. 442 examinations performed on 16 working days in the Dispensary for Tuberculosis Control (Chest Clinic) were completely analysed and served as a 1 in 15 sample for this institute. In one general hospital, and in a department of the University hospital, the total number of examinations and the distribution according to type of examination were the only data available. Nevertheless these examinations were recorded on punch cards, assuming that the sex and age distribution of the patients would be the same as for patients submitted to the same types of examinations elsewhere. In some University hospital departments, and in some institutes and private offices the only examinations performed were chest examinations. Here estimates of the total number of examinations during 1959 were based on the submitted information about daily or weekly workload. It was assumed that the two physicians (a chest physician and a general practitioner), not co-operating with the survey, also performed only chest examinations. A tentative estimate of the number of their examinations in 1959 was also made.

The completeness of the analysis is reviewed in table VIII.

Fairly complete data were collected of 36350 examinations or 60.7 per cent of all examinations. This percentage is regrettably low. The collection of sufficient information about chest examinations especially turned out to be difficult. This is mainly caused by the great number of chest examinations performed outside hospitals. In most institutes and private offices no separate records are kept of roentgendiagnostic examinations. In the last two columns of table VIII only the examinations other than radio-

TABLE VIII

Completeness of the analysis of examination records

(Dental radiography and population mass survey excluded)

	all examinations		chest examinations excluded	
	number	%	number	%
Completely analysed	26765	44.7	12754	70.4
No names available, but sex and age distribution known	2955	4.9	—	—
Sample 1 in 15; 442 examinations completely analysed	6630	11.1	225	1.2
Fairly complete data:	36350	60.7	12979	71.6
Only distribution according to type of examination known	6211	10.4	5139	28.4
Estimated number of chest examinations * (not mentioned above)	17310	28.9	—	—
Incomplete data:	23521	39.3	5139	28.4
TOTAL	59871	100.0	18118	100.0

* Including an estimate of the number of examinations performed by two physicians not co-operating with the survey.

graphy and fluoroscopy of the chest are considered. Of these examinations, which contribute the major part to the genetically significant dose, complete information was collected in 70.4 per cent. Information about sex and age of the patients is lacking in 28.4 per cent. The total number of these examinations is known exactly.

It is of interest to note what percentages of the examinations are performed in hospitals, institutes and private offices respectively. This is analysed in table IX.

The total number of inhabitants of Leiden and Oegstgeest was 109247 on Jan. 1st, 1959 and 109908 on Jan. 1st, 1960 (see section 3 of this Chapter). It was assumed that 109578 would be the average number of inhabitants during 1959. From this figure a number of 537 recruits in active military service during 1959, and thus temporarily not inhabitating the area, was subtracted. Thus a total number of 59871 examinations was performed on a population of 109041 individuals, or 0.55 per capita

TABLE IX

Distribution of examinations according to place of performance

(see also table I)

Place	Number of examinations	%	
Hospitals			
University Hospital	24123	40.3	
General Hospital I	4361	7.4	
General Hospital II	4516	7.5	59.5
Orthopaedic Hospital	878	1.5	
Mental Hospital	1692	2.8	
Institutes			
Dispensary for Tuberculosis Control	9272	15.5	
Industrial Health Services	1433	2.4	31.9
Municipal Health Department	2150	3.6	
Medical Examination Bureau	6247	10.4	
Private Offices			
Medical Specialists (5)	5001	8.4	8.6
General Practitioners (3)	198	0.2	
TOTAL	59871	100.0%	

of population. As is evident from table VIII, the number of chest examinations (no's 21, 22 and 42, see table XI) is extremely high: 41753 or nearly 70 per cent of all examinations and 0.38 per capita of population.

As name and initials of the patients were noted in 26765 instances it was possible to analyse whether some individuals had been submitted to a great number of examinations in the year of survey. Chest examinations were not considered to be of great importance in connection with individual gonad doses. So only the other examinations, comprising a number of 12754 punch cards (see table VIII) were taken into account. The results of this analysis are presented in table X. In 1959 12754 roentgendiagnostic examinations, other than chest examinations, have been performed on 7358 individuals. In this year 35 individuals have been submitted to more than 8 examinations. One person even had 19 examinations.

2. NUMBER OF EXAMINATIONS, AGE AND SEX OF PATIENTS

In the U.N.S.C.E.A.R. REPORT (1958) the radiological examinations are classified according to 22 types of examinations. For the psesent investigation the sequence of this classification was adopted, but several subdivisions were made. During the analysis of examination records the

TABLE X

Number of roentgendiagnostic examinations per individual in 1959
(chest examinations excluded)

Number of examinations	Number of individuals	Number of examinations per individual
4588	4588	1
3132	1566	2
1761	587	3
1184	296	4
645	129	5
516	86	6
280	40	7
248	31	8
72	8	9
60	6	10
99	9	11
12	1	12
65	5	13
28	2	14
45	3	15
19	1	19
TOTAL 12754	7358	

examinations were coded in 42 types. In table XI are listed the recorded numbers of each examination type. Due to some subdivisions only a low number of examinations was recorded in several exposure groups. Thus it was considered that too many subdivisions were made and the examinations were reclassified according to the U.N.S.C.E.A.R. REPORT list, but with fewer subdivisions. Due to this reclassification the data can be compared directly with foreign data (see section 4).

In table XII the sex and age distribution is analysed. 56.1 per cent of all examinations was performed on males. Only a few types of examinations, namely hip (no. 1), gallbladder (no. 16), sternum-ribs-shoulder-clavicle (no. 18) and cervical spine-trachea (no. 21b) were performed more frequently on females than on males. Pelvimetries are performed very seldom in the Netherlands; in this material no pelvimetries were recorded at all. Males were submitted to a notably higher percentage than females to urological examinations (no.'s 7, 8 and 9). The age distribution is given in 5 year classes up to the age of 60 and subsequently in 10 year classes. As most children are born below the parental age of 40 (see table XVII) it is of interest to note the percentage of examinations performed below this age. On the other hand, the genetically significant dose is sometimes calculated on the basis of the gonad doses received by individuals below the age of 30. The percentage of examinations performed below both ages is noted for males and females respectively in

TABLE XI

Distribution of roentgendiagnostic examinations, according to type of examination
Leiden and Oegstgeest — 1959

Examination types	Number of examinations	% of total
1. hip and femur (upper third)	398	0.66
2. femur (middle and lower third)	198	0.33
3. pelvis	735	1.23
4. lumbosacral region	370	0.62
5. lumbar spine	781	1.30
6. aorto-arteriography and phlebography	48	0.08
7. myelography	18	0.03
8. dorsal spine	321	0.54
9. intravenous urography	938	1.57
10. retrograde pyelography	117	0.20
11. urethrocystography	152	0.25
12. pelvimetry	0	0.00
13. hysterosalpingography	33	0.06
14. obstetrical abdomen	12	0.02
15. abdomen (general)	674	1.13
16. colon (barium enema)	651	1.09
17. stomach (barium meal)	1972	3.29
18. small intestine (barium meal)	171	0.29
19. cholecystography	1375	2.30
20. other examinations of the abdomen	10	0.02
21. radiography of the chest (lungs)	11216	18.73
22. fluoroscopy of the chest	21758	36.34
23. heart analysis and angiocardiography	216	0.44
24. bronchography	41	0.07
25. tomography (lungs)	341	0.57
26. oesophagus	224	0.37
27. ribs, sternum, mammography	117	0.20
28. shoulder and clavicle	603	1.00
29. upper arm	118	0.20
30. elbow, forearm, wrist	1218	2.03
31. hand (no-screen)	182	0.30
32. hand, fingers	1036	1.73
33. arthrography of the knee	12	0.02
34. knee, lower leg, ankle	1960	3.27
35. foot, toes	882	1.47
36. skull (general)	1087	1.82
37. encephalography, ventriculography etc.	75	0.13
38. mandible, temporal bones, orbita, sinuses	201	0.33
39. cervical spine	653	1.09
40. trachea	118	0.20
41. dental radiography *	15	0.02
42. miniature radiography of the chest **	8779	14.66
TOTAL	59871	100.00%

* Dental radiography, performed by dentists not included.
** Population mass survey not performed in 1959.

MALES

Table XII. Survey of age and sex distribution of 59871 roentgendiagnostic examinations

Examination types	number of examinations		percent. males	percentage numbers in age groups (males)														
	total	males		0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-69	70-79	80+ total
1. hip and femur (upper third)	398	174	43.7	2.3	2.9	0.6	0.6	4.6	0.6	5.2	0	2.3	3.4	8.0	17.2	14.4	23.5	14.4 (100.0)
2. femur (middle and lower third)	198	118	59.6	32.2	3.4	1.7	4.2	16.1	0.9	0.9	11.8	0.9	0.9	5.1	1.7	6.8	12.6	0.8 „
3. pelvic region	735	367	49.9	4.6	10.9	5.2	3.0	6.0	2.2	3.0	3.0	6.5	6.3	7.9	9.8	17.7	9.0	4.9 „
4. lumbosacr. region	370	208	56.2	0.5	0	1.9	1.9	11.5	7.2	11.5	7.2	12.5	7.2	10.1	12.0	12.0	3.5	1.0 „
5. lumbar spine	847	491	58.0	2.3	0.2	1.8	0.8	7.2	3.3	12.5	10.5	9.2	9.6	8.2	12.2	11.5	8.4	2.3 „
6. dorsal spine	321	181	56.4	6.6	4.4	11.6	3.3	5.6	2.8	5.0	6.5	9.4	6.6	5.5	11.6	11.2	8.8	1.1 „
7. intravenous urography	938	612	65.2	1.0	1.5	1.1	1.5	6.0	4.7	6.4	7.5	6.7	8.2	6.9	9.0	20.4	14.4	4.7 „
8. retrogr. urography	117	76	65.0	0	0	4.0	0	4.0	9.2	13.1	7.9	4.0	25.0	17.0	4.0	7.8	4.0	0 „
9. urethrocystography	152	121	79.6	0.8	0.8	0	0	2.5	4.1	5.0	7.4	2.5	3.3	6.6	14.0	26.5	25.7	0.8 „
10. pelvimetry	—	—	—															
11. hysterosalpinogr.	33	—	—															
12. obstetrical abdomen	12	—	—															
13. abdomen (general)	684	406	59.4	4.7	3.0	2.2	3.3	4.2	4.4	5.2	9.6	10.8	6.9	7.9	8.1	14.9	9.9	4.9 „
14. lower gastroint. tr.	822	405	49.3	1.0	0	1.2	0.5	3.5	2.7	5.4	10.1	6.2	8.2	7.6	10.6	22.5	16.8	3.7 „
15a. oesophagus	224	118	52.7	5.9	0	0.8	0	0	5.1	2.5	10.2	3.4	14.4	3.4	17.0	23.7	13.6	0 „
15b. stomach and duodenum	1972	1140	57.8	1.3	0.2	0.7	1.5	5.1	8.1	8.4	10.0	8.9	11.2	11.7	11.9	13.2	6.7	1.1 „
16. gallbladder	1375	506	36.8	0	0	0	0.8	5.1	6.9	7.1	12.7	9.3	7.9	13.3	13.6	13.8	7.3	2.2 „
17a. chest (fluor.)	21758	12690	58.3	3.2	4.6	14.6	13.6	9.8	8.4	8.4	7.6	7.3	3.9	7.5	3.9	4.6	1.9	0.7 „
17b. chest (radiogr.)	11859	6170	52.0	6.0	2.2	2.3	2.7	6.5	4.2	6.1	5.3	6.8	7.4	8.4	11.2	17.2	10.5	3.2 „
18. sternum, ribs etc.	720	340	47.2	2.6	0.9	2.4	4.7	2.9	5.3	4.4	6.0	3.2	10.0	12.1	14.1	23.9	6.0	1.5 „
19. arm and hand	2554	1501	58.8	5.4	9.3	15.5	13.8	10.2	8.3	5.2	6.6	5.2	5.4	4.9	2.3	6.4	1.5	0 „
20. lower leg and foot	2854	1641	57.5	4.8	7.4	8.6	8.6	12.2	7.2	8.3	5.7	3.7	6.3	7.7	5.7	7.8	5.4	0.6 „
21a. head	1378	808	58.6	10.9	10.9	8.9	6.0	7.9	9.5	6.0	8.4	4.5	4.9	6.4	4.0	6.7	4.5	0.5 „
21b. cervical spine, trachea	771	351	45.5	1.4	1.1	3.1	1.1	2.6	4.8	2.9	10.3	7.1	10.3	14.0	17.1	17.1	7.1	0 „
23. miniature radiogr.	8779	5139	58.5	0.3	0.3	1.7	7.6	8.4	12.3	11.6	12.6	9.9	10.4	8.2	6.2	8.1	2.1	0.3 „
all examinations	59871	33563	56.1	3.5	3.5	7.9	8.3	8.3	7.6	8.0	8.0	7.3	6.6	8.0	6.9	9.7	5.0	1.4 „

FEMALES

Examination types	number of examinations		percent. females	percentage numbers in age groups (females)															
	total	females		0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-69	70-79	80+	total
1. hip and femur (upper third)	398	224	56.3	0	0.4	0	0	6.1	0	0.4	0	4.5	4.5	9.4	10.3	20.6	23.2	20.6	(100.0)
2. femur (middle and lower third)	198	80	40.4	8.7	5.0	1.2	0	0	1.2	0	1.3	2.5	1.3	6.2	17.5	21.3	31.3	2.5	„
3. pelvic region	735	368	50.1	5.4	1.9	4.9	3.8	3.0	0.6	3.8	3.5	5.2	5.7	9.5	9.0	25.8	13.8	4.1	„
4. lumbosacr. region	370	162	43.8	0	0	1.4	4.9	6.8	6.8	7.3	5.5	14.8	13.6	13.6	3.1	14.8	4.9	2.5	„
5. lumbar spine	847	356	42.0	2.8	1.4	1.1	3.4	4.5	5.9	7.0	9.3	12.6	6.8	11.2	7.9	14.9	10.1	1.1	„
6. dorsal spine	321	140	43.6	2.9	4.3	7.1	7.1	7.1	5.0	2.1	2.9	13.6	5.7	10.0	5.0	12.2	12.9	2.1	„
7. intravenous urography	938	326	34.8	0	2.8	1.5	2.8	4.0	5.2	8.0	6.8	7.4	8.6	8.9	14.7	14.7	13.4	1.2	„
8. retrogr. urography	117	41	35.0	0	7.3	0	0	7.3	0	0	0	7.3	7.3	0	14.7	34.1	22.0	0	„
9. urethrocystography	152	31	20.4	0	6.5	9.7	9.7	3.1	6.5	6.5	3.1	12.9	6.5	9.7	9.7	6.5	9.6	0	„
10. pelvimetry	—	—	—																
11. hysterosalpinogr.	33	33	100.0	0	0	0	0	0	15.2	30.4	54.4	0	0	0	0	0	0	0	„
12. obstetrical abdomen	12	12	100.0	0	0	0	8.3	16.7	25.0	25.0	25.0	0	0	0	0	0	0	0	„
13. abdomen (general)	684	278	40.6	5.0	2.2	1.8	5.4	3.6	5.8	6.5	6.5	6.1	7.5	8.3	9.8	14.7	12.9	3.9	„
14. lower gastroint. tr.	822	417	50.7	0.2	0.2	0.2	3.8	1.2	3.8	6.5	6.0	9.4	7.5	10.6	7.5	22.4	17.8	2.9	„
15a. oesophagus	224	106	47.3	0	0	1.8	0	2.8	5.7	5.7	7.5	8.5	12.3	14.2	3.8	22.7	13.2	1.8	„
15b. stomach and duodenum	1972	832	42.2	0.5	0.1	0.1	3.1	5.8	4.9	5.2	8.9	7.9	11.6	11.3	9.2	18.5	11.5	1.4	„
16. gallbladder	1375	869	63.2	0	0	0.1	2.5	3.9	4.9	7.3	7.3	8.4	10.2	12.9	8.6	22.4	11.0	0.5	„
17a. chest (fluor.)	21758	9068	41.7	4.9	4.3	13.1	15.6	13.6	6.3	9.2	5.9	8.3	4.2	3.6	3.2	3.6	2.9	1.3	„
17b. chest (radiogr.)	11859	5689	48.0	7.1	2.2	2.3	10.1	11.7	7.4	7.7	5.1	5.8	4.8	6.3	5.7	12.1	9.3	2.4	„
18. sternum, ribs etc.	720	380	52.8	1.6	1.1	3.7	3.9	2.6	3.2	2.6	10.0	7.4	7.6	7.6	11.3	18.4	16.6	2.4	„
19. arm and hand	2554	1053	41.2	6.2	10.4	17.1	11.9	3.8	3.5	4.3	2.9	3.8	4.5	5.9	5.7	9.0	8.3	2.7	„
20. lower leg and foot	2854	1213	42.5	5.0	5.8	8.8	8.0	7.2	3.1	4.8	6.0	7.3	5.0	12.1	6.8	13.3	5.4	1.4	„
21a. head	1378	570	41.4	9.5	11.4	9.1	6.7	7.2	6.0	8.2	6.9	5.1	4.2	6.5	4.7	9.3	4.0	1.2	„
21b. cervical spine, trachea	771	420	54.5	1.2	0	0.7	2.4	0.7	3.6	5.5	6.7	10.5	11.2	18.0	15.8	16.6	4.5	2.6	„
23. miniature radiogr.	8779	3640	41.5	0	0.4	0.5	13.8	15.7	11.0	13.1	12.1	8.5	7.3	5.9	4.8	4.0	2.0	0.9	„
all examinations	59871	26308	43.9	4.2	3.1	6.7	11.1	10.7	6.6	8.3	6.7	7.5	5.7	6.5	5.5	9.3	6.4	1.7	„

table XIII. The high figure for femur examinations (no. 2) in males is mainly caused by some frequently repeated examinations on 4 boys in age class 0–4. Of all examinations 55.1 and 57.4 per cent was performed on males and females respectively below the age of 40. More than 50 per cent of chest fluoroscopies and of examinations of the extremities and the head was performed below this age. For all other examinations (except hysterosalpingraphy and obstetrical abdomen) this percentage was in general lower than 40. The contribution of each examination type to the genetically significant dose is influenced by these examination-specific age distributions. On the basis of these distributions the values for w_j^* (mean subsequent child-expectancy) are calculated in the next section.

TABLE XIII

Percentage of examinations performed below the age of 30 and 40 respectively

(expressed as the percentage of the total number of examinations of each type performed on males and females respectively)

Examination type	percentage of the total number of examinations of each type:			
	below the age of 30		below the age of 40	
	males	females	males	females
1. hip and femur (upper 1/3)	11.6	6.5	16.8	6.9
2. femur (lower 2/3)	58.5	16.1	71.2	17.4
3. pelvic region	31.9	19.6	37.9	26.9
4. lumbosacral region	23.0	19.9	41.7	32.7
5. lumbar spine	15.6	19.1	38.6	35.4
6. dorsal spine	34.3	33.5	45.8	38.5
7. intravenous urography	15.8	16.3	29.7	31.1
8. retrograde urography	17.2	14.6	38.2	14.6
9. urethrocystography	8.2	35.5	20.6	45.1
10. pelvimetry	—	—	—	—
11. hysterosalpingography	—	15.2	—	100.0
12. obstetrical abdomen	—	50.0	—	100.0
13. abdomen (general)	21.8	23.8	36.6	36.8
14. lower gastrointest. tract	8.9	9.4	24.4	21.9
15a. oesophagus	11.8	10.3	24.5	23.5
15b. stomach and duodenum	16.9	14.5	35.3	28.6
16. gallbladder	12.8	11.4	32.6	26.0
17a. chest (fluoroscopy)	54.2	57.8	70.2	72.9
17b. chest (radiography)	23.9	40.8	35.3	53.6
18. sternum, ribs, shoulder	18.8	16.1	29.2	28.7
19. arm, hand	62.5	50.0	74.3	57.2
20. lower leg, foot	48.8	37.9	62.8	48.7
21a. head	54.1	49.9	68.5	65.0
21b. cervical spine, trachea	14.1	8.6	27.3	20.8
23. miniature radiography	30.6	41.4	54.8	66.6
all examinations	39.1	42.4	55.1	57.4

TABLE XIV

Distribution of 33138 roentgendiagnostic examinations according to the month of examination

	MALES			FEMALES			ALL
	Chest Examinations	All other Examinations	Total	Chest Examinations	All other Examinations	Total	Examinations
Jan.	1380	594	1974	999	513	1512	3486
Febr.	455	543	998	280	490	770	1768
March	454	553	1007	346	521	867	1874
April	1349	648	1997	759	527	1286	3283
May	2402	574	2976	1777	448	2225	5201
June	994	621	1615	1055	490	1545	3160
July	445	494	939	341	390	731	1670
Aug.	691	495	1186	601	444	1045	2231
Sept.	864	562	1426	892	460	1352	2778
Oct.	796	604	1400	717	488	1205	2605
Nov.	366	591	957	465	470	935	1892
Dec.	1415	560	1975	743	472	1215	3190
Total	11611	6839	18450	8975	5713	14688	33138

The distribution of the examinations over the months of the year is listed in table XIV. The month of performance was recorded for a total of 33138 examinations. For males as well as for females considerable differences exist in the number of examinations performed in various months. Far more examinations were recorded in May than in any other month, while relatively few examinations were performed in February, March, July and November respectively. The monthly differences are much smaller when the chest examinations (no.'s 17a, 17b and 23) are subtracted. However some fluctuations are still found when the remaining examinations are considered apart. In July and August relatively low numbers of these examinations were performed. As is evident from this table reliable data can only be collected by analysis of either the examination records of a whole year or by analysis of a sample consisting of the examinations performed on days, equally distributed over the months of a year.

3. DEMOGRAPHIC DATA, SUBSEQUENT CHILD-EXPECTANCY

Data on age and sex distribution were submitted by the Central Bureau of Statistics (C.B.S.) for Leiden and by the local Municipal Registry Office for Oegstgeest. The number of male and female inhabitants of both municipalities on Jan. 1st, 1959 and Jan. 1st, 1960 respectively is noted in table XV.

TABLE XV

Population of Leiden and Oegstgeest — 1959

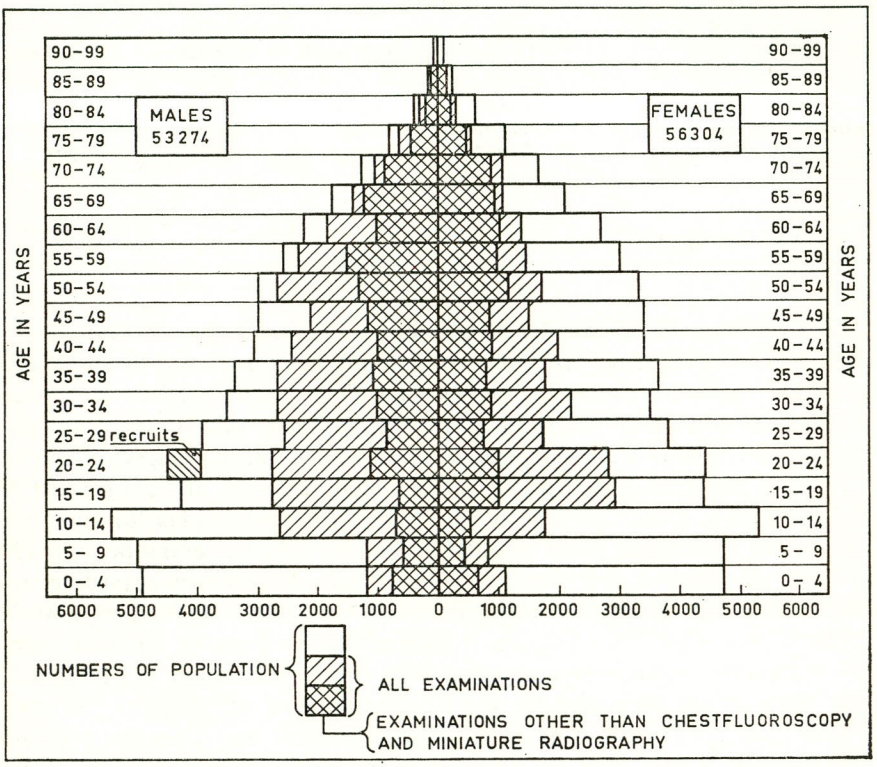
date	Males		Females	
	Leiden	Oegstgeest	Leiden	Oegstgeest
Jan. 1st, 1959	46898	6178	48984	7187
Jan. 1st, 1960	47226	6245	49214	7223
mean for 1959	47062	6212	49099	7205
mean for 1959 (Leiden & Oegstgeest)	53274		56304	

For the purpose of calculation the data on sex and age distribution for Jan. 1st, 1959 and Jan. 1st, 1960 respectively were averaged to give mean data for the year 1959. In Leiden and Oegstgeest together the mean number of inhabitants in 1959 was 109578. From this figure a number of 537 recruits out of the area and in active military service during 1959 was subtracted (see p. 39). It was assumed that all recruits would fall in the age group 20—24. In all subsequent calculations for the total number of individuals of the population involved (N, see equation 3, p. 15) a figure of 109041 was used. In *figure I* the distribution regarding sex and 5-year age groups of the population of Leiden and Oegstgeest in 1959 is presented. The diagram is plotted on the basis of absolute numbers. This diagram can be compared with that for the whole population of the Netherlands presented by the Central Bureau of Statistics (STATISTISCH ZAKBOEK, 1960). The population of Leiden and Oegstgeest represents about 1 per cent of the whole population of the Netherlands (11,417,254 inhabitants on Dec. 31, 1959). The sex and age distributions of both populations show only slight differences. In *figure I* also the absolute numbers of all roentgendiagnostic examinations and of examinations other than chest fluoroscopy and miniature radiography, performed on the population under consideration, are plotted. (The percentage distribution of the examinations in 5-year groups is presented in table XII). The number of examinations per capita of population in 1959 was estimated at 0.55 (see section I of this Chapter). However, as is already evident from *Figure I,* some age groups are subjected to roentgendiagnostic examinations in higher percentages than other age groups. The number of examinations per capita is analysed for various age groups separately in table XVI.

For calculation of the genetically significant dose, data on subsequent child-expectancy are necessary. These data could be assessed for the population of Leiden. It was assumed that the childbirth data of Oegst-

FIGURE I.

Diagram of the sex and age distribution of the population of Leiden and Oegstgeest (1959), also indicating the absolute numbers of roentgendiagnostic examinations



geest would not differ significantly from those of Leiden. For the calculation of the age-specific subsequent child-expectancy essentially the same method as recommended in the U.N.S.C.E.A.R. REPORT (1958) was used. Birth records of the population of the Netherlands are deposited with the Central Bureau of Statistics. The age of the father of illegitimate children is not recorded. However, it was assumed that this would not introduce a great inaccuracy in the calculations, as in the Netherlands the illegitimates form a small percentage of all live births (1.2—1.4 per cent in the years 1955—1959, C.B.S. STATISTISCH ZAKBOEK 1960). For each live child, born to Leiden inhabitants during the years 1954—1959, the age of the parents was noted. Next the age distribution (in one year groups) of the population of Leiden was used to calculate the average number of children born yearly to males and females of any given age. The resulting figures were corrected by the probability for a live born

TABLE XVI

Number of roentgendiagnostic examinations per capita * for various age groups Leiden and Oegstgeest — 1959

Age groups	Males			Females		
	Number of examinations	Number of individuals	Number of examinations per capita	Number of examinations	Number of individuals	Number of examinations per capita
0—9	2364	9889	0.24	1926	9478	0.20
10—14	2649	5445	0.49	1756	5325	0.33
15—39	13485	19037	0.71	11414	19804	0.58
40 & older	15065	18366	0.82	11212	21697	0.52
All ages	33563	52737	0.64	26308	56304	0.47

* Dental radiography performed by dentists excluded.
Population mass survey not performed in 1959.

child to reach the age under consideration. For this correction factors were derived from life tables for the Netherlands, 1951—1955 (C.B.S., 1957). It was assumed that in future the age specific annual birth rate will not change. The number of children still to be expected by the average individual of any given age (subsequent child-expectancy) can then be calculated by summation. Thus data on subsequent child-expectancy are available for any given age in years. For the calculation of the genetically significant dose according to equation 3 (p. 15) weighted subsequent child-expectancies were calculated for individuals in 5-year age groups. These data are given in table XVII, together with comparable figures presented by HAMMER-JACOBSEN (1958) for Denmark and by the ADRIAN COMMITTEE (1960) for the United Kingdom. The data presented by LARSSON (1958) for Sweden are not included in this table, as the age groups used in his table are not the same as those in table XVII. The figures for Danish males are only applicable to married men. According to HAMMER-JACOBSEN, the 6—7 per cent illegitimate children born in Denmark would cause too large an error to calculate figures for all males.

On the basis of the subsequent child-expectancy data, together with the data on the percentage distribution of the roentgendiagnostic examinations in age groups (table XII) the future number of children expected by the average individual of either sex, undergoing a specified type of roentgendiagnostic examination (w_j^*, see equation 3, p. 15), can be calculated. However, several assumptions must first be made. It could be argued that for instance individuals subjected to urological examinations may have relatively low fertility. The future child-expectancy of an individual

TABLE XVII

Subsequent child-expectancy
Compared for Leiden *, Denmark and the United Kingdom

Age groups	Subsequent Child-Expectancy					
	Leiden ('54-'59)		Denmark ('55-'56) Hammer-Jacobsen, 1958		United Kingdom (1951) Adrian Committee, 1960	
	males	females	males **	females	males	females
0—4	2.634	2.598		}	2.229	2.323
5—9	2.663	2.620		} 2.589	2.239	2.331
10—14	2.671	2.625		}	2.245	2.325
15—19	2.678	2.613		2.484	2.221	2.207
20—24	2.627	2.405	3.611	1.954	1.999	1.733
25—29	2.232	1.737	2.092	1.145	1.460	1.017
30—34	1.396	0.914	1.122	0.531	0.840	0.462
35—39	0.693	0.363	0.544	0.187	0.389	0.157
40—44	0.272	0.077	0.229	0.038	0.141	0.030
45—49	0.081	0.004	0.084	0.002	0.044	0.002
50—54	0.024		0.029		0.013	
55—59	0.006		0.011		0.002	
60 & older	0.001		0.005			
			(0.002)			
			(0.001)			

* Based on birth records of Leiden (1954-1959) and life tables for the Netherlands (1951-1955);
Centraal Bureau voor de Statistiek: Sterftetafels voor Nederland, Uitg. W. de Haan, Zeist 1957.

** Figures for married men only;
Figure for age group 20 —24 calculated by averaging the figures for the ages of 20, 21 and 22—24 years.

may be influenced by the nature of the condition for which he is examined. As no estimate of the magnitude of this influence seems to be available at the moment this source of inaccuracy will be neglected for all examinations except two.

Normal age-specific child-expectancy data are not applicable to females subjected to hysterosalpingography, which usually is performed for the reason of sterility. Again no quantitative data seem to be available about the number of children born to women after hysterosalpingography. The ADRIAN COMMITTEE (1960) assumed that the fertility of such a woman would be one-tenth of the average for her age group. OSBORN & SMITH (1956) supposed that, on the average, one child would be born to a woman subsequent to hysterosalpingography. LARSSON (1958) assumed that the subsequent child-expectancy would be lower than normal by a factor of 2. Having regard to the small number of hysterosalpingographies

(33) collected, the exact magnitude of the correction does not seem to be of great importance in the present study. The factor of 2, as suggested by LARSSON was used.

Also the subsequent child-expectancy of a female subjected to an obstetrical abdominal examination may not be the average for her age group. The child of which the woman is pregnant at the moment of the examination is also exposed. For the latter exposure the high child-expectancy of a foetus in utero must be used as a weighting factor. On the other hand the foetus in utero should be subtracted from the future number of children expected by the mother. However, simple subtraction of the age-specific subsequent child-expectancy by one does not seem to be appropriate. It can be argued that a woman who had a child has a subsequent child-expectancy higher than the subsequent child-expectancy minus one of the average woman of her age. On the basis of birth statistics in the Netherlands it would be possible to ascertain this assumption. However, as the number of obstetrical abdominal examinations found in the sample is extremely low (12), here also the magnitude of the correction does not seem of great importance. For this reason the method of correction suggested by LARSSON was followed. The subsequent child-expectancy for a pregnant woman in a given age group was substituted by that of a woman in the subsequent, older age group. Thus the correction for the future number of children of a pregnant woman ranged from −0.208 to −0.823.

Relative subsequent child-expectancy data ($\frac{w_j^*}{w}$) can be calculated by division of w_j^* by the future number of children expected by the average individual of a population (w). For the population involved the factor w was calculated on the basis of the sex and age distribution (see *figure I*), together with the data on subsequent child-expectancy (table XVII). Thus w was established at 1.394 (Denmark: 0.92; England and Wales: 0.93; New Zealand: 0.71; Sweden: 0.91; ref. U.N.S.C.E.A.R. REPORT, 1958).

In table XVIII the results of the calculation of $\frac{w_j^*}{w}$ are presented together with the comparable data for England and Wales, 1956 (U.N.S.C.E.A.R. REPORT, 1958). It should be noted that the British figures are in general the higher ones. This is partly due to the difference of the factor w for both populations (1.394 and 0.93 respectively). The values for w_j^*, which are not presented here, show a much higher degree of similarity.

4. FREQUENCY DATA IN VARIOUS OTHER COUNTRIES

In the preceding section some data collected in the present investigation were compared with data from various other countries. A few additional

TABLE XVIII

Relative child-expectancy $(\frac{w_j}{w}^*)$

Examination types	relative child-expectancy			
	Leiden (1959)		England and Wales (1956)	
	Males	Females	Males	Females
1. hip and femur (upper third)	0.279	0.118	1.13	0.75
2. femur (middle and lower third)	1.176	0.298		
3. pelvic region	0.664	0.396	0.56	0.93
4. lumbosacral region	0.596	0.391		
5. lumbar spine	0.489	0.392	0.83	0.63
6. dorsal spine	0.751	0.615	0.80	0.67
7. intravenous urography	0.407	0.341	0.53	0.81
8. retrograde urography	0.495	0.270		
9. urethrocystography	0.239	0.679	0.23	0.30
10. pelvimetry	—	—	—	0.94
11. hysterosalpingography	—	0.265	—	1.07
12. obstetrical abdomen	—	0.594	—	1.08
13. abdomen (general)	0.528	0.467	1.54	
14. lower gastroint. tract	0.284	0.214	0.58	0.22
15a. oesophagus	0.301	0.215	0.43	0.40
15b. stomach and duodenum	0.457	0.294		
16. gallbladder	0.382	0.248	0.28	0.16
17a. chest (fluoroscopy)	1.148	1.105	1.3*/0.85**	1.3*/0.50**
17b. chest (radiography)	0.548	0.768		
18. ribs, sternum & shoulder	0.431	0.326	0.74/0.88	0.38/0.67
19. arm, hand	1.266	1.003	1.5	1.1
20. lower leg, foot	1.032	0.732	1.2	0.98
21a. head	1.115	0.962	1.6	1.5
21b. cervical spine	0.357	0.199	1.1	0.52
23. miniature radiography	0.747	0.806	0.88	1.32

* "large film" ** "special film"

tables may serve further comparisons. However, it should be noted that the methods of collection of data may differ considerably. As was mentioned in Chapter II, in some countries a relatively small sample of hospital data served to estimate the genetically significant dose for the population of a whole country. In these cases it was assumed that the sample would be representative for the population at large. In the recent survey in the United Kingdom (ADRIAN COMMITTEE, 1960) great care was taken to select representative hospitals and chest clinics. In some other surveys, such as in Buenos Aires (see table XIX), Rome (BIAGINI et al., 1960) and Hamburg (HOLTHUSEN et al., 1961) the whole population of a city has been scanned. As the authors stressed the resulting estimates are not directly applicable to the population of the whole country. In comparing the results of estimates made in various countries, these differences in methodology should be kept in mind.

TABLE XIX

Annual numbers of roentgendiagnostic examinations
(mass miniature radiography and dental radiography excluded)

Country or City	Period of study	Annual number of examinations per capita of population
Argentine: *Buenos Aires*	1950—'59	0.27
Austria	1955—'57	0.38
Denmark	1956	0.26
Fed. Rep. of Germany: *Hamburg*	1957—'58	0.57
France	1957	0.77*
Italy: *Rome*	1957	0.50
Netherlands: *Leiden*	1959	0.55
Sweden	1955	0.29
United Kingdom (except North. Ireland)	1957—'58	0.29
U.S.A.	1955—'56	0.33

* 0.45 fluoroscopic examinations due to mass survey included.

In the U.N.S.C.E.A.R. REPORT (1958) a table is presented in which, amongst other things, the estimated number of roentgendiagnostic examinations per capita of population is noted for some 10 countries.

In the REPORT OF THE I.C.R.P./I.C.R.U. JOINT STUDY GROUP (1960) a comparable table is given. The latter table includes some more recent estimates and also the preliminary estimate for the population of Leiden. In Table XIX an extract of this table is given. The final estimate for the population of Leiden and Oegstgeest differs little from the preliminary estimate. The annual number of examinations per capita of population is nearly the same as that in Hamburg and slightly higher than that in Rome.

It will not be attempted to compare the data on the percentage distribution of the examinations regarding sex and age of the patients, as this would require a large set of tables. Some examples of these distributions are presented in the I.C.R.P./I.C.R.U. JOINT STUDY GROUP REPORT (1960).

Subsequent child-expectancy data are compared in table XVII. The figures for $\frac{w_j^*}{w}$ in table XVIII give some impression about the percentage sex and age distribution of the patients. However, it must be kept in mind

TABLE XX

Distribution of roentgendiagnostic examinations regarding to type (miniature radiography and dental radiography excluded)

Examination Types	Percentage of total number of examinations		
	Leiden & Oegstgeest 1959	Hamburg 1957/58	United Kingdom * 1957
1. hip and femur (upper third)	0.78	1.05	1.90
2. femur (middle & lower third)	0.39	1.49	1.10
3. pelvic region	1.44	1.36	1.49
4. lumbosacral region	0.72	0.23	1.76
5. lumbar spine	1.66	3.86	2.63
6. dorsal spine	0.63	1.43	1.11
7. intravenous urography	1.84	1.57	1.69
8. retrograde urography	0.23	0.41	0.28
9. urethrocystography	0.30	0.08	0.08
10. pelvimetry	—	0.01	0.14
11. hysterosalpingography	0.06	0.04	0.07
12. obstetrical abdomen	0.02	0.06	0.61
13. abdomen (general)	1.34	1.34	2.40
14. lower gastrointest. tract	1.61	1.39	1.52
15a. oesophagus	0.44	7.36	4.03
15b. stomach and duodenum	3.86		
16. gallbladder	2.69	2.25	1.32
17a. chest (fluoroscopy)	42.58	50.78	48.52
17b. chest (radiography)	23.20		
18. ribs, sternum, shoulder, clavicle	1.41	2.47	3.04
19. arm, hand	5.00	7.53	9.52
20. lower leg, foot	5.59	6.99	8.22
21a. head	2.70	8.30	7.22
21b. cervical spine (& trachea)	1.51		
others			1.35
All examinations	100.00	100.00	100.00
absolute number of examinations	51,092	995,674	12,839,600
Population:	109,041	1,755,000	50,000,000

* National Health Service Hospitals only.
Figures derived from ICRP/ICRU Joint Study Group Report (1960).

that for Leiden and Oegstgeest "w" amounts to 1.394, while for England and Wales a figure of 0.93 was used for "w".

It is of interest to compare the percentage distribution of certain types of examinations in various countries. For this the data of the recent surveys in Hamburg and the United Kingdom were chosen. As mass survey and dental radiography are not included in the present investigation these examinations are not considered. A marked difference exists in the

amount of chest examinations as a percentage of the total, this being nearly 66 per cent * for Leiden and Oegstgeest and about 51 and 49 per cent for Hamburg and the United Kingdom respectively. This difference may mainly be due to the quite large number of fluoroscopic examinations of the chest outside hospitals in Leiden. Due to the high percentage of chest examinations most other examinations form a lower percentage of the total in Leiden than in either Hamburg or the United Kingdom. Therefore the relatively high percentages of urological examinations (no.'s 7 and 9), examinations of the lower gastrointestinal tract (no. 14) and gallbladder examinations (no. 16) are the more remarkable. It is not known whether this is typical for the average Dutch radiological practice.

The major portion of the genetically significant dose results from those examinations during which the gonads usually lie in the primary beam (U.N.S.C.E.A.R. REPORT, 1958). This will be discussed in greater detail in Chapter VI. In table XXI the examinations are divided in those where the gonads usually lie inside and outside the primary beam respectively (miniature radiography and dental radiography again excluded). For Leiden and Oegstgeest the first group of examinations constitutes about 10 per cent of the total number of examinations. This percentage is higher for Hamburg (about 13 per cent) and again higher for the United Kingdom (about 16 per cent). This difference is mainly due to the high percentage of chest examinations in Leiden and Oegstgeest.

TABLE XXI

Distribution of examinations in 2 groups
(miniature radiography and dental radiography excluded)

Examination group	Percentage of total number of examinations		
	Leiden & Oegstgeest 1959	Hamburg 1957/58	United Kingdom 1957
Gonads often in the primary beam (type no.'s 1—5 and 7—14)	10.39	12.89	15.67
Gonads usually outside the primary beam (type no.'s 6 and 15—21)	89.61	87.11	84.33
All examinations	100.00	100.00	100.00

* When mass miniature radiography (not mass survey) is included this percentage is even about 70.

CHAPTER V

GONAD DOSES

1. Methods of measurement. Instruments

Many authors have stressed the extreme difficulty of performing gonad dose measurements during roentgendiagnostic examinations. Strictly speaking gonad doses cannot be measured directly on patients. However, for men the dose measured at the surface of the scrotum nearest to the roentgen tube can be considered as a good approximation to the actual testis dose. The ovary dose can be assessed in several ways:

a. It has been assumed that the dose measured in either the posterior fornix of the vagina or in the rectum gives a fair representation of the actual ovary dose. Several authors have based their ovary dose assessments on this assumption (amongst others Zimmer, 1935; Weens et al., 1954; Martin, 1955; Seelentag et al., 1958c and Larsson, 1958). However, Mac Gregor & Oliver (1952) found the ovary dose recorded during hysterosalpingography in a cadaver about 1.5 times as high as the dose in the vagina. Hammer-Jacobsen (1957) found that during hysterosalpingography the vaginal dose may be twice as high as the rectal dose. He concluded that the actual ovary dose may be 50 to 100 per cent higher than the doses measured in either vagina or rectum.

b. Direct ovary dose measurements can be carried out in a cadaver (Feldman et al., 1958; Hartung, 1958; Oeser et al., 1958; Devik et al., 1960). This method has mainly been used to assess ovary doses during specified types of roentgendiagnostic examinations, such as hysterosalpingography (Mac Gregor & Oliver, 1952). Stanford & Vance (1955) made simultaneous measurements in a cadaver of ovary doses and doses on the skin directly above the place of the ovary. They used the ovary dose/surface dose ratios, thus determined, to calculate ovary doses on the basis of skin doses measured directly on patients.

c. Various authors have used a phantom, either to measure directly the doses at the assumed place of the ovary or in combination with measurements on patients (amongst others Hol & Koren, 1955; Koren & Maudal, 1957; Billings et al., 1957; Webster & Merrill, 1957; Lincoln & Gupton, 1958; Mohr et al., 1959; Thurau & Distel, 1961). As was stated by several authors a phantom is most suitable to study the influence of exposure techniques on the magnitude of gonad doses. An extensive dosimetric study was carried out on a phantom by Wolfson &

GARRETT (1959). A phantom was also used by physicists of the ADRIAN COMMITTEE (1960) to derive ovary dose/surface dose conversion factors for a large variety of roentgendiagnostic procedures. The phantoms used by the authors quoted above varied from simple plastic bags filled with water, via model-mannikins filled with paraffin, to polythene forms filled with soft-tissue-equivalent material and incorporating a human skeleton.

d. Finally, ovary doses can also be calculated. Most authors have based their calculations on skin dose measurements and used ovary dose/skin dose conversion factors derived from cadaver- or phantom-studies. Rougher calculations may be based on the output of the roentgendiagnostic unit (PIZON, 1959). Instead of conversion factors depth-dose tables or formulae may also be used (PAPE & ZAKOVSKY, 1960; ZIELER, 1960).

It must be noted that most of the authors quoted above have combined the various methods to assess ovary doses.

When a method of gonad dose measurement had to be chosen for the present investigation several considerations were taken into account. Measurements on patients are inconvenient to busy roentgen departments. Even if only skin doses are measured the supervision of a physicist will usually be needed. A scheme such as that carried out by the ADRIAN COMMITTEE, where some 50 physicists together made some 14,000 skin dose measurements on patients, was not possible in the present investigation. Instead of some rather haphazard measurements on patients in one or a few hospitals a systematic study with the aid of a phantom was considered to be more worthwhile. A phantom was also essential for the assessment of bone marrow doses, which were measured in addition to the gonad doses. (The results of the bone marrow dose measurements will not be reported here). As was described in Chapter II and III the exposure techniques were studied in the hospitals, institutes and private offices in Leiden and Oegstgeest. The magnitude of the gonad dose as a function of the exposure technique was studied on a phantom. This phantom will be described in the next section.

For the measurements on a patient, cadaver or phantom most authors have used ionization chambers. In some instances film dosimetry can also be applied (BISHOP et al., 1959; MEYERS et al., 1959; BLATZ & EPP, 1961). For the present investigation various ionization chambers were constructed in the laboratory of the Netherlands Institute for Preventive Medicine *. Also various Philips chambers and P.T.W. (Physikalisch-Technische-Werkstätten, Freiburg, Germany) chambers were used. Some important properties of the chambers are listed in table XXII. The Philips ionization chambers were connected to a Philips Universal Dosemeter. The normal P.T.W. measurement equipment was substituted by a vibrat-

* Mr. J. Weber. — Netherlands Institute for Preventive Medicine (N.I.P.G.).

TABLE XXII

Ionization chambers used for the measurements in the phantom

Chamber type	H.V.L. range (less than 5% quality dependence)	approximate volume (cm^3)	used for measurement of:
Philips type 37480	1 mm Al — 4 mm Cu*	3	ovary dose testis dose
Philips type 37482	0.4 mm Al — 7 mm Al*	1	incident dose ovary dose
Philips type 37488	2 mm Al — 2 mm Cu	90	exit dose testis dose
P.T.W. Bomke chamber	4 mm Al — 10 mm Al	122	testis dose
P.T.W. catheter chamber	3 mm Al — 8 mm Al	0.016**	ovary dose bone marrow dose
N.I.P.G. catheter chamber	2 mm Al — 6.5 mm Al	0.3	ovary dose bone marrow dose
N.I.P.G. catheter chamber	2 mm Al — 9 mm Al	3.6	ovary dose

* Manufacturers calibration checked.

** The sensitive volume of this chamber was enlarged.

ing reed electrometer (Cary 31; A.P.C.) and a recorder (Honeywell). * All chambers were calibrated against the Dutch standard **, while special attention was paid to quality – and directional – dependence.

The P.T.W. chambers and the chambers constructed in the laboratory of the Institute for Preventive Medicine show some directional dependence. The magnitude of this depends on the radiation quality. In the diagnostic quality range (1st H.V.L. of 1 to 7 mm Al) the chambers are some 5 to 10 per cent less sensitive in the axial direction than in a radial direction. Deviations of about the same magnitude were found by SEELENTAG (1958a) for various P.T.W. chambers. The directional dependence was taken into due account in calibrating the chambers.

The influence of radiation quality on sensitivity was studied for all chambers in a H.V.L. range of 1 mm Al to 2.8 mm Cu. In the range of 2 to 7 mm Al (1st H.V.L.) the chambers used for the measurement of gonad doses show in general deviations of less than 5 per cent. Experiments have shown that the quality of side-scattered radiation, though influenced by the geometry, is usually lower than 7 mm Al (1st H.V.L.) for an incident beam quality of a 1st H.V.L. of at most 4 mm Al (SCHAAL, 1958). Measurements of radiation qualities in the primary beam (SCHAAL,

* Thanks are due to the Director of the Netherlands Institute for Preventive Medicine for the permission to work in the laboratory and to use the equipment.

** Mr. A. Somerwil. Radiotherapeutisch Instituut, Rotterdam.

1958, 1960; WEBER, 1961) show that the quality of X-rays generated below 90 kVp will not increase to a 1st H.V.L. of more than 7 or 8 mm Al after filtration by 20 cm of water. Thus the chambers that are indicated in table XXII are suitable for the present measurements of gonad doses inside and outside the primary beam, without the need of correction factors for radiation quality.

As is indicated in table XXII the incident dose (or skin dose in patients) was measured with a Philips chamber (type 37482 – volume about 1 cm^3). For this the chamber was placed in the centre of the incident beam on the surface of the phantom nearest to the roentgen tube. During the measurements the chamber was half immersed in surrounding presswood plates. The dose incident on the grid, or on the cassette ("exit dose") was measured with a Philips chamber type 37488. Testis doses were measured at the supposed place of the scrotum. For these measurements the Bomke- or Philips-scatter dose chambers cannot always be used. If during a roentgendiagnostic examination the testes lie partly inside the primary beam, or close to its edge, the shape and size of the chamber must be about the same as that of the testis (LARSSON, 1958). Thus for measurements in or near to the primary beam a Philips chamber type 37480 (volume about 3 cm^3) was used. In some instances the "ovary" doses were measured with a Philips chamber (type 37482 – volume about 1 cm^3), inserted in the "rectum" of the phantom up to the supposed place of an ovary (see section 2 of this Chapter). The ionization chamber was protected by a thin-walled perspex tube. However, during many roentgendiagnostic examinations the ovary doses are too low to be measured accurately with this Philips chamber. In a few instances type 37480 could be used, but the ionization chambers constructed in the Institute for Preventive Medicine proved to be most useful for this purpose. In combination with the Honeywell recorder the 3.6 cm^3 chamber is extremely sensitive and will measure accurately doses in the order of 0.1 mr.

2. THE PHANTOM

For the present investigation a phantom was constructed with materials that have approximately the same attenuation and absorption coefficients as those of the tissues of the human body. Theoretical considerations concerning tissue-equivalency and the details of the construction of the phantom will be published elsewhere. According to authorities on the subject (SPIERS, 1946; HARRIS et al., 1956; KROKOWSKI, 1957), for a phantom to be used in the low energy region tissue-equivalency can be acquired by using materials of the same effective atomic numbers and the same numbers of electrons per unit of volume as that of the human tissues to be simulated.

Water is a suitable and much used substitute for soft tissues. It is used

as such in the phantom constructed for the present investigation. The water is contained by a layer of 4 mm perspex (I.C.I.) moulded on plaster forms corresponding to the dimensions of a typical Dutch male. The phantom incorporates a male human skeleton, impregnated with natural beeswax and fixed together with an epoxy resin ("Araldit", C.I.B.A.). The vertebral disks and other cartilaginous parts, such as rib cartilages, are also moulded of "Araldit". The lungs are simulated by acetobutylate shells filled with a mixture of sawdust and polystyrene granules to a density of 0.35. The lung shells were formed on plaster moulds, shaped to fit the rib-cage of the skeleton and further shaped according to anatomical diagrams. The phantom thus was constructed according to the same pattern as that of MOHR et al. (1959) and that of the ALDERSON RESEARCH LABORATORIES INC. The latter phantom is commercially available.

The phantom consists of 7 parts: head, chest, abdomen and upper legs, two lower legs and two arms. It is shown in *figure II*. Several radiographs were made in order to check whether the radiographic image of the phantom approximates that of the human body. *Figure III* is a reproduction of a radiograph of the chest. In *figure IV* a radiograph of the pelvis is shown. In this figure also some ionization chambers are visible. These radiographs indicate that the construction of the phantom has been quite successful.

As the phantom was designed for gonad dose measurements as well as for bone marrow dose measurements it contains a large number of openings for insertion of ionization chambers. For the measurement of ovary doses an ionization chamber, protected by a perspex shell, was introduced into an opening at the place of the "anus". In anatomical textbooks the information about the position of the ovaries is scarce. Actually their position can differ considerably for different females and at various attitudes. In the literature various average ovary positions were indicated. WEBSTER & MERRILL (1957) measured ovary doses in their phantom at 8 cm above the symphysis, 4 cm aside from the mid line and 10 cm deep. BILLINGS et al. (1957) indicated 8.5 cm above the symphysis, 4.5 cm from the mid line and 9 cm deep, while LINCOLN & GUPTON (1958) measured at 11.5 cm above the symphysis, 4.5 cm from the mid line and 9 cm deep. HOLTHUSEN et al. (1961) measured near the anterior part of the linea terminalis, at 3.5 cm from the mid line and 9 cm deep. As the present phantom incorporates a male skeleton the distances quoted above seem not to be applicable. For this pelvis a place 2.5 cm above the symphysis, 2.5 cm from the mid line and 9 cm deep seems to be reasonable. The assumed position of the ovaries in the pelvis of the phantom are indicated by lead squares on *figure V*.

The testis dose was measured at 8 cm below the symphysis and 4.5 cm below the upper level of the thighs. It should be noted that the position of the scrotum also can vary considerably and is specially influenced by the

FIGURE II. Perspex-water phantom incorporating a human skeleton. X-ray tube and couch used for the dose measurements.

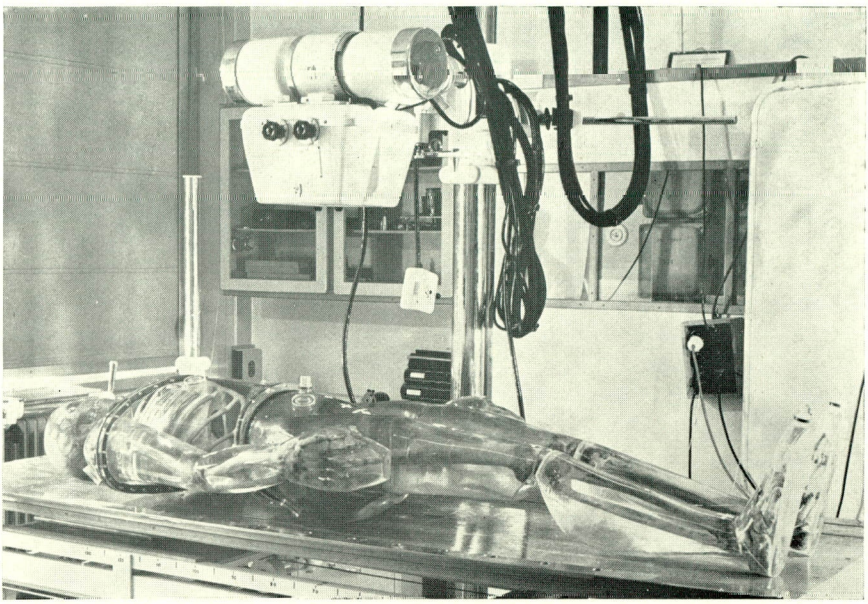


FIGURE III. Radiograph of the chest of the phantom. Bucky grid. 4-valve rectified unit, 88 kV, 2 mm Al added filter, 240 mAs, 150 cm T-F distance.

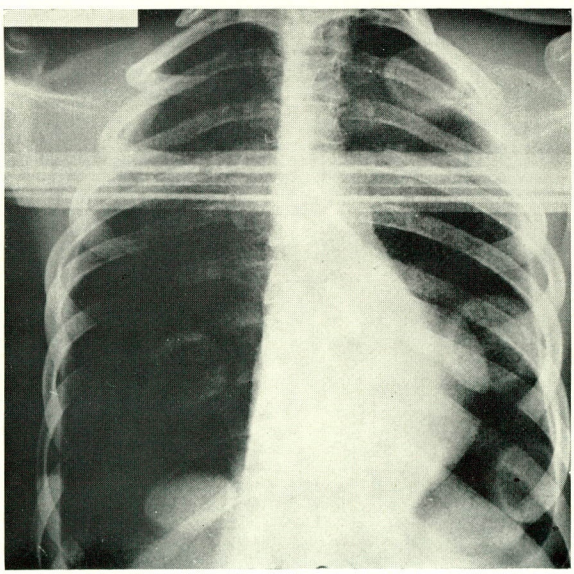


FIGURE IV. Radiograph of the pelvis of the phantom. Ionization chambers to measure incident dose, exit dose and ovary dose visible. Bucky grid. 4-valve rectified unit, 76 kV, 2 mm Al added filter, 250 mAs, 100 cm T-F distance.

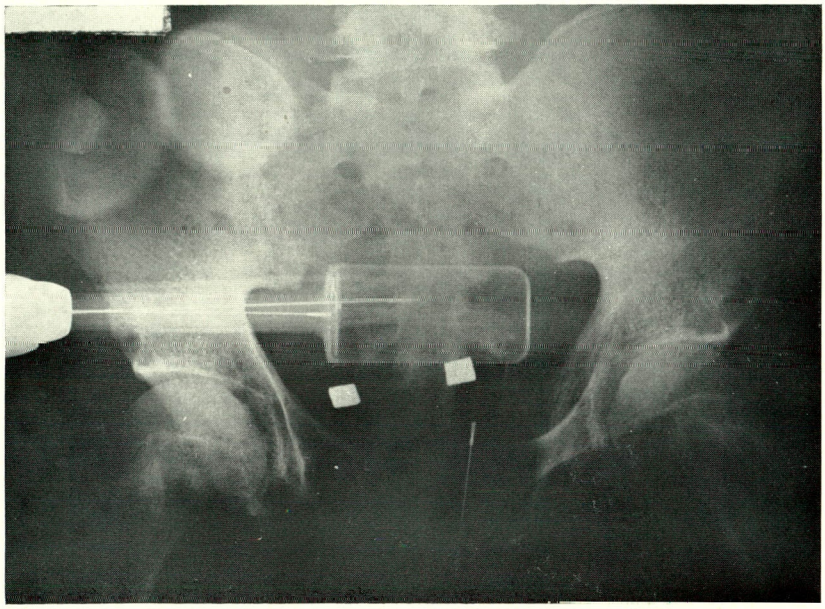
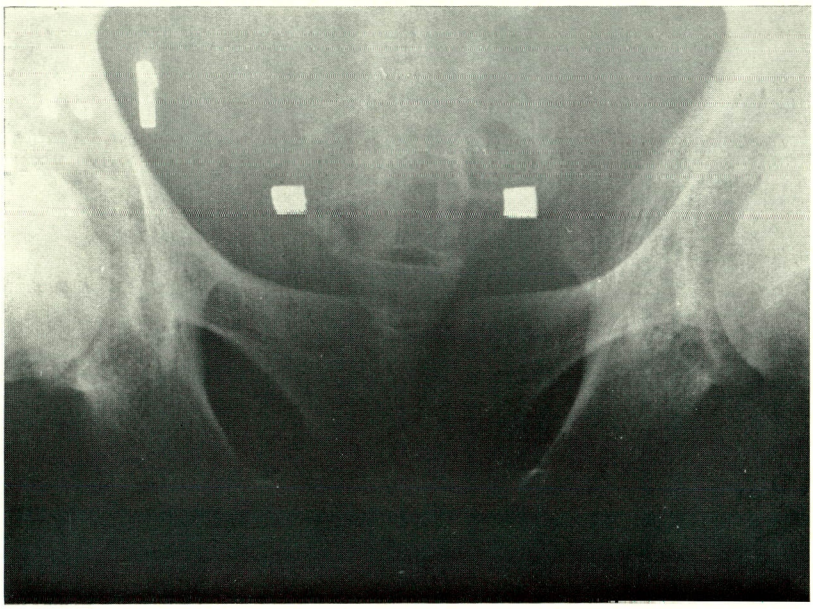


FIGURE V. Assumed position of the ovaries in the pelvis of the phantom indicated by lead squares.



attitude. In a lying position the testes can be covered and shielded by the medial parts of the thighs. In A.P. projections this can have an appreciable influence on the testis dose.

On the whole the phantom was found to be most suitable for studies on the influence of the radiographic technique on the magnitude of gonad doses. However, it must be kept in mind that only standardized techniques can be studied.

3. Dose measurements in the phantom

Most fundamental studies on doses inside and outside the primary beam have been made with water phantoms. A classical study of the influence of the energy of the primary beam on the amount of scatter outside the beam is that of Keane & Spiegler (1951). When the scatter dose values were expressed as percentages of the incident dose the scatter outside the beam was found to increase with increasing tube tension. However, when reference was made to the exit dose the percentage scatter dose decreased with increasing tube tension. The magnitude of this effect did depend on the geometry, i.e. on the position of the measuring point in relation to the edge of the beam. Evidently the amount of side scatter further did depend on the volume irradiated by the primary beam and thus on the size of the entrance field.

Haybittle (1957) made measurements at points inside and outside the primary beam and expressed the doses as ratios of the film dose. The influence of tube tension, filtration and field size was found to be small for a measuring point at the centre of the phantom in the primary beam. The relative doses due to side scatter also were not greatly influenced by tube tension and filtration, but the field size proved to be of major importance.

The amount of side scatter as a function of the tube tension and of filtration was also studied in great detail by Cen & Frik (1958). The results of their study seem to relate closely to the results of the study that will be described in the next section. Cen & Frik used a water phantom 40 cm square, and with a depth of 20 cm. The target-surface distance was 50 cm and the size of the exit field was 10 cm square. The doses outside the primary beam were determined at a great number of measuring points. They were expressed as a ratio of the exit dose. At all measuring points less than 4 cm deep the ratio of scatter dose to exit dose was found to decrease with increasing radiation quality. However, the relative scatter dose increased with increasing quality at a point 4 cm deep and 17.5 cm from the central axis. The deeper in the phantom, the nearer to the central axis this increase was demonstrated. At a depth of 17 cm the influence of radiation quality on the relative scatter dose was negligible. It was concluded that for a radiographic examination where the gonads

lie at some depth and at some distance from the edge of the primary beam the gonad dose may increase with increasing radiation quality. The results of some experiments of KLOTZ (1958), KLOTZ & SEELENTAG (1958) and SCHAAL (1959) support this conclusion. However, as was stressed by CEN & FRIK the above conclusion is only valid if, in actual practice, the exit dose can be used as a reference. This means that the same exit dose would have to result in the same diagnostic value of the radiograph at various radiation qualities. The diagnostic value of a radiograph is determined by film density, contrast and image definition. The influence of radiation quality or tube voltage on the density of radiographs of homogeneous phantoms can easily be studied. Experiments with homogeneous phantoms have shown that with increasing quality of the incident beam the cassette dose required to give a constant film density decreases. This is partly due to the lesser absorption in the cassette material (WIDENMANN, 1957) and partly to the higher sensitivity of the intensifying screens (FROMMHOLD, 1954; MATTSON, 1955; WIDENMANN, 1957). On the other hand the sensitivity of film emulsions to roentgen rays decreases with increasing radiation quality (MATTSON, 1955), but this effect is negligible if radiographs are made with intensifying screens. FRIK (1961) analysed the results of several investigators and concluded that, for a given cassette – screen combination, and at the same total beam filtration, the cassette dose at 120 kV need only be 50 per cent of that at 50 kV in order to obtain the same film density. If a grid is used the influence of radiation quality on the "grid factor" (the factor by which the dose incident on the grid must be multiplied to obtain the same cassette dose as without the use of a grid) must also be taken into account. FRIK (1961) presented factors by which the exit dose must be multiplied to give the same film density at voltages ranging from 90 kV and with and without grids respectively. These factors were calculated relative to the exit dose at 90 kV. At 100 kV the exit dose must be multiplied by a factor of about 0.9. At this voltage the influence of a grid on the magnitude of the correction factor is negligible. At 150 kV the correction factor is about 0.7 if no grid is used and considerably lower with a grid.

SCHAAL (1960) studied in a 5 and a 10 cm deep water phantom the influence of tube voltage and filtration on density as well as on contrast. He demonstrated that in the voltage range from 50 to 200 kV and with various added filters the film density varies less than 15 per cent for a constant exit dose. However, the contrast rapidly decreases with increasing quality of the incident and transmitted beam. This is of course a well known effect and has demonstrated before (WACHSMANN et al., 1952).

The image definition finally is shown to decrease with increasing voltage (BÜCKER et al., 1959). This is mainly due to increasing screen blurring.

The studies quoted above have been of great importance in planning the experiments with the inhomogeneous phantom used in the present

investigation. According to the results of CEN & FRIK (1958) the use of high radiation qualities for gonad dose reduction seems to be questionable. A further study on the influence of radiation quality on the magnitude of gonad doses was considered to be worthwhile. One of the most difficult points in this study was already mentioned above. If it can be assumed that at various radiation qualities the same exit dose, or dose incident on the grid or cassette, will give radiographs of about the same diagnostic value than the exit dose can be used as a reference. According to KEANE & SPIEGLER (1961) this is appropriate where "decrease in contrast at higher kilovoltage is not only tolerable but desirable". "Where any reduction in contrast cannot be tolerated comparison of scatter outside the beam for two techniques ought to be based on radiographs of equal contrast". According to these authors the ratio of incident dose to exit dose is a measure of contrast. They point out that reference can be made to the same contrast and film dose if the scatter dose is multiplied by $\frac{1}{\text{incident dose}}$.

These considerations somewhat clarify the situation but do not offer a simple solution to the problem of reference dose in experiments with inhomogeneous phantoms. One way to circumvent this problem is to express the scatter dose in mr per mAs integrated tube current. However, this method, followed amongst others by WOLFSON & GARRETT (1959) does not permit one to judge whether a given change in the radiographic technique results in higher or lower tissue doses. EPP et al. (1961) expressed bone marrow doses in mr per mAs but also tried to solve the reference dose problem in an interesting, though subjective way. They made chest radiographs of their phantom at various kV-filter combinations and with exposures ranging from 4 to 40 mAs in steps of about 15 per cent. The same type of cassette-screen-film combination was used in all instances, while the development technique was also kept constant. A radiologist evaluated the films and selected an "optimum film" for each kV-filter combination. Next the mAs values needed for "optimum films" were expressed as ratios relative to the value at 80 kVp and 2 mm Al added filtration. Though EPP et al. did not compare the exit doses needed for optimum films these can be calculated from their tables. It appears that the selected radiographs were made with approximately the same exit dose at 60 kVp and 80 kVp respectively and with 1 mm Al as well as with 2 mm Al added filtration at both tube tensions. However, at 100 kVp and 2 mm Al added filtration, and also at 120 kVp and 3 mm Al added filtration higher exit doses were needed to satisfy the radiologist. It is hardly possible to repeat this test for all types of radiographic examinations. During the present investigation a series of radiographs of the hip of the phantom was made at radiation qualities ranging from 1.0 to 4.3 mm Al (1st H.V.L.). The dose incident on the grid was kept constant.

The radiographs thus acquired seem to be subjectively comparable, that is if the differences in contrast are disregarded. It is not clear how the radiographs can be compared objectively. The film density cannot be compared as easily as that of radiographs of homogeneous phantoms; densitometry at various areas gives insufficient information. Also the difference between the highest and the lowest density on the radiographic image ("Bildumfang") can be measured. This difference however cannot serve as a direct parameter of the diagnostic value of the radiograph. As was indicated by SCHRÖCK-VIETOR (1958) autocorrelography may prove to be a reliable, objective method to study the technical quality (contrast and image definition) of a radiograph. More fundamental work seems to be indicated for the further development of this method.

The ADRIAN COMMITTEE (1960) studied the influence of radiation quality on gonad doses in an inhomogeneous phantom and stated that the exposures were adjusted to give identical radiographic density. As they pointed out, with increasing H.V.L. both the amount and penetration of scattered radiation increases and the sensitivity of film decreases. From the analysis of their survey data they concluded that the gonad dose increased in most examinations as the H.V.L. of the radiation increased beyond the range of 1.0—1.4 mm Al. The only exceptions were the lateral spine in males and the posterior-anterior chest. In its report the Committee did not explain these discrepancies. Also, it was not considered that in most radiographic procedures intensifying screens are used and that, in the diagnostic range, the sensitivity of film-screen-cassette combinations usually increases with increasing quality.

In a recent article ARDRAN & CROOKS (1962) discussed some of the interpretations of the Adrian Committee. These authors specially stressed the effects of leakage, off-focus radiation and filter scatter and stated: "when these factors are ignored male gonad doses outside the useful beam may be considerably increased". In their measurements ARDRAN & CROOKS kept constant the density in a specified area, i.e. in the abdominal region an area corresponding to the psoas muscle. In preliminary experiments they had found that this area is of fairly constant density when good quality films are obtained at various radiation qualities. However, the film dose (or rather cassette dose) needed to obtain good densities (0.8—1.0) in the specified area was shown to change relatively little in the range of 60 to 180 kVp.

It must be concluded that the problem of what parameter to use as a reference in varying the exposure technique is not completely solved. For the present investigation the dose incident on the cassette, or on the grid, was used as a reference. This dose was not corrected by a factor such as that indicated by FRIK (1961), as this correction was considered to be of little importance as long as contrast and image definition differences are neglected. However, as the method of measurement, which will be des-

cribed below, permits the expression of doses in mr per mAs, it was reasoned that recalculation would be possible if a better reference eventually became available.

The influence of radiation quality on the magnitude of gonad doses was studied for some 25 conventional radiographic views. Before a series of measurements started radiographs were first made with techniques normally used for the radiographic view under consideration. A 4-valve rectified roentgendiagnostic unit (Philips Medio D 100) was used for the exposures. The incident dose was measured at the centre of the entrance field. In addition the dose incident on the cassette, or on the grid, was measured at the centre of the exit field ("exit dose"). Next, when a radiograph of adequate blackening * was acquired, the exposure techniques were varied. Incident dose, exit dose and gonad doses were measured at various qualities of the incident beam. In order to record the gonad doses with sufficient accuracy high mAs exposures were frequently needed. The results of the measurements were finally corrected on the basis of the same exit dose for a given radiographic view at each radiation quality. For a few radiographic views the influence of field size, target-film distance and lead shielding of the testes was also studied. For studies on the influence of field size on the magnitude of scatter doses it is questionable whether the exit dose can be used as a reference (see p. 97). In all experiments the beam was restricted to cover adequately the film size specified in the measurements.

In a study on the influence of tube filtration and voltage on the magnitude of gonad doses in fluoroscopy the problem of reference dose is about the same as in radiography. The screen brightness may for instance be measured with the aid of a photomultiplier, as was done by ALBRECHT et al. (1959). These authors studied amongst other things the ratio of "fluorescence output" to the dose-rate incident on 11 to 23 cm thick homogeneous phantoms. When the entrance field was restricted to 8×8 cm, for the normally used zinc cadmium sulphate screens this ratio was found to vary about 10 per cent for tube voltages ranging from 100 to 180 kV and with added filtration of 0.2, 0.4 and 0.6 mm Cu successively. However, the screen brightness is very dependent on the size of the entrance field, while the dose-rate measured at the tubeside of the phantom is scarcely influenced by this. As a reference the exit dose-rate would seem more suitable than the incident dose-rate. As of course this dose-rate is not constant during fluoroscopy with a moving beam and an inhomogeneous phantom it can only be used when integrated over a

* The appreciation of this is somewhat subjective. According to SPIEGLER (1957), for exposures with medium speed intensifying screens, the film dose needed for optimal density is usually in the order of 5 mr. The exit dose must be higher than this of a grid is used. With a few exceptions, in our series the exit dose ranged from 5 to 11 mr.

given period. In experiments with homogeneous phantoms the ratio of screen brightness to exit dose was shown to decrease with increasing voltage (WACHSMANN et al., 1958; BÜCKER et al., 1959; BUCHHEIM & MAURER, 1959). Apart from the screen brightness the contrast and image definition also are of great importance. Little experimental work has been performed on image definition in fluoroscopy, that is if the work on image definition with image intensifiers (OOSTERKAMP & ALBRECHT, 1959) is not valued as such. In his experiments FROST (1957) demonstrated that the unsharpness caused by luminescent layers increases with tube voltage and also with total filtration. Experiments of FRIK & BUCHHEIM (1955) and FRIK (1961) have shown that the image definition of Landolt's rings in a 10 cm deep water phantom is practically constant for fluoroscopy in the range of 55 kV, 2 mm Al total filtration to 90 kV, 6 mm Al total filtration. However, the image definition rapidly decreases if the voltage is raised above 100 kV, no matter what added filtration is used.

Thus it seems that for tube voltages below 100 kV the screen brightness is the most important parameter when fluoroscopic techniques are to be compared. As suitable instruments to measure the brightness were not at the moment available to us we cannot yet present such a comparance. The results of the measurements that will be described in the next section therefore are presented as gonad doses in mr per mA-minute and also as gonad doses in mr per r incident dose.

Before the method of measurement of gonad doses during fluoroscopy is described it is stressed that in a phantom only the doses delivered during standardized techniques can be studied. Also the phantom is too heavy to be moved during fluoroscopic procedures, such as is normally done with the patient. However, during some radiological examinations fluoroscopy contributes the major part to the total gonad dose of both fluoroscopy and radiography (LARSSON, 1958). Thus, in order to assess the genetically significant dose, some gonad dose measurements during fluoroscopy of the phantom were considered to be necessary. Chest fluoroscopy was performed according to a scheme which is thought to represent the normal technique of fluoroscopy on a patient. First a large field (35 $\times$ 35 cm on the screen) was used during 30 seconds. Next the screening field was restricted to 15 $\times$ 30 cm during 30 seconds and to 15 $\times$ 15 cm during 60 seconds. During the last 90 seconds the beam was moved over the phantom. Approximately the same scheme was used for fluoroscopy of the lower gastrointestinal tract, i.e. screening during 30 seconds with a large stationary field (35 $\times$ 35 cm) and during 90 seconds with a moving small field (15 $\times$ 15 cm on the screen). Fluoroscopy of the stomach was simulated with a stationary screening field of 24 $\times$ 30 cm during 30 seconds and a stationary field of 8 $\times$ 10 cm during 90 seconds. In all instances the target-"skin" distance was 45 cm and the target-screen

distance was 75 cm. The measurements were carried out with an ionization chamber fixed at the place of the testes or an ovary and connected to the vibrating reed electrometer. Via the recorder a curve of the dose-rates during the fluoroscopy was obtained. Measurements were made at 5 different kV-filter combinations and at a tube current of 3.2 to 3.4 mA.

The results of the study of the influence of radiation quality on gonad doses will be presented in the next section. A few examples of the influence of field size, target-film distance and lead shielding of the testes will be used in Chapter VII to illustrate the methods of gonad dose reduction in diagnostic radiology.

4. Gonad doses as a function of radiation quality

The quality of roentgen radiation as used in diagnostic radiology is usually expressed as the first half value layer in aluminium. The inhomogenity of the radiation can be indicated by the ratio of the 2nd half value layer to the 1st half value layer. Radiation of a given 1st half value layer may be produced at different combinations of tube tension and beam filtration. According to Oliver & Kemp (1949) and Cohen (1955) the way in which a given radiation quality is acquired does not appreciably influence the depth dose curves. Also the sensitivity of various condenser chambers is not much influenced by this (Procter & Greening, 1960). Nevertheless, it is felt that in describing experiments on the magnitude of tissue doses as a function of radiation quality, the kV-filter combinations used should be stated. During the present investigation the gonad doses delivered during radiographic procedures were usually measured at 5 different kV-filter combinations, as are indicated in table XXIII. Due to the deposition of tungsten on the tube window the inherent tube filtration, which was originally about 1 mm Al-equivalent, increased somewhat during the course of the experiments. As a result the radiation qualities where not wholly constant. In table XXIII are indicated the 1st and 2nd H.V.L.'s measured in the primary beam before and after the series of gonad dose measurements. The mean values were used in the tables and curves, which indicate the influence of radiation quality on the magnitude of gonad doses.

As has already been stated, the comparative assessment of incident doses and gonad doses at various radiation qualities during radiography was based on a constant exit dose. The exit dose was measured with a Philips ionization chamber (type 37488) at the centre of the cassette or the grid. The exit dose needed for a radiograph of adequate blackening may differ considerably for various radiographic views. This is partly due to the subjective appreciation of what can be considered to be adequate blackening. Another factor is the relatively small size of the ionization chamber used to measure the exit doses.

TABLE XXIII

kV-filter combinations and radiation qualities (radiography)
4-valve rectified unit (Philips Medio D 100)
inherent tube filtration: ca. 1 mm Al-equivalent *

nominal tube tension (kVp)	added filtration (mm Al)	1st H.V.L. (mm Al) before-after	2nd H.V.L. (mm Al) before-after
52	none	1.0—1.0	1.4—1.5
68	1	2.0—2.0	3.0—3.1
83	1	2.5—2.6	4.0—4.4
85	2	3.1—3.3	4.9—4.8
83	1 + 0.1 mm Cu	4.1—4.6	5.7—5.7

* The inherent tube filtration increased slightly during the measurements.

As has been found by many investigators before, the magnitude of the incident dose (or the skin dose in patients) is greatly influenced by the quality of the incident beam. However, the influence of radiation quality on the magnitude of gonad doses can be expected to be quite different for various radiographic views. In table XXIV and XXV the variation of the incident dose and gonad doses is exemplified for A.P. radiographic views of the pelvis and the femur respectively. For both radiographic views a striking reduction of the incident dose is found when the radiation quality is changed from 1.0 to 2.0 mm Al (1st H.V.L.). At higher qualities the incident dose is further reduced but the magnitude of the reduction becomes gradually smaller. The incident dose shows essentially the same trend for all radiographic views that were studied.

For the radiographic views in table XXIV and XXV the influence of quality on the magnitude of testis doses shows the same trend as that found for the incident doses. However, for the two examples given the

TABLE XXIV

Influence of radiation quality on incident dose and gonad doses

Radiographic view: Pelvic region A.P. stationary grid: ratio 4.3 : 1, 55 lines/inch

size of film: 30 × 40 cm target-film distance: 100 cm

1st H.V.L. (mm Al)	mAs	exit dose (mr)	incident dose (r)	testis dose (mr)	ovary dose (mr)
1.00	1345	6.5	9.3	220	160
2.00	299	6.5	2.4	97	129
2.55	113	6.5	1.4	67	110
3.20	115	6.5	1.1	61	107
4.35	139	6.5	0.8	51	106

TABLE XXV

Influence of radiation quality on incident dose and gonad doses

Radiographic view: Femur A.P. (middle and lower third) stationary grid: ratio 4.3 : 1, 55 lines/inch

size of film 15 × 40 cm target-film distance: 100 cm

1st H.V.L. (mm Al)	mAs	exit dose (mr)	incident dose (r)	testis dose (mr)	ovary dose (mr)
1.00	297	11.8	2.0	54.4	0.73
2.00	107	11.8	0.8	35.6	1.28
2.55	50	11.8	0.6	30.6	1.52
3.20	53	11.8	0.5	27.7	1.58
4.35	74	11.8	0.4	25.3	1.69

influence of radiation quality on the magnitude of ovary doses is distinctly different. This will be studied in more detail in table XXVII and *figure VII*.

For further analysis the testis doses and the ovary doses are to be considered separately. In table XXVI the major results of the testis dose measurements are presented. In this table the radiographic views are arranged according to decreasing testis dose per film in the first column (radiation quality: 1 mm Al). It is realised that for a number of radiological views, such as that of the lumbosacral spine, the gonad doses at a H.V.L. of 1 mm Al have no practical application. At this radiation quality the exit dose needed for an adequatly blackened radiograph of the lumbosacral region can only be acquired at an unduly high mAs and thus with extremely long exposure times. As is evident from table XXVI the range of testis doses for various radiographic views is very great. The testis dose for a radiograph of the hip and the upper part of the femur is some 2×10^4 to 5×10^4 times the testis dose measured for a P.A. view of the chest. For nearly all radiographic views studied the testis dose decreases with increasing radiation quality. In general, it can be said that the pattern of this decrease is approximately the same as that found for the incident dose. The major decrease is found when the quality is changed from 1 to 2 mm Al. Although in all these radiographic views the lowest testis dose is found at the highest radiation quality used (with two exceptions, see below) it is suggested that further decrease of the testis dose at higher qualities may be small or indeed negligible. A distinctly different pattern was found for two radiographic views: the lateral views of both the lumbosacral region and the lumbar spine. Here the testis dose increases with increasing radiation quality. It is conceivable that this increase is related to the lateral position of the patient. This point will be considered again below. To illustrate some typical results of the testis dose

FIGURE VI: Testis dose as a function of radiation quality

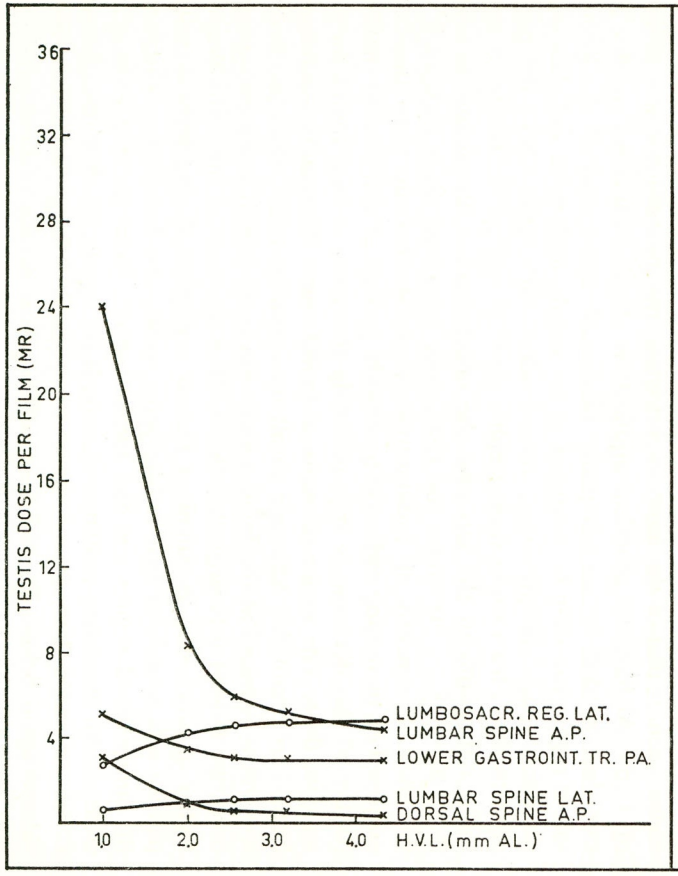


FIGURE VII: Ovary dose as a function of radiation quality

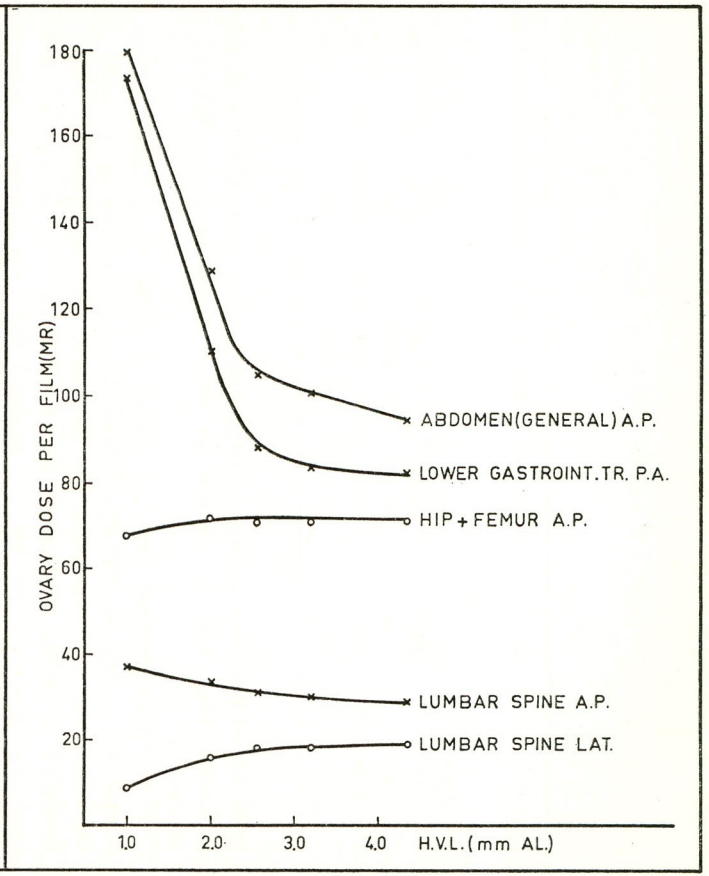


TABLE XXVI

Testis dose as a function of radiation quality
Radiographic views arranged according to decreasing testis dose

Radiographic view		Classification No.	Size of film (cm²)	Testis dose per film (mr)			
				H.V.L. (mm Al)			
				1.00	2.00	3.20	4.35
Hip and femur (upper third)	A.P.	1	24×30	2402	874	498	400
Pelvic region	A.P.	3	30×40	220	97	61	51
Cystography	P.A.	9	24×30	203	92	64	55
Abdomen (general)	A.P.	13	30×40	194	68	39	35
Lumbosacral region	A.P.	4	24×30	57	18	12	11
Femur (middle + lower third)	A.P.	2	15×40	54	36	28	25
Lumbar spine	A.P.	5	24×30	24	8.3	5.3	4.4
Lower gastroint. tract	P.A.	14	35×35	5.1	3.5	3.1	3.0
Dorsal spine	A.P.	6	30×40	3.1	0.93	0.55	0.45
Lumbosacral region	LAT.	4	24×30	2.7	4.3	4.7	4.8
Stomach and duodenum	P.A.	15 b	24×30	0.92	0.49	0.42	0.41
Lumbar spine	LAT.	5	24×30	0.59	0.92	1.12	1.14
Gallbladder	P.A.	16	18×24	0.39	0.35	0.36	0.34
Shoulder	A.P.	18	24×30	0.39	0.29	0.22	0.19
Dorsal spine	LAT.	6	30×40	0.34	0.27	0.22	0.21
Head	A.P.	21 a	24×30	0.23	0.19	0.19	0.18
Chest	LAT.	17 b	35×35	0.22	0.18	0.15	0.14
Lower leg	A.P.	20	15×40	0.15	0.13	0.13	0.12
Cervical spine	A.P.	21 b	18×24	0.082	0.068	0.068	0.064
Chest	P.A.	17 b	35×35	0.049	0.024	0.021	0.017

measurements the testis doses for a few examinations are plotted in relation to radiation quality in *figure VI.*

In table XXVII the results of ovary dose measurements are presented in the same way as was done for testis dose measurements in table XXVI. The range of ovary doses is about as large as that of testis doses. However, comparison of both tables shows that the highest ovary dose is about a fourth of the highest testis dose. For those examinations where the testes and the ovaries lie in the primary beam the testis dose can be almost as high as the incident dose, while the ovary dose always will be considerably lower than that. On the other hand, when the beam is restricted adequately the testes very seldom need to lie in the primary beam, while the ovaries are included in the primary beam in nearly all examinations of the abdomen and of the lumbosacral and pelvic regions. Thus it is understandable that the exposure of the ovary is relatively high in a great number of radiographic views. When both ovaries lie in the primary beam (first 6 radiographic views in table XXVII) the ovary dose is found to decrease with increasing radiation quality. The dose to the left and the

TABLE XXVII

Ovary dose as a function of radiation quality
Radiographic views arranged according to decreasing ovary dose

Radiographic view		Classification No.	Size of film (cm²)	Ovary dose per film (mr)			
				H.V.L. (mm Al)			
				1.00	2.00	3.20	4.35
Cystography	P.A.	9	24×30	637	380	281	267
Lumbosacral region	A.P.	4	24×30	504	260	178	170
Hysterosalpingography	P.A.	11	24×30	411	258	164	159
Abdomen (general)	A.P.	13	30×40	180	129	101	95
Lower gastroint. tract	P.A.	14	35×35	174	111	84	83
Pelvic region	A.P.	3	30×40	160	129	107	106
Hip and femur (upper third)	A.P.	1	24×30	68	72	71	72
Lumbosacral region	LAT.	4	24×30	63	93	93	96
Lumbar spine	A.P.	5	24×30	37	34	30	29
Lumbar spine	LAT.	5	24×30	8.5	16	18	19
Stomach and duodenum	P.A.	15 b	24×30	3.5	4.4	4.7	4.9
Dorsal spine	A.P.	6	30×40	1.9	1.8	1.8	2.0
Gallbladder	P.A.	16	18×24	1.8	2.6	3.1	3.1
Femur (middle + lower third)	A.P.	2	15×40	0.73	1.3	1.6	1.7
Dorsal spine	LAT.	6	30×40	0.19	0.22	0.25	0.24
Chest	LAT.	17 b	35×35	×	0.062	0.096	0.095
Chest	P.A.	17 b	35×35	0.018	0.017	0.022	0.023
Lower leg	A.P.	20	15×40	×	0.019	0.030	0.031
Shoulder	A.P.	18	24×30	×	0.018	0.027	0.027
Head	A.P.	21 a	24×30	×	0.014	0.026	0.030
Cervical spine	A.P.	21 b	18×24	×	0.003	0.007	0.008

× Dose too small to be measured in these series.

right ovary respectively differ much in lateral views of the lumbosacral region and the lumbar spine and in the A.P. view of the hip and upper femur. In these instances the mean ovary dose increases with increasing radiation quality. In the quality range of 2.00 to 4.35 mm Al, which is generally used in actual practice, this increase is very slight or indeed negligible. If correction factors for cassette-screen response (see p. 62) were applied probably no increase would be found at all. For radiographic views where both ovaries are exposed to scattered radiation only, the ovary dose is also highest at the highest quality used. The increase of ovary doses with quality is usually slight, but may be quite considerably in examinations with a very low ovary dose. Some of the results of the ovary dose measurements are plotted in *figure VII*.

On the basis of the results of the measurements described above it can be concluded that the increase of radiation quality in radiography will

usually result in a decrease of testis doses, but may give higher ovary doses in those instances where one or both ovaries lie outside the primary beam. In the quality range of 2.00 to 4.35 mm Al this increase is usually slight. Two factors are of importance for the influence of radiation quality on the magnitude of gonad doses in radiography. With the increase of radiation quality the ratio of incident dose to exit dose decreases such that for the same exit dose a lower incident dose is needed. This will result in relatively lower depth doses and less scattered radiation. However, with the increasing quality of the incident radiation the quality of scattered radiation also increases. Inside the primary beam the first effect may be expected to outweigh the second effect. This was shown in many experiments, of which several were quoted in the preceding section. As was found by CEN & FRIK (1958) and by KLOTZ & SEELENTAG (1958), outside the primary beam the ratio of scatter dose to exit dose may increase with increasing quality of the primary radiation. This must be the result of the second effect outweighing the first. It is conceivable that the effect of higher qualities of scattered radiation is only apparent when measurements are made at a certain depth of scattering medium. This may explain why, in general, the testis dose does not increase with increasing quality of the primary radiation, but does increase when the testes are shielded by the upper leg in a lateral position.

The influence of radiation quality, or of a number of kV-filter combinations, on the magnitude of incident doses and gonad doses was discussed above. A given increase of radiation quality may be acquired by an increase of tube tension, by an increase of beam filtration or by a combination of both. As was stated before, the way in which a given radiation quality is acquired is not expected to influence the depth doses to an appreciable extent. However, from the point of view of dose reduction it may be of interest to study how much filtration must be added to influence incident dose and gonad doses to the same extent as does a given increase of tube tension. A great set of curves would be required for a complete study on the equivalency of beam filtration and tube tension from the dose point of view. In order to outline the problem the influence of kV and filter was studied in a restricted range and for the A.P. radiographic view of the pelvic region only. To study the influence of tube tension the peak voltage was increased from 46 to 95 kV in steps of about 10 kV. No filtration was added. Incident dose, testis dose and ovary dose were recorded, while the comparison of doses was again based on a constant exit dose (6.5 mr in this case). The results of these measurements are plotted in *figure VIII*. The relation between peak voltage and ovary dose appears to be roughly linear. The greatest decrease of incident dose and testis dose is found in the lower voltage range. In the range from 78 to 95 kVp the incident dose decreases by 36 per cent, the testis dose by 27 per cent and the ovary dose by nearly 14 per cent. Next, the influence

FIGURE VIII. Influence of peak voltage on incident dose and gonad doses. Pelvic region A.P. No added filtration.

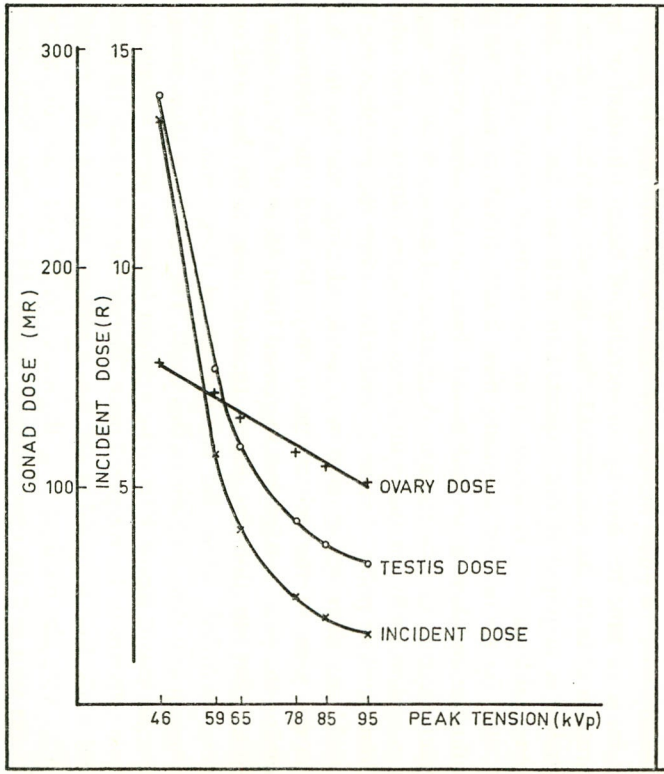
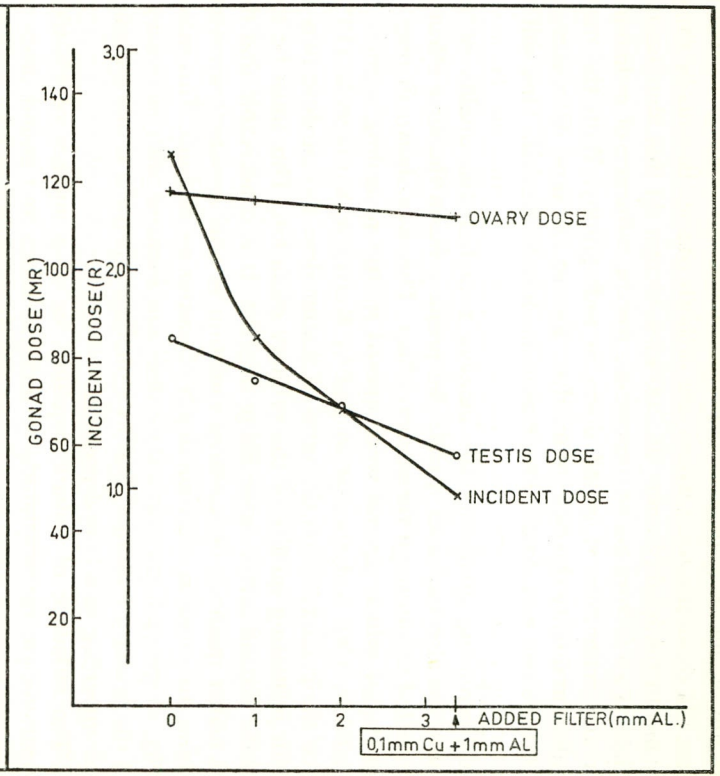


FIGURE IX. Influence of beam filtration on incident dose and gonad doses. Pelvic region A.P. 78 kVp.



of filtration was studied at 78 kVp and with 0, 1 and 2 mm Al and 0.1 mm Cu + 1 mm Al* successively. The results of these measurements are plotted in *figure IX*. In the filtration range studied the incident dose decreases by 60 per cent, the testis dose by 32 per cent and the ovary dose by only 5 per cent. Thus in the case of the A.P. view of the pelvic region and at 78 kVp an added filter of 0.1 mm Cu + 1 mm Al is more effective to reduce incident dose and testis dose, but less effective to reduce the ovary dose than is an increase of tube tension by 17 kV. Evidently, as could be expected, beam filtration has little influence on ovary doses and much more influence on doses to the more superficial tissues, such as the skin and the testes. This conclusion may be expected to be generally valid for other radiographic views.

The question may arise whether the results of the measurements, as described above, carry any practical consequences regarding dose reduction in diagnostic roentgenology. If gonad doses alone were to be reduced perhaps for a number of radiographic views low radiation qualities should be advocated. However, as is pointed out in Chapter VII, the magnitude of other tissue doses, such as the bone marrow dose and the integral dose, should also be considered. Sufficient information is not yet available about the influence of radiation quality on these doses. Thus a definite answer cannot yet be given to the question what radiation quality is most favourable from the point of view of doses to all important body tissues. At any rate the possible slight increase of gonad doses with quality does not seem to carry much weight in this connection (FRIK, 1961).

As was described in section 3 of this Chapter gonad doses were also measured in the phantom during fluoroscopy. For this a fixed field sizes-time scheme was used and measurements were made at 5 different kV-filter combinations. The kV-filter combinations are noted in Table XXVIII, together with the radiation quality (1st and 2nd H.V.L.) and the output in r per mA-minute at 45 cm from the target (incident dose-rate).

In Table XXIX the gonad doses measured during fluoroscopy of the chest, the "stomach" and the abdominal region ("lower gastro-intestinal tract") respectively are expressed in mr per mA-minute. In all instances the ovary dose is higher than the testis dose. As during fluoroscopy of the lower abdomen the ovaries may lie in the primary beam, in this case the ovary dose per mA-minute is some 20 times the testis dose. During

* This filter was also used in the preceding experiments. The slit for the insertion of filters between tube window and diaphragm is too narrow to permit the insertion of more than 2 mm Al. To be able to plot figure IX it was considered that for X-rays generated at 78 kVp the ratio of the linear absorption coefficients of Cu and Al would range from 12.6 (80 keV) to 36.9 (20 keV). As the maximum intensity of the X-ray spectrum generated at 78 kVp lies at about 50 keV, the ratio of the absorption coefficients at this energy (23.5) was used. According to this at 78 kVp 0.1 mm Cu is equivalent to 2.35 mm Al.

TABLE XXVIII

kV-filter combinations, radiation qualities and output (fluoroscopy)
4-valve rectified unit (Philips Medio D 100)
inherent tube filtration : ca. 1 mm Al-equivalent

nominal tube tension (kVp)	added filter (mm Al)	1st H.V.L. (mm Al)	2nd H.V.L. (mm Al)	output at 45 cm (r / mA-min.)
67	none	1.2	2.0	0.90
76	1	2.3	3.4	0.79
76	none	1.4	2.4	1.28
86	2	3.4	4.8	0.85
86	none	1.6	3.1	1.58

fluoroscopy of the stomach and the chest the ovaries will normally lie outside the primary beam, but much nearer to its edge than the testes. The difference between the ovary dose and the testis dose is very large for stomach examinations and still significant for chest examinations. The gonad doses in mr/mA-minute at 86 kVp without added filtration are about 3 times the doses at 67 kVp without added filtration.

This shows that the use of relatively high tube voltages in fluoroscopy is only justified if the tube current is sufficiently reduced. In the example quoted a reduction of the mA by a factor 3 is needed to give approximately the same gonad doses. The influence of added filtration can be studied by comparing table XXVIII and XXIX. An added filter of 1 mm Al at 76 kVp reduces the output in mr per mA-minute by 39 per cent, while 2 mm added filtration reduces the output at 86 kVp by 46 per cent. The influence of added filtration on the gonad dose per mA-minute is much slighter, the reduction varying from 0 to 28 per cent. At any rate the use

TABLE XXIX

Gonad doses during fluoroscopy, in mr per mA-minute

type of fluoroscopy	67 kVp no added filter	76 kVp 1 mm Al filter	76 kVp no added filter	86 kVp 2 mm Al filter	86 kVp no added filter
abdomen ("lower gastroint.tr.")					
testis	1.03	1.88	2.17	2.94	3.69
ovary	20.3	33.9	37.0	53.5	61.5
"stomach"					
testis	0.09	0.19	0.23	0.37	0.37
ovary	4.0	7.2	8.7	11.4	13.9
chest					
testis	0.013	0.021	0.021	0.031	0.043
ovary	0.022	0.032	0.037	0.062	0.065

of some added filtration in fluoroscopy can be advocated as both incident dose and gonad doses are thus reduced. Presumably other tissue doses will also be reduced, though perhaps to a very small amount (see Chapter VII). It is difficult to indicate the optimum amount of added filtration. In general it can be said that the filter must not be so thick that the tube current is raised in order to obtain sufficient screen brightness.

In Table XXX the gonad doses during fluoroscopy of the phantom are expressed in mr per r incident dose and are tabulated according to the radiation quality. The ratio of gonad dose to incident dose does not increase regularly with radiation quality. In influencing this ratio 10 kV is about equivalent to 1 mm Al, but 1 mm Al has much more influence on radiation quality than has 10 kV.

TABLE XXX

Gonad doses during fluoroscopy, in mr per r incident dose

type of fluoroscopy	1st H.V.L. of the incident beam				
	1.2	1.4	1.6	2.3	3.4
	67 kV no filter	76 kV no filter	86 kV no filter	76 kV 1 mm Al	86 kV 2 mm Al
abdomen ("lower gastroint.tr.")					
testis	1.14	1.70	2.33	2.38	3.46
ovary	22.6	29.0	38.9	42.8	62.9
"stomach"					
testis	0.10	0.18	0.23	0.24	0.43
ovary	4.4	6.8	8.8	9.1	13.4
chest					
testis	0.014	0.017	0.027	0.027	0.036
ovary	0.024	0.039	0.041	0.041	0.073

The results of the measurements of gonad doses during radiography and fluoroscopy are used in the next Chapter to calculate the genetically significant dose. For this the information collected and the measurements made during the survey of roentgendiagnostic units (Chapter III) are used to define the techniques used in actual practice.

CHAPTER VI

CALCULATION OF THE GENETICALLY SIGNIFICANT DOSE

1. Method of calculation

As is described in Chapter II, section 1, the method indicated in the U.N.S.C.E.A.R. Report (1958) is used for the present calculation. In the U.N.S.C.E.A.R. Report the basic equation was simplified considerably to give the equation used for the calculation of the genetically significant dose in a number of countries. The simplified equation is as follows:

$$D_j^* = d_j^* \cdot \frac{N_j^*}{N} \cdot \frac{w_j^*}{w}.$$

For the explanation of the equation the reader is referred to page 14 and 15. To derive this formula it was assumed that for a given radiological examination the mean gonad dose would be the same for all age classes. It may be questioned whether this assumption is justified.

Hartung (1959) studied gonad doses in pediatric diagnostic radiology and based his conclusions on about 3000 measurements, mainly on male children of various ages. This author found that in general the testis doses in children below the age of 1 year are twice as high as those in elder children. Doses in pediatric radiology were also discussed by Miller (1953) and Lössl (1957). The latter author assessed ovary doses in small children on the basis of abdominal skin dose measurements. He calculated that in fluoroscopy of the chest the ovary dose in a three months old child may be 16 times that in a 7½ years old child. As his measurements are few and only concern fluoroscopy this tremendous difference needs not carry much weight. Tubiana (1958) stressed that in pediatric radiology the gonads of children are only too often unnecessarily included in the primary beam. This author presented curves that can be used to assess the gonad doses in children if the distance of the gonads to the edge of the primary beam and the magnitude of the entrance dose are known. These curves are mainly based on experiments on phantoms. Thurau & Distel (1961) measured gonad doses in male children between 0 and 16 years of age. They were able to demonstrate that in radiography of the chest, the hands and the lower legs, the gonad dose is independent of age. The distance of the gonads to the edge of the primary beam may be small in young children, but the exposure dose needed for adequate radiography also is relatively small. For radiographs of the skull the gonad

dose decreases significantly with increasing age, but for instance in radiography of the pelvis the testis dose is higher in elder children than in younger children. Measurements on a phantom showed that in chest radiography the gonad dose in young girls is about twice as high as that in boys of the same height. In adults the gonadal exposure during radiography of the chest differs less for males and females (see tables XXVI and XXVII).

In Leiden and Oegstgeest (1959) children below the age of 5 make up 3.8 per cent, and children below the age of 10 make up about 7 per cent of all persons examined. Though these children have relatively high child-expectancies, it appears that no gross errors will probably be made when the gonad doses are assumed to be uniform for all age classes.

2. Data used for the calculation

In the foregoing Chapters the data collected during the present investigation have been described in detail. They have already been partly presented in the form they will be used for the calculation of the genetically significant dose.

The figures for $\frac{N_j^*}{N}$ are derived from the analysis of the frequency of roentgendiagnostic examinations in Leiden and Oegstgeest, 1959 (see Chapter IV). The contributions to the genetically significant dose are calculated separately for males, females and foetuses. $\frac{N_j^*}{N}$ is calculated by division of N_j^* (the annual number of individuals of either sex, of the population concerned, subjected to a class j exposure) by N (the total number of individuals in the population under consideration). For this population N amounts to 109041 (see p. 47). No allowance was made for the number of foetuses. The figures for N_j^* can be derived from table XII, that is as far as males and females are concerned. For the assessment of the number of foetuses exposed during roentgendiagnostic examinations of the pregnant mother an approximate calculation must be made. In Leiden in 1959 19084 women in the fertile age (15 to 40 years) had together 1791 live-born children. This means that 9.4 per cent of the women in this age group was pregnant in 1959, that is if no allowance is made for the durance of pregnancy. If no restrictions were made of roentgendiagnostic examinations of pregnant women then the number of foetuses exposed is about 9 per cent of the number of examined females in the age of 15 to 40 years. In hysterosalpingography no foetus is supposed to be irradiated. Further, it may be assumed that the women subjected to obstetrical abdominal radiography will, in the average, give birth to one live child. Admittedly this calculation of the number of foetuses exposed is quite rough. However, as will be seen, the contribution of foetal

exposure to the total genetically significant dose is small and will still be small even if the number of foetal exposures were twice as large.

As has been discussed before, relative child-expectancy data ($\frac{w_j^*}{w}$) are calculated by division of w_j^* (future number of children expected by the average individual of the specified sex, subjected to class j exposure) by w (future number of children expected by the average individual of the population under consideration). The child-expectancy data were calculated on the basis of childbirth data of the population of Leiden during the years 1954—1959 and from life tables for the Netherlands, 1951—1955. Together with the data on the percentage distribution of roentgendiagnostic examinations in age groups these childbirth data permit the calculation of w_j^*. For the population concerned w was established at 1.394 (see p. 51). The figures for $\frac{w_j^*}{w}$ are presented in table XVIII. As is discussed on p. 50 some assumptions had to be made to correct for abnormal child-expectancies of women subjected to hysterosalpingography or obstetrical abdominal radiography. The average subsequent child-expectancy of a foetus (W) can be calculated on the basis of the average child-expectancy of a new-born child (w_o), this being 2.576 for male children and 2.553 for female children of the population concerned. In the Netherlands in 1960 out of 1000 live-born children 512 were males (C.B.S., 1960). Thus it can be calculated that W amounts to 2.565 and $\frac{W}{w}$ to 1.840. As only live-born children are taken into consideration in the calculations no corrections for prenatal death have to be made.

The figures for d_j^* are mainly derived from dose measurements in the phantom. As is described in Chapter V a study was made of the gonad dose as a function of radiation quality in 22 conventional radiographic views. The exposure techniques normally used for the various types of examinations were noted during the survey of roentgendiagnostic tubes in the area investigated. The radiation qualities used for all types of examinations with the surveyed roentgendiagnostic units were assessed, based on the collected data regarding tube voltage and total amount of filtration. For this standard curves showing the relation between radiation quality, total filtration, tube voltage and wave-form (REINSMA, 1960a) were used (see p. 33). Next, the curves indicating the influence of radiation quality on the gonad doses (see for instance *figures VI* and *VII*) were used to assess the gonad doses in the various types of examinations, performed with each of the roentgendiagnostic units surveyed. The final average gonad doses per examination were calculated by weighting the doses to the number of examinations per roentgendiagnostic unit. Some

remarks have still to be made about the calculation of these weighted averages:

a. In all instances it was assumed that the beam had been restricted to the normally used film size. Therefore the gonad doses must be considered as those, given at good techniques as far as field restriction and alignment are concerned.

b. Lead gonad shields were found in regular use in a few clinics only. The effect of gonad shielding therefore has been neglected.

c. The influence of radiation quality on the magnitude of gonad doses was studied on the phantom for a limited number of radiological views. As hips and shoulders of the phantom are not movable it was not possible to study lateral views of the hip, the femur and the shoulder. Only A.P. views were studied in the case of examinations of the head, the cervical spine and the lower leg. For the assessment of gonad doses for these examinations the A.P. and LAT. views were assumed to give equal gonad doses.

d. For the oblique views of the lumbosacral region the gonad doses were taken to be the average of that of the A.P. and LAT. views respectively. For the oblique views of the bladder the gonad doses were taken as equivalent to those measured for a P.A. view.

e. For intravenous and retrograde urography the doses per film were taken as equivalent to those measured at A.P. radiography of the abdomen.

f. To estimate the ovary dose during an obstetrical abdominal examination an attempt was made to simulate the shape of the abdomen of a woman in late pregnancy. Measurements were made on the phantom while its abdomen was covered by an additional amount of bolus material (paraffin with 10% SiO_2, HARRIS et al., 1956).

g. Data on fluoroscopy times were not collected during the present investigation in Leiden and Oegstgeest. Mean fluoroscopy times during examinations of the stomach, the lower gastrointestinal tract and the chest were derived from figures published by BEEKMAN & KRUIZINGA (1961). These figures were based on 1096 fluoroscopic examinations at St. Bonifatius' Hospital, Leeuwarden. The mean fluoroscopy times at that hospital were:

1. Lower gastrointestinal tract : 2.3 minutes
2. Stomach and duodenum : 4.2 minutes
3. Chest; fluoroscopy only : 0.5 minutes (see also DRION et al., 1961)
4. Chest; fluoroscopy followed by radiography : 1.3 minutes.

h. As the gonad doses delivered during fluoroscopy do not increase regularly with radiation quality (p. 77; table XXX) calculations based on radiation quality and incident dose-rate were considered to be not wholly reliable. Therefore these doses were also assessed on the basis of the collected data regarding kV and mA, used at the various roentgendiagnostic units. However, both methods of assessment yielded nearly equal average gonad doses. The mean results were taken to be the most probable values for the gonad doses during fluoroscopy.

i. In the phantom no measurements were made during photofluorography of the chest. Figures for gonad doses due to this type of examination were derived from STANFORD & VANCE (quoted by the ADRIAN COMMITTEE, 1959, 1960).

Table XXXI gives a list of the views, the number of films and the film sizes normally used for the various types of examinations. The average gonad doses, assessed by the methods described above are noted in the last two columns. These figures are used in the next paragraph to estimate the genetically significant dose.

It may be questioned whether gonad doses, assessed on the basis of relatively few measurements on a phantom, really can be used in the estimate of the genetically significant dose. Various other authors have also based dose estimates on measurements on phantoms (for instance: KOREN & MAUDAL, 1957; LAUGHLIN et al., 1957). In table XXXII the gonad doses in table XXXI are compared with doses indicated by other authors. The data given by STANFORD & VANCE (1955) and by the ADRIAN COMMITTEE (1960) were both based on measurements on patients, while a cadaver, or a phantom respectively, was used to derive ovary dose/skin dose conversion factors (see p. 56 and 57). LARSSON (1958) and SEELENTAG et al. (1958c) measured testis doses at the skin of the scrotum and ovary doses in the rectum or the fornix posterior of the vagina respectively. HOLTHUSEN et al. (1961) based their calculations on measurements partly on patients and partly on a phantom.

Comparison of the doses noted in table XXXII shows in the first place that for a number of examinations the various authors indicated widely different gonad doses. Interesting examples of these differences were given by HOLTHUSEN et al. (1961) in some of their tables (Tab. 22 and 23). For instance, in urography, urethrography and plain radiography of the abdomen in males LARSSON indicated far higher testis doses than did any other author. In general, the ovary doses are in slightly better agreement, that is as far as the relatively high doses are concerned. These discrepancies may be explained by the differences in exposure technique and, especially for testis doses, by the differences in field size. On the whole the figures in table XXXI are perhaps in best accordance with those from

TABLE XXXI

Average gonad doses in mr per examination
(field sizes adapted to the specified film sizes)

Examination type	Views	Film sizes cm² (and numbers)	Gonad doses	
			Testis dose mr	Ovary dose mr
1. hip and femur (upper third)	1 A.P. + 1 LAT.	24×30 (2)	3323	140
2. femur (middle and lower third)	1 A.P. + 1 LAT.	15×40 (2)	91	2.0
3. pelvic region	1 A.P.	30×40 (1)	157	142
4. lumbosacral region	1 A.P. + 1 LAT. + 2 Obl.	24×30 (4)	60	790
5. lumbar spine	1 A.P. + 1 LAT.	24×30 (2)	16	47
6. dorsal spine	1 A.P. + 1 LAT.	30×40 (2)	2.2	2.2
7. intravenous urography	4 A.P.	30×40 (4)	512	604
8. retrograde urography	2 A.P.	30×40 (2)	356	348
9. urethrocystography	2 P.A. + 2 Obl.	24×30 (4)	423	1608
11. hysterosalpingography	3 P.A.	24×30 (3)	—	664
12. obstetrical abdomen	1 A.P.	35×35 (1)	—	100
13. abdomen (general)	1 A.P.	30×40 (1)	92	132
14. lower gastrointest. tract.	4 P.A. + fluorosc.	35×35 (4)	25	613
15a. oesophagus	1 P.A. + 1 LAT.	15×40 (2)	0.76	2.2
15b. stomach and duodenum	4 P.A. + fluorosc.	24×30 (4)	4.0	110
16. gallbladder	2 P.A.	18×24 (2)	0.74	5.3
17a. chest (fluoroscopy)	fluorosc.	—	0.069	0.12
17b. chest (radiography)	1 P.A.	35×35 (1)	0.026	0.020
18. sternum, ribs, shoulder	1 A.P. + 1 LAT.	24×30 (2)	0.74	0.026
19. arm and hand	1 A.P. + 1 LAT.	24×30 (2)	0.82	0.022
20. lower leg and foot	1 A.P. + 1 LAT.	15×40 (2)	0.40	0.016
21a. head	1 A.P. + 1 LAT.	24×30 (2)	0.41	0.030
21b. cervical spine	1 A.P. + 1 LAT.	18×24 (2)	0.14	0.009
23. miniature radiography	1 P.A.	35 mm	0.25 *	0.35 *

* Figures based on measurements made by STANFORD & VANCE (ADRIAN COMMITTEE, 1959).

SEELENTAG et al. (1958c) and HOLTHUSEN et al. (1961) and in some instances with those from the ADRIAN COMMITTEE (1960).

There is a striking accordance with quite a number of figures presented by WEBSTER & MERRIL (1957), who also measured on a phantom. Their data are not included in Table XXXII. The exceptionally high figure for the examination of the hip and upper femur in males is probably a result

TABLE XXXII (A)

Comparison of average testis doses in mr per examination (or per film)
(based on data published by various authors)

Examination type	figures in table XXXI	STANFORD & VANCE (1955) per film *	LARSSON (1958) probable dose (adults) per examination	SEELENTAG et al. (1958c) average dose per examination	ADRIAN COMMITTEE (1960) dose (adults) per examination	HOLTHUSEN et al. (1961) d_j (Erw.)
1. hip and femur (upper third)	3323	710	1090	—	1120	731
2. femur (middle and lower third)	91	—	830	107	118	28
3. pelvic region	157	1100	870	480		193
4. lumbosacral region	60	22	940	62	387	482
5. lumbar spine	16	24				27.6
6. dorsal spine	2.2	8	3.3	4.5	6.1	1.8
7. intravenous urogr.	512	69	1240	380	804	158.5
8. retrograde urography	356		—	97	1040	180
9. urethrocystography	423	93	3700	—	964	475.5
11. hysterosalpingogr.	—	—	—	—	—	—
12. obstetrical abdomen	—	—	—	—	—	—
13. abdomen (general)	92	69	1360	65	103	47.25
14. lower gastroint. tr.	25	40***	310	300	146	820
15. upper gastroint. tr.	4.8	20***	14	19f	43.5	6.07
16. gallbladder	0.74	0.6	6.3	9.4	7.5	4.00
17a. chest (fluor.)	0.069	—	—	1.2	1.34	0.24
17b. chest (radiogr.)	0.026	0.36	1.8	0.042		
18. sternum, ribs, shoulder	0.74	0.35**		0.7	0.21fff	0.48
19. arm and hand	0.82	0.13		—	4.7	1.84
20. lower leg and foot	0.40	0.62	1	1.14	3.2	0.72
21a. head	0.41	0.2		1.12	0.32	2.0
21b. cervical spine	0.14	0.27		0.97ff		—
23. photofluorography of the chest	—	0.25	0.21	0.66	0.05—0.16	0.16

TABLE XXXII (B)

Comparison of average ovary doses in mr per examination (or per film)
(based on data published by various authors)

Examination type	figures in table XXXI	STANFORD & VANCE (1955) per film *	LARSSON (1958) probable dose (adults) per examination	SEELENTAG et al. (1958c) average dose per examination	ADRIAN COMMITTEE (1960) dose (adults) per examination	HOLTHUSEN et al. (1961) d_j (Erw.)
1. hip and femur (upper third)	140	210	260	—	117	255
2. femur (middle and lower third)	2.0	—	35	—	7.3	24
3. pelvic region	142	180	200	242		166
4. lumbosacral region	790	220	490	126	405	415
5. lumbar spine	47	227				174.6
6. dorsal spine	2.2	11	6.2	—	11.7	3.6
7. intravenous urogr.	604	200	925	291	637	475
8. retrograde urography	348		—	—	399	656
9. urethrocystography	1608	230	1940	—	1285	498
11. hysterosalpingogr.	664	—	2600	—	313	1992
12. obstetrical abdomen	100	260	265	—	367	660
13. abdomen (general)	132	200	1150	48	212	165.8
14. lower gastroint. tr.	613	12***	1520	441	464	2905
15. upper gastroint. tr.	112.2	9***	29	150f	339	64.15
16. gallbladder	5.3	5.2	16.8	44	299	44
17a. chest (fluor.)	0.12	—	4.1	1.28	5.53	0.49
17b. chest (radiogr.)	0.020	0.07		—		
18. sternum, ribs, shoulder	0.026	0.10**		0.28	0.31fff	0.96
19. arm and hand	0.022	0.026		—	2.16	0.8
20. lower leg and foot	0.016	0.012	0.5	1.14	3.59	0.13
21a. head	0.030	0.05		—	1.91	1
21b. cervical spine	0.009	0.06		6.8ff		—
23. photofluorography of the chest	—	0.15	0.5	—	0.02—0.23	0.32

* Where doses differ for A.P. and LAT. views only those for A.P. views are included.
** Mean of figures given for shoulder and ribs respectively.
*** Fluoroscopy during 3 minutes, no radiography.
f Complete examination (barium meal) of gastrointestinal tract.
ff A.P. view for males, LAT. view for females.
fff Shoulder only.

of the (too) low radiation qualities found in use for this examination in Leiden. On the phantom very low gonad doses were measured for radiography and fluoroscopy of the chest. Although chest examinations contribute little to the total genetically significant dose (table XXXIII) they constitute a large percentage of the total number of examinations. Gonad doses during various types of examinations of the chest were studied by OESER et al., 1958 and by MOHR & STARKE (1960), who also compared doses reported in the literature. It appears that the reported doses for chest examinations are also widely different. Some authors do indicate gonad doses of the order of magnitude found in the present study. The testis dose found in fluoroscopy of the chest is nearly equal to the mean dose measured by DRION et al. (1961) on patients of a chest clinic. According to MELLINK & VERHOEF (1959) the gonad doses delivered during A.P. radiography of the chest, performed with a good technique, are most difficult to measure accurately in patients. Their figures are in accordance with those given by STANFORD & VANCE (1955), i.e. about 0.1 to 0.2 mr. Thus, it may be concluded that the gonad doses assessed on the basis of the measurements on the phantom do not fall outside the range of gonad doses measured on patients and may be accepted for the estimate of the genetically significant dose.

3. CALCULATION. RESULTS COMPARED WITH FOREIGN DATA

The genetically significant dose is calculated by the method described in paragraph 1 of this Chapter. Table XXXIII gives a survey of the data used and the steps involved in this calculation. The genetically significant dose due to diagnostic radiology to the population of Leiden and Oegstgeest, 1959, is estimated at a minimum of **6.8 mr.** This must be considered as the dose given if the radiographic field sizes and the number of radiographs per examination were actually restricted as specified in table XXXI, and if the average fluoroscopic times did not exceed the figures given on p. 81.

In Chapter II genetically significant dose estimates in various countries were discussed. The methods used and the results obtained are not always comparable. The data presented for various countries are given in table XXXIV. It is indicated in this table whether the authors estimated a minimum, a probable or a maximum dose. The earlier minimum estimates in some countries yielded much higher values than the more recent minimum estimates in other countries. At that time the minimum estimate calculated by HAMMER-JACOBSEN (1957) for Denmark was lowest. Most illustrative are the figures presented by SEELENTAG et al. (1959), who estimated for the population of Bavaria a minimum, a probable and a maximum dose of 5, 14 and 160 mr respectively. This great difference between maximum and minimum estimate is a result of the great gonad dose differences in "bad" and "good" techniques respectively.

TABLE XXXIII

Calculation of the genetically significant dose from diagnostic radiology to the population of Leiden and Oegstgeest (1959) (dental radiography and population mass survey excluded)

Examination type	MALES				FEMALES				FOETUSES				TOTAL	
	1000 Nj/N	wj/w	dj (mr)	Dj (mr)	1000 Nj/N	wj/w	dj (mr)	Dj (mr)	1000 Nj/N	W/w	dj * (mr)	Dj (mr)	Dj (mr)	per cent
1. hip and femur (upper)	1.60	0.279	3323	1.4834	2.05	0.118	140	0.0339	0.009	1.840	140	0.0023	1.5196	22.37
2. femur (middle + lower)	1.08	1.176	91	0.1156	0.73	0.298	2.0	0.0004	0.000	,,	2.0	0.0000	0.1160	1.71
3. pelvic region	3.37	0.664	157	0.3513	3.37	0.396	142	0.1895	0.055	,,	142	0.0144	0.5552	8.17
4. lumbosacral spine	1.91	0.596	60	0.0683	1.49	0.391	790	0.4602	0.046	,,	790	0.0668	0.5953	8.76
5. lumbar spine	4.50	0.489	16	0.0352	3.27	0.392	47	0.0602	0.092	,,	47	0.0080	0.1034	1.52
6. dorsal spine	1.66	0.751	2.2	0.0027	1.28	0.615	2.2	0.0017	0.028	,,	2.2	0.0001	0.0045	0.07
7. intrav. urography	5.61	0.407	512	1.1690	2.99	0.341	604	0.6158	0.073	,,	604	0.0811	1.8659	27.47
8. retrogr. urography	0.70	0.495	356	0.1234	0.38	0.270	348	0.0357	0.000	,,	348	0.0000	0.1591	2.34
9. urethrocystogr.	1.11	0.239	423	0.1122	0.28	0.679	1608	0.3057	0.009	,,	1608	0.0266	0.4445	6.54
11. hysterosalpingogr.	—	—	—	—	0.30	0.265	664	0.0528	—	,,	—	—	0.0528	0.78
12. obstetrical abdomen	—	—	—	—	0.11	0.594	100	0.0065	0.110	,,	100	0.0202	0.0267	0.39
13. abdomen (general)	3.72	0.528	92	0.1807	2.55	0.467	132	0.1572	0.064	,,	132	0.0155	0.3534	5.20
14. lower gastroint. tr.	3.71	0.284	25	0.0263	3.82	0.214	613	0.5011	0.073	,,	613	0.0823	0.6097	8.98
15a. oesophagus	1.08	0.301	0.76	0.0002	0.97	0.215	2.2	0.0005	0.018	,,	2.2	0.0001	0.0008	0.01
15b. stomach + duod.	10.46	0.457	4.0	0.0191	7.63	0.294	110	0.2468	0.193	,,	110	0.0391	0.3050	4.49
16. gallbladder	4.64	0.382	0.74	0.0013	7.97	0.248	5.3	0.0105	0.183	,,	5.3	0.0018	0.0136	0.20
17a. chest (fluoroscopy)	116.38	1.148	0.069	0.0092	83.16	1.105	0.12	0.0110	3.788	,,	0.12	0.0008	0.0210	0.31
17b. chest (radiography)	56.58	0.548	0.026	0.0008	52.17	0.768	0.020	0.0008	1.972	,,	0.020	0.0001	0.0017	0.03
18. sternum, ribs, shoulder	3.12	0.431	0.74	0.0009	3.49	0.326	0.026	0.0000	0.073	,,	0.026	0.0000	0.0009	0.01
19. arm and hand	13.76	1.266	0.82	0.0143	9.66	1.003	0.022	0.0002	0.229	,,	0.002	0.0000	0.0145	0.22
20. lower leg and foot	15.05	1.032	0.40	0.0062	11.12	0.732	0.016	0.0001	0.293	,,	0.016	0.0000	0.0063	0.09
21a. head	7.41	1.115	0.41	0.0034	5.23	0.962	0.030	0.0002	0.165	,,	0.030	0.0000	0.0036	0.05
21b. cervical spine, trachea	3.22	0.357	0.14	0.0002	3.85	0.199	0.009	0.0000	0.064	,,	0.009	0.0000	0.0002	0.00
23. photofluor. (chest)	47.13	0.747	0.25	0.0088	33.38	0.806	0.35	0.0094	1.972	,,	0.35	0.0013	0.0195	0.29
Totals	307.80			3.7325	241.27			2.7002	9.509			0.3605	6.7932	100.00%

* Foetal gonad doses assumed to be equivalent to the mother's gonad doses.

N = 109041 (no allowance made for foetus)

w = 1.394

W = 2.565

TABLE XXXIV

Annual genetically significant dose due to diagnostic radiology
(Estimates in various countries and cities)

Country or city	Period of Study	Authors		Genetically significant dose (mr, mrad or mrem)		
				minimum	probable	maximum
Australia	1953-'55	Martin	1958	28	162	
Denmark	1956	Hammer-Jacobsen	1957	17		
England & Wales	1955	Osborn & Smith	1956	23.2		
Bavaria	1957-'58	Seelentag et al.	1959	5	14	160
Hamburg (F.R.G.)	1957-'58	Holthusen et al.	1961		17.7	
Leiden (Netherlands)	1959			6.8		
Rome (Italy)	1957	Biagini et al.	1960		44 ± 36	
Sweden	1955	Larsson	1958		37.9	
United Kingdom	1957-'58	Adrian Committee	1960	9.9 *	14.1	
U.S.A.	1955-'56	Laughlin & Pullman	1957	50 **	140 **	

* Excluding worst techniques. If only the best techniques are included the dose is estimated at 2.4 mr.

** Originally a 30-year dose was calculated.

The ADRIAN COMMITTEE (1960) mainly based their calculations on actual (skin dose) measurements on patients and found great differences at the various hospitals and institutes. On the basis of these differences they were able to calculate the possible reduction of the genetically significant dose by the general introduction of better techniques. As was stated by the Committee: "excluding the worst techniques reduced 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." If, in the present investigation, the gonad doses assessed on the basis of measurements during standardized exposure techniques on the phantom are held representative for the best techniques, the present estimate of 6.8 mr may, accordingly, be only 20 per cent of the actual value. The data collected in the present investigation do not permit the estimation of a probable or a maximum value of the genetically significant dose. However, the result of the minimum estimate shows clearly that, if good techniques are generally used, the genetically significant dose due to diagnostic radiology can be low. In Chapter VII, where the methods of dose reduction in diagnostic radiology are described, it is stressed that the restriction of the field size is by far the most important method. Adequate instruction and education of doctors and radiographers should suffice to keep the genetically significant dose at the level calculated as the minimum dose in the present investigation.

There seems to be little point in trying to calculate the accuracy of the

present estimate. Quite a number of assumptions had to be made. The possible errors associated with the calibration of ionization chambers and dosemeters are in general less than 5 per cent. These errors may be neglected in comparison with other possible errors, introduced by some assumptions. The most important possible sources of error are listed below:

a. It was not possible to collect all necessary frequency data. Fairly complete data were collected from 60.7 per cent of all examinations (see table VIII). The incomplete data concern mainly chest examinations. In 10.4 per cent of the total number of examinations, data regarding sex and age of the patients are lacking. The number of foetuses exposed during examinations of pregnant women was calculated by a rather rough method (p. 79).

b. Child-expectancy data were based on an analysis of birth records of children born in Leiden during 1954–1959. It was assumed that these fertility data would not differ significantly for the population of Oegstgeest. It was furthermore assumed that in future the age specific annual birth rate for the population concerned will not change. Finally, no corrections were introduced for the possible abnormal child-expectancy of patients subjected to most roentgendiagnostic examinations, while the corrections introduced for women subjected to hysterosalpingography or obstetrical abdominal examinations were based on some rather unfounded assumptions (p. 50).

c. The gonad doses dere assessed on the basis of measurements made on a tissue-equivalent phantom, representing a typical Dutch male. Although, in general, the doses assessed by this method lie in the range of doses measured on patients there is no way to ascertain whether these doses are equivalent to the average gonad doses actually received by patients. Moreover, to derive the gonad doses per examination as used in the calculations a number of assumptions had to be made. These assumptions are listed in the preceding paragraph. Foetal gonad doses were assumed to be equivalent to the mother's gonad doses.

d. In the actual calculation of the genetically significant dose the simplified equation was used, for which it must be presumed that the gonad doses are uniform for all age classes. The general validity of this presumption is discussed on p. 78 and 79.

The shortcomings of the present investigation may partly cancel each other in the results, but are of such nature that the extent of their influence on the result of the genetic dose calculation cannot be outlined and even less calculated. The calculation of possible errors by other authors, such as BIAGINI et al. (1960) and by the ADRIAN COMMITTEE (1960) does not seem to be wholly justified. A number of the shortcomings listed above adhere to any estimate of the genetically significant dose.

Some authors (amongst other LAUGHLIN & PULLMAN, 1957) have cal-

culated the mean gonad dose to the population below the age of 30 years. This dose has been used as a first estimate to the genetically significant dose. This dose, D_{30}, may be calculated according to the equation:

$$D_{30} = \sum_j D_{j30} = \sum_j \frac{n_j}{n} \cdot d_j \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where:

n_j = the number of individuals below the age of 30, subjected to a class j exposure.

n = the number of individuals below the age of 30 in the population.

d_j = mean gonad dose per individual undergoing class j exposure.

For the population concerned n amounts to 58427.

Data for $\frac{n_j}{n}$ and D_{j30} are presented in table XXXV. For d_j the same figures were used as for the calculation of the genetically significant dose in table XXXIII. D_{30} (1959) is estimated at **5.7 mr** (minimum value). For the population concerned calculation of D_{35} or even D_{40} would probably give better results. For males the subsequent child-expectancy in age group 30–34 is still high (1.396, while W = 2.565). However, the result of this calculation shows that the D_{30} may give a fair estimate of the genetically significant dose. This method of calculation may be used if, for some reason, child-expectancy data are lacking.

In some instances the per capita gonad dose also has been used as an estimate of the genetic dose. The per capita gonad dose is calculated according to:

$$D_{p.c.} = \sum_j \frac{N_j}{N} \cdot d_j \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The actual calculation of this dose for the population concerned is not presented here. The same data may be used as in table XXXIII, but the values are not weighted to relative child-expectancy factors. The calculation of the per capita gonad dose (1959) yields a value of **18.7 mr**. Only if, in general, the relative child-expectancy factors differ little from unity (as in the estimate for England and Wales, see table XVIII) are the genetically significant dose and the per capita gonad dose of about the same magnitude.

4. Roentgen diagnostic examinations with greatest genetic significance

In the preceding section the (minimum) genetically significant dose due to diagnostic radiology to the population of Leiden and Oegstgeest, 1959, was estimated at 6.8 mr. This figure is low compared with most figures estimated in other countries or cities (table XXXIV). The result of the

TABLE XXXV

Calculation of mean gonad dose to the population below the age of 30 (1959) (dental radiography and population mass survey excluded)

Examination type	MALES		FEMALES		FOETUSES	
	$1000 \frac{n_j}{n}$	D_{j30} (mr)	$1000 \frac{n_j}{n}$	D_{j30} (mr)	$1000 \frac{N_j}{n}$	D_{j30} (mr)
1. hip and femur (upper third)	0.34	1.1298	0.26	0.0364	0.017	0.0024
2. femur (middle & lower third)	1.18	0.1074	0.22	0.0004	0.000	0.0000
3. pelvic region	2.00	0.3140	1.23	0.1747	0.103	0.0146
4. lumbosacral region	0.80	0.0480	0.55	0.4345	0.086	0.0679
5. lumbar spine	1.32	0.0211	1.16	0.0545	0.171	0.0080
6. dorsal spine	1.06	0.0023	0.80	0.0018	0.041	0.0001
7. intravenous urography	1.66	0.8499	0.91	0.5496	0.137	0.0827
8. retrograde urography	0.22	0.0783	0.10	0.0348	0.000	0.0000
9. urethrocystography	0.17	0.0719	0.19	0.3055	0.017	0.0273
11. hysterosalpingography	—	—	0.09	0.0598	—	—
12. obstetrical abdomen	—	—	0.10	0.0100	0.206	0.0206
13. abdomen (general)	1.52	0.1398	1.13	0.1492	0.120	0.0158
14. lower gastrointest. tract.	0.62	0.0155	0.67	0.4107	0.137	0.0840
15a. oesophagus	0.24	0.0002	0.12	0.0002	0.034	0.0001
15b. stomach and duodenum	3.30	0.0132	2.07	0.2277	0.359	0.0395
16. gallbladder	1.11	0.0008	1.69	0.0090	0.340	0.0018
17a. chest (fluoroscopy)	117.72	0.0081	89.70	0.0108	7.069	0.0008
17b. chest (radiography)	25.25	0.0007	39.73	0.0008	3.680	0.0001
18. sternum, ribs, shoulder	1.10	0.0008	1.04	0.0000	0.137	0.0000
19. arm and hand	16.05	0.0132	9.02	0.0002	0.428	0.0000
20. lower leg and foot	13.71	0.0055	7.87	0.0001	0.548	0.0000
21a. head	7.48	0.0031	4.86	0.0001	0.308	0.0000
21b. cervical spine, trachea	0.84	0.0001	0.62	0.0000	0.120	0.0000
23. photofluorography (chest)	26.92	0.0067	25.79	0.0090	3.680	0.0013
TOTALS		2.8304		2.4798		0.3670

Notes: see table XXXI and XXXIII for d_j.

$n = 58427$, n_j calculated on the basis of figures in table XII and XIII.

present investigation is perhaps best comparable to that of the investigation in Bavaria by SEELENTAG et al. (1959). Apart from the low gonad doses found for a number of examinations during the measurements on the phantom, there are some other factors that might explain the comparatively low final figure. As is pointed out in Chapter IV the weighting factors for relative child expectancy ($\frac{w_j^*}{w}$) are low compared with, for instance, the factors for England and Wales, 1956. This is partly due to the high figure for w (1.394) calculated for the population of Leiden and Oegstgeest. In other countries this figure usually was found to be less than unity.

Furthermore, as is evident from table XXXIII, the exposure of both

TABLE XXXVI

Contributions to the genetically significant dose and to the total number of examinations
(population mass survey and dental radiography excluded)

Examination type	Percentage contribution			
	to genetically significant dose		to total number of examinations	
7. intravenous urography	27.47		1.57	
1. hip and femur (upper third)	22.37		0.66	
14. lower gastrointestinal tract	8.98		1.38	
4. lumbosacral region	8.76		0.62	
3. pelvic region	8.17		1.23	
9. urethrocystography	6.54		0.25	
13. abdomen (general)	5.20		1.15	
15b. stomach and duodenum	4.49		3.29	
8. retrograde urography	2.34		0.20	
2. femur (middle and lower third)	1.71		0.33	
5. lumbar spine	1.52		1.41	
		97.55		12.09
11. hysterosalpingography	0.78		0.06	
17a., 17b., 23. chest examinations	0.63		70.79	
12. obstetrical abdomen	0.39		0.02	
19., 20. extremities	0.31		9.02	
16. gallbladder	0.20		2.30	
6., 15a. dorsal spine and oesophagus	0.08		0.91	
18., 21. sternum, ribs, shoulder head, cervical spine, trachea	0.06		4.81	
		2.45		87.91
		100.00%		100.00%

females and foetuses contributes less to the genetically significant dose than does the exposure of males. To the genetically significant dose of 13.24 mr estimated for the National Health Service Hospitals in the United Kingdom 8.41 mr was contributed by female and foetal exposures (ADRIAN COMMITTEE, 1960). To the total genetically significant dose 4.54 mr, or 34 per cent was contributed by obstetrical abdominal examinations and pelvimetries. As was noted before no pelvimetries were recorded at all in the present survey, while the number of obstetrical

abdominal examinations was very small. As is shown in the last column of table XXXIII obstetrical abdominal examinations contribute only 0.39 per cent to the total genetically significant dose. This is an important reason why the outcome of the present calculation is comparatively low.

It is of great practical interest to indicate the examinations with the greatest genetic significance. As far as genetic doses are concerned, it is with these examinations that dose reduction is most effective. In table XXXVI the contributions to the total genetically significant dose and to the total number of examinations are compared for various types of examinations. In this table is shown that the first 11 types contribute nearly 98 per cent to the genetically significant dose but constitute only 12 per cent of the total number of examinations. It should be noted that this table is not directly comparable to the tables XX and XXI as in the latter tables photofluorography (or miniature radiography) of the chest was excluded to enable comparison with some foreign data. In general, the sequence of the genetically most important examinations is comparable to that found by other authors. In their report HOLTHUSEN et al. (1961) present a survey of these sequences in various countries and cities. The actual sequence differs from country to country, this being partly the result of differences in current radiological practices.

Another interesting feature of table XXXVI is that all chest examinations together (fluoroscopy, plain radiography and photofluorography) constitute nearly 71 per cent of the total number of examinations but contribute only 0.63 per cent to the genetically significant dose. Of course the latter percentage may be higher if, in chest examinations, the exposure fields are chosen unnecessarily large. The importance of field restriction in diagnostic roentgenology is stressed again in the next Chapter.

CHAPTER VII.

DOSE REDUCTION IN DIAGNOSTIC ROENTGENOLOGY

1. General measures

Obviously an important method to decrease the population dose due to diagnostic radiology is the reduction of the frequency of roentgendiagnostic examinations. This should especially involve reduction of a number of examinations unnecessary from a medical standpoint. Roentgen examinations should not be performed merely for the sake of documentation (von Ronnen, 1956). Pre-employment chest radiography should not be repeated unnecessarily within a short period of time (see: Zielhuis, 1960, van Joost, 1962). For some conditions, such as low back pain and vague abdominal pains, a roentgendiagnostic examination should not automatically be prescribed. It is questionable whether frequent roentgen examinations are indeed needed to control a peptic ulcer (U.N.S.C.E.A.R., 1957; Thomas & van Voorthuizen, 1959). One of the conclusions that might be drawn from a recent article (Fermin, 1962) is that some other types of examinations also are carried out too frequently and without real need for the diagnosis or the control of a disease. As was stated by Ardran (1957): "the first duty is for the prescribers to limit their demands to what is essential; the advisability of radiographing the patient in any individual instance must be reviewed in view of the potential hazards". However: "This will require education on the part of the medical and legal professions and the general public". For a radiologist it is most difficult to refuse the performance of a roentgendiagnostic examination merely because he feels it is not really necessary. General practitioners and medical specialists often have particular interests in some diagnostic methods and consequently prescribe such methods more often than their colleagues. Much depends on the professional education of these doctors. In many countries pelvimetry is performed in a high percentage of pregnant women; in the Netherlands obstetricians seem to be able to do without this diagnostic method.

To avoid unnecessary repetitions and at the same time to record the exposures, some authors have advocated the introduction of personal radiation records (Poppel et al., 1951, 1957; Dameshek & Gunz, 1957). The latter authors stated: "This booklet could tell the doctor at a glance whether the patient was beginning to exceed his lifetime quota for permissible X-ray dosage and, through its psychological effect, would tend to

curtail the use of possibly unnecessary diagnostic and therapeutic procedures". As was pointed out by the I.C.R.P./I.C.R.U. JOINT STUDY GROUP (1957) dose data must be obtained either by individual measurements or by estimation from doses previously measured during surveys. For the first method no practical instruments are available for use on a large scale; the second method would require "copious filling of forms". The cost of medical care would thereby be considerably increased. Moreover the carrying of records by individuals might have serious psychological and legal consequences. According to HODGES (1958) it is not at all easy to estimate tissue doses in patients and it is not justified simply to add partial body doses in the hope that the sum will give an indication of the somatic or genetic hazards. The collection of pseudo-quantitative data may have harmful effects. National and international bodies and committees have uniformly advised against the introduction of these personal radiation records.

This situation might have changed with the introduction of instruments for the evaluation of the integral absorbed dose (REINSMA, 1959, 1960b; GOLDMAN et al., 1960; ZIELER, 1960). It was held by some authors that these instruments would permit easy and exact registration of the patient's dose. However, these instruments measure the incident radiation energy, which is by no means identical to the integral absorbed dose (ARNAL & PYCHLAU, 1961; MORGAN, 1961). Nor is the integral absorbed dose a constant fraction of the incident energy (ZIELER, 1961). And even if the integral absorbed dose could be evaluated by this method, it still would not give a reliable indication of the possible somatic hazards (SANCHES, 1961). At any rate the integral absorbed dose gives no indication at all about the magnitude of gonad doses and the possible genetic hazards. Thus the routine registration of the incident radiation energy does not seem to be indicated at the moment.

Once it is decided that a roentgendiagnostic examination should be performed care should be taken that this is done by properly qualified doctors or radiographers and that proper methods to reduce the patient's dose are taken into account. Evidently the general standard of radiological work can only be raised by proper education and instruction of all radiological workers. National and international committees have issued recommendations about the reduction of doses in diagnostic and therapeutic radiology. In the Netherlands the Radiological Society sent recommendations to its members in 1959, while for the use of the whole medical profession recommendations were published by the National Health Council (GEZONDHEIDSRAAD, 1959). These recommendations will not be repeated here. However, a few methods of gonad dose reduction require some attention in this Chapter.

It is clear that fluoroscopy should only be performed after adequate dark adaptation and in the shortest possible time (FRIK, 1958). Tube

current and field size should be kept at a minimum and adequate filtration should be provided. The fluoroscopic equipment must comply with the necessary standards of safety. Regarding radiography it is recommended by the "GEZONDHEIDSRAAD":

1. That the exit dose is the highest possible fraction of the incident dose.
2. To use techniques such that a minimum exit dose will suffice for a radiograph of good quality.
3. To restrict the field size as much as possible.

In the next sections some important measures to restrict gonad doses in diagnostic radiology will be described in more detail.

2. FIELD SIZE AND TARGET-SKIN DISTANCE

The restriction of the field size is by far the most important (and the easiest) method to reduce the patient's dose in diagnostic radiology. This concerns the gonad dose as well as the bone marrow dose and the integral absorbed dose. The influence of beam restriction on the magnitude of the skin dose is relatively unimportant (HAYBITTLE, 1957). The technical quality of a radiograph is favourably influenced by beam restriction. In quite a number of radiological views the gonads, and specially the male gonads, can be kept outside the primary beam by careful centring and adjustment of the field to the film size used. In urological radiography in males exact adjustment of the field size may decrease the testis dose by a factor of 25 (STANFORD, 1957). In radiography of the extremities the reduction of scattered radiation and the increase of the distance between the gonads and the edge of the primary beam also reduces the gonad doses. During chest radiography with a bad technique the female gonads, and in the case of children the gonads of both sexes, may lie in the primary beam. This may increase the gonad dose by a factor of 100 or more (ARDRAN, 1957; ARDRAN & CROOKS, 1957). If this were general practice chest radiography could give the largest single contribution to the genetically significant dose (ARDRAN, 1957). ARDRAN & CROOKS (1952) stressed the importance of dose reduction in chest radiography. They use a specially designed lead diaphragm near to the patient's skin in addition to a diaphragm on the tube. WARRICK & FORSTER (1959) devised a protection shield for use in chest radiography in children. For mass miniature radiography ZUTZ (1958) designed a lead slit connected to the footboard and automatically adjusted to the length of the patient. Other lead shielding consisting of adjustable rectangles was described by JAEGER (1959b). For use in dental radiography NOLAN & PATTERSON (1953) recommended a shield to protect the patient's neck. ARDRAN & CROOKS (1959) advised covering the trunk and the gonads of patients in dental X-ray procedures with a 0.3 mm Pb-equivalent apron in cases

where there is any doubt as to the other protective measures. Special shielding of gonads will be discussed in the next section.

While the size of the entrance field is not important regarding the magnitude of the skin dose, the target-skin distance has much more influence on this. At a short target-skin distance (or target-film distance) the tissue doses tend to be also higher, though for gonad doses this distance is not of major importance.

It is not easy to demonstrate experimentally the influence of the field size on the magnitude of gonad doses. In the case of a large field scattered radiation contributes much to the exit dose. If an efficient grid is used much of this radiation will be absorbed before it reaches the film. Consequently, the exit dose cannot be used as a parameter for film density. Table XXXVII shows the influence of field size and target-film distance for an A.P. view of the hip. Measurements were made at two different voltages, while the total amount of filtration was kept constant. For these measurements it was assumed that the same exposure data would be used for a small as well as for a large field. The comparison of doses at different target-film distances was based on the same exit dose.

When the target-film distance is changed from 100 to 80 cm at both voltages the incident dose increases about 20 per cent and the ovary dose 7 to 8 per cent. However, the testis dose decreases slightly. This may be because the size of the entrance field is smaller at 80 cm target-film distance than at 100 cm target-film distance when the exit field is kept constant. In this radiographic view the testes lie at the very edge of the entrance field and thus even small reduction of this field will have some effect on the testis dose. When the size of the exit field is increased from 24×30 cm^2 to 45×45 cm^2 and tube current, exposure time and tube

TABLE XXXVII

Influence of field size and target-film distance on doses
Radiographic view: hip and upper femur A.P.
Philips Medio D 100. added filter: 1 mm Al. grid: ratio 4.3 : 1
55 lines/inch

kV	mAs	field size (at film) (cm^2)	target-film distance (cm)	exit-dose (mr)	incident dose (r)	testis dose (mr)	ovary * dose (mr)
68	190	24×30	100	10.6	1.51	874	72
68	104	24×30	80	10.6	1.83	862	78
68	190	45×45	100	22.8	1.77	1300	104
83	83	24×30	100	10.6	1.08	598	71
83	46	24×30	80	10.6	1.29	563	76
83	83	45×45	100	19.2	1.14	791	92

* mean dose to left and right ovary.

voltage are kept constant the gonad doses and exit dose increase considerably (by a factor 1.3 to 2.1). The incident dose at the centre of the field also increases, this increase being smaller at 83 kV than at 68 kV.

Another example of the influence of field size and target-film distance will be given in the next section, where the effectiveness of some lead shielding will also be considered.

3. Lead shielding of the gonads

In roentgen examinations where the gonads cannot be kept outside the primary beam suitable shielding can considerably decrease the gonad dose. Various devices have been recommended for the protection of the testes in diagnostic radiology. As Larsson (1958) stated merely a sheet of lead rubber is very effective. The easily constructable and applicable protective shield as described by Ardran & Kemp (1957) consists mainly of a 2 mm thick lead plate. According to the authors this shield reduces the testis dose from 500–2000 mr to 20–50 mr during examinations of the pelvis, hip and femur and bladder. In examinations where the major part of the testicular exposure is caused by scattered radiation a simple lead sheet is relatively less effective. For these examinations shielding can be used that surrounds the scrotum as far as possible. Magnusson (1952) uses capsules made of 1.5 mm nickeled copper; Viernstein & Hipp (1958) described a capsule consisting of two halves and made of 2 mm Pb-equivalent lead rubber. According to Bretland (1959) a "closed box" of 0.5 mm Pb-equivalent "Plastoled" is most effective, as it also shields to some extent against scattered radiation arising in the pelvis and the abdomen. However, the application of this box is quite inconvenient to the patient. The author stated that in many instances a simple 0.5 mm Pb-equivalent lead rubber strip is surprisingly effective, reducing the dose to about 0.5 per cent. In his article summarizing the measures to reduce testis doses Stieve (1959) also exemplified the influence of the various protective measures. This author concluded that field restriction is by far the most effective measure. In addition, for persons in the pre-reproductive and reproductive ages, gonad shielding should be used. As this shielding should be usable for all types of radiological examinations and should at the same time be easily applied and cleaned, Stieve advocated 1 mm Pb-equivalent lead rubber capsules, consisting of two halves. By this device at least 98 per cent of the primary radiation is absorbed at tube voltages below 150 kV. Hartung (1959) uses capsules specially designed for children and stated that by these capsules the testis dose can be reduced by 99 per cent. Whitehead & Griffiths (1961) recommended a combination of a 3 mm lead piece attached to the (light) diaphragm and a 2 mm lead sheet directly shielding the testes.

In females gonadal shielding is more difficult. In a number of examina-

tions a lead shield will invalidate the diagnostic quality of the radiograph. However, in conditions like congenital dislocation of the hip, *Perthes* disease, epiphysiolysis of the hip and chronic coxitis roentgen examinations are performed with high frequency and specially in young girls. In these instances lead shielding of the ovaries can be succesfully used without hampering the control of the disease. ABRAM et al. (1958) divised 2 mm Pb-equivalent lead rubber shields of various dimensions. VIERNSTEIN & HIPP (1958) advocated shields of a slightly different form, consisting of 1 mm Pb-equivalent lead rubber and decreasing the ovary dose by about 80 per cent. Special devices for children were again described by HARTUNG (1959). The shields advised for protection of the foetus in pelvimetry (APPLEBY et al., 1958; KENDIG, 1960) fall outside the scope of this section and moreover are not of great practical importance for radiologists in the Netherlands.

It may be concluded that gonad shielding should be used whenever possible in those instances where the gonads of young persons lie in or near to the primary beam. In general a simple lead rubber sheet of 1 to 2 mm Pb-equivalent will give efficient protection. That a simple lead shield also gives some protection when the gonads lie far outside the primary beam is illustrated in table XXXVIII, based on measurements on the phantom. In this table the influence of field size and target-film distance is also illustrated. Comparisons were made by the same methods as described for table XXXVII. As is evident, for this radiographic view lead shielding is most effective when a large field is used. However, when the beam is exactly adapted to a film size of 18 $\times$ 24 cm^2 a sheet of 1 mm lead, which in this case did not completely surround the ionization cham-

TABLE XXXVIII

Influence of field size, target-film distance and lead shielding on testis dose
Radiographic view: knee A.P.
Philips Medio D 100. Added filter: 1 mm Al. No grid.

kV	mAs	field size (at film) (cm^2)	target-film distance (cm)	exit dose (mr)	incident dose (r)	testis dose	
						unshielded (mr)	shielded* (mr)
68	20	18×24	100	4.8	0.14	0.49	0.34
68	14	18×24	80	4.8	0.17	0.64	— **
68	20	45×45	100	7.9	0.15	3.24	1.83
83	9	18×24	100	4.8	0.10	0.43	0.31
83	7	18×24	80	4.8	0.14	0.52	— **
83	9	45×45	100	6.7	0.11	2.47	1.54

* Ionization chamber covered by a 1 mm lead plate.
** Not measured.

TABLE XXXIX

Contribution of leakage radiation to testis dose
Radiographic view: shoulder A.P.

Philips Medio D 100. Inherent filtration ca. 1 mm Al-equivalent.
Field size: 24 × 30 cm². Target-film distance: 100 cm. Grid: ratio 8 : 1
90 lines/inch

kV	mAs	added filter (mm Al)	exit dose (mr)	incident dose (r)	testis dose (mr)	testis dose with closed diaphr. (μr)
52	333	none	7.3	2.05	0.39	2.12
68	104	1	7.3	0.75	0.29	3.03
83	47	1	7.3	0.54	0.23	4.15
85	49	2	7.3	0.44	0.22	6.12
83	62	1 + 0.1 mm Cu	7.3	0.35	0.19	5.22

ber, nevertheless absorbs some 30 per cent of the scattered radiation. Field size and target-film distance influence the incident dose and the exit dose in the same way as was found for the A.P. radiographic view of the hip (table XXXVII). While for the latter view the testis dose decreases somewhat with the target-film distance, this is not the case during radiography of the knee. For the radiography of the knee in particular the field size influences greatly the magnitude of the testis dose.

That leakage via the tube housing cannot have been of great importance is demonstrated in table XXXIX. During radiography of the shoulder, leakage radiation contributed only 0.5 to 2.8 per cent to the testis dose, this contribution being highest at the highest tube voltage used. At this place it may be remarked that lead shielding should be added if leakage radiation contributes more than a few per cent to the testis dose.

4. TUBE VOLTAGE AND FILTRATION

In diagnostic radiology the main advantages of "high-voltage technique" are the low mAs exposures (short exposure time, VAN DIJK, 1959) and the low exposure dose needed to give sufficient film blackening. With increasing tube voltage the ratio of incident dose to exit dose decreases (WACHSMANN et al., 1952) because of the greater penetration of the beam. Perhaps the major disadvantage of high-voltage technique is the poor contrast, which however is held to be favourable in a number of radiographic examinations, such as those of the lungs and those with negative contrast (FRIK, 1961). According to FRIK (1961) only techniques using tube tensions above 100 kV (constant potential) are to be called high-voltage techniques.

The reduction of the dose to the patient by the use of high-voltage

techniques has perhaps been overstressed. At first only the influence on the magnitude of skin doses was noted. The skin dose can be greatly decreased by the use of high voltages, and especially when at the same time the beam is heavily filtered. Other doses, such as gonad doses, bone-marrow doses and integral doses are much less influenced. Nevertheless, according to DIETZ (1956), in radiography of the pelvic region the ovary dose is reduced by a factor of 3 by using 125 kV and 7 mAs instead of 70 kV and 100 mAs. In experiments with a complex phantom of the pelvic region MOHR et al. (1959) found that the ovary dose can be reduced by a factor of about 2, and the testis dose by a factor of about 5 if in an A.P. radiographic view of the pelvis the tube voltage is raised from 70 to 200 kV. The latter authors found the major decrease of gonad doses in the range from 70 to 100 kV. In the present investigation the influence of tube voltage was studied in the range from 46 to 95 kV during radiography of the pelvic region (see *figure VIII*). In this range the incident dose was shown to decrease by a factor 8, the testis dose by a factor 4.5 and the ovary dose by a factor 1.5. Although the voltage range is not the same, these figures are of the same order of magnitude as those quoted above. Good agreement is also found with some of the figures given by TROUT et al. (1952). These authors found during measurements on a phantom of the pelvic region that at the same film dose and the same beam filtration (1 mm Al added) the incident dose is reduced by 75 per cent and the ovary dose by 38 per cent if the voltage is raised from 60 to 130 kV. In A.P. radiographic views where the male or the female gonads lie in the primary beam it is to be expected that the increase in tube voltage will result in a larger decrease of the testis dose than of the ovary dose. Due to the superficial position of the testes, in some instances the testis dose reduction may be nearly as large as the skin dose reduction. However, not all authors accept the conclusion that in examinations where the gonads lie in the primary beam the increase of tube voltage always means reduction of gonad doses, however slight. STANFORD & VANCE (1957) stated that in some instances the ovary dose may increase. According to LARSSON (1958) this statement seems to be based on an excessive estimate of the ratio of grids believed to be necessary at high voltages. Rightly V. D. PLAATS (1959) warns against the indiscriminate use of the so-called high-voltage grids.

As has been stated in Chapter V it is at least questionable whether high-voltage techniques will also reduce scatter doses in diagnostic radiology. This point was studied experimentally on homogeneous phantoms by CEN & FRIK (1958); KLOTZ (1958); KLOTZ & SEELENTAG (1958); SCHAAL (1959) and KEANE & SPIEGLER (1961). The general conclusion of these experiments is that if reference is made to a constant exit dose the relative scatter dose at a specified distance from the primary beam and at a specified depth may increase with increasing radiation quality or tube

voltage. This conclusion was one of the reasons of carrying out the experiments with the inhomogeneous phantom, as described in Chapter V. The results of these experiments are in essential agreement with those on the homogeneous phantom: if reference is made to a constant exit dose in a number of radiographic views the ovary doses, and occasionally the testis doses also, are higher at higher radiation qualities. As specified kV-filter combinations were used, on the basis of these experiments it cannot be stated whether this possible increase is due to raised voltage, to increased filtration or to both factors simultaneously. However, the same applies to the experiments of the authors quoted above.

It may be concluded that in examinations where the gonads lie in the primary beam some gonad dose reduction may be acquired by the use of relatively high voltages. However, when the gonads lie outside the primary beam the doses may increase with the radiation quality. Both decrease or possible increase are relatively small and at any rate much less important than the variations in the magnitude of gonad doses due to other factors, such as field size, field alignment and eventually gonad shielding. From the point of view of gonad doses the use of high-voltage techniques is neither strictly indicated nor strictly contra-indicated. The same is possibly true regarding the bone-marrow dose and the integral dose, which also seem to be scarcely influenced by the quality of the incident beam (Epp et al., 1961; Zieler, 1960).

The above considerations regarding high-voltage techniques and gonad doses are, with slight alterations, also applicable to added filtration. In fact both factors cannot be considered separately. It is unquestionable that increased filtration gives a reduction of the ratio of incident dose to exit dose and thus reduces the skin dose if the exit dose is kept constant. The influence of beam filtration on the ratios of depth doses to exit dose is much less important. According to Trout et al. (1952) the reduction of the ratio of depth dose to exit dose, resulting from 3 mm Al added filtration, is already quite small at a depth of 9 cm in the primary beam. Stanford (1957) found that the relative dose at 12 cm depth in the primary beam was only reduced by 7 per cent if at 70 kV a 2 mm Al filter was added. In most radiographic views of the abdomen and pelvic region the ovaries will lie at a depth of 9 to 12 cm. It should be noted that usually the testes will lie at a much lesser depth, such that by additional beam filtration the testis dose can be reduced nearly as much as the incident dose.

According to Stanford & Vance (1955) at 20 cm from the edge of the primary beam, inside a phantom, the ratio of side scatter dose to exit dose decreases about 3 per cent if 2 mm Al is added at 70 kV. However, Haybittle (1957) found that at 25 cm from the central axis and at a depth of 10 cm this ratio may increase with filtration. At any rate, as is evident from this author's figures and diagrams this increase is only slight.

Thus, as far as gonad doses are concerned the amount of beam filtration is usually not of great importance. The same applies again to bone-marrow doses and to integral doses (REINSMA, 1959, 1960b). As added filtration does reduce skin doses without impairing the quality of the film or of the fluoroscopic image it should always be recommended. In each kV range that beam filtration should be selected that gives appreciable decrease of the skin dose without necessitating the use of unduly high mAs exposures. Various kV-filter combinations have been recommended. TROUT et al. (1952) recommended an additional filter of 2 mm Al in the range of 50 to 70 kV; 3 mm Al in the range of 70 to 100 kV and 0.25 mm Cu at tensions higher than 100 kV. ARDRAN & CROOKS (1952) agreed with these recommendations. KIRSH (1957) recommended to use at all voltages 2 mm Al added filtration in radiography and 3 mm Al in fluoroscopy. For fluoroscopy FRIK & BUCHHEIM (1955) found that at 90 kV with 6 mm Al total filtration the conflicting demands regarding the ratio of incident to exit dose and the image definition are best satisfied (see Chapter V, section 3). WILHELM et al. (1958) preferred the use of 0.2 mm Cu at all voltages in diagnostic radiology.

5. SPECIAL MEASURES

At this point it is not intended to discuss extensively all newer technical developments which, apart from having other advantages, also can contribute, to a greater or lesser extent, to the reduction of doses in diagnostic radiology. These techniques are merely to be mentioned here, while some remarks may serve to indicate their relative importance.

From the point of view of dose reduction the introduction of *image intensification* has been a most important technical advance. For a number of years image intensifiers have been successfully used in fluoroscopy. If the voltage and milliamperage are kept constant, with image intensification the brightness of the screen is about 1000 times that in plain fluoroscopy (JANKER, 1956). This means that the milliamperage can be lowered significantly, even if dark adaptation is omitted. The skin dose can easily be reduced by a factor of at least 10. The reduction of gonad doses and other tissue doses can be of the same order of magnitude. Also in *cineradiographic procedures* the use of image intensifiers is highly advantageous. Cineradiography with the aid of an image intensifier gives doses of about 1 to 5 per cent of those in cineradiography with lens - or mirror-cameras (ARDRAN, 1956). As is pointed out by ARDRAN (1957) in cineradiography with image intensification dose restriction should nevertheless be kept in mind; "the dose per frame may be low, the total dose when many frames are exposed may be unduly high".

The further refinement of the technical possibilities of image intensification by way of television cameras carries no consequences as far as

doses to patients are concerned. However, as in cineradiography, this refinement should not induce the radiologist unduly to lengthen the duration of examinations.

In *photofluorography* the dose to skin, gonads and other organs is reported to be lower than in plain fluoroscopy, but higher than in plain radiography. In mass surveys the magnitude of the gonad doses is an important consideration. According to measurements published by the ADRIAN COMMITTEE (1959) the average skin dose in P.A. photofluorography of the chest (mass miniature radiography) is 0.63 r per examination. The ovary dose was reported to vary from 0.10 to 0.23 mr, the testis dose from 0.07 to 0.16 mr. In its 1960 report the ADRIAN COMMITTEE stated that the mean gonad dose per examination of the chest was 1.34 mr for males and 5.53 mr for females. It should be noted that these figures are applicable to complete examinations, in this case to a mean of 1.1 or 1.2 exposures and 0.5 minutes of fluoroscopy. The dose for females was derived from measurements at the iliac crest, using a conversion factor determined on a phantom. The gonad doses for single fluoroscopy were not stated in this report. The mean testis dose in photofluoroscopy measured by LARSSON (1958) is 0.21 mr, a figure which is not much different from that of the ADRIAN COMMITTEE. LARSSON measured a mean ovary dose of 3.5 and 4.6 mr (two different roentgen departments) and a mean testis dose of 1.5 and 2.0 mr respectively per examination of the chest. He stated that the contribution of fluoroscopy to these doses was 90 and 60 per cent respectively. This would mean ovary doses of about 3 mr by fluoroscopy and 0.35 to 1.85 mr by radiography. Correspondingly, for males figures of about 1.3 mr for fluoroscopy and 0.15 to 0.80 mr for radiography can be calculated. According to this, photofluorography of the chest does not always give higher gonad doses than plain radiography. For testis doses the same conclusion may be drawn from figures of STANFORD & VANCE (1957), who indicated doses of 0.15 mr and 0.25 mr for the female and male gonads respectively in photofluorography and corresponding figures of 0.07 mr and 0.36 mr respectively for straight radiography of the chest. However, during the experiments as described in Chapter V an ovary dose of 0.018 to 0.023 mr and a testis dose of 0.017 to 0.049 mr was measured during P.A. radiography of the chest. A mean ovary dose of 0.13 mr and a mean testis dose of 0.07 mr were calculated for fluoroscopy of the chest during 1 minute (Chapter VI). These figures are considerably lower than those quoted above, but are in better agreement with those measured for instance by SEELENTAG et al. (1958). In the present investigation no measurements were made during photofluorography. The discrepancy of the data given by the various authors may partly be explained by the differences in radiographic and fluoroscopic techniques but, and not in the least, also by the extreme difficulty of measuring small gonad doses.

On the basis of the data given above it seems not to be possible to state categorically that plain radiography of the chest gives lower gonad doses than photofluorography, which again would give lower gonad doses than fluoroscopy of the chest. Much depends on the technique, the field alignment and, concerning fluoroscopy, on the fluoroscopic time needed by the physician.

A most interesting technical development is that of *logetronography*. By means of this procedure underexposed films may be improved sufficiently to yield diagnostic information. Apart from other applications of logetronography, this may be valuable from the point of view of dose reduction (MOHR et al., 1959; WERNER et al., 1959).

In tomography the use of multiple film cassettes is useful, again especially from the point of view of doses to patients. According to ANGERSTEIN (1960) the dose to the male gonads in *simultaneous tomography* of the chest (7 films) is in the order of 1 mr. During plain tomography of the chest SEELENTAG et al. (1958c) measured a mean testis dose of 0.74 mr per film; for a tomography of the chest requiring 6 films STANFORD & VANCE (1957) indicated an ovary dose of 0.9 mr and a testis dose of 6.2 mr. The corresponding figures presented by the ADRIAN COMMITTEE (1960) are 1.12 mr (females) and 1.32 mr (males) respectively for a mean of about 7 films per examination. Here again the differences of the data given by the various authors may be noted.

Finally the magnitude of the patient's doses can also be influenced by the choice of grids, cassette-screen-film combinations and the development technique. The exposure dose required for radiography through a grid is higher than the dose for a radiograph of the same part of the body without a grid. The quality of the grid chosen for a given radiographic view is largely a matter of opinion. The higher the lead content (and usually the ratio) of the grid, the higher the so-called grid factor, but the better the improvement of contrast (BONENKAMP & HONDIUS BOLDINGH, 1959).

Regarding screen-film combinations it may be stated that, in general, the faster this combination, the poorer the definition. ARDRAN (1957) compared various screens and films and pointed out that where fine detail is not required fast screens and fast films may be used for barium meal and barium enema work without real loss of information. This may be extended to other types of examinations, such as obstetrical radiography (BEWLEY et al., 1957). Fast screens and films, with good definition, may solve the problem, and indeed some of the newer types seem to have excellent qualities. It may be remarked that non-screen films should only be used for their special purpose, namely for radiographs of the distal parts of the extremities in cases where fine details are required. The optimum development technique for the type of film concerned should always be used. Interesting, but perhaps not generally applicable, is the technique of *chemical intensification,* performed with Du Pont or Adefo

solutions (CHANTRAINE & VIETEN, 1958; BUCHHEIM & FRIK, 1959; MOHR et al., 1959). One of the drawbacks of this technique is a reduced definition, such that in order to acquire acceptable details high definition screens and relatively slow films must be used.

That great dose reduction can be acquired by simple means is demonstrated by figures of ARDRAN & CROOKS (1957), who were able to reduce the testis dose in radiography of the pelvis (A.P.) by a factor of 100 and in radiography of the lumbar spine (A.P.) by a factor of nearly 50. According to SEELENTAG (1958b) the ratio of testis doses with "good" and "bad" techniques respectively is 1 : 150 in radiography of the chest and 1 : 32 in radiography of the abdomen. The importance of being "dose-conscious" in diagnostic radiology cannot be stressed enough. With this consciousness, together with some simple, inexpensive measures more dose reduction may be acquired than with expensive equipment.

SUMMARY AND CONCLUSIONS

In recent years attention has been focussed on the genetic and somatic effects of ionizing radiation. Studies in various countries indicated that at present medical uses of roentgen rays, and especially diagnostic roentgenology, are responsible for the major man-made exposure of many populations. As a result investigations have been performed in many countries to assess population doses due to diagnostic and therapeutic radiology. On the basis of these and other investigations recommendations have been made to reduce these doses. The present study gives the theoretical considerations leading to, and the results of an investigation concerning the genetically significant dose due to diagnostic roentgenology to a defined population in the Netherlands. This investigation was designed such that it would be comparable to investigations on the same subject in a number of other countries or cities.

In the *Introduction* some general considerations are given. Also the investigation method is outlined.

In *Chapter I* the present knowledge of the genetic effects of ionizing radiation is reviewed. Quite recently, in animal studies, dose-rate effects were demonstrated and different germ-cell stages and germ-cell lines were found to have different radiation sensitivities. Nevertheless, a linear dose-effect relation is still thought to exist for the induction of mutations by ionizing radiation. A threshold below which doses would be genetically ineffective has not been demonstrated. Radiation induced mutations are random changes and in most cases have deleterious effects. Human data concerning the genetic effects of ionizing radiation are scarce. Therefore, it is most difficult to assess the effects of various radiation exposures on the genetic characteristics of human populations. Genetic risk calculations for human populations usually have been based on the concept of a mutation frequency doubling dose. In the light of recent experimental data the value of the latter concept is highly debatable. Although reliable genetic risk estimates cannot at present be made, nevertheless it is important to assess existing and possible future levels of genetically significant doses.

In *Chapter II* a definition is given of the genetically significant dose. The methods to be used in its evaluation are described. It is stressed that the concept of genetically significant dose is valid only if, in fact, the genetic effects are linearly related to gonad doses and if no threshold exists. A method of calculation was introduced by English authors and worked out by two international committees. This method is used in the present investigation, carried out in the area of Leiden and Oegstgeest.

The investigation consists of three parts, the results of which are presented in the Chapters III, IV and V respectively. In Chapter II methods and results of simular investigations in various countries or cities are discussed. A general description of the method of the present investigation is given in this Chapter.

In *Chapter III* the results of the first part of the investigation are presented. A survey was carried out of the roentgendiagnostic units, used for medical purposes in the area of Leiden and Oegstgeest. The survey included 37 units in hospitals, 9 in institutes and 6 in private offices. Two other units in private offices could not be included in the survey. Various characteristics of the units were studied. The conclusions of this survey are as follows:

1. In the area surveyed few roentgendiagnostic units were found in use outside hospitals or institutes.
2. No obsolete or inadequately shielded units were found to be in use.
3. In general, low tube voltages were used for chest fluoroscopy. As there was no added beam filtration in nearly half the number of tubes, the radiation qualities used in fluoroscopy and radiography were generally soft.
4. The dose-rates measured under normal fluoroscopic conditions at the couch or at 25 cm before the screen ("tube outputs") ranged from 0.7 to 13.8 r per minute. In 12 of the 35 tubes used for fluoroscopy this output was more than 3.9 r per minute.

For each unit surveyed a record was made of the techniques normally used for various types of roentgendiagnostic examinations. These data were used in the assessment of average gonad doses per examination.

In *Chapter IV* the results of the analysis of examination records are discussed. Only examinations performed in 1959 on inhabitants of Leiden and Oegstgeest were taken into account. Population mass survey (not performed in Leiden or Oegstgeest in 1959) and dental radiography were excluded. A complete analysis included name, initials, sex and age of the patient, month of examination, the roentgendiagnostic unit used and the type of examination performed. In the case of chest examinations specially, a complete analysis was not always possible. The conclusions of this analysis are listed below:

5. The total number of examinations performed in 1959 was estimated at 59871 in a population of 109041 individuals, or 0.55 per capita of population.
6. Only about 9 per cent of these examinations was performed in private offices.
7. 35 individuals had together 400 examinations other than chest examinations.

8. In older age groups the frequency of roentgendiagnostic examinations was, in general, higher than in younger age groups.
9. 56.1 per cent of all examinations was performed on males. Only a few types of examinations were performed more frequently on females than on males.
10. Of all examinations 55.1 and 57.4 per cent was performed on males and females respectively below the age of 40 years.
11. The number of chest examinations was extremely high: 41753 or about 70 per cent of all examinations and 0.38 per capita of population.
12. Compared with that in other countries the frequency of obstetrical abdominal examinations was low. No pelvimetries were recorded at all.
13. Examinations during which the gonads necessarily lie in the primary beam constituted only about 10 per cent of the total number of examinations.
14. The examinations were not equally distributed over the months of the year.

Some of the frequency data collected during the analysis of examination records are compared with data presented by other authors. This comparison yields some interesting features.

In this Chapter also data are presented on subsequent child-expectancy for the population concerned. The future number of children expected by the average individual of the population concerned was calculated at 1.394. This figure is high compared with figures valid for populations in other countries. Partly due to this, the figures calculated for mean relative child-expectancies of men or women subjected to various roentgendiagnostic examinations are comparatively low. The latter figures are used as weighting factors in the calculation of the genetically significant dose.

In *Chapter V* the dosimetric study is described. For several reasons the gonad doses were not measured on patients, but on a tissue-equivalent phantom. The dimensions of this phantom were adapted to those of the typical Dutch male. The construction of the phantom is briefly described. Measurements were made with the aid of various Philips- and P.T.W.-ionization chambers, while also some chambers constructed in the Netherlands Institute for Preventive Medicine were used. Incident dose, exit dose and gonad doses for some 25 conventional radiographic views were measured at 5 different kV-filter combinations. A four-valve rectified roentgendiagnostic unit was used for the exposures. The first half value layers of the primary radiation ranged from 1.0 to 4.6 mm Al. For comparison of incident doses and gonad doses at various qualities of the incident beam the exit dose was used as a constant. It is discussed whether,

in fact, the exit dose may be used as a parameter in comparing tissue doses at various exposure techniques. Attention is drawn to some fundamental studies on this subject. In this Chapter the results of a study on the influence of the quality of the incident beam on the magnitude of gonad doses are presented. Also the results of some gonad dose measurements during fluoroscopy are discussed. The following conclusions are drawn:

15. The increase of radiation quality in radiography will usually result in a decrease of testis doses. In the case of two radiographic views only, namely the lateral views of both lumbosacral region and lumbar spine, the testis dose was found to increase with increasing radiation quality.
16. The increase of radiation quality in radiography will result in higher average ovary doses in those instances where one or both ovaries lie outside the primary beam.
17. In the quality range studied the influence of radiation quality on the magnitude of gonad doses is relatively slight.
18. In fluoroscopy the use of relatively high tube voltages is only justified if the tube current is sufficiently reduced. The influence of beam filtration on gonad doses in fluoroscopy is slight, provided that the mAs product is kept constant.

In combination with the frequency data (Chapter IV) and the data collected during the survey of roentgendiagnostic units (Chapter III) the results of the measurements of gonad doses on the phantom were used in the assessment of the genetically significant dose.

In *Chapter VI* is described how the data collected in all three parts of the investigation are used in the calculation of the genetically significant dose due to diagnostic roentgenology in 1959 to the population concerned. In the dosimetric study it was assumed that in practice the beam had been restricted to the film size used in all instances. As a result the gonad doses, and the genetically significant dose assessed in the present study, must be regarded as minimum doses. Also, it is stressed that the data are only valid for the population for which they were collected, i.e. the population of Leiden and Oegstgeest. Apart from the genetically significant dose some average gonad doses were calculated. The following conclusion are drawn:

19. For the population concerned the genetically significant dose due to diagnostic roentgenology in 1959 is estimated at a minimum of **6.8 mr.** This dose is low compared with some minimum doses estimated for populations in other countries.
20. For 1959, the mean gonad dose to individuals below the age of 30 years is estimated at a minimum of **5.7 mr.** If child-expectancy data are lacking, this dose may be used as an approximation to the genetically significant dose.

21. For 1959, the mean gonad dose to the population (the "per capita gonad dose") is estimated at a minimum of **18.7 mr.** In general, this dose may not be used as an approximation to the genetically significant dose.
22. Some 11 types of roentgendiagnostic examinations together contribute more than 97 per cent to the genetically significant dose, but constitute only about 12 per cent of the total number of examinations.
23. If good techniques are generally used the genetic dose due to diagnostic roentgenology need not be high.

In *Chapter VII* the literature on the subject of dose reduction in diagnostic roentgenology is reviewed. A few experiments on the phantom are used to illustrate the relative importance of some of the methods of dose reduction. The conclusions of this review are listed below:

24. The magnitude of the reduction of the patient's tissue doses by the use of high-voltage techniques in diagnostic roentgenology has been overstressed.
25. For dose reduction in diagnostic roentgenology careful restriction and alignment of the incident beam is of major importance.
26. In some instances simple gonadal shielding may succesfully be used without hampering the diagnostic quality of the radiograph.
27. Some recent technical developments may also contribute to the reduction of doses in diagnostic roentgenology.
28. However, in general, more dose reduction is acquired with some simple, inexpensive measures than with expensive equipment.

SAMENVATTING EN CONCLUSIES

In de laatste jaren wordt grote aandacht geschonken aan de genetische en somatische effecten van ioniserende straling. Onderzoekingen, welke in een aantal landen zijn verricht, wezen uit dat voor vele populaties de medische toepassingen van ioniserende straling, en vooral de röntgendiagnostiek, thans verantwoordelijk zijn voor de belangrijkste blootstelling aan kunstmatige straling. Op grond van deze bevinding zijn in vele landen diepergaande onderzoekingen ter schatting van de bevolkingsdoses tengevolge van diagnostische en therapeutische radiologie verricht. Op basis van deze en andere onderzoekingen zijn aanbevelingen ter beperking van deze doses opgesteld. De hier beschreven studie geeft de resultaten van een onderzoek naar de genetische dosis * tengevolge van de röntgendiagnostiek voor een omschreven populatie in Nederland. Tevens wordt een uiteenzetting gegeven van de theoretische overwegingen, waarop dit onderzoek is gebaseerd. Het onderzoek werd dusdanig opgezet dat het vergelijkbaar zou zijn met onderzoekingen over hetzelfde onderwerp in een aantal andere landen of steden.

In de *Inleiding* worden enkele algemene beschouwingen gegeven, terwijl tevens de onderzoekmethode kort wordt omschreven.

In *Hoofdstuk I* worden de huidige inzichten betreffende de genetische effecten van ioniserende straling kort weergegeven. Van vrij recente datum zijn de dier-experimenten waarbij invloed van de doseringssnelheid werd vastgesteld en waarbij tevens werd aangetoond dat verschillende stadia en soorten geslachtscellen verschillende stralingsgevoeligheid kunnen hebben. Dit betekent echter niet dat hiermee de hypothese van een lineair verband tussen dosis en effect voor de genetische effecten van straling vervalt. Een drempel, waaronder de doses genetisch onwerkzaam zouden zijn, kon niet worden aangetoond. De door straling opgewekte mutaties zijn volgens de wetten van het toeval optredende veranderingen. Meestal zijn deze veranderingen nadelig. De gegevens betreffende genetische effecten van ioniserende straling bij de mens zijn zeer beperkt. Het is daarom uiterst moeilijk de gevolgen te schatten van blootstelling aan diverse stralingsdoses voor de genetische eigenschappen van menselijke populaties. Deze schattingen werden gewoonlijk gebaseerd op het begrip „mutatiefrequentie-verdubbelingsdosis". Volgens recente experimentele gegevens is dit begrip echter zeer aanvechtbaar. Hoewel dus thans de genetische gevolgen niet op goed gefundeerde wijze kunnen worden geschat, is het toch van groot belang gegevens te verzamelen over de orde van grootte van huidige en toekomstig mogelijke bevolkingsdoses.

* „Genetically significant dose" is hier vertaald door „genetische dosis".

In *Hoofdstuk II* wordt een definitie gegeven van het begrip „genetische dosis". De methoden welke kunnen worden gebruikt voor de schatting van deze dosis worden besproken. Er wordt met nadruk op gewezen dat het begrip genetische dosis alleen inhoud heeft indien de genetische effecten inderdaad lineair toenemen met de gonadendoses en indien geen drempelwaarde bestaat. Door Engelse auteurs werd een berekeningsmethode ingevoerd, welke werd uitgewerkt door een tweetal internationale commissies. Deze methode is bij het huidige onderzoek toegepast. Het onderzoek werd uitgevoerd in Leiden en Oegstgeest en bestond uit drie gedeelten. Deze gedeelten worden achtereenvolgens in de Hoofdstukken III, IV en V besproken. In Hoofdstuk II worden verder methoden en resultaten besproken van soortgelijke onderzoekingen in een aantal landen en steden. Tenslotte wordt de bij het huidige onderzoek toegepaste methode aan een algemene beschouwing onderworpen.

In *Hoofdstuk III* worden de resultaten van het eerste deel van het onderzoek besproken. De in Leiden en Oegstgeest voor medische doeleinden gebruikte röntgendiagnostiek apparaten werden onderzocht. Dit gedeelte van het onderzoek betrof 37 apparaten in ziekenhuizen, 9 in instituten en 6 bij artsen thuis. Twee andere apparaten bij artsen thuis konden niet worden onderzocht. Verschillende eigenschappen van de apparaten werden bestudeerd. De volgende conclusies kunnen worden getrokken:

1. Weinig röntgendiagnostiek apparaten werden elders dan in ziekenhuizen of instituten gebruikt.
2. Er werden geen obsolete of onvoldoend afgeschermde apparaten aangetroffen.
3. Thoraxdoorlichting vond veelal met lage buisspanning plaats. In bijna de helft der gevallen bleek bovendien geen extra filter op het buisvenster aanwezig te zijn. De bij thoraxdoorlichting gebruikte stralenkwaliteiten bleken daarom meestal zacht.
4. De, bij gewoonlijk voor thoraxdoorlichting gebruikte buisspanning en buisstroom, ter hoogte van het tafelblad of op een afstand van 25 cm voor het doorlichtingsscherm gemeten doseringssnelheid („output") varieerde voor 35 apparaten van 0,7 tot 13,8 r per minuut. Bij 12 van de 35 voor doorlichting gebruikte apparaten was deze doseringssnelheid meer dan 3,9 per minuut.

Voor ieder bij het onderzoek betrokken apparaat werd een lijst samengesteld waarop de bij diverse soorten röntgenopnamen gewoonlijk toegepaste werkwijzen werden genoteerd. Deze gegevens zijn gebruikt bij het berekenen van de gemiddelde gonadendosis per type van onderzoek.

In *Hoofdstuk IV* worden de resultaten van een onderzoek naar de frequentie van röntgendiagnostische verrichtingen besproken. Bij de

analyse hiervan werden alleen onderzoekingen, welke in 1959 werden verricht bij inwoners van Leiden of Oegstgeest, in aanmerking genomen. Bevolkingsonderzoek (dat in 1959 in Leiden of Oegstgeest niet plaats vond) en door tandartsen verrichte röntgenonderzoekingen werden buiten beschouwing gelaten. Bij een volledige analyse werden naam, initialen, geslacht en leeftijd van de patiënt, maand van onderzoek, het gebruikte röntgenapparaat en het type van onderzoek genoteerd. Speciaal van thoraxonderzoekingen was een volledige analyse niet altijd mogelijk. De uit dit gedeelte van het onderzoek te trekken conclusies luiden:

5. Het totaal aantal onderzoekingen, in 1959 verricht bij een populatie van 109041 personen wordt berekend op 59871; d.w.z. op 0,55 per hoofd van de bevolking.
6. Slechts ongeveer 9 procent van deze onderzoekingen werd bij artsen thuis verricht.
7. 35 personen ondergingen in totaal 400 onderzoekingen; thoraxonderzoekingen zijn hierbij niet inbegrepen.
8. In het algemeen was in oudere leeftijdsgroepen de frequentie van röntgendiagnostische verrichtingen hoger dan in jongere leeftijdsgroepen.
9. 56,1 procent van alle onderzoekingen werd bij mannen verricht. Slechts enkele types van onderzoek werden vaker bij vrouwen dan bij mannen verricht.
10. Bij mannen werd 55,1 procent der onderzoekingen verricht beneden de leeftijd van 40 jaar. Voor vrouwen was dit 57,4 procent.
11. Het aantal thoraxonderzoekingen bedroeg ongeveer 70 procent van alle onderzoekingen en 0,38 per hoofd van de bevolking.
12. De frequentie van röntgenologische obstetrische buikonderzoekingen is zeer laag, vooral in vergelijking met deze frequentie in sommige andere landen. Er werden in het geheel geen pelvimetrieën geregistreerd.
13. Bij slechts ongeveer 10 procent van alle onderzoekingen is niet te vermijden dat de gonaden in de primaire bundel liggen.
14. Het aantal per maand verrichte röntgenonderzoekingen kan vrij sterk wisselen.

Sommige van de in dit Hoofdstuk besproken resultaten worden vergeleken met door andere auteurs gepubliceerde gegevens. Bij deze vergelijking komen enkele interessante punten naar voren.

In dit Hoofdstuk wordt verder mededeling gedaan van een aantal gegevens over de gemiddelde kinderverwachting. Het aantal kinderen, gemiddeld nog te verwachten door een persoon uit de desbetreffende populatie wordt berekend op 1,394. Deze uitkomst is hoog in vergelijking met die van soortgelijke berekeningen voor populaties in andere landen. Ge-

deeltelijk tengevolge hiervan zijn de berekende waarden voor de gemiddelde relatieve kinderverwachting, voor een man of vrouw die een bepaald type röntgenonderzoek ondergaat, vergelijkenderwijze laag. Deze laatste waarden worden als gewichtsfactoren gebruikt bij de berekening van de genetische dosis.

In *Hoofdstuk V* wordt het dosimetrische gedeelte van het onderzoek beschreven. Om verschillende redenen werden de gonadendoses niet bij patiënten, maar in een weefselequivalent phantoom gemeten. De afmetingen van dit phantoom zijn aangepast aan de meest voorkomende afmetingen van de Nederlandse man. De constructie van het phantoom wordt kort beschreven.

De metingen werden verricht met behulp van verschillende Philips- en P.T.W.-ionisatiekamers, terwijl verder enkele in het Nederlands Instituut voor Praeventieve Geneeskunde geconstrueerde kamers werden gebruikt. Voor een 25-tal gebruikelijke röntgenopnamen werden intreedosis, uittreedosis en gonadendoses bij 5 verschillende kV-filter combinaties gemeten. Voor de belichtingen werd gebruik gemaakt van een 4-ventiels röntgendiagnostiek apparaat. De eerste halveringsdikte van de primaire straling varieerde van 1,0 tot 4,6 mm Al. Om vergelijking van intreedosis en gonadendoses bij verschillende stralenkwaliteiten mogelijk te maken werd de uittreedosis als constante gebruikt. In dit Hoofdstuk wordt overwogen of deze methode verantwoord is. Hierbij wordt o.a. verwezen naar enige fundamentele onderzoekingen op dit gebied.

Vervolgens worden de resultaten van een onderzoek naar de invloed van de kwaliteit van de primaire straling op de grootte van de gonadendoses besproken. Ook wordt mededeling gedaan van enkele metingen van gonadendoses tijdens doorlichting. De volgende conclusies werden getrokken:

15. Bij een röntgenopname heeft een hardere stralenkwaliteit gewoonlijk een lagere testisdosis tengevolge dan een zachtere kwaliteit. Slechts bij twee opnametypes, nl. de laterale opname van het lumbosacrale gebied en de laterale opname van de lumbale wervelkolom bleek verharding van de primaire straling gepaard te gaan met toename van de testisdosis.
16. Verharding van de primaire straling geeft toename van de gemiddelde ovariumdosis bij die opnamen waar één of beide ovaria buiten de primaire bundel liggen.
17. In het onderzochte kwaliteitsbereik is de invloed van de stralenkwaliteit op de grootte van de gonadendoses in het algemeen gering.
18. Bij doorlichting is het gebruik van hoge buisspanningen alleen verantwoord als de buisstroom voldoende wordt verlaagd. Filtratie van de primaire bundel heeft weinig invloed op de grootte van de gona-

dendoses bij doorlichting, indien althans het product van buisstroom en tijd constant wordt gehouden.

De resultaten van de metingen der gonadendoses in het phantoom werden, tezamen met de frequentiegegevens (Hoofdstuk IV) en de gegevens betreffende de röntgendiagnostiek apparaten (Hoofdstuk III), gebruikt bij de berekening van de genetische dosis.

In *Hoofdstuk VI* wordt beschreven op welke wijze de in de drie gedeelten van het onderzoek verzamelde gegevens werden gecombineerd bij de berekening van de genetische dosis tengevolge van de röntgendiagnostiek bij de in het onderzoek betrokken populatie in 1959. Daar voor de bepaling der gonadendoses werd aangenomen dat in de praktijk steeds zorgvuldige bundelbeperking was toegepast, moeten de op grond van dit onderzoek bepaalde gonadendoses, en eveneens de genetische dosis, als minima worden beschouwd. Er wordt verder op gewezen dat de gegevens alleen gelden voor de populatie waarover zij werden verzameld, dus voor de bevolking van Leiden en Oegstgeest. Behalve de genetische dosis werden enkele gemiddelde gonadendoses berekend. De volgende conclusies kunnen worden getrokken:

19. De genetische dosis tengevolge van de röntgendiagnostiek in 1959 wordt voor de betrokken populatie geschat op een minimum van **6,8 mr.** Deze dosis is laag in vergelijking met de voor populaties in andere landen geschatte minimale doses.

20. De gemiddelde gonadendosis voor personen beneden de leeftijd van 30 jaar wordt voor 1959 minimaal geschat op **5,7 mr.** Deze dosis mag worden gebruikt als benadering van de genetische dosis indien geen gegevens betreffende de kinderverwachting beschikbaar zijn.

21. De gemiddelde gonadendosis voor de gehele in het onderzoek betrokken populatie (de „per capita gonadendosis") wordt voor 1959 minimaal geschat op **18,7 mr.** Deze dosis mag in het algemeen niet worden gebruikt als benadering van de genetische dosis.

22. 11 types van röntgenonderzoek dragen tezamen meer dan 97 procent bij tot de genetische dosis, terwijl zij tezamen slechts ongeveer 12 procent uitmaken van het totaal aantal onderzoekingen.

23. Indien steeds goede werkwijzen worden toegepast behoeft de genetische dosis tengevolge van de röntgendiagnostiek niet hoog te zijn.

In *Hoofdstuk VII* wordt een overzicht gegeven van de in de literatuur aangegeven methoden ter beperking van de doses in de röntgendiagnostiek. Het relatieve belang van een aantal van deze methoden wordt toegelicht met enkele resultaten van metingen in het phantoom. Hierbij gelden de volgende conclusies:

24. De „hardstraal" techniek heeft minder waarde voor de beperking van de door de patiënt ontvangen weefseldoses dan wel werd gemeend.
25. Zorgvuldig instellen en afperken van de primaire bundel zijn voor de dosisbeperking van veel meer belang.
26. In sommige gevallen kan afscherming van de gonaden op eenvoudige wijze worden verwerkelijkt zonder dat daarbij de diagnostische waarde van de röntgenbeeld nadelig wordt beïnvloed.
27. Enkele recente technische ontwikkelingen kunnen eveneens bijdragen tot dosisbeperking in de röntgendiagnostiek.
28. In het algemeen echter wordt door enkele eenvoudige, weinig kostbare maatregelen meer dosisbeperking verkregen dan door gebruik van kostbare apparatuur.

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STELLINGEN

I

Verlaging van de huiddosis in de röntgendiagnostiek gaat niet altijd gepaard met verlaging van de gonadendosis.

II

In verband met de dosisbeperking in de röntgendiagnostiek dient men bij de „hardstraaltechniek" zeer terughoudend te zijn met het gebruik van zgn. hardstraalrasters en kruisrasters.

III

Op grond van theoretische en practische overwegingen dient te worden afgezien van de algemene invoering van persoonlijke stralings-registers („stralingskaarten").

IV

Recente bevindingen betreffende de zuurstofdruk in tumorweefsels vóór en na bestraling, en betreffende bestraling van weefselculturen, maken wellicht enige rationalisering mogelijk van de thans nog overwegend empirische radiotherapeutische methodieken.

V

Bij passagiersvluchten op een hoogte van ca. 20 km dient rekening te worden gehouden met de mogelijkheid van plotselinge toename van de stralingsintensiteit tengevolge van zonne-erupties.

VI

Uit de door Wesley * gesuggereerde correlatie tussen het aantal congenitaal misvormden per 1.000 levendgeborenen en de geomagnetische breedtegraad mogen geen conclusies betreffende de genetische effecten van straling bij de mens worden getrokken.

* J. P. Wesley
Int. J. Rad. Biol., 1960, *2*, 97.

VII

Daar bij de mens de frequentieverdeling van vele anatomische, physiologische en biochemische kenmerken niet bekend is, zijn vaak noch het

gemiddelde, noch de modus, noch de grenzen van het „normale" aan te geven.

VIII

Het verdient aanbeveling een systematisch, statistisch verantwoord onderzoek in te stellen naar de kwantitatieve verdeling van het actieve beenmerg in het skelet van kinderen en volwassenen.

IX

De beoordeling van de waarde van een „fellowship", voor de „fellow" zelf en voor zijn land van herkomst, is ontoereikend door gebrek aan objectieve criteria.

Appraisal of Fellowships.
W.H.O. Techn. Rep. Ser. no. 186, 1960.

X

Uit de verdere studie betreffende het physiologische en het versnelde verouderingsproces zijn gegevens te verwachten, die bij kunnen dragen tot beter inzicht in de rol van veranderingen aan het genetisch materiaal bij de carcinogenese.

XI

De onvolledige, inconsequente en niet genormaliseerde registratie van medische gegevens in en buiten ziekenhuizen in Nederland veroorzaakt tijd- en geld-verlies bij, en in sommige gevallen tekortschieten van medisch-wetenschappelijk onderzoek.