DETERMINATION OF THE GENETICALLY-SIGNIFICANT DOSE

FROM DIAGNOSTIC RADIOLOGY

FOR

THE SOUTH AFRICAN POPULATION,

1990 - 1991.

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Dedication

To Rita, Johan and Jacques; and

to my mother and to the memory of my father.

ABSTRACT

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The International Commission on Radiological Protection (ICRP) determines the policy regarding radiation safety internationally. To the ICRP, **hereditary changes** as a result of either high or low doses, are of a major concern. The SA Forum for Radiation Protection recommended that a research project to determine the genetically-significant dose (GSD) for the South African population should be done as such a project has never been undertaken to date. This term was at first defined by UNSCEAR in 1958. The National Radiological Protection Board derived a formula from this definition as shown in the NRPB Report, NRPB-R106 (1980). This formula was implemented in the project. It combines the frequency of radiological examinations obtained during the country-wide survey and estimates of gonadal doses for different examination types, together with population and child expectancy data .

New procedures, techniques and data processing that were relevant to this project had to be developed because the available information and conditions are unique to South Africa. The task was set to find a model in order to draw the best representative sample of the population and it was determined in a unique way, namely the so-called Dollar Unit Sampling method. A sample of 27 institutions out of a possible 292 (9%) was drawn in comparison, e.g., with the 8% of France and 8% in Great Britain. It was necessary to rely mainly on the calculation of gonad doses due to a shortage of manpower, contrary to other countries that were able to physically measure doses. Information obtained in the survey was used in this regard. The "RADCOMP Entrance Skin Exposure Software Program " of Nuclear Associates was used to produce parametric Free Air Exposure tables based on doses from Table B.3, NCRP Report No. 102. After the skin entrance doses were calculated, it was possible to calculate the gonad doses. A computer program was obtained from the Food and Drug Administration in the USA for this purpose. Data analysis was performed by means of the software package Microsoft Excel version 4.0.

The above-mentioned formula was used in order to obtain the final results. The GSD for the **total** SA-population was calculated as **94.6 μGy**. The breakdown of the GSD for the various South African race groups was Asian - 229.0 μGy, Black - 66.5 μGy, Coloured - 112.2 μGy and White - 463.4 μGy.

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Chapter 1

INTRODUCTION

Medical irradiation is the largest man-made contributor to the radiation dose received by mankind and diagnostic radiology is the most important component of medical irradiation. The radiation exposure of the world population has recently been reviewed by the United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR). According to González (1993), UNSCEAR revealed in its 1993 report to the UN General Assembly that the collective exposure committed to the world population by a 50-year period of operation for continuing practices or by single events (e.g. nuclear weapon testing) from 1945 to 1992 (as a percentage) were as follows: 76.58% from natural sources; 10.68% from medical diagnostic exposure; 8.83% from radiotherapy; 3.53% from atmospheric nuclear weapons tests; 0.24% from nuclear power; 0.07% from severe accidents and 0.07% from occupational exposures (González, 1993). The collective exposure due to medical diagnostic examinations could be further subdivided. It was found in the UK (Hughes, Shaw and O'Riordan, 1989) that 93% was due to diagnostic X-rays, 6% to nuclear medicine and 1% to dental X-rays.

In South Africa reliable as well as representative information was expected to be obtained in a nation-wide survey regarding the determination of the genetically-significant dose (GSD). All diagnostic X-ray equipment in the country had already been inspected on various occasions since 1973 and recommendations had been made according to international standards regarding the safety of X-ray units as well as the relevant technique factors and quality assurance procedures.

The benefits of such a study in the South African context would include:

(i) A comparison of the contribution of various examinations to the GSD with those of other countries (the technique factors required to calculate the GSD, i.e., kV, mA, etc., can be compared too).

(ii) A determination by means of follow-up studies whether the above-mentioned contributions are increasing or decreasing (as well as a change in technique factors).

(iii) The identification of examinations where special hereditary (as well as somatic) health risks exist.

At the time that the survey was done for this project, 54 per cent of the population lived within South Africa's four provinces (Cape Province, Natal, Orange Free State and Transvaal) and the remainder in the black ethnic states or Bantu Homelands. Six of these states (Gazankulu, KaNgwane, KwaNdebele, KwaZulu, Lebowa and Qwa-Qwa) were designated self-governing and the other four (Bophuthatswana, Ciskei, Transkei and Venda) were independent. Data from the independent or so-called TBVC States (6.6 million people) was excluded from any data referring to the Republic of South Africa and was therefore not included in this project (Chief Directorate: Planning Support, 1992).

Under the old Population Registration Act, the population was classified under four ethnic groups, namely Asians, Blacks, Coloureds and Whites. Approximately 75% of the population was Black, 13% White, 9% Coloured and 3% Asian (Chief Directorate: Planning Support, 1992). The population groupings can be defined as follows:

(a) Asians - mainly of Indian descent.

(b) Blacks - descendants of African peoples who migrated in a southerly direction from Central Africa. They comprise ten different ethnic groupings: Xhosa, Zulu, Swazi, South Ndabele, North Ndabele, Northern Sotho, Southern Sotho, Tswana, Venda and Shangaan.

(c) Coloureds - people of mixed parentage. Mainly descendants of the indigenous Khoikhoi people, the Malay slaves (introduced to the Cape by the Dutch East India Company) and the White settlers.

(d) Whites - descendants of the European settlers, mainly Dutch, British, German, French, Portuguese, Greek, Italian and Jewish.

Under the previous government South Africa was therefore in the unique position that information was available to calculate the GSD for four different race groups.

The possible adverse genetic effects of exposure of the human population to low doses of ionising radiation regarding the population of the future, are discussed in Chapter 2. This might occur if deleterious mutations (change in the structure of DNA) to the gametes were caused by the radiation exposure of people and was put in the gene pool, i.e. transmitted to the descendants.

This study is primarily concerned with doses to the reproductive cells due to medical X-ray examinations. These doses will make no contribution to genetic effects in subsequent generations when received after completion of a person's reproductive cycle. The "genetically-significant dose" (GSD) is therefore obtained by multiplying the estimated

doses of the individuals with a weighting factor, namely the child expectancy of the patient. Doses thus obtained for different countries vary by a factor of almost ten. The GSD is a prime index of risk to the descendants of a population from diagnostic radiology and the definition as well as the assumptions and considerations that it is based on, are discussed in detail.

During the early days of radiological experience, there was no precise unit of radiation measurement that was suitable either for radiation protection or for radiation therapy. When X-rays interact with matter, energy is absorbed mainly by the process of ionisation and this principle provides a very good method for radiation measurement. It is a feature of ionisation radiation that the energy absorption in the body and its distribution in specific organs and tissues can be determined either by measurement or calculation. Various units and quantities that are applicable to this project, are reviewed in Chapter 3.

X-rays were used medically almost immediately after their discovery in 1895 for a multitude of purposes that involved some necessity for visualising the interior of the human body. Biological harmful effects of X-rays were already noted in 1896 in some of the early X-ray workers. According to Mould (1980), Edison for example reported in March 1896 that his eyes were sore after experimenting with X-rays and radiation burns to hands were reported by Stevens on 18 April 1896. The Röntgen Society (Mould, 1980) appointed a committee in April 1898 to collect data on the harmful effect of X-rays. Aspects investigated by this committee included nature of injurious effect, duration of effect, nature of radiographic investigation, condition of subject, type of apparatus used, distance of patient from the tube, number and duration of each exposure. This could be perhaps considered as a first step in the direction of the radiation protection programs that followed later.

Albers-Schönberg was the first person to realise that there was a possibility of an adverse effect of ionising radiation on biological reproductive systems when he discovered in 1903 that X-rays were capable of sterilising guinea pigs without any other obvious change in the well-being of the animals (Albers-Schönberg, 1903). In spite of these early discoveries of deleterious effects the idea of setting up "safe" exposures for radiation workers was only developed in the 1920's. The biological effects and radiation protection standards are discussed in Chapter 4.

The International Commission on Radiological Protection (ICRP) determines the policy regarding radiation safety internationally. Although no hereditary abnormalities have been

observed in human beings, hereditary changes as a result of either high or low doses are of a major concern to the ICRP (ICRP, 1982). This does not implicate that somatic changes are of minor concern (it is not dealt with in this project, however). The South African Forum for Radiation Protection thus recommended that a research project to determine the genetically-significant dose (GSD) from diagnostic radiology for the South African population should be carried out. Due to the limited available manpower and budgetary constraints it was recommended that it should be mainly a theoretical study.

The genetically-significant dose is an index of the presumed genetic impact of radiation exposure on the whole population. This quantity, with particular reference to medical diagnostic radiology, has been determined in various countries. The main details of survey methods in sixteen countries and some large districts, between 1958 and 1986, are presented in Chapter 5.

New procedures, techniques and data processing that were relevant to the current project had to be developed because the available information and conditions are unique to South Africa. The task was set to find a model in order to draw the best representative sample of the population who had undergone X-ray examinations. It was decided to make use of the so-called Dollar Unit Sampling (DUS) method since it appeared to provide definite advantages above other sampling methods. A sample of 27 institutions out of a possible 292 (9%) was thus drawn which represented 25.8% of all examinations per week.

Survey forms were designed for distribution to the various institutions that finally agreed to participate. Distribution of the forms started in July 1990. The survey was done during one week of the second semester of 1990 or the first semester of 1991 for all X-ray units at a specific institution. Data was requested for 96 diagnostic examinations of which 30 were chosen for inclusion in the calculation of the GSD. These 30 were considered as most likely to make an appreciable contribution to the gonad doses on the basis of the number of exposures associated with an examination and the gonad dose associated with each exposure.

The "RADCOMP Entrance Skin Exposure Software Program" of Nuclear Associates was used to produce parametric free air exposure (FAE) tables (Nuclear Associates and Zamenhof, 1990) that were applied to determine skin entrance doses. A computer program was obtained from the FDA, US Department of Health and Human Services, in the USA (Peterson and Rosenstein, 1989) in order to calculate the gonad doses (Table 8.6).

The number of examinations, $N_{k\ell}$, in the various age-gender-race groups (k) that underwent an examination of type ℓ was obtained from the database and the population data (Figures 8.1 and 8.2) was obtained from the Central Statistical Service (Population Census 1991, 1992). Child expectancy for people in different age groups was obtained by means of the total fertility numbers for the different races and of the data of Darby *et al.*, (1980). These quantities, namely the gonad doses, the $N_{k\ell}$ values, child expectancies and the population data were used in Chapter 9 to calculate the GSD for the various groups.

Chapter 2

THE CONCEPT OF GENETICALLY-SIGNIFICANT DOSE

A possible consequence of exposure of the human population to low doses of ionising radiation is an adverse effect on the population of the future. This might occur if deleterious mutations (change in the structure of DNA) to the gametes were caused by the radiation exposure of people and was put in the gene pool, i.e. transmitted to the descendants. This study is primarily concerned with doses to the reproductive cells due to medical X-ray examinations. These doses will make no contribution to genetic effects in subsequent generations when received after completion of a person's reproductive cycle. The "genetically-significant dose" is therefore obtained by multiplying the estimated doses of the individuals with a weighting factor, namely the child expectancy of the patient. Doses thus obtained for different countries vary by a factor of almost ten.

2.1 The genetic effects of radiation

The substance, DNA (deoxyribonucleic acid), carries within its structure the hereditary information that determines the structure of proteins. The instructions that direct cells to grow and divide are encoded by DNA as well as the messages that cause the differentiation of fertilised ova into many specialised cells that are necessary for the successful functioning of higher plants and animals. Heredity is transmitted through ovum and sperm.

2.1.1 Basic genetic terms and principles

In all cells, excluding bacteria, the inner cellular mass is partitioned into a membrane-bound, spherical body, the nucleus, and an outer surrounding, namely the cytoplasm. The DNA is located in the nucleus in the form of coiled rods known as chromosomes. All the information that specifies a particular human being with his or her individual characteristics are carried in code form by the chromosomes.

The fundamental unit of DNA is at present considered to be two intertwined polynucleotide chains, i.e. a multichained molecule or a double helix. Sugar-

phosphate backbones are on the outside of the DNA molecules and the purine and pyrimidine bases are on the inside, oriented in such a way that they can form hydrogen bonds to bases on opposing chains, i.e. a purine on one chain is always hydrogen-bonded to a pyrimidine on the other chain. This implies that the area occupied by the paired bases would always be the same throughout the length of the DNA molecule, therefore it is a very regular-appearing structure despite the irregular sequence of bases on any one chain. Further, the two purines, adenine and guanine, do not unselectively bond to the two pyrimidines, thymine and cytosine. Adenine (A) can pair only with thymine (T) and guanine (G) can bond only with cytosine (C). Each of these pairs possesses a symmetry that permits it to be inserted into the double helix in two ways, namely A–T and T–A as well as G–C and C–G (Figure 2.1); thus along any given DNA chain, all four bases can exist in all possible permutations of sequence (Watson *et al.*, 1992).

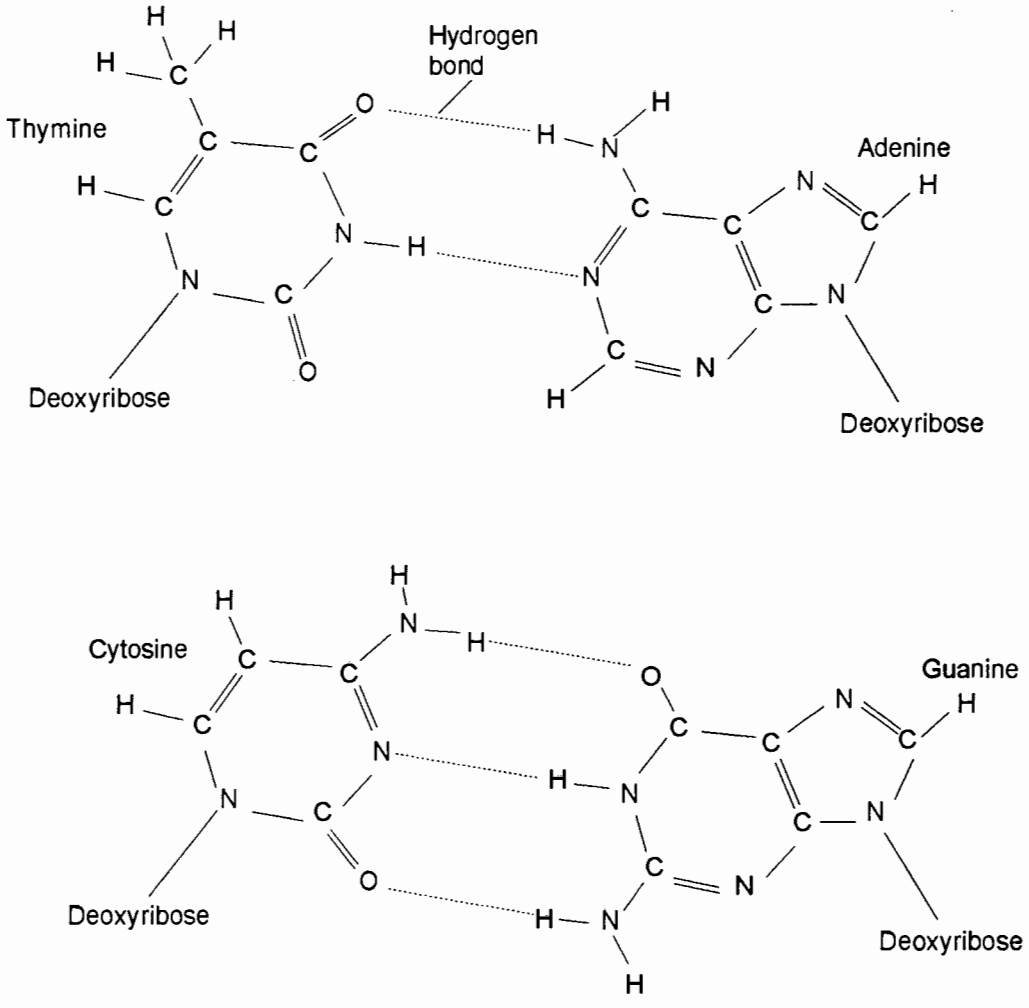


Figure 2.1 *Bonding between the adenine-thymine and guanine-cytosine base pairs.*

The gene is a finite segment of DNA specified by an exact sequence of bases, i.e. the portion of DNA transcribed to ultimately result in the synthesis of a protein is known as a gene. Genes occur along chromosomes in linear order like beads on a string,

and the position of a gene is referred to as its locus. In the case of humans, every normal cell has 46 chromosomes where 23 were derived from the mother and 23 from the father. Each chromosome of a pair usually has the same genes for given characteristics, is lined up in the same sequence and it is said to be homologous. The pair of chromosomes that determine the gender are XX in the female and XY in the male. The two chromosomes for the male do not contain parallel genes and are said to be heterologous. Some genes, dominant genes, express themselves when they are present in only one copy, whereas other genes, recessive genes, require two copies for expression.

An example to illustrate this is that the gene for blue eyes is recessive, while that for brown eyes is dominant. The Y sex chromosome in humans appears to have a few other genes except for those that determine maleness. The X chromosome, however, has many genes. If a mother carries a recessive mutant (see next paragraph) gene on the single X chromosome that she donates to her son, there will be no matching gene from the father, and consequently the recessive gene will be expressed. If the descendant is a daughter, there may well be a dominant gene on the X chromosome supplied by the father, which would suppress the expression of the recessive mutant. The daughter could transmit the mutant gene to her sons, in whom it would be expressed. The characteristics that are due to recessive genes on the X chromosome, so that they are expressed almost exclusively in male children, are said to be sex-linked. The most common examples are colour blindness and hemophilia. Most characteristics are, however, the result of an interplay in the expression of many genes.

Radiation does not result in genetic effects that are new but only increases the frequencies of the same mutations that already occur spontaneously or naturally in that species. Radiation-induced genetic changes, like mutations caused by any other agent, may be a consequence of a gene mutation or chromosomal changes.

2.1.2 Gene mutations

A gene mutation is a change in the structure of DNA. This may involve either the base composition, the sequence, or both. An alteration even so small that it involves the substitution, gain, or loss of a single base can be the cause of significant inheritable changes. Because they usually are small and do not involve large segments of the genome, they are known as point mutations. A very good example is sickle cell anaemia, which results from the substitution of only one base and where a

dominant gene mutation is expressed in the first generation after its occurrence. A large number, namely 736, such conditions have been identified with certainty, and an additional 753 are less well established. Examples in this regard are polydactyly, Huntington's chorea and retinoblastoma (Hall, 1988).

Recessive mutations, unless sex-linked, require that the gene be present in duplicate to produce the trait, i.e. the mutant gene must be inherited from each parent; thus it could be expressed for the first time after many generations. Five hundred and twenty one recessive diseases are known and another 596 are suspected. Examples of this are sickle cell anaemia, cystic fibrosis, and Tay-Sachs disease (Hall, 1988).

The best known examples of sex-linked disorders are hemophilia, colour blindness, and a severe form of muscular dystrophy. Altogether there are 80 well established and 60 probable conditions of this sort (Hall, 1988). Males have only one X chromosome and a sex-linked recessive mutation can thus be expressed if only a single gene complement is present.

The possible adverse effect on the population of the future from low doses of ionising radiation, has occupied the thought and concern of many people. These adverse effects could occur if radiation exposure of people living now causes significant numbers of deleterious mutations in their gametes and those mutations were put in the gamete pool, i.e. transmitted to descendant generations. A possible consequence, therefore, of the use of ionising radiation to benefit people living today might be an injury to people yet to be born - and a shortening of the average life expectancy of future populations. The use of ionising radiation is widespread, at least in the so-called "developed nations" of the world, and is thus considered as a problem of considerable potential importance.

Exposure to ionising radiation increases the mutation frequency. It must be stressed that radiogenic mutations are not unique and do not differ from those that occur spontaneously. Mutations enter the gene pool spontaneously at low rates. For humans this number is in the region of 10^{-5}/gene/generation, i.e. in a human generation (about 30 years) the chance that any given gene will mutate is about 1 in 100000. There are, however, many thousands of genes in every cell and many cells in every body, so the chance of a few mutations occurring within a generation is good. The rate of entry and elimination are, in undisturbed populations, about equal (in equilibrium). The equilibrium therefore implies that more or less a constant but

small fraction of the pool being mutant. This fraction is called the population's or gene pool's mutation burden or load.

The increase in mutation frequency resulting from diagnostic radiation procedures is estimated to be approximately 10^{-7}/gene/cGy for human beings (Pizzarello & Witcofski, 1982). Gonadal exposure of one cGy would then increase the mutation frequency with an extremely small fraction of the spontaneous mutation frequency, i.e. by 1% or a relative risk of 0.01.

The following aspects need special reference, however.

(a) **Mutations per cGy.** The above-mentioned estimation of 10^{-7}/gene/cGy implies that a GSD of 94.6 μGy (the overall South African value, this work) will result in an extremely small mutation induction frequency. It is true, however, that the actual increase in mutation frequency from such GSD's remains uncertain because there are a number of unanswered or unsatisfactorily answered questions about the relationship between radiation dose and mutation frequency. An ad hoc committee of the National Academy of Sciences reported in 1974 that a wide variety of biologic end points, including mutation, studied over an extensive dose range, showed a linear-quadratic relationship (Figure 2.2).

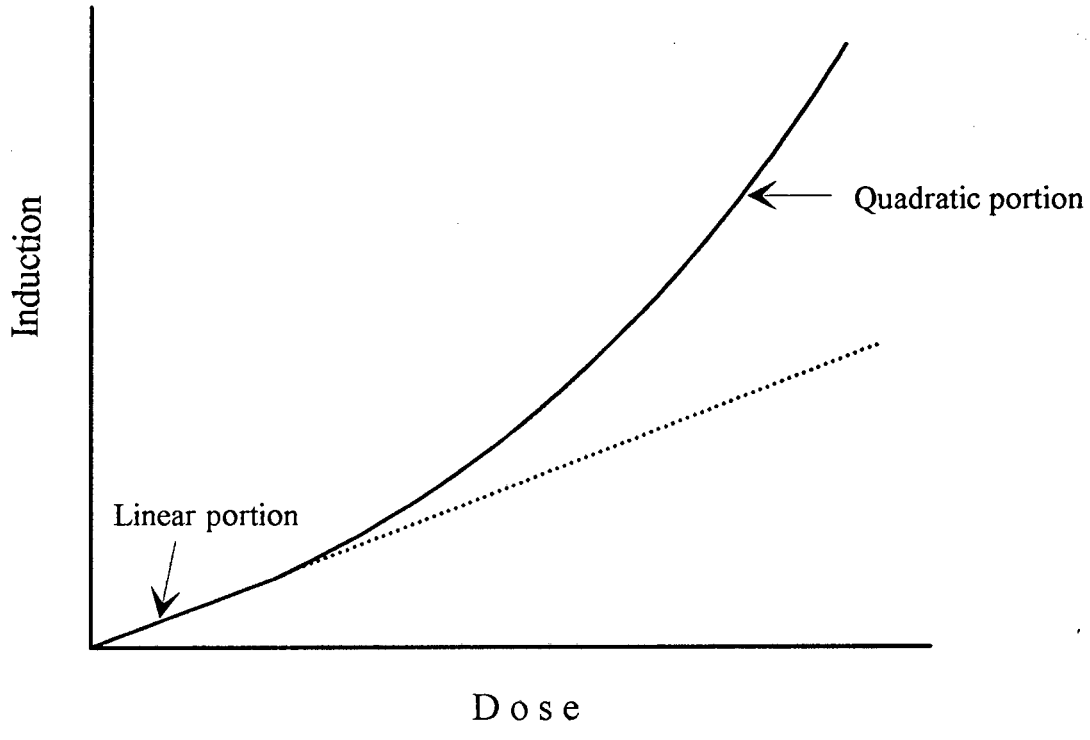


Figure 2.2 *The relationship between mutation frequency and radiation dose.*

The important factor, however, from the point of view of the population, is not necessarily how much the mutation frequency is increased by the GSD, but that it is low and not increasing continuously.

(b) **Doubling dose.** The 1980 BEIR Report gave a doubling dose for mutations as 50 to 250 cGy (National Research Council-BEIR III, 1980). A later report, based on an analysis of the survivors of the atomic explosions at Hiroshima and Nagasaki, suggested that the doubling dose should be at the upper end of the above-mentioned scale and fixed at 156 cGy for acute exposures (Schull, Otake and Neel, 1981).

(c) **Dose rate.** Differences in the frequency of the mutations are observed when the rate at which radiation is delivered, is altered. The increase in mutation frequency is affected to a degree by the stage of the germ cell maturation at which irradiation occurs. It appears, however, that the lower the rate of radiation, the less the increase in mutation frequency for a specific dose. These results were obtained from animal experiments.

It has been postulated that mutation is at least a two-step process and that all steps in the process must occur before a true mutation exists. The first of these steps, "premutational" change or damage, is supposed to be reversible or reparable. If more steps follow this phase before the change is either reversed or repaired, a mutation will occur. During irradiation at low doses, all the premutational changes can be repaired or reversed so that no mutation will occur. Increasing dose rate will result in events taking place so closely that no reversal or reparation will occur. Larger numbers of mutations, per unit dose, will therefore be produced at high rather than at low dose rates.

Low-LET radiation have a smaller expectation of bringing about several changes within a given molecule than high-LET radiation. For low doses, low-LET radiation may produce a relatively large number of premutational changes in most nuclei. Only a few mutations will be produced if the changes are reversible. At higher doses, the probability that several ionisations will occur in a given molecule is high since the number of low-LET radiations to which cell nuclei are exposed, is larger. Low-LET radiation, therefore, have a good chance of producing premutational as well as any additional events that must take place for subsequent mutations.

(d) **Time.** In order to minimise the transmission of mutations into the gene pool, it has been suggested that after testicular irradiation men wait about three months before attempting conception. It can be explained as follows. Germ cells in the late stages of maturation, spermatids and spermatozoa, have about twice the probability of mutation induction as do earlier, less mature forms (National Research Council-BEIR III, 1980 and Searle, 1974), but they are quite resistant to being killed by ionising radiation (Pizzarello & Witcofski, 1982). The chances of males transmitting mutations is thus the highest directly after gonadal irradiation. The immature, premeiotic forms (spermatogonia) are radiosensitive, but those surviving radiation are less susceptible to mutation induction than mature forms. Sperm appearing after about three months are produced from immature premeiotic forms which have survived radiation, and will have relatively low mutation content.

No data is available directly from irradiated women regarding the probability of inducing mutation in ova. Experiments with mice showed that no mutations were transmitted when conception was delayed two months or longer following irradiation (National Research Council-BEIR III, 1980 and Searle, 1974). It is uncertain, however, whether the mouse data can be extrapolated to humans.

(e) **Cancer.** The induction of cancer from ionising radiation was always considered as a stochastic effect, i.e. the probability of occurrence depends on the dose received. It was generally agreed that any dose, no matter how small, carries some risk without any threshold.

The contemporary view of cancer is that a malignancy originates from the transformation of the genetic material of a normal cell, followed by successive mutations, ultimately leading to uncontrolled proliferation of progeny cells. Despite the large amount of data that is available, it is still unknown how many mutations are required for the pathogenesis of a specific tumour. There is, however, no evidence at this stage that gene mutations in germ cells lead to cancer in future generations.

The work that was done by Renan (1993) in this regard, is very significant. He used as a starting point the mathematical models based on the work of Nordling and of Armitage and Doll. The models are in essence the same and they are represented by the function

$$\lambda(a) = ka^{m-1} \qquad \text{(equ. 2.1)}$$

where $\lambda(a)$ represents the age-specific incidence rate and a the age of an individual. The constant, k, represents the product of the probabilities of each of m somatic alterations in the DNA of the progenitor tumour cell. A malignancy appears as a clinical entity only after the requisite set of m sequential alterations has occurred in the cell (Nordling, 1953; Armitage and Doll, 1954).

The model provides a useful framework and has met with some success. Armitage and Doll obtained a reasonably good straight line in a plot of the log of death rate vs. the log of age. Regression coefficients varied between 4.97 and 6.48 for the various examinations (Armitage and Doll, 1954). The statistics available at that time were not sufficiently reliable, however, for a detailed analysis. The mortality rates for individuals with age less than 25 could not be analysed at all, and the contributions of sub-populations with different predispositions were not considered.

Renan addressed some of the deficiencies in this work. He used a much more extensive database, namely the Atlas of Cancer Mortality for US Counties: 1950-1969 (Mason *et al.*, 1975). Statistics for 28 different tumour types were analysed in detail. This database made it possible to consider the contributions of different sub-populations. The log of the age-specific mortality rate (per 100,000 of the population) against the log of age in years were plotted for 28 different malignancies. Best-fit linear regression coefficients were determined from these figures for each tumour type (Renan, 1993).

The results indicated that approximately 8 mutations are required for a cell to become malignant with the actual values for the various sites of the primary cancers varying between 3 and 12 (Renan, 1993). X-rays from diagnostic X-ray examinations can cause mutations, so that it is theoretically possible that if there are already 7 mutations present, the radiation dose could lead to the 8th mutation and consequently to a malignancy. The development of the malignancy may also depend on the number of cells with the 7 mutations that might undergo further mutation. The higher the dose, therefore, the greater the probability that a particular mutation can be induced in more than one cell and thus the possibility of cancer induction .

2.1.3 Chromosome aberrations

Cells may contain too many or too few chromosomes in individuals. Mongolism, for example, results from an extra chromosome. An incorrect chromosome number, either a deficiency or an excess, results mostly in embryonic death. It is estimated that at least 40% of spontaneous abortions that occur from the fifth to the twenty-eighth week of pregnancy and about 6% of stillbirths are associated with chromosomal anomalies (Hall, 1988). This kind of chromosome error is believed not to be strongly influenced by radiation, particularly at low doses. Chromosome breakage appears less frequently than aberrations among spontaneous instances of severe human anomalies, but radiation is much more effective at breaking chromosomes than in causing errors in chromosome distribution.

Chromosomes that are broken may rejoin in various ways. A translocation involves the reciprocal exchange of parts between two or more chromosomes and is not necessarily harmful so long as both rearranged chromosomes are present and contain the full gene complement. Children of a person with a translocation often receive only one of the rearranged chromosomes, and their cells are therefore genetically unbalanced. The harm to the individual ranges from rather mild to very severe, depending on the extent of the abnormality. If the chromosome imbalance does not cause the death of the embryo, it typically leads to physically abnormalities and is usually accompanied by mental deficiency.

2.1.4 Genetically-significant dose

It is only the fraction of medically-given doses of radiation absorbed in gonads of people who subsequently reproduce, that will have genetic impact or significance. Gonads receive probably some radiation during every medical procedure - either in or outside the collimated beam. The genetically-significant dose (see definition in paragraph 2.2) will only be a fraction of the total dose and would be absorbed in the gonads of persons who produce children. Only mutations produced in gametes which are placed in the gene pool, are of significance to the population of the future.

If the gonad dose in persons with childbearing expectancy is continuously increasing, it is reasonable to assume that mutation frequency and mutation load may also be increasing. It must be kept in mind too that the genetically-significant dose is an

index of the presumed genetic impact of medical radiation on the whole population. It is not applicable to any individual or to his or her unborn children.

The gene pool consists of all the genes placed in it by any generation. Therefore, a situation may exist where some people put many mutations in the pool and others only a few. It has the same effect on the population or pool in the situation in which everyone contributing to the pool puts in an equal number. This concept is used in determining the GSD.

The GSD measures ***genetic impact*** of medical irradiation, but it does not measure or estimate the actual increase in mutation frequency as a result of the GSD. The GSD's that have been determined are small and, presumably, increase mutation frequency by only a small amount, but the actual increases are unknown.

2.2 Definition of the genetically-significant dose

The genetically-significant dose (GSD) is defined as "the dose which, if received by every member of the population, would be expected to produce the same total genetic injury to the population as do the actual doses received by the various individuals" (UNSCEAR, 1972). This annual dose is the weighted population dose commitment from a year of radiological practice.

This definition is based on the following ***assumptions and considerations***:

2.2.1 The relevant tissue dose is that accumulated by the gonads;

2.2.2 The dose-effect relationship is linear without threshold;

2.2.3 The rate of delivery of radiation can be neglected;

2.2.4 Differences in sensitivity of the gamete with age and sex are ignored.

(UNSCEAR, 1972)

The following mathematical expression has been derived for the GSD:

$$GSD = \frac{\sum_k \sum_\ell N_{k\ell} P_{k\ell} \overline{D}_{k\ell}}{\sum_k N_k P_k} \qquad \text{(equ. 2.2)}$$

where $N_{k\ell}$ is the number of individuals in the kth age-sex-race group who underwent an examination of type ℓ during the year in question;

$P_{k\ell}$ is the child expectancy of an individual in the kth age-sex-race group who underwent an examination of type ℓ;

$\overline{D}_{k\ell}$ is the mean gonadal dose received by an individual in the kth age-sex-race group from an examination of type ℓ;

N_k is the number of individuals in the kth age-sex-race group in the population;

and P_k is the child expectancy of an individual in the kth age-sex-race group.

(Darby *et al.*, 1980)

The child expectancy of an individual will generally not be independent of the type of examination. Certain types of examinations, for example, will be carried out only on individuals who are thought to have diseases which reduce fertility. In practice the determination of $P_{k\ell}$ will present great difficulties, however, and approximations have to be applied. A great variation could be obtained for $P_{k\ell}$, since it would be seriously effected by the condition of the patients in the above-mentioned cases. It must be assumed therefore that $P_{k\ell} = P_k$ (Darby *et al.*, 1980).

An individual may undergo an examination of type ℓ more than once a year. If the repeat had to be conducted on a different patient, its contribution to the total genetic injury would have been the same. Such an examination is therefore to be considered as an examination on an additional individual in the $N_{k\ell}$-group.

2.3 Comments on the definition

One of the assumptions on which the definition is based, states that "the dose-effect relationship is linear without threshold". This assumption therefore implies that the term "significant" in the definition of the GSD refers to any value bigger than zero, although according to A Dictionary of Statistical Terms an effect is said to be significant if the value of the statistic used to test it lies outside acceptable limits. A test of significance is one which, by use of a test statistic, endeavours to provide a

test of the hypothesis that the effect is absent (Kendall & Buckland, 1971). The term "significant" could therefore be considered as not relevant in the definition of the GSD. Since the definition refers to the dose that is accumulated by the gonads, multiplied by a weighting factor (the child expectancy), an appropriate heading for this definition could be the "weighted gonad dose" or "genetically-weighted gonad dose" or just "genetically-weighted dose.

The word "significant" in this expression is, however, not used in the strict statistical sense but rather, as in the more common dictionary definition, as a synonym for "relevant" or "signifying". It is the gonad dose weighted in such a way as to make it relevant for predicting the likely genetic injury to future generations.

Chapter 3

RADIATION QUANTITIES AND UNITS

3.1 The history of X-rays and radiation units

W.C. Röntgen, a professor in Physics at the University of Würzburg, found in 1895 that some photographic plates, kept carefully wrapped in his laboratory, had become fogged. Instead of merely throwing them aside, he set out to find the cause of the fogging. He traced it to a gas-discharge tube that he was using with a low pressure and high voltage. This tube appeared to emit radiation that could penetrate paper, wood, glass, rubber, and even aluminium a centimetre and a half thick. Röntgen could not find out whether the radiation was a stream of particles or a train of waves - Newton had the same problem with light - and he decided to call it X-rays. Within a month of his paper describing the new rays, a radiograph of a weld had been published, and by the end of 1896 the number of applications of X-rays that had already been described was remarkable.

We now regard X-rays as waves, similar to light waves, but of much shorter wavelength: about 10^{-8} cm, or 1 angström. They are produced when fast electrons strike a target, such as the walls or anode of a low-pressure discharge tube. In a modern X-ray tube there is no gas, or as little as high-vacuum technology can achieve: the pressure is about 10^{-5} mm Hg. The electrons are provided by thermionic emission from a white-hot tungsten filament. From the a.c. mains, transformers provide about 10 volts for heating the filament and about 20 kV to 150 kV for diagnostic X-ray machines for accelerating the electrons.

Radiation dosimetry originated at the end of the nineteenth century. The newly discovered X-rays were put to almost immediate medical use. Both the successes, like that of the first recorded tumour treatment in 1899, and the failures of the early attempts underlined the necessity for some quantitative measurement of the radiation emanating from an X-ray tube. Most of the earlier workers used photographic fluorescence methods for measuring X-ray intensities. Chemical methods were also tried and early as 1897 a measurement was made of the heat produced by the complete absorption of an X-ray beam in a metal. These early physical techniques were eventually displaced by ionisation methods due to a lack of sensitivity, unreliability or of unwanted quality dependence. The röntgen (R) was adopted as an

internationally accepted method of defining a measuring and X-ray dose at the Second International Congress of Radiology in Stockholm in 1928.

Prior to 1928 the principles on which dose-measurement of X-rays were based were:

(i) *Blackening of photographic film.* Kienböck used in 1905 as the basis of his X-unit the ability of radiation to blacken silver bromide film. Rollins in 1902 and Tousey in 1921 applied the same principles.

(ii) *Change in colour and chemical reactions.* Sabouraud and Noire (1904) used a small capsule of platino-barium cyanide. The Pastille unit is the most well known radiation unit depending upon a chemical colour change subsequent to exposure to radiation. The Sabouraud Radiometer consisted simply of a booklet containing platino-barium cyanide pastilles and two standard tints, namely Tint A (unexposed) and Tint B (the Epilation Dose). Tint B was found empirically. The colour of the pastille can be measured in terms of fractions and multiples of Tint B by means of the Lovibond Tintometer. Similar principles applied for the H-unit and the Bordier-unit. Units defined with regard to the quantity of a chemical substance deposited during an exposure, are the Kalom and I-unit.

Holzknecht developed his chromoradiometer which was a mixture of salts that changed from yellow to green when irradiated. The change was calibrated in Holzknecht (H) units and it is more or less the same as the unit that is presently being used for dose, namely the Gy (Thames and Hendry, 1987).

(iii) *Tube current.* Such an indirect method was clearly not satisfactory.

(iv) *The uranie.* Butcher defined in 1905 the uranie-unit as "the quantity of radiation given out by one gram of uranium" stating "a gram of radium may be roughly said to give one million uranies" and that the output from an X-ray tube is in the range 10^8 to 10^{10} uranies (Mould, 1980).

(v) *Temperature variation.* Dr Kohler of Wiesbaden suggested the measurement of the quantity of X-rays by the variation of temperature in the X-ray tube. This was recorded using a thermometer placed in a depression in the wall of a tube.

(vi) *Fluorescence.* The most widely used unit based on the fluorescent effect produced by X-rays was suggested by Guilleminot in 1907. He used as his standard a radium source of activity 50 000 (A pure radium source has about 2000000 times the activity of an equal weight of uranium. Its activity is thus said to be 2000000. A radium source with activity of 50000 is thus a source with activity that is only 50000 times that of an equal weight of uranium.) and quantified the X-ray tube output by placing the tube at a distance from the platino-cyanide screen that gave an equal illumination, when compared with that given by his radium standard behind the screen. His unit was denoted by

M and defined as "the quantity of X-rays falling on one square centimetre of the surface during one minute". X-ray intensities at different distances were calculated using the inverse square law.

(vii) *The erg per cm³.* The idea of a quantity to specify the amount of energy deposited by the radiation per unit mass (or volume) was proposed by Christen in 1912, but it was not until 1953 that the quantity absorbed dose, and its relevant unit the rad, was adopted. A few similar units were also proposed in the intervening time.

(viii) *Selenium cell measurement.* A dose rate unit, the F per minute, was proposed by Furstenau (1915), and based on the change in electrical resistance of a layer of selenium caused by exposure to X-rays. The F/min was not a reliable unit.

(ix) *The skin erythema dose.* It was fairly quickly recognised that X-rays could produce a burn if used long enough and at sufficiently high intensity. This burn was called erythema, and the amount of radiation exposure that was sufficient to cause such skin reddening was called the *erythema dose.* The tolerance of the skin to radiation was also the limiting factor in determining the fractionation of the radiation dose and Holfelder, for example, defined 1 S.E.D. (skin erythema dose) = 500 r and Quimby gave the conversion of T.E.D. (Threshold Erythema Dose) to radium gamma-röntgen as: 1 T.E.D. = 1 000 r_γ (Mould, 1980). The T.E.D. and S.E.D. are essentially the same.

(x) *Biological units.* Biological material such as rabbit muscle, ascari eggs, drosphilia eggs and tadpoles were used for radiation experiments. Biologically based units were impractical, however, since they were too indefinite and required too many tests for each measurement. There was therefore never any idea of developing units from biological material by most investigators.

(xi) *Ionisation units.* Villard is credited as being the first to suggest the use of an ionisation chamber as a dosemeter and a quantitative unit based on the ionisation effect (1908). The Villard unit was defined as "that quantity of x-radiation which liberates by ionisation one e.s.u. of electricity per cm^3 of air under normal conditions of temperature and pressure" (Mould, 1980). It was essentially the same as the first definition of the *röntgen unit,* denoted by r, in 1928. It remained largely unused for several years, until it was readopted by Kronig and Friedrich in 1918 as the *e-unit,* and later modified by Behnken in 1924 to become the *R-unit.*

(xii) However, in 1928 at the Second International Congress of Radiology, Stockholm, an absolute unit of X-ray dose was internationally accepted. This replaced the earlier e and R units and finally an acceptable international unit was defined as the "quantity of x-radiation which, when the secondary electrons are fully utilised and the wall effect of the chamber is avoided, produces in 1 cc

of atmospheric air at 0°C and 76 cm of mercury pressure such a degree of conductivity that 1 esu of charge is measured at saturation current". This unit was called the *röntgen* and was denoted by the small letter r to avoid confusion with the Solomon and Behnken R-units (Mould, 1980).

In 1934 the International Commission on Radiological Units could still not bring itself to recommend that the *röntgen (r)* be accepted as an appropriate unit for both X and gamma rays. The recommendation had to wait until 1937 when the *röntgen* was defined slightly differently than in 1928 as "The *röntgen* shall be that quantity of X- or γ-radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign" (ICRU, 1954).

3.2 Quantities and units in X-ray monitoring

During the early days of radiological experience, there was no precise unit of radiation that was suitable either for radiation protection or for radiation therapy. Various principles for radiation measurement were discussed in the previous section. When X-rays interact with matter, energy is absorbed mainly by the process of ionisation and this principle provides a very good method for radiation measurement. It is a feature of ionisation radiation that the energy absorption in the body and its distribution in specific organs and tissues can be determined either by measurement or calculation.

3.2.1 Exposure

Exposure is a measure of the ionisation caused by the absorption of X- or gamma-rays in a specified mass of air - at the point of interest. A quantity of X-rays can be specified either in the presence or the absence of a patient. The unit for exposure is the *röntgen* and the definition is given at the end of paragraph 3.1. This unit was originally denoted by the small letter "r". In the 1960's, the International Conference on Weights and Measures decided that the use of the small "r" was out of keeping with their system of terminology and to replace it with the large "R" that is still in use.

The new SI unit of exposure has no historical name. It is a measure of the photon flux, and it is related to the amount of energy transferred from the X-ray field to a unit mass of air. One exposure unit is therefore defined as that quantity of X- or gamma radiation that produces in air, ions carrying 1

coulomb of charge (of either sign) per kg air. The unit is therefore expressed as "C kg^{-1}". The exposure unit is based on ionisation of air because of the relative ease with which radiation induced ionisation can be measured. The *röntgen* corresponds to the production of ions (of one sign) carrying a charge of 2,58 x 10^{-4} coulombs per kilogram (C kg^{-1}) of air or 1 C kg^{-1} is equivalent to 3876 R.

Exposure (X) was defined by the ICRU in 1968 as "the quotient of dQ by dm where the value of dQ is the absolute value of the total charge of the ions of one sign produced in air when all the electrons (negatrons and positrons) liberated by photons in air of mass dm are completely stopped in air" (ICRU, 1980).

$$X = \frac{dQ}{dm} \quad (C\ kg^{-1}) \qquad \text{(equ. 3.1)}$$

The ICRU (1980) has pointed out that a number of factors need to be considered as regards exposure.

(a) Bremsstrahlung is emitted by the liberated electrons. The ionising arising from this radiation is, however, not to be included in dQ. Exposure, as defined above, is therefore the ionisation equivalent of the air kerma (definition section 3.2.2), except for the contribution of the bremsstrahlung, which is significant only at high energies.

(b) It is difficult to measure exposure when the photon energies involved are $\geq$ 3 MeV or below 12 keV.

(c) It is often required to refer to a value of exposure or exposure rate at a point inside a material different from air or in free space. The value thus obtained will be that which would be determined for a small quantity of air placed at the point of interest.

(d) The mass of the ionisation chamber should be so small that its introduction does not appreciably disturb the photon field. In some cases an appropriate correction must be applied.

(e) When transient charged-particle equilibrium exists, the numerical value of the exposure in *röntgens* is approximately equal to the numerical value of the absorbed dose in rads to air, water, or soft tissue. It does not hold, however, when SI units are used. The air kerma, expressed in gray, would be useful in this regard. An even better approximate numerical equality may exist between it and the absorbed dose to air, water, or soft tissue, in gray, under transient charged-particle equilibrium conditions.

(ICRU, 1980).

The exposure rate, $\dot{X}$, is the quotient of dX by dt, where dX is the increment of exposure in time interval dt.

$$\dot{X} = \frac{dX}{dt} \quad (C\ kg^{-1}\ s^{-1}) \qquad \text{(equ. 3.2)}$$

3.2.2 **Kerma**

In the SI-system the *röntgen* can also be replaced by the quantity "air kerma", kerma being an acronym for Kinetic Energy Released per unit MAss. Air kerma can be taken to have the same value as the absorbed dose in air in diagnostic radiology and can be used to describe the radiation field either in the presence or the absence of a patient.

"The *kerma*, K, is the quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all the charged ionising particles liberated by uncharged ionising particles in a material of mass dm" (ICRU, 1980).

$$K = \frac{dE_{tr}}{dm} \qquad \text{(equ. 3.3)}$$

The unit of kerma is J kg^{-1} with the special name of gray (Gy).

In the case of kerma, the ICRU has again indicated a number of factors that need to be considered.

(a) The sum of the initial kinetic energies of the charged ionising particles, liberated by the uncharged ionising particles, also includes the energy of those charged particles that have been produced by Bremsstrahlung. The energies of any charged particles are also included when these are produced in secondary processes occurring within the volume element, like Auger electrons.

(b) Kerma or kerma rate may often be referred to, for a specified material, at a point inside a different material or in free space. Such a value would be obtained if a small quantity of the specified material is placed at the point of interest. Therefore, one can speak, for example, of the air kerma at a point inside a water phantom.

(c) The mass of the ionisation chamber should be so small that its introduction does not appreciably disturb the field of the uncharged ionising particles, especially if the material for which kerma is measured, is different from the ambient medium. In some cases, an appropriate correction must be applied.

(d) It may be convenient to describe the field of indirectly ionising particles in terms of the kerma rate for a suitable material. The material could be air for electromagnetic radiation of moderate energies, pertinent tissue composition for all indirectly ionising radiation applied in medicine or biology, or any relevant material for studies of radiation effects.

The kerma rate, $\dot{K}$, is the quotient of dK by dt, where dK is the increment of kerma in the time interval dt.

$$\dot{K} = \frac{dK}{dt} \quad (J\ kg^{-1}\ s^{-1}\ or\ Gy\ s^{-1}) \qquad \text{(equ. 3.4)}$$

3.2.3 Absorbed dose

Radiation damage depends on the absorption of energy from the radiation, and is approximately proportional to the concentration of absorbed energy in tissue. For this reason, the basic unit of radiation dose is expressed in terms of absorbed energy per unit mass of tissue.

The energy imparted, ε, by ionising radiation to matter in a volume, as well as the mean energy imparted, $\bar{\varepsilon}$, need to be defined at first.

The energy imparted, ε, by ionising radiation to matter in a volume is:

$$\varepsilon = R_{in} - R_{out} + \sum Q \qquad \text{(equ. 3.5)}$$

where

R_{in}= the radiant energy incident on the volume, i.e., the sum of the energies (excluding rest energies) of all those charged and uncharged ionising particles which enter the volume;

R_{out}= the radiant energy emerging from the volume, i.e., the sum of the energies (excluding rest energies) of all those charged and uncharged ionising particles which leave the volume;

and $\sum Q$= the sum of all changes (decreases: positive sign, increases: negative sign) of the rest mass energy of nuclei and elementary particles in any nuclear transformations which occur in the volume.

(ICRU, 1980).

Two points are important, namely that (a) ε is a stochastic quantity (see section 4.1), and (b) the expectation value of ε, termed the mean energy imparted, $\bar{\varepsilon}$, is a non-stochastic quantity (see section 4.1).

The absorbed dose, D, was introduced in 1953 by the ICRU and was defined as "the quotient of $d\bar{\varepsilon}$ by dm, where $d\bar{\varepsilon}$ is the mean energy imparted by ionising radiation to matter of mass dm" (ICRU, 1980).

$$D = \frac{d\bar{\varepsilon}}{dm} \quad (J\ kg^{-1}\ or\ Gy) \qquad \text{(equ. 3.6)}$$

The absorbed dose rate, $\dot{D}$, is the quotient of dD by dt, where dD is the increment of absorbed dose in the time interval dt.

$$\dot{D} = \frac{dD}{dt} \quad (J\ kg^{-1}\ s^{-1}\ or\ Gy\ s^{-1}) \qquad \text{(equ. 3.7)}$$

Before the universal adoption of the SI units, radiation dose was measured by a unit called the rad (Radiation Absorbed Dose).

One rad is an absorbed radiation dose of 100 ergs per gram.

Since 1 J = 10^7 ergs, and since 1 kg = 1 000 g,

$$1\ Gy = 100\ rad.$$

Although the gray is the newer unit, the rad nevertheless continues to be widely used.

3.2.4 The relation between kerma, absorbed dose and the röntgen

The kerma decreases continuously with increasing depth in an absorbing medium because of the continuous decrease in the flux of the indirectly ionising radiation. The absorbed dose, however, increases with increasing depth as the density of the primary ionising particles and the secondary particles that they produce increases, until a maximum is reached, after which the absorbed dose decreases with continuing increase in depth. The maximum dose occurs at a depth approximately equal to the maximum range of the secondary ionising particles. The relation between kerma and dose which holds for both photon and fast neutron irradiation, is illustrated in Figure 3.1.

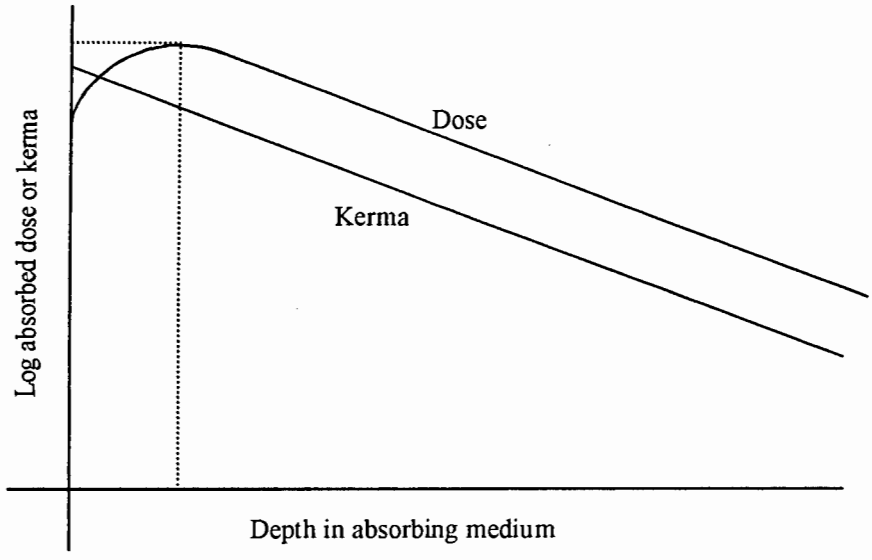


Figure 3.1 *Relationship between kerma and dose.*

In diagnostic radiology, the close approximation of absorbed dose to air and air kerma for X-rays is due to the secondary electron range being much less than the mean free path of the primary photons. Charged particle equilibrium is thus easily achieved, while bremsstrahlung losses (which affect the absorbed dose but not the kerma) are negligible. Either absorbed dose to air or air kerma can be used to describe the radiation field in the presence or absence of a patient.

Since an exposure of 1 R results in an energy deposition of 0.00873 J kg^{-1} in air (see Johns and Cunningham, 1983) and the rad is defined as an energy deposition of 0.01 J kg^{-1}, it follows that 1 R gives an absorbed dose of

$$\frac{0.00873}{0.01} = 0.873 \text{ rad in air.}$$

An air kerma in air of 1 Gy represents a transfer of 1 J of energy from the X-ray beam to air per kg of air. An exposure of 1 R corresponds thus to an air kerma of 8.73 mGy (8.69 mGy in air per R previously).

For X-rays used in diagnostic radiology, soft-tissue kerma is approximately equal to air kerma and for the purposes of radiation protection they can be considered equal. Thus the value of the air kerma is interchangeable with that of the absorbed dose in soft tissue, as was the case previously for the exposure measured in röntgen and the absorbed dose measured in rad (an exposure of 1 R gives an absorbed dose of 0.96 rad in tissue, i.e., for practical purposes the same numerical value).

3.2.5 Equivalent dose

The fundamental dosimetric quantity in radiological protection is the absorbed dose, D. Absorbed dose is defined in terms that allow it to be specified at a point, but it is often used to mean the average dose over a tissue or organ (ICRP, 1991). The use of the average dose as an indicator of the probability of subsequent stochastic effects depends on the linearity of the relationship between the probability of inducing an effect and the dose - a reasonable approximation over a limited range of dose. The dose-response relationship is not linear for deterministic effects (see section 4.1), so the average absorbed dose is not directly relevant to deterministic effects unless the dose is fairly uniformly distributed over the tissue or organ.

The probability of stochastic effects is found to depend also on the type and energy of the radiation causing the dose. Provision is made for this by multiplying the absorbed dose with a weighting factor which is determined by the quality of radiation. Therefore the ICRU (1962) and the ICRP (1966) have introduced the concept of dose equivalent (H), i.e., a dose at a point, which is evaluated by multiplying the dose in rads by certain factors. Thus

$$H\,(\text{rem}) = D\,(\text{rad}) \times Q \times DF_1 \times DF_2 \times \ldots \quad \text{(equ. 3.8)}$$

where Q is a quality factor (see section 3.2.7) and DF_1 , DF_2 , etc. stand for various distribution factors. When isotopes, for example, are ingested and deposited, the spatial distribution of the isotopes is not uniform and result in high dose regions. Abnormally large biological effects may be produced and therefore the distribution factor (DF) may be set at some value greater than 1.0. The unit of dose equivalent is the rem.

The most recent principles in this regard are stated in the ICRP Publication 60. "In radiological protection, it is the absorbed dose averaged over a tissue or organ (rather than at a point) and weighted for the radiation quality that is of interest" (ICRP, 1991). The weighting factor to be used for this purpose is called the radiation weighting factor, ω_R, selected for the type and energy of the radiation involved. Since this is strictly a dose, the ICRP decided to call it again equivalent dose, using the symbol H_T. The equivalent dose in tissue T is given by the expression

$$H_T = \sum_R \omega_R . D_{T,R} \quad (\text{J kg}^{-1} \textit{ or } \text{Sv}) \qquad \text{(equ. 3.9)}$$

where $D_{T,R}$ is the average absorbed dose over the tissue or organ T and due to radiation R. The radiation weighting factors are given in Table 3.1. These

weighting factors are different to those used in the previously used equation of dose equivalent. It is shown on page 25 that 1 Gy = 100 rad and by inspection of equations 3.8 and 3.9, it follows that the equivalent dose in tissue (H_T) in sievert = 100 x dose equivalent (H) in rem.

Table 3.1 *Radiation weighting factors.*

Type and energy range	Radiation weighting factor ω_R
Photons	1
Electrons and muons, all energies	1
Neutrons, energy < 10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 Mev to 20 MeV	10
> 20 MeV	5
Protons, other than recoil protons, energy > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

(ICRP, 1991).

The equivalent dose rate in tissue T, $\dot{H}_T$, is the quotient of dH_T by dt, where dH_T is the increment of equivalent dose in the time interval dt.

$$\dot{H}_T = \frac{dH_T}{dt} \quad (J\,kg^{-1}s^{-1}\ or\ Sv\ s^{-1}) \qquad \text{(equ. 3.10)}$$

3.2.6 **Effective dose**

The ICRP introduced the concept of effective dose equivalent in 1977 in the ICRP Publication 26. It is based on the principle that the risk of a stochastic effect per unit effective dose equivalent should be equal whether the whole body is uniformly irradiated or whether the radiation dose is non-uniformly distributed. The effective dose equivalent, H_E, is given by

$$H_E = \sum_T W_T . H_T \qquad \text{(equ. 3.11)}$$

where W_T is the weighting factor for tissue T, tabled in the ICRP Publication 26, and H_T is the dose equivalent to tissue T.

The ICRP considered the term "effective dose equivalent", however, as unnecessarily cumbersome and therefore decided to change it to effective dose, E, in the ICRP Publication 60. It is given by the expression

$$E = \sum_T \omega_T . H_T \qquad \text{(equ. 3.12)}$$

where H_T is the equivalent dose in tissue or organ T and ω_T is the weighting factor for tissue T. The new factors of ω_T are the result of a re-estimation for radiation induced cancers resulting from the recent (1986) follow-up studies on the Japanese sub-populations. The effective dose can also be expressed as the sum of the doubly weighted absorbed dose in all the tissues and organs of the body. The tissue weighting factors, published in the ICRP (1991), are given in Table 3.2.

Table 3.2 *Tissue weighting factors.*

Tissue or organ	Tissue weighting factor ω_T
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder*	0.05

* The remainder is composed of the following tissues and organs: adrenals, brains, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus. Some organs in the list are known to be susceptible to cancer induction and if other tissues and organs subsequently become identified as having a significant risk of induced cancer, they will then be included either with a specific ω_T or in this additional list constituting the remainder. The latter may also include other tissues or organs selectively irradiated. (ICRP 60, 1991).

Exposure conditions that are not dealt with by means of the radiation and tissue weighting factors, are dealt with by using different values for the coefficients relating effective dose and the probability of stochastic effects. This method is preferred above the possibility of using additional weighting factors in the definitions of the quantities.

Both equivalent dose and effective dose are quantities intended for use in radiological protection. Only the probability of stochastic effects can be estimated by means of these two units. The absorbed doses must be well below the threshold for deterministic effects. It will sometimes be better, however, to use absorbed dose and specific data with regard to the relative biological effectiveness of the radiation involved and the probability coefficients relating to the exposed population for the estimation of the likely consequences of an exposure of a known population (ICRP 60, 1991).

3.2.7 **Relative biological effectiveness (RBE)**

The Quality Factor (Q) weights the absorbed dose for the biological effectiveness of the charged particles producing the absorbed dose. The term RBE was formerly used to describe the factors Q x DF (ICRP, 1955). This practice is no longer recommended, since it is felt that the RBE should be used solely to describe the results of radiobiological experiments and should not be used for radiation protection (Johns and Cunningham, 1974).

One physical parameter which describes the quality of a beam, is the linear energy transfer (LET). The LET, expressed in keV per micron, gives the rate at which an ionising particle deposits energy along its track.

When comparing the relative toxicity, or damage-producing potential of various radiations, comparison is being done on the basis of equal amounts of energy absorption. Generally, the higher the the rate of linear energy transfer of the radiation, the more effective it is in damaging an organism. The ratio of the amount of energy of 250 kVp X-rays required to produce a given effect to the energy required of any radiation to produce the same effect, is called the relative biological effectiveness of the radiation (Hall, 1988). The RBE of a specific radiation depends on the exact biological effect on a given species of

organism under a given set of experimental conditions. The RBE is thus restricted to radiation biology.

For health physics purposes, a conservative upper limit of the RBE for the most important effect due to radiation other than the reference radiation (250 kVp X-rays) is used as a normalising factor in adding doses from different radiations. This normalising factor, which is called the quality factor (Q), is related to LET as shown in Table 3.3.

Table 3.3 *Relationship between Q and LET.*

LET keV/μm in water	Quality Factor Q
3.5 or less	1
3.5 - 7.0	1 - 2
7.0 - 23	2 - 5
23 - 53	5 - 10
53 - 175	10 - 20

(Cember, 1983).

Chapter 4

RADIATION PROTECTION

X-rays were used medically almost immediately after their discovery in 1895 for a multitude of purposes that involved some necessity for visualising the interior of the human body. Biological harmful effects of X-rays were already noted in 1896 in some of the early X-ray workers: Edison reported in March 1896 that his eyes were sore after experimenting with X-rays; radiation burns to hands were reported by Stevens on 18 April 1896; Gilchrist reviewed 23 cases of X-ray injury which had been reported in the literature before January 1897; in May 1897 Scott reviewed 69 reports of X-ray injury and the Röntgen Society appointed a committee in April 1898 to collect data on the harmful effect of X-rays. Aspects investigated by this committee included nature of injurious effect, duration of effect, nature of radiographic investigation, condition of subject, type of apparatus used, distance of patient from the tube, number and duration of each exposure. This could be perhaps considered as a first step in the direction of the radiation protection programs that followed later.

Albers-Schönberg was the first person to realise that there was a possibility of an adverse effect of ionising radiation on biological reproductive systems when he discovered in 1903 that X-rays were capable of sterilising guinea pigs without any other obvious change in the well-being of the animals (Albers-Schönberg, 1903). In spite of these early discoveries of deleterious effects the idea of setting up "safe" exposures for radiation workers was only developed in the 1920's.

4.1 Historical background for radiation protection

It was fairly quickly recognised that X-rays could produce a burn if used long enough and at sufficiently high intensity. This burn was called erythema, and the amount of radiation exposure that was sufficient to cause such skin reddening was called the erythema dose. Investigators and practitioners quickly became careful to avoid the sufficiently high exposures necessary to produce this particular effect. Indeed, the first actual experimental effort in the United States to determine whether X-rays were injurious was provided by Elihu Thomson, an American, in November 1896 when he exposed one of his fingers to X-rays for several days and noted injury over a week later. Within several years other and more unpleasant long-term effects of this new type of irradiation became apparent among those who had used it most

extensively. These included cancerous sores of the skin as well as other more deep-seated cancers, principally of bone in the extremities. It can be stated that most of the physicians who worked extensively with X-rays in the early days, eventually developed cancers and in many cases suffered amputations.

There is today no way to do an accurate estimation of the doses to which people were exposed during those early days. However, according to one estimate annual exposures to medical practitioners prior to 1930 in the United States may have been greater than 100 R as compared with present averages of much less than 5 R; another estimate of 2000 R was also stated (Henry, 1969). One of the reasons for the variety of doses was the technical fact that the early X-ray tubes were of the cold-cathode type, similar to the Crooke's tube, which gave useful results only under limited ranges of air pressure and voltage that were interdependent. Since the pressure inside the sealed tubes changed with use and time, wide variations also occurred in the voltages and exposure times and consequently in the total exposures necessary to produce a desired and useful result. It was not until the development in the 1920's of the hot-cathode X-ray tube invented in 1913 by W.D. Coolidge, an American physicist, that easily reproducible exposures could be produced (Henry, 1969).

Almost all of this early medical work was fluoroscopic, which, because of the comparatively long viewing time and the necessity for the viewer to be at least partly within the direct X-ray beam during exposures, resulted in much higher exposures than does the photographic work that comprises most of the current work. In addition, each user had his own manipulation techniques and variations in the respective planned or unplanned shielding had unknown effects on their exposures.

By about the time of World War I, it was recognised that X-rays could exert deleterious effects and there was increasing insistence on information concerning safe exposure limits and methods of determining them. The war itself had two effects of interest. First, the need for information obtainable only with X-rays in treating battle casualties pushed considerations of safety into the background, and second, more physicians and other individuals became acquainted with the art. Thus the coming of peace in late 1918 permitted further attention to be given to the matter of limiting exposure.

However, the general acceptance of protection procedures was too late to prevent radiation injuries to superficial tissues, blood and internal organs of some of the early workers in the radiation field - Mutscheller (1925), Barclay and Cox (1928),

Glaser (1932). In 1936 the German Röntgen Society erected a monument for the X-ray and radium "martyrs". This memorial originally contained 169 names from 15 different nations, but by 1959 the total had risen to 360. Röntgen is not among them, probably because his experiments were mainly photographic and his X-ray tubes were housed within a metal box (Mould, 1980).

4.2 Biological effects

The biological effects of ionising radiation have been studied since about 1900. These effects may be classified in various ways. Radiation energy initiates physical and chemical reactions, resulting in biological changes. Some diagnostic X-ray equipment (for example fluoroscopy) is capable of delivering radiation doses that may be high enough to produce cellular reactions which will be manifested as acute radiation reaction or injury. In properly conducted diagnostic X-ray examinations, however, these acute radiation effects do not occur because the radiation doses are well below the threshold for such effects. Nevertheless, there may be no lower limit of dose for the limitation of some deleterious biological changes. Even small doses of radiation may increase the risk of development of neoplasia and small doses of radiation absorbed in the gonads may induce mutations or chromosomal changes leading to hereditary effects. The ICRP introduced the term "stochastic", i.e., only the probability of occurrence of the effect depends on the dose of radiation absorbed whereas the severity of the effect is independent of dose.

Cancer induction and heritable effects are the principal stochastic effects of irradiation. It is generally assumed that it is caused by injury to one or a small number of cells. The probability that such an effect will occur, increases with the number of cells at risk and the nature of the effect depends on the particular change. Although the dose may be very small, there is always a finite probability for the effect to occur, since it is assumed that only a single cell need to be affected. The conclusion, namely that there is no threshold, could therefore be derived from this argument. There exists therefore no dose for a stochastic effect below which it cannot possibly occur.

The result of exposure to a carcinogen or a mutagen is an increase in the probability of the occurrence of the effect. The increase in the probability is directly proportional to the magnitude of the dose (Figure 4.1). People can develop cancer whether or not they are exposed to carcinogenic agents. Exposure to a carcinogen, however, increases the likelihood of cancer; and the greater the exposure the greater

is the increased likelihood. At no time, regardless of the size of the exposure, is it certain that cancer will result from exposure to a carcinogen. The best that we can do is to estimate the probability that the cancer was caused by a carcinogen.

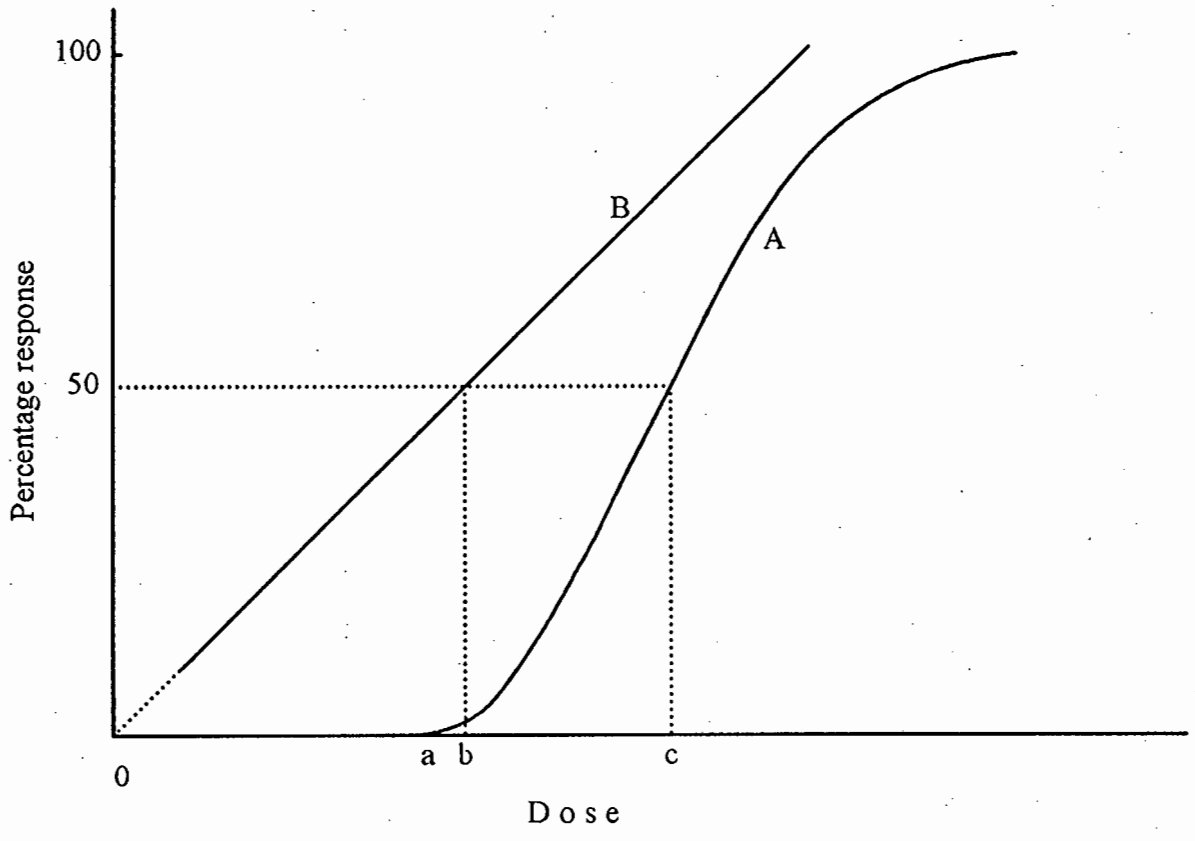


Figure 4.1 *Dose-response curves. Curve A is the characteristic shape for a biological effect that exhibits a threshold dose (point a). The shape of the curve, from the threshold at a until the 100% response is thought to be due to "biological variability" around the mean dose, point c, which is called the 50% dose. Curve B represents a zero-threshold, or linear response; point b represents the 50% dose for the zero-threshold biological effect.*
(Cember, 1983)

When frequency of occurrence of a stochastic effect is plotted against size of dose, a linear dose-response relationship is observed rather than the sigmoid curve that is characteristic of agents associated with a threshold response. The biological model that is compatible with this straight line dose-response relationship and with our knowledge of molecular biology predicts that cancer can be initiated or a genetic change can be wrought by altering the genetic information coded in DNA. Thus, carcinogenesis and mutagenesis are merely different manifestations of the same basic molecular phenomenon. In this context, cancer can be initiated by damaging DNA of a somatic cell, whereas a genetic change may be caused by damage to the DNA of a germ cell. On the basis of this model, no threshold should exist for a stochastic effect, and even the smallest amount of the carcinogen or mutagen - a single

molecule in the case of chemicals or a single photon in the case of X-rays - can produce the effect. For these reasons, stochastic effects are often called linear, zero-threshold dose-response effects (Figure 4.1, curve B).

Most biological effects fall into the category of deterministic effects or as it was previously called, non-stochastic effects. Deterministic effects are considered to be types of damage resulting from collective injury to substantial numbers of cells. A given number or proportion of cells must therefore be affected so that there will be a threshold dose below which the number of cells affected is insufficient for the specific injury to occur. The level of injury would increase for any increase in dose above the threshold and effects that are "all or none", such as death, may also occur.

These effects are characterised by three qualities: First, a certain minimum dose must be exceeded before the particular effect is observed. Additionally, the magnitude of the effect increases with the size of the dose. Furthermore, there is a clear causal relationship between the exposure to the noxious agent and the observed effect. When the magnitude of the effect or the proportion of individuals who responded at a given dose is plotted as a function of dose to obtain a quantitative relationship between dose and effect for such non-stochastic effects, a curve like A in figure 4.1 is obtained. Non-stochastic effects are also called threshold effects because of the minimum-dose that must be exceeded before the effect is shown by an individual.

This type of effect is characterised by a severity that increases with dose above some clinical threshold. Although the initial cellular changes are essentially random, the large number of cells involved in the initiation of a clinically observable, non-stochastic effect gives the effect a deterministic character. For this reason the ICRP now calls such effects "deterministic" effects.

Examples of deterministic effects include bone marrow damage, gonadal injury leading to impairment of fertility, and lung damage leading to impaired function. Injuries are attributed to damage that was caused in the individual cells resulting in the loss of their reproductive capacity. Hulse and Mole pointed out in 1982 that it is the nature of the damage to cells that determines whether the final injury is stochastic or deterministic, since events that cause injuries to individual cells, occur at random (Field and Upton, 1985). An example to illustrate this statement, is the fact that neither malignant nor hereditary effects can result if the cell is killed.

The ICRP consider certain concepts of risks as follows: The detrimental effects against which radiation protection is required, are known as hereditary if they affect the exposed individual's descendants and somatic if they manifest themselves in the exposed individual (ICRP, 1982).

4.2.1 The somatic effects of radiation

Acute whole body overexposure affects all the organs and systems of the body. Not all the organs are equally sensitive to radiation, however. The pattern of response, or disease syndrome, in an overexposed individual therefore depends on the magnitude of the dose.

(a) *Early radiation effects*

Early effects are those which occur in the period from a few hours up to a few weeks after an acute exposure, that is, a large dose received over a few hours or less. The effects are due to major depletion of cell populations in a number of body organs due to cell-killing and the prevention or delay of cell division. The main effects are attributable to bone marrow, gastrointestinal or neuromuscular damage depending on the dose received. Acute absorbed doses (whole body) above about 1 Gy give rise to nausea and vomiting. This is known as radiation sickness and it occurs a few hours after exposure as a result of damage to cells lining the intestine. Absorbed doses above 2 Gy may lead to death, usually 10 to 15 days after exposure.

There is no well defined threshold dose below which there is no risk of death due to acute doses. Below about 1.5 Gy the risk of early death would be very low. Similarly, there is no well defined point above which death is certain, but the chances of surviving an acute dose of about 8 Gy would be very low. For doses of up to about 10 Gy, death is usually due to secondary infections because of depletion of the white blood cells which normally provide protection against infection. The range of doses from 3 to 10 Gy is often called the region of infection death. For doses above about 10 Gy survival time drops abruptly to between 3 - 5 days. Gross damage occurs in the lining of the intestine. This is called the region of gastrointestinal death.

At much higher doses, survival times become progressively shorter. From animal experiments, the symptoms indicate some damage to the central

nervous system; hence the region is called the region of CNS (central nervous system) death. However, it is found that death is not instantaneous even in animals irradiated with doses in excess of 500 Gy.

Another effect which shows up soon after an acute over-exposure to radiation is erythema, that is reddening of the skin. An exposure of about 3 Gy of low energy X-rays will result in erythema and larger exposures may lead to other symptoms such as changes in pigmentation, blistering and ulceration.

(Martin and Harbison, 1979).

Although changes in blood have been seen in individuals with gamma-ray doses as low as 140 mGy, they usually do not appear until doses of 250 - 500 mGy are experienced. Beyond 500 mGy, blood changes are almost certain to appear (Cember, 1983).

The blood consists of about 55% (by volume) of plasma and about 45% of formed elements, including leucocytes, erythrocytes and platelets. The white blood cells, which number about 7 000/mm^3 of blood in the average adult, function as a major line of defence against bacterial invasion. An infection anywhere in the body stimulates the production of leucocytes in order to combat the infective organisms. Several major types of leucocytes are found: the granulocytes and the lymphocytes, each with certain specialised functions. Under normal conditions, the relative proportions of each of these remain approximately constant - the granulocytes form about 70 - 75% of the white blood cells while the lymphocytes account for about 25 - 30%. The granulocytes are produced in the bone marrow, and circulate for about 3 days before their death and destruction, while the lymphocytes are produced in the lymph nodes and spleen and remain in the peripheral blood for years. The red blood cells are the most abundant of the formed elements; their concentration in the blood is about 5 million per cubic millimetre. The main function of the red blood cells is to transport oxygen from the lungs to the cells in the body and to carry the carbon dioxide waste from the cells to lung. The erythrocytes are formed in the bone marrow, and survive in the circulating blood for about 90 - 120 days. The platelets, which number about 200000 - 400000 / mm^3 blood, are concerned with the clotting of the blood. They are manufactured in the marrow, and have a useful lifetime of about 8 - 12 days.

After an acute whole body radiation exposure in the sub-lethal range (<±2.0 Gy), there is a transitory sharp increase in the number of granulocytes followed within a day by a decrease which reaches a minimum several weeks after exposure, and then returns to normal after a period of several weeks to several months. The number of lymphocytes drops sharply after exposure, and remain depressed for a period of several months. In contrast to the very rapid response of the white cells to radiation overexposure, the red blood cell count does not reflect an overexposure until about a week after exposure. Depression in the erythrocyte count continues until a minimum is reached between 1 to 2 months after exposure, followed by a slow recovery over a period of weeks. The platelet count falls steadily until a minimum is reached about a month after exposure; recovery is very slow, and may take several months. In all cases, the degree of change in the blood, as well as the rate of change, is a function of the radiation dose.

(b) *Late effects*

It became clear in the early part of the twentieth century that groups of people such as radiologists and their patients, who were exposed to relatively high levels of radiation, showed a higher incidence of certain types of cancer than groups not exposed to radiation. More recently, detailed studies of the populations exposed to radiation from atomic bombs, of patients exposed to radiation therapy, and of groups exposed occupationally, particularly uranium miners, have confirmed the ability of radiation to induce cancer.

Cancer is an over-production of cells in the body. It is thought that cancer may result from damage to the control system of a single cell, causing it to divide more rapidly than a normal cell. The defect is transmitted to the daughter cells so the population of abnormal cells builds up to the detriment of the normal cells in the organ. The estimation of the increased risk of cancer is complicated by the long and variable latent period, from about 5 to 30 years or more, between the exposure and the appearance of the cancer. The possibility cannot be ruled out that there is a threshold dose below which there is no risk of radiation-induced cancer. This is impossible to demonstrate, however, and it is generally agreed that the only practicable basis for radiological protection is to assume that any dose, no matter how small, carries some risk (Martin and Harbison, 1979).

Although any organ or tissue may develop neoplasia after overexposure to radiation, certain organs and tissues seem to be more sensitive in this respect than others. Radiation-induced cancer is observed most frequently in the hemopoietic system, in the thyroid, in the bone, and in the skin. Leukaemia, especially acute myelogenous leukaemia, and to a lesser extent chronic myelogenous or acute lymphocytic leukaemia, are among the most likely forms of malignancy resulting from overexposure to total body radiation. Chronic lymphocytic leukaemia does not appear to be related to radiation exposure. Radiologists and other physicians who used X-rays in their practice before strict health physics practices were common, showed a significantly higher rate of leukaemia than did their colleagues who did not use radiation. Historically, occupational radiation-induced cancers of the bone and of the lung are important in emphasising the carcinogenicity of internally deposited radioisotopes (Cember, 1983).

Ionising radiation may also be the cause of cataracts. The incidence rate of cataracts among physicists in cyclotron laboratories whose eyes had been intermittently exposed for long periods of time to relatively low radiation fields, showed that chronic overexposure of the eyes could lead to cataracts. The incidence rate of cataracts among atomic-bomb survivors whose eyes had been exposed to a single high radiation dose, however, showed that acute overexposure of the eyes could also lead to cataracts. Radiation may injure the cornea, conjunctiva, iris, and the lens of the eye. In the case of the lens, the principal site of damage is the proliferating cells of the anterior epithelium. This results in abnormal lens fibres after the differentiation of the damaged epithelial cells. These fibres eventually disintegrate to form an opaque area, or cataract, that prevents light from reaching the retina (Cember, 1983).

The cataractogenic dose to the lens is in the order of 5 Gy of beta or gamma radiation and cataracts have been reported after a dose of 2 Gy from mixed gamma and neutron irradiation (Cember, 1983). The annual recommended limits for the lens of the eye was set by the ICRP as 150 mSv for radiation workers and 15 mSv for members of the public (ICRP, 1991). From patients who suffered irradiation of the eye in the course of X-ray therapy and developed cataracts as a consequence, the cataractogenic threshold is estimated at about 2 Gy. In cases either of occupationally or therapeutically induced radiation cataracts, a long latent period, in the order of several years, usually elapsed between exposure and the appearance of the lens opacity.

It had been observed among groups of experimental animals that large radiation doses may shorten the life span by increasing the rate of physiological ageing. The exact cause of death among these animals cannot be uniquely attributed to radiation; the causes of death are those that are expected among an animal population. Although this life-shortening effect has been clearly demonstrated in animals, no similar clear-cut effect has been seen among man. Comparison of the duration of life among medical specialists who used X-rays in their work with other medical practitioners who did not use radiation in their work gives conflicting conclusions. While some of the data suggests an increased death rate from non-specific causes among users of X-rays, other data shows no statistically significant difference in life expectancy between these two population groups (Cember, 1983). It is therefore clear that radiation exposure at the levels encountered by radiologists and other X-ray users among physicians is not high enough to accelerate the ageing process to the degree that will cause a statistically significant shortening of life span in reasonably large sample sizes.

4.2.2 **The hereditary effects of radiation**

The hereditary effects (also regarded as a stochastic effect) of radiation result from damage to the reproductive cells. This damage takes the form of alterations (mutations) in the hereditary material of the cell. This aspect has already been discussed in Chapter 2, paragraph 2.1.

Examples of the harmful somatic effects of radiation are the depression of the red blood cell count, the production of eye cataracts (a deterministic effect) and the induction of a number of malignant conditions such as leukaemia (a stochastic effect). The severity of many somatic effects, rather than the probability of their occurrence, may depend on the dose of radiation received, the duration of the irradiation, whether the dose is delivered as a number of fractions spread over a period of time, and the total volume of tissue irradiated. As an example, if the hand is given a single short duration dose of 5 Gy the skin will react soon after the irradiation and turn red. If the same dose is given in separate fractions spread over a long period there may be no obvious effect. If, alternatively, the whole body is irradiated with a dose of 5 Gy there is a high probability that death will shortly ensue.

The main difference between genetic effects and somatic effects is that somatic effects affect only the irradiated individual whereas genetic effects do not affect this person but may appear in future generations, possibly many generations after the irradiation. At the dose levels met with in radiation protection, genetic effects are regarded as stochastic effects and are treated as though their incidence is proportional to dose.

It is sometimes argued that genetic effects are not necessarily harmful and may in fact be beneficial since new and "better" types of species may be produced. This is unlikely to be the case since mutations occur spontaneously and natural selection has tended to weed out those mutants which are poorly adapted to survive. Although the spontaneous mutation rate is not high, during the many generations that man has existed the species has tended to become more adapted to its environment and radiation induced mutations are therefore likely to be deleterious (Lovell, 1979).

4.3 The genetically-significant dose (GSD)

Genetic effects consist of mutations in the reproductive cells that affect later generations. Since genetic effects occur only when reproductive cells are irradiated, the gonads should be shielded during X-ray studies when possible.

The GSD due to an exposure depends on the dose to the ovaries and testes as well as the age of the individual, which determines the probability of that person becoming a parent in subsequent years. Thus X-raying women over 50 years old, who normally have little chance of having offspring, contributes very little to the GSD of the population. Exposure of the reproductive organs of children results in the maximum contribution to the GSD of the population, since their potential for producing offspring is at maximum. In the United States, X-raying young men results in a major contribution to the GSD. An X-ray that includes the testes, which have little shielding tissue, results in a larger genetic dose than a similar X-ray that includes the ovaries. On the other hand, it is easy to shield the testes without losing any diagnostic information, while this is not true for the ovaries. The 1972 BEIR report estimated that in the United States the GSD due to medical X-rays could be reduced by 50% by proper limitation of the beam and use of gonadal shielding (Cameron and Skofronick, 1978).

4.4 Radiation protection standards

Generalised radiation protection measures were eventually adopted. A British X-ray and Radiation Protection Committee was formed in 1921. The basic responsibility for providing guidance in matters of radiation safety has been assumed by the International Commission on Radiological Protection (ICRP). This organisation was established in 1928 by the Second International Congress of Radiology as the International X-ray and Radium Protection Committee in 1928. In 1950 it was restructured and renamed. The first consideration by a national protection organisation of the principle of maximum tolerance dose of X-rays was by the US Advisory Committee on X-ray and Radium Protection in 1934. This dose was derived essentially from a 1921 recommendation that representative protective measures could be gleaned from the working conditions of a number of experienced radiologists who had escaped injury and were enjoying normal health at that time (Mould, 1980).

At its establishment and for many years afterwards, the main concern of the ICRP was the safety aspects of medical radiology. Its interests in radiation protection expanded with the widespread use of radiation outside the sphere of medicine, and in 1950 its name was changed to the ICRP in order to more accurately describe its area of interest. The policy adopted by the Commission in preparing recommendations, was to deal with the basic principles of radiation protection. The responsibility of introducing the detailed technical regulations, recommendations, or codes of practice best suited to the needs of the individual countries, was left to the various national protection committees (ICRP, 1964).

The maximum permissible doses at various points in time were traced. In the 1958 Recommendations of the ICRP (1959) the maximum permissible total dose accumulated in the ***gonads, blood-forming organs and lenses*** of the eyes at any age over 18 years was determined by the relation

$$D = 5(N-18) \qquad \text{(equ. 4.1)}$$

where D is the tissue dose (rem) and N is the age (years). A maximum dose of 8 rem/13 weeks for the ***skin***, limited to 30 rem per year; and 20 rem/13 weeks for the ***hands and forearms, feet and ankles***, limited to 75 rem per year, were recommended. For the exposure of internal organs ***other*** than the ***thyroid, gonads and blood-forming organs*** a maximum dose of 4 rem/13 weeks, limited to 15 rem per year, was recommended.

The suggested maximum dose to the population was 5 rem per year. All the above-mentioned limits did not include any medical exposure or exposure to natural radiation. Background radiation is more or less 0.1 μSv per hour.

In order to prevent deterministic (non-stochastic) effects the 1977 Recommendations of the ICRP (1977) for radiation workers recommended an annual dose-equivalent limit of 0.5 Sv (50 rem) to all tissues except the lens, for which 0.3 Sv (30 rem) was recommended. To prevent stochastic effects for whole body radiation, the recommended limit was set at 50 mSv (5 rem). The annual dose-equivalent limit to individual members of the public was set at 5 mSv (500 mrem).

The term "effective dose equivalent" (Section 3.2.6) was introduced by the 1978 Stockholm meeting of the ICRP and changed to "effective dose" in the 1990 recommendations. The latest recommendations by the ICRP (1991) is an effective dose limit of 20 mSv per year, averaged over 5 years, for occupational exposure. A further provision is that the effective dose should not exceed 50 mSv in any single year. The limit for public exposure is 1 mSv per year. In special circumstances a higher effective dose could be allowed, provided that the average over 5 years does not exceed 1 mSv per year.

In the ICRP Publication 60 (1991) the latest recommendations regarding radiological protection are published. Like all its predecessors, these recommendations of the ICRP are concerned only with protecting man from ionising radiation. The recommendations are an extension of those made in ICRP Publication 26 in 1977 and the aims are the same: to prevent detrimental non-stochastic effects (now called deterministic effects) and to reduce the stochastic effects of cancer and hereditary diseases to acceptable levels. As before, this is to be achieved by a system of protection that requires justification of a practice to ensure it produces a net benefit, optimisation of protection to keep exposures as low as reasonably achievable (ALARA) and the protection of individuals by imposing either dose limits or controls on the risks from potential exposures.

4.4.1 The basic framework of radiological protection

The basic framework is intended to prevent the occurrence of deterministic effects, by keeping doses below the relevant thresholds, and to ensure that all reasonable steps are taken to reduce the probability of stochastic effects.

Most decisions about human activities are based on an implicit form of balancing benefits against costs and disadvantages, leading to the conclusion that a particular course of action or practice is, or is not, worthwhile. It is also recognised that the conduct of a practice should be adjusted to maximise the net benefit to the individual or to society. This may often be a difficult goal to obtain since the objectives of the individual and society may not coincide. It is possible, however, to formalise and quantify procedures that could be helpful in reaching these decisions. Under these conditions attention has not only to be paid to advantages and disadvantages for the society as a whole, but also to the protection of individuals.

Three classes of radiation exposure can be distinguished: occupational exposure, which occurs at work and principally as a result of work; medical exposure which can principally be attributed to diagnostic examinations and therapeutic treatment; and public exposure which comprises all other exposures.

It is usually possible to apply controls at three points in the control of occupational exposure: at the source by fixing its characteristics, shielding and containment; in the environment, by ventilation or additional shielding; and at the individual, by requiring working practices and the use of protective clothing and equipment.

These controls also apply at the three points in medical exposures, but mainly as part of the primary function of diagnosis or treatment, rather than as part of a separate system of protection. The controls should be applied at the source in public exposure. If it cannot be made effective, controls should be applied to the environment or to individuals.

The appropriate control measures also depend on whether they are to be applied to practice causing exposures or to intervention aimed at reducing exposures. In the case of a new practice, there is the option of accepting the practice, as proposed or with modifications, or of rejecting it outright. Existing practices can be reviewed in the light of new information or changed standards of projection and, at least in principle, can be withdrawn. Any further changes then require intervention. Accidents give rise to situations which make some form of intervention unavoidable. It will often be virtually

certain in practices and in intervention that exposures will occur and their magnitude will be predictable, although with some degree of uncertainty.

4.4.2 The system of radiological protection

According to ICRP Publication 60 (1991) the system for proposed and continuing practices is based on a number of general principles.

(a) Radiation should be adopted only if produces sufficient benefit to the exposed individuals or to the society to offset any detrimental effects it may have.

(b) With respect to any radiation source, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received, should all be kept as low as reasonably achievable, taking cognisance of the economic and social factors. Any procedure involving radiation is subjected to certain restrictions, namely in dose, in risk, and in optimisation of protection.

(c) All individuals who are exposed to radiation should be subjected to dose limits or to some control of risk in the case of potential exposures. No individual should be exposed to radiation risks that in normal circumstances are judged to be unacceptable.

(ICRP, 1991)

The report (ICRP, 1991) also addresses those principles to be followed during intervention (intervention is the decrease of exposures to radiation).

(a) It should do more good than harm. The reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention.

(b) The form, scale, and duration of the intervention should be optimised so that the net benefit of the reduction of dose should be maximised.

Dose limits do not apply in the case of intervention. There will be, however, some level of projected dose above which, because of serious deterministic effects, intervention will almost always be justified. It is also stressed that any system of protection should include an overall assessment of its effectiveness in practice. This should be based on the distribution of doses achieved and on an appraisal of the steps taken to limit the probability of potential exposures. No one part should be taken in isolation, for example mere compliance with the dose limits, is not a sufficient demonstration of satisfactory performance.

Radiation protection is considerated today at the technical, political and international fronts. Many research projects are undertaken and are currently in progress to determine various aspects of radiation and its effects on the human body and its various organs. It includes studies of animals, theoretical estimates of radiation effects, data from anthropomorphic phantoms, and a review of human data such as the results of radiation therapy to terminally ill cancer patients. In addition to observations of actual measurable injuries in people and animals, estimates and theories of radiation injury have been proposed. Much attention has also been given to an individual and his descendants.

As important as the generation of data is, so is the interpretation thereof by various national and international scientific groups and others who have continued with the determination and estimation of permissible exposure limits. These have subsequently been published and are widely used as bases for action.

Professional organisations are also involved. Just after the invention of X-rays, the American Roentgen Ray Society and the Radiological Society of North America were organisations with membership primarily among physicians who used X-rays regularly; similar organisations were instituted in other countries as well. During World War II other disciplines, particularly physics, became very strongly involved in this subject. Hence the term "health physics" has been used essentially as a synonym for radiation protection and those engaged in radiation protection activities identify themselves as health physicists. Their activities culminated in 1955 in the formation of the professional Health Physics Society in America and the establishment of the International Radiation Protection Association some ten years later.

Large research and development organisations have produced more useful and sensitive radiation determination and measuring devices. Methods have been developed for increasing the accuracy with which actual radiation exposures can be measured, and analytical procedures for bioassay determinations of potential exposure have been refined.

Chapter 5

GENETICALLY-SIGNIFICANT DOSE SURVEY METHODS

In many countries, medical exposure of patients represents the greatest man-made contribution to the population dose. The genetically-significant dose is an index of the presumed genetic impact of radiation exposure on the whole population. This quantity, with particular reference to medical diagnostic radiology, has been determined in various countries. The main details of survey methods in sixteen countries and some large districts, between 1958 and 1986, are presented in the following sections.

5.1 Federal Republic of Germany, Bavaria (1956-1958)

Statistical data regarding the admission of patients to hospitals in Bavaria were obtained in 1956. The classification by type of examination, age and sex was obtained for a population of 0.75 million. Gonad-dose measurements were made on 1759 patients in 10 different types of hospitals and private practices. Some 705 measurements on children and 700 on adults were also carried out at the University of Munich. The gonad doses of adult females were measured in the vagina and for female children in the rectum. The national child-expectancy figures were used in the calculation of the GSD (UNSCEAR, 1972).

5.2 Yugoslavia: Slovenia (1960-1963)

The total number of radiographic and fluoroscopic examinations was determined during 1960 for all the institutions in Slovenia. Information on a 25 percent sample of these examinations was obtained in terms of age, sex and type of examination. The gonad-dose survey was biased towards those examinations which contribute most to the GSD. The centres to be visited were deduced on the basis of the 1960 workload. Some 2000 gonad-dose measurements were made. The gonad dose was measured at the scrotum for male patients and at the iliac crest for female patients. The data from the British survey and some additional data were used to convert the iliac crest doses to ovary doses. The child-expectancy figures were derived from national statistics. For examinations unconnected with pregnancy, the foetal contribution was taken into account, by assuming the proportion of pregnant women

of a particular age group in the population and reducing this by a factor of 0.75 to take into account the reluctance of the staff to subject women known to be pregnant to X-ray examination (UNSCEAR, 1972).

5.3 Finland (1963-1964)

All medical institutions, hospitals and private physicians were asked to supply details of all radiological examinations carried out during four weeks in 1963, together with the total number or estimated total number, of X-ray examinations during 1963. A second survey was instituted to complete the required information. The frequency of dental examinations was estimated from film consumption. A total of 2.7 million examinations plus 80000 dental examinations were done in 1963. One hundred and forty three thousand examinations were recorded in the study period, i.e. 5.1%. Gonad dose measurements were obtained by using 1960 fluoroglass dosemeters sent to 124 hospitals. In the case of males, fluoroglass rods were in contact with the testes; in females the dosemeter was placed on the back, near the ovaries. The ovary dose was obtained by phantom measurements using a calibration factor dependent on the type of X-ray unit used. National child-expectancy figures were used in the calculation of the GSD. Six per cent of the women examined were assumed to be pregnant and a foetal dose equal to the female gonad dose was assumed (UNSCEAR, 1972).

5.4 United Kingdom: Sheffield (1964)

The frequencies of the examinations in the Sheffield area (population 4.5 million) were collected in all the X-ray departments during a one-week period. Gonad doses were measured using ionisation chambers placed at the scrotum in males and at the level of the iliac crest in females. Over 2000 measurements on 800 patients in 30 hospitals were made. The ovary dose was calculated using the conversion data measured on a phantom in the 1957 British survey. The same child expectancies, based on national statistics, that were used in the earlier survey, were utilised in the later one (UNSCEAR, 1972).

5.5 United States: 1964 and 1970 national surveys

In the 1964 National Survey in the United States the survey was conducted on the basis of interviews of 9653 households. The sampling plan followed a multistage probability design which permitted a continuous sampling of the civilian population of the United States. The first stage of this design consisted of drawing a sample of 357 geographically defined primary sampling units (PSU's) from the 1900 units into which the United States had been divided. A PSU was a county, a group of contiguous counties, or a standard metropolitan statistical area (Gitlin *et al.*, 1966). Within the PSU's there were ultimate stage units called segments. Each segment consisted of a cluster of neighbouring households or addresses and was defined to contain an expected nine households. A random sample of approximately 90 segments were drawn each week and members of the approximately 800 households were interviewed concerning factors related to health (Gitlin *et al.*, 1966).

Since the household members interviewed each week were a representative sample of the population, samples from successive weeks could be combined into larger samples. Thus, the design permitted both continuous measurement of characteristics of high incidence or prevalence in the population and, through the larger consolidated samples, more detailed analysis of less common characteristics and smaller categories. For this study, 13 weeks of interviewing (from April to June 1964) provided a sample of 10029 households that included 94 refusals and 282 households in which no one could be found at home during repeated calls. The 9653 completed households included 31289 persons of whom 4525 had had an X-ray examination during the previous three months (Gitlin *et al.*, 1966).

The 1970 study was designed to provide data directly comparable to the previous study. The first stage of the sampling consisted again of drawing 357 PSU's from approximately 1900 geographically defined PSU's. This study, 26 weeks of interviewing (from April through September 1970), provided a sample of 22500 households. The 21500 completed households that were ultimately interviewed included approximately 67000 persons for whom X-ray visit data and other survey information were obtained (US Dept. of Health, 1973).

The follow-up for both surveys consisted of an approach to each clinic or hospital where a selected person had had an X-ray examination with requests for details on the examination together with a film from which the X-ray quality and the field size could be determined. The gonad doses were determined on the basis of these exposure factors by processing the results of comprehensive scatter measurements made on a phantom. These were checked by *in vivo* thermoluminescent dosemeters applied to 360 patients undergoing a variety of examinations. Child-expectancy figures were derived from national statistics (US Dept. of Health, 1976 and UNSCEAR, 1972).

5.6 Russian Republic (1964)

The results of the surveys at the Moscow X-ray Radiology Research Institute concluded that 65 million X-ray examinations were carried out annually on the 82 million people in the Russian Republic (14 million radiographs, 36 million fluoroscopies and 15 million chest photo-fluorographs). Measurements of the skin dose, gonad dose and the integral dose were made for a number of X-ray examinations. Ninety one per cent of the total integral dose was from fluoroscopy, 6 per cent from photofluorography and 3 per cent from radiography (UNSCEAR, 1972).

5.7 United States: Other local surveys

Four surveys have been completed in local areas: New York City (1962); New Orleans (1962-1963); Johns Hopkins Hospitals (1965); and in Texas (1963). Each of these surveys have had to depend on the national child-expectancy figures. In the New York survey 68 out of 234 institutions took part and each reported the annual number of X-ray examinations and a breakdown by age and type for a period of a few days. Physicians' offices reported over a four-week period. In New Orleans 262 X-ray units and 144 physicians' offices, 73 per cent of those in the area, reported data for a six-month period and the details of the exposure of 8000 patients comprising 9000 examinations and 18000 projections were collected and used to derive the gonad doses using relevant phantom data. The Johns Hopkins survey was based on the radiographic examinations of 100000 patients. The 220000 examinations at the hospitals of the University of Texas over a 30-month period were used together with gonad and skin dose measurements to derive the GSD (UNSCEAR, 1972).

5.8 Czechoslovakia, Bohemia (1965-1966)

The survey covered three out of the 11 regions of the Czechoslovak Socialist Republic (population 4341000 or 30.5 per cent of the country total). The number of examinations carried out in all radiological and fluoroscopic units over a period of one year was collected, together with those carried out during a three-month period in all mass chest survey units and during two one-week periods in 219 out of 570 dental X-ray departments. The breakdown by age was obtained for 253853 examinations, i.e. for 6.4% of the annual number. Central-axis skin-dose and gonad-dose measurements were carried out on 5602 patients in 70 departments at 28 industrial and agricultural localities. To obtain the ovary dose, phantom measurements were carried out on each machine immediately following an examination on the specific machine (UNSCEAR, 1972).

5.9 Netherlands (1967)

The radiological examinations carried out in one year on 4.9 million people covered by 53 insurance companies were used to derive the annual total number of examinations. A subsample of nine companies which covered 1 million people was used to obtain the breakdown by age and sex. Both samples, i.e. the sample to derive the annual total number of examinations as well as the sub-sample to obtain the breakdown, were geographically scattered. The gonad doses were obtained from measurements done on patients and on a phantom. National child-expectancy figures were used, except for the examinations of pregnant women (UNSCEAR, 1972).

5.10 United States: Puerto Rico, Southern and Western regions (1968)

The average number of patients radiographed per week over the year 1968 was presented from all hospitals in these two regions of Puerto Rico. These statistics were broken into types of examinations. An earlier investigation had been carried out in the western region in 1967. The majority of dosimetric work was carried out on one unit. Thermoluminescent dosemeters and ionisation chambers were used for a limited number of in vivo dose measurements at one centre and agreed reasonably with phantom measurements. The average gonad doses were derived from the

returns from the 47 facilities with one or more X-ray units in the Southern region and from 65 facilities in the Western region. The child-expectancy figures were derived by the Department of Health but not published (UNSCEAR, 1972).

5.11 Japan (1969)

The frequencies of examinations were obtained during 30 consecutive days from a number of hospitals of various sizes with regard to number of beds and from 1000 physicians. Answers giving the numbers of examinations and the physical conditions used, were received from 60 per cent of the hospitals approached. Gonad doses were measured on four phantoms using X-ray units from different manufacturers operating at the particular conditions used for each examination type in the various hospitals included in the survey. The phantoms represented 8-month, 5-year and 10-year old children and the adult. The output of 54 X-ray generators was surveyed to obtain a mean output per unit. The child expectancies were derived from national statistics (UNSCEAR, 1972).

5.12 New Zealand (1969)

A survey in which details of 40000 radiological examinations were collected and analysed, sampled 3.5 per cent of the annual number of examinations. A field survey was conducted in which the gonad or skin doses were measured in 1400 examinations and 2460 technique forms were used to derive the gonad dose. The male measurements were carried out directly and the ovary dose was calculated from the data used in the British national survey of 1957. Child expectancies were derived from national statistics (UNSCEAR, 1972).

5.13 Thailand (1970)

The total number of patients radiographed in all centres was requested for January 1970 and the 56 per cent return represented some 45 per cent of the estimated number of examinations carried out. A very low frequency of 30 examinations per year per 1000 persons was reported. Gonad-dose measurements were made in one hospital during fluoroscopic procedures using thermoluminescent dosemeters placed on the scrotum of male patients and in the vagina of female patients. Phantom measurements were undertaken in five hospitals utilising the exposure data of

patients. As data was insufficient to make an accurate estimate of the GSD, a "most possible" value was derived. The female child-expectancy data derived in 1966 by the Ministry of Public Health was used and the male fertility was deduced from it, using as a basis the relationships observed in New Zealand (UNSCEAR, 1972).

5.14 Great Britain (1977)

5.14.1 Selection of the sample

Every National Health Service (NHS) hospital in England completed an annual return giving details of the workload of its various departments. For radiology departments the workload was given using a system of radiography units in which each unit represented approximately one minute of a radiographer's time. At the time the sample was selected the most up-to-date information available was from the 1974 returns, with a total of about 211 million radiography units (Table 5.1). A standard stratified sampling technique was used and it was estimated that about 7% of the hospitals was enough in order to make an estimation of the total numbers of examinations with sufficient accuracy. The returns were stratified into nine workload ranges as shown in Table 5.1. The single returns with a workload of over 2 million units were automatically included in the survey. Thus, 78 institutions in England were allocated to the individual strata as shown in Table 5.1 and the institution with radiography units larger than 2000000 was automatically included to bring the total to 79 (Kendall *et al.*, 1980).

Wales used the same radiography workload unit system as England. For 1974 a total of 15 million units were recorded for 131 hospitals. From these, five were selected on an informal basis. This sample comprised one large, two medium-sized, and two small hospitals.

The Scottish system of radiography workload units was not identical with that for England, although similar, and the Scottish sample was chosen along similar lines to the English one. Information was available for 1976 when a total of 43 million units were recorded for 151 hospitals. The two hospitals with recorded workloads of over 2 million units were included in the survey, while the remaining were stratified using the same eight workload ranges as used for England. From these hospitals 26 were

selected using the same allocation procedure as was used for England with individual hospitals selected within each stratum, i.e. the workload ranges (Table 5.1), with probability proportional to the recorded workload. The total sample for Scotland therefore consisted of 28 hospitals (Kendall *et al.*, 1980).

Table 5.1 *Structure of the sample for England.*

Radiography units	Number of NHS hospital returns in England for 1974	Numbers NHS Hospitals included in sample
<20 000	307	4
20 000 - 49 999	226	4
50 000 - 99 999	154	5
100 000 - 199 999	123	7
200 000 - 299 999	109	6
300 000 - 499 999	102	11
500 000 - 999 999	102	28
1 000 000 - 1 999 999	25	13
≥2 000 000	1	1
	1 149	79

5.14.2 Data collection

Among the hospitals contributing to the 79 English hospital returns initially selected for this survey, 54 consented to take part, including the three hospitals which submitted a joint return (≥2000000). The five Welsh hospitals all consented to taking part in the survey, as did 22 of the 28 Scottish hospitals. Each of the 81 consenting hospitals was then sent a supply of forms to be completed and asked to record details of all radiological examinations carried out during the week beginning 13 June 1977, before returning the completed forms to the NRPB. The details included the sex and age of the patients and the types of examination, as well as technical factors like the number of films used, the fluoroscopic screening time, and the extent of gonadal shielding. The overall response rate in the survey was 68%.

The first step in the processing of the completed forms was the coding of examination types and data was then transferred to a computer.

The first stage in the analysis was the generation of summarised information for each hospital. At this stage, further plausibility checks were carried out and it was necessary to introduce some assumptions about incomplete or incorrect information. A number of errors were detected when the data was first entered into a computer. During the course of the analysis further checking was carried out on certain examinations, and some further errors were corrected. Although the residual error rate cannot be stated with certainty, it was believed to be below 1%. This was considered acceptable since the standard error due to sampling is never less than 5% of the estimated overall total. The identification and correction of errors was found to be a very time-consuming process. Additional to the wide variety of transcription errors which could be introduced, there was the problem of different interpretations of those originally completing the forms (Kendall *et al.*, 1980).

5.14.3 **The gonadal dose survey**

To derive a value for the GSD it is necessary to establish accurate values for the gonadal doses delivered by only those types of examinations which make a significant contribution to GSD. These are likely to be examinations of the lower abdomen, where the ovaries and testes will be in the X-ray beam or close to its edge, or examinations that occur very frequently and consistently make a large contribution to the population dose even if the individual gonadal doses may be low. Consequently, 13 examination types were selected which, between them, were likely to contribute at least 95% to the GSD.

The number of patients included in the survey for each examination type was necessarily a compromise between the time and effort available and the desired accuracy in the measurement of the mean gonadal dose. It was also recognised that a large number of measurements would be needed at each hospital if any forms of inter-hospital comparisons were to be made. In practice, large variations were found to occur in the same hospital.

Separate samples were required, not only for each examination type, but also for each category of patient that might be considered to have its own peculiar dose

distribution. It was found that at least four different patient categories were required: male and female, child and adult, but it was not realistic to expect to be able to measure doses on 50 patients from each category for the 13 selected examinations at every hospital in the survey. For any one hospital therefore, there were only two patient categories, male and female, and the intention was to gather data on at least 50 patients of each sex for the more common examination types. This proved to be possible within a period of one or two months for all but the smallest hospitals in the survey. For the less frequent examination types as many measurements as possible were made during the survey period.

A dosimetry system had been developed that was based upon small sachets, approximately 4 mm x 4 mm, of lithium borate thermoluminescent powder that could easily be attached to the patients to measure directly the skin dose received during X-ray examinations. These sachets were stuck directly on to the patient. At the end of the examination and after removal from the patient it remained sufficiently adhesive to stick to a form on which were entered the relevant details concerning the patient and the examination technique. Technique factors that were unlikely to vary from patient to patient such as the X-ray tube filtration and the film/screen combinations were recorded separately when the surveys were being initiated to avoid unnecessary duplication on the individual patient forms.

For male patients the sachets were positioned on the inside of the thigh level with the testes and left there throughout the examination. The dosemeter reading was consequently taken as a direct indication of the gonadal dose for male patients. If gonadal shields were used the radiographers were instructed to shield the dosemeters to the same extent as they shielded the gonads. For female patients, the entrance skin dose at the level of the ovaries was measured by attaching the sachets to the lower abdomen at the level of the anterior-superior iliac spines on the side of the body on which the X-rays were incident. For non-fluoroscopic examinations a separate dosemeter was attached to the patient for each projection whilst for fluoroscopic examinations, like barium enemas, where the projection, field size and beam position constantly change, four dosemeters were attached to the patient throughout the examination. They were positioned one at the front , one at the back and one at each side at the level of the ovaries, so that the entrance dose was monitored for all projections.

For chest X-rays an elastic belt was attached around the hips containing six lithium borate sachets on the anterior midline and a further six on the posterior midline. Since the absorbed dose at the level of the gonads from radiography of the chest was too low to be measured accurately with TLD's for single examinations, the same belt was used repeatedly to integrate the dose for up to 100 patients. The mean dose recorded for each batch of six sachets was used as an indication of the amount of leakage and scattered radiation reaching the level of the gonads. Different factors were then applied to convert these mean doses into ovarian and testicular doses. Factors for converting entrance skin doses to ovary doses have been derived by exposing a Rando standard-man phantom to a range of diagnostic X-ray fields, with lithium borate dosemeters located on the skin and at the sites of the ovaries (Wall *et al.*, 1980).

5.14.4 **The genetically-significant dose**

The annual GSD was then calculated using the formula:

$$GSD = \frac{\sum_{k_1,\ell} e_{k_1\ell} d_{k_1\ell}}{\sum_{k_1,k_2} N_{k_1k_2} p_{k_1k_2}} \qquad \text{(equ. 5.1)}$$

where $d_{k_1\ell}$ is the estimated mean dose received among persons in age-sex group k_1 who undergo examination type ℓ

$e_{k_1\ell}$ is an estimate of the total number of future children expected by persons in age-sex group k_1, who underwent examinations of type ℓ in 1977

$p_{k_1k_2}$ is the estimated child expectancy of an individual in the k_2 th subdivision of the k_1 th age-sex group

$N_{k_1k_2}$ is the 1977 mid-year population of Great Britain in the k_2 th subdivision of the k_1 th age-sex group. This will include a category for the number of foetuses *in utero* estimated from the number of live births in 1977.

The estimate of GSD calculated in this report is subject to a number of different types of uncertainty. These are mainly due to the fact that the frequency data was collected at only a sample of hospitals rather than at all hospitals which carry out diagnostic radiology, and that the estimates of gonadal doses received from the

various categories of radiological examination were based on relatively few measurements. The sampling error in the estimated GSD from these two sources can be approximated, using detailed results from the frequency survey and the values for the gonadal doses and their standard errors.

This method of calculating the sampling error ignores sources of error such as inaccuracies in the data collection and measurement procedures. Bias due to hospitals not responding to requests to take part in the project and the fact that data for the frequency survey were collected during a single week which may not have been typical of the year as a whole were ignored. There will also be some error introduced by the assumption that the child expectancy of an individual is not related to the type of examination he or she undergoes, and by the use of child expectancies for 1974, rather than 1977. However, the estimate of GSD can be shown to be relatively insensitive to small changes in child expectancies. In spite of these deficiencies the sampling error calculated in this way should be useful as a rough guide to the interpretation of this estimate of GSD (Darby *et al.*, 1980).

5.15 France (1982)

A national survey was undertaken in 1982 in France to establish the collective effective dose and the genetically-significant dose associated with the main types of radiological examinations (excluding nuclear medicine, CT scans, dental radiology and mass chest screening) performed annually in France.

5.15.1 The national survey

The survey was conducted in two separate phases: (i) About 500 radiology departments, private clinics and offices practising diagnostic radiology were initially selected throughout the country by a stratified sampling procedure (average sample rate of $\frac{1}{10}$). The stratification was based on a rough evaluation of their annual X-ray film consumption. All the necessary information about the provision of staff and facilities for diagnostic radiology, in terms of numbers of radiologists, radiographers and X-ray units available, was finally gathered in 386 public hospitals and private practices that actually participated in the survey.

(ii) In order to estimate the total number of X-ray examinations annually being done in France, a questionnaire was sent to a sub-sample selected among the X-ray units (549 out of 1372) that equipped the 386 radiological departments mentioned above. The questionnaire was broken down by age and sex of patients and technical data about each of 13000 X-ray examinations, such as the number of films, the fluoroscopic screening time, the X-ray beam projection, the applied potential (kV_p), the tube current (mA) and the exposure time (s), were collected over a specified one-week period in June 1982. It was estimated that a total of 45.4 million X-ray examinations were performed in France in 1982 by extrapolating the weekly figures and taking into account the seasonal radiological activity variations.

5.15.2 **Dosimetry**

Measurements were performed either on an anthropomorphic phantom or directly on the patient by using thermoluminescent dosimeters (lithium borate). These dosimeters were previously calibrated with a standard source of Co-60.

(i) **Adult phantom dosimetry**

Three major problems had to be solved. The first one was the selection of parameters to be used in the experimental measurements. There were almost 1500 configurations expressed in terms of combinations of physical and anatomical parameters such as kVp, mAs, film size, X-ray beam projections and centring point position observed in the survey. This number was reduced to 37 configurations by considering either the relative low frequency or the low contribution to the collective population dose.

The second problem to be addressed was the selection of a representative X-ray table on which dosimetry measurements were to be performed. Seventeen different X-ray tables, installed in five hospitals which participated in the dosimetry survey, were selected. Free-in-air exposure variations were checked as a function of kVp, mAs and quality of the detector (standard film and rare earth screen film) by using ionisation chambers and TLD's. Finally, the selected X-ray table, having the closest values of technical parameters as compared to the average was a model made by Compagnie Générale de Radiologie.

The third problem was the method of the organ dose assessment. Dose measurements were done inside the Rando-man phantom for particularly radiosensitive organs. It must be kept in mind that the objective of this study was to evaluate the equivalent dose and not the GSD only. Two different procedures were followed in measuring organ doses:

(a) For lenses (6 TLD's), lungs (57 TLD's), testes (6 TLD's), ovaries (9 TLD's), mammary glands (9 TLD's) and thyroid (3 TLD's), TLD's were inserted into the corresponding organ positions and systematically irradiated 30 times to obtain significant dose values, especially at different points outside the primary beam. Three TLD's were also attached to the surface of the phantom at the centre of each X-ray field to determine the entrance skin dose (Maccia *et al.*, 1988).

(b) For red bone marrow, bone surface and the "remainder" organs, the estimation of doses was mainly based on the entrance skin dose measurements, carried out for each radiograph. These organ doses had been obtained through Monte Carlo calculations using standardised X-ray field size and positions, corresponding to 37 configurations. A mathematical phantom (MIRD) was used to represent the patient. To validate this procedure, the organ doses obtained from a Rando phantom and the MIRD had been compared and reasonable agreement was obtained (Maccia *et al.*, 1988).

(ii) **Children**

Some *in-vivo* measurements were also performed on a sample of young patients (less than 10 years old) for a limited number of X-ray examination types, namely pelvis, intravenous urography, abdomen, lumber spine and barium meal. Measurements were carried out by using TLD's attached to the patient's skin. Thyroid, gonads (only for boys) and lung doses were estimated directly from skin dose measurements: one TLD over the thyroid, one TLD over the testes and two TLD's respectively on the front and back of the thorax. Doses for other organs were, as in the case of the adult patients, deduced from measurements of entrance skin dose using Monte Carlo conversion factors adapted to a paediatric phantom (Maccia *et al.*, 1988).

5.15.3 The genetically-significant dose

The results of both frequencies and gonadal doses associated with each examination type in this survey were combined with child expectancy of the patients to obtain the GSD. It was recognised that many of the X-rayed individuals may have had life and child expectancies quite different from the general population because of the effect of their medical condition. Due to a lack of specific data on this subject, it was assumed that persons who underwent radiological examinations had the same future child expectancy as the general population.

5.16 Spain (1985 - 1986)

The Medical Physics Group at the School of Medicine of the Complutense University of Madrid initiated a study of radiation doses in relation to diagnostic radiology in the area of Madrid in 1986 in co-operation with the Department of Health and Consumer Affairs and several Madrid hospitals as well as some outpatient centres. Many of the results and conclusions could be extrapolated to the rest of Spain. A second phase of the study was however designed in co-operation with the Department of Health to involve sampling throughout Spain in order to obtain the required results without extrapolation. A first assessment and in some cases making use of preliminary figures and a few indirect estimations, was published in January 1989 in The British Journal of Radiology.

5.16.1 The survey

The National Health Service (NHS) through the National Institute of Health (NIH) is responsible for the health of approximately 96% of the population of Spain. Each person affiliated to the NHS has a card which entitles his/her family to receive health care in the NHS network. Radiological examinations are performed mainly in hospitals and outpatient centres. Private diagnostic radiology is used by the remaining population, excluding those served by military hospitals, and by patients, although they have access to NHS services, prefer the private sector. Data was available from all the Autonomous Communities through the Directorate General of the NIH. The Communities Andalucia and Cataluña were excluded, but the available data still amounted to 67% of the population in Spain. The effect of the exclusion would not be significant, since its average characteristics should be close to that of

the whole population. Data had also been supplied by national, regional and local health institutions including the Nuclear Safety Council (NSC).

A partial analysis of different diagnostic radiology sectors was made to estimate the annual number of radiological examinations. There are three well differentiated types of diagnostic radiology practice : (i) hospitals belonging to the Department of Health network (or to the Department of Health of the Autonomous Communities, as in the case of Andalucia and Cataluña); (ii) outpatient centres (also depending on the corresponding department); and (iii) the private sector (private hospitals, clinics and offices). The diagnostic radiology performed in any of the 36 centres of the Department of Defence or in local administration centres is not included. It was found to be difficult to obtain data from the private sector. Information reflected in the Department of Health and Consumer Affairs internal reports, namely that about 20% of the total radiographic film sold annually in Spain is used in private radiology, led to the assumption that 26% of the examinations were performed in the private sector.

5.16.2 Frequency of some examinations

Data from the San Carlos University Hospital was used for analysing the frequency of hospital radiological examinations. This centre was a good representation of the functioning and patient population in Spain during the year of the analysis (1986). The hospital had also a very good data-processing centre which enabled some of the data obtained to be compared by using different methods of analysis. The following information was available for the San Carlos Hospital during the year of the survey:

- 18 radiodiagnostic rooms
- 13 portable X-ray machines (excluding the catheterisation room or dental equipment)
- 141578 radiological examinations (ultrasound examinations excluded)
- 414265 radiographs were taken
- 2.86 films per examination
- total of 265990 patients (26348 patient admissions; 191355 outpatient visits and 72898 emergency admissions)
- 0.53 radiological examinations per attended patient.

Data from a national insurance company and of one private centre in Madrid was analysed for the private sector. The results from 16 additional private centres, comprising 43 rooms and 96320 annual examinations were also used. Table 5.2 refers to an estimation of the frequency of the radiological examinations in Madrid and the whole of Spain. Values for Spain as a whole were extrapolated from the frequency distribution of examinations in Madrid.

Table 5.2 *Estimate of the frequency of radiological examinations.*

Examination	Number of examinations (per 1000 inhabitants per year)		
	Madrid	Whole of Spain	Whole of Spain %
Skull	18	15	3.1
Spine	110	97	19.8
Chest	154	128	26.0
Mammography	17	14	2.9
Abdomen	53	45	9.2
GI tract	45	40	8.2
Urography	15	13	2.6
Hip and pelvis	18	15	3.1
Extremities	90	75	15.3
CT	10	7	1.4
Other	50	41	8.4
Total	**580**	**490**	**100.0**

(Vañó *et al.*, 1989).

5.16.3 **Dose measurement**

Not all the necessary dose values for the different examinations were obtained during the first year of the project. It was possible, however, to obtain technical information for more than 60000 hospital examinations of the technique factors, operator and

equipment involved, place where performed, patient sex and age, as well as a smaller number of examinations performed in outpatient centres.

Exposure measurements were made at skin level using mean values of parameters like kVp, mAs, screening time, etc. The measurements were done in several rooms of the different centres and for a large number of examination modes. Calibrated Victoreen Radcheck ion chambers were used for this purpose. Measurements of the area-exposure-product for some complex examinations (digestive tract, intravenous urography, etc.) were also made by using a Diamentor (PTW Freiburg) transmission ionisation chamber.

Measurements in urography of the absorbed dose (in muscle) at the point of entry were done directly on patients. TLD-100 dosemeters from Harshaw were used for this purpose. Organ dose measurements were conducted on a Remab phantom from Alderson which was specially designed for diagnostic radiology. Between 40 and 50 TLD-100 chips were used in each radiological examination for dose estimations. Results had been obtained for digestive tract examinations, chest, conventional chest tomography, computed tomography and urology.

5.16.4 **The genetically-significant dose**

At the time of the report it was possible to perform a more detailed analysis of the chest and urographic examinations so that the GSD in these cases could be calculated. The report of the National Institute of Statistics made it possible to analyse the population of the different Autonomous Communities. It was therefore possible to derive the child expectancy as a function of age from their age distribution and number of descendants. This was assumed to be identical for the whole of Spain and thus the GSD could be calculated.

An evaluation of all the above-mentioned survey methods will be done in the discussion in Chapter 10, namely with special reference to the properties that an acceptable sample and sampling procedure should comply with. The sampling method that was used in the South African survey will serve as the standard.

Chapter 6

SAMPLE DEFINITION

In the present investigation of the GSD in South Africa, the format of the sample to be drawn to assess the value of the GSD depended on the available information. It is required by the Directorate: Electromedical Devices and Radiological Health, Department of National Health, that records of patients receiving therapy or diagnostic examinations should be kept. In addition to the prescribed information to be included in the patients' medical records, registers are also kept or in some cases the information is stored in a computer. Registers usually include some basic information such as the name of the patient, date of birth, gender and type of X-ray examination.

Letters were written to all private radiologists during the third quarter of 1989 with the request to supply total number of exposures, total number of examinations and total number of patients for 1987 and 1988. The best response was obtained regarding the total number of patients for 1988. Summaries of the workload of all government aided hospitals were obtained from the four provinces (Natal Provincial Administration, 1987/88; Orange Free State Provincial Administration, 1988; Provincial Administration of the Cape of Good Hope, 1987/88 and Transvaal Provincial Administration, 1987/88). In two of the four provinces, namely in the Cape and in the Orange Free State, only the number of patients who underwent X-ray examinations, was available. In Natal, however, both the number of patients and examinations for the years 1986, 1987 and 1988 were available. It was therefore possible to calculate an average factor of the ratio of the number of X-ray examinations to the number of patients in Natal, namely 1.265. The number of patients examined in all the government aided hospitals, clinics as well as in the private practices, where the number of examinations was not available, was multiplied by a factor 1.265 in order to obtain the number of X-ray examinations. A total of 5576235 examinations were thus obtained for South Africa. **It was assumed that the frequency of examinations during this period would be the same as that at the time of the actual survey (1990-1991).**

Statistical information from a total of 292 institutions, i.e., the complete total of private practices, government aided hospitals and clinics, was thus obtained (a few other institutions, discussed on pages 174 and 175, were omitted since their contributions were believed to be negligible). It was therefore considered necessary to present the data more visually in order to determine a suitable method of sampling.

6.1 Stem-and-leaf display

In order to decide what process could be used to draw a random and representative sample, it was necessary to get more clarity on aspects like the following:

(i) The symmetry of the sample distribution.
(ii) The extent of the range of examinations of each participant in the survey.
(iii) Whether a few values were far removed from the rest.
(iv) Whether there were concentrations of data.
(v) Whether there were gaps in the data.

A stem-and-leaf display (Hoaglin, Mosteller and Tukey, 1983) provides answers to all the above aspects and is similar to a histogram. By using the digits of the data values themselves instead of merely enclosing area, this display offers advantages in some situations. The median and other summaries can be readily found on the ordered batch. Two problems with histograms are that they are somewhat difficult to construct and that the sense of what the actual sample points are within the respective groups, is often lost. It can be of help to see the distribution of data values within each interval, as well as patterns in the data values.

An example of the stem-and-leaf display is represented in Figure 6.1. A line exists of a stem and one or more leaves, the stem just left of the vertical line and the leaves at the right. Line number 10, for example, has a stem with value 4 and three leaves with values 50, 80 and 55. Since a unit represents 100 in this representation, a leaf with value 50 represents 5000. The number 45000 is thus represented on the line with stem 4 and by the leave with number 50.

The choice of the number of lines in a stem-and-leaf display involves the number of data values in the batch and the range to be covered. The maximum number of lines can be calculated according to the equation

$$L = [10x\ell og_{10}n] \qquad \text{(equ. 6.1)}$$

where n is the number of data values. According to this rule, it was experienced in practice that values of L between 20 and 300 were obtained (Hoaglin, Mosteller and Tukey, 1983).

Since n is the number of data values, it represents the number of institutions (292) in this model. Thus for n = 292, the maximum number of lines calculated according to equation 6.1 was L = 25. The range of the batch (R) was obtained by subtracting the smallest number of examinations from that of the largest. The actual largest value was ignored, however, since it was considered to be an outlier with a value nearly

double that of the second largest one. In order to determine the interval width, the range is divided by the maximum number of lines, i.e.

$$\frac{R}{L} = \frac{233400}{25} = 9336.$$

Rounding to the nearest power of 10 gave the value 10000 as the interval width. Since the first line was too crowded (having too many leaves on the line) it was necessary to split lines and repeat each stem. Leaves from 0 to values <5000 were put on the * line and from 5000 to values <10000 on the • line.

In Figure 6.1, the first column on the left refers to the total number of institutions in the survey and the second column refers to the government aided hospitals and clinics only. The third column represents the interval widths, i.e. the stems, and the numbers to the right of the vertical line in italic/bold refer to the private practices.

A data value can be assigned a rank by counting in from each end of the ordered batch (columns one or two). When the total number of examinations are considered in Figure 6.1, the number with stem 6 and leaf 99 (i.e. 69900) has rank 271 when counting up from 300 (first item, first row, top, left) and rank 22 when counting down from 390400. If the government aided hospitals and clinics only (all numbers excluding the italic/bold numbers) are considered only, 65200 has rank 225 when counting up from 300 and rank 15 when counting down from 390400. The depth of the data value is the smaller of the two ranks for each of the columns, namely 22 and 15 respectively.

Except for one middle line (indicated with a number in brackets), the number in the depth column is the maximum depth associated with data values on that line. Thus the depth of 35700 is 40 for the total number of institutions and 28 for the hospitals only. The "middle line" includes the median, and the depth column shows in parentheses the number of leaves on this line.

6.2 Sampling method

The stem-and-leaf display made it possible to organise numbers graphically in a way that directed attention to various features of the data. The properties of the sample distribution were well identified in correspondence with the aspects mentioned in Section 6.1. The task was therefore set to find a model in order to draw the best representative sample of the population and it was obtained in a very unique way. The parameters required in the sample were the numbers of examinations in the various age-gender-race groups as well as the technique factors regarding the various examinations, namely screening time (min.), receptor size (cm), view (AP, PA, LAT, Oblique), tube voltage (kV), workload (mAs) and FFD (cm).

It was decided to make use of the so-called Dollar Unit Sampling (DUS) method after the data in the stem-and-leaf display was subjected to each one of the guide-lines enunciated in Section 6.1 and arguments in favour of this method considered:

(i) The annual usage data is skewed to the small numbers (Figure 6.1). The Dollar Unit Sampling method is especially applicable to such circumstances. This method is a special case of probability proportional to size sampling (PPS sampling). All institutions with an annual examination number larger than 200000 were included (Section 6.3.3) and the other institutions were proportionally and effectively randomly drawn.

(ii) Figure 6.1 clearly indicates how spread out the range of examinations of each participant was in the survey. Proportional sampling is, however, a safe way to conduct a sampling procedure, since every class-size has an equal opportunity to be drawn.

(iii) It can easily be observed that a few values are far removed from the rest, that there are concentrations of data and that there are gaps in the data. Proportional sampling is again a reliable way to conduct a sampling procedure, however, since it does not matter whether any or all of these conditions occur, every class-size has still an equal opportunity.

This demonstrates why the stem-and-leaf display was considered to be an essential aid in the process to make a decision on the sampling method to be implemented.

6.3 Dollar Unit Sampling (DUS)

In this section it is not the intention to compare several methods of sampling. Proportional to size sampling appears to be an effective way, however, to deal with data like this and the Dollar Unit Sampling is thus an obvious choice. This section is therefore a representation of the historical development and theory of the DUS (not all the theoretical principles mentioned are applicable to this study but reveal the necessary background) as well as its application to South African conditions.

6.3.1 Non-standard mixtures

The Dollar Unit Sampling method originated with the analysing of non-standard mixtures of distributions in auditing. A number of people were concerned about the fact that there were no appropriate statistical methods available for certain non-standard distributions. Statistical methods have only recently begun to be developed for analysing this non-standard type of data. The first significant contribution was that of Aitchison (1955), with the larger number of contributions after 1972 (Guthrie, 1989).

Figure 6.1 *Stem and leaf display of radiological examinations in government aided hospitals, clinics, and private practices for 1987/88.*

Interval width: 5000

n (total) = 292 n (hospitals) = 239

DEPTHS Total	Hospitals		(Unit = 100 examinations)
143	(137)	0*	00 00 00 00 01 01 01 01 01 01 01 01 01 02 02 02 02 02 02 02 03 03 03 04 04 04 04 05 05 05 05 05 05 06 06 06 07 07 08 08 08 08 09 09 09 09 10 10 10 10 10 10 10 10 10 11 11 11 12 12 13 13 13 13 14 14 14 14 14 14 15 15 15 16 16 17 17 17 17 18 18 18 18 18 19 19 19 19 **19** 20 20 20 21 22 22 23 25 25 25 **25** 26 26 26 26 **26** **27** 28 28 29 29 30 30 31 31 32 33 33 34 35 35 36 38 38 40 40 40 40 40 40 41 41 43 44 44 45 45 45 45 45 46 **46** **47** 48
(36)	102	0•	50 52 52 53 54 54 57 58 59 59 59 **59** 60 **60** 62 62 63 63 70 70 72 74 74 75 76 80 82 83 84 **84** 85 86 88 88 90 94
113	69	1*	**01** 02 06 **09** 10 13 **13** 14 17 17 **17** 19 **19** **20** **22** 23 **23** 27 31 31 **32** **33** **34** 39 40 41 **47**
86	54	1•	**51** 52 61 63 70 74 **76** **81** 82 82 85 89 **96** 97
72	44	2*	**00** **06** 15 **17** 21 21 31 31 32 33 41
61	36	2•	**52** **54** **56** 58 62 65 **65** **80** **87** 92 **93**
50	32	3*	**03** **05** **16** 22 23 **23** **38** 41 42 **42**
40	28	3•	57 60 **79** **84** 94
35	25	4*	21 25 30 **38** 42
30	21	4•	50 **55** 80
27	19	5*	26
26	18	5•	53
25	17	6*	01 47
23	15	6•	52 ***99***
		7*	
21	14	7•	**64** 88
19	13	8*	18 20
17		8•	**60**
16		9*	**11** **29** **43**
13	11	9•	50 73
11	9	10*	29
10	8	10•	55 97

Figure 6.1 (cont.)

DEPTHS

Total	Hospitals		(Unit = 100 examinations)
8		11*	**38**
7	6	11•	97
		12*	
		12•	
		13*	
		13•	
6		14*	**01**
5	5	14•	82
		15*	
		15•	
		16*	
		16•	
		17*	
4	4	17•	75 (King Edward VIII Hospital)
3	3	18*	28 (Tygerberg Hospital)
		18•	
		19*	
		19•	
		20*	
		20•	
		21*	
		21•	
		22*	
		22•	
2	2	23*	34 (Groote Schuur Hospital)
		23•	
1	1	39*	04 (Baragwanath Hospital)

Note: The bold numbers refer to private practices.

The terminology "mixture of distributions" usually refers to a situation in which the jth of k underlying distributions is chosen with probability $p_j, j = 1, \ldots, k$. The selection probabilities are usually unknown and the number of underlying distributions k may be fixed or random. The special case of two underlying distributions, with probabilities p and p-1, is an important classical problem. There are many examples of models that are best described as mixtures of two or more other models in the above sense. A probability model for the heights of 16 year old children would probably best be described as the mixture of two unimodal distributions, one representing the model for the heights of girls and one for the boys. Similar mixtures of distributions are mixtures of normal distributions, mixtures of χ^2 distributions, mixtures of exponential distributions and mixtures of binomial distributions.

The literature contains very few papers that provide and deal with special "non-standard" mixtures that mix discrete and continuous distributions. The word mixture refers in general to a convex combination of distributions of random variables. Suppose X and Y are random variables with distribution functions F and G, respectively. If $0 \leq p \leq 1$, then $H = pF + (1-p)G$ is a distribution function that may be called a mixture of F and G. The function H represents a model in which the distribution F is used with a probability p while G is used with a probability 1-p (Guthrie, 1989). H is therefore a model of observation Z that is obtained as follows: With probability p observe X having distribution F, and with probability 1-p observe Y having distribution G. This may be interpreted as the outcome of a two-stage experiment: In the first stage, a population is randomly selected and in the second stage, an observation is made from the chosen population. Every distribution may be expressed as a mixture in infinitely many ways, however, when mixture models are formulated reasonably, they can provide useful tools for statistical analysis.

This same type of non-standard model has applications in many quite different applications covering almost all other disciplines, for example, medicine and engineering (Guthrie, 1989). The descriptions of the following applications are brief and somewhat simplified. Fundamental differences do occur, however, since in some of the applications the mixtures are distinguishable in the sense that one can tell from which population an observation has come, whereas in others the mixtures are indistinguishable.

(a) A particular service, for example a specific medical care, may not be utilised by all families in the community and those who subscribe to it, do so in varying amounts. The distribution of the consumption of the service may be represented by a mixture of zeros and positive values.

(b) In the mass production of certain components, some components may fail on installation (zero life lengths). The other components will have a life length that is a positive random variable whose distribution may take different forms. The overall distribution of lifetimes which includes the non-functional ones is a non-standard mixture.

(c) Genetic birth defects. Children can be characterised by two variates: (i) a *discrete* or *categorical variable* to indicate if one is not affected, affected and stillborn, or affected and born alive; and (ii) a *continuous variable* measuring the survival time of affected children born alive. The conditional distribution of survival time given this first variable is undefined for children who are not affected, a mass point at 0 for children who are affected and stillborn, and non-trivial for children who are born alive.

(d) The last application to be considered is the measurement of the physical performance scores of patients with a debilitating disease such as multiple sclerosis. Frequent zero measurements would be observed from those giving no performance and many observations with graded positive performance.

6.3.2 **Implementation of the Dollar Unit Sampling method**

Since the late 1950's, Kenneth Stringer began to investigate the practicality of incorporating statistical sampling into the audit practices of his firm, Deloitte, Haskins & Sells. It was not until 1963, however, that some results of his studies were communicated to the statistical profession (Stringer, 1963).

Two pieces of information, the book (recorded) amount and the audited (correct) amount, are produced by an item in an audit sample. The difference between the two is called the error amount. It is not uncommon to observe only a few items with errors in an audit sample. An audit sample may not yield any non-zero error amounts. For those samples in which most observations are zero, the classical interval estimation of the total error amount based on the asymptotic normality of the sampling distribution is not reliable.

Alternatively, one could use the sample mean of the audited amount to estimate the total mean audited amount for the population. The value obtained, is then multiplied by the known number of items in the population to estimate the population total. This method is referred to in the audit profession as *mean-per-unit estimation.* (This method was implemented in this work in order to calculate radiological average technique values).

The mean-per-unit estimation is imprecise, however, because of the large variance of the audited amount that may arise in simple random sampling. A further result, however, is when the sample does not contain any item in error. The difference between the estimate of the total audited amount and the book balance must be interpreted as the sampling error. Assuming a population with no error in it, Stringer (1963) stated that statistical estimates of total error for each of the possible distinct samples of a given size that could be selected from it, would result in a different estimate and precision limit under this approach. Otherwise, however, all samples which include no errors should result in identical evaluations (Stringer, 1963).

Stringer therefore reported in the same presentation that he, in collaboration with F.F. Stephan, had developed a new statistical procedure in auditing that was not dependant on the normal approximation of the sampling distribution. It could also provide a reasonable inference for the population error amount when all items in the sample are error-free (Stringer, 1963). This procedure is apparently the original implementation of the dollar unit sampling and it is one of the first workable solutions proposed for non-standard mixtures in accounting. The procedure is described in more detail in the following section, as well as how it was implemented for the present study.

6.3.3 **Definitions and notation**

In accountancy an account is considered as a population of individual accounts. The constituent individual accounts, when used as audit units, are defined as line items. Y_i and X_i denote the book (recorded) and the audited (correct) amount respectively for the *i*th line item of an account of N line items. Book and audited balances of the account are respectively

$$Y = \sum_{i=1}^{N} Y_i \qquad \text{(equ. 6.2)}$$

called the population book amount, and

$$X = \sum_{i=1}^{N} X_i \qquad \text{(equ. 6.3)}$$

called the population audited amount. The error amount is defined as

$$D_i = Y_i - X_i \qquad \text{(equ. 6.4)}$$

When $D_i > 0$, it is known as an overstatement and if $D_i < 0$, an understatement. If $Y_i \neq 0$, the fractional error

$$T_i = \frac{D_i}{Y_i} \qquad \text{(equ. 6.5)}$$

is called the tainting (or just the taint) of the *i*th item and

$$D_i = T_i Y_i. \qquad \text{(equ. 6.6)}$$

The error of the book balance of the account is thus

$$D = Y - X = \sum_{i=1}^{N} D_i = \sum_{i=1}^{N} T_i Y_i \qquad \text{(equ. 6.7)}$$

A large proportion of items in an audit population will likely be error-free, therefore $D_i = 0$ for many values of *i* (Guthrie, 1989).

Aitchison (1955) was the first to consider an inference problem for such a population ($D_i = 0$ for many values of *i*). The error d of an item randomly chosen from an accounting population may be represented by

$$d = \begin{cases} z \text{ with probability } p \\ 0 \text{ with probability } (1-p) \end{cases} \qquad \text{(equ. 6.8)}$$

where p is the proportion of items with errors in the population and $z \neq 0$ is a random variable representing the error amount. The variable z may depend on the book amount.

A useful sampling design for statistical auditing is to select items with probability proportional to book values. A process that can be applied, is the so-called Dollar Unit Sampling (DUS) or Monetary Unit Sampling (MUS) since the sampling design is modelled in terms of use of individual dollars of the total book amount as sampling units. (Neter, Wasserman and Whitmore, 1988; Guthrie, 1989). Similar populations are common in many disciplines, for example the cases described Section 6.3.1 numbers (a), (b), (c) and (d). Such a sampling method is very appropriate for the present project.

In the above-mentioned case of the books, the book amounts of the N items could be taken to be cumulated sequentially to a total of Y dollars. One may then choose systematically n dollar units at fixed intervals of I (= Y/n) from the cumulative total dollars. The items with book amounts exceeding I dollars, and hence items that are certain to be sampled, are separately examined. For the purposes of this project, the total number of X-ray examinations (Y) was considered. A table was constructed of

all the institutions as well as the cumulative number of examinations at every institution (Table 6.1). The fixed interval (I) was taken as 200000 examinations and 27 institutions (n) were drawn in this way. This implies, therefore, that all institutions where more than 200000 examinations were done during the period (one year) for which the statistics was obtained, were included automatically in the sample. In this case 100000 could be chosen for example for the fixed interval (I), but the amount of data that would have been obtained, would be difficult to manipulate. It is a sampling technique that results in a sample proportional to size, i.e. the larger the volume of X-ray examinations of the hospital or private radiological practice, the larger the likelihood to be included into the final sample.

Table 6.1 *Sample selection of institutions performing radiological investigations.*

Institution	Number of examinations	Cumulative number of examinations
1	3019	3019
2	4560	7579
3	390415	**397994**
4	7047	**405041**
5	5711	410752
6	10280	421032
7	8610	429642
8	7455	437097
9	108	437205
10	32309	469514
11	2068	471582
12	1802	473384
13	246	473630
14	55382	529012
15	2091	531103
16	68739	599842
17	2275	**602117**
18	850	602967
		etc.

Intervals of 200000 were chosen in order to draw the samples. Institution number 3 was the first institution that fell in an interval that is a multiple of 200000 and was

chosen. The next interval is 400001 to 600000 and institution number 4 is the first institution to fall in it. Thus number 4 was chosen. The next interval is 600001 to 800000 and institution number 17 is the first institution to fall in it and was therefore chosen. The whole process was thus completed this way. It can also be mentioned that the entries in the table were not entered by means of a statistical random method. It was entered in the same order as supplied in the provincial annual reports and in the order received from the various private radiologists in the four provinces. This would have no effect on the sample, however, since it was ensured that institutions were drawn in a random way by means of the Dollar Unit Sampling method.

This method differs from that used for example in the UK and France as was discussed in Section 5.14.1 and Section 5.15.1 respectively. In the UK the drawing of the sample was based on a system of radiography units, while in France their annual X-ray film consumption was considered during a first phase and a sub-sample of X-ray units during the second phase. A sample of 27 institutions out of a possible 292 (9%) was drawn in the local survey, in comparison with the 386 out of a possible 4958 (8%) public hospitals and private practices and clinics in France (Maccia *et al.*, 1988) and 112 out of a possible 1431 (8%) hospitals in Great Britain (Kendall *et al.*, 1980).

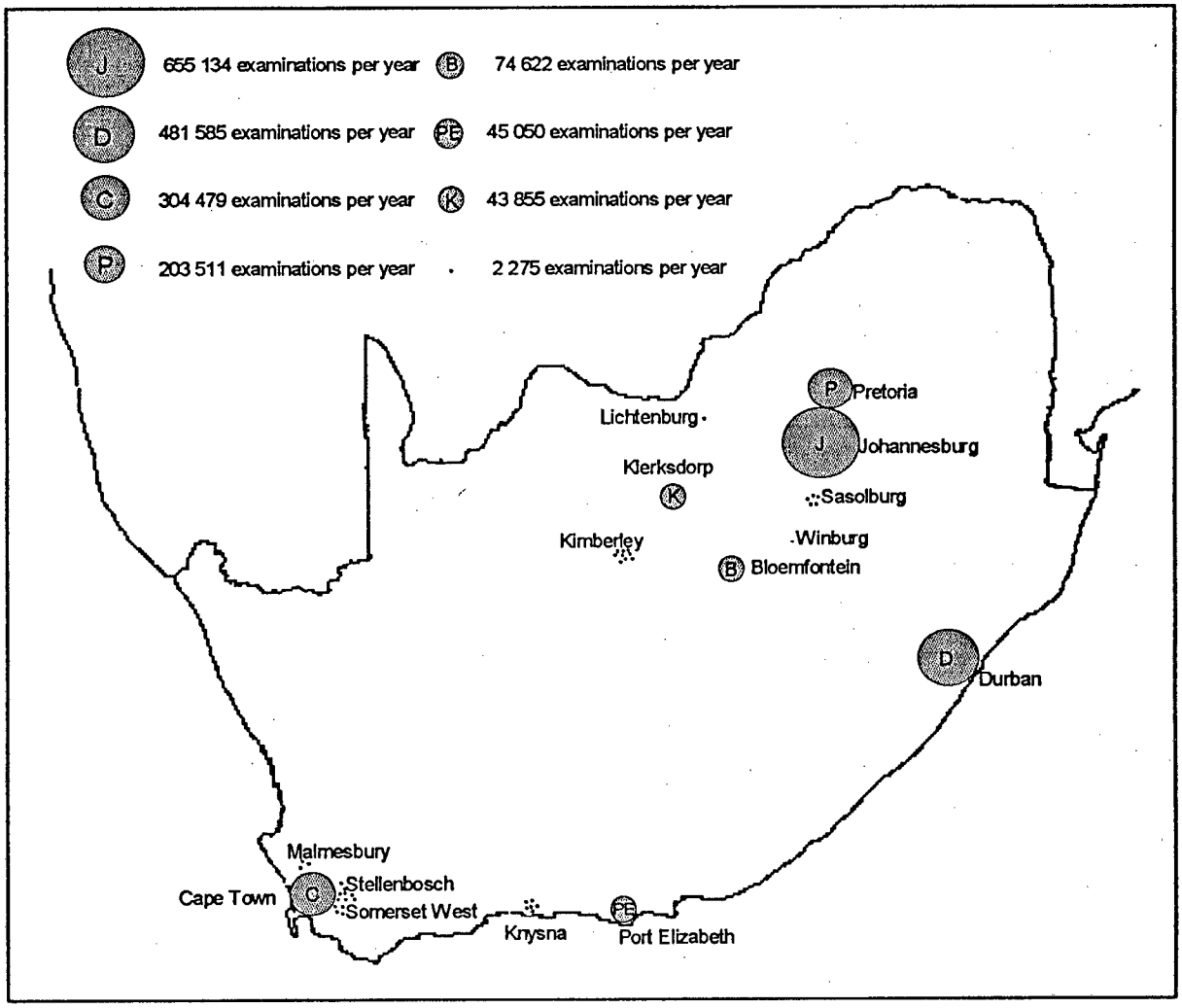
With the resources available, it was possible to successfully draw the sample. In the theoretical discussion, Section 6.3.3, one could choose systematically n units (institutions) at fixed intervals of I from the cumulative total Y according to the formula I = Y/n. In the South African survey the fixed interval I was chosen systematically and an interval of 200000 examinations served this purpose very well, resulting in a manageable number of institutions and automatically included the few extremely large ones. A sample of adequate size was obtained according to the discussions in the previous paragraph and in Section (a) of Chapter 10.

Chapter 7

THE PROCESS OF DATA COLLECTION

In Chapter 6 the procedure of how the sample was selected, was described. Letters were written to all the hospitals and private practices (27 in number) that were drawn in the sample, requesting them to participate in the survey. The initial response was poor (approximately 50% of the institutions did not respond). A second letter was written before the end of May 1990 and sent to hospitals and private practices reluctant to participate in the survey. In July 1990, all the institutions that had not responded to the two requests to take part in the survey were visited. Survey forms were handed out during these visits to people who seemed willing to help, and in some cases an agreement was reached on the format of the available information that could be supplied. A 100% response was obtained in this way. The sample distribution is represented by Figure 7.1. The circles and dots represent regions and not institutions.

Figure 7.1 *Sample distribution (examinations per year).*



7.1 Design

7.1.1 Longitudinal versus the cross-sectional approach

A problem may be investigated in a variety of different ways. To decide upon a method of approach, it is necessary to understand the types of studies that might be done, and two were considered for this project.

A ***longitudinal study*** collects information on study units, for example a cohort, over a specified time interval. A ***cross-sectional study*** collects data on study units at some fixed time (Fisher and van Belle, 1993).

The difference is illustrated Figure 7.2. The longitudinal study might collect information on the six new examinations appearing over the specified time interval. The cross-sectional study would identify the nine available examinations at the fixed time point. The cross-sectional study will have proportionately more examinations with a long duration.

The GSD is a dose allocated to the population over a period of one year by definition so that a longitudinal study over a period of one year would be appropriate for its determination (see section 2.2). However, for the present study, the cross-sectional approach was used with the fixed time being one week during which the survey was done at the various units.

There were two reasons for using the cross-sectional approach.

Firstly, it was considered to be too much of a burden for those radiographers involved should the survey continue for longer than one week. Secondly, differences exist between the respective X-ray units regarding certain technical aspects. There are also variations in technique in the various institutions as well as within X-ray departments. Since fewer units could be involved in a longitudinal study, the contribution of certain units that were not representative as regards physical properties of the unit as well as the technique factors applied, may lead to unreliable results.

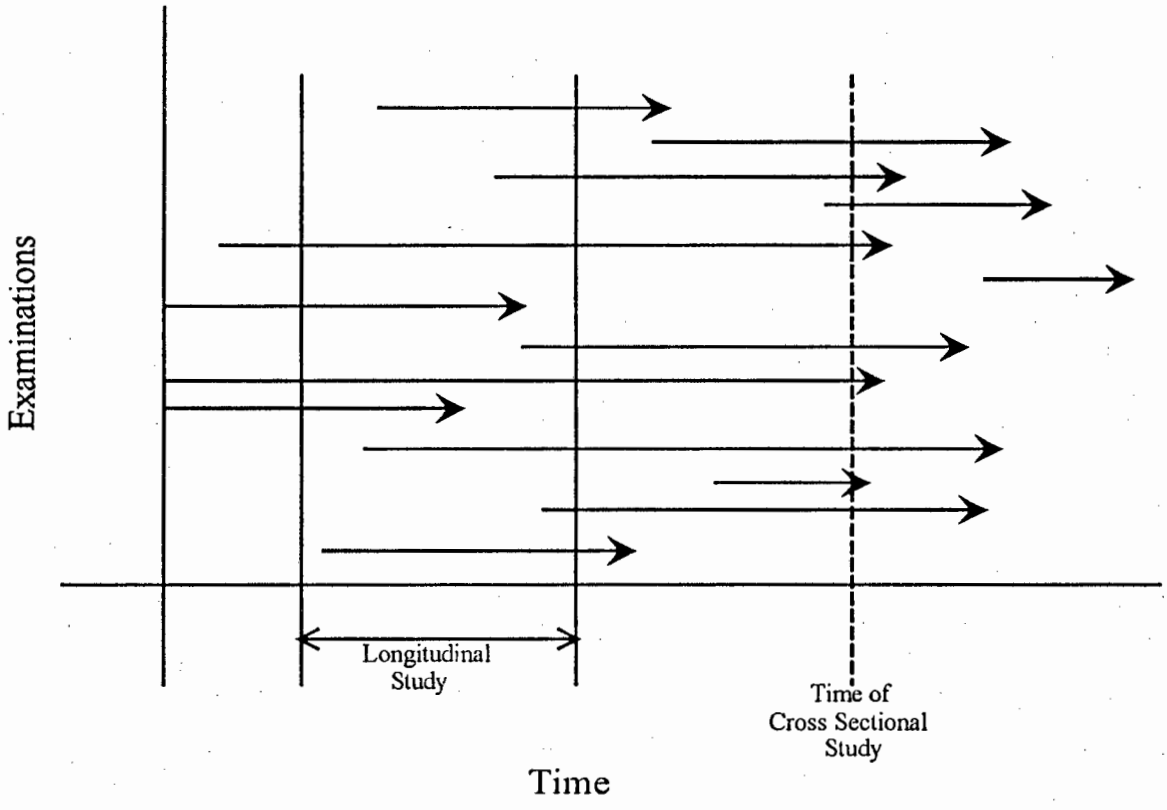


Figure 7.2 *Illustration of a longitudinal and a cross-sectional study of examinations* (Fisher and van Belle, 1993).

The principal disadvantage of the cross-sectional approach is the fact that a limited number of cases are observed for short periods only with no quantification for the interim periods. Conclusions have to be made in many instances without taking into account the contributions of events such as accidents or public disturbances. It is also difficult to compensate for events like holidays which may cause an increase in the workload at certain institutions and a decrease at others.

7.1.2 **Data acquisition**

Survey forms were designed for distribution to the various institutions that finally agreed to participate. Senior radiography personnel of the academic hospitals in the Western Cape and the Directorate: Electromedical Devices and Radiological Health were consulted in the planning of a survey form and the list of radiological examinations. Two types of forms as detailed in Appendix A were designed and finalised in June 1990. One form made provision only for the general information and some technical information

(short form). The other form was designed to provide all the information necessary to do the required calculations for the skin-entrance doses and gonad doses (detail form). Ninety six different examinations were selected, and a code was allocated to each examination (Appendix A). This information was distributed with the survey forms.

The information required to determine the GSD can be divided into two categories:

(a) **General information.** This category of information is relevant in the calculation of the GSD. The type of examination, age, gender and race were essential in order to do the calculations. The race must be known as there is a difference in the child expectancies of the different races (Health trends in South Africa, 1993; Demographic trends (1950-1990), 1994). Although the mass was included, it was not required for the calculation of the GSD and was often left out by the participants.

(b) **Technical information.** This data is required for the calculation of the skin-entrance doses and subsequently, the gonad doses. The technique factors for each examination, namely the view (for example AP, PA and LAT), tube voltage (kV), tube current (mA), workload (mAs), focal-film-distance (FFD) and whether the unit was automatic or not, were essential for the calculations. The other factors involved were the screening time, cassette sizes, number of exposures (or CT cuts) per examination and retake views. Although information regarding the use of gonad shields was also requested, the information supplied was incomplete.

It was initially planned that the average values under the heading "Technique" should be calculated for age-sex-view groups for all examinations. These values could then be imputed into corresponding records of the short form, as well as for the missing data on the detail form. This would have been a lengthy task and it was decided in preference to calculate average values and standard deviations. It would then be possible to calculate the skin entrance and gonad doses from these average values for all the examination types for the age-sex-projection groups.

7.1.3 Procedure

The "detail" forms were distributed to those institutions who responded initially in a positive manner. The remaining institutions were supplied with the "short" forms. Radiation control officials of the Directorate: Electromedical Devices and Radiological Health are familiar with working conditions in the various hospitals and private practices under their control and were also consulted before a decision was made regarding the type of forms to be distributed.

Distribution of the forms started in July 1990. The distribution in the Cape Province and in the Orange Free State was undertaken personally. The assistance of some of the senior personnel of the Directorate: Electromedical Devices and Radiological Health was obtained in this regard for Natal and the Transvaal. Their involvement was greatly appreciated since their personal contact with the personnel in charge at the institutions ensured the co-operation of the institutions involved and that reliable data could be obtained.

The survey was done during one week of the second semester of 1990 or the first semester of 1991 for all X-ray units at the specific institution. A typical week had to be chosen throughout all sections of the X-ray and allied departments. It was preferred that all the units be done during the same week. If it was not possible, the survey was split, for example, unit A during the third week of September 1990, units B and C during the first week of October, etc. Therapy units (kV units and linear accelerators) were not included in the survey.

7.2 Problems experienced

The problems experienced during the progress of the survey were never of such a nature that it put the continuation of the project in danger at any time. Problems that were experienced were as follows:

(a) The project had been delayed because of serious illness of key personnel who were responsible for the distribution of the forms in the Transvaal. To ensure

that accurate and reliable information was obtained, as well as the co-operation of those persons who were initially not willing to take part in the survey, the assistance of the above-mentioned workers was essential.

(b) The political upheaval and stay-aways in the country at the time, as well as dissatisfaction amongst certain groups of radiographers regarding problems in their profession also contributed to a delay in the return of the survey forms. In some cases only a small number of radiographers was available for duty and under these circumstances, it was difficult to obtain the co-operation of the senior people. It was also impossible to enter certain areas to deliver the survey forms and to explain the completion of the forms. Arrangements had to be made to deliver , and later to collect the forms, elsewhere.

(c) Supplementing and transferring of data into the computer started in July 1991. The extent of the task to transfer the raw data to a computer database was not fully realised previously. A need thus arose for financial aid in order to employ people for this task. An amount was made available shortly after the request which made it possible to complete this aspect in March 1992.

7.3 Return of information

The responses from the various institutions, could be classified into six categories, namely

(a) Detail form (10 institutions)
(b) Short form (7 institutions)
(c) Register (4 institutions)
(d) Computer printouts (2 institutions)
(e) Detail form and register (1 institution)
(f) Short form and register (3 institutions)

Due to a shortage of staff or a heavy workload or both, it was not possible for some of the institutions to handle the extra burden of completing the survey forms. It was possible for other institutions to complete the survey forms during the day, but not after hours. These institutions were therefore willing to supply copies of their registers or computer printouts. This explains why registers and registers together with forms were supplied.

7.4 Database

The software package used was Microsoft® Excel version 4.0 which was used and run on a 486 DX personal computer. The database ultimately consisted of 43100 records. It was found that in some instances it was difficult to extract data for entry into the database due to the format in which the raw data was supplied by the institutions.

7.4.1 Data processing

Data supplied by means of photostatic copies, and often data supplied on the standard forms, needed to be checked and edited before it could be transferred to the computer (for example the allocation of codes to the various examinations). Instructions and other information to assist the persons who were involved with the transfer of the data and to interpret it correctly are given in Appendix B.

Due to a shortage of staff, some institutions completed the standard forms only during the day. Copies of the registers were obtained and compared with the available completed forms. By means of a thorough investigation of the forms and registers, it could be decided what patient information did not appear on the forms and needed to be entered on the database. These decisions were based on information such as birthdays, types of examinations, and in some cases the date and time indicated on the copy of the register.

In some instances during the transfer of data, the original records were found to be incomplete or unclear. These were marked and the data was later supplemented before entry into the database.

7.4.2 Imputation of missing data

Item non-response imputation and adjustment procedures. When there was a failure by a patient to respond to an item, there was still some information available from the completed form. Two possible non-response

imputation and adjustment procedures as described by Madow, Nisselson and Olkin (1983) were applicable to this survey.

(a) **The Hot-deck imputation procedure.** The individuals included in the survey were divided into categories and an initial value was determined for each category based on available data. The category to which each individual belonged, was determined as the new data was processed. If the form that was processed was complete, then that individual's response replaced the responses stored in the relevant category of the hot deck. When a form was encountered with a missing item, the response in the same cell of the hot deck was imputed for the missing response. When all forms were processed and the missing data imputed, the means and variances were again computed in the usual manner.

(b) **The Weighting-class imputation procedure.** Basically, the weighting-class adjustment procedure assigns sample members to various classes, based on information available for both respondents and non-respondents. Within these classes an adjusted sampling weight can be assigned to each individual.

The size of the database, however, hampered the implementation of the above-mentioned types of imputation to the extent that they could not be used. It was therefore necessary to resort to more simple types of imputation. Since standard film sizes and divisions are used, for example, in various types of examinations, a deterministic imputation could be applied in cases where film sizes and divisions were omitted. When the gender was omitted for example, a probability imputation was applied. The imputation that was done in this survey will be further explained in Section 8.3(a) and Section 8.6.1.

Chapter 8

RESULTS

In order to calculate the gonad doses, it was decided to calculate the average values of the technique factors, with respect to the different age groups and views, for certain examinations. As mentioned previously, some results need to be imputed and these included age, gender, tube potential, tube current, exposure time and focal-film distance. The method used to calculate skin entrance and gonad doses is also described in the ICRP (1982).

8.1 X-ray examinations

Table 8.1 indicates the 96 diagnostic X-ray examinations for which data was requested. The table also lists the number of records in the database for the various examinations. Thirty of the 96 examinations were chosen for inclusion in the calculation of the genetically-significant dose as shown in Table 8.2. The examinations chosen were those that were considered as most likely to make an appreciable contribution to the gonad doses. This contribution was determined by the number of exposures in the sample associated with an examination (an indication was obtained from the number of records in the file) as well as the gonad dose associated with each exposure.

8.2 Age groups

Four main age groups were distinguished in order to calculate the gonad doses, namely 0-0.5 years; >0.5-5 years; >5-15 years; and >15 years. It was assumed that average properties of the population such as weight and height, and therefore the average technique factors, could in an optimum way be represented by these four age groups. In order to calculate the GSD, these doses needed to be associated with the frequency of the X-ray examinations and that of the population distribution represented in the population census (Population Census 1991, 1992). The following procedure was followed:

gonad doses in the 0-0.5 - age group were associated with the (-1) - age group of the population;

gonad doses in the >0.5-5 - age group were associated with the (1 - 4) - age group of the population;

gonad doses in the >5-15 - age group were associated with the (5 - 9) and (10 - 14) - age groups of the population;

gonad doses in the >15 - age group were associated with the ≥15 - age groups of the population.

8.3 Average technique factors

From the above-mentioned file, tables were constructed that comprised the average values of the technique factors, and are given in Table 8.2. Since these tables were arranged according to age and view, it was essential that these aspects had to be present in all records. The following replacements and imputations therefore had to be performed:

(a) In some cases the age of patients were unknown and was either left blank or an indication was given like "U" for unknown, "A" for adult, etc. Except when there was reason to replace the vacancy or symbol with something else, a 30 was imputed. This was based on the principle that fewer X-ray examinations are being done on younger people. The child expectancy is also lower than at a younger age (Darby *et al.*, 1980), with the result that it had minimal effect on the GSD. It must be stressed, however, that this was only a problem for a small number of the records, namely 1.4%.

(b) It was apparent from the data supplied, as well as from consultation with workers active in this field, that in general the PA-view for fluoroscopy and AP for radiography are most often used. Missing values were therefore respectively imputed.

(c) In some records the size of the film of the camera that was entered on the form, i.e. 10 cm x 10 cm, had to be replaced with 18 cm x 24 cm. The computer program that was used to calculate gonad doses, makes provision only for the views AP, PA and LAT. It was therefore necessary to replace AP-Oblique with AP and PA-Oblique with PA.

Table 8.1 *Diagnostic X-ray examinations.*

A. GENERAL EXAMINATIONS	No. records
HEAD	
SKULL	674
SELLA TURCICA	9
ORBITS	25
SINUSES	342
FACIAL BONES	128
MASTOIDS	73
ZYGOMATIC BONE	5
T-M JOINTS	10
MANDIBLE	81
ORTHOPANTOMOGRAM	45
TEETH	14
SPINE	
CERVICAL SPINE	530
THORACIC SPINE	207
LUMBAR SPINE	709
SCOLIOSIS X-RAYS (FULL SPINE)	24
CHEST	
LUNGS	6349
RIBS	99
STERNUM	6
STERNOCLAVICULAR JOINTS	4
MASS-MINIATURE	2
ABDOMEN	
ABDOMEN SURVEY	480
GALL-BLADDER VIEW	3
PELVIS	
PELVIS	300
SACRUM	22
COCCYX	8
S-I JOINTS	19
JOINTS AND EXTREMITIES	
SHOULDER GIRDLE	234
HUMERUS	72
ELBOW	187
FOREARM	203
WRIST	253
HAND	384
HIP JOINT	201
FEMUR NECK	16
FEMUR	204
KNEE	451
TIB & FIB	364
ANKLE	375
FOOT	279
PELVIMETRY	0

B. SPECIAL EXAMINATIONS	No. records
HEAD	
ANGIOGRAM	13
AIR ENCEPHALOGRAM	5
MASTOID TOMOS	15
SPINE	
MYELOGRAM (CERVICAL)	6
MYELOGRAM (THORACIC)	10
MYELOGRAM (LUMBAR)	62
DISCOGRAPHY	5
SPINE TOMOGRAPHY	17
CHEST	
AORTOGRAM	6
BARIUM SWALLOW	204
BRONCHOGRAM	5
MAMMOGRAM	196
TOMOGRAPHY (LUNGS)	10
HEART CATHETERISATION	669
SCREENING OF DIAPHRAGM	4
ABDOMEN	
AORTOGRAM	27
ARTERIOGRAMS: MESENTERIC, RENAL, HEPATIC	15
CHOLANGIOGRAM, CHOLECYSTOGRAM	32
RETROGRADE PYELOGRAM	55
INTRAVENOUS PYELOGRAM	372
EMBOLISATION, LITHOTRIPSY, NEPHROSTOMY	14
BARIUM MEAL	434
ECRP	23
KIDNEY TOMOGRAPHY	82
PELVIS	
CYSTOGRAM	107
URETHROGRAM	18
SALPINGOGRAM	39
BARIUM ENEMA	317
HIP TOMOGRAPHY	0
HIP OPERATIONS	2
BIFURCATION ARTERIOGRAMS / ANGIOPLASTY	12
LYMPHANGIOGRAMS	0
JOINTS AND EXTREMITIES	
ARTHROGRAM (SHOULDER)	10
ARTHROGRAM (ELBOW)	5
ARTHROGRAM (HIP)	2
ARTHROGRAM (KNEE)	0
PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (UPPER LEG)	33
PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (LOWER LEG)	29
LYMPHANGIOGRAPHY: TOTAL LEG	0
VENOGRAPHY: LOWER LEG	0
ARTEROGRAPHY: UPPER LEG	0
SCREENING OF EXTREMITIES FOR REDUCTION OF FRACTURES OR DISLOCATIONS	36
SCREENING UPPER LEG (FEMUR)	5
EXTREMITY TOMOGRAPHY	3

C. COMPUTER TOMOGRAPHY	No. records
BRAIN	336
ORBITS	13
FACIAL BONES / SINUSES	37
PETROUS BONE / AUDITORY CANAL	7
CERVICAL SPINE	8
THORACIC SPINE	6
LUMBAR SPINE	47
LUNGS / MEDIASTINUM	66
ABDOMEN - LIVER, SPLEEN, KIDNEYS, VESSELS, LYMPH NODES	110
PELVIS	15
EXTREMITIES (KNEE, ETC.)	6
PITUITARY FOSSA	0

Table 8.2 *Average technique values for diagnostic examinations.*

(mAs - workload; SD - standard deviation; kV - tube voltage; FFD - focus-film distance; SSD - source-skin distance; FieldX - X-ray field in x-direction at image receptor; FieldY - X-ray field in y-direction at image receptor; Fluoro - screening time; O/AP - overview/AP; AX - axial; O/LAT - overview/lateral).

CERVICAL SPINE

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP	12.5	*8.8*	69.7	*11.0*	105.7	*5.3*			16.6	*2.4*	22.3	*2.9*		
	PA														
	LAT	12.6	*6.4*	60.2	*7.1*	114.2	*25.4*			19.5	*2.7*	25.5	*2.7*		
>5-15	AP	10.5	*6.4*	64.5	*10.6*	100.0	*0.0*			24.0	*0.0*	24.0	*8.5*		
	PA														
	LAT	10.3	*4.5*	65.0	*9.2*	116.7	*28.9*			24.0	*0.0*	26.0	*6.9*		
>15	AP	37.6	*34.7*	68.7	*7.0*	117.4	*23.3*			18.7	*3.3*	24.9	*3.0*		
	PA	45.7	*14.1*	65.8	*8.1*	105.7	*13.4*			17.6	*1.3*	23.6	*1.6*		
	LAT	43.9	*41.3*	70.7	*7.1*	138.1	*30.2*			20.8	*3.0*	26.8	*3.0*		

THORACIC SPINE

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP	6.0	*0.0*	57.0	*0.0*	180.0	*0.0*			20.0	*3.5*	26.0	*3.5*		
	PA														
	LAT														
>15	AP	88.6	*71.2*	70.4	*8.6*	107.6	*16.1*			19.1	*5.1*	39.5	*4.7*		
	PA														
	LAT	282.7	*284.7*	67.3	*11.4*	114.7	*21.8*			19.9	*5.2*	39.0	*5.3*		

LUMBAR SPINE

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA	4.0		55.0		150.0				24.0		30.0			
	LAT														
>5-15	AP	148.0	*33.9*	66.5	*5.9*	110.5	*7.2*			22.6	*4.3*	36.4	*6.0*		
	PA	64.0	*0.0*	72.0	*1.7*	100.0	*0.0*			18.0	*0.0*	24.0	*0.0*		
	LAT	173.6	*99.0*	74.7	*8.5*	117.2	*24.6*			22.0	*4.9*	33.6	*7.9*		
>15	AP	130.1	*80.3*	76.5	*9.3*	103.2	*8.0*			22.8	*5.2*	35.9	*6.2*	2.0	
	PA	130.0	*42.4*	77.0	*15.6*	106.7	*7.6*			22.7	*6.4*	41.0	*1.7*		
	LAT	194.2	*127.6*	86.9	*10.7*	103.3	*10.7*			21.5	*5.2*	33.5	*7.6*		

SCOLIOSIS X-RAYS (FULL SPINE)

Age (years)	View	mAs	SD	kV	SD	FFD (cm)	SD (cm)	SSD (cm)	SD (cm)	FieldX (cm)	SD (cm)	FieldY (cm)	SD (cm)	Fluoro (min.)	SD (min.)
0-0.5	AP	3.0		55.0		100.0				24.0		30.0			
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP	106.7	24.6	72.0	5.3	140.0	46.2			37.7	4.1	73.7	30.0		
	PA														
	LAT	122.5	3.5	75.0	2.8	180.0				35.0	0.0	93.0	2.8		
>15	AP	99.1	47.9	70.7	9.3	148.6	35.8			32.0	6.3	52.5	25.2		
	PA														
	LAT	114.0	72.6	76.0	11.8	140.0	43.8			30.3	6.8	52.1	28.5		

LUNGS

Age (years)	View	mAs	SD	kV	SD	FFD (cm)	SD (cm)	SSD (cm)	SD (cm)	FieldX (cm)	SD (cm)	FieldY (cm)	SD (cm)	Fluoro (min.)	SD (min.)
0-0.5	AP	4.3	1.2	53.0	7.1	108.1	14.7			18.9	2.6	25.0	2.9		
	PA	4.4	3.0	62.0	8.7	150.0				32.2	6.9	33.2	4.5		
	LAT	6.4	3.3	62.6	9.7	124.6	27.2			21.8	5.6	28.4	6.6		
>0.5-5	AP	5.3	4.0	61.4	9.0	118.7	29.3			22.3	3.4	28.4	3.6		
	PA	8.0	10.0	65.0	11.3	150.4	19.7			25.5	5.0	31.4	5.0		
	LAT	6.8	5.7	76.8	15.4	142.5	30.7			22.5	4.7	28.8	5.3		
>5-15	AP	9.6	16.2	66.2	12.1	138.3	35.9			27.3	4.5	34.7	5.2		
	PA	9.6	10.5	79.0	16.2	163.7	22.1			29.8	5.0	36.8	5.4		
	LAT	19.6	21.7	90.2	20.6	164.3	27.6			29.3	4.8	37.1	5.9		
>15	AP	8.4	13.6	89.3	28.8	143.2	30.0			34.7	2.0	41.0	3.6		
	PA	13.2	13.1	110.4	31.9	167.3	18.6			34.9	1.2	40.7	3.6	2.2	0.8
	LAT	21.4	22.8	123.5	26.9	167.3	18.3			33.0	2.8	41.6	2.1		

RIBS

Age (years)	View	mAs	SD	kV	SD	FFD (cm)	SD (cm)	SSD (cm)	SD (cm)	FieldX (cm)	SD (cm)	FieldY (cm)	SD (cm)	Fluoro (min.)	SD (min.)
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP														
	PA	11.0	7.1	63.0	4.2	140.0	56.6			24.0	0.0	30.0	0.0		
	LAT														
>15	AP	53.6	36.2	70.0	12.7	130.5	32.1			32.5	3.0	40.9	2.8		
	PA	67.7	87.4	83.9	31.7	143.8	32.8			33.9	2.1	41.2	2.8		
	LAT	19.3	8.7	102.2	22.6	156.0	37.8			31.0	2.2	40.6	1.3		

ABDOMEN SURVEY

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP	35.6	*99.9*	51.7	*1.7*	104.0	*5.2*			18.6	*1.9*	24.7	*1.9*		
	PA														
	LAT	6.0		52.0		110.0				18.0		25.0			
>0.5-5	AP	18.5	*16.0*	60.3	*5.5*	100.6	*2.4*			23.6	*4.2*	29.9	*4.9*		
	PA														
	LAT	10.0		60.0		180.0				24.0		30.0			
>5-15	AP	19.7	*20.3*	68.3	*6.5*	111.3	*28.0*			31.1	*3.8*	39.9	*4.3*		
	PA														
	LAT	23.0	*24.0*	70.0	*21.2*	100.0	*0.0*			32.5	*3.5*	41.5	*2.1*		
>15	AP	69.2	*49.5*	77.6	*13.5*	109.3	*12.8*			34.4	*3.1*	42.1	*3.6*	2.8	*2.8*
	PA	31.5	*26.2*	105.0	*26.1*	118.8	*25.6*			34.6	*1.4*	41.8	*2.7*	16.0	
	LAT	52.6	*39.3*	80.6	*17.2*	111.7	*15.9*			31.8	*6.1*	39.3	*6.9*		

PELVIS

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP	28.0	*6.8*	58.8	*5.0*	102.0	*2.7*			20.4	*3.3*	26.4	*3.3*		
	PA														
	LAT														
>5-15	AP	52.6	*42.2*	67.2	*6.8*	101.0	*2.1*			31.2	*4.3*	40.1	*5.3*		
	PA														
	LAT														
>15	AP	78.2	*54.8*	70.9	*7.7*					33.7	*3.6*	41.1	*4.3*		
	PA	241.6	*353.7*	78.0	*19.1*	100.0	*0.0*	38.0	*0.0*	27.1	*4.3*	28.0	*5.1*	6.2	*6.2*
	LAT	301.5	*303.5*	85.5	*23.5*	104.3	*5.2*	38.0	*0.0*	27.5	*5.1*	34.2	*5.3*		

SACRUM

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP	175.0	*215.8*	61.7	*2.0*	103.3	*5.2*			28.7	*5.4*	36.0	*6.7*		
	PA														
	LAT	332.6	*351.4*	64.8	*6.6*	104.0	*5.5*			25.0	*7.5*	32.2	*8.9*		
>15	AP					105.0	*7.5*			21.0	*3.2*	27.0	*3.2*		
	PA														
	LAT	135.0	*105.8*	86.2	*5.1*	102.5	*6.1*			18.9	*2.3*	24.9	*2.3*		

HIP JOINT

Age (years)	View	mAs	SD	kV	SD	FFD (cm)	SD (cm)	SSD (cm)	SD (cm)	FieldX (cm)	SD (cm)	FieldY (cm)	SD (cm)	Fluoro (min.)	SD (min.)
0-0.5	AP	3.0		48.0		100.0				18.0		24.0			
	PA														
	LAT														
>0.5-5	AP	35.2	23.8	53.8	6.3	114.0	20.4			28.4	6.0	35.2	7.1		
	PA														
	LAT	71.0		45.0		110.0				24.0		30.0			
>5-15	AP	68.6	65.3	64.0	3.3	102.1	2.7			18.0	4.9	27.4	3.2		
	PA														
	LAT														
>15	AP	109.0	72.7	70.0	8.3	104.9	6.3			27.4	6.6	34.9	7.4		
	PA	73.0	7.2	75.0	2.4	87.0	2.7			24.0	0.0	30.0	0.0	4.7	
	LAT	160.5	92.5	76.9	7.2	107.5	5.3			24.1	3.5	31.2	4.7		

FEMUR NECK

Age (years)	View	mAs	SD	kV	SD	FFD (cm)	SD (cm)	SSD (cm)	SD (cm)	FieldX (cm)	SD (cm)	FieldY (cm)	SD (cm)	Fluoro (min.)	SD (min.)
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP	6.0	0.0	59.0	1.7	100.0	0.0			30.7	4.1	39.3	4.8		
	PA														
	LAT	6.0		63.0		100.0				24.0		30.0			
>15	AP	12.7	3.1	62.0	3.5	100.0	0.0			19.8	3.6	38.7	7.5		
	PA	12.3	2.2	62.0	3.6	100.0	0.0			25.0	0.0	25.0	0.0		
	LAT	28.4	21.4	70.4	5.8	100.0	0.0			22.8	2.7	32.6	5.8		

FEMUR

Age (years)	View	mAs	SD	kV	SD	FFD (cm)	SD (cm)	SSD (cm)	SD (cm)	FieldX (cm)	SD (cm)	FieldY (cm)	SD (cm)	Fluoro (min.)	SD (min.)
0-0.5	AP	5.0		50.0		100.0				18.0		24.0			
	PA														
	LAT														
>0.5-5	AP	9.3	3.1	57.3	5.5	100.0	0.0			20.2	6.6	38.6	5.0		
	PA														
	LAT	9.3	3.1	57.3	5.5	100.0	0.0			23.7	6.5	37.7	6.8		
>5-15	AP	21.0	29.9	64.5	9.2	100.0	0.0			21.8	7.8	41.5	3.6		
	PA														
	LAT	26.5	33.8	57.1	16.9	105.6	16.7			16.9	1.3	42.2	1.4		
>15	AP	44.5	50.4	67.1	8.8	109.2	20.2			22.1	8.0	39.9	4.3		
	PA	11.0	0.0	57.0	1.8	100.0	0.0			25.0	0.0	25.0	0.0		
	LAT	29.3	48.6	65.4	7.3	105.1	16.7			18.8	5.6	39.8	5.0		

MYELOGRAM (LUMBAR)

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP														
	PA														
	LAT														
>15	AP	43.9	*29.1*	76.5	*5.5*	112.0	*6.1*			17.3	*8.5*	33.6	*2.5*	3.5	
	PA	34.6	*20.0*	81.2	*6.7*	77.8	*13.9*	38.0	*0.0*	16.5	*5.9*	30.0	*0.0*	4.1	*1.9*
	LAT	87.4	*60.1*	94.3	*10.6*	91.3	*23.2*			16.0	*6.5*	30.8	*2.4*		

BARIUM SWALLOW

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA	800.0	*0.0*	96.0	*0.0*	68.0	*0.0*	38.0	*0.0*	20.6	*5.6*	30.0	*0.0*	2.2	*0.7*
	LAT	800.0	*0.0*	96.0	*0.0*	68.0	*0.0*	38.0	*0.0*	24.0	*0.0*	30.0	*0.0*		
>5-15	AP														
	PA	800.0	*0.0*	109.0	*0.0*	68.0	*0.0*	38.0	*0.0*	12.0	*0.0*	30.0	*0.0*	2.0	
	LAT	800.0	*0.0*	109.0	*0.0*	68.0	*0.0*	38.0	*0.0*	12.0	*0.0*	30.0	*0.0*		
>15	AP	294.0	*375.4*	82.4	*12.1*	102.8	*15.1*	38.0	*0.0*	23.7	*8.0*	31.7	*3.2*		
	PA	389.2	*368.2*	107.8	*17.4*	72.2	*9.1*	39.9	*2.4*	13.9	*5.6*	31.3	*2.7*	3.1	*2.9*
	LAT	651.8	*311.0*	105.5	*17.9*	71.8	*10.4*	39.3	*2.2*	16.5	*6.1*	30.3	*1.5*		

HEART CATHETERISATION

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP													0.2	
	PA														
	LAT														
>5-15	AP														
	PA														
	LAT														
>15	AP														
	PA	128.7	*44.1*	82.8	*17.8*	91.1	*3.2*	55.0	*0.0*	19.8	*7.8*	19.2	*6.8*	13.5	*9.9*
	LAT	118.0	*41.7*	92.4	*22.9*	91.2	*3.3*	55.0	*0.0*	20.3	*8.0*	19.7	*7.0*	5.8	*6.6*

AORTOGRAM (ABDOMEN)

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP														
	PA														
	LAT														
>15	AP	38.0	*0.0*	70.0	*4.7*	100.0	*0.0*			35.0	*0.0*	35.0	*0.0*		
	PA	37.7	*13.2*	70.3	*6.6*	88.1	*12.1*	38.0	*0.0*	25.0	*1.6*	27.0	*2.6*	3.6	*2.8*
	LAT														

RETROGRADE PYELOGRAM

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP			57.5	*2.7*	110.0	*0.0*			24.0	*0.0*	30.0	*0.0*		
	PA														
	LAT														
>5-15	AP														
	PA														
	LAT														
>15	AP	40.0	*0.0*	80.2	*3.6*	109.7	*1.8*			34.7	*1.7*	42.7	*2.0*		
	PA	800.0	*0.0*	109.0	*0.0*	68.0	*0.0*	38.0	*0.0*	17.8	*9.7*	30.8	*2.0*	4.0	*0.0*
	LAT														

INTRAVENOUS PYELOGRAM

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP	16.0	*0.0*	62.0	*0.0*	100.0	*0.0*			18.0	*0.0*	24.0	*0.0*		
	PA														
	LAT														
>0.5-5	AP	25.0	*0.0*	60.0	*0.0*	100.0	*0.0*			21.6	*3.1*	27.6	*3.1*		
	PA														
	LAT														
>5-15	AP	88.6	*10.1*	61.0	*2.9*	110.2	*4.6*			27.1	*3.6*	35.4	*5.6*		
	PA														
	LAT														
>15	AP	93.1	*53.3*	71.4	*8.0*	105.6	*6.3*			29.7	*6.1*	37.3	*7.0*		
	PA	94.8	*83.7*	80.1	*27.3*	122.5	*27.6*			35.0	*0.0*	43.0	*0.0*		
	LAT	136.6	*91.0*	105.2	*25.3*	114.0	*20.1*			28.4	*6.0*	35.2	*7.1*		

BARIUM MEAL

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP					68.0		38.0		18.0		24.0			
	PA	401.6	*207.4*	96.0	*0.0*	71.8	*10.6*	38.0	*0.0*	21.1	*7.1*	26.6	*8.6*	3.1	*2.1*
	LAT	500.0	*0.0*	96.0	*0.0*	68.0	*0.0*	38.0	*0.0*	23.0	*2.4*	29.0	*2.4*		
>15	AP	71.4	*57.2*	89.0	*12.3*	100.7	*20.0*	65.5	*23.3*	19.8	*8.0*	29.7	*5.5*		
	PA	77.3	*146.3*	96.5	*15.4*	68.7	*5.3*	41.8	*6.2*	15.7	*6.8*	24.7	*7.7*	4.9	*2.2*
	LAT	256.2	*377.9*	98.7	*14.2*	71.6	*12.3*	44.5	*12.4*	19.7	*5.4*	26.3	*7.0*		

KIDNEY TOMOGRAPHY

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP	80.0	*0.0*	56.0	*0.0*	110.0	*0.0*			24.0	*0.0*	30.0	*0.0*		
	PA														
	LAT														
>15	AP	106.5	*53.6*	71.4	*6.4*	106.3	*5.6*			26.3	*3.2*	33.8	*5.1*		
	PA														
	LAT														

CYSTOGRAM

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP	25.0	*0.0*	49.0	*0.0*	68.0	*0.0*	38.0	*0.0*	35.0	*0.0*	35.0	*0.0*	1.7	
	PA														
	LAT														
>0.5-5	AP	28.5	*3.7*	50.0	*1.0*	68.0	*0.0*	38.0	*0.0*	35.0	*0.0*	35.0	*0.0*	4.0	*1.9*
	PA			60.0	*0.0*	68.0	*0.0*	38.0	*0.0*	24.0	*0.0*	30.0	*0.0*	1.6	
	LAT														
>5-15	AP														
	PA														
	LAT														
>15	AP	84.6	*32.6*	77.0	*11.8*	76.6	*18.2*	54.1	*22.4*	30.3	*6.6*	32.7	*4.4*	2.2	*1.8*
	PA	100.8	*22.9*	95.6	*16.1*	71.8	*2.2*	44.1	*8.0*	17.9	*7.5*	29.8	*5.6*	4.1	*1.5*
	LAT	400.0		85.3	*13.3*	73.0		43.0		31.3	*6.4*	33.3	*2.9*		

URETHROGRAM

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP														
	PA														
	LAT														
>15	AP	59.4	*35.8*	82.8	*3.8*	114.3	*3.4*			19.1	*5.3*	27.8	*5.5*		
	PA														
	LAT			120.0	*0.0*	115.0	*0.0*			12.0	*0.0*	30.0	*0.0*		

SALPINGOGRAM

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP														
	PA														
	LAT														
>15	AP	34.0	*11.3*	81.9	*17.4*	110.6	*5.0*	38.0		21.4	*3.1*	27.4	*3.1*		
	PA	11.6	*7.3*	113.0	*6.1*	69.5	*2.3*	38.9	*2.0*	22.2	*2.8*	28.2	*2.8*	3.4	*1.1*
	LAT														

BARIUM ENEMA

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP														
	PA														
	LAT														
>0.5-5	AP														
	PA														
	LAT														
>5-15	AP	24.6	*23.6*	65.0	*9.4*	109.0	*15.9*	78.0	*17.1*	30.3	*5.9*	35.1	*5.8*		
	PA	69.3	*42.6*	90.1	*15.1*	83.5	*18.8*	52.7	*18.4*	22.7	*9.3*	33.3	*4.8*	6.7	*7.4*
	LAT			85.0	*0.0*	115.0	*0.0*	85.0		12.0	*0.0*	30.0	*0.0*		
>15	AP	58.3	*134.6*	95.8	*13.0*	99.6	*17.9*	57.8	*22.0*	31.1	*5.3*	37.2	*6.0*		
	PA	139.6	*188.5*	106.5	*10.0*	77.1	*13.5*	43.6	*8.2*	22.4	*8.7*	31.1	*6.0*	6.1	*3.3*
	LAT	291.4	*356.6*	111.8	*10.9*	80.0	*15.5*	43.5	*10.6*	24.8	*4.3*	30.8	*4.5*		

BIFURCATION ARTERIOGRAMS / ANGIOPLASTY

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP PA LAT														
>0.5-5	AP PA LAT														
>5-15	AP PA LAT														
>15	AP PA LAT	38.0 24.5	*0.0* *0.5*	69.0 68.0	*0.0* *8.3*	68.0 68.0	*0.0* *0.0*	38.0 38.0	 *0.0*	35.0 27.2	*0.0* *4.2*	35.0 27.2	*0.0* *4.2*	 3.0	 *2.1*

PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (UPPER LEG)

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	FieldY (cm)	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	AP PA LAT														
>0.5-5	AP PA LAT														
>5-15	AP PA LAT			60.0	*0.0*	68.0	*0.0*	38.0	*0.0*	25.0	*0.0*	25.0	*0.0*	1.5	
>15	AP PA LAT	38.0 20.8	*0.0* *6.7*	56.4 64.1	*8.0* *8.3*	68.0 68.8	*0.0* *5.0*	38.0 38.0	*0.0* *0.0*	20.8 25.8	*6.5* *2.2*	25.8 26.1	*4.2* *2.4*	 9.7	 *15.8*

LUMBAR SPINE (CT)

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	No. of slits	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	O/AP AX O/LAT														
>0.5-5	O/AP AX O/LAT	 507.0	 *0.0*	 120.0	 *0.0*	 250.0	 *0.0*					 10.0			
>5-15	O/AP AX O/LAT	320.0 420.0 960.0	 *0.0*	120.0 120.0 120.0	 *0.0*							1.0 15.0 1.0			
>15	O/AP AX O/LAT	499.6 552.6 847.2	*121.0* *103.8* *149.8*	120.0 125.1 123.8	*0.0* *5.0* *5.1*	 311.4	 *48.9*			40.0 35.0	 *0.0*	1.0 26.6 1.0	*0.0* *13.2* *0.0*		

LUNGS / MEDIASTINUM (CT)

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	No. of slits	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	O/AP														
	AX														
	O/LAT														
>0.5-5	O/AP														
	AX														
	O/LAT														
>5-15	O/AP	314.0	*178.2*	122.5	*3.5*					51.2		1.0	*0.0*		
	AX	411.0	*36.2*	121.2	*2.1*	250.0	*0.0*					22.7	*14.2*		
	O/LAT														
>15	O/AP	335.5	*123.7*	124.2	*3.8*					50.3	*2.2*	1.0	*0.0*		
	AX	336.3	*73.6*	124.5	*4.6*	295.5	*51.0*					14.3	*4.9*		
	O/LAT	527.5	*480.1*	120.0	*0.0*							1.0	*0.0*		

ABDOMEN - LIVER, SPLEEN, KIDNEYS, VESSELS, LYMPH NODES (CT)

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	No. of slits	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	O/AP	24.0		120.0								1.0			
	AX	80.0	*0.0*	120.0	*0.0*							30.0			
	O/LAT														
>0.5-5	O/AP														
	AX														
	O/LAT														
>5-15	O/AP	440.0		125.0						51.2		1.0			
	AX	410.0	*0.0*	125.0	*0.0*							19.0			
	O/LAT														
>15	O/AP	355.7	*104.6*	124.5	*3.4*					48.5	*6.8*	1.0	*0.1*		
	AX	394.2	*47.5*	123.5	*3.4*	319.5	*72.9*					21.2	*8.3*		
	O/LAT														

PELVIS (CT)

Age (years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD (cm)*	SSD (cm)	*SD (cm)*	FieldX (cm)	*SD (cm)*	No. of slits	*SD (cm)*	Fluoro (min.)	*SD (min.)*
0-0.5	O/AP														
	AX														
	O/LAT														
>0.5-5	O/AP	380.0		120.0						25.0		1.0			
	AX	380.0	*0.0*	120.0	*0.0*							22.0			
	O/LAT														
>5-15	O/AP														
	AX														
	O/LAT														
>15	O/AP	234.4	*84.3*	122.0	*2.7*					28.7	*5.4*	1.0	*0.0*		
	AX	352.0	*102.6*	115.6	*9.4*	325.8	*85.2*					17.5	*9.7*		
	O/LAT														

8.4 The determination of skin entrance doses

The following procedure was followed:

(a) Two methods were available. The method described by McCullough and Cameron (1970) involved the interpolation of tube potential values (kV) on a graph to obtain an exposure in mR/mAs. The "RADCOMP Entrance Skin Exposure Software Program" of Nuclear Associates was used, however, to produce parametric free air exposure (FAE) tables (Nuclear Associates and Zamenhof, 1990) based on doses from Table B.3, NCRP Report No. 102 (1989). Additional information such as the phase (single or three phase), Rad or Fluoro or Mammo, total filtration and focus-chamber-distance was also required by RADCOMP. The total filtration could be assumed to be 2.5 mm Al in all calculations according to the NCRP Report No. 54 (NCRP, 1977). It was assumed that all the units were three phase and different tables were drawn up for Radiography and Fluoroscopy.

In Table B.3 of NCRP Report No. 102 (1989), average air kerma rates produced by diagnostic X-ray equipment at certain distances from source to point of measurement are provided in centigray per 100 mAs. Since the FDA-program that was used to determine the gonad doses (see 8.3) requires that the FAE at skin entrance must be in mR, it was therefore necessary to convert the values in the above-mentioned Table B.3 to röntgen (see 3.2.4). The conversion is shown in Table 8.3.

This method was therefore preferred above the one described by McCullough and Cameron since no relatively inaccurate interpolation on a graph was required. More reliable results could also be obtained by using Table B.3 in the NCRP Report No. 102 (1989) in order to obtain the free air exposure tables. This report contains recent information that is better applicable to the present technology. Nine such tables were produced, five for radiographic examinations with FFD 43 cm, 60 cm, 100 cm, 140 cm and 180 cm, and four for fluoroscopic examinations with FFD 43 cm, 60 cm, 100 cm and 140 cm. One such a table for the radiographic mode is represented by Table 8.5.

Table 8.3 *Exposure rates produced by three phase diagnostic X-ray equipment.*

Distance from Source to Point of Measurement	Tube Potential kVp									
	50	60	70	80	90	100	110	120	130	140
cm	röntgen per 100 mAs									
30	3.80	5.87	7.94	10.24	13.00	14.73	16.92	20.48	24.28	26.35
45	1.73	2.65	3.57	4.49	5.75	6.56	7.48	9.09	10.82	11.74
60	0.96	1.50	1.96	2.53	3.22	3.68	4.26	5.06	6.10	6.56
100	0.34	0.53	0.71	0.92	1.15	1.27	1.50	1.84	2.19	2.42
137	0.18	0.28	0.38	0.48	0.62	0.70	0.80	0.98	1.15	1.26
183	0.10	0.16	0.21	0.28	0.34	0.39	0.45	0.55	0.66	0.71

(b) Skin entrance doses were calculated for all the views in the various age groups for the chosen examinations and as shown in Table 8.6. Values from Table 8.2 were used to obtain these doses and a current of 3 mA was used for screening. The free air exposure was calculated first at the image receptor and then by means of the inverse square law at the surface of the skin. In order to obtain the focus-skin-distance, information regarding average patient-thickness was required. It was obtained from practical measurements and from the literature (Rosenstein, 1988 and Rosenstein, Beck, Warner, 1979). These values are shown in Table 8.4.

Table 8.4 *Patient thickness.*

Age (years)	View	Patient thickness (in cm)
0 - 0.5	AP	11.2
	LAT	12.4
>0.5 - 5	AP	15.0
	LAT	20.0
> 5 - 15	AP	20.0
	LAT	25.0
> 15	AP	24.0
	LAT	31.0

Table 8.5 *RADCOMP entrance skin exposure at an FSD of 60 cm.*

kVp	FAE - Free Air Exposure (mR)															
	mAs															
	1	2	3	5	10	15	20	25	30	40	50	60	80	100	120	140
40	5	10	16	26	52	78	104	130	156	207	259	311	415	519	622	726
45	7	15	22	37	73	110	147	184	220	294	367	441	588	735	882	1029
50	10	19	29	48	96	144	192	240	288	385	481	577	769	961	1154	1346
55	12	24	36	60	120	180	240	300	360	479	599	719	959	1199	1438	1678
60	14	29	43	72	145	217	289	362	434	578	723	868	1157	1446	1735	2025
65	17	34	51	85	170	256	341	426	511	682	852	1022	1363	1704	2045	2385
70	20	39	59	99	197	296	394	493	591	788	986	1183	1577	1971	2365	2760
75	22	45	67	112	225	337	450	562	674	899	1124	1349	1799	2248	2698	3148
80	25	51	76	127	253	380	507	634	760	1014	1267	1521	2028	2535	3042	3549
85	28	57	85	142	283	425	566	708	849	1132	1415	1698	2264	2830	3396	3962
90	31	63	94	157	313	470	627	784	940	1254	1567	1881	2508	3135	3762	4388
95	34	69	103	172	345	517	690	862	1034	1379	1724	2069	2758	3448	4137	4827
100	38	75	113	188	377	565	754	942	1131	1508	1885	2262	3015	3769	4523	5277
105	41	82	123	205	410	615	820	1025	1230	1640	2050	2459	3279	4099	4919	5739
110	44	89	133	222	444	666	887	1109	1331	1775	2218	2662	3549	4437	5324	6211
115	48	96	143	239	478	717	956	1196	1435	1913	2391	2869	3826	4782	5739	6695
120	51	103	154	257	514	770	1027	1284	1541	2054	2568	3081	4108	5135	6162	7189
125	55	110	165	275	550	824	1099	1374	1649	2198	2748	3297	4396	5495	6594	7694
130	59	117	176	293	586	879	1173	1466	1759	2345	2931	3518	4690	5863	7035	8208
135	62	125	187	312	624	936	1247	1559	1871	2495	3118	3742	4989	6237	7484	8732
140	66	132	199	331	662	993	1324	1654	1985	2647	3309	3971	5294	6618	7941	9265
145	70	140	210	350	700	1051	1401	1751	2101	2802	3502	4203	5604	7005	8405	9806
150	74	148	222	370	740	1110	1480	1849	2219	2959	3699	4439	5918	7398	8877	10357

(c) Unlike most other gonad dose surveys which have used direct measurements of entrance surface doses, this survey relies on published standard X-ray tube output tables for a fixed filtration and waveform to estimate entrance skin exposure for average technique factors. Table 8.2 illustrates that the standard deviations for the tube voltage (kV) and focus-film-distance (FFD) are estimated as 25% of the mean values, while that for the workload (mAs) could be as high as 100% of the mean value (see Chapter 10). Another factor that adds to the uncertainty of the FFD is the average patient thickness (Table 8.4) that is required in order to determine the focus-skin-distance. It was assumed that all units were three phase and the total filtration to be 2.5 mm Al (ICRP, 1982), although it is known that it is more than 3 mm Al in many instances.

8.5 Gonad doses

After the skin entrance doses were calculated, it was possible to calculate the gonad doses. A computer program was obtained for this purpose from the FDA, US Department of Health and Human Services, in the USA (Peterson and Rosenstein, 1989). It was originally developed for radiographic projections. Many common radiographic projections can be specified in the program by projection codes. The following information is required to calculate the gonad doses for radiography and fluoroscopy of adult patients, namely

(a) The examination and view (AP, PA and LAT only)

(b) Entrance exposure (free in air) at skin surface

(c) Focus-film distance (focus-skin distance for undercouch tubes too)

(d) High voltage of tube (kV) and half value layer (HVL)

(e) Workload (mAs)

(f) Film size (X-ray field size at image receptor)

(g) Screening time

(h) Thickness of patient (AP and LAT)

(i) X-ray field location relative to anatomical landmarks.

The computer program makes an estimation of the absorbed doses to several tissues of a reference patient for a specified X-ray projection using tissue-air ratios. These ratios were previously generated by a Monte Carlo technique. The free-in-air exposure at the tissue plane is computed from the free-in-air exposure at the skin entrance, using the inverse square law. The absorbed dose to the tissue is the product of the exposure at the tissue plane and the tissue-air ratio. Tissue doses for a female are obtained by minor adjustments to the tissue doses computed for the male reference patient. Conversion factors are applied to certain tissue doses (active bone marrow, lungs, and total trunk) to account for the effect of shielding or scattering due to female breasts (Peterson and Rosenstein, 1989).

The same input data are required for fluoroscopic projections. The source-to-image receptor distance and the source-to-skin entrance distance are both required, since the patient, X-ray source and image receptor geometry may not be the same as that selected for radiographic projections. The dynamic components of a fluoroscopic examination is simulated with stationary X-ray fields.

Tables from the "Handbook of Selected Organ Doses for Projections Common in Pediatric Radiology" were used for children up to five years (Rosenstein, Beck and Warner, 1979). The available literature did not make provision for children over 5 years regarding the gonad dose conversion coefficients and were therefore assumed to be the same as for adults. The computer program was thus also applied for children over 5 years.

The NRPB-R249 Report was used to make an estimation of the gonad doses during CT examinations (Shrimpton *et al.*, 1991). Estimates of patient doses were based on the use of Monte Carlo computer techniques and a mathematical phantom to simulate the rotational beam characteristics of 27 types of CT scanners generally used. The calculations provide organ doses normalised to the dose on the axis of rotation of each scanner in the absence of the phantom. Values of such free-in-air axial doses for a range of scanner models have been determined by dose profile measurements using thermoluminescent dosemeters. Estimates of typical patient doses for 18 general types of examinations at a sample of National Health Service scanners have been obtained. It had been deduced from data provided by questionnaires and from Monte Carlo techniques and axial doses regarding the model of each scanner (Shrimpton *et al.*, 1991). There is no data available regarding children and the available data has thus to be applied. The number of children involved were very small, however (see Table 8.8).

Gonad doses were calculated for each of the views in the four age groups (Table 8.6) by means of the average technique factors in Table 8.2. The method to calculate the average gonad dose for a specific age-gender group is discussed on page 118, paragraphs 1 and 2. This means that the number of exposures are indeed implicitly included in the average technique factors. For the CT-examinations, an average gonad dose for each age group was obtained by means of the NRPB-R249 Report (Shrimpton *et al.*, 1991). Data from five scanners that are in use in South Africa, were used. Since the average gonad doses were calculated (NRPB-R249 Report) for specific examinations with the corresponding mean mAs values as well as the number of slices, an estimation of gonad doses was made for South Africa using the average mAs values and number of slices per examination that was obtained in the survey (Table 8.2). The average gonad dose for an age group was thus obtained for each scanner and then afterwards the average for the five scanners was calculated.

Table 8.6 *Skin entrance and gonad doses for diagnostic X-ray examinations.* (FAE at IR - Free Air Exposure at Image Receptor; FAE at SE.- Free Air Exposure at Skin Entrance; GD - Gonad Dose; O/AP - Overview / AP; AX - Axial; O/LAT - Overview / Lateral)

CERVICAL SPINE

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP	78.80	119.70	0.05	0.05						
	PA									0.08	0.10
	LAT	50.40	82.70	0.05	0.05						
> 5-15	AP	64.10	114.00	0.05	0.05						
	PA									0.10	0.10
	LAT	46.10	83.40	0.05	0.05						
> 15	AP	189.10	334.30	0.05	0.05						
	PA	256.50	486.10	0.05	0.05					0.19	0.18
	LAT	167.90	307.30	0.05	0.05						

THORACIC SPINE

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP	8.8	11.9	0.05	0.05						
	PA									0.0	0.15
	LAT										
>15	AP	537.4	1004.4	0.05	0.4						
	PA									0.12	0.70
	LAT	1388.0	2941.2	0.05	0.2						

Table 8.6 (cont.)

LUMBAR SPINE

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA	7.8	10.4	0.2	2.8					0.0	2.8
	LAT										
>5-15	AP	780.0	1299.4	1.7	188.0						
	PA	477.9	849.6	0.3	29.0					3.6	660.0
	LAT	1023.4	1850.9	0.5	41.0						
>15	AP	1014.3	1965.1	3.2	316.0						
	PA	962.4	1811.1	5.2	324.0					9.9	792.0
	LAT	1937.7	4579.4	1.5	116.0	2805.0	5434.0	3.8	459.0		

SCOLIOSIS X-RAYS (FULL SPINE)

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP	13.0	18.5	2.0	7.0						
	PA									2.0	0.0
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP	405.9	601.6	410.0	132.0						
	PA									697.3	132.0
	LAT	306.3	441.1	21.0	28.0						
>15	AP	324.0	499.5	7.4	106.0						
	PA									12.4	225.3
	LAT	870.4	480.3	2.5	53.0						

Table 8.6 (cont.)

LUNGS

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP	14.3	19.8	0.3	1.0					0.35	1.36
	PA	10.9	13.7	0.2	0.8						
	LAT	23.6	31.8	0.2	1.9						
>0.5-5	AP	29.2	20.2	0.05	0.05					0.13	0.31
	PA	21.7	28.9	0.05	0.60						
	LAT	28.7	42.3	0.3	0.8						
>5-15	AP	31.5	47.0	0.05	0.05					0.07	0.09
	PA	31.7	44.1	0.05	0.05						
	LAT	82.8	124.0	0.05	0.1						
>15	AP	45.3	71.3	0.05	0.1					0.08	0.45
	PA	75.3	110.3	0.05	0.3	2257.0	3305.0	0.05	2.4		
	LAT	147.9	240.4	0.05	0.3						

RIBS

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP									0.1	0.0
	PA	32.0	47.5	0.05	0.05						
	LAT										
>15	AP	220.3	363.4	0.05	0.2					0.1	0.50
	PA	324.3	508.5	0.05	0.3						
	LAT	110.6	186.9	0.05	0.1						

Table 8.6 (cont.)

ABDOMEN SURVEY

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP	124.6	174.8	159.0	68.0					202.0	68.0
	PA										
	LAT	18.5	26.1	13.0	11.0						
>0.5-5	AP	94.2	146.5	157.0	40.0					131.5	50.0
	PA										
	LAT	16.0	21.6	4.0	4.0						
>5-15	AP	106.7	177.8	2.0	33.0					2.0	38.6
	PA										
	LAT	162.6	331.8	0.8	14.0						
>15	AP	505.4	938.2	17.0	215.0	3725.0	6915.0	26.0	1296.0	26.8	407.5
	PA	326.5	570.8	9.2	146.0	16812	29392.0	65.0	3916.0		
	LAT	390.4	847.8	2.7	52.0						

PELVIS

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP	135.1	209.0	224.0	56.0					224.0	84.0
	PA										
	LAT										
>5-15	AP	335.3	592.1	196.0	108.0					235.2	135.0
	PA										
	LAT										
>15	AP	568.4	1127.6	461.0	220.0					663.8	350.6
	PA	2097.6	4161.1	41.0	617.0	9697.0	19236.0	188.0	2720.0		
	LAT	2890.2	6760.5	83.0	431.0						

Table 8.6 (cont.)

SACRUM

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP	916.8	1598.7	110.0	273.0						
	PA									215.3	420.0
	LAT	1878.9	3711.1	24.0	147.0						
>15	AP	1319.0	2517.7	73.0	486.0						
	PA									82.4	918.0
	LAT	1319.4	3118.2	9.4	162.0						

HIP JOINT

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP	9.2	13.1	14.0	3.0						
	PA									14.0	
	LAT										
>0.5-5	AP	111.8	164.4	176.0	35.0						
	PA									292.5	52.5
	LAT	154.7	259.1	233.0	62.0						
>5-15	AP	390.7	685.6	115.0	46.0						
	PA									115.0	115.0
	LAT										
>15	AP	699.2	1334.6	1000.0	149.0						
	PA	777.7	1749.8	85.0	106.0	9003.0	20257.0	947.0	1121.0	1478.0	314.5
	LAT	1188.5	2699.3	86.0	119.0						

Table 8.6 (cont.)

FEMUR NECK

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP	30.0	53.4	40.0	6.0						
	PA									120.8	
	LAT	34.7	70.8	1.5	2.0						
>15	AP	70.6	140.1	40.0	12.0						
	PA	68.2	135.3	5.7	6.9					33.9	19.8
	LAT	201.1	491.0	11.0	16.0						

FEMUR

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP	17.0	24.2	26.0	5.0						
	PA									26.0	
	LAT										
>0.5-5	AP	43.5	68.0	73.0	14.0						
	PA									143.0	30.5
	LAT	43.5	77.3	70.0	19.0						
>5-15	AP	128.2	227.9	92.0	0.7						
	PA									105.2	0.85
	LAT	109.7	213.4	1.7	0.2						
>15	AP	244.5	453.9	209.0	1.2						
	PA	51.2	101.6	3.5	0.05					310.5	1.85
	LAT	162.2	375.6	4.6	0.3						

Table 8.6 (cont.)

MYELOGRAM (LUMBAR)

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP	289.8	527.7	0.6	57.0	4152.0	7560.0	5.6	707.0		
	PA		1755.1	0.9	56.0		37252.0	17.0	1125.0	18.6	1231.2
	LAT	1281.5	3508.1	0.6	43.0						

BARIUM SWALLOW

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA		54942.4	3.0	1099.0		26888.0	0.05	5.1		6200.6
	LAT		54942.4	385.0	1044.0						
>5-15	AP										
	PA		68358.4	0.05	9.8					0.55	
	LAT		68358.4	0.05	5.5						
>15	AP	2636.6	5108.1	0.05	0.6						
	PA		32741.8	0.05	6.2		46067.0	0.05	9.7	0.44	42.3
	LAT		53110.0	0.05	4.9						

Table 8.6 (cont.)

HEART CATHETERISATION

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP										
	PA	1511.7	3256.6	0.05	0.2	28594.0	61599.0	0.05	7.3	178.2	491.9
	LAT	1666.0	4560.7	0.05	0.3	14813.0	40551.0	0.05	7.6		

AORTOGRAM (ABDOMEN)

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP	268.8	533.2	2.9	98.0						
	PA	344.6	766.6	0.9	72.0	5903.0	13132.0	16.0	1203.0	42.8	3699.0
	LAT										

Table 8.6 (cont.)

RETROGRADE PYELOGRAM

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP	160.0	239.0	5.0	65.0						
	PA										195.0
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP	300.8	554.7	11.0	131.0						
	PA		68358.4	180.0	7780.0		61368.0	150.0	8433.0	42.2	4092.5
	LAT										

INTRAVENOUS PYELOGRAM

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP	89.1	126.9	14.0	49.0						
	PA										98.0
	LAT										
>0.5-5	AP	130.0	203.1	4.0	55.0						
	PA									40.0	
	LAT										
>5-15	AP	393.3	658.7	3.3	109.0						
	PA									28.05	436.0
	LAT										
>15	AP	602.3	1141.4	8.8	211.0						
	PA	568.7	973.7	11.0	173.0					58.3	1225.8
	LAT	1545.7	3301.8	12.0	299.0						

Table 8.6 (cont.)

BARIUM MEAL

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP		4267.8	0.2	10.0						
	PA		4876.3	0.6	20.0		37619.0	5.1	170.0		204.0
	LAT		13735.6	0.3	21.0						
>15	AP	772.2	1519.5	0.2	10						
	PA		5403.5	0.3	13.0		61283.0	8.3	279.0	8.8	344.0
	LAT		18562.2	0.4	21.0						

KIDNEY TOMOGRAPHY

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP	296.0	495.7	1.4	71.0						
	PA										355.0
	LAT										
>15	AP	689.2	1306.1	6.4	231.0						
	PA									17.0	765.9
	LAT										

Table 8.6 (cont.)

CYSTOGRAM

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP		447.8	407.0	175.0		5474.0	247.0	535.0	3096.0	
	PA										
	LAT										
>0.5-5	AP		535.8	573.0	145.0		13351.0	612.0	1328.0	2925.3	
	PA		805.7	32.0	177.0		7976.0	180.0	591.0		
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP		2477.9	842.0	454.0		11360.0	2692.0	1988.0	5505.3	9653.4
	PA		6611.7	351.0	752.0		47944.0	2272.0	7161.0		
	LAT		22140.0	302.0	864.0						

URETHROGRAM

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP	445.0	800.4	226.0	135.0						
	PA						55440.0	655.0	9156.0	1661.0	135.0
	LAT	975.0	2066.1	17.0	147.0						

Table 8.6 (cont.)

SALPINGOGRAM

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP	262.8	481.6	16.0	93.0						
	PA		1053.5	3.4	55.0		55440.0	655.0	9156.0		6319.9
	LAT										

BARIUM ENEMA

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP		247.5	1.3	43.0						
	PA		2796.7	9.1	379.0		48846.0	88.0	5792.0		9048.0
	LAT		1137.9	0.8	49.0						
>15	AP		2191.5	28.0	604.0						
	PA		10864.0	36.0	1672.0		85640.0	188.0	11026.0	485.4	16111.2
	LAT		24899.8	31.0	1426.0						

Table 8.6 (cont.)

BIFURCATION ARTERIOGRAMS / ANGIOPLASTY

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP										
	PA										
	LAT										
>15	AP		1425.3	63.0	234.0						
	PA		894.4	4.7	89.0		19632.0	96.0	1642.0	96.9	2222.0
	LAT										

PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (UPPER LEG)

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
>5-15	AP										
	PA		566.0	26.0	0.2					1071.0	
	LAT										
>15	AP		927.7	28.0	0.3						
	PA		670.6	36.0	0.3					1250.2	16.8
	LAT										

Table 8.6 (cont.)

LUMBAR SPINE

COMPUTERISED TOMOGRAPHY			
Age (years)	View	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	O/AP AX O/LAT		
>0.5-5	O/AP AX O/LAT	3.0	138.0
>5-15	O/AP AX O/LAT	4.0	172.0
>15	O/AP AX O/LAT	8.0	400.0

LUNGS / MEDIASTINUM

COMPUTERISED TOMOGRAPHY			
Age (years)	View	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	O/AP AX O/LAT		
>0.5-5	O/AP AX O/LAT		
>5-15	O/AP AX O/LAT	0.6	7.0
>15	O/AP AX O/LAT	0.3	4.0

ABDOMEN - LIVER, SPLEEN, KIDNEYS, VESSELS, LYMPH NODES

COMPUTERISED TOMOGRAPHY			
Age (years)	View	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	O/AP AX O/LAT	11.0	181.0
>0.5-5	O/AP AX O/LAT		
>5-15	O/AP AX O/LAT	37.0	586.0
>15	O/AP AX O/LAT	40.0	630.0

PELVIS

COMPUTERISED TOMOGRAPHY			
Age (years)	View	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	O/AP AX O/LAT		
>0.5-5	O/AP AX O/LAT	173.0	2519.0
>5-15	O/AP AX O/LAT		
>15	O/AP AX O/LAT	127.0	1856.0

Many blanks do appear in the tables and it was assumed that only those views in the age groups with data are the examinations involved for the total population. In order to calculate the GSD, the average gonad dose for an age-sex group was required and not for the views (AP, PA, LAT) separately. It was obtained by multiplying the number of exposures in an age-gender-view interval by the respective dose. This was done for the total age-gender group, the resultant dose was obtained and divided by the number of patients in the specific age-gender group. Thus the average gonad doses ($\overline{D}_{k\ell}$) for both males and females were calculated for all age groups.

It must be stressed that gonad doses were calculated for both male and female patients for the various views in Table 8.6 if the average technique factors were available for that specific age group in Table 8.2. The average gonad dose with reference to the overall age group could only be calculated, however, if there were patients in the specific male or female group. It may occur, therefore, that the gonad doses for both males and females were calculated, but the average gonad dose could only be calculated for either one of the genders (for example Table 8.6, Barium swallow).

It was motivated in Section 8.1 why 30 out of 96 examinations were chosen for the calculation of the genetically-significant dose. The gonad doses are major contributors in the determination of the GSD. In order to confirm that the remaining examinations could be ignored, an additional 8 examinations were chosen and their respective gonad doses calculated or estimated. These examinations were chosen in view of the fact that the respective contributions to the GSD are potentially larger than any of the remaining examinations, based on the distances of the exposures from the gonads as well as the frequency. Gonad doses were calculated for six of the examinations (Table 8.7) and the results of all 8 examinations are discussed on page 160.

Table 8.7 *Skin entrance and gonad doses for a special sub-group of diagnostic X-ray examinations.* (FAE at IR - Free Air Exposure at Image Receptor; FAE at SE.- Free Air Exposure at Skin Entrance; GD - Gonad Dose)

SKULL

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP	103.0	147.0	0.0	0.0					0.0	0.0
	PA										
	LAT	63.0	88.0	0.0	0.0						
>0.5-5	AP	190.0	315.0	0.0	0.0					0.0	0.0
	PA	196.0	318.0	0.0	0.0						
	LAT	174.0	261.0	0.0	0.0						
> 5-15	AP	189.0	334.0	0.05	0.05					0.15	0.14
	PA	211.0	380.0	0.05	0.05						
	LAT	165.0	248.0	0.05	0.05						
> 15	AP	302.0	533.0	0.05	0.05					0.13	0.12
	PA	334.0	594.0	0.05	0.05						
	LAT	200.0	302.0	0.05	0.05						

S-I JOINTS

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP	27.0	42.0	45.0	11.3					45.0	
	PA										
	LAT										
> 5-15	AP										
	PA										
	LAT										
> 15	AP	802.0	1542.0	20.0	185.0					60.8	469.5
	PA										
	LAT	364.0	889.0	3.0	42.0						

Table 8.7 (cont.)

KNEE

Age (years)	View	RADIOGRAPHY FAE at IR (mR)	RADIOGRAPHY FAE at SE (mR)	RADIOGRAPHY GD male (mrad)	RADIOGRAPHY GD female (mrad)	FLUOROSCOPY FAE at IR (mR)	FLUOROSCOPY FAE at SE (mR)	FLUOROSCOPY GD male (mrad)	FLUOROSCOPY GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP	66.2	103.0	0.3	0.05					0.35	0.12
	PA										
	LAT	55.4	98.0	0.05	0.05						
> 5-15	AP	64.8	115.0	0.3	0.05					0.35	0.15
	PA	33.3	59.0	0.1	0.05						
	LAT	60.8	124.0	0.05	0.05						
> 15	AP	146.2	279.0	0.8	0.05					1.39	0.15
	PA	55.3	110.0	0.1	0.05						
	LAT	161.4	378.0	0.1	0.05						

ANGIOGRAM (HEAD)

Age (years)	View	RADIOGRAPHY FAE at IR (mR)	RADIOGRAPHY FAE at SE (mR)	RADIOGRAPHY GD male (mrad)	RADIOGRAPHY GD female (mrad)	FLUOROSCOPY FAE at IR (mR)	FLUOROSCOPY FAE at SE (mR)	FLUOROSCOPY GD male (mrad)	FLUOROSCOPY GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA	151.0	208.0	0.0	0.0	6364.0	8752.0	0.05	0.05	0.05	
	LAT										
>0.5-5	AP										
	PA										
	LAT										
> 5-15	AP										
	PA										
	LAT										
> 15	AP										
	PA	206.0	413.0	0.05	0.05	8191.0	16439.0	0.05	0.05	0.5	1.73
	LAT	133.0	218.0	0.05	0.05						

Table 8.7 (cont.)

SPINE TOMOGRAPHY

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP	21.0	33.0	35.3	8.9						
	PA									35.3	
	LAT										
> 5-15	AP										
	PA										
	LAT										
> 15	AP	819.0	1464.0	0.6	69.0						
	PA									3.8	222.0
	LAT	1389.0	2898.0	0.5	36.0						

CHOLANGIOGRAM, CHOLECYSTOGRAM

		RADIOGRAPHY				FLUOROSCOPY					
Age (years)	View	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	FAE at IR (mR)	FAE at SE (mR)	GD male (mrad)	GD female (mrad)	**av. GD male** (mrad)	**av. GD female** (mrad)
0-0.5	AP										
	PA										
	LAT										
>0.5-5	AP										
	PA										
	LAT										
> 5-15	AP										
	PA										
	LAT										
> 15	AP	1276.0	2369.0	0.3	20.0						
	PA	604.0	1153.0	0.05	1.8		23386.0	0.1	23.0	0.9	86.8
	LAT	838.0	1852.0	0.1	8.7						

8.6 Age-gender-race groups

The next stage in the calculation of the GSD was the determination of the number of patients, $N_{k\ell}$, in the various age-gender-race groups (k) that underwent an examination of type ℓ. Population data (Figures 8.1 and 8.2) was obtained from the Central Statistical Service (Population Census 1991, 1992). The last SA population census was in March 1991 which coincided very well with the present survey. The complete sample was used to determine these values. In order to determine $N_{k\ell}$ the age, gender and race had to be known. With the exception of three institutions, the missing information regarding these aspects was estimated less than 2% of the sample. Missing data was imputed according to certain principles as detailed below. In 3 institutions, there was a higher incidence of missing information, in that there was no indication of race or age of patients for two of the institutions, and only a partial response on age for the third. However, all three institutions serve a predominantly black population, so that it was assumed that the race of the patients undergoing radiological examinations was black.

8.6.1 Imputation

(a) Age. The same principle was applicable here as was discussed in paragraph 8.3(a), i.e. where there was no indication of the age, 30 was imputed. In some cases there were indications of patients being children. Further investigation into the ages of children for specific types of examinations indicated that 6 years could be an acceptable value for imputation.

(b) Gender. In cases where the gender was omitted, where possible it was derived from the patient's name in the registers. Otherwise "male" and "female" were imputed alternatively - starting with a different gender than the preceding one that was available.

(c) Race. As in (b) above it was also possible in some instances to impute the race by virtue of a person's name. Alternatively, White (W); Coloured (C); Asian (A); and Black (B) were imputed sequentially. If, for example, the latest entry on the form was a "C", the cycle started with an "A".

8.6.2 Correction factors

(a) Three institutions should theoretically have been omitted from the present survey since the ages of the patients were not entered on the sources for two of the institutions as well as the larger part of the third one. Since the examinations were being performed on Black patients only at these institutions, the correction that had to be carried out, applied to the Black population only. The following numbers were obtained from the database:

Total number of examinations in country (292 institutions; p.66) = 5576235
Total number of examinations in complete sample, $N_{TOT.}$ = 27696
Number of examinations on Black males in sample, N_{MB}(a.u.), with age unknown* = 2677
Number of examinations on Black females in sample, N_{FB}(a.u.), with age unknown* = 1808
Total number of examinations on Black males in sample, N_{MB} = 6661
Total number of examinations on Black females in sample, N_{FB} = 4335

*N_{MB}(a.u.) and *N_{FB}(a.u.) refer to the above-mentioned three institutions only.

The correction, k_M, regarding the number of examinations for Black males that was not included in the age-gender groups, can therefore given by

$$k_M = \frac{2677}{6661-2677} = 0.6719$$

Similarly the correction for Black females is given by

$$k_F = \frac{1808}{4335-1808} = 0.7155$$

The number of examinations for the various Black age-gender groups can therefore be calculated according to the formulas:

$N_{k\ell}(B_M) = (k_M + 1).N_{k\ell}$(Black, three institutions excluded)

$N_{k\ell}(B_F) = (k_F + 1).N_{k\ell}$(Black, three institutions excluded).

(b) The following correction was made in order to extend the sample to represent the number of examinations in the country:

$$k = \frac{5576235}{27696} = 201.3372.$$

Using the above-mentioned correction factors (k_M, k_F and k), the examination frequencies for the entire South Africa was estimated. These results are given in Figures 8.3 to 8.8 and in Table 8.8.

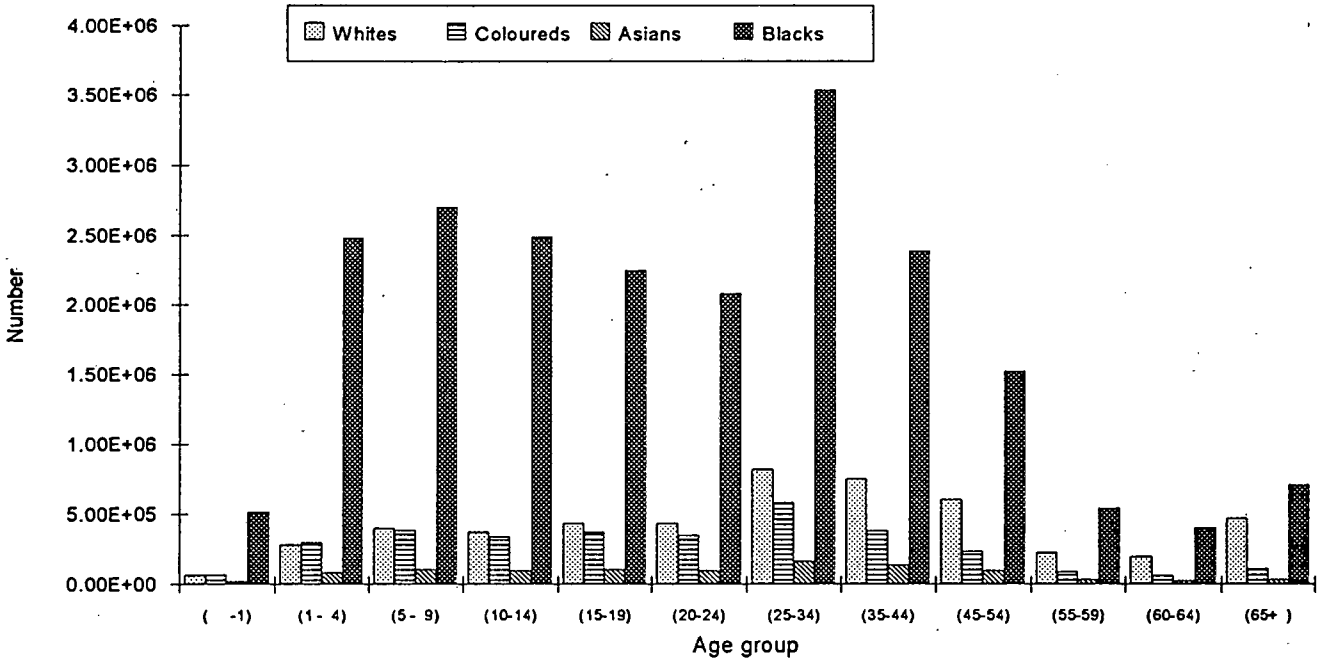


Figure 8.1 *Total population (male and female).*

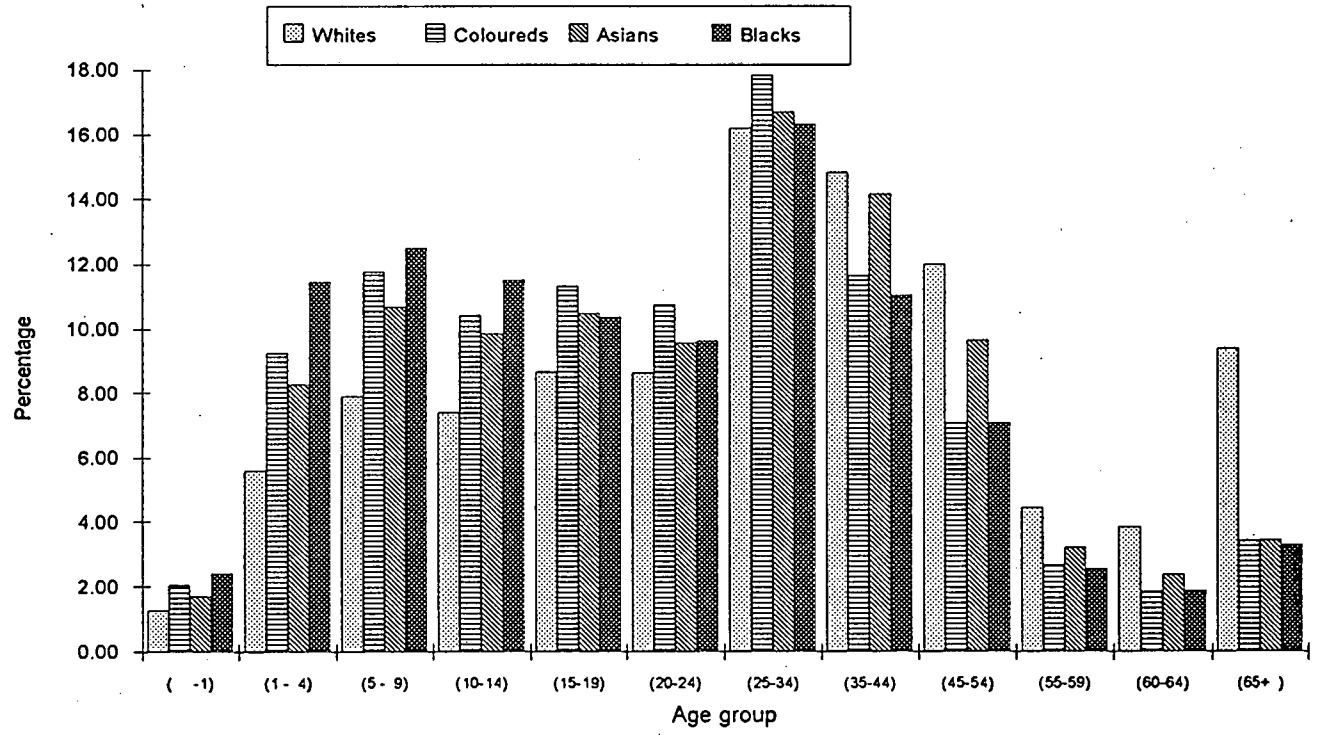


Figure 8.2 *Percentage of total population (male and female) with respect to race groups.*

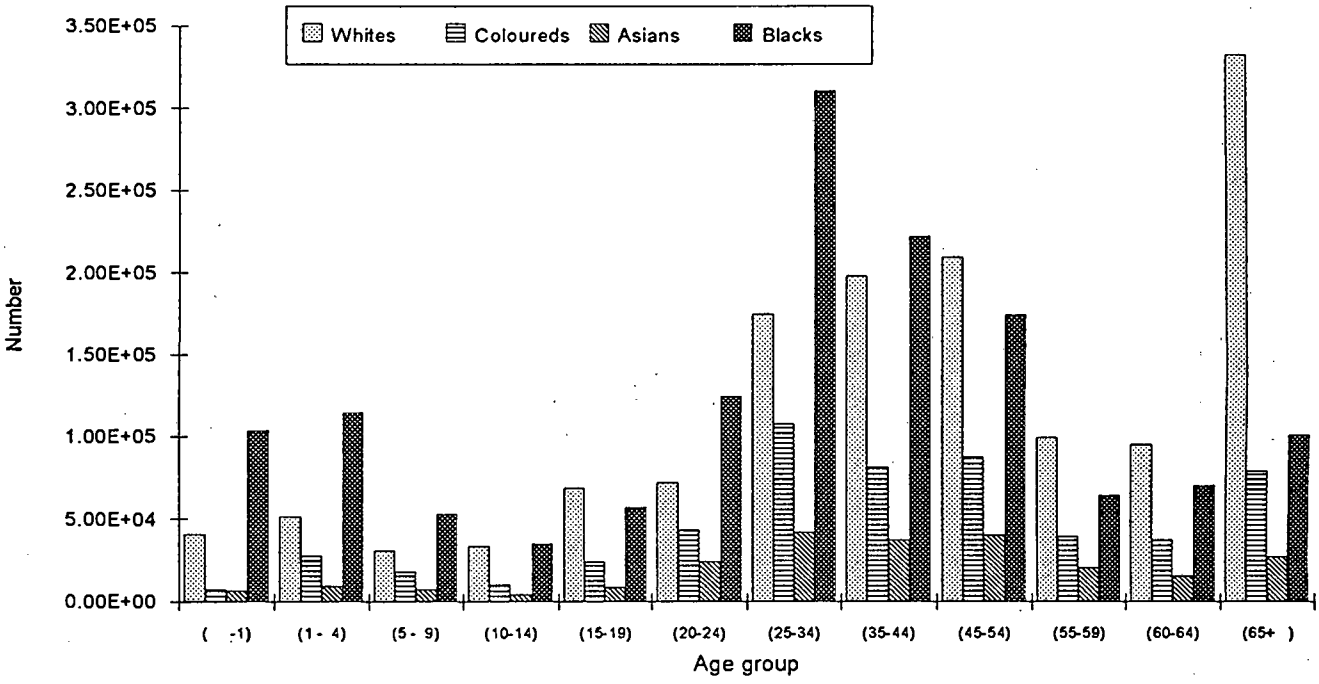


Figure 8.3 *Total number of examinations (male and female).*

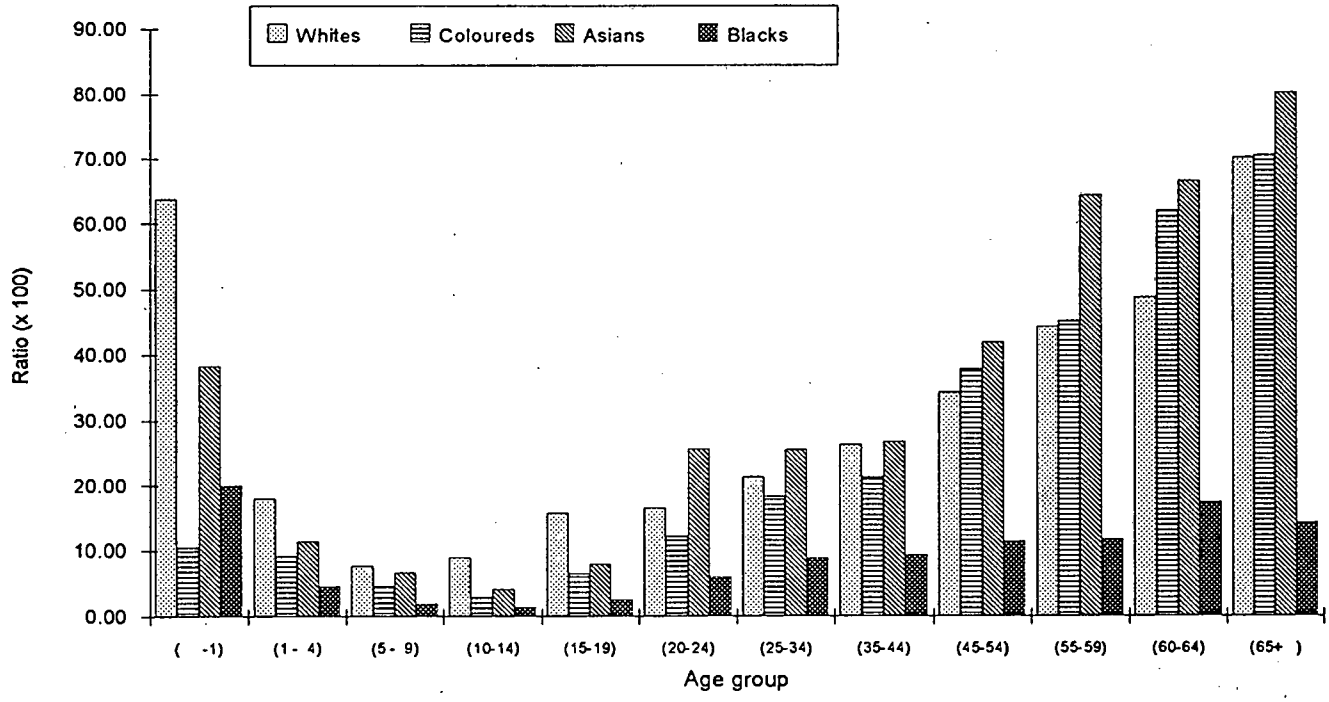


Figure 8.4 *Ratio of total number of examinations (male and female) to census population (x 100) with respect to race group in the various age intervals.*

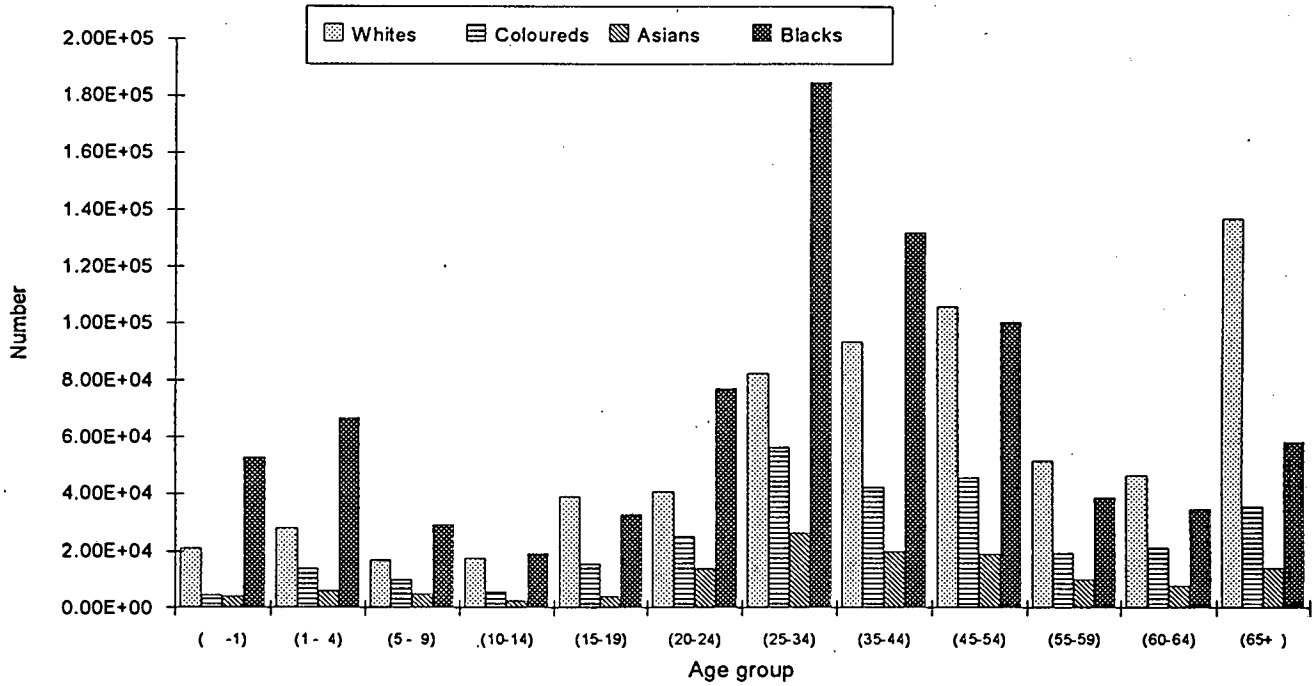


Figure 8.5 *Total number of examinations (male).*

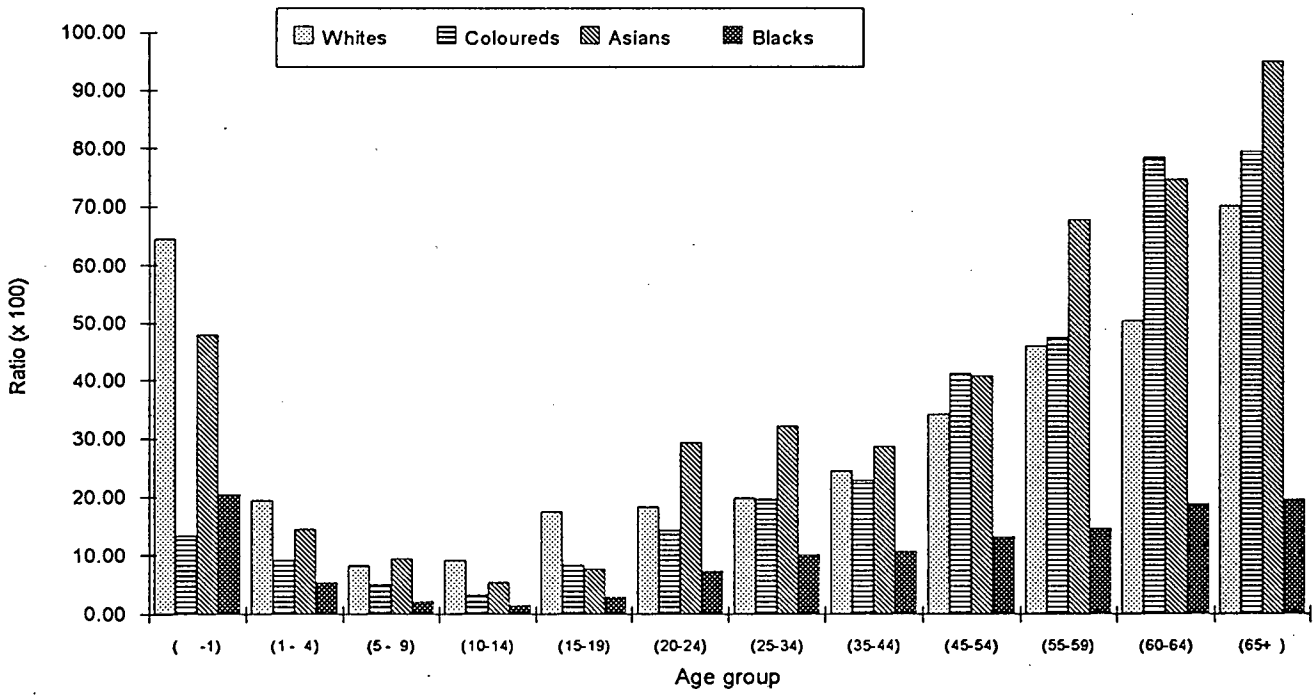


Figure 8.6 *Ratio of total number of examinations (male) to census population (x 100) with respect to race group in the various age intervals.*

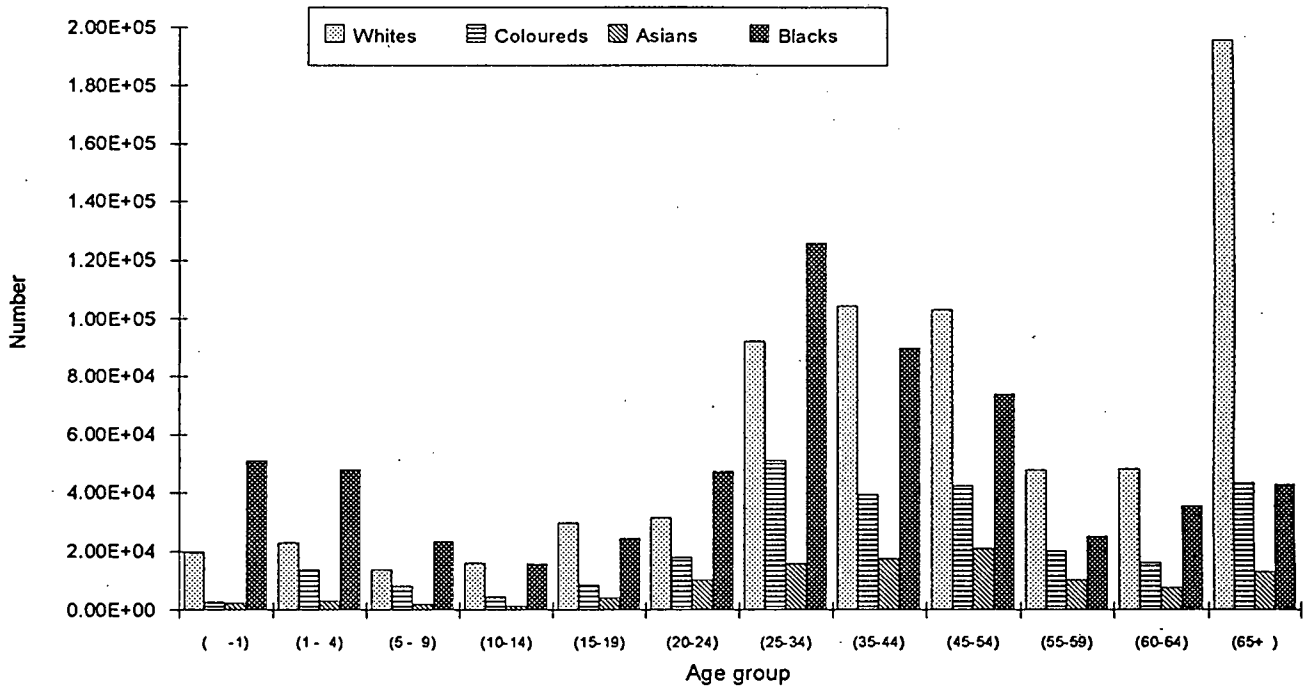


Figure 8.7 *Total number of examinations (female).*

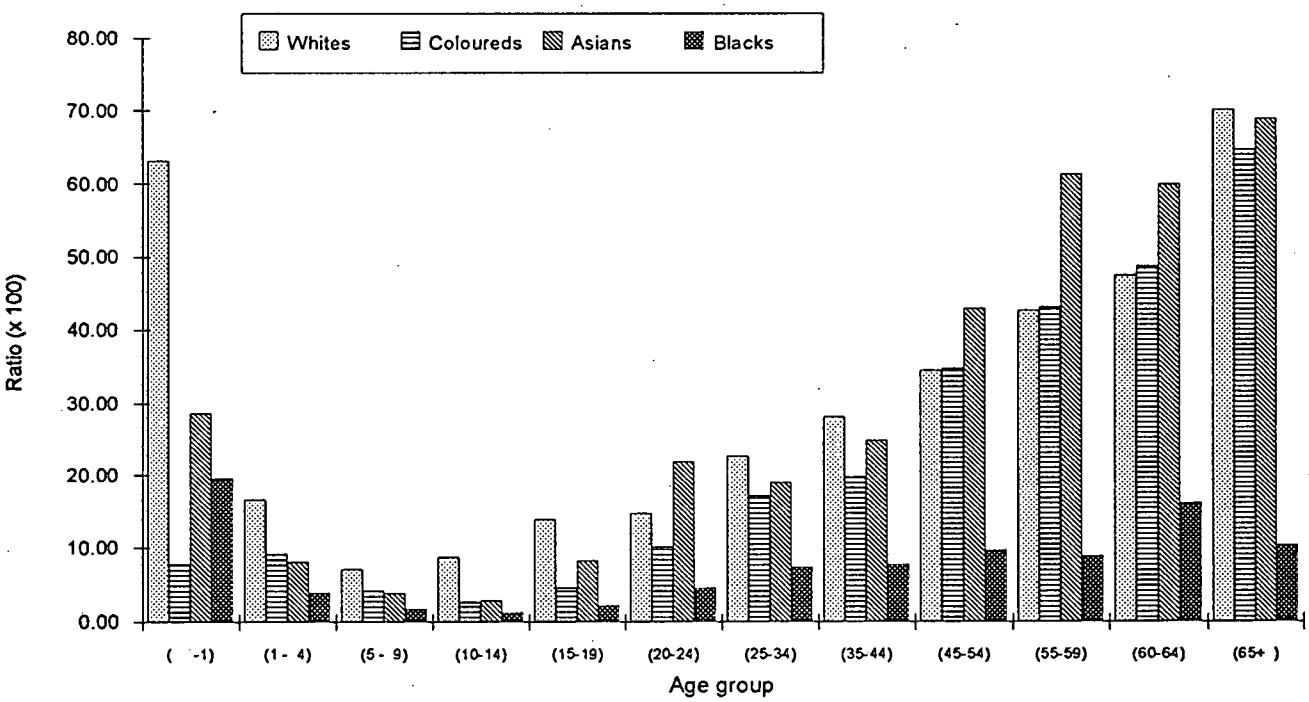


Figure 8.8 *Ratio of total number of examinations (female) to census population (x 100) with respect to race group in the various age intervals.*

Table 8.8 *Calculated frequency of radiolgical examinations for entire population for a one year period (M=male; F=female; W=White; C=Coloured; A=Asian; B=Black).*

Note: If the numbers are added, it may differ by 1 with the totals. This is due to the correction factors mentioned in section 8.6.2 and the decimals that are not shown.

CERVICAL SPINE

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	201	673	201	0	0	691	**1767**
(1 - 4)	1007	403	201	2020	805	201	0	1036	**5673**
(5 - 9)	403	201	805	673	0	0	0	691	**2773**
(10-14)	1007	0	201	1010	604	0	201	345	**3369**
(15-19)	4228	805	201	673	3423	0	201	345	**9877**
(20-24)	6241	604	604	3703	3020	403	403	2763	**17741**
(25-34)	8255	1812	1007	14474	11476	2215	1611	4836	**45685**
(35-44)	8255	2013	805	6396	10268	1208	1812	5181	**35938**
(45-54)	6443	2416	1409	4713	11476	2416	1409	3109	**33391**
(55-59)	3020	805	403	1010	3221	201	805	345	**9811**
(60-64)	1611	201	604	2356	2617	403	201	1036	**9030**
(65+)	3020	403	805	2020	6644	604	0	691	**14187**
Total	**43489**	**9664**	**7248**	**39721**	**53757**	**7651**	**6644**	**21069**	**189243**

THORACIC SPINE

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	345	**345**
(1 - 4)	201	201	0	0	0	0	0	0	**403**
(5 - 9)	604	0	0	0	201	0	0	0	**805**
(10-14)	1611	0	0	337	1208	0	0	691	**3846**
(15-19)	3221	604	201	337	2617	201	0	0	**7182**
(20-24)	1208	403	201	1683	1007	0	201	345	**5049**
(25-34)	2013	403	1208	2693	4228	1007	604	2072	**14228**
(35-44)	1812	1007	403	2356	3825	805	604	1727	**12539**
(45-54)	1812	201	201	2356	1812	1409	201	1036	**9030**
(55-59)	805	0	0	337	1812	201	0	0	**3155**
(60-64)	201	201	201	1010	3020	201	0	0	**4835**
(65+)	1812	201	201	337	3825	1007	403	0	**7786**
Total	**15302**	**3221**	**2617**	**11445**	**23556**	**4832**	**2013**	**6217**	**69204**

LUMBAR SPINE

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	337	0	0	0	691	**1027**
(1 - 4)	0	201	0	0	201	201	0	0	**604**
(5 - 9)	403	0	201	0	604	0	201	345	**1755**
(10-14)	2416	0	0	337	2215	201	0	691	**5859**
(15-19)	7248	1611	403	0	4027	201	604	691	**14784**
(20-24)	5436	1812	805	4039	3221	805	1007	1382	**18508**
(25-34)	12684	2617	2617	7406	10268	2215	1409	2763	**41980**
(35-44)	12080	3423	1208	5722	14698	1007	1208	5181	**44527**
(45-54)	9664	3423	1007	5722	13691	1812	805	6217	**42341**
(55-59)	3825	805	201	1346	5235	1409	403	1036	**14262**
(60-64)	2617	805	0	2356	5033	1208	403	2418	**14841**
(65+)	6845	1007	403	2693	12684	1208	1007	345	**26192**
Total	**63220**	**15704**	**6845**	**29959**	**71877**	**10268**	**7047**	**21760**	**226681**

Table 8.8 (cont.)

SCOLIOSIS X-RAYS (FULL SPINE)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	**Total**
(-1)	0	0	0	337	0	0	0	0	**337**
(1 - 4)	201	0	0	0	0	0	0	1036	**1238**
(5 - 9)	201	0	0	0	201	0	0	0	**403**
(10-14)	1208	0	0	0	2215	0	0	0	**3423**
(15-19)	2013	201	0	0	1409	0	0	0	**3624**
(20-24)	201	0	0	337	201	0	0	0	**739**
(25-34)	0	0	201	337	201	201	0	0	**941**
(35-44)	201	0	0	0	0	0	201	345	**748**
(45-54)	0	0	0	0	201	201	0	0	**403**
(55-59)	0	0	0	0	201	0	0	0	**201**
(60-64)	0	0	0	0	0	0	0	0	**0**
(65+)	0	0	0	0	0	0	0	0	**0**
Total	**4027**	**201**	**201**	**1010**	**4631**	**403**	**201**	**1382**	**12056**

LUNGS

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	18120	3825	3020	43423	15100	2617	1812	42483	**130402**
(1 - 4)	21946	11476	4631	57561	15704	12080	2215	42138	**167751**
(5 - 9)	10067	8859	2617	24573	8255	7852	1409	16924	**80557**
(10-14)	6443	3624	1208	12455	4631	3221	1007	11398	**43987**
(15-19)	12080	9664	2215	23563	8657	7248	3221	19342	**85991**
(20-24)	15906	18523	6845	52175	10872	12282	6040	30049	**152693**
(25-34)	31006	37449	13288	109400	31610	34630	8456	80131	**345970**
(35-44)	35435	24362	10671	83481	33221	25771	9463	58372	**280775**
(45-54)	49328	29597	12886	60927	39059	26979	13087	48010	**279872**
(55-59)	28389	11879	7449	27266	18322	14094	7449	17960	**132808**
(60-64)	23355	15100	5033	20197	18322	11275	5235	24178	**122695**
(65+)	79126	24563	9262	42414	96642	31409	9262	29704	**322380**
Total	**331200**	**198921**	**79126**	**557436**	**300395**	**189458**	**68656**	**420690**	**2145881**

RIBS

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	**Total**
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	201	0	0	**201**
(5 - 9)	201	0	0	673	0	0	0	0	**875**
(10-14)	201	0	0	337	201	0	0	0	**739**
(15-19)	0	0	0	337	403	0	0	0	**739**
(20-24)	2013	201	0	1683	201	201	0	691	**4991**
(25-34)	3020	1611	403	5049	1007	403	201	691	**12384**
(35-44)	1812	1409	0	4039	2013	403	0	1036	**10713**
(45-54)	1611	403	201	1683	1812	0	0	691	**6401**
(55-59)	1007	201	0	337	403	201	0	345	**2494**
(60-64)	201	403	0	337	403	201	0	345	**1890**
(65+)	1007	201	0	673	3825	1007	0	691	**7404**
Total	**11074**	**4429**	**604**	**15148**	**10268**	**2617**	**201**	**4490**	**48832**

Table 8.8 (cont.)

ABDOMEN SURVEY

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	1007	403	201	5386	1409	0	403	3454	**12263**
(1 - 4)	2215	805	604	4713	2416	604	805	2072	**14234**
(5 - 9)	1208	201	604	1683	604	0	0	2072	**6373**
(10-14)	1007	201	403	1010	1007	0	0	691	**4318**
(15-19)	2819	604	604	1346	2617	0	0	1036	**9027**
(20-24)	1611	1611	1812	3030	4429	1812	805	4490	**19600**
(25-34)	4228	3825	3825	15148	6241	3423	1812	11398	**49901**
(35-44)	3825	4027	2617	10772	6845	2617	1007	3799	**35510**
(45-54)	4429	2215	1812	3366	5839	2819	2215	3454	**26148**
(55-59)	3020	1208	805	2020	4027	1208	805	1727	**14820**
(60-64)	4429	1208	1208	2356	1611	604	201	691	**12309**
(65+)	7852	3221	604	3703	12684	2416	604	3799	**34884**
Total	**37650**	**19530**	**15100**	**54532**	**49730**	**15503**	**8657**	**38684**	**239387**

PELVIS

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	604	0	0	337	805	0	201	691	**2638**
(1 - 4)	403	403	201	337	604	0	201	345	**2494**
(5 - 9)	201	201	201	673	201	0	0	1382	**2860**
(10-14)	604	403	201	1010	1007	403	0	691	**4318**
(15-19)	3825	805	201	1346	2617	201	201	691	**9889**
(20-24)	3624	1007	1007	3703	1208	805	805	2763	**14922**
(25-34)	6644	3624	1409	11445	7449	1409	403	4145	**36529**
(35-44)	7248	805	805	4039	8859	1208	201	4145	**27311**
(45-54)	5436	1409	604	4713	7248	1611	604	4145	**25770**
(55-59)	1208	805	201	673	5235	805	403	691	**10022**
(60-64)	1812	403	201	673	4631	403	604	1036	**9763**
(65+)	7449	1409	403	1346	19127	1611	403	691	**32439**
Total	**39059**	**11275**	**5436**	**30295**	**58992**	**8456**	**4027**	**21414**	**178955**

SACRUM

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	0	0	0	0	**0**
(10-14)	201	0	201	337	403	0	0	0	**1142**
(15-19)	0	201	0	0	201	201	0	0	**604**
(20-24)	0	0	0	0	0	0	0	0	**0**
(25-34)	0	403	0	337	0	201	0	0	**941**
(35-44)	0	0	0	0	403	201	0	0	**604**
(45-54)	201	0	0	0	604	201	0	0	**1007**
(55-59)	0	201	0	0	403	0	0	0	**604**
(60-64)	0	0	0	0	201	201	0	0	**403**
(65+)	201	0	0	0	805	0	0	0	**1007**
Total	**604**	**805**	**201**	**673**	**3020**	**1007**	**0**	**0**	**6311**

Table 8.8 (cont.)

HIP JOINT

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	201	0	0	673	604	0	0	0	**1479**
(1 - 4)	604	403	0	337	805	403	0	345	**2897**
(5 - 9)	604	201	0	0	201	0	0	345	**1352**
(10-14)	201	403	201	337	805	0	0	0	**1947**
(15-19)	201	201	0	337	0	201	0	0	**941**
(20-24)	604	201	805	1346	604	403	201	345	**4511**
(25-34)	1007	201	604	3366	1007	604	0	1036	**7825**
(35-44)	2819	604	201	2693	1007	805	403	2763	**11295**
(45-54)	3221	604	403	1683	2416	403	1007	1727	**11464**
(55-59)	403	0	201	337	2416	201	201	691	**4450**
(60-64)	1007	403	0	1010	2215	403	403	691	**6130**
(65+)	6241	805	201	0	14496	1007	403	1036	**24190**
Total	**17114**	**4027**	**2617**	**12118**	**26577**	**4429**	**2617**	**8980**	**78480**

FEMUR NECK

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	337	0	0	0	0	**337**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	201	0	0	0	0	0	**201**
(10-14)	0	0	0	337	0	0	0	0	**337**
(15-19)	0	0	0	337	0	0	0	345	**682**
(20-24)	0	0	201	0	0	0	0	0	**201**
(25-34)	0	0	0	337	0	0	0	345	**682**
(35-44)	0	0	0	337	0	0	201	0	**538**
(45-54)	403	0	0	673	0	0	0	0	**1076**
(55-59)	0	201	0	0	0	0	0	0	**201**
(60-64)	0	201	0	0	0	201	201	0	**604**
(65+)	0	0	0	0	604	0	0	0	**604**
Total	**403**	**403**	**403**	**2356**	**604**	**201**	**403**	**691**	**5463**

FEMUR

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	337	201	0	0	691	**1229**
(1 - 4)	201	0	201	673	201	201	0	691	**2169**
(5 - 9)	201	0	201	673	604	0	403	1036	**3119**
(10-14)	604	1007	0	673	403	201	0	1382	**4270**
(15-19)	604	201	201	3703	0	0	0	345	**5055**
(20-24)	805	403	604	3366	201	201	201	1382	**7164**
(25-34)	2617	805	604	6059	604	403	0	1727	**12819**
(35-44)	604	604	403	5386	0	201	604	1382	**9183**
(45-54)	1409	805	201	4039	201	604	201	2072	**9534**
(55-59)	0	604	403	337	201	201	0	0	**1746**
(60-64)	201	403	0	673	604	604	403	1382	**4270**
(65+)	1611	805	201	337	2013	604	0	691	**6262**
Total	**8859**	**5637**	**3020**	**26256**	**5235**	**3221**	**1812**	**12780**	**66820**

Table 8.8 (cont.)

MYELOGRAM (LUMBAR)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	0	0	0	0	**0**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	0	0	0	0	0	0	345	**345**
(20-24)	201	0	0	0	201	0	0	0	**403**
(25-34)	805	403	201	673	1208	0	201	345	**3837**
(35-44)	1208	403	0	337	805	201	0	0	**2954**
(45-54)	1208	0	0	337	201	201	0	0	**1947**
(55-59)	0	201	0	0	201	0	0	0	**403**
(60-64)	0	0	0	0	201	0	0	0	**201**
(65+)	604	201	0	0	805	0	0	0	**1611**
Total	**4027**	**1208**	**201**	**1346**	**3624**	**403**	**201**	**691**	**11701**

BARIUM SWALLOW

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	201	0	0	337	0	0	0	1382	**1920**
(1 - 4)	0	0	0	0	201	0	0	345	**547**
(5 - 9)	0	0	0	0	0	0	0	0	**0**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	201	0	337	201	0	0	0	**739**
(20-24)	0	0	201	673	0	0	0	0	**875**
(25-34)	403	201	0	673	1007	0	201	691	**3176**
(35-44)	403	0	201	1346	604	403	403	345	**3705**
(45-54)	604	604	0	4039	1208	201	403	345	**7405**
(55-59)	403	0	0	2020	201	0	0	345	**2969**
(60-64)	201	201	0	673	201	0	0	1382	**2659**
(65+)	2215	0	0	1346	3423	0	0	2072	**9056**
Total	**4429**	**1208**	**403**	**11445**	**7047**	**604**	**1007**	**6908**	**33050**

HEART CATHETERISATION

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	337	0	0	0	0	**337**
(5 - 9)	0	0	0	0	0	0	0	0	**0**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	0	0	0	0	0	0	0	**0**
(20-24)	0	0	0	0	0	201	0	0	**201**
(25-34)	1007	0	0	0	0	201	0	0	**1208**
(35-44)	1812	403	0	0	604	201	201	345	**3567**
(45-54)	5033	604	0	0	805	1208	0	0	**7651**
(55-59)	1812	0	0	0	201	201	0	0	**2215**
(60-64)	2819	201	0	0	1007	0	0	0	**4027**
(65+)	4027	403	0	0	1208	201	0	345	**6184**
Total	**16510**	**1611**	**0**	**337**	**3825**	**2215**	**201**	**691**	**25389**

Table 8.8 (cont.)

AORTOGRAM (ABDOMEN)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	0	0	0	0	**0**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	0	0	0	0	0	0	0	**0**
(20-24)	0	0	0	0	0	201	0	0	**201**
(25-34)	0	0	0	0	0	0	0	0	**0**
(35-44)	403	0	0	673	201	0	0	0	**1277**
(45-54)	0	0	0	0	403	0	0	0	**403**
(55-59)	403	201	0	337	201	0	0	0	**1142**
(60-64)	0	201	0	0	0	0	0	345	**547**
(65+)	201	0	0	337	805	0	0	0	**1343**
Total	**1007**	**403**	**0**	**1346**	**1611**	**201**	**0**	**345**	**4913**

RETROGRADE PYELOGRAM

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	403	0	0	0	**403**
(5 - 9)	0	0	0	0	201	0	0	0	**201**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	201	0	0	0	0	0	0	0	**201**
(20-24)	0	0	0	0	403	0	201	0	**604**
(25-34)	403	0	201	0	1208	201	0	345	**2359**
(35-44)	2416	0	0	0	1611	0	0	0	**4027**
(45-54)	1611	0	0	0	1007	0	0	0	**2617**
(55-59)	1007	0	0	0	0	0	0	0	**1007**
(60-64)	604	0	0	0	604	0	0	0	**1208**
(65+)	2013	0	201	0	403	0	0	0	**2617**
Total	**8255**	**0**	**403**	**0**	**5839**	**201**	**201**	**345**	**15244**

INTRAVENOUS PYELOGRAM

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	403	0	0	0	0	345	**748**
(1 - 4)	201	0	0	337	403	0	0	0	**941**
(5 - 9)	1208	0	0	0	1007	0	0	0	**2215**
(10-14)	1208	0	0	0	0	0	201	0	**1409**
(15-19)	1007	0	0	0	1208	0	0	0	**2215**
(20-24)	604	0	201	673	1208	201	201	345	**3435**
(25-34)	3221	805	201	1683	2819	604	201	691	**10226**
(35-44)	2819	403	1409	673	3423	1409	805	345	**11287**
(45-54)	2819	604	0	1010	2416	604	604	1727	**9784**
(55-59)	805	805	201	0	805	0	0	0	**2617**
(60-64)	2416	0	604	1346	805	403	0	0	**5575**
(65+)	2819	805	1007	673	1409	0	403	0	**7116**
Total	**19127**	**3423**	**4027**	**6396**	**15503**	**3221**	**2416**	**3454**	**57567**

Table 8.8 (cont.)

BARIUM MEAL

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	403	0	0	337	805	0	0	345	**1890**
(1 - 4)	805	0	0	0	201	0	0	0	**1007**
(5 - 9)	604	0	0	0	403	0	0	345	**1352**
(10-14)	201	0	201	337	805	0	0	0	**1545**
(15-19)	1007	0	0	0	1409	0	0	1036	**3452**
(20-24)	805	0	403	337	604	0	0	345	**2494**
(25-34)	1812	604	201	2020	3624	805	201	1382	**10649**
(35-44)	2617	805	0	673	3825	604	0	345	**8871**
(45-54)	1812	201	0	2020	3825	403	0	0	**8261**
(55-59)	1007	0	201	1010	805	1208	0	0	**4231**
(60-64)	1409	201	0	337	2013	0	0	0	**3961**
(65+)	2215	201	0	337	3423	1208	0	345	**7729**
Total	**14698**	**2013**	**1007**	**7406**	**21744**	**4228**	**201**	**4145**	**55442**

KIDNEY TOMOGRAPHY

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	201	0	0	0	**201**
(10-14)	201	0	0	0	0	0	0	0	**201**
(15-19)	201	0	0	0	0	0	0	0	**201**
(20-24)	0	0	0	0	1007	0	0	0	**1007**
(25-34)	805	201	0	337	1409	201	0	345	**3299**
(35-44)	1409	201	604	337	1812	1007	201	345	**5917**
(45-54)	604	604	0	0	1208	201	201	0	**2819**
(55-59)	403	403	0	0	403	0	0	0	**1208**
(60-64)	1007	0	0	673	1007	0	0	0	**2687**
(65+)	1208	403	403	337	604	0	201	0	**3155**
Total	**5839**	**1812**	**1007**	**1683**	**7651**	**1409**	**604**	**691**	**20696**

CYSTOGRAM

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	201	201	337	403	0	0	0	**1142**
(1 - 4)	201	0	201	337	604	0	0	0	**1343**
(5 - 9)	201	0	0	337	403	201	0	0	**1142**
(10-14)	0	0	0	337	0	0	0	0	**337**
(15-19)	0	201	0	0	201	0	0	0	**403**
(20-24)	201	201	201	0	403	201	201	691	**2100**
(25-34)	0	201	201	1010	0	201	0	1036	**2650**
(35-44)	201	0	201	337	805	0	201	691	**2437**
(45-54)	403	0	0	2356	604	0	0	691	**4054**
(55-59)	0	0	0	0	0	0	201	0	**201**
(60-64)	0	201	0	337	0	0	0	345	**883**
(65+)	201	403	0	337	805	0	201	0	**1947**
Total	**1409**	**1409**	**1007**	**5722**	**4228**	**604**	**805**	**3454**	**18639**

Table 8.8 (cont.)

URETHROGRAM

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	201	0	0	0	**201**
(5 - 9)	0	0	0	0	201	0	0	0	**201**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	201	0	0	0	0	0	0	**201**
(20-24)	0	0	0	0	0	0	0	0	**0**
(25-34)	0	0	0	0	0	0	0	691	**691**
(35-44)	201	0	0	0	0	0	0	345	**547**
(45-54)	0	0	0	0	0	0	0	0	**0**
(55-59)	0	201	0	0	0	0	0	0	**201**
(60-64)	0	0	0	0	0	0	0	0	**0**
(65+)	0	0	0	0	0	0	0	345	**345**
Total	**201**	**403**	**0**	**0**	**403**	**0**	**0**	**1382**	**2388**

SALPINGOGRAM

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	0	0	0	0	**0**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	0	0	0	0	0	0	0	**0**
(20-24)	0	0	0	0	403	0	0	1382	**1784**
(25-34)	0	0	0	0	1611	1208	201	7944	**10964**
(35-44)	0	0	0	0	201	0	0	1036	**1238**
(45-54)	0	0	0	0	0	0	0	0	**0**
(55-59)	0	0	0	0	201	0	0	0	**201**
(60-64)	0	0	0	0	0	0	0	0	**0**
(65+)	0	0	0	0	0	0	0	0	**0**
Total	**0**	**0**	**0**	**0**	**2416**	**1208**	**201**	**10362**	**14187**

BARIUM ENEMA

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	201	0	0	0	201	0	0	0	**403**
(5 - 9)	0	0	201	0	403	0	0	0	**604**
(10-14)	201	0	0	0	201	201	0	0	**604**
(15-19)	0	0	0	0	403	0	0	0	**403**
(20-24)	403	201	0	0	1208	0	0	0	**1812**
(25-34)	604	201	0	337	2013	0	0	2072	**5228**
(35-44)	805	805	403	337	5436	403	0	345	**8534**
(45-54)	2215	201	201	337	4228	201	0	345	**7729**
(55-59)	1409	201	0	673	1007	0	0	1727	**5018**
(60-64)	1007	201	0	337	2416	0	0	345	**4306**
(65+)	3020	0	403	673	6845	604	201	691	**12438**
Total	**9866**	**1812**	**1208**	**2693**	**24362**	**1409**	**201**	**5526**	**47077**

Table 8.8 (cont.)

BIFURCATION ARTERIOGRAMS / ANGIOPLASTY

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	0	0	0	0	**0**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	0	0	0	0	0	0	0	**0**
(20-24)	0	0	0	0	0	0	0	0	**0**
(25-34)	0	0	0	0	0	0	0	345	**345**
(35-44)	201	0	0	337	0	0	0	0	**538**
(45-54)	201	0	0	0	0	201	0	0	**403**
(55-59)	0	0	0	337	0	0	0	0	**337**
(60-64)	0	0	0	0	0	0	0	345	**345**
(65+)	0	0	0	337	0	0	0	0	**337**
Total	**403**	**0**	**0**	**1010**	**0**	**201**	**0**	**691**	**2305**

PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (UPPER LEG)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	201	0	0	0	0	0	0	**201**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	0	0	0	0	0	0	0	**0**
(20-24)	0	0	0	0	0	0	0	0	**0**
(25-34)	0	0	0	673	0	0	0	0	**673**
(35-44)	201	0	0	0	0	0	0	345	**547**
(45-54)	0	0	0	0	0	0	0	0	**0**
(55-59)	201	201	0	337	201	0	0	0	**941**
(60-64)	0	0	0	0	0	0	0	345	**345**
(65+)	403	201	0	337	201	0	0	0	**1142**
Total	**805**	**604**	**0**	**1346**	**403**	**0**	**0**	**691**	**3849**

LUMBAR SPINE (CT)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	0	0	0	345	**345**
(10-14)	0	0	0	0	201	0	0	0	**201**
(15-19)	0	0	0	0	0	0	0	345	**345**
(20-24)	604	0	0	0	604	0	0	0	**1208**
(25-34)	1409	0	201	1010	2215	0	201	345	**5382**
(35-44)	3423	201	0	337	3020	0	0	345	**7326**
(45-54)	3221	0	0	0	1007	0	201	0	**4429**
(55-59)	1208	0	0	0	1007	201	0	0	**2416**
(60-64)	0	0	0	0	403	0	0	0	**403**
(65+)	805	0	0	0	403	0	0	0	**1208**
Total	**10671**	**201**	**201**	**1346**	**8859**	**201**	**403**	**1382**	**23264**

Table 8.8 (cont.)

LUNGS / MEDIASTINUM (CT)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	0	0	0	0	0	0	0	0	**0**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	201	0	0	0	0	0	0	0	**201**
(10-14)	201	0	0	337	0	0	0	0	**538**
(15-19)	0	0	0	337	403	0	0	0	**739**
(20-24)	0	0	0	0	0	0	0	0	**0**
(25-34)	201	201	0	0	403	604	0	0	**1409**
(35-44)	403	201	0	1010	0	403	0	345	**2362**
(45-54)	403	201	0	0	201	201	0	0	**1007**
(55-59)	403	0	0	337	403	0	0	0	**1142**
(60-64)	403	201	0	0	201	0	0	345	**1151**
(65+)	403	201	0	0	201	201	0	0	**1007**
Total	**2617**	**1007**	**0**	**2020**	**1812**	**1409**	**0**	**691**	**9556**

ABDOMEN - LIVER, SPLEEN, KIDNEYS, VESSELS, LYMPH NODES (CT)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	201	0	0	0	201	0	0	0	**403**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	0	0	0	0	201	0	0	0	**201**
(10-14)	0	0	0	0	0	201	0	0	**201**
(15-19)	201	0	0	0	0	0	0	0	**201**
(20-24)	0	0	0	337	201	201	0	345	**1085**
(25-34)	201	403	0	337	201	403	0	345	**1890**
(35-44)	805	604	0	337	604	403	0	691	**3443**
(45-54)	1409	1409	0	337	1611	403	0	345	**5514**
(55-59)	604	403	0	0	604	0	0	345	**1956**
(60-64)	1208	403	0	0	604	201	0	0	**2416**
(65+)	1611	0	0	0	1611	403	0	691	**4315**
Total	**6241**	**3221**	**0**	**1346**	**5839**	**2215**	**0**	**2763**	**21626**

PELVIS (CT)

Age groups	MW	MC	MA	MB	FW	FC	FA	FB	Total
(-1)	201	0	0	0	0	0	0	0	**201**
(1 - 4)	0	0	0	0	0	0	0	0	**0**
(5 - 9)	403	0	0	0	0	0	0	0	**403**
(10-14)	0	0	0	0	0	0	0	0	**0**
(15-19)	0	0	0	0	0	201	0	0	**201**
(20-24)	201	0	0	0	201	0	0	0	**403**
(25-34)	0	201	0	0	403	0	0	0	**604**
(35-44)	0	0	0	0	403	0	0	0	**403**
(45-54)	201	0	0	0	0	0	0	0	**201**
(55-59)	201	0	0	0	0	0	0	0	**201**
(60-64)	0	0	0	0	201	0	0	345	**547**
(65+)	201	0	0	0	403	0	0	691	**1295**
Total	**1409**	**201**	**0**	**0**	**1611**	**201**	**0**	**1036**	**4459**

8.7 Child expectancy

The child expectancy for people in the different age groups was not available for South Africa. Total fertility numbers are available, however, for the different races. It is defined as the average number of children born to a woman during her fertile years (15 - 49), assuming that the prevailing fertility rates are unchanged (Chief Directorate: Population Development, 1988). Child expectancy (fertility numbers) regarding the period 1988 - 1990, were supplied by the Population Development Program (Department of Health, 1994) as

1.7 for Whites

2.5 for Coloureds

2.3 for Asians

4.5 for Blacks
(Chief Directorate: Planning Support, Division: Contextual Information, 1994 and Chief Directorate: Population Development, Directorate Demographic Monitoring and Evaluation, 1994).

These fertility numbers were adapted in order to obtain child expectancy values for the various age groups that are appropriate to South African conditions by making use of the data of Darby *et al.*, (1980), which is shown in Table 8.9.

Table 8.9 *Child expectancy by age and sex in the UK.*

Age group	Male	Female
0 - 1	1.82	1.86
2 - 4	1.86	1.89
5 - 9	1.86	1.89
10 - 14	1.87	1.90
15 - 19	1.84	1.80
20 - 24	1.62	1.39
25 - 29	1.10	0.76
30 - 39	0.39	0.19
40 - 49	0.05	0.01
50 - 59	0.01	-
60 +	-	-

In order to calculate child expectancy in various age groups in South Africa for using in the calculation of GSD, the age groups in Table 8.9 was associated with the age groups specified in the population census as follows:

Age group (0-1) in Table 8.9 with age group (-1) in the census population where the group (-1) denotes that group with age less than one year; age group (2-4) in Table 8.9 with age group (1-4) in the census population; age groups (5-9), (10-14), (15-19) and (20-24) in Table 8.9 correspond exactly with those in the census population; age group (25-29) in Table 8.9 with age group (25-34) in the census population; age group (30-39) in Table 8.9 with age group (35-44) in the census population; age group (40-49) in Table 8.9 with age group (45-54) in the census population; and age group (50-59) in Table 8.9 with age group (55-59) in the census population.

The child expectancies for the various race-gender-age groups were calculated by means of the normalisation of the numbers in all columns in Table 8.9 with respect to the highest number in each column respectively, and then multiplied by the relevant fertility number (Table 8.10). This implies, for example, in order to obtain the MW-values in Table 8.10, that all the "Male" values in Table 8.9 have to be divided by 1.87 and multiplied by 1.7. All numbers were rounded to two decimals except for values in two age groups.

Table 8.10 *Child expectancy by age, sex and race in SA (M - male; F - female; W - White; C - Coloured; A - Asian; B - Black).*

Age group	MW	MC	MA	MB	FW	FC	FA	FB
- 1	1.65	2.43	2.24	4.38	1.66	2.45	2.25	4.41
1 - 4	1.69	2.49	2.29	4.48	1.69	2.49	2.29	4.48
5 - 9	1.69	2.49	2.29	4.48	1.69	2.49	2.29	4.48
10 - 14	1.70	2.50	2.30	4.50	1.70	2.50	2.30	4.50
15 - 19	1.67	2.46	2.26	4.43	1.61	2.37	2.18	4.26
20 - 24	1.47	2.17	1.99	3.90	1.24	1.83	1.68	3.29
25 - 34	1.00	1.47	1.35	2.65	0.68	1.00	0.92	1.80
35 - 44	0.35	0.52	0.48	0.94	0.17	0.25	0.23	0.45
45 - 54	0.05	0.07	0.06	0.12	0.01	0.01	0.01	0.02
55 - 59	0.01	0.01	0.01	0.02	0	0	0	0
60 - 64	0	0	0	0	0	0	0	0
65 +	0	0	0	0	0	0	0	0

Chapter 9

THE DETERMINATION OF THE GENETICALLY-SIGNIFICANT DOSE

The final results were obtained with the aid of the formula stated in Chapter 2, paragraph 2.2 (equation 2.2). Procedures for the processing of the data in order to obtain a new set of data to be used in the formula, were described in Chapter 8. The GSD can be calculated for many different groups as well as the contribution of the different types of examinations.

It can be stressed, however, that this is actually a weighted population dose from a year of radiological practice. The accumulated gonad doses were multiplied by a weighting factor, namely the child expectancy.

9.1 General Determination

The General Determination refers to the population as a whole. All the age-gender-race groups, $N_{k\ell}$, were used in this calculation (Table 8.8). These values were multiplied by the respective gonad doses (Table 8.6) and child expectancies (Table 8.10). The GSD for the overall SA-population was thus calculated, namely **94.6 μGy**.

9.2 Determination within race groups

The GSD was also calculated for the various races, using the tables mentioned in 9.1. The terms in the formula in Chapter 2 were a representation of a specific race only, when the GSD was calculated for that race. The results are shown in Table 9.1.

Table 9.1 *GSD within race groups.*

Asian	Black	Coloured	White	Overall population
229.0 μGy	66.5 μGy	112.2 μGy	463.4 μGy	94.6 μGy

9.3 Determination within race-gender groups

In a next phase, the GSD was calculated for the various race-gender groups, i.e. the terms in the formula in Chapter 2 were a representation of a specific race-gender group only, when the GSD was calculated for that group. The results are shown in Table 9.2.

Table 9.2 *GSD within race-gender groups.*

	Asian	Black	Coloured	White	Overall population
Male	230.4 μGy	37.1 μGy	83.1 μGy	136.3 μGy	49.4 μGy
Female	227.4 μGy	99.5 μGy	144.4 μGy	850.7 μGy	145.3 μGy

9.4 Determination within race-gender-examination groups

The contributions to the GSD from the various examinations were calculated for the population groups and the results given in Figure 9.14. Detailed results are enumerated in Appendix C. The GSD's due to the race groups were calculated according the following formula:

$$GSD(\text{race - examination}) = \frac{\sum_k \sum_\ell N_{k\ell} P_{k\ell} \overline{D}_{k\ell} (\text{race - examination group})}{\sum_k N_k P_k (\text{race group})} \qquad \text{(equ. 9.1)}$$

(cf. equ. 2.2) and the percentage by

$$GSD(\text{percentage}) = \frac{GSD(\text{race - examination group})}{GSD(\text{race group})} \text{x} 100\%. \qquad \text{(equ. 9.2)}$$

The GSD's due to the race-gender groups were calculated according the following formula:

$$\mathrm{GSD(race-gender-examination)} = \frac{\sum_k \sum_\ell N_{k\ell} P_{k\ell} \overline{D}_{k\ell}\,(\text{race-gender-examination group})}{\sum_k N_k P_k\,(\text{race-gender group})} \qquad \text{(equ. 9.3)}$$

(cf. equ. 2.2) and the percentage by

$$\mathrm{GSD(percentage)} = \frac{\mathrm{GSD(race-gender-examination\ group)}}{\mathrm{GSD(race-gender\ group)}} \times 100\%. \qquad \text{(equ. 9.4)}$$

Factors like the change in child expectancy, change in socio-economic conditions and development in technology play a major role regarding the uncertainties of the GSD. These aspects are discussed in more detail on pages 179 and 180. It can finally be noted that although the population may be homogeneous, there would still be variation and variance in the individual determinations.

(a) The contributions of the various examination types to the GSD of the overall population are presented in Figure 9.1.

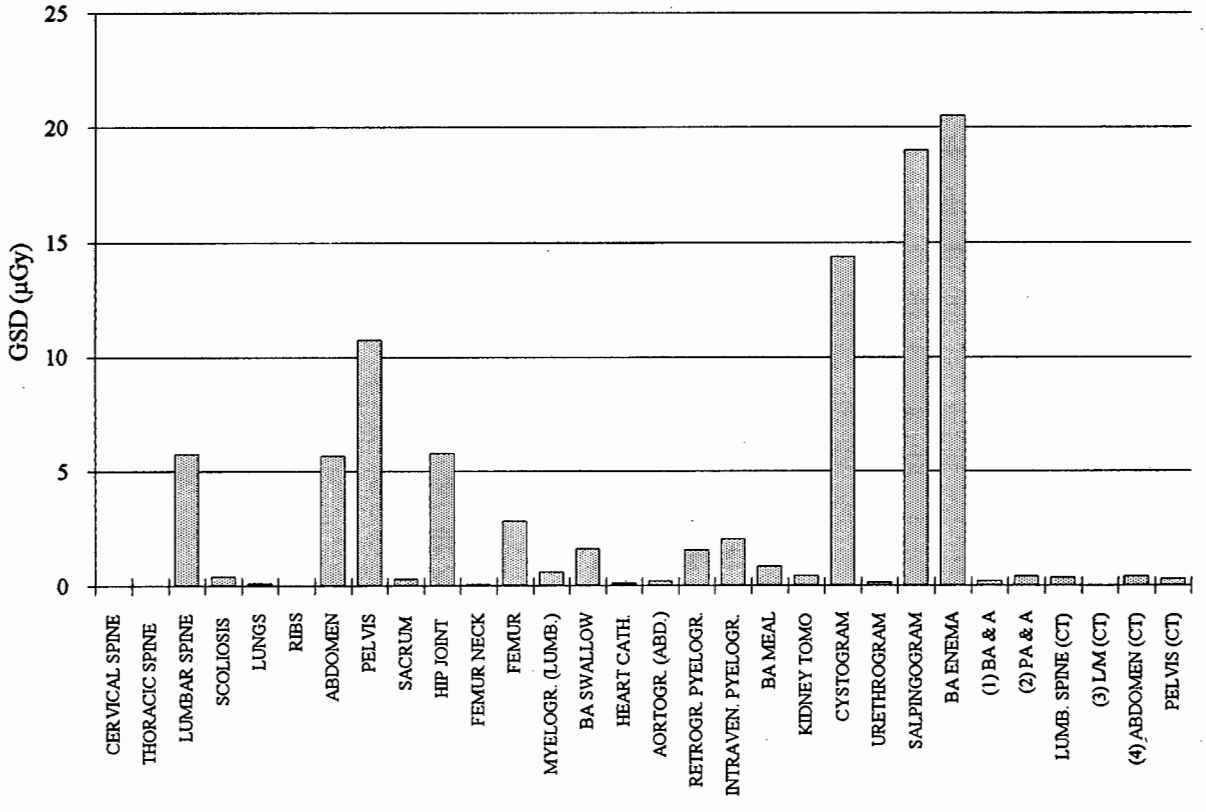


Figure 9.1 *Contribution of the various examinations to the GSD of the overall population.*

(1) Bifurcation arteriograms and angioplasty
(2) Peripheral arteriogram and angioplasty (upper leg)
(3) Lungs / mediastinum
(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

(b) The same presentation is being done for the various race groups (both genders included) in figures 9.2 to 9.5.

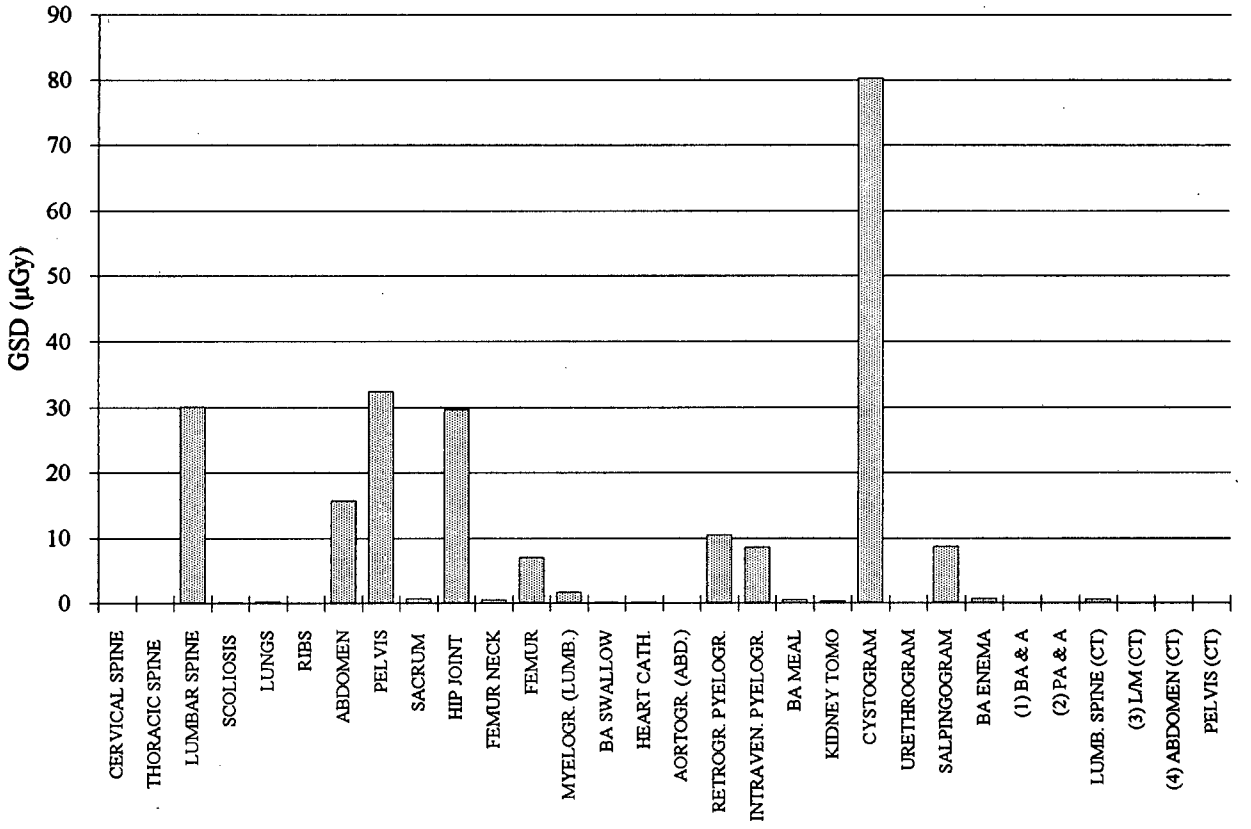


Figure 9.2 *Contribution of the various examinations to the GSD of Asians.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

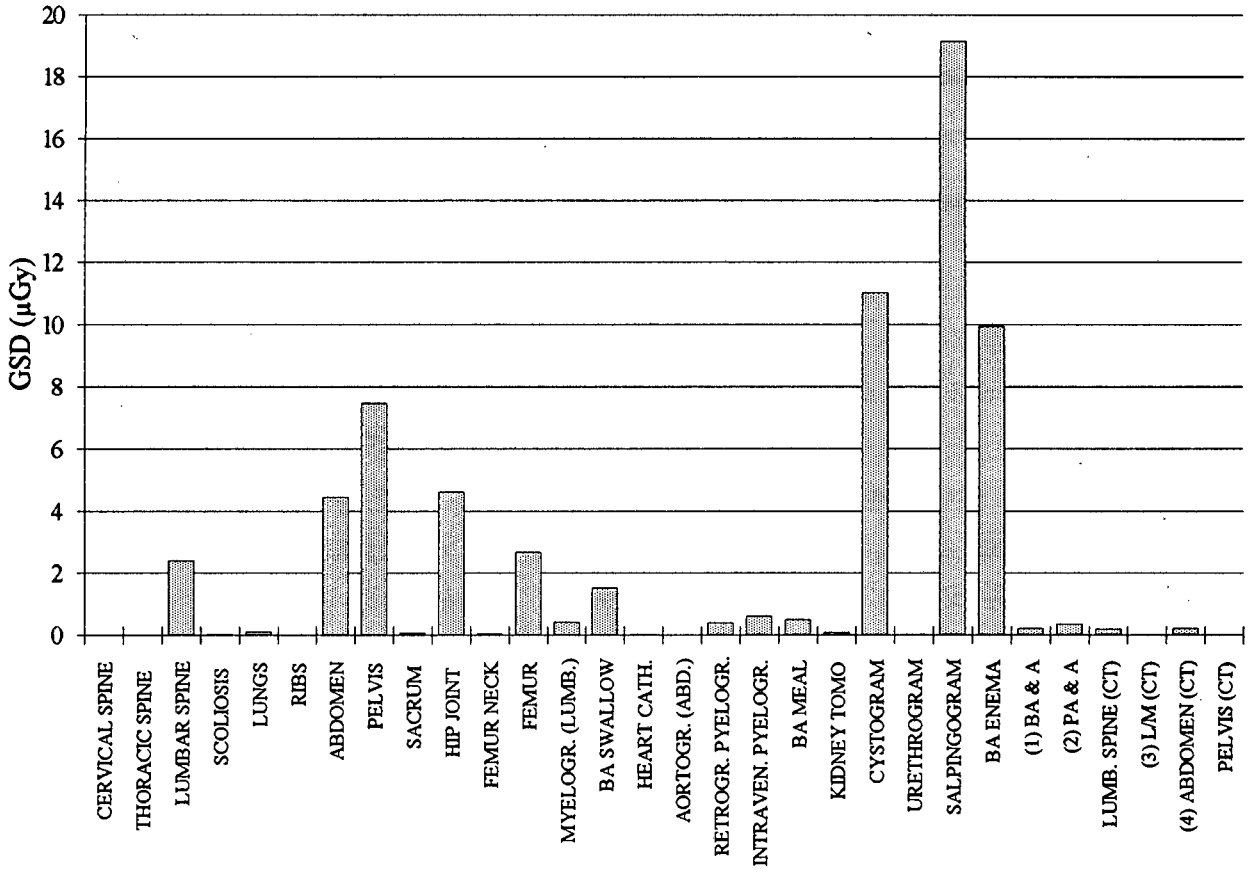


Figure 9.3 *Contribution of the various examinations to the GSD of Blacks.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

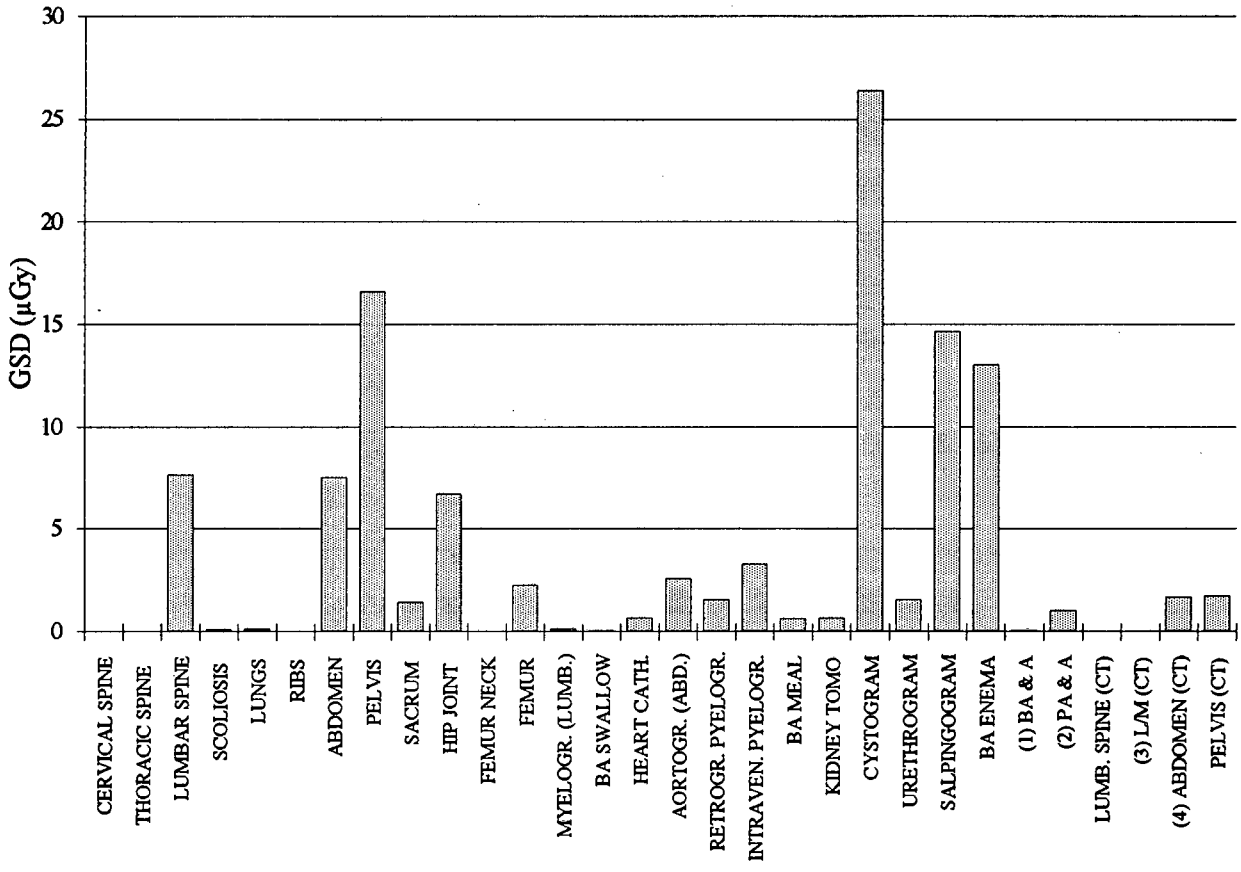


Figure 9.4 *Contribution of the various examinations to the GSD of Coloureds.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

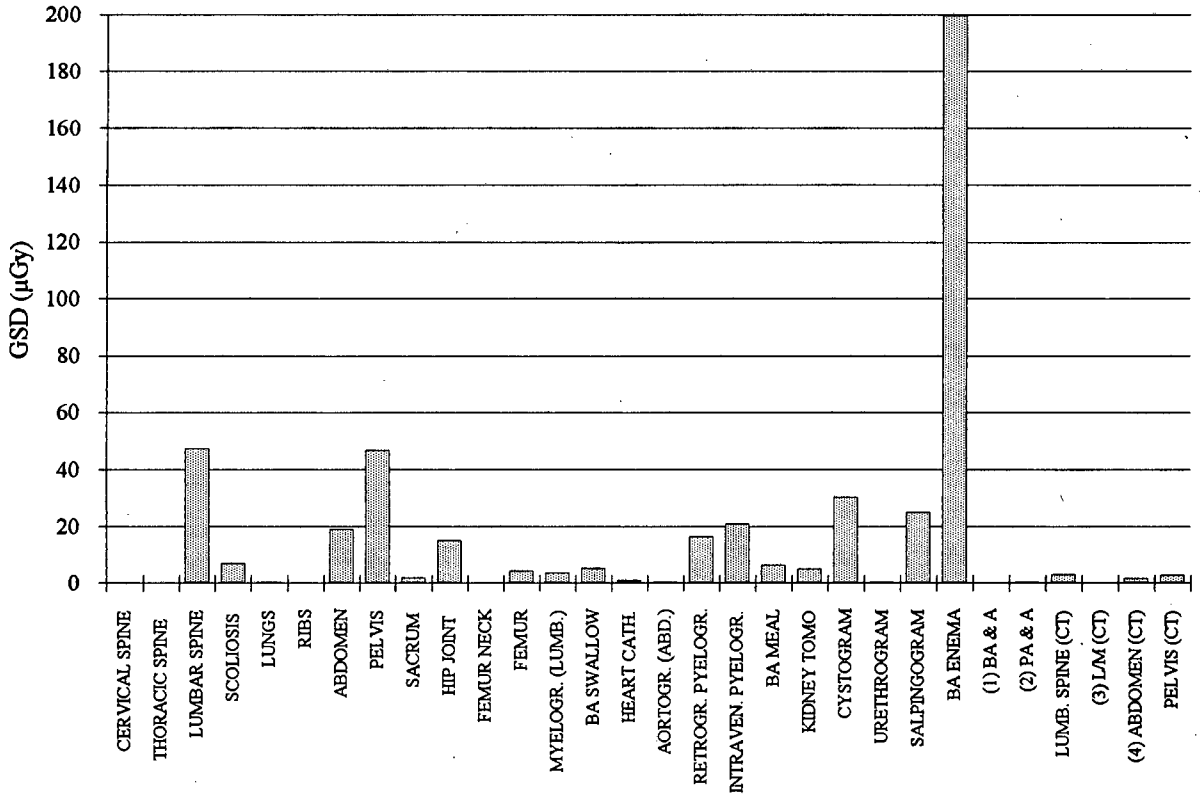


Figure 9.5 *Contribution of the various examinations to the GSD of Whites.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

(c) The contributions of the various examination types to the GSD of each of the race-gender groups, are represented in figures 9.6 to 9.13.

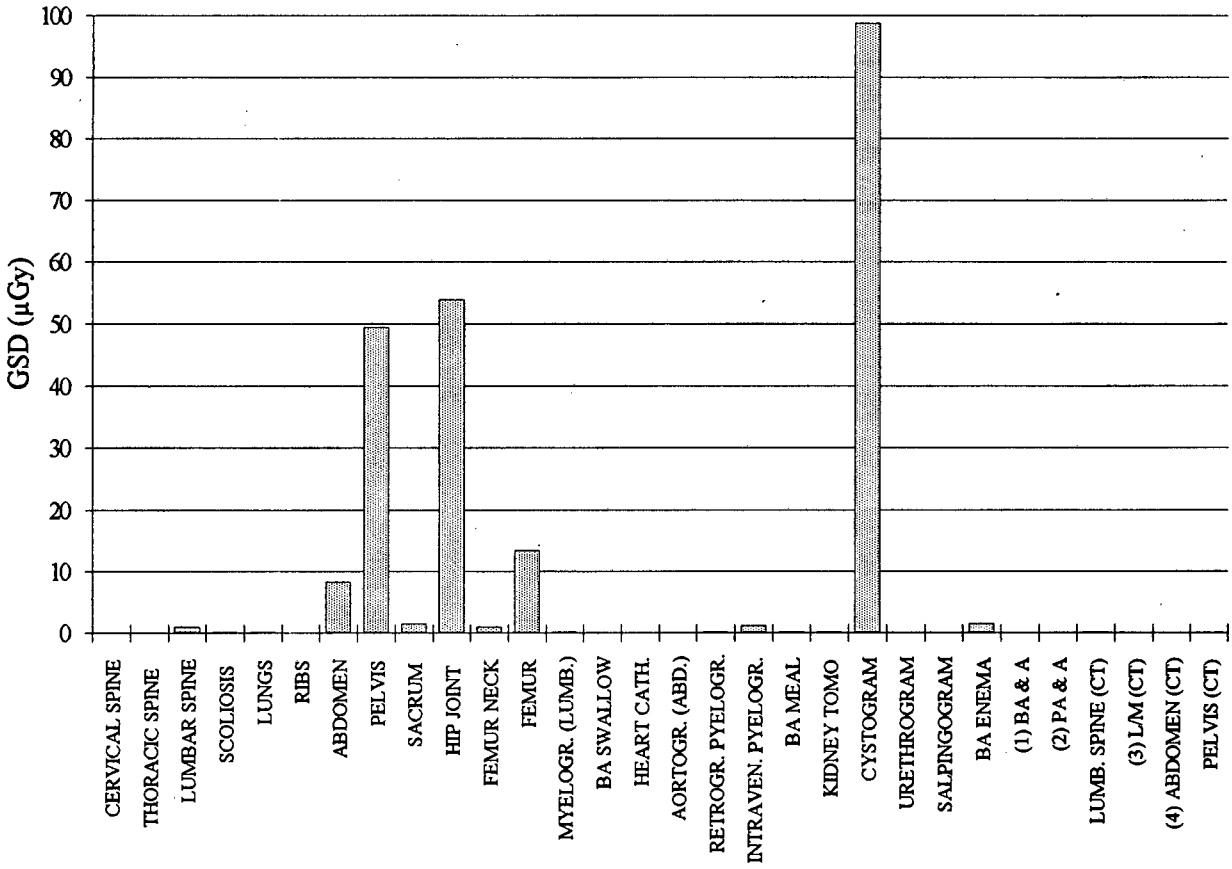


Figure 9.6 *Contribution of the various examinations to the GSD of Asian males.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

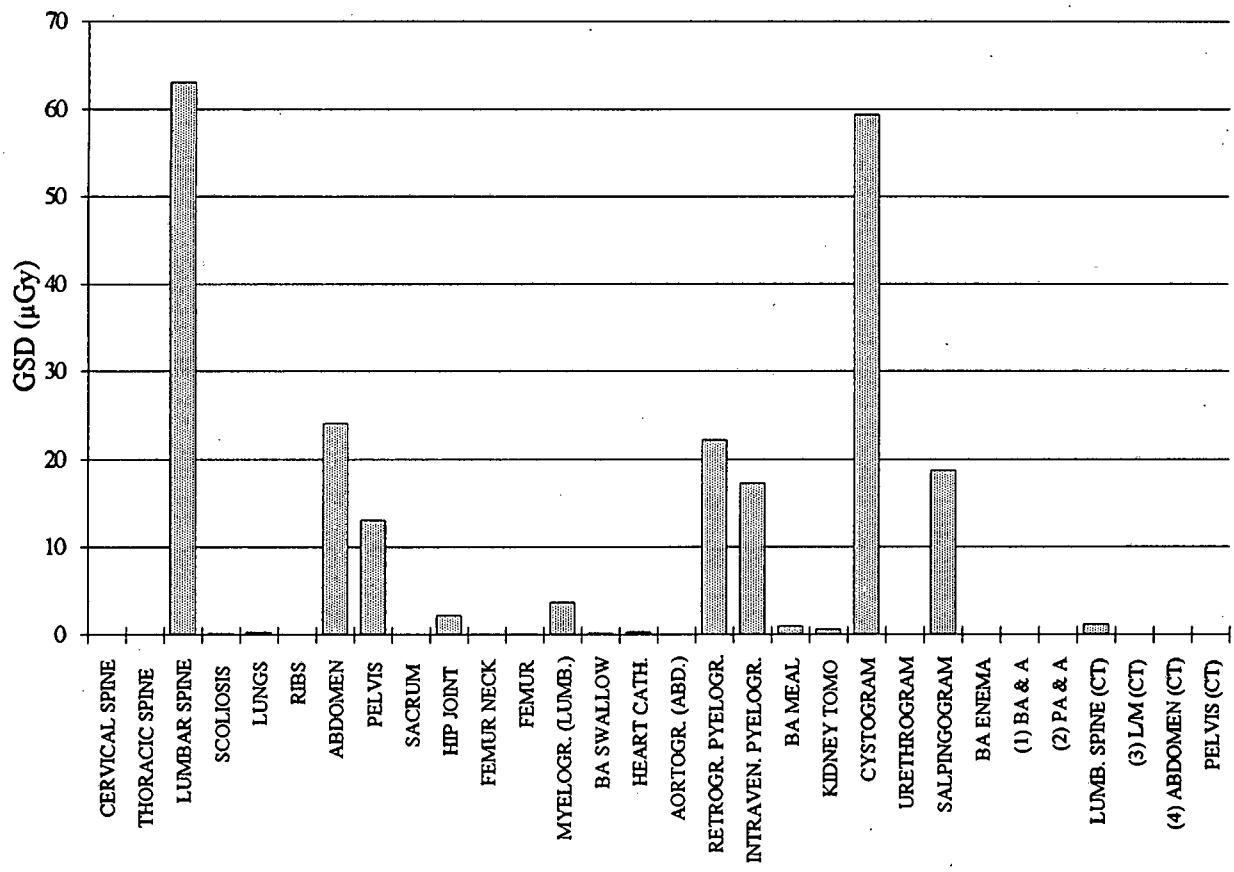


Figure 9.7 *Contribution of the various examinations to the GSD of Asian females.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

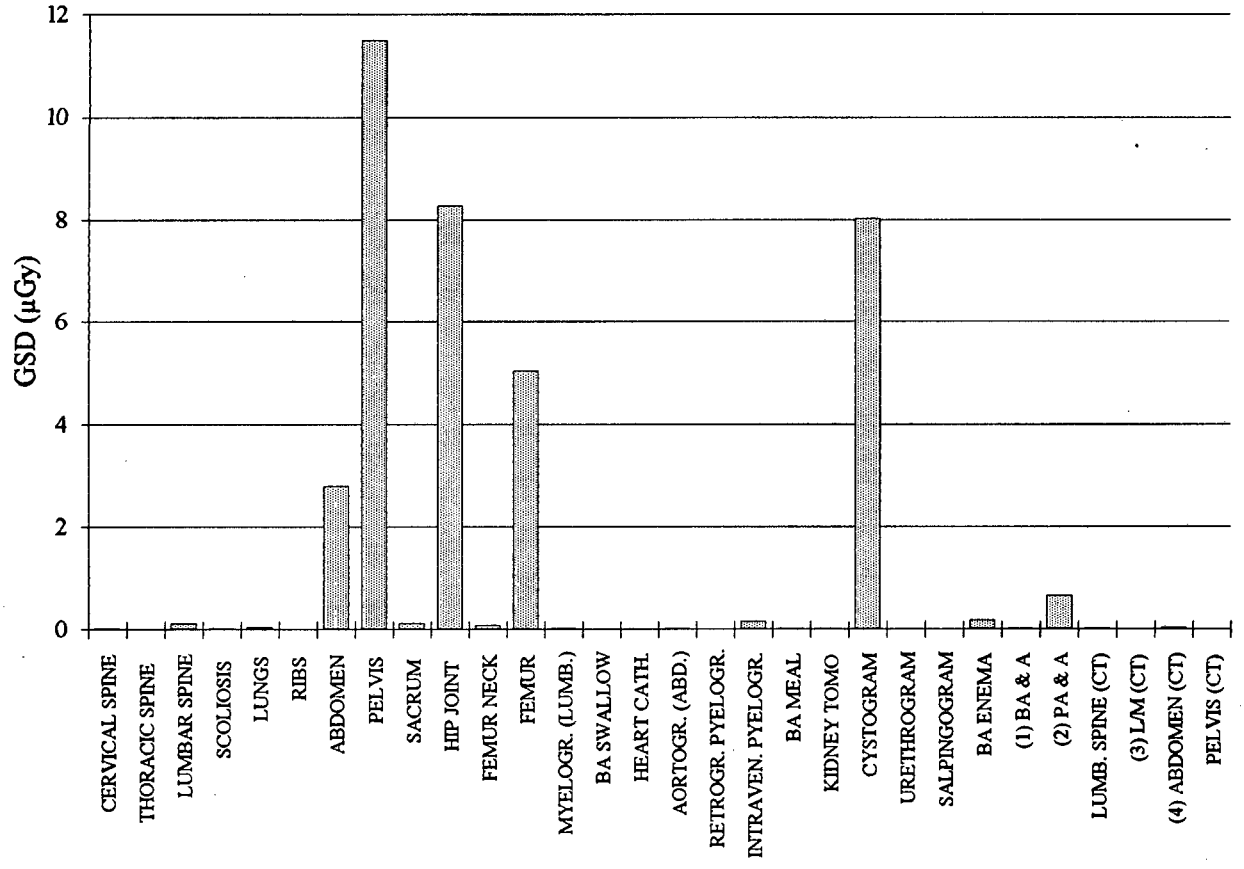


Figure 9.8 *Contribution of the various examinations to the GSD of Black males.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

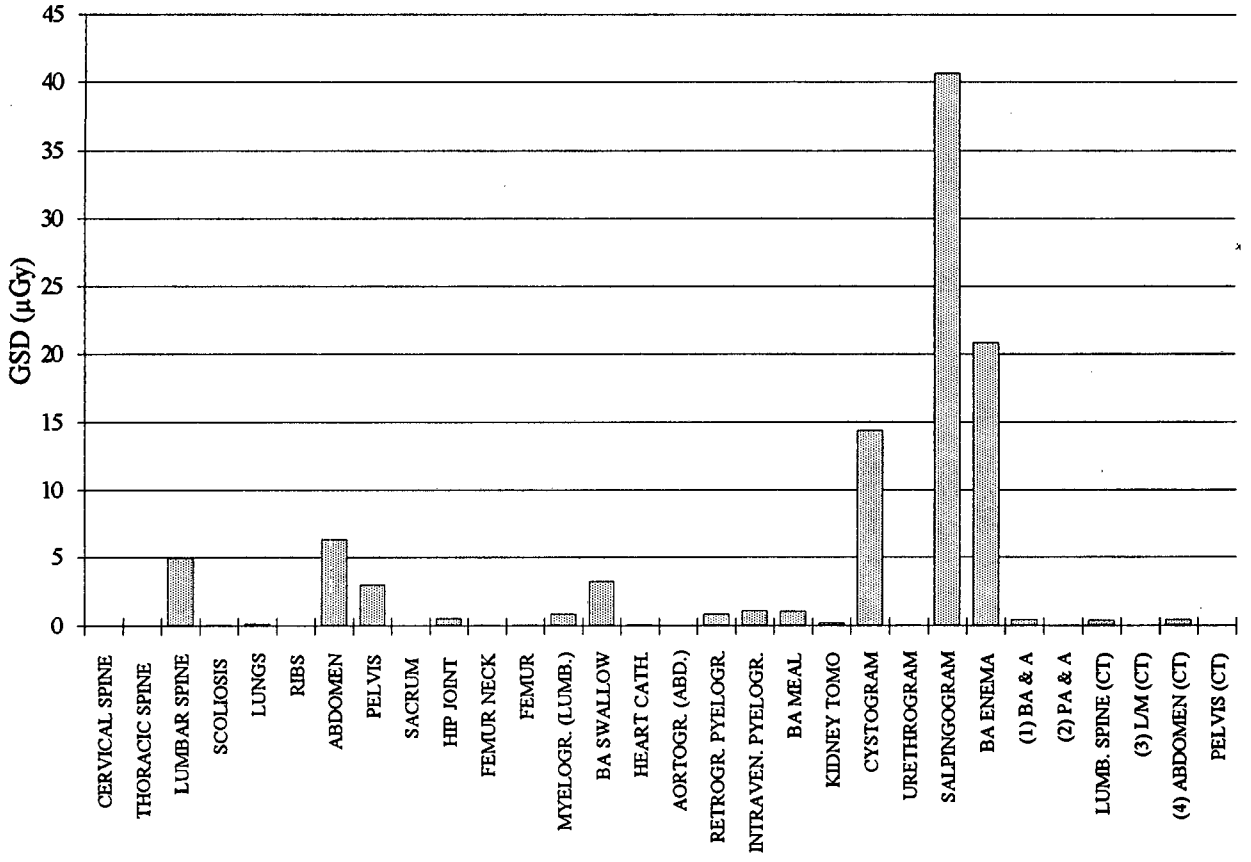


Figure 9.9 *Contribution of the various examinations to the GSD of Black females.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

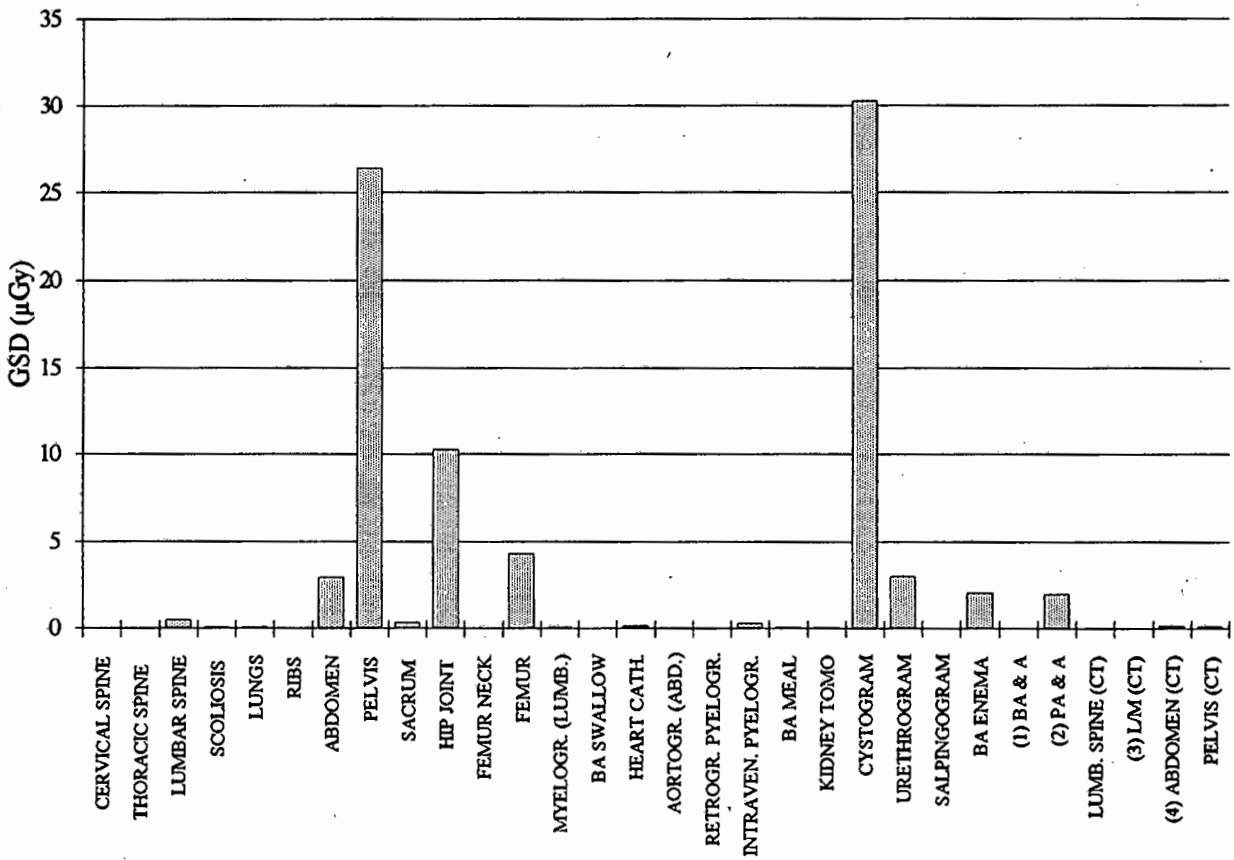


Figure 9.10 *Contribution of the various examinations to the GSD of Coloured males.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

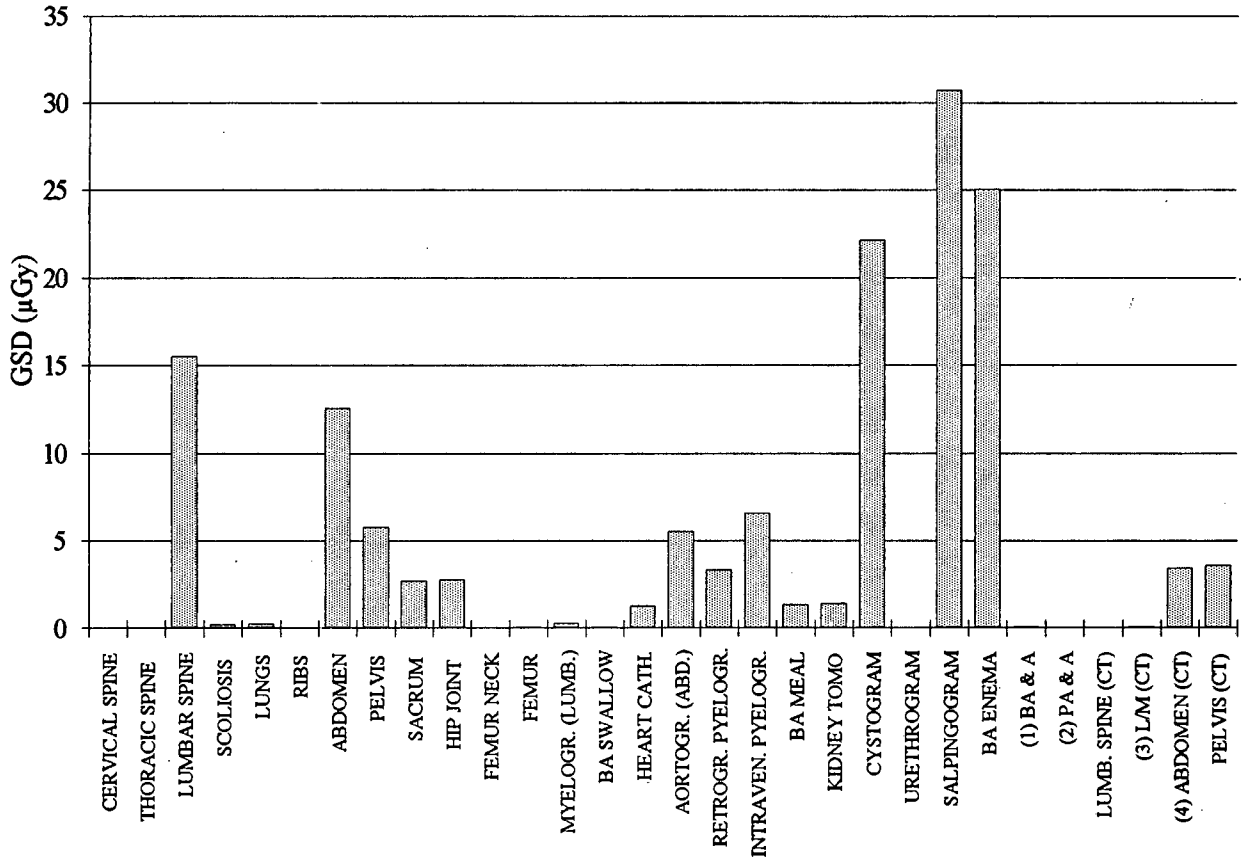


Figure 9.11 *Contribution of the various examinations to the GSD of Coloured females.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

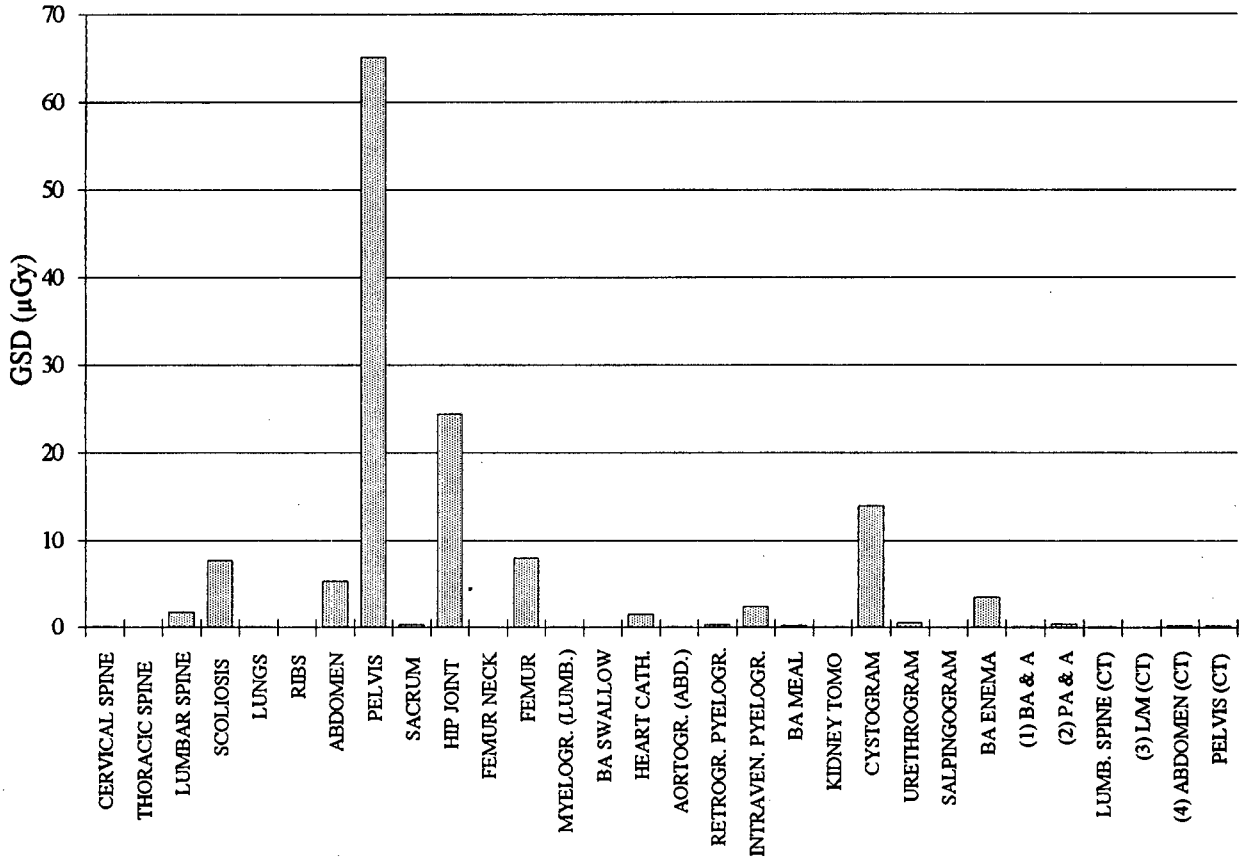


Figure 9.12 *Contribution of the various examinations to the GSD of White males.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

Note: Intraven. pyelogr. *also known as* excretory urogram

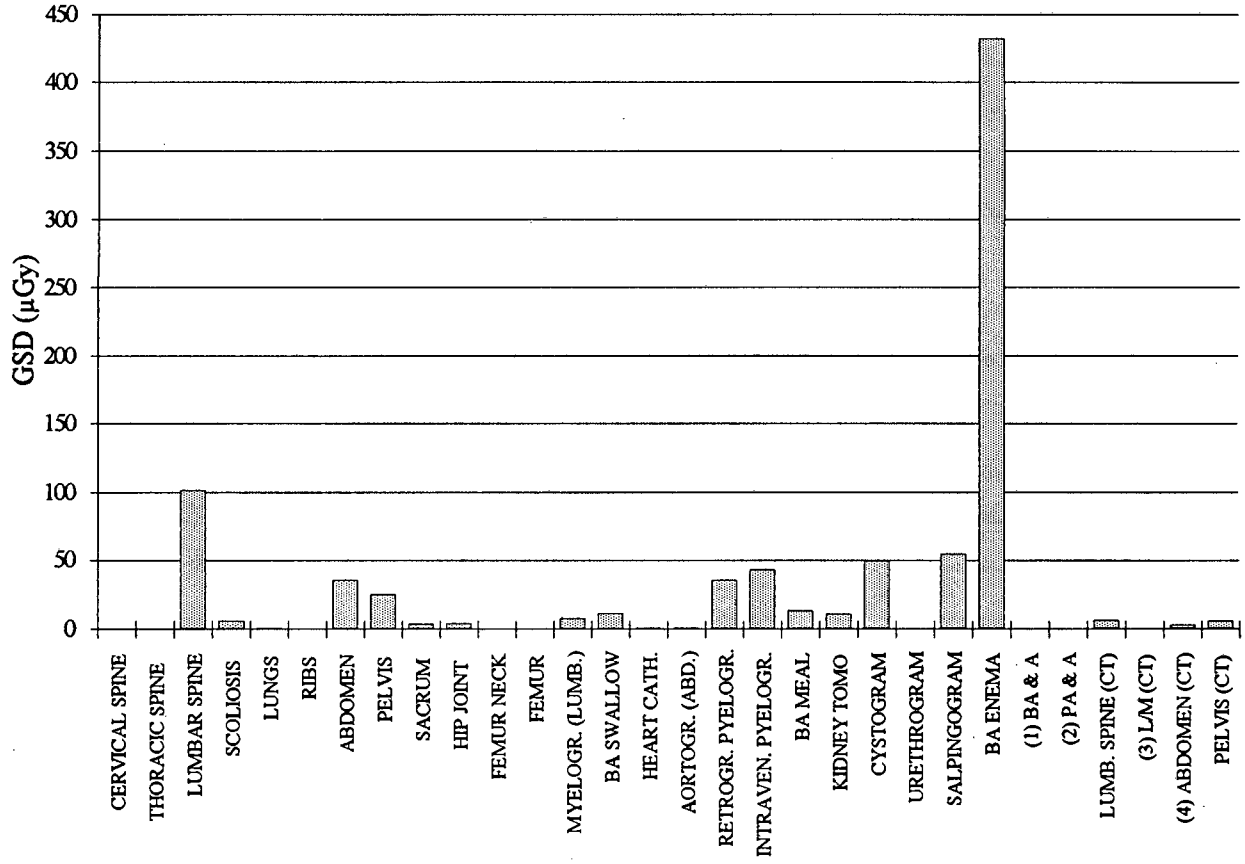


Figure 9.13 *Contribution of the various examinations to the GSD of White females.*

(1) Bifurcation arteriograms and angioplasty

(2) Peripheral arteriogram and angioplasty (upper leg)

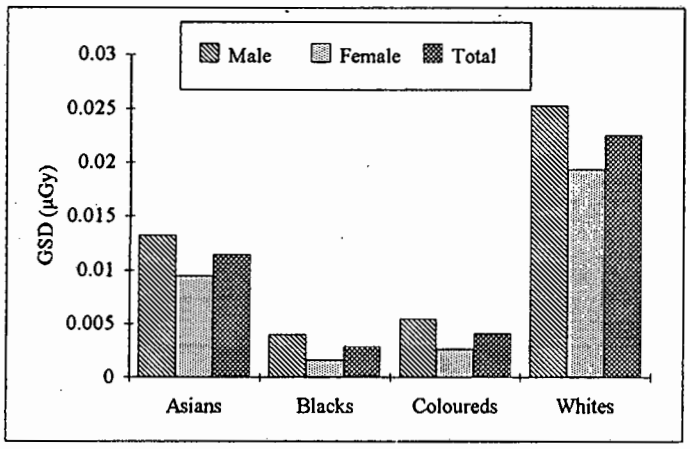
(3) Lungs / mediastinum

(4) Abdomen - liver, spleen, kidneys, vessels, lymph nodes

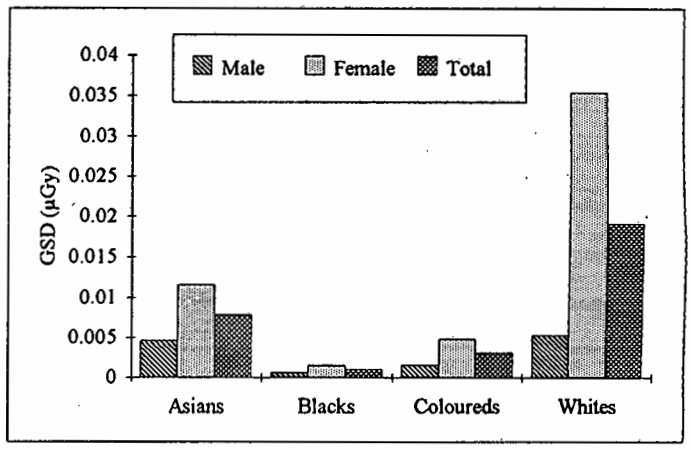
Note: Intraven. pyelogr. *also known as* excretory urogram

(d) A comparison of the contribution to the GSD from the various race-gender groups for each radiological examination is presented in Figure 9.14.

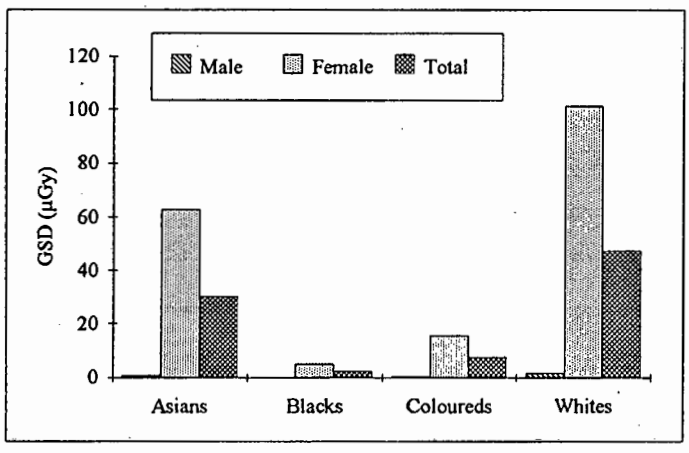
Figure 9.14 Bar graphs showing GSD contribution by various radiological examinations.



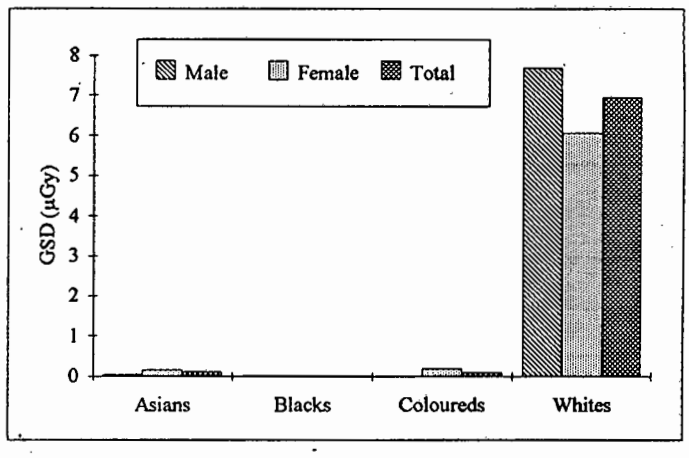
(1) CERVICAL SPINE



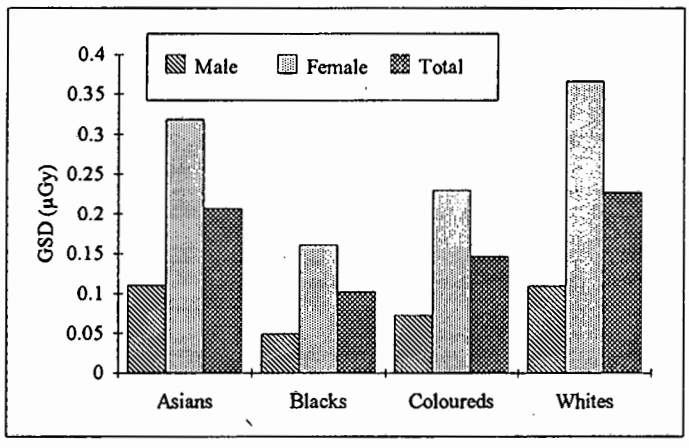
(2) THORACIC SPINE



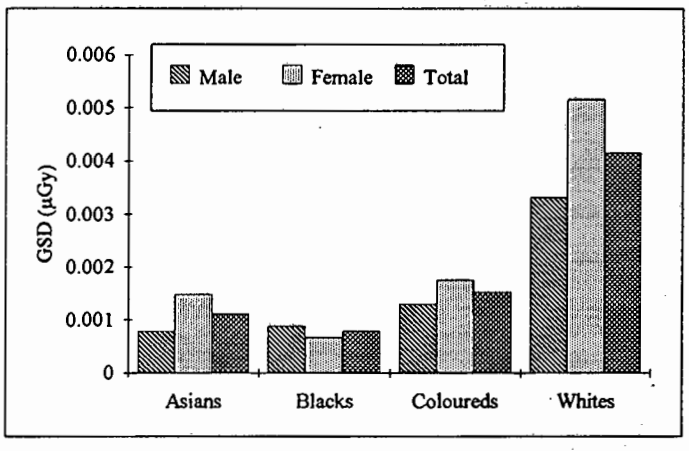
(3) LUMBAR SPINE



(4) SCOLIOSIS X-RAYS (FULL SPINE)



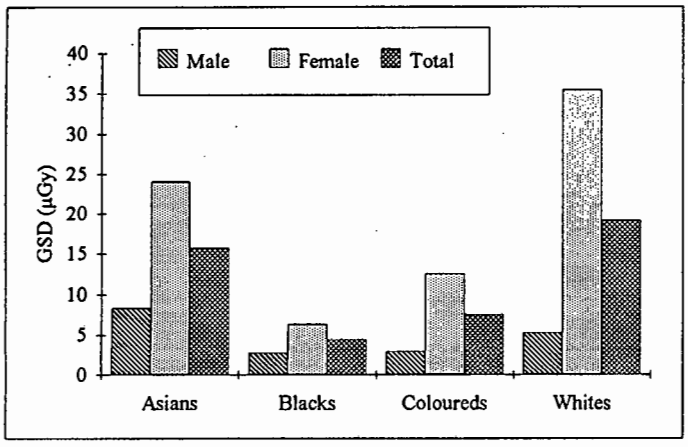
(5) LUNGS



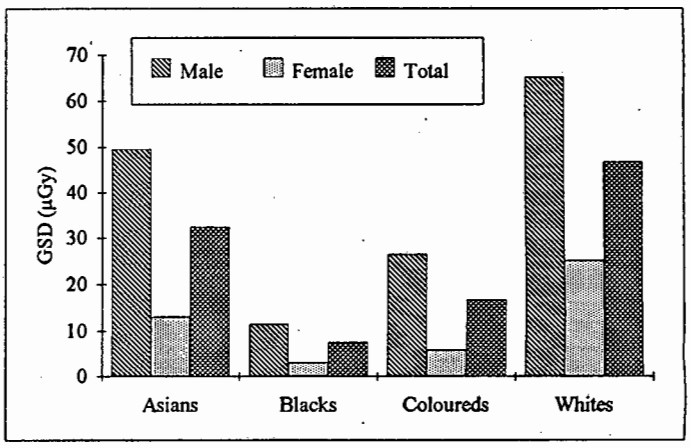
(6) RIBS

Note: Observe that all vertical scales are different.

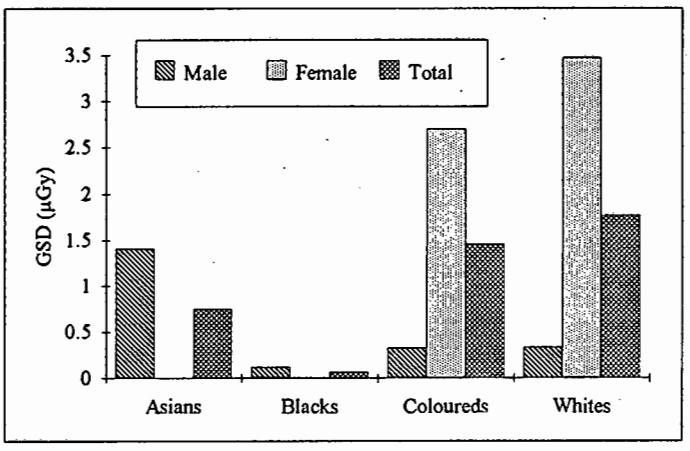
Figure 9.14 (cont.)



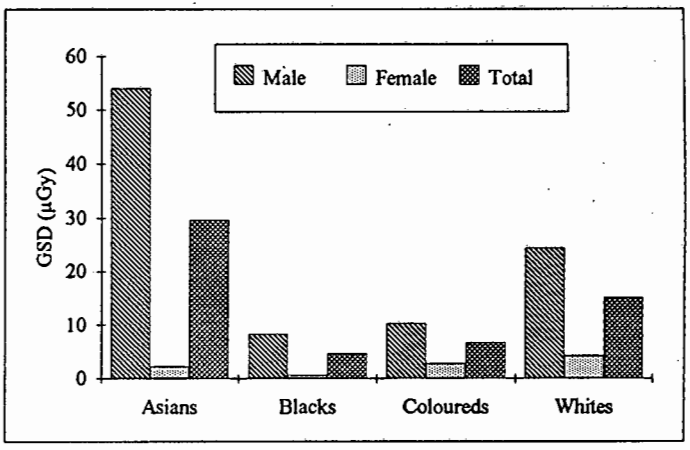
(7) ABDOMEN SURVEY



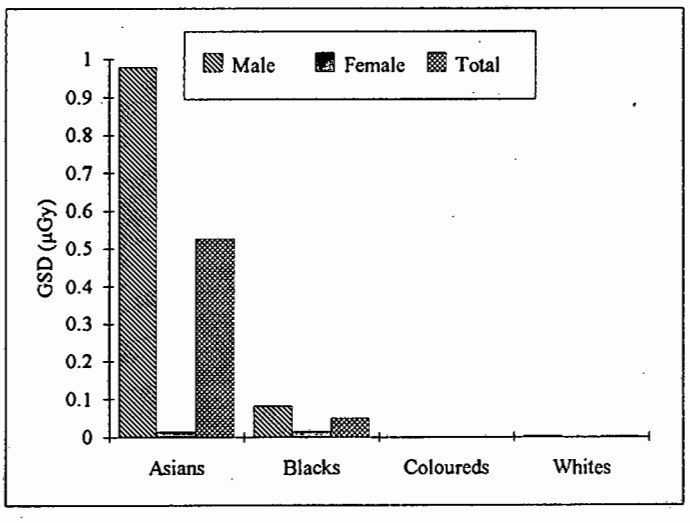
(8) PELVIS



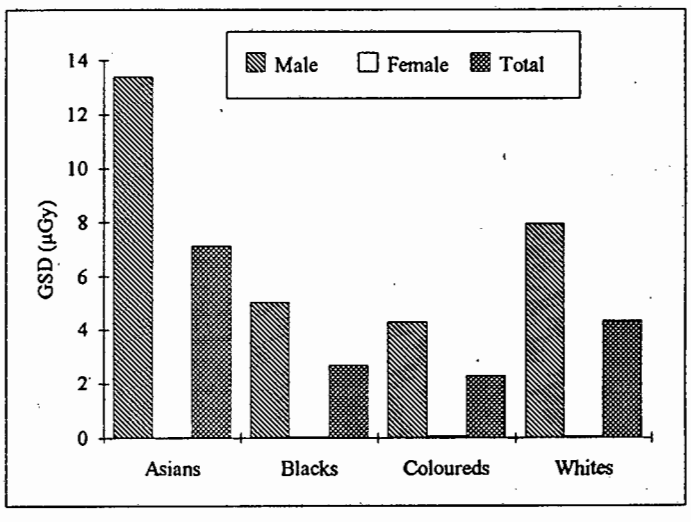
(9) SACRUM



(10) HIP JOINT



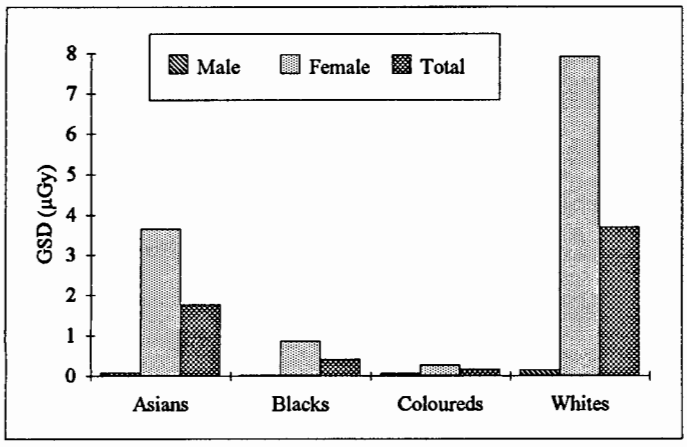
(11) FEMUR NECK



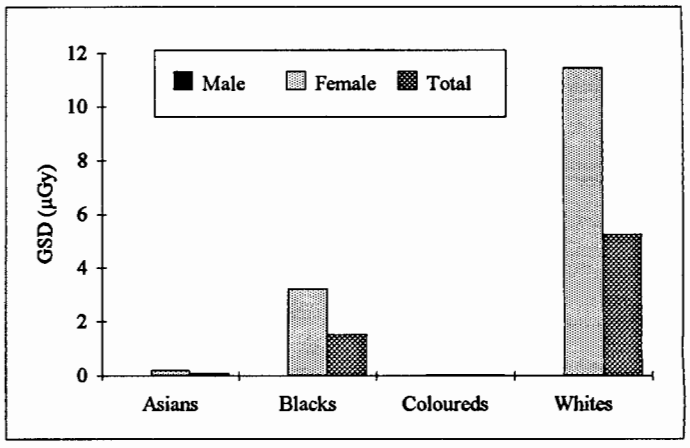
(12) FEMUR

Note: Observe that all vertical scales are different.

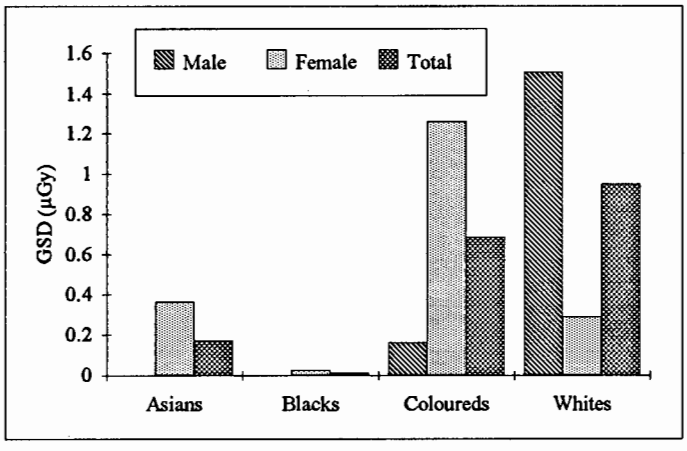
Figure 9.14 (cont.)



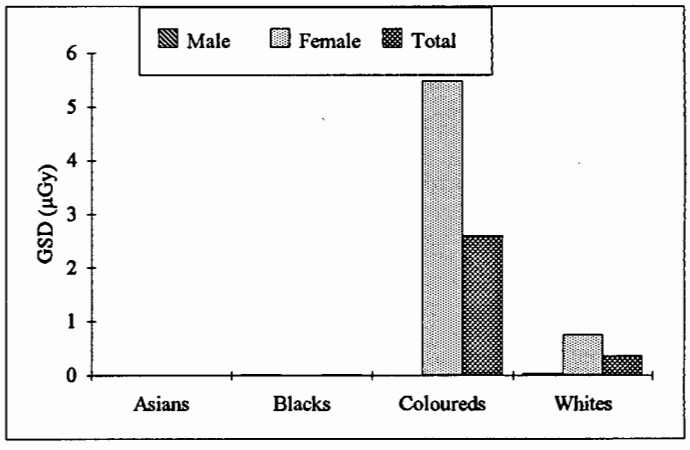
(13) MYELOGRAM (LUMBAR)



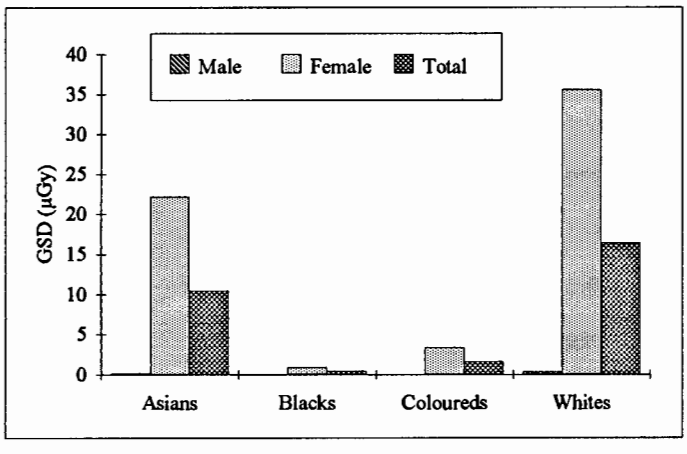
(14) BARIUM SWALLOW



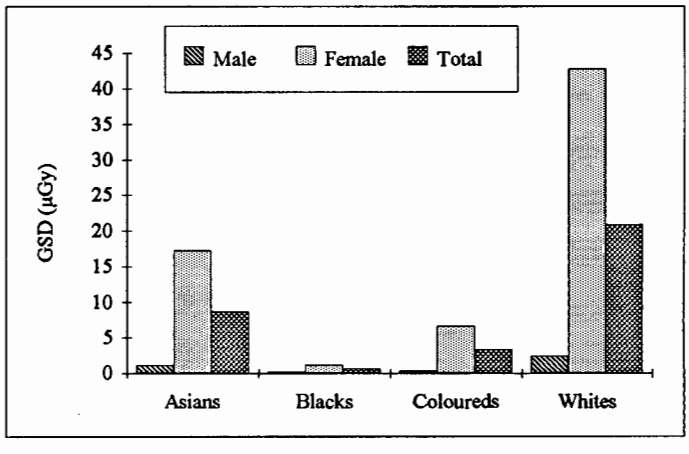
(15) HEART CATHETERISATION



(16) AORTOGRAM (ABDOMEN)



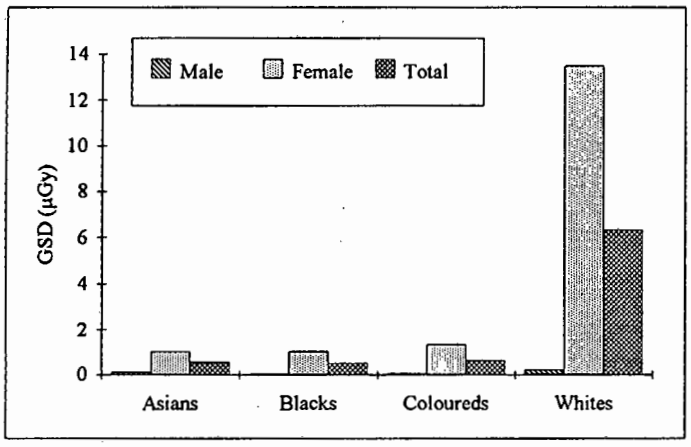
(17) RETROGRADE PYELOGRAM



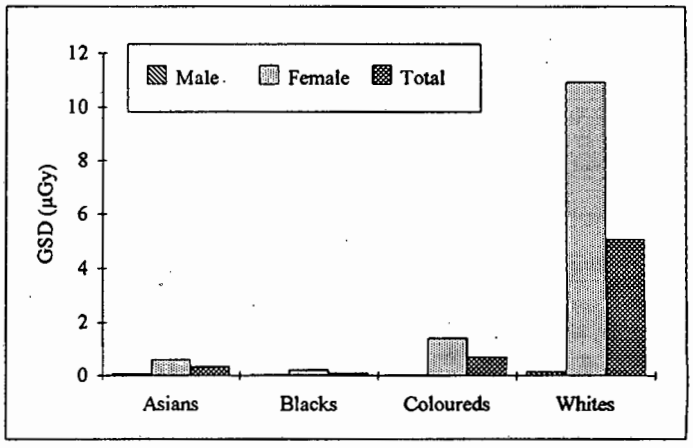
(18) INTRAVENOUS PYELOGRAM

Note: Observe that all vertical scales are different.

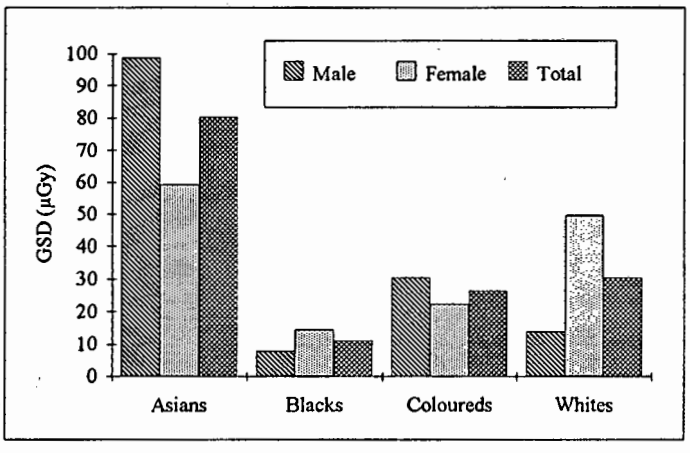
Figure 9.14 (cont.)



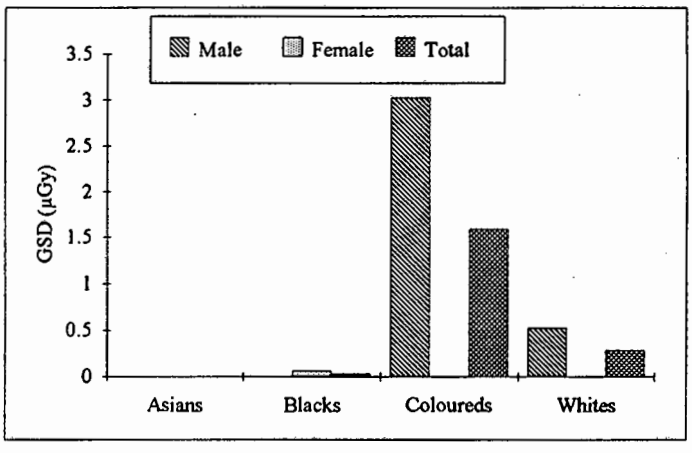
(19) BARIUM MEAL



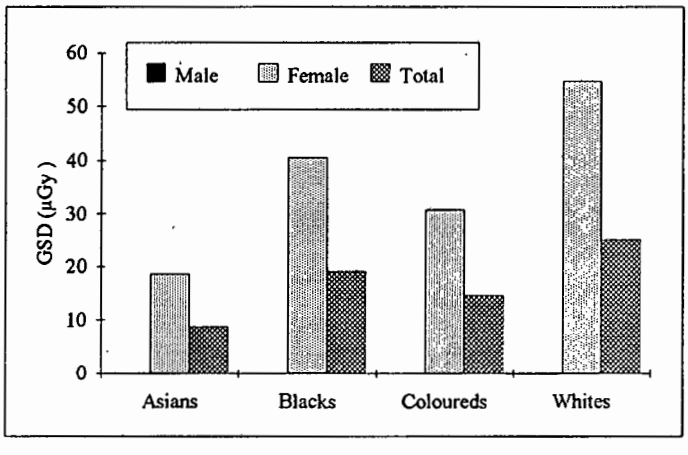
(20) KIDNEY TOMOGRAPHY



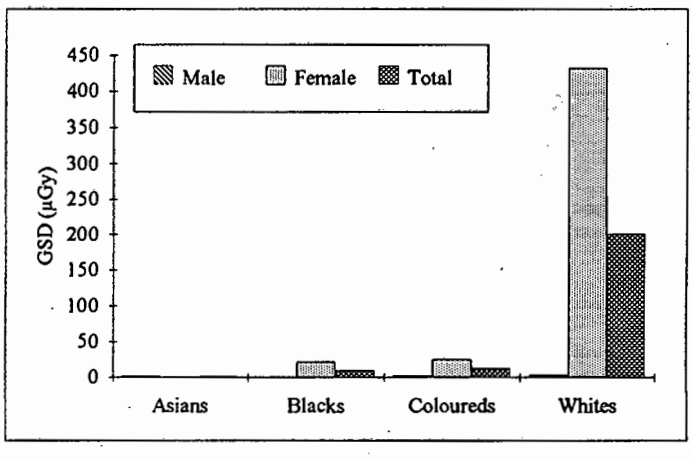
(21) CYSTOGRAM



(22) URETHROGRAM



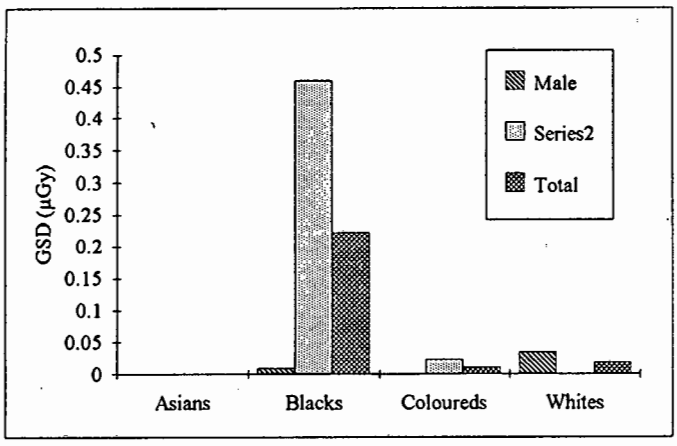
(23) SALPINGOGRAM



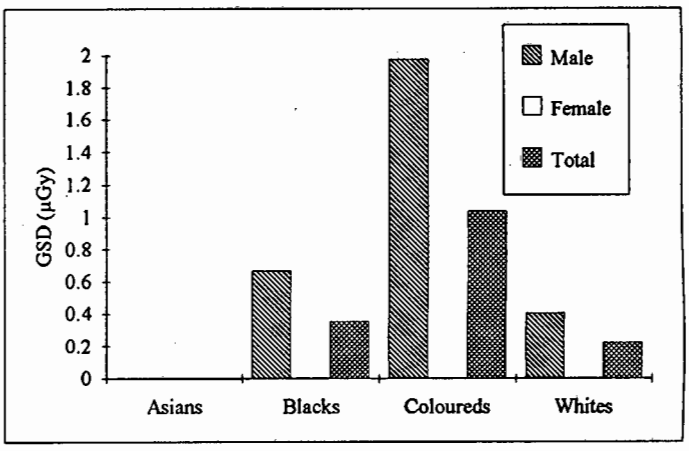
(24) BARIUM ENEMA

Note: Observe that all vertical scales are different.

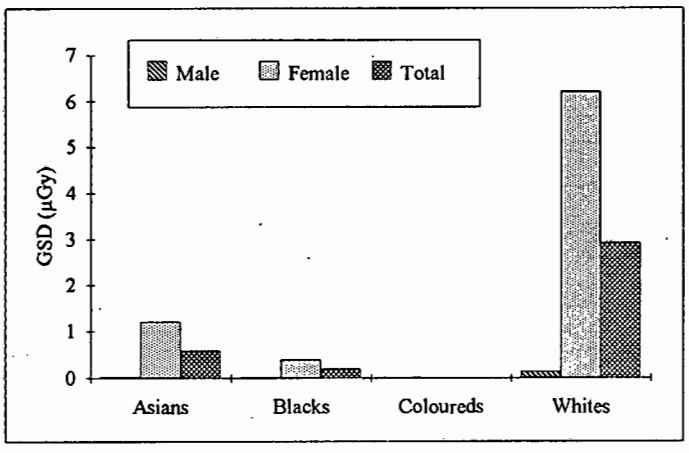
Figure 9.14 (cont.)



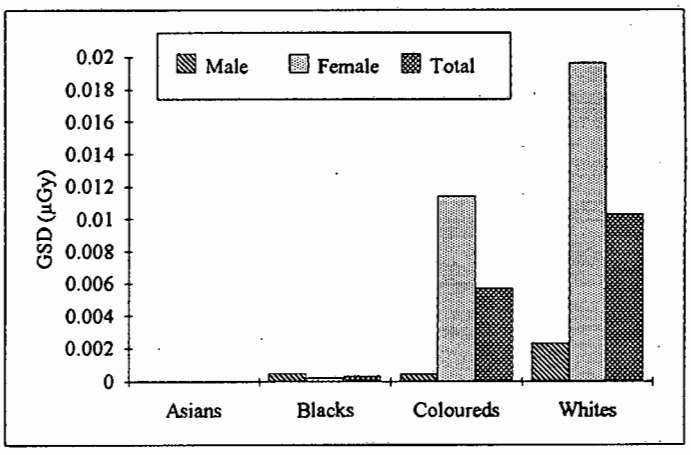
(25) BIFURCATION ARTERIOGRAMS / ANGIOPLASTY



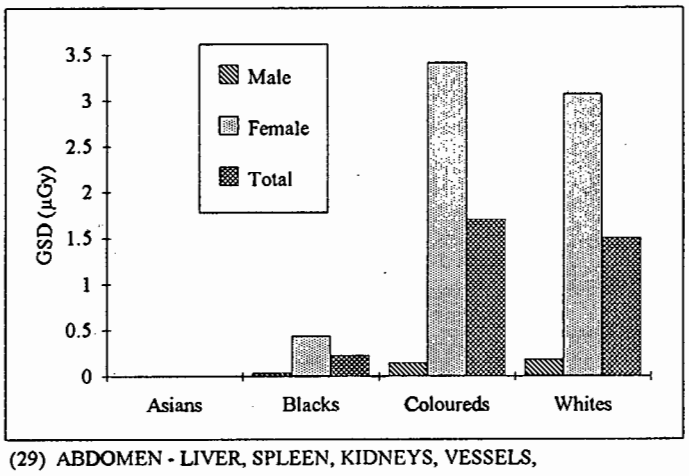
(26) PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (UPPER LEG)



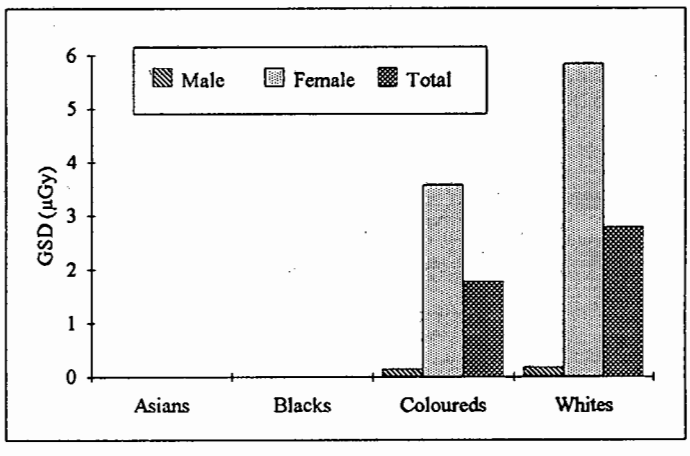
(27) LUMBAR SPINE (CT)



(28) LUNGS / MEDIASTINUM (CT)



(29) ABDOMEN - LIVER, SPLEEN, KIDNEYS, VESSELS, LYMPH NODES (CT)



(30) PELVIS (CT)

Note: Observe that all vertical scales are different.

9.5 Determination of a special sub-group

It was motivated in Section 8.1 why 30 out of 96 examinations were chosen for the calculation of the genetically-significant dose. In order to confirm that the remaining examinations could be ignored, an additional 8 examinations were chosen and their respective gonad doses calculated or estimated.

In order to estimate the contribution of six of these examinations to the overall GSD, the gonad doses in Table 8.7 were used, i.e. doses due to examinations of the skull, S-I joints, knee, angiogram (head), spine tomography and cholangiogram/ cholecystogram. The GSD was obtained by comparing the respective average gonad doses in the various age groups with those of similar examinations regarding the contribution to the gonads and the sizes of the files, where the GSD's had already been calculated. A value less than 0.3 % of the overall GSD was thus obtained.

The CT examination of the brain was chosen on account of the high frequency with which this procedure was requested. The average gonad doses for the various age groups were obtained in the same way as was explained in Chapter 8 (section 8.5). All values obtained were zero, however, and the contribution of this examination could therefore be ignored.

Mammography was also chosen on account of the relative high frequency of the examinations. The low energy X-ray beam (25 - 60 kVp) is greatly attenuated by the tissue structures and the image receptor support. If a unit complies with the safety requirement that a mammographic image receptor support must limit transmission of the primary X-ray beam so that the exposure 5 cm beyond the plate of the receptor does not exceed 0.1 mR for each activation of the tube, the gonad dose is negligible (NCRP, 1980).

It can therefore be concluded that the total additional contribution of the chosen sub-group is less than 0.3 % of the calculated overall GSD and that the contribution from the remainder of the examinations would be less than this.

9.6 Evaluation of the South African results

The examinations that make the largest contributions to gonad doses are summarised

in Table 9.3. It is illustrated clearly in this table that women are much more exposed to high risk examinations than men - not only regarding the high gonad doses involved, but examinations also occur more frequently. In these examinations, therefore, the ovaries often receive higher doses than the testes from abdominal X-ray examinations which, moreover, are more frequently conducted on women than on men. The following examinations deserve serious attention: lumbar spine; intravenous pyelogram; salpingogram; and the barium enema. It is further indicated that by far the largest number of intravenous pyelograms and barium enemas, and salpingograms to a lesser degree, were performed on White women. The seriousness of these results are reflected in the final results. The real problem might be, however, the gross underprovision of radiology services to some of the other races. The individual contributions of the various examinations to the GSD of the race-gender groups are presented in Appendix C.

Table 9.3 *Examinations with large gonad doses.**

Examination	GONAD DOSES (cGy)					
	Male			*Female*		
	> 0.7	**> 3.0**	**No. Exam.**	**> 0.7**	**> 3.0**	**No. Exam.**
LUMBAR SPINE				0.792		105602
SACRUM				0.918		3624
HIP JOINT	1.478		31711			
MYELOGR.(LUMB.)				1.231		4919
BA SWALLOW					6.2 (>0.5-5a)	546
AORTOGR.(ABD.)					3.699	2157
RP					4.092	5982
IP				1.226		22638
KIDNEY TOMO				0.766		10154
CYSTOGRAM	2.925(>0.5-5a)	3.096(0-0.5a) 5.505	739 739 7194		9.653	7480
URETHROGRAM	1.661		604			
SALPINGOGRAM					6.320	14187
BA ENEMA					9.048(>5-15) 16.111	805 30492
BA & A				2.222		892
PA & A	1.071(>5-15a) 1.250		201 2554			
PELVIS				1.856		2848

* Age interval >15 years, except where otherwise indicated in brackets.

Legends for RP, IP, BA & A and PA & A on next page.

RP	Retrograde pyelogram
IP	Intravenous pyelogram
BA & A	Bifurcation arteriogram and angioplasty
PA & A	Peripheral arteriogram and angioplasty

In Appendix D, the frequency of examinations per thousand population as well as the genetically-significant dose from diagnostic radiology are compared regarding the various countries and it will be discussed in more detail under the graphical presentations in Figures 9.18 and 9.19. Figures 9.15 and 9.16 are graphical representations of the different race-gender groups regarding the examinations per 1000 population and the GSD respectively.

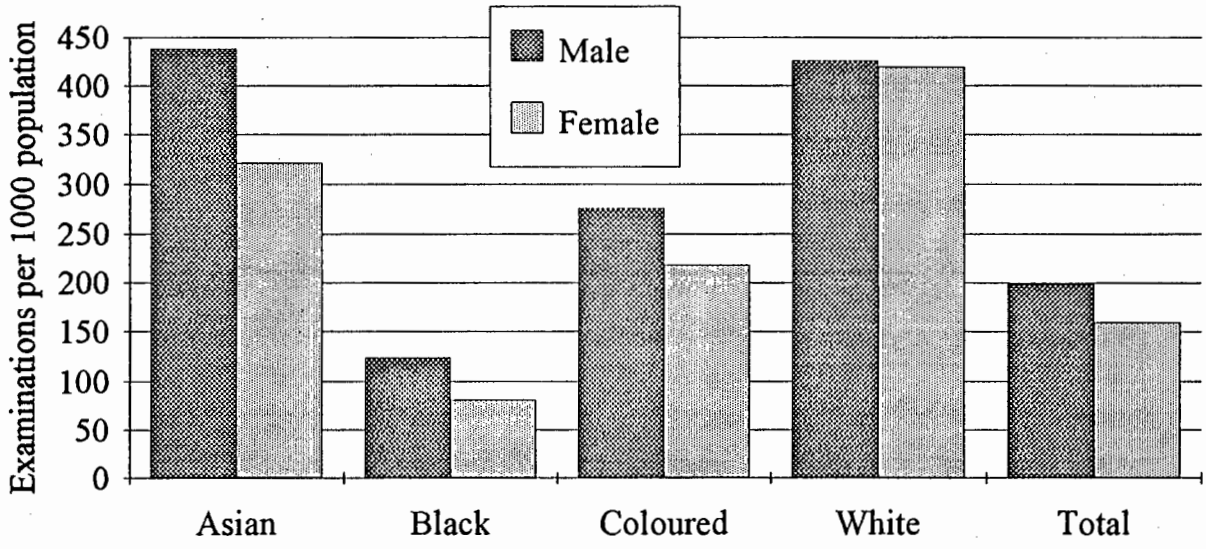


Figure 9.15 *Number of examinations per thousand population for the race-gender groups in South Africa.*

The South African population is composed of four races and the distribution has already been discussed above under the heading "Geographical distribution of sample". The small number of examinations per thousand population as well as the small GSD of the Black population can be attributed to socio-economic grounds. In this regard the income per capita must be considered. The income per family member is dependent on the income earned and/or received and on the dependency ratio, i.e. amongst how many persons must this income be divided. In South Africa the per capita monthly income per population group varies substantially. At the time

of this survey, the highest income (Whites) being approximately three times larger than for Asian, five times more than Coloured and eight times greater than that for Blacks (Chief Directorate: Planning Support, 1992). The usual medical care is not readily available for the low income groups, especially for people in rural areas. Specialised procedures like diagnostic radiology would therefore be even more of a problem.

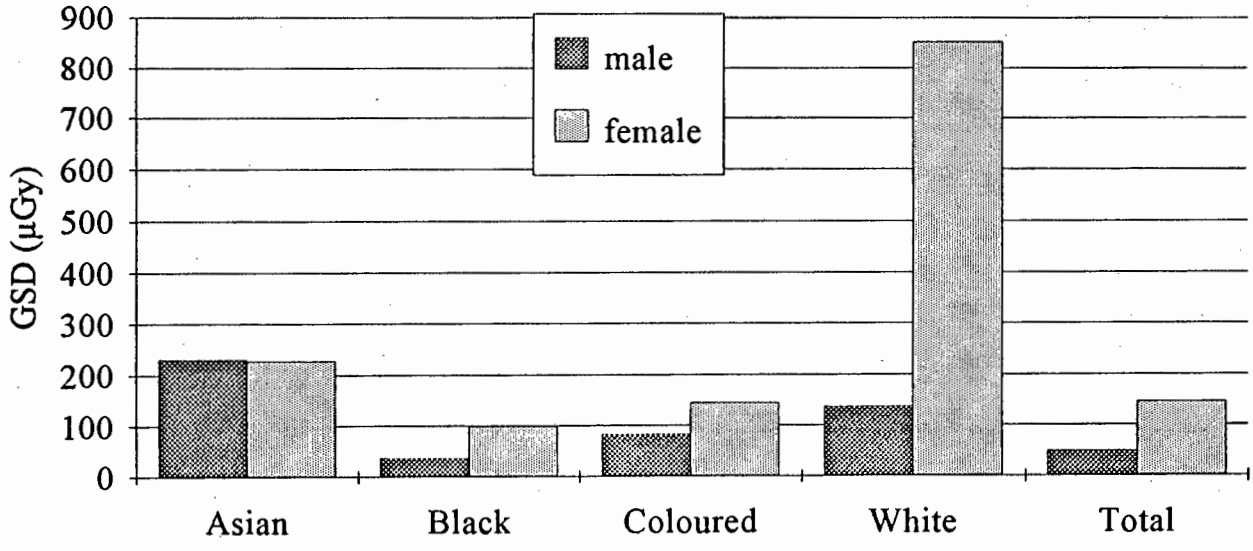


Figure 9.16 *GSD within race-gender groups.*

It is observed that the examination frequency (Figure 9.15) is higher for the male groups than for the female groups. The opposite is true, however, when the genetically-significant dose is considered (Figure 9.16). The only exception exists for the Asians where the GSD is slightly higher for the males. The higher GSD's can be attributed to the higher gonad doses to women in the majority of the examinations (Table 8.6). The GSD's for the various race-gender groups are given in Table 9.2 where all calculations were performed with respect to a specific race-gender group. The female to male ratio is 0.99 for Asians, 2.68 for Blacks, 1.74 for Coloureds, 6.24 for Whites and 2.94 for the overall population.

In order to compare the results of the South African survey with those of countries like Great Britain, the United States and France, the contribution to the GSD of each gender in a specific race group was calculated and is presented in Figure 9.17. The female to male ratio of the GSD thus calculated is 0.87 for Asians, 2.39 for Blacks,

1.58 for Coloureds, 5.27 for Whites, 2.62 for the overall SA population, 1.04 in 1957 and 0.89 in 1977 for Great Britain (Darby *et al.*, 1980), 2.13 for the United States in 1980 (NCRP Report No. 100, 1989) and 2.31 for France in 1982 (Maccia *et al.*, 1988).

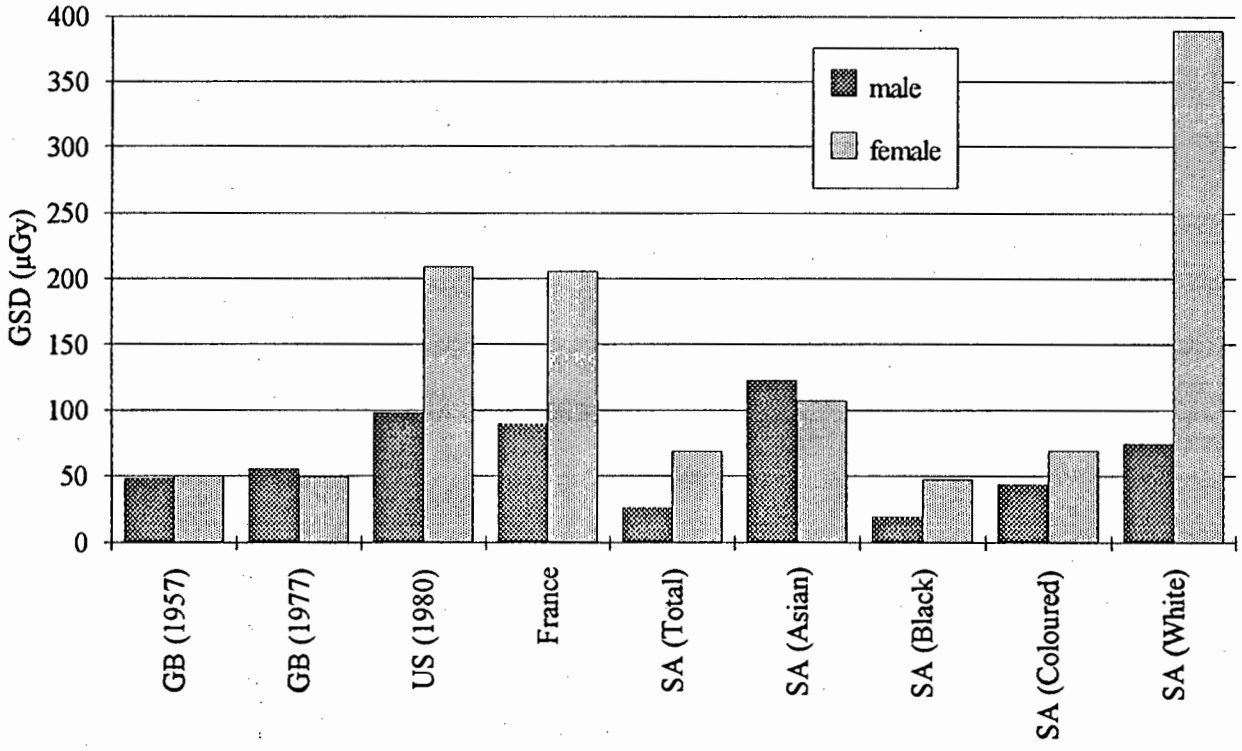


Figure 9.17 *Contribution by gender to the GSD.*

Except for the Asians (the same phenomenon was observed in the 1977 survey in Great Britain), the contribution of females to the GSD is always larger than that of males. This can be attributed to the fact that the largest proportions of examinations involve examinations of the abdomen, pelvis and lumbar spine. In these areas the doses to female gonads are much larger than those to the male gonads.

A tendency is observed that the contribution of females to the GSD is much larger than that of males. The only exceptions are the 1977 survey in Great Britain and for the Asian population group with a remarkable correspondence of the female to male ratio's, namely 0.89 for Great Britain and 0.87 for Asians. It is further observed that the contributions of the males and females to the GSD for Coloureds are in good agreement with those of the surveys during 1957 and 1977 in Great Britain.

Contributions of White and Asian males resemble those of the United States and France, while the value of Asian females is between those of Great Britain on the one side and the United States and France on the other. The small GSD contributions of the Black population can be attributed to socio-economic conditions and the large GSD due to White females was caused by the exceptionally large contribution of the barium enema examinations.

Figure 9.18 is a graphical display of the frequency of the examinations and Figure 9.19 represents the genetically-significant dose of various countries. The values were obtained from Appendix D. It is observed that Iraq has a rather low examination frequency but the GSD is the highest of all countries. The child expectancy could be a cause for this feature, but high gonad doses administered during X-ray examinations could be a more probable cause. Sweden has a relatively low examination frequency but a high GSD too. The same is true for the White South African population. It has already been indicated that barium enema examinations for women make a major contribution to the GSD.

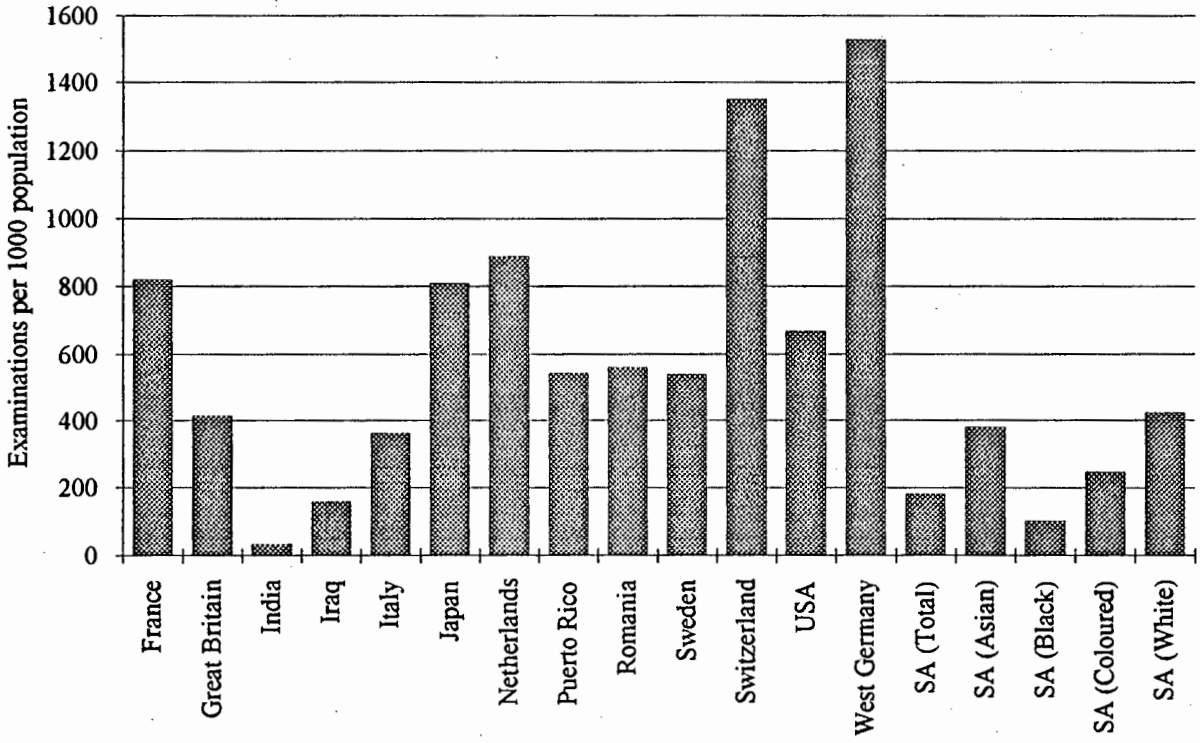


Figure 9.18 *Number of examinations per thousand population for various countries.*

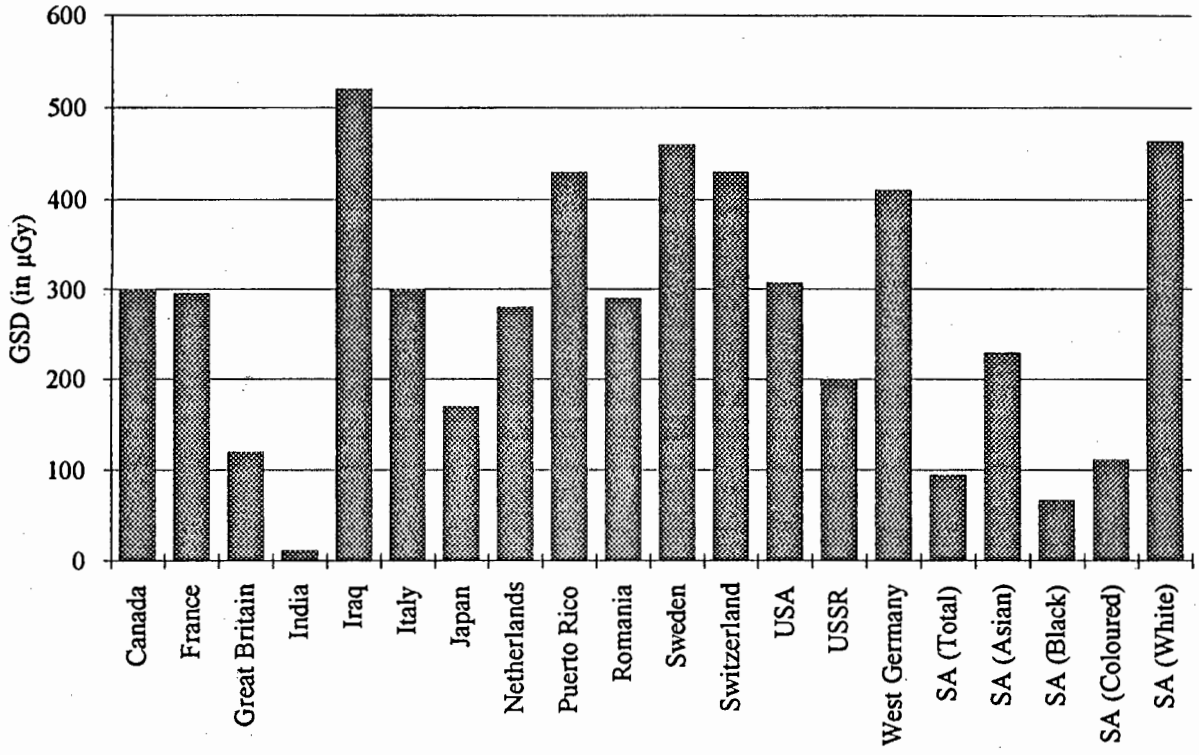


Figure 9.19 *The genetically-significant dose for various countries.*

The genetically-significant dose is a useful index for comparing the radiation safety of practices in the various countries as well as in cases of follow-up studies. South Africa compares favourably with other countries, except in the case of White females. Certain factors must be kept in mind, however, when the results of the various countries are compared. Comparison of organ dose data with results from similar surveys indeed indicates great discrepancies for certain organs and examinations (Wall et al., 1980 and ICRP, 1982). This must be due at least in part to the differences in dosimetric technique used.

Chapter 10

DISCUSSION

The need for particular biomedical studies may arise in many ways. These studies may be triggered, for example, by observation of interesting cases or may be instigated by a government agency in response to a question perceived to be of national importance. In view of the information being unavailable, the South African Forum for Radiation Protection recommended that a research project to determine the genetically-significant dose from diagnostic radiology for the South African population should be performed.

The need to evaluate the data statistically forces an investigator to sharpen the focus of the study. Intuitive ideas need to be translated into an analytical model capable of generating data that may be evaluated statistically. Many different studies may have to be considered in order to answer a given scientific question. As regards the present study, it was necessary to devise a suitable sampling method of institutions involved in radiological practice in South Africa. After due consideration, a novel and unique approach to sampling for the purpose of GSD determination was employed, namely the Dollar Unit Sampling method, developed for the auditing profession.

An acceptable sample and sampling procedure should comply with the following properties:

(a) The size of the sample must be sufficiently large in order to represent the sample variation.

(b) The sample should be representative of the temporal position (conditions at that specific period as services may deteriorate or improve or types of examinations may change).

(c) The sample must not be taken during short term changes of the prevailing conditions (for example, political upheaval or work stay-aways).

(d) The sample should be representative of the geographical position.

(e) The sample should be representative of the development regarding applied technology (for example the improvement of X-ray units and the implementation of MRI and CT scanning).

The survey presented in this thesis as well as other survey methods mentioned in Chapter 5 can be evaluated by consideration of these properties, and each one is considered separately.

(a) **Sample size**

For the South African survey, a sample of 27 institutions out of a possible 292, namely 9%, was drawn. The sample was drawn by consideration of the number of examinations performed in one year (1988). The sample of 27 institutions represented a total of 27696 examinations performed over a period of one week at each institution. This week was chosen during the second half of 1990 or during the first half of 1991. The total number of examinations performed during 1988, namely 5576235, was divided by 52 in order to obtain 107235 examinations per week and it was assumed that this rate of examination was the same for the period when the survey was done. Therefore, 27696 examinations out of a possible 107235 examinations represents 25.8% of all the examinations per week in a recent and typical year and although the sample drawn represented only 9% of the number of institutions, it represented a much larger 25.8% of all the examinations performed during a specific week. This must be expressed as the percentage per week since the survey was done over periods of one week and effectively randomly throughout the year. The resulting sample was thus well representative of the prevailing conditions over a complete calendar year.

It can be concluded that the South African survey was quite comprehensive in comparison with surveys that were done in the following countries:

In France, 386 out of a possible 4958 institutions (8%) were drawn but technical data from 13000 X-ray examinations per week was collected only. This number represented only 1.49% of the total number of an estimated 873077 examinations per week (Maccia *et al.*, 1988). A similar result was obtained in Great Britain where 112 out of a possible 1431 hospitals were drawn (8%) while 81 (5.7%) consented to take part in the survey, but only information supplied by 77 (5.4%) could be used (Kendall *et al.*, 1980). Technical data from 15% of the total number of an estimated 457692 examinations per week was obtained (Wall *et al.*, 1984). Gonadal dose measurements were made on a total of 4565 patients (examinations) covering the 13 selected types of diagnostic X-ray examinations (Wall *et al.*, 1980), i.e. 0.019% of the annual number of examinations or 1% of the number of examinations per week.

In Czechoslovakia (Bohemia, 1965 - 1966), a breakdown of the examinations by age was obtained for 253853 examinations over one year, i.e., only 6.4% of the annual number of examinations (UNSCEAR, 1972). For Finland 143000 examinations out of the annual 2.7 million examinations were recorded over a period of 4 weeks, i.e. 5.1% of the annual number of examinations and 69% of the number examinations during the month of the sampling. No sampling process was implemented, however, since all medical institutions were requested to supply details of radiological examinations (UNSCEAR, 1972).

In New Zealand (1969) a survey, in which details of 40000 radiological examinations were collected and analysed, represented 3.5% of the annual number of examinations (UNSCEAR, 1972). The total number of patients radiographed in all centres in Thailand was requested for January 1970 and the 56% return represented some 45% of the estimated number of examinations carried out monthly. Although this value seems high, a very low frequency of 30 examinations per year per thousand persons was reported. Since there was such a relatively small number of X-ray examinations conducted in Thailand, it could be expected that the percentage of examinations per month in the sample would be large (UNSCEAR, 1972). For Yugoslavia the total number of radiographic and fluoroscopic examinations was determined during 1960 for all the institutions in Slovenia. The annual information on a 25% sample of these examinations was obtained in terms of age, sex and type of examination (UNSCEAR, 1972).

In comparison with studies in other countries and regions it may be concluded that the South African survey was of sufficient size.

(b) **Temporal position**

It is essential to keep in mind that results refer to the time at which the survey was done. Services may deteriorate or improve or the types of examinations may change with time. It was found that during the 1977 survey in the UK (Kendall *et al.*, 1980) that the frequency of bronchography, chest tomography and mass miniature chest radiography has fallen dramatically compared with the 1957 results (Kendall *et al.*, 1980). A sharp fall was also found in the frequency of chest fluoroscopy (Kendall *et al.*, 1980). The same results were obtained from Sweden (UNSCEAR, 1977). It may

be assumed that these changes were mainly associated with the declining prevalence of pulmonary tuberculosis and bronchiectasis.

In the UK the advent of computerised tomography has been found to be associated with a significant drop in the number of cerebral angiographic examinations (Kendall *et al.*, 1980). The increased number of films per barium examinations (barium enemas in particular) compared to that of 1957, was presumably associated with the increased diagnostic information afforded by the double contrast techniques developed since that time (Kendall *et al.*, 1980).

Details regarding radiological examinations were collected over periods that range from one week to one year for the 16 countries or regions described in Chapter 5. It would be the ideal condition if results could be obtained for a full year since the genetically-significant dose refers to one year. This is impossible, however, when detailed information is required as for the local survey. The additional workload would be too much of a burden to radiological practices if such a survey had to be carried on for a longer period than one week, and was clearly demonstrated on many occasions in the present study.

(c) Short term changes

Short term changes, like political upheaval and work stay-aways, may occur in any radiological practice and results thus obtained, would not be totally reliable. In Great Britain and in France, data was collected over a specific one-week period. In order that short term changes were minimised, the survey in South Africa was done over one week, effectively randomly chosen, during the second semester of 1990 or the first semester of 1991 for all X-ray units at a particular institution. By so doing the effects of short term changes were minimised.

(d) Geographical distribution of sample

The Dollar Unit Sampling is a special case of probability proportional to size-sampling (PPS-sampling). In the present study all the large institutions (>200000 examinations per year) were included in the sample and the other institutions were

drawn proportionally. The large hospitals are situated in the more densely populated areas and this sampling method would ensure that the probability to be drawn, would be the largest for the large institutions. It was expected that the more dense distribution of examinations being drawn for the sample would appear in the more densely populated areas. The results obtained in this way were exactly in agreement with the expected values. This is illustrated in Figure 7.1.

The vast majority of the 986620 Asians (Population Census 1991, 1992) are Indians and more than 11000 are Chinese. More than 80 per cent of Indians live in Natal with the majority in a radius of 150 km from Durban of which 90 per cent of the total are urbanised (South African Profile, 1991). The Coloured community of 3285719 (Population Census 1991, 1992) is mainly settled in the Cape Province. About 85 per cent of the total Coloured population live in the Cape Province, mostly in the Cape Peninsula and vicinity and 78 per cent of the total have been urbanised (South African Profile, 1991). Considering the density of the sample distribution in Figure 7.1, it is evident that these two large groups were well represented in the sample since the respective areas constitute the second and third largest sample density areas. The other races are distributed over the country as a whole while the sample and population densities are in good correspondence. The effectiveness of the Dollar Unit Sampling method is herewith clearly illustrated.

The various previous surveys made use of the number of examinations available (Maccia *et al.*, 1988; UNSCEAR, 1972 and Vañó *et al.*, 1989). In the Netherlands insurance companies were approached to derive the annual total number of examinations. Although it was stated that the samples were geographically scattered (UNSCEAR, 1972), certain factors like the density of the population distribution must be taken into account when a random sample is being drawn and it is therefore difficult to understand how it is possible to obtain a sample in this way that is a good representation of the population.

In Chapter 5 (Section 5.5) the national surveys that were done in the United States during 1964 and 1970 were discussed. The sampling procedure was thus population-based, rather than institution-based as was the case in Germany, Yugoslavia, Finland, Great Britain, United States of America, Russian Republic, Czechoslovakia, Japan, New Zealand, Thailand, France, Spain and the current survey. However, it is

arguable whether a population-based sampling procedure would yield a more representative sample than an institution-based sampling procedure.

In 1957 in Great Britain, the Adrian Survey used information from a random sample of about 25% of the hospitals in the country to estimate the total number of examinations that took place (Wall et al., 1984). In the 1977 survey the workload at radiology departments was described in terms of radiography units where each unit represents approximately one minute of a radiographer's time.

The returns regarding the radiography units of the English hospitals were stratified according to workload ranges as detailed in Table 5.1. By using a standard stratification sampling technique (Kendal *et al.*, 1980), the sample consists of 78 institutions. However, a single hospital that had a workload of more than 2 million units per year, although not being part of the sample, was nevertheless included in the survey. Considerations of proportional sampling would suggest that it is better to include this one exceptionally large hospital rather than to reject it. The Dollar Unit Sampling method automatically included the large institutions which performed large numbers of diagnostic examinations.

In Wales, as discussed in Chapter 5, no sampling technique was used, and the 5 participant hospitals were selected informally. The same sampling procedure as that used for English hospitals was used for Scottish hospitals.

Although a sufficient geographical representation should be obtained by means of simple random sampling or the stratified sampling method, Dollar Unit Sampling is a simple method that may yield a more representative sample.

In France, the survey was conducted in two phases. Firstly, about 500 institutions were selected based on a rough evaluation of their annual film utilisation. As a second phase, in order to estimate the total number of X-ray examinations done annually as well as certain technique factors, a questionnaire was sent to a sub-sample selected among the X-ray units that equipped the radiological departments mentioned above (Maccia *et al.*, 1988). The survey was done in June 1982 over a period of one week. No special provision was made for good geographical representation.

For Spain, data was available from all the Autonomous Communities through the Directorate General of the National Institute of Health (Vañó *et al.*, 1989). Although the communities Andalucia and Cataluña were excluded the available examinations constituted 67% of the population in Spain which should be a good representation of the total population (Vañó *et al.*, 1989). It appears that a good geographical representation was obtained since data was available from all the Autonomous Communities through the Directorate General of the National Institute of Health. Diagnostic radiology performed in any of the 36 centres of the Department of Defence or in local administration centres were not included, however, but one of the participating hospitals in the project was the Gomez Ulla Central Military Hospital (Vañó *et al.*, 1989). It would therefore in future be possible to obtain some parameters in relation to diagnostic radiology at this type of centre. It was also most difficult to obtain data from the private sector.

(e) **Development in applied technology**

This aspect is reflected in Table 8.1 since it is an indication of the types of examinations that are applied as well as the technology involved in South Africa. It is the responsibility of the Directorate: Electromedical Devices and Radiological Health of the Department of Health to license all new X-ray units in South Africa. From this information it can be determined that the latest and most advanced technology is sold in South Africa. For examinations like heart catheterisation and computerised topography, the most recent techniques are applied involving new and advanced equipment. This was the state of affairs at the time of the survey during 1990 / 1991. Due to budgetary constraints, there has been a tendency since 1993 to import second hand equipment that are three to five years old. This could cause a negative effect on future services, i.e., higher doses may be the result of second-hand units that are not of the same standard as new ones.

Intensive study regarding the sizes of files (Table 8.1), the gonad doses associated with the various examinations (Table 8.6) as well as the estimated contribution to the GSD from 8 additional examinations (Section 9.5), led to the conclusion that the examinations other than the chosen ones could be ignored. This was confirmed by the NRPB-Report of July 1980 in which it was stated that 13 examination types had been selected which probably contributed to at least 95% of the GSD (Wall *et al.*, 1980). The NRPB collection, which forms a part of the 30 examinations chosen for the current project, was composed of the following examinations:

- Foetal maturity
- Pelvis
- Lumbar spine and Lumbo-sacral joint
- Pelvis, Lumbar spine and Lumbo-sacral joint combined
- Intravenous pyelography (excretory urography)
- Upper femur, hip
- Pelvimetry
- Abdomen
- Barium meal
- Chest, heart and lungs
- Barium enema
- Cystography
- Lumbar myelography

A few examination types and institutions were ignored in the present South African survey since their contribution to the GSD was believed to be negligible. General Practitioners perform in the majority of the cases examinations of lungs and extremities only. All users of X-ray equipment must obtain a user's licence from the Department of Health and certain types of X-ray units supplied to general practitioners are often restricted to be used for lungs and extremities only. The contribution to the gonad dose from examinations of lungs and extremities is very small and can therefore be ignored. It can further be stressed that the need to take their own X-ray films exists mainly for general practitioners in rural areas and that the workload is usually very low.

About sixty to seventy percent of the licence holders for the use of medical X-ray equipment in South Africa are dentists. Since the X-ray beam is very well collimated and the X-ray output is relatively low, the gonad doses are very low and no significant contribution to the GSD could be expected. Indeed, the contribution to the GSD was determined in Great Britain in 1977 as 0.3 μGy (Darby *et al.*, 1980).

Examinations perform by chiropractors usually involve high gonad doses, but it was ignored because of the expected low frequency. Although the frequency of mass miniature chest examinations is high, the contribution to the gonad doses are low for chest examinations, taking into account the fact that shielding is always used during examinations. Examinations perform by specialists like physicians, orthopaedic surgeons, urologists, surgeons, and gynaecologists will result in some instances in high gonad doses but low frequencies. These specialists often perform certain examinations in a theatre at a private hospital. The workload regarding the use of X-ray units in such hospitals is low.

Table 8.2 illustrates that the wide variability in patient exposure is caused by the differences in technique factors. The standard deviations for the tube voltage (kV), focus-film distance (FFD) and the film sizes are estimated as 25% of the mean values, while that for the workload (mAs) and screening time (min.), more than 100% of the mean values. This phenomenon of excessively large standard deviations originates from the fact that some of the observed investigations contributed a small number of high values, for example workload (mAs) and screening time (min.). These mean exposures are transferred to the entrance and gonad doses. The choice of such parameters is partly dictated by the needs of the particular patient, partly by the limitations of the available equipment, and partly by the preferences and experience of the radiologists and radiographers conducting the examinations.

It was not possible and meaningful to apply the uncertainties of the technique factors to certain procedures in order to obtain, for example, the uncertainty in GSD, due to the following reasons:
(i) It would have been a very complicated task since the uncertainties in the skin-entrance doses had to be calculated due to the uncertainties in the technique factors. These uncertainties calculated for skin-entrance doses as well as uncertainties of the technique factors have next to be applied in order to calculate the uncertainties for the gonad doses. These results could then be used in order to calculate the uncertainties for the GSD.
(ii) The uncertainties in the calculation of the skin-entrance as well as the gonad doses depend on numerous factors and the relevant uncertainties are unknown.
(iii) The uncertainties of the population census as well as the child expectancy values are unknown.

According to Wall *et al.* (1980), there is ample evidence from other surveys of diagnostic X-ray techniques that if patient differences are eliminated by substituting a standard phantom, there still remains considerable variation in doses delivered by different practitioners. Operators of diagnostic X-ray equipment were asked to select their usual techniques for

conducting a particular examination on a well defined standard sized adult patient and exposure measurements were made and organ doses calculated for this standard patient. The more recent UK survey certainly found that 2 orders of magnitude for a "standard" patient examination were not uncommon. Patient heterogeneity would consequently not appear to be the major cause for gonadal dose variability (Wall *et al.*, 1980).

A parallel that could be drawn between the UK and SA is the assumption that diagnostic radiology contributes about 90% to the overall GSD of the population from all man-made sources of radiation exposure. It was determined heuristically that a reduction as small as 10% in diagnostic medical exposures could therefore have the same effect as the elimination of all the other sources (Wall *et al.*, 1980). A relatively modest expenditure would consequently be required to obtain a significant reduction in medical exposure. On the other hand, to achieve this in the non-medical sector would certainly be much more costly. Thus, by simply improving techniques in order to reduce unnecessary exposures, a substantial reduction in the gonad dose to the population could be obtained without reducing the benefits of diagnostic radiology. The cost should be insignificant, however, compared to the investment to be made in radiological protection in other fields.

It must be noted that the GSD for the SA population is 94.6 μGy; 463.3 μGy for Whites is the largest GSD when the races are considered separately; when even smaller sub-groups are considered making provision for the males and females, an extremely high 850.7 μGy for the White females is calculated (the second largest value is that for the Asian males, namely 230.4 μGy). The barium enema contributes an alarming 432.4 μGy to the GSD of White females.

Although the number of examinations per 1000 population in White and Asian males is similar, the number in White females is 23% greater than that in Asian females (Figure 9.15) but the GSD in White females is some four times that in Asian females (Figure 9.17). When Figure 9.7 (Contribution of the various examinations to the GSD of Asian females) is compared with Figure 9.13 (Contribution of the various examinations to the GSD of White females), it becomes obvious that the barium enema is by far the largest contributing factor to the large GSD of the White female group.

It can be seen from Table 8.8 that the number of barium enema examinations performed on White females differs distinctly from those performed on any other race group. For the Asian females, however, the number of those females in their reproductive age is zero. This is contrary in what is to be expected since Asians and Whites have more or less the same

standard of health care. There is no obvious explanation but it could possibly be attributed to the geographical distribution of the population. In this chapter, under the heading "Geographical distribution of sample" it is indicated that more than 80 per cent of Indians live in Natal with the majority in a radius of 150 km. All groups and examinations should be well represented in the two large institutions that were drawn in this area. Regarding the barium enema's it appears, however, that Indian females prefer to consult Indian radiologists. Two large Indian practices exist in this area, but none of them was drawn for the sample. The demographic distribution in the Durban area has thus to be taken into account in a future survey. Such a value can possibly be estimated by increasing the frequency of barium enema examinations of Asian females proportionally with reference to the total Asian female and White female population.

According to the ICRP Report 34 (1982), a typical skin dose (median value) in the primary beam is 1.5 cGy for radiography and the exposure due to fluoroscopy is 20 R (17.46 cGy in air) for a barium enema (ICRP, 1982). The NRPB (Wall *et al.*, 1980) determined in their latest survey that the average screening time is 3.06 minutes with a lowest value of 1.35 minutes and a highest value of 4.96 minutes. The mean ovary dose was determined as 1.66 cGy to the ovaries for females older than 45 years of age (Wall *et al.*, 1980). The value determined for South Africa is 16.1 cGy. High average tube voltages and mAs values (Table 8.2) were obtained during the survey. The average fluoroscopy times (6.74 and 6.13 minutes) also seem exceptionally long, i.e., more than twice those quoted in the UK survey results published in 1980 (and also in 1986).

Long screening times of barium enema's by radiologists at the beginning of their training period could actually provide only a small contribution to the average of the gonad doses and thus to the GSD of White females since they comprise only a small group relatively to the total group of practising radiologists. Personal communication with a previous head of the Department Gastrointestinal Radiology of one of the training hospitals in South Africa led to the conclusion that the contribution to the GSD is exceptionally high for Whites merely on account of better Health Care to them. The person was not aware of any statistics to confirm the existence of specific diseases to cause the higher frequency of barium enema examinations. It was remarkable to him that only a few examinations were requested for Black women over many years. An inherent aversion to such an examination and/or cultural values could make a contribution too. These arguments could also be valid with regard to the Coloureds and Asians.

Two factors play a major role regarding the contribution, from various examinations, to the GSD of a population, namely the frequency and gonad doses. The number of barium enema

examinations per thousand population for all White females in South Africa is 9.6. The corresponding value obtained in the 1977 survey in Great Britain was 5.7 examinations per thousand (Kendall *et al.*, 1980). The frequency of these examinations for the total population (males and females) in Great Britain was estimated as 4.8 examinations per thousand (Kendall *et al.*, 1980). The values estimated for the total populations of France and the United States are 15.4 (Maccia *et al.*, 1988) and 21.4 (NCRP, 1989) examinations per thousand population respectively.

Although the frequency is less for Great Britain than for the White females in South Africa, its GSD is also less (Figures 9.17 and 9.19). For France and the United States the frequency is much higher, however, while the contribution to the GSD is not as large as that of the White females in South Africa. It can therefore be concluded that the frequency of the barium enema examinations is not the cause of the exceptionally high GSD of white females. The large doses involved in barium enema's are likely to be responsible for the large contribution of this type of examination to the GSD of White females.

The reason for the higher gonad doses with regard to values obtained in the literature, for example 16.1 cGy for South Africa compared with 1.66 cGy for the UK, is not obvious. An attempt should be made, however, to use technique factors that would result in lower entrance and gonad doses. This aspect is discussed on page 181.

It is meaningless, however, to treat a dose as an index of risk in isolation from the benefits resulting from an examination. Therefore, if a high dose examination is associated with high quality information the benefits may outweigh the risks. Alternatively, a low dose examination may produce minimal information with little or no benefit to the patient.

Conclusions

The following aspects may be referred to regarding the way it may affect future results with regards to the GSD.

(a) Demographic changes like child expectancies, will have certain definite results on the composite SA population. One of the main policies of the new South African government is the upliftment of the living standards of the entire population to acceptable levels. It is a well known fact that an improvement in living standard causes a decrease in the child expectancy. Inspection of equation 2.2 in Chapter 2 shows that a decrease of the child expectancy would affect the genetically-significant dose.

(b) Other factors may also play a major role to obtain different results than that is to be expected. The Department of Health has five requirements for an applicable health service - all services should be accessible, efficient, acceptable, affordable and equitable (DNHPD, 1992). Previously, large amounts of money was made available for advanced and expensive medical equipment and other specialised projects. At the present the Department strives for a health service, however, that is acceptable to the community and which addresses their real needs. Special attention is paid to the poor, the elderly and the children. Primary health care (PHC) is therefore focused on the elimination and control of preventable diseases and deaths. Primary health care, which is directed particularly at prevention, must bring basic health services as close as possible to users.

In a special document the Health Priorities contained in the Reconstruction and Development Programme (RD.) are categorised, however. In this document specialised equipment, particularly expensive technology, enjoys a low priority. This policy, together with the economic climate, apparently precludes the possibility of an increase in the use of X-ray units and thus an increase in the GSD for at least during the next decade.

Another outcome of the Reconstruction and Development Programme is free medical care to pregnant women and children up to six years of age as well as the intention to make mobile X-ray units available for the diagnosis of tuberculosis. The latter aspect

is still in the planning phase, however. Free medical care could be a cause for more exposure to X-rays, especially in urban areas, and could thus result in an increase in the GSD. It is not expected that the tuberculosis examinations would cause a significant increase in the GSD due to the low doses to the gonads during chest X-ray examinations.

(c) The development in technology must always be taken into account. Newer techniques and technology may be the cause for higher patient doses, for example in the application in double contrast techniques (with the resulting increase in frequency) and digital subtraction angiography (DSA) as used in cardiac catheterisation. The development in technology would more often be the cause of lower patient doses by introducing, for example, more sensitive image intensifiers and rare earth film/screen combinations. The new generation high frequency X-ray generators can deliver an excellent X-ray output in order to obtain radiographs of a very good quality. The resulting decrease in the requirement to repeat some of the exposures would therefore be the cause of a lower patient dose.

(d) The types as well as the frequency of examinations are also determined to a certain degree by the expectations and perceptions of individuals. Medical practitioners have in many instances to be guided by patients regarding the symptoms if an illness and thus the requests for X-ray examinations. It can therefore be concluded that the GSD is also determined by the expectations and perceptions of individuals.

(e) The ideal is that conditions should be the same for all race groups, that is, the RDP should result amongst others in the same GSD to the four race groups. That could be theoretically obtained only over a very long period (e.g. over a few decades). No accurate forecast could thus be obtained, however, since it would be determined by various factors like the development in the technology, new radiographic techniques and the willingness of the government to invest in equipment in view of the available resources. There exists also no further scientific grounds to motivate why anyone of the other racial groups could serve as a model for the Black population in view of the changes in availability of health care. Both the Asians and Coloureds are predominantly concentrated in a single province and between 70% and 80% of these people are urbanised. The Black population, on the contrary, is distributed in dense populated urban areas, as well as in remote rural areas over the country as a whole. This aspect as well as the low income per capita and limited amount of money

available from the government prevents the comprehensive upgrading of high technology equipment. None of the existing groups could therefore provide at the present time a model that will hold for the Black population under the envisaged improved health care conditions.

Certain minor changes to the GSD may be obtained, however, by a future investigation of barium enema examination procedures. If the co-operation of radiologists could be obtained, the technique factors could be reduced with the resulting lower gonad doses. For technique factors like 85 kV and 58.3 mAs for the AP view; 90 kV and 80 mAs for PA; 95 kV and 100 mAs for the lateral view as well as a shorter screening time, say 2.5 minutes, the skin entrance exposure could be reduced from 85.64 R to 26.29 R for screening (this value is in good agreement with the value that appears in the ICRP Report 34 (1982)). The gonad doses for males and females could thus be reduced to 154.6 mrad and 5394.5 mrad respectively. For this calculation, the other quantities (technique factors) used, were exactly the same as appears in Table 8.2 for the barium enema, age group > 15 years (for the fluoroscopy calculations, the tube current was assumed to be 3 mA and the field size at the image intensifier as 25 cm x 30 cm). The average gonad dose of females in the >5-15 years age group was reduced in the same proportion as that of the >15 years age group, i.e., 3029.5 mrad.

From Table 8.8 it is observed that the number of barium enema examinations performed on Asian females in their reproductive age is zero. This is contrary to what is to be expected since Whites and Asians have more or less the same standard of health care. If the frequency of barium enema examinations for Asians females is taken the same as for White females and the newly estimated gonad doses are used in all calculations, a future estimation of the GSD could be done. The new results obtained were Asians - 282.7 μGy, Black - 60.0 μGy, Coloured - 103.6 μGy and White - 330.4 μGy. The total GSD was calculated as 81.9 μGy. These estimated results are represented in Figure 10.1.

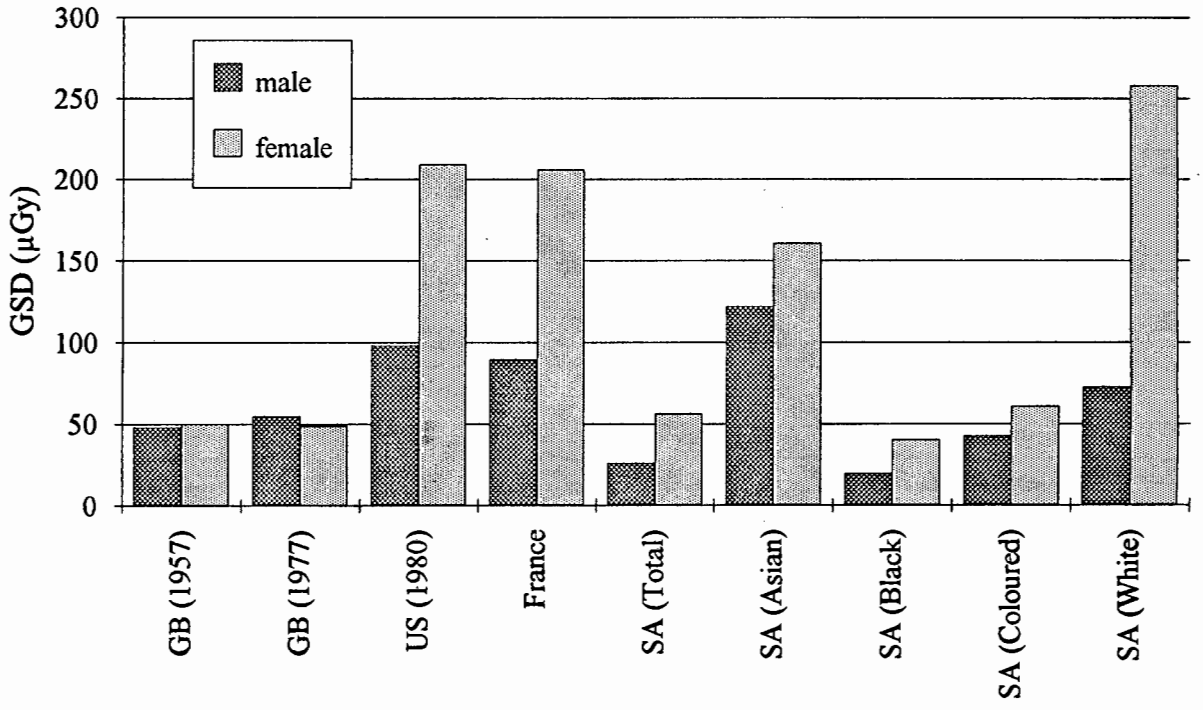


Figure 10.1 *Contribution by gender to the GSD (estimated values for South Africa).*

(f) The ideal is that the GSD should decrease or at least stay constant in subsequent studies. To state that ideally the GSD should decrease or at least remain constant, however, assumes that any increase in genetic detriment from an increase in provision of radiology services would not be outweighed by the concomitant improved health benefits to the population. The assumption is not self-evident, particularly for those sections of the South African population which currently experience poor living standards. By means of follow-up studies it could be determined whether or not techniques and circumstances have improved and examinations where special health risks are involved, can be identified. This ideal could be pursued within the scope of a study like this and a future similar study is therefore recommended.

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Appendix A

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT

Institution: _____ Room: _____
Unit(Make & Model): _____ Date: _____
File number: _____ CDU(yes or no): _____

Patient number (1; 2; etc.)	Examination CODE (If not listed, name examination)	Age (years)	Weight (estimate) (kg)	* C O D E or Sex (M or F)	Race Asian (A) Black (B) Coloured (C) White (W)	Gonad shield used (Y or N)	*Screening time* (in min.)	#Radiograph (R) or Cut film (C) or Cine film (35/70 mm)	No. of exp. (Radiograph / Cut film/Cine) or CT cuts per examination	Retake views (e.g. AP; LAT; etc.) (if any)

* Any one of the two columns may be used if a code is used for sex and race.
\# If the cassette(s) is(are) divided, e.g. when strips or spot films are taken, the size(s) of cassette(s) and divisions must be noted, e.g. 24 x 30 (1/4).

I N S T R U C T I O N S

1. Complete the form in pencil (in order to make changes easily if necessary).

2. The column headed "No. of exposures" must include all retake views as well as all sub-division exposures. For Computerised Tomography the length of the patient scanned for the overview film must be put in brackets after the number of CT cuts.

3. An example of a partially completed form can be seen below.

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT

Institution: _____ Room: _____
Unit(Make & Model): _____ Date: _____
File number: _____ CDU(yes or no): _____

Patient number (1; 2; etc.)	Examination CODE (If not listed, name examination)	Age (years)	Weight (estimate) (kg)	* C O D E or Sex (M or F)	Race Asian (A) Black (B) Coloured (C) White (W)	Gonad shield used (Y or N)	*Screening time* (in min.)	Radiograph (R) or Cut film (C) or Cine film (35/70 mm)	No. of exp. (Radiograph / Cut film/Cine) or CT cuts per examination	Retake views (e.g. AP; LAT; etc.) (if any)

See overleaf for CODES

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT

Institution: ______________________________ Room: ____________________
Unit(Make & Model): ______________________________ Date: ____________________
File number: ______________________________ CDU(yes or no): ____________________

Pat. no. (1,2; etc.)	Exami-nation CODE (If no code, name exam.)	Age	Weight (esti-mate) (kg)	* CODE or		Gonad shield used (Y or N)	*Screen-ing time* (in min.)	# *Size* of cassette (cmxcm) or Cut film (C) or Cine (35/70)	*No.* of exposures (X-photo/ Cut film/ Cine) or CT cuts per exam.	Retake views (e.g. AP; LAT; etc.)	T E C H N I Q U E						
				Sex (M or F)	Race Asian(A) Black(B) Colour-ed(C) White(W)						View e.g. AP; etc.	*kV*	and/ or *Time* per exp. (s)	and/ or *mA*	and/ or *mAs*	*FFD* (cm)	Au-to (Y or N)

* Any one of the two columns may be used if a code is used for sex and race.
\# If divided, note fraction in brackets after the film size, e.g. 24 x 30 (1/4).

I N S T R U C T I O N S

1. Complete the form in pencil (in order to make changes easily if necessary).

2. The section under the heading "TECHNIQUE" may be ignored should it be difficult to provide the required information (e.g. in the case of radiographs taken during screening procedures of Ba enemas).

3. The column headed "No. of exposures" must include all retake views as well as all sub-division exposures for specific technique factors. For Computerised Tomography the length of the patient scanned for the overview film must be put in brackets after the number of CT cuts.

4. An example of a partially completed form can be seen below.

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT

Institution: _____ Room: _____
Unit(Make & Model): _____ Date: _____
File number: _____ CDU(yes or no): _____

Pat. no. (1,2; etc.)	Examination CODE (If no code, name exam.)	Age	Weight (estimate) (kg)	* CODE or Sex (M or F)	Race Asian(A) Black(B) Coloured(C) White(W)	Gonad shield used (Y or N)	*Screening time* (in min.)	#*Size* of cassette (cmxcm) or Cut film (C) or Cine (35/70)	*No.* of exposures (X-photo/ Cut film/ Cine) or CT cuts per exam.	Retake views (e.g. AP; LAT; etc.)	T E C H N I Q U E *View* e.g. AP; etc.	*kV*	and/ or *Time* per exp. (s)	and/ or *mA*	and/ or *mAs*	*FFD* (cm)	Auto (Y or N)

See overleaf for CODES

A. GENERAL EXAMINATIONS

HEAD

A1 SKULL
A2 SELLA TURCICA
A3 ORBITS
A4 SINUSES
A5 FACIAL BONES
A6 MASTOIDS
A7 ZYGOMATIC BONE
A8 T-M JOINTS
A9 MANDIBLE
A10 ORTHOPANTOMOGRAM
A11 TEETH

SPINE

A12 CERVICAL SPINE
A13 THORACIC SPINE
A14 LUMBAR SPINE
A15 SCOLIOSIS X-RAYS (FULL SPINE)

CHEST

A16 LUNGS
A17 RIBS
A18 STERNUM
A19 STERNOCLAVICULAR JOINTS
A20 MASS- MINIATURE

ABDOMEN

A21 ABDOMEN SURVEY
A22 GALL-BLADDER VIEW

PELVIS

A23 PELVIS
A24 SACRUM
A25 COCCYX
A26 S-I JOINTS

JOINTS AND EXTREMITIES

A27 SHOULDER GIRDLE
A28 HUMERUS
A29 ELBOW
A30 FOREARM
A31 WRIST
A32 HAND
A33 HIP JOINT
A34 FEMUR NECK
A35 FEMUR
A36 KNEE
A37 TIB & FIB
A38 ANKLE
A39 FOOT
A40 PELVIMETRY

B. SPECIAL EXAMINATIONS

HEAD

B1 ANGIOGRAM
B2 AIR ENCEPHALOGRAM
B3 MASTOID TOMOS

SPINE

B4 MYELOGRAM (CERVICAL)
B5 MYELOGRAM (THORACIC)
B6 MYELOGRAM (LUMBAR)
B7 DISCOGRAPHY
B8 SPINE TOMOGRAPHY

CHEST

B9 AORTOGRAM
B10 BARIUM SWALLOW
B11 BRONCHOGRAM
B12 MAMMOGRAM
B13 TOMOGRAPHY (LUNGS)
B14 HEART CATHETERISATION
B15 SCREENING OF DIAPHRAGM

ABDOMEN

B16 AORTOGRAM
B17 ARTERIOGRAMS: MESENTERIC, RENAL, HEPATIC
B18 CHOLANGIOGRAM, CHOLECYSTOGRAM
B19 RETROGRADE PYELOGRAM
B20 INTRAVENOUS PYELOGRAM
B21 EMBOLISATION, LITHOTRIPSY, NEPHROSTOMY
B22 BARIUM MEAL
B23 ECRP
B24 KIDNEY TOMOGRAPHY

PELVIS

B25 CYSTOGRAM
B26 URETHROGRAM
B27 SALPINGOGRAM
B28 BARIUM ENEMA
B29 HIP TOMOGRAPHY
B30 HIP OPERATIONS
B31 BIFURCATION ARTERIOGRAMS / ANGIOPLASTY
B32 LYMPHANGIOGRAMS

JOINTS AND EXTREMITIES

B33 ARTHROGRAM (SHOULDER)
B34 ARTHROGRAM (ELBOW)
B35 ARTHROGRAM (HIP)
B36 ARTHROGRAM (KNEE)
B37 PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (UPPER LEG)
B38 PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (LOWER LEG)
B39 LYMPHANGIOGRAPHY: TOTAL LEG
B40 VENOGRAPHY: LOWER LEG
B41 ARTEROGRAPHY: UPPER LEG
B42 SCREENING OF EXTREMITIES FOR REDUCTION OF FRACTURES DISLOCATIONS
B43 SCREENING UPPER LEG (FEMUR)
B44 EXTREMITY TOMOGRAPHY

C. COMPUTER TOMOGRAPHY

C1 BRAIN
C2 ORBITS
C3 FACIAL BONES / SINUSES
C4 PETROUS BONE / AUDITORY CANAL
C5 CERVICAL SPINE
C6 THORACIC SPINE
C7 LUMBAR SPINE
C8 LUNGS / MEDIASTINUM
C9 ABDOMEN - LIVER, SPLEEN, KIDNEYS, VESSELS, LYMPH NODE
C10 PELVIS
C11 EXTREMITIES (KNEE, ETC.)
C12 PITUITARY FOSSA

SEE OVERLEAF FOR INSTRUCTIONS

Appendix B

B1 Database fields

Field A:	**LineNo**	(Line number)
Field B:	**FileNo**	(File number)
Field C:	**Page**	
Field D:	**CDU**	(Capacitor Discharge Unit: Y or N)
Field E:	**PatientNo**	(Patient number)
Field F:	**ExamCode**	(Examination code)
Field G:	**Age**	(Age in years or date of birth)
Field H:	**Weight**	(in kg)
Field I:	**Sex**	(M or F)
Field J:	**Race**	[Asian (A); Black (B); Coloured (C); White (W)]
Field K:	**Code**	(Describing patient's sex and race - see later)
Field L:	**GShield**	(Gonad shield: Y or N)
Field M:	**ScrTime**	(Screening time: in min.)
Field N:	**CassetteS - X**	(Size of cassette: X-axis)
Field O:	**CassetteS - Y**	(Size of cassette: Y-axis)
Field P:	**NoDivisions**	(Number of divisions of film)
Field Q:	**TotNoExp**	(Total number of exposures per examination)
Field R:	**NoExpPerView**	(Number of exposures per view)
Field S:	**NoRetakePerView**	(Number of retakes per view)
Field T:	**View**	(e.g. AP; LAT; etc.)
Field U:	**kV**	
Field V:	**Time**	
Field W:	**mA**	
Field X:	**mAs**	
Field Y:	**FFD**	(Focus-Film Distance)
Field Z:	**Auto**	(Automatic: Y or N)
Field AA:	**SSD**	(Source-Skin Distance)

B2 Instructions

1. Number all the patients for a specific institution.
2. Replace "No" with "0" and
   "Yes" with "1" at CDU; GShield; Auto.
3. Replace in ExamCode: A with 1
   B with 2
   C with 3
4. Replace the view:

AP with	1
PA with	2
LAT (lateral) with	3
OBL (oblique) with	4
Overview (AP) scan (CT scanner) with	5
Axial scan (CT scanner) with	6
Overview (LAT) scan (CT scanner) with	7
Cranio Caudal (CC) with	8
Axilla with	9
AP - Oblique with	10
PA - Oblique with	11

5. Press F2 to repeat a record (for Works spreadsheet only).
6. If "Cut film (C)" or "Cine film (35/70)", fill in only in the CassetteS-X-field the symbol "C" or "35" or "70".

   Short form: Fill in "R" in the CassetteS-X-field.

   For Axial scan (CT): Insert number of cuts in "NoExpPerView"
   Time in "Time"-column of database
   For Overview scan (CT): Fill in only in the CassettS-X-field (in cm)
7. The sum of the number of "Retakes" must be subtracted from the total number of exposures and entered under "TotNoExp".

   When an exposure is repeated (entered under "Retake views"), press F2 (Works only). Enter the view and total number of exposures there. Each retake must have its own record.
8. If it is not clear how the data must be entered, the form must be kept aside and the patient number and specific data marked. All data must be transferred as far as possible.
9. Use a point instead of a comma in decimal fractions, for e.g. 0.006 instead of 0,006.
10. If something omitted, leave an open space (do not insert a "0", etc.)
11. **Short form**
    *Tot NoExp $\Rightarrow$ total number of exposures <u>minus</u> retakes (nothing in NoExp column).
    *When more than one examinations are entered in a line, as well as retakes $\Rightarrow$ ignore retakes and divide examinations according to TotNoExp. (If the number of retakes can be determined, however, it must be entered in the retake-column and the distribution of exposures being done according to TotNoExp with no retakes included in it.)

B3 Film sizes for chest X-ray examinations (A16)

Male:

Fixed units: PA (35 x 43); LAT (35 x 43)

Mobile units: AP (35 x43)

Female:

Fixed units: PA (35 x 35); LAT (30 x 40)

Mobile units: AP (35 x 35)

Children under 10 years

Film sizes are the same as for female.

Always AP and LAT

B4 Long bones

Adults:	A28	⇒	(30 x 40) ½	2 x AP
	A30	⇒	(24 x 30) ½	2 x AP
	A35	⇒	(35 x 43)	AP
	A37	⇒	(35 x 43)	AP
Babies:	A35	⇒	(24 x 30)	AP
	A28	⇒	(24 x 30) ½	2 x AP
or	one big film:		(35 x 43)	

B5 Pelvimetry

Four views:	AP	2 slit records (entrance field: 4 X 12 cm)	85 kV	200 mAs
	LAT	1 x (35 x 43)	102 kV	130 mAs
	PA	1 x (35 x 35)	85 kV	200 mAs

or

Five views:	AP	2 slit records (entrance field: 4 x 12 cm)	85 kV	200 mAs
	LAT	1 x (35 x 43)	102 kV	130 mAs
	PA	1 x (35 x 35)	85 kV	200 mAs
	AP	1 x (35 x 43)	85 kV	150 mAs

B6 Field sizes (General)

10 x 10 cm (camera)	⇒	18 x 24 cm
Panorex (P)	⇒	10 x30 cm

B7 Examinations where films are divided

A8:	2 full films + 2 films divided in 2	(6 exposures)
A26:	1 full film + 1 film divided in 2	(3 exposures)
A30:	1 film divided in 2	(2 exposures)
A31:	1 film divided in 3 or 4	(3 or 4 exposures)
A32:	1 film divided in 3	(3 exposures)
A36:	1 film divided in 2	(3 exposures)
A38:	1 full film + 1 film divided in 2	(3 exposures)
A39:	1 full film + 1 film divided in 2	(3 exposures)

B8 Film sizes

inch x inch	cm x cm
* 5 x 7	13 x 18
*6 x 15	15 x 38
8 x 10	18 x 24
10 x 12	24 x 30
12 x 15	30 x 40
14 x 14	35 x 35
14 x 17	35 x 43
7 x 17	20 x 40

* Do not exist in the metric system.

B9 **Views**

A12 and occasionally A13:	**Flying**	⇒	LAT
Mammography:	**CC**	⇒	AP ?
	Macro	⇒	AP
Dental	**P (Panorex)**	⇒	P
A1	**OM**	⇒	PA
	OF	⇒	PA
	FO	⇒	AP
	Townes	⇒	AP
	SMV/Basal	⇒	AP
A12; A14; A33; B4; B5; B6; B7	**Shoot through**	⇒	LAT
A12; A14	**Flexion & Extension(stress)**	⇒	LAT
A14	**Angle**	⇒	LAT
#####	**Stenvers**	⇒	AP or PA
#####	**Shillers(SHL)**	⇒	LAT
All oblique is AP-OBL except A3 and A8	**Oblique**	⇒	AP-OBL
#####	**Open mouth**	⇒	AP
Lying on side; X-ray horizontal	**Decubitus**	⇒	AP or PA
Lying on back	**Supine**	⇒	AP(or PA)
Lying on stomach	**Prone**	⇒	PA(or AP)
CT scanner (surview; topogram; planar; pilot ⇒ overview scan)			
(a) spine & head	**Overview**	⇒	LAT
(b) abdomen & chest	**Overview**	⇒	AP
CT scanner (Pituitary fossa: pituitary gland in brain)	**Coronal**	⇒	Angle

B10 Gender-race codes

0 Gender & Race	Code
MW	1
FW	2
MC	3
FC	4
MA	5
FA	6
MB	7
FB	8

F ⇒ female
M ⇒ male
A ⇒ Asian
B ⇒ Black
C ⇒ Coloured
W ⇒ White

B11 Age

Age (days)	Age (year)	Age (months)	Age (year)
1	0	1	0.08
2	0	2	0.17
3	0.01	3	0.25
4	0.01	4	0.33
5	0.01	5	0.42
6	0.02	6	0.50
7	0.02	7	0.58
		8	0.67
		9	0.75
		10	0.83
		11	0.92
		12	1.00

APPENDIX C

CONTRIBUTIONS TO THE GSD FROM VARIOUS RADIOLOGICAL EXAMINATIONS USING TABLES 8.6, 8.8 AND 8.10 (SECTION 9.1).

(M - male; F - female; A - Asian; B - Black; C - Coloured; W - White)

Note: Numbers at the top of each section of the table, refer to the contribution to GSD for the overall population.

(1) CERVICAL SPINE

	0.004 µGy ;	0.004 %		
	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.01	0.006
FA	0.01	0.005	0.009	0.004
MB			0.004	0.01
FB	0.003	0.004	0.002	0.002
MC			0.005	0.007
FC	0.004	0.004	0.003	0.002
MW			0.03	0.02
FW	0.02	0.005	0.02	0.002

(1) THORACIC SPINE

	0.002 µGy ;	0.002 %		
	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.005	0.002
FA	0.008	0.003	0.01	0.005
MB			0.001	0.002
FB	0.001	0.002	0.001	0.001
MC			0.002	0.002
FC	0.003	0.003	0.005	0.003
MW			0.005	0.004
FW	0.02	0.004	0.04	0.004

(3) LUMBAR SPINE

	5.75 µGy ;	6.08 %		
	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.96	0.42
FA	30.11	13.15	63.05	27.72
MB			0.12	0.33
FB	2.41	3.62	4.96	4.99
MC			0.50	0.60
FC	7.64	6.81	15.51	10.74
MW			1.74	1.28
FW	47.32	10.21	101.27	11.90

(4) SCOLIOSIS X-RAYS (FULL SPINE)

	0.40 µGy ;	0.42 %		
	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.05	0.02
FA	0.10	0.05	0.17	0.07
MB			0.01	0.02
FB	0.01	0.02	0.01	0.01
MC			0.02	0.03
FC	0.10	0.09	0.19	0.13
MW			7.70	5.65
FW	6.95	1.50	6.06	0.71

(5) LUNGS

	0.11 µGy ;	0.12 %		
	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.11	0.05
FA	0.21	0.09	0.32	0.14
MB			0.05	0.13
FB	0.10	0.15	0.16	0.16
MC			0.07	0.09
FC	0.15	0.13	0.23	0.16
MW			0.11	0.08
FW	0.23	0.05	0.37	0.04

(6) RIBS

	0.001 µGy ;	0.001 %		
	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.001	0.000
FA	0.001	0.000	0.001	0.001
MB			0.001	0.002
FB	0.001	0.001	0.001	0.001
MC			0.001	0.002
FC	0.002	0.001	0.002	0.001
MW			0.003	0.002
FW	0.004	0.001	0.005	0.001

(7) ABDOMEN SURVEY

5.68 μGy ; 6.00 %

	RACE		RACE-GENDER	
	GSD (μGy)	%	GSD (μGy)	%
MA			8.30	3.60
FA	15.67	6.84	24.01	10.56
MB			2.79	7.52
FB	4.45	6.69	6.31	6.34
MC			2.95	3.56
FC	7.51	6.69	12.53	8.68
MW			5.30	3.89
FW	19.10	4.12	35.45	4.17

(8) PELVIS

10.73 μGy ; 11.34 %

	RACE		RACE-GENDER	
	GSD (μGy)	%	GSD (μGy)	%
MA			49.51	21.48
FA	32.39	14.14	13.05	5.74
MB			11.50	30.97
FB	7.47	11.23	2.97	2.98
MC			26.43	31.81
FC	16.59	14.78	5.75	3.98
MW			65.13	47.79
FW	46.72	10.08	24.93	2.93

(9) SACRUM

0.27 μGy ; 0.28 %

	RACE		RACE-GENDER	
	GSD (μGy)	%	GSD (μGy)	%
MA			1.41	0.61
FA	0.75	0.33		
MB			0.12	0.32
FB	0.06	0.09		
MC			0.33	0.40
FC	1.46	1.30	2.70	1.87
MW			0.33	0.25
FW	1.77	0.38	3.47	0.41

(10) HIP JOINT

5.80 μGy ; 6.13 %

	RACE		RACE-GENDER	
	GSD (μGy)	%	GSD (μGy)	%
MA			53.92	23.40
FA	29.66	12.95	2.23	0.98
MB			8.28	22.30
FB	4.63	6.95	0.54	0.54
MC			10.26	12.35
FC	6.70	5.97	2.78	1.92
MW			24.39	17.90
FW	15.12	3.26	4.14	0.49

(11) FEMUR NECK

0.05 μGy ; 0.06 %

	RACE		RACE-GENDER	
	GSD (μGy)	%	GSD (μGy)	%
MA			0.98	0.425
FA	0.53	0.23	0.01	0.006
MB			0.08	0.222
FB	0.05	0.08	0.01	0.014
MC			0.000	0.000
FC	0.000	0.000		
MW			0.003	0.002
FW	0.001	0.000		

(12) FEMUR

2.83 μGy ; 2.99 %

	RACE		RACE-GENDER	
	GSD (μGy)	%	GSD (μGy)	%
MA			13.41	5.82
FA	7.13	3.11	0.03	0.01
MB			5.05	13.59
FB	2.69	4.04	0.04	0.04
MC			4.29	5.17
FC	2.28	2.03	0.07	0.05
MW			7.95	5.83
FW	4.34	0.94	0.07	0.01

(13) MYELOGRAM (LUMBAR)

0.60 µGy ; 0.63 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.07	0.03
FA	1.75	0.76	3.65	1.60
MB			0.01	0.03
FB	0.41	0.62	0.86	0.86
MC			0.05	0.07
FC	0.15	0.14	0.26	0.18
MW			0.13	0.10
FW	3.69	0.80	7.91	0.93

(14) BARIUM SWALLOW

1.59 µGy ; 1.68 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.003	0.001
FA	0.09	0.04	0.19	0.08
MB			0.001	0.003
FB	1.52	2.28	3.21	3.23
MC			0.001	0.002
FC	0.009	0.008	0.02	0.01
MW			0.001	0.001
FW	5.25	1.13	11.46	1.35

(15) HEART CATHETERISATION

0.11 µGy ; 0.12 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA	0.17	0.07	0.36	0.16
MB				
FB	0.01	0.02	0.03	0.03
MC			0.16	0.20
FC	0.68	0.61	1.26	0.87
MW			1.51	1.11
FW	0.95	0.20	0.29	0.03

(16) AORTOGRAM (ABDOMEN)

0.21 µGy ; 0.22 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA				
MB			0.008	0.02
FB	0.004	0.006		
MC			0.000	0.000
FC	2.61	2.33	5.49	3.80
MW			0.03	0.02
FW	0.36	0.08	0.74	0.09

(17) RETROGRADE PYELOGRAM

1.55 µGy ; 1.64 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.16	0.07
FA	10.48	4.58	22.14	9.74
MB				
FB	0.40	0.60	0.85	0.85
MC				
FC	1.58	1.41	3.32	2.30
MW			0.32	0.23
FW	16.46	3.55	35.57	4.18

(18) INTRAVENOUS PYELOGRAM

2.06 µGy ; 2.17 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			1.12	0.48
FA	8.70	3.80	17.27	7.59
MB			0.15	0.41
FB	0.60	0.90	1.10	1.11
MC			0.31	0.37
FC	3.29	2.93	6.58	4.56
MW			2.38	1.75
FW	20.88	4.51	42.77	5.03

(19) BARIUM MEAL

0.83 µGy ; 0.88 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.13	0.06
FA	0.55	0.24	1.02	0.45
MB			0.02	0.05
FB	0.50	0.76	1.04	1.05
MC			0.04	0.05
FC	0.66	0.58	1.33	0.92
MW			0.22	0.16
FW	6.30	1.36	13.49	1.59

(20) KIDNEY TOMOGRAPHY

0.42 µGy ; 0.44 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.07	0.03
FA	0.32	0.14	0.60	0.26
MB			0.006	0.02
FB	0.10	0.15	0.20	0.20
MC			0.03	0.03
FC	0.68	0.61	1.41	0.97
MW			0.13	0.09
FW	5.07	1.09	10.92	1.28

(21) CYSTOGRAM

14.39 µGy ; 15.21 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			98.77	42.86
FA	80.28	35.06	59.38	26.11
MB			8.02	21.61
FB	11.01	16.54	14.35	14.42
MC			30.26	36.42
FC	26.40	23.52	22.15	15.34
MW			13.97	10.25
FW	30.25	6.53	49.53	5.82

(22) URETHROGRAM

0.15 µGy ; 0.16 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA				
MB				
FB	0.03	0.04	0.06	0.06
MC			3.02	3.64
FC	1.58	1.41		
MW			0.53	0.39
FW	0.28	0.06		

(23) SALPINGOGRAM

18.98 µGy ; 20.07 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA	8.79	3.84	18.73	8.23
MB				
FB	19.16	28.80	40.63	40.83
MC				
FC	14.63	13.03	30.74	21.30
MW				
FW	25.04	5.40	54.68	6.43

(24) BARIUM ENEMA

20.49 µGy ; 21.67 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			1.41	0.61
FA	0.75	0.33		
MB			0.18	0.49
FB	9.95	14.95	20.89	20.99
MC			2.07	2.49
FC	13.00	11.58	25.04	17.34
MW			3.46	2.54
FW	199.86	43.13	432.37	50.83

(25) BIFURCATION ARTERIOGRAMS / ANGIOPLASTY

0.19 µGy ; 0.20 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA				
MB			0.01	0.03
FB	0.22	0.33	0.46	0.46
MC				
FC	0.01	0.01	0.02	0.02
MW			0.03	0.03
FW	0.02	0.00		

(26) PERIPHERAL ARTERIOGRAM AND ANGIOPLASTY (UPPER LEG)

0.39 µGy ; 0.41 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA				
MB			0.67	1.79
FB	0.35	0.53	0.001	0.001
MC			1.97	2.38
FC	1.04	0.92		
MW			0.41	0.30
FW	0.22	0.05		

(27) LUMBAR SPINE (CT)

0.33 µGy ; 0.35 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA			0.03	0.01
FA	0.58	0.25	1.20	0.53
MB			0.007	0.02
FB	0.19	0.28	0.39	0.39
MC			0.003	0.004
FC	0.002	0.001		
MW			0.13	0.10
FW	2.92	0.63	6.21	0.73

(28) LUNGS / MEDIASTINUM (CT)

0.001 µGy ; 0.001 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA				
MB			0.000	0.001
FB	0.000	0.001	0.000	0.000
MC			0.000	0.001
FC	0.006	0.005	0.01	0.008
MW			0.002	0.002
FW	0.01	0.002	0.02	0.002

(29) ABDOMEN - LIVER, SPLEEN, KIDNEYS, VESSELS, LYMPH NODES (CT)

0.39 µGy ; 0.41 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA				
MB			0.03	0.08
FB	0.22	0.33	0.44	0.44
MC			0.15	0.18
FC	1.70	1.52	3.41	2.36
MW			0.18	0.13
FW	1.50	0.32	3.07	0.36

(30) PELVIS (CT)

0.28 µGy ; 0.29 %

	RACE		RACE-GENDER	
	GSD (µGy)	%	GSD (µGy)	%
MA				
FA				
MB				
FB				
MC			0.14	0.17
FC	1.77	1.58	3.57	2.47
MW			0.17	0.13
FW	2.77	0.60	5.84	0.69

Estimated annual frequency of examinations per thousand population and the GSD from diagnostic radiology (excluding mass miniature and dental examinations).

Country	Year	Population x 10^6	Number of examinations per 1000 population	GSD (μGy)	Reference
Canada	1980			300	NCRP, 1989
France	1982	55.4	820	295	Maccia *et al.*, 1988
Great Britain	1977	55	415	120	Darby *et al.*, 1980
India	1967 - 72	550	35	11	Darby *et al.*, 1980
Iraq	1972	10	158	520	Darby *et al.*, 1980
Italy	1974	55	363	300	Darby *et al.*, 1980
Japan	1974	108	810	170	Darby *et al.*, 1980
Netherlands	1972	12.6	890	280	Darby *et al.*, 1980
Puerto Rico	1968	3	542	430	Darby *et al.*, 1980
Romania	1970	20.5	560	290	Darby *et al.*, 1980
Spain	1986		490		Vãnó *et al.*, 1989
Sweden	1974 - 76	8.1	540	460	Darby *et al.*, 1980
Switzerland	1971	6.3	1350	430	Darby *et al.*, 1980
USA	1964			170	US Dept. Health, 1976
USA	1970	195		200	US Dept. Health, 1976 Darby *et al.*, 1980
USA	1970		669		US Dept. Health, 1976 Wall *et al.*, 1984
USA	1980			307	NCRP, 1989
USSR	1980-81			200	NCRP, 1989
West Germany	1974	1.8	1530	410	Darby *et al.*, 1980
SA (Total)*	1990 - 91	31*	180	95	Present survey
SA (Asian)	1990 - 91	1	379	229	Present survey
SA (Black)*	1990 - 91	21.6*	102	67	Present survey
SA (Coloured)	1990 - 91	3.3	246	112	Present survey
SA (White)	1990 - 91	5.1	423	463	Present survey

* The previous TBVC States (Transkei, Bophuthatswana, Venda and Ciskei) were not included (±6.6 million people).