RADIATION EXPOSURE OF PATIENTS AND ASSOCIATED HEALTH RISKS IN SOME DIAGNOSTIC X-RAY EXAMINATIONS

BY

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A thesis submitted in fulfilment for the Degree of Doctor of Philosophy in the University of Nairobi 1988
DECLARATIONS

This thesis is my original work and has not been presented for a degree in any other University.

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SUMMARY

Exposure to ionizing radiation is associated with the possibility that harmful health effects may be induced in the irradiated individuals, or in their descendants. In order to obtain quantitative assessments of such hazards, it is necessary to determine the radiation absorbed doses, or some related quantities, from various sources of radiation exposure. Medical irradiation during x-ray diagnosis is an important source because it contributes the largest proportion of the collective population dose from man-made sources of radiation exposure.

This thesis is based on studies of the radiation doses received by patients from a sample of diagnostic x-ray examinations at the Withington Hospital, Manchester, United Kingdom, between 1982 and 1983, and at six different x-ray centres in Kenya between 1984 and 1986. A survey of the frequency of radiological examinations at x-ray departments in Kenya during 1986 is also incorporated into the thesis.

The objectives of the studies conducted in Kenya were to provide a data base of patient doses during some diagnostic x-ray examinations, to examine which factors were important in influencing the magnitudes of patient doses, to indicate priority areas for dose reduction, and to make an assessment of the
current annual radiological workload in the country. Attention has previously been drawn to the scarcity of data from the developing countries on both the frequency of radiological examinations and on the magnitudes of patient doses (UNSCEAR, 1982). The major motivation in conducting these studies was to help fill this gap in knowledge.

The studies at the hospital in the United Kingdom were aimed at providing patient dose data over an extended period of time from examinations of relatively low frequency, following a national survey which had yielded few data for these particular types of examination (gastro-intestinal investigations).

Radiation dose measurements were based on thermoluminescence dosimetry (TLD) techniques, using the laboratory facilities of the Christie Hospital and Holt Radium Institute, Manchester, U.K., and the Kenyatta National Hospital, Nairobi, Kenya.

The types of radiological examination for which dose surveys were conducted included barium meal, barium enema, chest radiography and photofluorography, hysterosalpingography, and pelvimetry. The studies involved monitoring some 912 patients, on whom a total of 1,558 dose measurements were made. Preliminary reports of these studies have recently been published in the radiological literature (Tole,
The introductory chapters (1 & 2) review the literature on the hazards of low-level exposure to ionizing radiation and the methodologies employed in patient dosimetry studies, and consider the rationale behind patient dosimetry research.

Chapter 3 reviews the theoretical background of TLD, and examines some of the characteristics of the TLD system used in these studies.

An extensive survey of patient doses during chest radiography and photofluorography is reported in Chapter 4. Mass miniature techniques without image intensification are found to deliver high patient doses. Comparisons between direct dose measurements (TLD) and indirect estimates from technical exposure factors gave reasonable agreement, within a factor of about 2.

Chapters 5 and 6 report data on patient exposures during pelvimetry and hysterosalpingography, respectively. The dose reduction effect of using \( Y_{2}O_{2}S : Tb \) rare-earth intensifying screens in place of \( CaWO_{4} \) screens is demonstrated. Estimates are made of the risks of pelvimetry for the induction of juvenile leukaemia.
Studies of patient dose during gastrointestinal radiology, with special reference to intrahospital dose variations, are reported in Chapter 7. They indicate that overcouch fluoroscopy equipment may have an adverse effect on doses to organs outside the useful x-ray beam. Logistical constraints during national dose surveys are found to make such surveys unsuitable for detailed analyses of patient dose variations.

In Chapter 8, a statistical analysis of dose data from barium meal investigations suggests that depth dose relations derived from plain radiography should not be used for computing organ doses during fluoroscopic examinations.

A survey of the frequency of radiological examinations at x-ray departments in Kenya during 1986 is reported in Chapter 9. The results indicate that the current frequency of radiological examinations is about 32 examinations per thousand population. Examinations of the limbs and the chest were the most frequently performed routine investigations, while studies of the gastro-intestinal tract dominated the special examinations.

Chapter 10 presents an appraisal of the hazards of x-ray diagnosis in Kenya, on the basis of
the scope of radiological services, levels of patient dose, and age distribution in the population.

An overview of the main findings, observations, and recommendations appears in Chapter 11. The recommendations touch on restrictions in the use of photofluorographic equipment, the use of sensitive image receptors, wider dissemination of knowledge on patient referral criteria for radiological investigations, and a greater commitment to improving the status of radiological equipment in Kenya.

The limitations of the present studies are also discussed in Chapter 11, and suggestions made for further research. Further studies are indicated in the areas of patient dose measurements, quality assurance, and radiological manpower utilization.

This thesis makes some important contributions to the subject matter of patient dosimetry in diagnostic radiology. The studies in Kenya provide the first set of patient dose data from the Eastern Africa region. They indicate priority areas for the application of radiation protection measures. The frequency survey provides an insight into the current scope of radiological services in both government and private institutions. The studies in the United Kingdom provide a critical analysis of
some aspects of patient dosimetry methodology. They point out limitations in the analysis of patient dose variations within and between hospitals during national surveys. They examine the problems of relating measured skin doses to organ doses during fluoroscopic examinations.

Based on the findings and observations from these studies, some recommendations are made on measures to improve the radiation protection of the patient during x-ray diagnosis.
CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1. Radiation hazards of x-ray diagnosis

The diagnostic use of x-rays in medicine is concerned with low levels of exposure. The vast majority of examinations are performed with patient doses in the range $10^{-5}$ - $10^{-1}$ gray (Gy), and only in very exceptional cases, such as in extensive fluoroscopy during cardiac procedures, does the patient dose approach 1 Gy.

At these low levels of exposure, there are three possible categories of harmful effects of ionizing radiation:

(i) transformation of somatic cells leading to the induction of malignancy in the subjects exposed.

(ii) mutations in reproductive cells, with the potential for inducing genetic ill-health in the descendants of exposed persons.

(iii) injury to the proliferating and differentiating cells and tissues of the embryo or fetus in utero, leading to malformations and developmental abnormalities.

The International Commission on Radiological Protection (ICRP) has classified radiation effects as either stochastic or non-stochastic (ICRP, 1977).
Stochastic effects are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose, without threshold. The possibility that some radiation effects may be stochastic in nature implies that there may be no dose which is low enough to be regarded as completely safe. This realisation forms the basis of what has come to be known as the ALARA Principle in radiation protection, which stipulates that all unnecessary exposure to radiation should be avoided, and that the doses received during necessary exposures should be kept "As Low As Reasonably Achievable (ALARA)". These recommendations are applicable to patient exposures during x-ray diagnosis.

Non-stochastic effects are those for which the severity of the effect varies with the dose, and for which there may be a threshold dose below which the effect is not observed.

In the dose range encountered in diagnostic radiology, hereditary effects and carcinogenesis are regarded as being stochastic. Teratogenic effects, on the other hand, appear to exhibit some non-stochastic characteristics.

1.1.1. Carcinogenesis

Carcinogenesis in different organs and tissues of the body is now believed to be the major somatic
risk of low-level exposure to ionizing radiation. Evidence that radiation produces cancer in man is obtained from epidemiological studies among groups of people who received high doses of radiation. These include:

- early radiation workers.
- patients who received radiation treatment for various conditions, or underwent multiple x-ray examinations.
- survivors of the atomic bombings of Hiroshima and Nagasaki in 1945.
- victims of radioactive fallout from nuclear weapons testing.
- industrial workers in uranium mines and radium dial painting.

Evidence from epidemiological studies among patients undergoing diagnostic x-ray examinations includes excess childhood malignancies among children irradiated in utero (Stewart et al, 1956; MacMahon, 1962; Stewart & Kneale, 1970), an increased incidence of leukaemia and liver cancer among patients investigated using the $^{230}$Th-containing contrast medium Thorotrast (UNSCEAR, 1977), and an enhanced risk of breast cancer among young women who received multiple fluoroscopic examinations of the chest during management for tuberculosis (Mackenzie, 1965; Boice & Monson, 1977).

Numerical estimates of the risks of carci-
nogenesis induced by low doses of radiation are obtained by extrapolation from observations at high doses. Such estimates are highly dependent on the dose-effect relationships assumed in the extrapolation.

Most risk estimates in radiological protection are derived by linear extrapolation, assuming direct proportionality between dose and effect, although for radiation of low linear energy transfer (LET), such as x-rays, the linear-quadratic dose-effect model is found to fit a large number of experimental observations. This latter model relates an effect, $E$, to the radiation dose, $D$, causing it, through the expression:

$$E = aD + bD^2$$

where $a$ and $b$ are constants. If a biological effect actually follows the linear-quadratic dose-response relationship, then the application of a linear dose-response model to it in extrapolating from a high dose observation point to lower doses will tend to overestimate risks at these lower doses. Dose response models for carcinogenesis have been discussed by many authors (Holford, 1975; Mayneord & Clarke, 1975; Brown, 1976; UNSCEAR, 1977; Land, 1980; NCRP, 1980; Sinclair, 1981). Much uncertainty remains in this complex area of radiobiology.

Some epidemiological studies have attempted to estimate cancer risks at low doses directly from mor-
tality studies among groups of people who received low-level exposure. These groups have included children who received in utero exposure during obstetric examinations of their mothers (Stewart et al, 1956; MacMahon, 1962), and various occupationally-exposed workers (Braestrup, 1957; Mancuso et al, 1977; Najarian & Colton, 1978; Smith & Doll, 1981; Kneale et al, 1983; Aoyama et al, 1983). However, the validity of many such studies has been questioned on various epidemiological grounds, or for incompatibility with other observations (Mole, 1974; UNSCEAR, 1977; Anderson, 1978; Webster, 1981; AAPM, 1986). The epidemiological problems encountered in low-dose mortality studies have been discussed by a number of authors (Rossi & Kellerer, 1972; Pochin, 1976; Reissland et al, 1976; Reissland, 1982; Reissland et al, 1983). These problems include the very large sample sizes for both irradiated and control populations that are required to establish statistical significance at high confidence levels, the complicating effect of the usually long latent period between exposure and cancer induction (in view of the non-specificity of radiation carcinogenesis), and the uncertainties surrounding the possible synergistic role played by various physical, chemical and biological agents which may interact with radiation to induce cancer. In view of these problems, evidence adduced in support of increased cancer incidence from direct observations at low doses must currently be
regarded as inadequate.

Quantitative estimates for the risks of carcinogenesis in various organs and tissues have been made by authoritative expert organisations (BEIR, 1972, 1980; ICRP, 1977; UNSCEAR, 1977). These estimates show relatively high induction risks for the female breast during reproductive life, haematopoietic tissue, the thyroid gland, and the lung. The mortality risk from female breast cancer from low-LET radiation is estimated as \(2.5 \times 10^{-3}\) Gy\(^{-1}\), while for leukaemia and thyroid cancer the risks are \(2 \times 10^{-3}\) Gy\(^{-1}\) each. In addition, leukaemogenesis shows a generally shorter latent period than the solid malignancies. Incidence risks are higher than the mortality risks, typically by a factor of about 2. The total mortality risk from all cancers, averaged over both sexes and all age groups, is estimated as being about \(1.2 \times 10^{-2}\) Gy\(^{-1}\).

Irradiation of the embryo and fetus has been associated with an increased risk of childhood malignancies. This risk is considered in Section 1.1.3.

Epidemiological studies among the Japanese A-bomb survivors have been the most important single source of human data on the late effects of radiation. Individual doses to these survivors have for a long time been based on the tentative 1965 dose (T65D).
But in 1976, the United States Department of Energy released some previously-classified information which necessitated a re-evaluation of dose estimates (Marshall, 1981). The re-evaluation, and the potential effects of the revision on risk factors obtained from this important source of information, are still being studied. Some experts have predicted that risk factors for low-LET radiation are unlikely to be altered by more than a factor of about 2 (Charles et al, 1983).

1.1.2. Genetic harm

Genetic effects may be induced by radiation through gene mutations or chromosomal damage. Among the harmful effects of genetic origin are still births, mental retardation, mongolism, and various malformations. Radiation is only one of the many agents with the potential for causing genetic harm, and it is considered to be a minor contributor to genetic disorders in humans.

There is hardly any evidence of radiation-induced genetic effects from direct observations in man. Most of the data used to predict genetic harm in man are, therefore, derived from animal experiments, particularly in mice. Several important observations and inferences have been made from these laboratory
investigations:

(i) The frequency of radiation-induced mutations depends on the radiation dose, the dose rate, dose fractionation, and the time interval between irradiation and conception.

(ii) The sensitivities of different mutations vary considerably. Any quantitative evaluations of sensitivity, therefore, involve averaging procedures.

(iii) The radiation dose required to double the spontaneous rate of mutations is about 1 Gy (range 0.5 - 2.5 Gy) per generation, for radiation delivered at low dose rates, or in low doses. At genetic equilibrium, this level of exposure would induce genetic effects in about 10% of all live-born offspring in man.

(iv) The male spermatogonia are much more sensitive to radiation-induced mutations than the female oocytes.

Epidemiological studies among the descendants of A-bomb survivors in Hiroshima and Nagasaki have so far not revealed any evidence of excess genetic damage.
This observation suggests that humans are not more sensitive, and may be actually less sensitive, than mice to radiation-induced genetic harm.

Some quantitative estimates of genetic risks from radiation have been made (ICRP, 1977; Oftedal & Searle, 1980; UNSCEAR, 1982). For purposes of assessing individual distress, the risk of serious hereditary ill-health in children and grandchildren following the irradiation of either parent is taken to be about $10^{-2}\text{Gy}^{-1}$, and the additional risk to later generations to be the same. On the assumption that only 40% of gonadal dose is likely to be genetically significant, an average risk factor of $4 \times 10^{-3}\text{Gy}^{-1}$ has been recommended for hereditary effects, as expressed in the first two generations. This risk factor is about one-third the total risk for carcinogenesis.

Radiation-induced genetic effects are now considered to present a lesser degree of risk to populations than previously thought. The assessment of the potential genetic burden in a population from a given source of radiation exposure is based on an estimate of the genetically significant dose (GSD).
This is defined as that dose of radiation which, if it were received by each member of the population, would produce the same total genetic injury to the population as do the actual doses received by the individuals in that population. The GSD may be interpreted to represent the average dose to the gametes that will be effective for reproduction. Studies of the GSD from x-ray diagnosis in many different countries show values well below those that would cause concern (Hall, 1980; Wall et al, 1981). The estimated values of annual GSD, typically in the range 0.1 - 0.5 mGy, are lower than the estimated mutation doubling dose by a factor of several thousand times.

1.1.3. Effects on the embryo and fetus.

Exposure of the embryo or fetus in utero may result in prenatal death, malformations, growth defects, death in the neonatal and infant periods, and increased risk of cancer developing during childhood. These effects have been observed in both experimental animals and man, and are reported in a large body of the literature, for example by Warkany & Schraffenberger, 1947; Russel & Russel, 1952; Hulse, 1964; Ohzu, 1965; Rugh, 1971; Miller & Blot, 1972; Stewart et al, 1956; and Kato, 1971. It is significant that no excess childhood cancers were found in the Japanese A-bomb survivors irradiated in utero (Jablon & Kato, 1970).
In the United Kingdom, a large-scale survey of childhood malignancies among those pre-natally exposed during diagnostic x-ray examinations claimed a significant association between low dose in utero exposure and childhood malignancy, especially leukaemia (Stewart & Kneale, 1970), but this study has remained controversial. Its findings were not in agreement with an epidemiological survey by Court-Brown and colleagues (1960), or with A-bomb studies of pre-natal exposure in Japan (Jablon & Kato, 1970).

The observed effects of pre-natal exposure depend strongly on:

(i) the gestational age at the time of irradiation.

(ii) the total radiation dose.

(iii) the dose rate.

In man, during the first 2 weeks postconception the main effect is death of the conceptus. The period of major organogenesis, extending from the 3rd week to about the 10th week postconception, is associated with a high risk for malformations and developmental abnormalities. Sensitivity to a particular organ malformation varies with the stage of development, being highest during the relevant stage of organogenesis. Observed effects of embryonic exposure include growth retardation, microcephaly, hydrocephaly, mental retardation, co-ordination defects, and other teratogenic
effects. In man, the most important effect appears to be maldevelopment of the brain. Irradiation during the fetal stage (60 days to term) is associated mainly with growth retardation and the possibility of cancer induction in early life. Some evidence suggests that there may be increased sensitivity to mental retardation between weeks 8 and 15 of gestation (Otake & Schull, 1984). Exposure of the fetal oocytes may result in irreversible cell loss and consequently to reduced fertility of the offspring later in life. The risks of teratogenic effects are reduced during the fetal stage.

The probability of radiation effects on the embryo and fetus decreases with decreasing dose and dose rate. Pre-natal death, congenital abnormalities, growth deficiencies, and mental retardation appear to be non-stochastic effects. For most effects, experimental evidence suggests a threshold dose of the order of 0.1 Gy, but some animal studies have reported positive observations at lower doses (UNSCEAR, 1977). The whole question of whether or not thresholds exist for radiation effects arising from pre-natal exposure remains unresolved at the present time.

The available evidence with regard to quantitative risk estimates has been reviewed by BEIR (1972) and UNSCEAR (1977, 1986). The UNSCEAR 1977 report
estimates that the risk of fatal malignancies during the first 10 years of life following low-level exposure in utero would be $(20-25) \times 10^{-3}\text{Gy}^{-1}$, with about a half of the cases being leukaemia. Some sections of this report have been criticised by Mole (1979). Otake & Schull (1984) have estimated a risk coefficient of $400 \times 10^{-3}\text{Gy}^{-1}$ for mental retardation following exposure between gestational weeks 8 and 15. A recent report by UNSCEAR (1986) on the effects of pre-natal exposure has suggested a total weighted risk factor of $300 \times 10^{-3}\text{Gy}^{-1}$ as an upper limit for the combined risks of mortality, malformations, mental retardation, and childhood cancer.

During diagnostic x-ray examinations involving direct beam exposure of the fetus, the radiation dose to the fetus is typically about 10 mGy. The corresponding total risk for teratogenic effects and childhood cancer from such examinations should be lower than the natural incidence of such effects, in the absence of radiation, by at least one order of magnitude. For the four effects considered by UNSCEAR (1986) in proposing the weighted risk factor quoted above, the natural incidence was estimated as 60 cases per thousand children.
1.2. Patient dosimetry studies.

1.2.1. Why conduct dose surveys?

Studies of patient dose during x-ray diagnosis are conducted for several important reasons.

Medical exposure, and x-ray diagnosis in particular, has been identified as the largest source of man-made radiation exposure to populations. In some industrialized countries, medical exposure contributes nearly as much as natural background radiation (Bengtsson et al, 1978; UNSCEAR, 1982). Efforts to minimize population exposure from this important source are greatly aided by studies of patient dose.

The ICRP concept of ALARA has been mentioned briefly in Section 1.1. Measurements of patient dose provide a means of checking that radiological practice conforms with the ALARA principle.

The techniques employed by radiological personnel, and the status of the equipment they use, are important factors influencing patient dose. Determinations of patient dose provide an overall view of radiological practice and equipment status from the point of view of protecting the patient from the hazards of radiation.

A notable feature of patient doses during
x-ray diagnosis is the very wide variation which may be present in radiation doses from the same type of examination between different centres, or between different examination rooms in the same department. Implicit in such possible large variations is the implication that the scope exists for the reduction of patient doses at the centres, or facilities, recording the highest doses. Patient dosimetry studies help identify these variations, and their possible causes.

Measurements of patient dose provide a data base of levels of patient exposures at the times the studies are performed. The data can subsequently be used to monitor the effects on patient dose of new technological innovations, or the introduction of new techniques. They may also serve as useful references for future epidemiological studies.

In conjunction with quality assurance studies, patient dosimetry research offers the possibility for optimizing patient dose with image quality in diagnostic radiology.

1.2.2. Special considerations in developing countries.

There are several unfavourable factors in the developing countries which may lead to the delivery of high patient doses during x-ray examinations.
The operation of radiological equipment, and even the performance of examinations, are quite often in the hands of personnel who have not received specialized training in the radiological sciences. Due to economic constraints, old and sometimes obsolete equipment cannot always be put out of service. The continued use of direct fluoroscopy and photofluorography without image intensification are good examples of potentially high-dose techniques. The lack of proper maintenance facilities for radiological equipment is common, and quality assurance has made little impact as a tool for dose-reduction. Sometimes it is difficult to ensure fresh supplies of films and chemicals.

Larger proportions of younger patients are more likely to be subjected to radiological examinations than in the industrialized countries, partly because of age distributions in the population with more younger members, and partly because of a popular tendency among medical staff to extend more thorough examination to the younger patient. The significance of this point in considering radiation hazards is that the probability that a given low dose of radiation will induce a harmful effect during one's lifetime increases as the age at irradiation decreases, if only because of the usually long latent period associated with delayed radiation effects. Gonadal exposure of the younger is also associated with higher
risks for the induction of genetic effects, because on average their child expectancy is higher.

Finally, some developing countries may be carrying out rapid expansion programmes of their radiological services, and consequently increases in population exposures can be expected. All these considerations make radiation protection especially important in the developing countries.

1.3. Major dose surveys.

Data on patient doses from x-ray diagnosis are obtained from measurements carried out during surveys at x-ray departments. Such studies may vary widely in scope.

Surveys have been conducted on a national scale in Sweden (Larsson, 1958; Bengtsson et al, 1978), the United Kingdom (Adrian Committee, 1960, 1966; Wall et al, 1980), the U.S.A. (Gitlin & Lawrence, 1966; DHEW, 1973), Japan (Hashimuze et al, 1972), India (Supe et al, 1974), Italy (Bennasai et al, 1977), and other countries. Such studies may be aimed at assessing the population exposure from diagnostic x-rays to a particular organ of interest, for example the gonads, or at collecting data on doses to different organs from the various types of radiological examination.
Regional surveys confined to limited regions of the countries in which they were conducted have also been reported (Matthews & Miller, 1969; Norwood et al, 1959; Izenstark & Lafferty, 1968; Pasternack & Heller, 1968; Padovani et al, 1987).

The largest source of patient dose data comes from surveys conducted at single institutions. Institutional surveys are usually directed at selected types of radiological examination, chosen because of the special sensitivity to radiation of the organ or tissue exposed, for example mammography, or because the examination is generally associated with high patient doses, for example chest fluoroscopy during cardiac catheterization, or because the exposed group is regarded as being sensitive, for example in obstetric radiography. Institutional surveys for these and many other examinations are reported widely in the literature. Dose surveys for the examination types covered in this thesis are reviewed under the relevant chapters.

Early expert reports on the hazards of radiation emphasized genetic effects as being the major concern of population exposures. Reflecting this concern, early surveys of patient dose tended to concentrate on assessments of gonadal dose (Martin, 1955; Stanford & Vance, 1955; Ardran & Crooks, 1957; Clayton et al,
1957; Billings et al, 1957; Lincoln & Gupton, 1958; Larsson, 1958; Cooley & Beentjes, 1964). The concept of the genetically significant dose (GSD) was developed as a criterion for the assessment of genetic harm from population exposures (Osborn & Smith, 1956; ICRP/ICRU, 1957; UNSCEAR, 1958), and estimates of the GSD were made in many different countries (Osborn & Smith, 1956; Larsson, 1958; Adrian Committee, 1960; Beekman, 1962; Hammer-Jacobsen, 1963; Penfil & Brown, 1968; Reentjes, 1969; Hashimuze et al, 1972a; Supe et al, 1974; Bennasai et al, 1977; DHEW, 1976; Darby et al, 1980).

When the leukaemogenic effect of radiation became apparent, much attention was paid to doses received by the active bone marrow, regarded as the most relevant criterion for assessing the leukaemia risk from low doses of radiation. A suitable index for expressing this risk in an exposed population is the per caput mean bone marrow dose (CMD).

The first measurements of bone marrow dose were reported by Laughlin et al (1957) during chest radiography. The earliest comprehensive surveys to report estimates of the CMD were conducted in Australia (Martin, 1958), the United Kingdom (Spiers, 1963; Adrian Committee, 1966), the Netherlands (Weber, 1964), and Japan (Hashimuze et al, 1965, 1972b).
In the U.S.A., the first national estimate of the CMD was reported in 1977 by Shleien and colleagues, using data from the 1970 national survey. The results of these studies indicate that the CMD from diagnostic radiology in the industrialized countries fell in the range 0.3–1.9 mGy during the 1950s and 1960s.

Recently, it has become increasingly clear that the induction of solid malignancies by radiation in some organs may be as important, if not more so, as leukaemogenesis. This has led to studies of doses to other organs and tissues, besides the active bone marrow, and also to proposals for other risk indices for the assessment of somatic risk. These indices are mentioned in Chapter 2.

There have been few reports on surveys of patient dose from the developing countries. The UNSCEAR reports up to 1982 make reference to some data from Egypt, Argentina, Brazil, India, Iraq, Thailand, Romania and Yugoslavia. More studies should be encouraged in the developing countries.
CHAPTER 2

METHODOLOGY IN PATIENT DOSIMETRY

In this chapter, methods employed in the determination of radiation absorbed doses to patients and related radiation quantities are reviewed. Survey methods for estimating the frequencies of radiological examinations are considered separately in Chapter 9.

2.1. Dosimetry methods

Ionization, film, and thermoluminescence dosimetry methods have been used to measure radiation doses to patients during x-ray diagnosis.

Some major surveys employing ionization methods include those of Martin (1955) in Australia, Stanford & Vance (1955) and the Adrian Committee (1960) in the United Kingdom, Hammer-Jacobsen (1957) in Denmark, and Supe et al (1974) in India. For the Adrian survey, a special ionization chamber suitable for diagnostic x-radiation was developed (Osborn & Burrows, 1958).

In Sweden, Sievert developed condenser ionization chambers during the 1920s which could be exposed detached from the measuring instrument (Sievert, 1965). These chambers were used in some of the earliest measurements of patient dose in x-ray diagnosis in the
1930s, and later in some major surveys (Larsson, 1958; Epp et al, 1963). Their small size made them suitable for intracavitary measurements in both patient and phantom studies before the use of TLD became more popular.

Large, parallel-plate ionization chambers which intercept the whole of the x-ray beam directed at the patient have been developed and used for the measurement of exposure-area product (Reinsma, 1959; Morgan, 1961; Ardran & Crooks, 1963; Bushong et al, 1973). These "Diamentor" instruments have been found particularly useful in assessing patient exposures during fluoroscopic examinations, and in estimating the energy imparted from both radiographic and fluoroscopic examinations (Carlsson, 1963; Ardran & Crooks, 1965; Bengtsson et al, 1978; Gustafsson, 1979).

Film dosimetry can be used to measure very low doses of radiation. Ardran & Crooks (1957) used screen-film techniques to measure gonadal exposures as low as $2.58 \times 10^{-7}$C Kg$^{-1}$ (1 milliroentgen). For higher exposures, up to tens of roentgen, non-screen film may be used. Industrial non-screen film jackets have been used for dosimetry during fluoroscopic examinations in both phantom and patient studies (Blatz & Epp, 1961; Liuzzi et al, 1964; Yoshinaga et al, 1967; Takeshita
et al, 1972). Under certain conditions, personnel monitoring films have been found useful for assessing patient doses (Spalding & Cowing, 1964; Supe et al, 1974).

Nowadays, the most common method of patient dose measurement is thermoluminescence dosimetry (TLD), which has been the basis of many important studies, including national dose surveys in Sweden (Bengtsson et al, 1978) and the United Kingdom (Wall et al, 1980).

2.1.1. Special attributes of TLD

The widespread use of TLD in patient dose measurements is due to several attractive characteristics. Thermoluminescent (TL) materials can be made into small, robust dose meters, allowing for accurate positioning and reasonable spatial detail in dose measurement. They are suitable for use over wide ranges of dose and dose rate. Some TL materials, especially Li$_2$B$_4$O$_7$, have nearly the same photon effective atomic numbers as soft tissue, hence they will not cast shadows on image receptors, and their energy responses show little variation over wide ranges of photon energy. The radiation energy stored in TL crystals following radiation exposure can be retained over long periods of time before read-out. Finally, TL dose meters can be reused after suitable thermal treatment.
2.2. Assessment of patient dose.

2.2.1. Direct and indirect dose determination

The radiation dose received by a patient during a diagnostic x-ray examination may be deter¬mined by direct measurement, or estimated indirectly from recorded equipment factors and irradiation geo¬metry.

The direct method involves the positioning of a radiation dose meter at a suitable site on the patient during the examination to monitor the actual dose delivered at the site of measurement. Measurements are commonly made at positions on the patient's skin surface, for reasons of accessibility. Some workers have made direct estimates of organ doses in patients by performing intracavitary measurements. Dose meters have been inserted into the rectum or the vaginal fornix to estimate doses to the ovaries (Martin, 1955; Hammer-Jacobsen, 1957; Larsson, 1958). This approach is limited in scope and inconvenient to the patient. Nowadays such measurements are performed in anthropomorphic phantoms rather than in humans.

Indirect methods of dose assessment involve the determination of radiation output from an x-ray machine, usually free in air at a specified distance
from the tube target, for different combinations of exposure factors. The patient need not be in position during this exercise. The dose to the skin, or at some other point in the subject, is then calculated from the known output in conjunction with x-ray interaction data (such as backscatter factors, percent depth doses, and tissue-air-ratios) and the geometries of actual examinations.

Indirect methods are less demanding in terms of the numbers of measurements required to estimate average patient doses. They can also be employed to obtain retrospective dose estimates, provided the exposure parameters are known. On the other hand, direct methods are generally more accurate for the assessment of individual patient doses.

2.2.2. Assessment of organ dose

The point of measurement is rarely the endpoint of interest for purposes of dose determination. The absorbed dose (or some related quantity) to a particular organ in the subject undergoing a radiological examination is usually derived from the dose recorded at the point of measurement by applying appropriate factors relating the doses between the two positions.
Organ-to-skin dose ratios are applied to measurements made on the skin surface in deriving doses to other tissues and organs in the subject. Experimental studies are necessary to determine such ratios for the different organs and for the various radiological examinations and beam projections.

Stanford and Vance (1955) carried out measurements of ovary-to-skin dose ratios for different types of examination using human cadavers and tissue-equivalent phantoms. Water, pressed-wood, paraffin wax and other materials have been used to simulate the radiation attenuation properties of the human body. Anthropomorphic phantoms with natural human skeletons embedded in various synthetic materials have been designed for patient dosimetry studies. The ICRP (1975) has specified values for the anatomical, physical, and elemental constitution of a reference human phantom for use in radiation protection dosimetry.

Anthropomorphic phantoms have been used to determine doses at various positions in the body from both primary beam and scatter radiation during x-ray examinations (Rohrer et al, 1964; Archer et al, 1979; Wall et al, 1980; Gray et al, 1981; Ragozzino et al, 1981; Kumamoto, 1985). The most elaborate application of anthropomorphic phantoms in diagnostic radiology is probably in the determination of the mean dose to
the active bone marrow (Spiers, 1963; Adrian Committee, 1966; Ellis et al, 1975).

Indirect methods also employ tissue-air ratios for the calculation of organ doses. The tissue-air ratio (TAR) relates the absorbed dose to a small mass of tissue in the subject to the absorbed dose that would be measured at the same spatial point in free air within a volume of the tissue material just large enough to provide electronic equilibrium at the point of reference. The TAR may be determined experimentally in a tissue-equivalent phantom (Schulz & Gignac, 1976), or calculated using a Monte Carlo photon transport model.

The Monte Carlo method of organ dose determination is based on a computer simulation of the energy-deposition histories of x-ray photons, using known interaction coefficients, in a mathematically-described heterogeneous anthropomorphic phantom. The interaction histories of individual photons are statistically traced and recorded. The absorbed dose to a particular region of the phantom is calculated by averaging the energies deposited in that region over large numbers of photons.

Rosenstein (1976) has developed a Monte Carlo
photon transport model suitable for diagnostic quality x-rays. He presents the basic data for the practical user in the form of TAR tables for various organs using different beam projections and radiation qualities.

Although other photon transport methods of estimating organ doses have been proposed, the Monte Carlo technique remains the most preferred of the theoretical approaches to patient dosimetry problems.

2.3. Assessment of total risk

Diagnostic x-ray examinations involve non-uniform irradiation of the body tissues and organs. Furthermore, the various tissues and organs show differences in their susceptibility to radiation-induced harmful effects. These considerations make the assessment of the total risk associated with a diagnostic exposure a complicated subject.

Two indices of harm to an irradiated population, the GSD and the CMD, have so far been referred to (Chapter 1). Neither of these indices of risk provides a representative estimate of the total risk from a given exposure, because they do not address themselves to possible risks arising from exposures to organs and tissues other than the gonads (in the
2.3.1. **Effective dose equivalent**

In order to evaluate the total risk to an exposed individual, Jacobi(1975) introduced the concept of effective dose, which provides a weighted index of risk, taking into account the different radiation doses that may be received by the various organs and tissues, as well as their different radio-sensitivities. This concept was subsequently recommended by the ICRP (1977) for application to radiation protection problems in occupationally-exposed personnel. It has also been found useful in considering the total risk from medical exposures. Its main shortcomings here are:

(i) the practical difficulties in obtaining detailed data on the absorbed doses received by different organs and tissues during radiological examinations.

(ii) the use of risk factors averaged over both sexes and all age groups, whereas, in practice, some types of radiological examination, for example mammography, are performed on specific population groups.

The effective dose equivalent (ICRP, 1977)
incorporates an element of personal distress to the exposed individual from possible genetic effects expressed in the first two generations. It is significant to note that, in considering the relative importance of somatic versus genetic risks from low-level exposure, the weighting factor for genetic harm is currently taken to be 25% of the total personal risk of $1.65 \times 10^{-2} \text{Sv}^{-1}$ arising from uniform, whole-body irradiation.

The effective dose equivalent concept can be extended to provide a population index of detriment, the collective effective dose equivalent, by summing up the individual effective dose equivalents received by a large number of members of the population.

Other weighted risk indices similar in concept to the effective dose equivalent have been proposed for expressing the total somatic risk from diagnostic x-ray exposure (Laws & Rosenstein, 1978; Pauli, 1978, 1981; Kramer et al, 1981).

2.3.2. **Energy Imparted**

One of the concepts that have been proposed for expressing the somatic risk from radiation is that of the energy imparted (previously called integral dose, or volume dose). The energy imparted
is a measure of the total radiant energy deposited by ionizing radiation in a tissue volume in the patient during a radiological examination. Its application to problems of patient dosimetry in diagnostic radiology has been considered over several decades (Feddema & Osterkamp, 1953; Reinsma, 1959; Morgan, 1961).

The energy imparted is normally estimated from measurements of the exposure-area product using large, transparent, parallel-plate ionization chambers attached to the x-ray tube diaphragms. The ionization chamber intercepts the whole of the x-ray beam incident on the patient. Because its walls are made from transparent plastics, its presence in the beam path does not interfere with light-beam indication of the radiation field. Early models of the instrumentation for measuring the exposure-area product were developed by Reinsma (1959), Morgan (1961), and others. Diamentor transmission ionization chambers (PTW, Freiburg) have since become commercially-available.

The energy imparted may also be estimated from TLD measurements at various sites in phantom cavities, or by Monte Carlo calculations.

In order to assess the hazard associated
with an exposure, it is necessary to derive the energy imparted from the measured quantity. Carlsson (1963) proposed methods of relating exposure-area product to the energy imparted. His approach has been applied by others to assess patient exposures (Bengtsson et al, 1978; Gustafsson, 1980). Shrimpton et al (1981) have reported further experimental studies and provided a critical analysis on the subject.

The energy imparted does not use organ-weighted risk factors to assess total risk, but its magnitude has been said to be closely related to such risk (Bengtsson et al, 1978).

Other advantages usually cited for considering the energy imparted as a measure of potential radiation hazard from x-ray diagnosis are that it is easily derived from the exposure-area product, a readily measurable quantity, and that it is a less variable quantity than the absorbed doses to individual organs.

Bengtsson & Jensen (1979) have suggested that the energy imparted should be adopted as a general index for somatic and hereditary effects.
CHAPTER 3

TECHNICAL ASPECTS OF THERMOLUMINESCENCE DOSIMETRY

Throughout this work, absorbed doses to patients were measured using thermoluminescence dosimetry (TLD) techniques. In Part A of this chapter, the theoretical basis of TLD is briefly reviewed, while in Part B, some characteristics of the TLD system used for the measurements reported in this thesis are presented.

PART A: THEORETICAL BASIS OF TLD

3.1. Principle of TLD

Thermoluminescent (TL) materials are crystalline substances which can absorb energy from ionizing radiation, store some of the absorbed energy in the crystals, and subsequently release this stored energy in the form of visible electromagnetic radiation upon thermal stimulation. The emission of optical radiation takes place at a temperature below that of incandescence of the TL material: this is the distinguishing feature between thermoluminescence and visible black-body emission.

The phenomenon of thermoluminescence may be explained in terms of the band theory of solids. Possible mechanisms have been reviewed by McKinlay
The absorption of radiation energy results in the transfer of electrons from one energy state to another, causing excitation and some free movement of charge carriers within confined energy bands. Following excitation, some electrons get trapped in metastable positions which occur at crystal lattice imperfections, or at impurity centres created deliberately during manufacture of the TL material by addition of trace quantities of suitable activators. The input of external thermal energy in TLD is required to release such trapped electrons from the metastable positions. The probability, $p$, of an electron being released from a metastable state of trap depth $\Delta E$ is given by:

$$p = s \cdot \exp \left( -\frac{\Delta E}{kT} \right) \quad \text{Eq. 3.1}.$$

where $s$ is a constant characteristic of the trap centre, $k$ is the Boltzmann constant, and $T$ is the absolute temperature. The trap depth $\Delta E$ is effectively the energy difference between the metastable state and the free-electron energy state.

Thermoluminescent materials are characterized by large values of $\Delta E$ in comparison to other types (fluorescent, phosphorescent) of luminescent substances. The release of trapped electrons by heating
an irradiated TL material is followed by electron transitions to the ground state, with simultaneous emission of visible and other electromagnetic radiations. At a given heating temperature, the intensity of the light emitted from a given trap level will depend on the number of electrons trapped in the metastable positions at that trap depth. This number will in turn depend on the energy initially absorbed by the TL material from ionizing radiation. There is thus a relationship between the intensity of emitted light and the absorbed dose in the TL material. This relationship can be established by calibration.

3.2. **Glow Peaks**

Glow peaks are observed at different heating temperatures, corresponding to different amounts of thermal energy required for effective release of electrons from metastable positions at different trap depths. The glow peak characteristics of a TL material depend on the band structure of its crystals, the type(s) and amount(s) of activator(s) added, and the method of preparation. They are also influenced by many other factors, including thermal treatment, irradiation history, storage conditions and handling, and temperature-time profiles during dose read-out.
Equation 3.1. implies that, at a given ambient temperature, low temperature glow peaks (corresponding to small values of $\Delta E$) are more susceptible to fading of the stored energy than are higher temperature peaks. In practical TLD, the energy stored in these unstable "shallow traps" is released prior to measurement by a pre-read anneal in which the TL dose meter is heated for a suitable period of time at a temperature below the range covering the important dosimetry peaks.

3.3. Measurement of the TL signal

Dose read-out from an irradiated TL dose meter is carried out in a TLD Reader, whose essential components are a heating facility, a photomultiplier (PM) tube for measuring the intensity of the emitted light, and an electronic system for recording the magnitude of the TL signal. The TLD Reader must be capable of providing an accurate temperature-time profile, including timed temperature holds at pre-selected temperatures, and a controlled temperature-time gradient.

Only one or two glow peaks are chosen for measuring the light signal. A dosimetry peak is suitable if it has a relatively high emission of light, and if it is also well-resolved (small value
of the full-width at half maximum). The signal size may be determined by integrating the total area under the dosimetry peak(s), or by measuring the maximum height of a major dosimetry peak.

The pre-read anneal and read temperatures are selected on the basis of the glow peak characteristics of the phosphor preparation, while the time for signal measurement is carefully chosen to optimize the signal-to-noise ratio. Recording of the TL signal is restricted to the read zone.

3.4. Dose Erasure

One of the attractive features of TLD is that dose meters can be re-used after thermal dose erasure. To achieve effective release of residual stored energy after read-out, it is usually necessary to subject the TL material to further thermal treatment before re-use. Details of the required heating regime vary in different phosphor materials, depending on electron trap characteristics. This post-read (or pre-irradiation) anneal is sometimes carried out in the TLD Reader immediately after dose read-out, but more commonly, external oven anneal is used for effective erasure, especially from TL phosphors with complex glow peak characteristics, or following radiation exposures to high doses.
3.5. TL Phosphors for Clinical Dosimetry

Most TLD systems for patient dosimetry are based on the use of preparations of LiF and Li$_2$B$_4$O$_7$ in various physical forms. The important characteristics of these and other phosphors have been extensively reviewed by McKinlay (1981) and Horowitz (1981), among other authors. Lithium borate has better tissue-equivalence, simpler glow peak characteristics, and a higher intrinsic efficiency for TL emission. Its major disadvantage is its predominantly yellow-orange spectral emission, with peak wavelength at about 600 nm, which does not match the predominantly blue spectral response of most commercially-available PM tubes. The 400 nm peak emission of LiF is more efficiently detected, making this phosphor several times more sensitive than Li$_2$B$_4$O$_7$ when used in conjunction with TLD Readers with blue-sensitive PM tubes, despite the latter phosphor's higher intrinsic TL efficiency.

A TLD system based on Li$_2$B$_4$O$_7$, employing an instrument with an extended spectral response covering the peak wavelength of this phosphor efficiently, was developed for patient dose measurements in diagnostic radiology (Langmead & Wall, 1976), tested in a pilot survey (Langmead et al, 1976), and subsequently used in the 1977 national survey of gonadal doses in the United Kingdom (Wall et al, 1980).
Lithium fluoride has been more commonly used in clinical dosimetry. It has a photon effective atomic number of 8.2 (compared to 7.4 for soft tissue). Its glow peak characteristics are complex, making it necessary to subject the phosphor to elaborate anneal procedures prior to re-use. In LiF:Mg:Ti, as many as 12 glow peaks have been identified in the temperature range 60-400°C. Glow peaks 4 & 5, appearing in the temperature range 170-210°C, are normally used for dosimetry.

The main drawback of LiF at diagnostic X-ray qualities is its relatively poor energy-response characteristics, with an over-response of up to 40% relative to $^{60}$Co radiation quality. For energy spectra that are difficult to establish, such as the tissue-modified spectra at various organ positions during x-ray examinations, Li$_2$B$_4$O$_7$, with its maximum energy-response variation of about 10% relative to $^{60}$Co gamma rays, is a superior phosphor. When LiF dose meters are used, energy-dependence corrections in the range 10-40% are necessary for diagnostic beams, relative to $^{60}$Co radiation.

PART B: CHARACTERISTICS OF THE TLD SYSTEM USED

3.6. Description of the System

Measurement of radiation dose was carried out
using thermoluminescent LiF:Mg:Ti in conjunction with the Toledo 654 TLD Reader (Vinten Co. Ltd., Surrey, England).

3.6.1. The TLD Reader

The Toledo 654 TLD Reader (Fig. 1) is a versatile instrument capable of measuring a very wide range of radiation doses and accommodating many different physical forms of TL dose meter. Its design features have been described in a thesis by Robertson (1981).

The unit offers a choice of phosphor heating cycles between a "Standard Module" with pre-set temperature-time profiles, and a "Research Module" which allows the operator to select the important variables to suit different TL phosphors. The variable options of the "Research Module" include the heating rate, and the temperatures and times for the pre-read anneal, read, and post-read anneal zones. In both modules, it is possible to switch out the anneal zones independently, if external oven anneal is preferred. In the studies reported in this thesis, the "Research Module" was used throughout.

The light measurement system utilizes a bi-alkali (CsK) PM tube whose spectral sensitivity (peak at about 380 nm) closely matches the spectral emis-
Fig. 1. The Toledo 654 TLD Reader.
sion of LiF (peak at about 400 nm). The PM tube generates a current proportional to the light intensity incident upon its photoemissive surface. This current is converted to a digital signal by a current-to-pulse converter, then fed to a scaler, which registers the magnitude of the signal on a digital display. The sensitivity of light measurement may be electronically varied over a wide range by means of operator-selected switch positions. Internal and external light sources, consisting of $^{14}$C-impregnated plastic phosphors, provide means for checking the system performance.

A dual-pen chart recorder may be connected to the instrument, via a ratemeter, to plot glow curves. The count rate from the scaler is converted to an analogue signal by the ratemeter. The chart recorder displays simultaneously the relative thermoluminescence intensity and the relative phosphor temperature along the same time base.

A facility is provided for the controlled flow of dry nitrogen gas through the heating compartment during the heating cycle. This inert gas flow reduces triboluminescence.

3.6.2. The LiF:Mg:Ti dose meters
Lithium fluoride doped with magnesium
and titanium was used in 2 physical forms:

(i) as solid discs in a polytetrafluoroethylene (PTFE) base,

(ii) as pure loose powder sieved to particle size range 75 - 200 μm diameter.

These dose meters are shown in Figure 2.

The discs had a phosphor loading of 30% LiF by weight, a diameter of 12.7 ± 0.2 mm, a thickness of 0.40 ± 0.02 mm, and lithium isotopic concentrations of 99.99% $^7\text{Li}$ and 0.01% $^6\text{Li}$.

Powder was sieved to minimize grain-size effects on TL sensitivity (Driscoll, 1977; Driscoll & McKinlay, 1981).

3.7. Thermal treatment and read cycle parameters

Pre-irradiation anneal was carried out in external ovens. The high temperature anneal was 1 hr. at 300°C for LiF (PTFE) discs and 1 hr. at 400°C for pure powder. The temperature difference arises because, although the higher temperature is desirable for more effective dose erasure, PTFE undergoes a change of state at 327°C. For both powder and the discs, the high temperature anneal was followed by
Fig. 2. Thermoluminescent LiF:Mg:Ti dose meters; top, LiF powder in plastic sachet, and bottom, LiF (PTFE) discs.
a low temperature anneal of 16 hr. at 80°C. This reduces the number of electron traps associated with the low temperature peaks 1-3, thereby enhancing the contribution of the dosimetry peaks 4 and 5 to the TL signal after irradiation.

The read cycle parameters selected on the "Research Module" were identical for both forms of dose meter. These were as follows:

Ramp rate (temperature gradient): 25°Cs\(^{-1}\)
Pre-read anneal temperature hold: 135°C
Pre-read anneal time : 16s
Read temperature hold : 240°C
Read time : 16s
Anneal : OUT

A glow curve obtained using these parameters during a read-out cycle for an irradiated LiF (PTFE) 0.4 mm thick disc is shown in Figure 3.

The TL signal was measured by integrating the light output during the read time only (between the two spikes in Figure 3).

3.8. Calibration of the TLD system

The TLD Reader/powder dose meter and Reader/disc dose meter systems were calibrated differently
Fig. 3. Glow curve obtained with LiF (PTFE) disc, showing TL emission from dosimetry peaks 4 & 5.
and will be considered separately. Powder was used for monitoring patients during gastro-intestinal studies only, and the procedure used to calibrate the Reader/powder system is presented in Chapter 7. The rest of the studies employed LiF (PTFE) disc dose meters. Calibration of the Reader/disc system was carried out with the assistance of the Dosimetry Section of the International Atomic Energy Agency (IAEA) in Vienna, Austria. The procedures used will now be briefly considered.

3.8.1. IAEA calibration of the Toledo Reader/LiF (PTFE) disc dose meter system

For exposures in the range 10mR-10R, dose meter irradiations were carried out at a distance of 9m from a 60Co source, while for higher exposures a distance of 0.85 m was used. The field size at the shorter distance was 10 x 10 cm². The same collimator settings were used at 9m distance, giving a larger field size of 1.06 x 1.06 m² at this distance.

The exposure rates on reference date January 1, 1986 were 77.520 R min⁻¹ at 0.85 m distance and 11.78 mRs⁻¹ at 9 meters. The exposure rate at the longer distance was determined using a 30 cc spherical ionization chamber which serves as one of the tertiary standards at the Agency labora-
This instrument was calibrated against the Agency's secondary standard, a 0.325 cc ionization chamber type NE 2561 (Nuclear Enterprises Ltd., U.K.). The secondary standard was calibrated at the International Bureau of Weights and Measures (BIPM) in Sèvres, France.

The exposure rate at 0.85 m was determined directly with the secondary standard using free-in-air measurements. Calibration factors for this reference instrument had a combined uncertainty (1 S.D.) of 0.24% for $^{60}\text{Co}$ gamma rays and 0.11-0.15% for X-rays.

For $^{60}\text{Co}$ calibrations, the discs were irradiated in a perspex phantom at a depth of 5 mm, with a backscatter depth of at least 10 mm. The calibration geometry is shown in Figure 4.

Following calibration exposures in Vienna, dose read-out was done using the Toledo 654 TLD Reader in Nairobi. The sensitivity of the Reader was adjusted to give a digital display of 1 digit per nett exposure of 1 mR for calibration discs receiving exposures up to 1 R, and 1 digit per nett exposure of 10 mR for discs receiving exposures $>1$ R. The 2 sensitivity scales showed very good agreement – an important factor when reading out unknown exposures.
FIG. 4. CALIBRATION GEOMETRY. (a) Exposure of LI ionization chamber with secondary standard.
(b) Exposure of LiF discs in perspex phantom.

During the period covering these studies, IAEA calibrations were made twice for $^{60}\text{Co}$ radiation and once with x-rays of quality 100kVp, 4 mm Al HVT. The second $^{60}\text{Co}$ calibration, carried out 18 months after the first, resulted in a small adjustment of the Toledo Reader sensitivity settings. The main purpose of the x-ray calibration was to check the energy response correction factor for diagnostic x-rays relative to $^{60}\text{Co}$ radiation, and to determine sensitivity settings for the Reader appropriate to low-energy x-rays.

Before the x-ray calibration was performed, absorbed doses to patients were calculated using the $^{60}\text{Co}$ calibrations. In converting the measured exposure to absorbed dose in soft tissue for $^{60}\text{Co}$ radiation, an exposure of 1 roentgen ($2.58 \times 10^{-4} \text{C Kg}^{-1}$) was taken to be numerically equal to an absorbed dose of $10^{-2}$ gray (1 rad). This approximation derives from the relationship between the exposure, $X$, and the absorbed dose, $D_{ST}$, in soft tissue:

$$D_{ST} = \frac{W_{AIR}(\mu_{en}/\rho)_{ST}}{e (\mu_{en}/\rho)_{AIR}} X \ldots \ldots \text{Eq. 3.2.}$$

where $W_{AIR}$ is the mean energy expended in air per ion pair formed, $e$ is the electronic charge, and $\mu_{en}/\rho$ represents the mass energy absorption coefficients in soft tissue (ST) and in air.
The quotient \( \frac{(\mu_{en}/\rho)_{ST}}{(\mu_{en}/\rho)_{AIR}} \) is a function of photon energy. For \(^{60}\)Co gamma radiation, the simplifying approximation introduces a systematic over-estimate of the absorbed dose by about 5%.

The measured TL signal is proportional to the radiation absorbed dose, \( D_{LiF} \), in the LiF dose meter, which is related to \( D_{ST} \) by the equation:

\[
D_{LiF} = D_{ST} \frac{(\mu_{en}/\rho)_{LiF}}{(\mu_{en}/\rho)_{ST}} \quad \text{Eq. 3.3.}
\]

The mass energy absorption coefficient ratio in Eq. 3.3. varies considerably between \(^{60}\)Co radiation and diagnostic x-ray quality. Water is commonly used as a dosimetric substitute for soft tissue. The variation of the ratio \( \frac{(\mu_{en}/\rho)_{LiF}}{(\mu_{en}/\rho)_{H_2O}} \) with photon energy has been plotted by Greening (1981).

To obtain the absorbed doses to patients due to diagnostic x-rays, the apparent \(^{60}\)Co doses were divided by a factor of 1.40 to account for LiF over-response to x-rays. This factor was taken from the experimental results of Rudên (1976), who studied the energy response of LiF(PTFE) discs similar to those used in this work and obtained factors in the range 1.31-1.42 for radiation qualities ranging from 50kV with 1mm Al total tube filtration to 140kV with 4mm Al total filtration.
The results of the x-ray calibration (Appendix C) justified the use of this factor, despite some differences in x-ray quality between the IAEA calibration beam and the diagnostic beams used at the survey centres in Kenya, which were produced by single-phase generators, and had less filtration.

3.9. TLD System Performance Tests

3.9.1. Linearity

Measured signals showed a very good linear relationship to dose well beyond the range of interest for these studies (0-0.30 Gy). The variation of the TL signal with exposure is shown in Figures 5 a (low exposures) and 5 b (high exposures) for LiF(PTFE) discs exposed to known doses at the IAEA Dosimetry Section, Vienna. There is no evidence of supralinearity for exposures up to 200 R.

3.9.2. TL background signals on the LiF(PTFE) discs

The LiF (PTFE) discs showed high background levels, recording signals which were typically equivalent to about 30-40 mR of 60Co radiation immediately after the standard pre-irradiation
Fig. 5 a. Variation of TL signal with exposure (100–1000 mR).
Fig. 5 b. Variation of TL signal with exposure (50 - 200 R)
anneal. This background increased with storage time.

The increase of background TL signals on LiF phosphors during storage has been attributed largely to ultraviolet-induced phototransferred thermoluminescence (PTTL). This effect is caused by the transfer of charge carriers from deep traps to shallower traps following absorption of ultraviolet light, resulting in the regeneration of lower temperature glow peaks (including the dosimetry peaks 4 & 5) at the expense of the high temperature glow peaks which may not have been effectively emptied of charge carriers during the high temperature anneal. Polytetrafluoroethylene-based phosphors are particularly susceptible to PTTL because the temperature-restriction of the high temperature anneal to 300°C leaves residual charge carriers in higher temperature peaks (in LiF, glow peaks 9-12 have their emission peaks in the temperature range 315-385°C).

The accumulation of background on the LiF (PTFE) discs was studied under different illumination conditions using new discs which had not been previously irradiated. The discs were given an initial stabilisation anneal of 30 hrs. at 300°C followed by 16 hrs. at 80°C (Shaw & Wall, 1977).
Some of these discs were then stored in a light-proof box normally used for packing unused x-ray films, while others were kept in an ordinary envelope. The 2 sets of disc were then stored on the same laboratory shelf for a period of 40 days, and then read out. The results are shown in Table 1. Background accumulation was more rapid under ambient lighting conditions.

3.9.3. **Photomultiplier tube performance**

The reproducibility of the PM tube response to constant light intensities, and the time-variation in its response, were studied over a period of 2 years between 1983 and 1985, using an internal light source (ILS) and an external light source (ELS). The results are shown in Table 2. The long-term variations were quite satisfactory. Tests with the ILS showed less variation than those with the ELS, probably because the latter was more prone to contamination.

3.9.4. **Intrabatch variations**

The variability of TL signals recorded from different LiF discs from the same batch and
TABLE 1: ACCUMULATION OF TL BACKGROUND ON LIF (PTFE) DISCS STORED UNDER DIFFERENT ILLUMINATION CONDITIONS.

<table>
<thead>
<tr>
<th>Storage time (days)</th>
<th>Measured TL Signal (TLD Reader digits)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ambient lighting</td>
<td>Mean S.D. n</td>
<td>Dark Storage</td>
<td>Mean S.D. n</td>
</tr>
<tr>
<td>0</td>
<td>10.5 4.4 10</td>
<td>10.5 4.4 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>67.8 8.1 30</td>
<td>47.7 3.6 29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S.D. = Standard deviation, n = number of discs.

TABLE 2: VARIATIONS IN LIGHT-SOURCE READINGS OVER A PERIOD OF 2 YEARS.

<table>
<thead>
<tr>
<th>Absolute Reading (Reader digits)</th>
<th>ILS</th>
<th>ELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>9911</td>
<td>9981</td>
<td>17843</td>
</tr>
</tbody>
</table>

Coefficient of Variation (%)

<table>
<thead>
<tr>
<th>ILS</th>
<th>ELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>0.04</td>
<td>0.42</td>
</tr>
</tbody>
</table>
exposed to the same dose provides a broader assessment of the TLD system performance than the light source measurements because it is not restricted to checking the light measurement system only. Inter-disc variations were studied using the calibration dose meters exposed at the IAEA in Vienna, discs exposed to a high dose using a $^{60}$Co teletherapy unit in Nairobi, and control discs not exposed to any radiation. Table 3 shows that intrabatch variations of the order of 10% at 1 standard deviation were recorded.

**TABLE 3: VARIATIONS IN THE TL SIGNAL FROM LiF (PTFE) DISCS EXPOSED TO THE SAME DOSE OF RADIATION.**

<table>
<thead>
<tr>
<th>No. of discs</th>
<th>Exposure (mR)</th>
<th>Mean Reading (Reader digits)</th>
<th>Coefficient of Variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0</td>
<td>47</td>
<td>10.2</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>53</td>
<td>10.0</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>99</td>
<td>11.0</td>
</tr>
<tr>
<td>8</td>
<td>200</td>
<td>206</td>
<td>7.3</td>
</tr>
<tr>
<td>8</td>
<td>400</td>
<td>392</td>
<td>10.7</td>
</tr>
<tr>
<td>10</td>
<td>70,000</td>
<td>71,400</td>
<td>4.6</td>
</tr>
</tbody>
</table>

3.9.5. **Overall assessment of the TLD system**

The TLD System comprising the Toledo 654 TLD Reader and 0.4 mm thick LiF (PTFE) disc dose
meters was satisfactory with respect to dose linearity, PM tube response, and within-batch inter-disc variations. However, the high background TL signals of the LiF (PTFE) discs restricted the quantitative assessment of very low doses. Overall, the system was judged to be suitable for the patient dosimetry studies reported in this thesis.
4.1. Introduction

Radiological examinations of the chest constitute the most common single type of x-ray examination in Kenya, as in most other countries. In Chapter 9, it is shown that only the frequency of examinations of all the limbs combined exceeds that of chest x-rays. This high frequency renders chest imaging one of the leading contributors to the collective population dose from medical irradiation, despite the fact that, when good techniques are employed, the radiation dose per examination is usually quite low.

In this chapter, the findings of an extensive survey of patient doses during chest x-ray examinations at six hospitals in Kenya are reported. Variations of patient dose between different centres, and for the two imaging techniques considered, are discussed. Special reference is made to the high patient doses delivered during photofluorography without image intensification.

4.2. Chest Imaging options available in Kenya

The techniques available for chest x-ray
imaging include:

(1) Photofluorography (PFG) without image intensification, using Odelca camera units (Philips Co., Netherlands) with ZnCdS:Ag fluorescent screens, mirror optics of equivalent lens speed f/0.65, stationary grids of ratio 5:1 focussed at a source to image-receptor distance of approximately 90 cm, and 10 x 10 cm² green-sensitive, single emulsion fine grain film. In this technique, the subject's image is first projected onto the fluorescent screen, and then optically photographed, recording the final image on miniature-size x-ray film not in contact with the screen.

(2) Full-size screen-film radiography on General Purpose x-ray Units (GPUs) with calcium tungstate screens and various makes of medium-speed films. Conventional low kV techniques (up to about 90kV) are used without grid or air gap, and high kV techniques (typically 120kV) have recently been tried with grids on GPUs with battery-operated, high-frequency converter generators. This latter equipment is especially designed for the spread of Basic Radiological Services (BRS) to rural areas, a concept which has recently received increased support from the World Health Organization.
(3) Special contrast examinations performed only at specialized radiological centres, including cardiac fluoroscopy, and, much less frequently, bronchography.

Photofluorographic equipment was developed during the 1930s to cater for the need to screen large numbers of people for cardiopulmonary disease. The generally high patient doses and limitations on image quality associated with the technique were recognized early in its history (Hirsch, 1940; Potter et al, 1940). More recently, objective tests of image characteristics have also shown that PFG compares poorly with other x-ray chest imaging options (Manninen et al, 1982). The inferior image quality may have implications for diagnostic efficacy.

Although large-scale mass surveys have now become much less important in many parts of the world, PFG remains a popular method for routine chest examinations in some countries, including Kenya. The main attractions of the technique are the low film costs; the possibility for rapid patient turn-over when large numbers of patients have to be examined, and easy adaptability to mobile facilities.

In Kenya, Odelca camera units are used for the majority of chest imaging in almost all
provincial and district hospitals. It is, therefore, appropriate to assess the levels of patient exposure from these units, relate these levels to those from full-size radiography, and consider any necessary dose reduction measures.

Examinations performed using options (1) and (2) above, excepting those performed with BRS equipment, were included in this study.

4.3. Methods

Patient doses were monitored during routine examinations on 4 Odelca camera PFG units and 4 standard x-ray units at 6 different departments. At all facilities, the x-ray tubes were energized by single-phase, fully-rectified generators. The technical specifications of each facility, and the exposure factors used for each examination, were recorded on a special form designed for the project. These details are shown in Table 4.

Patients included those referred on various medical grounds after clinical examinations, follow-up cases of tuberculosis, those being screened as contacts of identified TB cases, and some referred for travel and insurance examinations.
<table>
<thead>
<tr>
<th>6.70</th>
<th>7.00</th>
<th>7.30</th>
<th>7.60</th>
<th>7.90</th>
<th>8.20</th>
<th>8.50</th>
<th>8.80</th>
<th>9.10</th>
<th>9.40</th>
<th>9.70</th>
<th>10.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-3-76</td>
<td>6-6-73</td>
<td>6-9-72</td>
<td>6-12-72</td>
<td>6-15-72</td>
<td>6-18-72</td>
<td>6-21-73</td>
<td>6-24-73</td>
<td>6-27-73</td>
<td>6-30-73</td>
<td>6-33-73</td>
<td>6-36-73</td>
</tr>
<tr>
<td>LAT</td>
<td>Ap</td>
<td>120</td>
<td>150</td>
<td>180</td>
<td>210</td>
<td>240</td>
<td>270</td>
<td>300</td>
<td>330</td>
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<td>390</td>
</tr>
<tr>
<td>6.70 Gpy</td>
<td>Gpy</td>
<td>0.1 Gpy</td>
<td>0.1 Gpy</td>
<td>0.1 Gpy</td>
<td>0.1 Gpy</td>
<td>0.1 Gpy</td>
<td>0.1 Gpy</td>
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<td>0.1 Gpy</td>
</tr>
<tr>
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<td>MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
<td>0.1 MSA</td>
</tr>
<tr>
<td>6.70 ELD</td>
<td>ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
<td>0.1 ELD</td>
</tr>
<tr>
<td>6.70 MIS Delen</td>
<td>MIS Delen</td>
<td>0.1 MIS Delen</td>
<td>0.1 MIS Delen</td>
<td>0.1 MIS Delen</td>
<td>0.1 MIS Delen</td>
<td>0.1 MIS Delen</td>
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</tr>
</tbody>
</table>

**Table 4: Technical Specifications of Equipment and Exposure Factors**
In adult patients, postero-anterior and lateral views were taken with the patient erect. For children, antero-posterior and lateral views were taken with the patient lying horizontally on a couch, except at one of the PFG units, where PA views in older children (age range 7 - 14 years) were taken in erect position.

Absorbed doses were monitored using LiF (PTFE) discs sealed in plastic. To monitor the skin-entry dose, a disc was positioned, with the aid of cellotape, at the centre of the x-ray field on the patient's skin-entry surface at about the level of the 4th thoracic vertebra. Thyroidal dose was assessed at 2 PFG units using a dose meter placed on the anterior surface of the neck, just below the laryngeal prominence. At the same 2 facilities, an attempt was made to measure gonadal doses in males and to assess the extent of direct-beam irradiation of the ovaries in female patients. In males, the TLD discs were positioned on the scrotum, while in female patients the dose meters were positioned on the posterior skin surface along the median plane at the level of the iliac crests (the PA projection was used for all examinations on PFG units).

High background levels on the LiF (PTFE) discs limited the value of the minimum dose which
could be measured with the TLD system. Doses were classified as being significant if the difference between the measured TL signal and the mean background signal (from 4 - 6 control discs) exceeded two standard deviations of the mean background signal. This criterion corresponds approximately to the 95% confidence level that the measured signal differed from the background signal. Recorded doses not meeting this criterion were, by definition, classified as insignificant. In practice, the lowest dose that could be measured with the system was about 0.2 mGy.

In order to improve the accuracy of results, skin-entry dose measurements during full-size radiography were carried out using one monitoring disc on 3 - 5 patients, and then calculating the average dose per patient from the total signal and the background. Initial measurements on PFG equipment had indicated that skin-entry doses from these units were much higher than the threshold of measurable doses, as defined above. For photofluorographic examinations, each patient was, therefore, monitored using a separate LiF dose meter. This applied also to the monitoring of thyroidal and gonadal doses.
4.4. Results

4.4.1. Skin-entry doses

Mean values of the skin-entry doses recorded are shown in Table 5 for both adults and children, and for the 2 imaging techniques employed. Individual doses recorded by the TLD dose meters include backscatter from the skin. Standard deviations are shown to indicate the spread of individual patient doses at each centre. In each case, the mean value recorded at each centre was quite representative of the centre, since the coefficients of variation at all centres were small enough to rule out undue influence of a few extreme values on the means.

The measured values for full-size radiography are normal for CaWO$_4$ intensifying screens. They compare well with those recorded by other workers (Harrison et al, 1983., Butler et al, 1985., Paulkner et al, 1986). There were no statistically-significant differences between the means of the adult doses for the PA view recorded at the 3 x-ray units at the 2 centres ELD and MSA. The frequency distribution of doses among all adult patients undergoing this examination is shown in Figure 6. Paediatric skin-entry doses at centre IDH were also satisfactorily low.

The doses delivered during PFG examinations were much higher, and the mean values show consider-
| CH, children (under 15 years); AD, adults; S.D., standard deviation. |
|------------------|------------------|------------------|------------------|
| 0.063            | 0.36             | 4.3              | 4.5              |
| 0.038            | 0.20             | 5.3              | 0.3              |
| 0.056            | 0.33             | 2.7              | 2.2              |
| 0.037            | 0.29             | 1.7              | 1.4              |
| 1.441            | 0.20             | 0.2              | 0.2              |
| 0.151            | 0.36             | 0.6              | 0.6              |
| 4.30             | 1.0              | 15.9             | 1.0              |
| 1.83             | 0.20             | 0.2              | 0.2              |
| 2.23             | 0.87             | 0.2              | 0.2              |

TABLE 5: MEAN SKIN-ENTRY DOSES DURING CHEST EXAMINATIONS
Fig. 6. Frequency distribution of skin-entry doses during full size chest radiography.
able variability between the 4 Odelca camera units at which measurements were made. Recent references on patient doses during chest PFG are summarized in Table 6. The doses recorded in the present work are on the higher side compared to most of these references. Measurements in the lateral projection at one of the centres (KNH) using PFG equipment showed excessively high doses.

Figures 7a and 7b show the frequency distributions of patient dose obtained in this study for PA examinations in adults at the PFG centre which had the largest number of patients (RHO), and at all the PFG units combined, respectively. The 2 histograms illustrate typical intrahospital dose variations among patients (Fig. 7a), and the variations in individual doses from a sample of x-ray departments in the country (Fig. 7b).
<table>
<thead>
<tr>
<th>Authors</th>
<th>Country</th>
<th>Mean dose (or dose range) (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bushong et al, 1973</td>
<td>U.S.A.</td>
<td>(a) 2.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) 6.01</td>
</tr>
<tr>
<td>Gaeta &amp; Burnett, 1975</td>
<td>U.S.A.</td>
<td>1.54 - 3.82</td>
</tr>
<tr>
<td>Jain et al, 1979</td>
<td>India</td>
<td>1.50 - 3.30</td>
</tr>
<tr>
<td>Wall et al, 1980</td>
<td>U.K.</td>
<td>1.20</td>
</tr>
<tr>
<td>Jankowski, 1984</td>
<td>Poland</td>
<td>(Female) 5.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Male) 6.30</td>
</tr>
<tr>
<td>Kumamoto, 1985</td>
<td>Japan</td>
<td>1.50</td>
</tr>
<tr>
<td>Padovani et al, 1987</td>
<td>Italy</td>
<td>2.64</td>
</tr>
</tbody>
</table>
Fig. 7a. Frequency distribution of skin-entry doses during chest photography: adult patients at centre RH.

Number of Patients per Dose Interval
NUMBER OF PATIENTS PER DOSE INTERVAL

Fig. 7b. Frequency distribution of skin-entry doses during chest fluorography.
Some technical factors were identified as likely contributors to levels of patient dose and dose variability. The 2 units recording the highest mean values of skin-entry dose (centres RHO and KNH) did not have adjustable beam-limiting collimators with light-beam indication. Fixed field sizes were therefore used, to the disadvantage of children and other patients of small stature, who could have been x-rayed using smaller fields. In addition, there was no added tube filtration at centre RHO. In the PFG unit recording the lowest mean dose (centre KIS), the anti-scatter grid had been removed.

4.4.1.1. Effect of retakes

A study of retakes and their effect on patient dose was carried out at one PFG centre (RHO). On-the-spot repeat examinations at this centre were noted and skin-entry doses monitored during these retakes. The retake rate was 10.1% during the survey period. All repeats were caused by failure in film transport in the Odelca camera. These retakes had the effect of increasing the mean skin-entry dose by 10.5%. This undesirable tendency for a high rate of retakes was not observed at the other centres.
4.4.2. Thyroidal dose

Of the 171 adults and 14 children in whom thyroidal monitoring was done, significant doses (as defined in Sec. 4.3) were recorded in only 66 patients. These doses ranged from 0.23 - 0.97 mGy, with a median value of 0.41 mGy. No attempt is made to provide a quantitative estimate of mean values of thyroidal exposure from chest radiography, since the sensitivity of the dosimetry system was clearly not high enough for this purpose.

In 27 of the patients for whom significant doses were recorded, data were also available for skin-entry doses, measured simultaneously. For these patients, the individual ratios of thyroidal to skin-entry dose were calculated. Ratios in the range 3.1 - 18.3%, with a median value of 6.9%, were obtained. These data compare with a considerably higher normalized thyroid dose of 243 millirad per roentgen entrance exposure reported by Gray et al (1981) during phantom studies of full-size chest examinations. These workers used a more penetrating x-ray beam than the qualities used in the present studies.

During postero-anterior chest examinations, the x-ray beam is attenuated by the tissues in the neck before reaching the dose meter monitoring the
thyroidal dose. The calculated percentage values obtained above are quite reasonable for transmission of the x-ray beam through approximately 10 cm. of tissue in the neck for the radiation qualities employed (Table 4). The lower range of values, and perhaps some of the insignificant thyroidal doses, are probably explained by the protection afforded to the thyroid gland by high absorption of diagnostic x-rays in the cervical vertebrae during PA chest examinations. It should also be mentioned that the use of short distances between the x-ray source and the image receptor in most PFG machines tends to reduce beam transmission ratios.

The sensitivity limitations of the TLD system suggest that only when the thyroid gland was included in the direct beam would a significant dose be recorded. The results suggest direct beam thyroidal exposure in at least one third of patients. Such direct beam exposure cannot be construed to imply poor technique, since the thyroid gland lies approximately at the upper margin of the radiation field during chest radiography. The data of Gray et al (1981) were clearly obtained under conditions of direct thyroidal exposure, as they report a normalized thyroid dose of 951 mrad/R for the AP view. Also suggestive of direct beam exposure are the data of Bengtsson et al (1978), who obtained a mean dose to the thyroid gland of 1 mGy from chest photofluoro-
graphy. The few subjects in whom significant thyroidal doses were recorded in this work suggest a small proportion of direct-beam exposure during chest examinations at the centres surveyed, considering that the measured skin-entry doses were high.

4.4.3. **Assessment of gonadal exposure**

As with thyroidal doses, the doses to the male gonads were too low to allow the quantitative estimation of mean values. Fifteen of the 97 patients monitored recorded significant doses (see Sec. 4.3.) in the range of 0.21 - 0.57 mGy (median value 0.36 mGy). Gonad shielding was not practised in adult patients.

Direct beam irradiation of the male gonads in adults during chest radiography suggests poor beam collimation. The distribution of the 15 subjects recording significant gonadal dose was 13 out of 32 patients monitored at centre KNH and only 2 out of 65 at centre RHO. An analysis of the skin-entry dose data by Student's t-method showed no statistically-significant differences between the mean values at these 2 centres. The pronounced differences in male gonadal exposure between these centres were most probably due to differences in x-ray beam collimation.
In female patients, doses monitored on the posterior midline at the level of the iliac crests were expressed as percentages of the skin-entry doses monitored at the x-ray field centre (level of T-4) for individual patients. These data were then used to assess the likelihood of direct beam exposure of the ovaries. The criteria used to express this likelihood are shown in Table 7.

The dose meters which were positioned in relation to the ovaries recorded significant doses in 59 out of the 107 female patients monitored. Insignificant doses were recorded as zero for purposes of calculating the percentages required. This measure did not affect the numbers of subjects in different probability classes (Table 7), as all insignificant doses were below 0.2 mGy, while most skin-entry doses at the field centre were greater than 3 mGy (i.e., percentages were <10%).

Table 7 shows the results of the assessment of direct beam exposure of the ovaries among the 107 patients. The criteria used to relate the percentage range with the probability classification is to some extent arbitrary, but consideration was given to factors such as the divergence of the x-ray beam between the skin surface and the plane of the ovaries, and variations in the x-ray beam intensities within
<table>
<thead>
<tr>
<th>Total</th>
<th>Percent of</th>
<th>No. of Patients</th>
<th>Probability Classification</th>
<th>Probability Range</th>
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<tr>
<td>100</td>
<td>107</td>
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<td></td>
</tr>
<tr>
<td>81.3</td>
<td>87</td>
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<td>Uncertainty</td>
<td>&gt; 10%</td>
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<tr>
<td>9.3</td>
<td>10</td>
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<td>Possibility</td>
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<td>9.3</td>
<td>10</td>
<td></td>
<td>Most probable</td>
<td>&lt; 30%</td>
</tr>
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</table>

**TABLE 7**: Probabilities that the ovaries were irradiated by the direct beam during chest photofluorography.
the useful beam (anode heel effect).

4.5. Discussion

It has already been observed that the skin-entry doses recorded from full-size chest radiography were within acceptable limits for the type of image receptors used. In children examined frequently, consideration could be given to reducing the doses further by using rare-earth intensifying screens. Because children are very often examined in the antero-posterior view, they receive higher doses to the thyroid and breast.

The data for chest PFG imply that a single chest x-ray examination in Kenya using this technique exposes the patient to a skin-entry dose amounting to 1- to 3- times the annual background radiation. Although the sensitivity of the dosimetry system was not high enough to allow the quantitative estimation of mean thyroidal and male gonadal doses during chest imaging, the few subjects in whom significant doses (see Sec. 4.3) were measured suggests a small proportion of direct-beam exposure for these organs. The extent of direct-beam irradiation of the ovaries, as estimated using the criteria defined, was also
found to be low.

Although the high skin-entry doses delivered by PFG are recognized as being basically inherent in the technique itself, appropriate dose reduction measures may go a long way in reducing patient exposures. Some of these measures are simple but very effective - for example, regular cleaning of the camera to remove dust from the optical components. Other aspects of equipment and technique, such as the use of adequate tube filtration and accurate collimation (both of which were found wanting at some centres), should be regarded as standard requirements.

Some suggestions have been put forward concerning upper limits of patient dose during chest PFG. The ICRP (1982) recommends that, with the use of efficient screens and optical systems, it should be possible to perform chest PFG with entry air kerma not exceeding 1 mGy. In the U.S.A., dose limits of 100 mrad (1 mGy) for new and 200 mrad for old PFG units have been set (Gaeta & Burnett, 1975). The mean skin-entry doses recorded in this work are considerably higher than these suggested limits.

An awareness of the high doses delivered by PFG without image intensification has led to recom-
mendations on the restrictive use of this technique. Following the Adrian survey in the United Kingdom, it was recommended that in the follow up of TB contact cases, PFG equipment should only be used for patients not examined more frequently than once a year (BIR, 1964). In some countries, children and pregnant women may not be x-rayed with PFG equipment.

An additional restriction which deserves consideration is to abolish the taking of lateral chest views with this equipment. The doses recorded in this survey for the lateral projection at one centre (KNH) were excessively high. The need for a lateral view in chest radiography may, in general, be reduced by the use of high kV techniques when taking the PA views (WHO, 1983).

From the point of view of stochastic risks of radiation, the important tissues at risk during chest radiography are the bone marrow, the lungs, the thyroid, and the breasts. Some quantitative estimates of the somatic hazards of chest PFG have been made by Bengtsson et al (1978) in Sweden and by Kumamoto (1985) in Japan. Even with the higher doses delivered by PFG, the individual risk per examination is quite low. However, some concern must be
shown for some patients (such as those undergoing follow-up examinations for tuberculosis) who may be subjected to repeated exposures over substantial periods of time. Photofluorographic equipment should be used restrictively for such patients.

It has been suggested that PFG without image intensification is an obsolete technique which should be abandoned altogether. In many of the developing countries, such action could deprive many people of a desirable diagnostic service without introducing an alternative. It is likely that, where this technique is still in use among such countries, it will continue to be used, of necessity, for quite some time to come. In this situation, the relevant issue is how this method of chest imaging may be used with minimal patient exposure. The observance of routine radiation protection procedures and the application of quality assurance measures should play a major role in achieving this goal. It is recommended that PFG equipment going out of use should, as a matter of policy, be replaced either by a different imaging system altogether - delivering much lower doses, or (if the continued use of PFG techniques is considered necessary) by more modern PFG units fitted with rare-earth fluorescent screens and the most efficient camera systems.

It was mentioned in Sec. 4.3. that the technical specifications of each x-ray unit and the exposure factors used for each examination were recorded. Some of this information appears in Table 4. In this section, published x-ray output data (HPA, 1977) are used in conjunction with the technical factors to estimate mean skin-entry doses during chest examinations. The results of these indirect evaluations are then compared with those of direct measurements using TLD (shown in Table 5).

4.6.1. Calculation of skin-entry dose

The x-ray output data used were extracted from graphs published by the Hospital Physicists' Association of the United Kingdom (HPA, 1977). These graphs are shown in Figure 8. Output data are given for fully rectified units in terms of mR/mAs for various kvp values at a distance of 75 cm. in free air from the tube focus. Using the mean values of kvp and mAs employed during the examinations, the exposure at 75 cm focal distance has been calculated for each x-ray facility and for each radiographic view, except for the PFG unit at centre RHO, for which the mAs product was not available because automatic timing was employed using a phototimer. A
Fig. 8. Output of x-ray tubes as a function of kVp and total tube filtration (M.P.A., 1977).
simple inverse square law correction was then applied to obtain the exposure at a distance equal to the average source-to-skin distance (SSD) actually used during the examinations. The average SSD was estimated from the source-to-image-receptor distances (SID) presented in Table 4 by subtracting from the SID average chest thicknesses of 20 cm for adults and 10 cm for children for the PA or AP views, and average thicknesses of 30 cm for adults and 15 cm for children for the lateral view. Measurements of PA chest thicknesses in a random sample of 22 adult patients at centre KNH during the survey had given a mean thickness of 20.5 cm (S.D. = 2.3).

Further correction factors were applied to account for backscatter and to convert the exposures to absorbed doses. Backscatter factors (BSFs) published by Harrison (1982) show that BSFs for diagnostic beams at 60-100 kVp, with first half-value layers of 1.5 - 2.5 mm Al lie in the range 1.25 - 1.35 for a field size of 30 x 30 cm². Gaeta & Burnett (1975) have measured BSFs on a tissue-equivalent phantom using PFG equipment. They obtained BSFs in the range 1.29 - 1.35 for a radiation quality of 85 kVp, 3 mm Al total filtration, and a field size of 40 x 40 cm². For purposes of the present estimates, a single BSF of 1.30 is applied in each calculation.
A correction factor,

\[ f = 0.88 \text{ rad/R (34 GyKgC}^{-1}) \],

is used to represent the exposure-to-absorbed dose conversion factor for the x-ray qualities used. This factor is taken from data published by the International Commission on Radiation Units and Measurements (ICRU, 1970), and applies to x-ray beams of equivalent photon energies in the range 20-40 keV.

In summary, the skin-entry dose, S.E.D., was calculated from the technical data using the formula

\[ \text{S.E.D.} = X_{75} \cdot \left(\frac{75}{\text{SSD}}\right)^2 \cdot BSF \cdot f \]  \text{Eq. 4.1.}

where \( X_{75} \) is the exposure free in air at a distance of 75 cm from the x-ray tube target, and other symbols are as explained above, with the SSD expressed in centimetres.

4.6.2. Results

The results of these calculations are shown in Table 8. The major source of uncertainty in the final result obtained with the indirect method lies in the value of \( X_{75} \), because the outputs of different x-ray tubes vary quite widely for the same exposure parameters. Figure 9 shows the extent of
<table>
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<th>Facility/Projection</th>
<th>Mean Skin-Entry Dose (msv)</th>
<th>Calculated</th>
<th>Measured</th>
<th>Ratio (a)/(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDH, GPu, LAt</td>
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<td>17.8</td>
<td>0.73</td>
<td>0.36</td>
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<td>12.1</td>
<td>0.52</td>
<td>0.36</td>
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<tr>
<td>MSA, GPu(B), PAt</td>
<td>88.4</td>
<td>9.4</td>
<td>8.7</td>
<td>0.33</td>
</tr>
<tr>
<td>MSA, GPu(A), PAt</td>
<td>85.3</td>
<td>8.7</td>
<td>8.3</td>
<td>0.33</td>
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<tr>
<td>ElO, GPu, PAt</td>
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<td>9.1</td>
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<td>0.33</td>
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<td>7.9</td>
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<td>KNH, Odeica, PAt</td>
<td>76.6</td>
<td>4.0</td>
<td>4.0</td>
<td>0.34</td>
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</tbody>
</table>

Parameters: The last column shows the ratio of calculated to measured doses.

TABLE 8: Mean Skin-Entry Doses During Chest Examinations, As Calculated From Technical
Fig. 9. Variation in the output of x-ray tubes from 181 single phase units (HPA, 1980).
these variations in a survey of 181 single phase units (HPA, 1980).

The last column in Table 8 shows the ratio of the doses calculated by the indirect method to those measured by TLD. There is good agreement between the direct and indirect methods of dose evaluation, within a factor of about 2. This is quite satisfactory in view of the wide variations possible in the x-ray outputs of different tubes.

4.6.3. Discussion

It was observed in Chapter 2 that although indirect methods of patient dosimetry are generally less accurate than direct methods, they may be advantageous in terms of the fewer measurements required for dose assessment. This point is particularly relevant where data on patient doses are scarce, in which case indirect methods may be considered for preliminary surveys to provide such data quickly. The value of such data will then depend on the accuracy of the indirect method.

The estimates of skin-entry doses evaluated in this addendum indicates reasonable agreement with direct measurement, suggesting that indirect methods
of patient dosimetry may provide a feasible approach to patient dose determinations in Kenya.
CHAPTER 5

MATERNAL AND FETAL EXPOSURE DURING ERECT LATERAL
PELVIMETRY

5.1. Introduction

Radiological pelvimetry is carried out in the late stages of pregnancy to evaluate maternal pelvic capacity in relation to fetal head size. The examination exposes both mother and fetus to ionizing radiation. It is usually classified as a high dose examination (ICRP, 1982), with special concern over the radiation risks to the fetus.

The frequency of radiological pelvimetry has been declining in many countries in recent years. This has been due to the increased use of ultrasound in obstetrics, a shift of opinion on the efficacy of pelvimetry in the management of labour, and the continued appreciation of the need to minimize radiation hazards to the fetus.

The impact of ultrasound services in reducing obstetric radiography has been assessed by Meire et al (1978), Meire & Farrant (1980), and Gordon et al (1984). Where available, ultrasonic imaging has replaced the use of x-rays in the assessment of fetal maturity, placental localization, possible multiple pregnancy, and fetal presentation, and in studying
possible fetal abnormalities or intrauterine death.

The value of pelvimetry in the management of patients who have had previous caesarean section has been questioned (Wilson, 1951; Gordon et al, 1984). However, it is still considered a useful examination in cases of breech presentation.

Fraser et al (1979) have previously analysed referral criteria for radiological pelvimetry at the Kenyatta National Hospital, Nairobi, and concluded that up to 70% of such investigations might have been unnecessary. In this chapter, an institutional survey of patient doses at this hospital is reported. Maternal skin-entry doses are measured in a series of 83 patients undergoing pelvimetry. Fetal doses are estimated from the maternal doses using published conversion data. An appraisal is made of the radiation hazards to mother and fetus. The effect of using rare-earth intensifying screens as a dose reduction measure is studied.

5.2. Methods

Erect lateral pelvimetry (ELP) is the standard examination used for nearly all patients referred for radiological evaluation of pelvic capacity at the Kenyatta National Hospital. The
indications for ELP, as shown on the x-ray request forms, are given in Table 9 for the 83 patients included in the dose survey.

The equipment used for radiography comprised an x-ray tube of total filtration 2.7 mm Al., energized by a single phase, fully-rectified generator. Tube potentials in the range 85-120kV were used. Patients were radiographed standing erect adjacent to a vertical bucky with a moving grid of ratio 8:1. A pelvimetry ruler held in position between the patient's inner thighs was the basis of subsequent distance measurements during image evaluation. Only one film was taken in the lateral projection, using 35 cm x 43 cm films at a focus-film distance of 1 metre.

There were 2 types of image receptor with an important difference in sensitivity affecting patient dose. In one set of patients, the x-ray cassettes used were loaded with a combination of standard CaWO$_4$ intensifying screens with medium speed, blue-sensitive films, while in a smaller series of (18) patients, Y$_2$O$_2$S:Tb rare-earth screens (Dr. Goos-Suprema, Heidelberg), with a blue-green emission, were used in conjunction with the same type of films.
<table>
<thead>
<tr>
<th>Indications</th>
<th>No. of Patients</th>
<th>Percent of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not stated</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>Other (specified)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Breach presentation</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Previous caesarean section</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>59</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 9. REASONS WHY PATIENTS WERE REFERRED FOR PELVIMETRY
Radiation doses were monitored using the LiF (PTFE) discs described in Chapter 3. The discs were positioned at the x-ray field centre on the patient’s skin-entry surface.

5.3. Results

Table 10 shows the mean and median values of the maternal skin-entry doses recorded with the 2 types of intensifying screens. The spread of individual doses is reflected in the ranges of the middle quartiles (25th-75th percentiles). For both types of image receptor, there was a wide spread in patient dose, depending largely on variations in physique. Figures 10a and 10b show the frequency distributions of dose.

The results clearly demonstrate the effectiveness of the $Y_2O_2S:Tb$ intensifying screens in keeping patient doses low. The median doses recorded with these screens were more than 5 times less than those with the $CaWO_4$ screens.

Although much lower doses were recorded with the $Y_2O_2S:Tb$ rare-earth screens, radiographs taken using these screens showed a lot of mottling. Apart from quantum mottle arising from the fewer photons contributing to image formation (in comparison to screens of lower intensification factor), the
<table>
<thead>
<tr>
<th>Marrow dose (mGy)</th>
<th>Marrow dose (mGy)</th>
<th>Range of Marrow dose (mGy)</th>
<th>Median Marrow dose (mGy)</th>
<th>Mean Marrow dose (mGy)</th>
<th>Marrow dose (mGy)</th>
<th>Mean Marrow dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3</td>
<td>1.3</td>
<td>0.0-2.4</td>
<td>1.5</td>
<td>1.5</td>
<td>2.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Table 10.** Maternal Skin-Entry Doses, and Crude Estimates of the Maternal and Fetal Bone Marrow Doses, During Direct Laternal Pelvimeter Using 2 Types of Intensifying Screens.
Fig. 10 a. Frequency distribution of skin-entry doses during erect lateral pelvimetry: CaWO\textsubscript{4} intensifying screens.
Fig. 10 b. Frequency distribution of skin-entry doses during erect lateral pelvimetry: $Y_2O_2S:Tb$ intensifying screens.
crystalline structure of this phosphor is reportedly associated with rather pronounced diffraction effects which introduce image unsharpness (Goos, 1985).

5.3.1. Crude estimates of the maternal and fetal bone marrow doses

The measured skin-entry doses have been used to estimate maternal mean bone marrow doses from ELP using the two types of image receptor, and, from these means, to obtain crude estimates of the fetal bone marrow dose. The estimation of bone marrow dose is a complex problem in radiation dosimetry, requiring a computer model combining data on the distribution of active bone marrow in different segments of the body with estimated radiation doses to the bone marrow in those segments (usually determined by measurements in anthropomorphic phantoms). Such an exercise was beyond the scope of these studies.

In this work, the bone marrow to skin-entry exposure ratio for lateral pelvimetry implied in the report of Shleien et al (1977) has been used to estimate maternal mean bone marrow doses. Using data from the 1970 U.S. national survey of x-ray exposure (DHEW, 1973), these authors reported a mean bone marrow dose of 333 mrad (3.33 mGy) for a mean skin-entry exposure of 5987 mR (1.54 x 10^{-3} Ckg^{-1})
during ELP. These values have been applied to the median maternal skin-entry doses to compute the bone marrow dose estimates, ignoring errors of the order of 10% arising from the differences between exposure and absorbed dose in soft tissue.

Fetal bone marrow doses have previously been estimated as being about $2^{\frac{1}{2}}$-4 times the maternal bone marrow dose during pelvimetry (Shleien, 1973). A factor of 3 is used here to estimate fetal mean bone marrow dose from the maternal values.

The crude estimates of maternal and fetal mean bone marrow dose are shown in Table 10. It should be emphasized that these are very crude estimates, varying perhaps by a factor of 3 or more. Variations will depend on many factors, such as differences in the distribution of the bone marrow (both maternal and fetal), maternal physique, fetal lie, fetal size, x-ray beam size, beam direction, and radiographic exposure factors.

5.3.2. Estimates of the risks of leukaemogenesis

It was mentioned in Chapter 1 that the radiation dose received by the active bone marrow is regarded as the most relevant criterion for assessing the risk of leukaemia from low doses
of radiation. In order to evaluate the risks of leukaemogenesis, risk coefficients taken from authoritative scientific organizations concerned with problems of radiation hazards have been used in conjunction with the mean bone marrow doses, as estimated above, to calculate the maternal and fetal leukaemia risks from a single pelvimetry examination as performed at the Kenyatta National Hospital during the survey period, using CaWO_4 intensifying screens. The ICRP (1977) has recommended a risk factor for radiogenic leukaemia of 20 x 10^{-4} \text{ Gy}^{-1} (20 \text{ cases per million exposed to } 1 \text{ rad}) as an average for both sexes and all age groups. This risk coefficient is used to estimate the maternal risk. UNSCEAR (1977) has estimated that following fetal exposure to doses in the range 0.2 - 20 \text{ rad} (2 - 200 \text{ mGy}), some 200-250 fatal childhood malignancies can be expected per million exposed per rad [ (200 - 250) x 10^{-4} \text{ Gy}^{-1} ] during the first ten years of life, about a half of which would be leukaemia. A risk coefficient of 100 x 10^{-4}\text{ Gy}^{-1} is used here to estimate the radiogenic leukaemia risk to the fetus.

Table 11 shows the calculated maternal and fetal leukaemia risks during ELP. The fetal risk is that of developing leukaemia during the first ten years of life, while the maternal risk is that of developing leukaemia subsequent to a single
<table>
<thead>
<tr>
<th></th>
<th>213 (UNSCEAR, 1977)</th>
<th>213.3</th>
<th>20 (ICRP, 1977)</th>
<th>7.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetal</td>
<td>213 x 10^-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal</td>
<td>14 x 10^-6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Estimated risk of leukaemia of toddler | \(x \times 10^{-4}_{\text{Gy}^{-1}}\) | Estimated mean bone marrow dose per examination (mgY) |

**Table II. The risk of Radiation-induced Leukaemia from a Single Pelvimeterx Examination, using Cavo 4 Intensifying Screens.**
pelvimetry examination. In both cases, the estimates represent excess cases, over and above normal incidence. The estimated figures incorporate uncertainties from both the risk coefficients and the mean bone marrow doses from which they have been derived.

5.4. Discussion

The patient doses recorded using CaWO₄ intensifying screens were high, comparable to those reported more than 20 years ago, as summarized in an article by Russel et al (1980). This study has demonstrated that such high doses can be effectively reduced by application of appropriate measures, such as the use of efficient image receptors.

Dose reduction using rare-earth screens is achieved at some sacrifice in image quality. However, it is generally agreed that, in obstetric radiography, less than optimum quality images are acceptable in the interests of dose reduction, provided the important anatomical landmarks are clearly seen. The extent of image degradation should be regarded as one of the major considerations in making a choice from the various commercially-available brands of rare-earth screens.
Other dose reduction measures which have been applied in pelvimetry include dispensing with the anti-scatter grid and using an air gap instead to reduce scatter, using high kilovoltage, limiting the volume of the fetus irradiated by means of partial shielding, and appropriately selecting the x-ray beam projection. By employing most of these measures in conjunction with very fast film-screen combinations, Russel et al (1980) were able to reduce maternal skin-entry doses to an impressive average of 2.2 mGy and the corresponding "fetal centre dose" to 0.13 mGy.

An examination of the risks of ELP, as estimated in the present studies, shows that, when imaging techniques associated with high patient doses are used, the excess risk to the fetus is substantial. The data in Table 11 imply a total fatal malignancy risk of about 40 cases per million pelvimetries per year (twice the annual leukaemia risk). This may be put into clearer perspective by comparison with the current risk of fatal road accidents in Kenya, which stands at about 100 deaths per million population per year, and is considered high by both the public and the authorities. The acceptability or otherwise of a given level of risk associated with medical radiology is, of course, a much more intricate subject.
The actual collective risk of pelvimetry is quite low because the annual frequency of the examination is much less than a million.

The maternal risks are much lower than those to the fetus, because in the maternal case a smaller proportion of the bone marrow is exposed in the direct beam, some other tissues and organs are completely excluded from direct exposure, and the risk coefficient per unit dose is smaller.

The ovaries receive a fairly high dose of radiation during ELP, with one ovary receiving a higher dose than the other. The contribution of pelvimetry to genetic hazards will depend on the ovary doses, the subsequent child expectancies of the irradiated mothers, and the frequency of the examination.

A majority of ELPs at the Kenyatta National Hospital were performed routinely on patients presenting with a history of previous caesarian section (Table 9). This situation was observed and criticised in an earlier study (Fraser et al, 1979), but has remained unchanged. Reduction in the number of x-ray pelvimetries performed is probably the most effective strategy in minimizing the collective detriment from this examination. The role of ultrasound has been
mentioned. Equally important is a review of referral criteria to match current policy guidelines on radiological practice (ICRP, 1982; WHO, 1983; ACR, 1985), and the dissemination of this information among those responsible for ordering radiological pelvimetries.
CHAPTER 6

PATIENT DOSES DURING HYSTEROSALPINGOGRAPHY

6.1. Introduction

Hysterosalpingography (HSG) is a contrast examination for the radiological evaluation of the female genital tract. It is performed on young to middle-aged women, typically in the age-bracket 20-40 years, who complain of primary or secondary infertility, or of habitual abortion. The examination may be used to investigate the internal cervical os, the uterine cavity, the Fallopian tubes, and the fimbria. It is rivalled in some of these applications by laparoscopy.

In Kenya, HSG is performed with a comparatively high frequency. Together with the gastrointestinal studies and intravenous urography, it is one of the commonest 3 types of contrast radiological examinations (see Chapter 9).

The radiological hazards associated with HSG arise from exposure of the bone marrow (a large proportion of which is irradiated in the direct beam), exposure of the ovaries, and (in a very unlikely event) inadvertent exposure of a conceptus in undiagnosed pregnancy. The radiation dose to the patient can be expected to be quite high.
during HSG, especially if fluoroscopic control of the flow of contrast medium is maintained throughout the examination.

In this chapter, the radiation doses measured in small samples of patients undergoing HSG at 2 x-ray centres in Kenya are reported.

6.2. Methods

Patient doses were monitored intermittently over a period of 6 months between September, 1984 and March, 1985 at one of the centres (KNH), and over a period of 2 weeks during September, 1985 at the other centre (MSA). At centre MSA, only over-couch tube radiography was done, with films being taken at appropriate times after the introduction of contrast medium. At the other centre, some examinations were performed under fluoroscopic control when the equipment was functioning, otherwise radiographic films only were taken. At both centres, HSG was performed only on one-half day per week, hence the small samples of patients included in this survey (Table 12). All examinations were performed under the supervision of either a radiologist or a gynaecologist.

The undercouch tube screening unit at the
centre KNH was old and in poor condition. Screening currents were generally high, typically in the range 3-5 mA. The screening voltage could not be ascertained, as it was indicated only by one of 3 selector knobs marked 'I', 'II' and 'III', whose corresponding numerical values were not known. During the duration of the dose survey, the unit could only be operated with the kV selector in position 'I', presumably the lowest of the 3 kV choices (this would explain the high screening currents, as the unit had automatic exposure control). It was also not possible to record the screening times precisely, as the timer only indicated the time elapsed after 5 minutes of screening, through audible and red-light warnings. It was noted, however, that the majority of patients were under fluoroscopy for less than 5 minutes.

At intervals during the flow of contrast, radiographic films were taken, one in the early phases of uterine filling, and one or two additional ones during tubal filling. A late film for checking peritoneal spill was always taken some 10-15 minutes after injection of contrast medium, using a separate overcouch tube x-ray set.

In the radiography only examinations, a total of 2-4 films was taken during the complete examination. Tube potentials of 70-90 kV and mAs
values ranging from 50-100 were used.

Radiation doses were monitored using LiF (PTFE) discs. For patients examined on the fluoroscopy machine, the dose meters were positioned on the posterior surface along the midline in relation to the uterus to monitor the combined dose due to screening and spot filming. The dose due to the late radiograph for peritoneal spill was separately measured using a dose meter on the anterior skin surface. This position was also used for monitoring all doses from the overcouch tube radiography only examinations.

6.3. Results

Table 12 shows the skin-entry doses recorded for the 2 examination techniques used, and for the late radiograph separately. A comparison of the screening plus radiography versus the radiography only examinations at centre KNH indicates that about 2/3 of the total radiation dose was due to screening. There appears to be a large difference between the mean doses recorded at the 2 centres for the radiography only examinations, but the small numbers of patients monitored at both centres suggest caution in drawing definitive conclusions.
<table>
<thead>
<tr>
<th>Patient</th>
<th>3.44</th>
<th>6.95</th>
<th>28</th>
<th>KHN</th>
<th>Late Films</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.92</td>
<td>41.38</td>
<td>12</td>
<td>MSA</td>
<td></td>
<td>Radiotherapy only</td>
</tr>
<tr>
<td>21.54</td>
<td>10</td>
<td>41.72</td>
<td>64.70</td>
<td>36</td>
<td>KHN</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deviation (mgY)</th>
<th>Standard Mean dose</th>
<th>Participants No. of centre</th>
</tr>
</thead>
</table>

**Table 1.2. Skin Entry Doses During Hysterosalpingography.**
6.4. Discussion

There appear to be only a few published reports on studies of patient dose during HSG. In a Swedish survey, Bengtsson et al (1978) reported mean ovary doses of 5.90 mGy per examination. Yulek & Soydan (1979), in a study in Turkey, recorded mean absorbed doses to the ovaries of 2.31 mGy per film and 6.95 mGy per examination. The skin-entry dose should be typically about 5 times the ovary dose, and so the doses reported in these references are similar to those recorded during the radiography only examinations in the present work. It would appear that in the Turkish study the examinations were performed by radiography only, as the total dose per examination corresponds to 3 times the dose per film. The report of the Swedish survey indicates that different techniques were employed at different hospitals, resulting in a variation of ovary doses by a factor of more than 3.

The advantages of observing the dynamic flow of contrast medium under fluoroscopic control during HSG must be weighed against the increased radiation dose to the patient. The large contribution of screening to the total radiation dose suggests that reduced screening should be an effective dose reduction measure. In this respect, the intermittent use of the fluoroscopic switch would be prudent.
With careful operation, this should allow the flow of contrast to be adequately followed, but without maintaining the radiation beam on throughout the examination.

Some workers have studied the impact of HSG findings on further patient management. In East Africa, such studies (Aggarwal, 1980; Ndosi, 1987), have reported poor utilization of the radiological findings and suggested that the frequency of HSG should be reduced and alternative methods of investigating female infertility be given more consideration. However, HSG remains an established method for the radiological evaluation of the mechanical causes of female infertility (Horwitz et al, 1979; Kasby, 1980), and the reported poor follow-up of patients subsequent to the examination may be attributed more to the inadequacy of the necessary resources for relevant patient management (for example, facilities for tubal surgery) than to the diagnostic efficacy of the examination itself.

One aspect of patient exposures from HSG which deserves more consideration is that of repeat examinations arising from psychological factors. Due to psychological stress arising from the problem of infertility, a large number of patients undergoing this examination are tempted to consult different specialists without making reference to
previous investigations and management. In the course of their independent investigations, these different specialists will often request for an HSG. The patient may consequently undergo several HSG examinations at different x-ray centres without revealing this to medical staff. Perhaps such repeats could be substantially reduced if liberal policies were formulated to allow these patients to transfer their relevant radiological records, including films.
CHAPTER 7

PATIENT EXPOSURES DURING RADIOLOGICAL EXAMINATIONS OF THE GASTRO-INTESTINAL TRACT, WITH SPECIAL REFERENCE TO INTRAHOSPITAL DOSE VARIATIONS.

7.1. Introduction

The work reported in this chapter was carried out in the United Kingdom shortly after the publication of the findings of the 1977 national survey of gonadal doses to the population of Great Britain, conducted by the National Radiological Protection Board (NRPB) (Wall et al, 1980).

For logistical reasons, national surveys of patient dose are restricted to selected institutions and conducted over short periods of time. Consequently, although the dose data from such exercises may provide a broad picture of the national situation, detailed studies of intrahospital and interhospital variations for any one type of examination are made difficult by the small numbers of examinations carried out at any one institution during national surveys. Detailed surveys of doses received in selected examinations at single institutions, or within limited regions, enable better analyses of such variations to be made.
The dose survey reported here was undertaken at the Withington Hospital, Manchester - the University Hospital of South Manchester in Great Britain. A large hospital with staff of varying levels of skill provides a suitable environment for studying within-hospital dose variations. When a particular type of examination is performed by several radiologists in rotation, the "personal factor" in dose variation tends to be evened out in the mean values obtained. Furthermore, the use of uniform film-processing conditions removes another of the traditional causes of variation.

Studies of the radiation exposure to patients during radiological examinations of the gastrointestinal tract (GIT) are important because this group of investigations gives large doses to the active bone marrow as well as the gonads of the irradiated individuals. During the Adrian survey of patient doses in the United Kingdom, GIT studies came second in importance to mass miniature chest radiography as a contributor to the per caput mean bone marrow dose (CMD), despite their low frequency compared to other diagnostic examinations (Adrian Committee, 1966). The NRPB frequency survey of radiological examinations in Great Britain in 1977 (Kendall et al, 1980) showed that the frequency of mass miniature radiography had declined sharply since
the time of the Adrian survey, thereby increasing (by implication) the relative contribution of GIT examinations to the CMD.

Although the individual gonad doses during GIT studies can be quite high, especially in the female patient, the relative contribution of these examinations to the genetically-significant dose was found to be quite low in the NRPB survey (Darby et al., 1980). This was due to a combination of their low frequency and the age distribution of the patients examined (these examinations were performed mainly in older patients, for whom subsequent child expectancy was low).

In the present institutional survey, gonadal doses in male patients, and abdominal skin-entry doses in female patients have been measured during the routine performance of barium meal and barium enema examinations. In female patients, ovary doses have been calculated from the skin-entry doses. The numbers of patients examined were larger than would normally be achieved at individual institutions during national surveys. Intrahospital dose variations are discussed and their implications for national dose surveys considered. The possible influence of over-couch tube fluoroscopy on patient exposures is discussed.
7.2. **Methods**

The dose survey covered a total of 144 patients undergoing double contrast barium meal and barium enema examinations. The examinations were performed by a team of several radiologists, including consultants and trainees, over a period of 4 months between June and October, 1982. Two x-ray machines with identical workloads were used – an undercouch tube unit situated in an outpatients' department and an overcouch tube set in an inpatients' department. Both equipments utilized automatic exposure control, but kV and mA meters on the control panel made it possible to record the ranges of these factors during operation. The main differences in technical factors during the examinations on the 2 machines were the focus-to-skin distances (FSDs) and the screening currents. On the overcouch tube unit, a focus-to-table-top distance of 110 cm was used, making the FSD typically 90 cm, while on the undercouch tube set the FSD was about a half of this value. Screening currents were of the order of 0.5 – 1.5 mA on the undercouch tube machine, but higher at 2 – 4 mA on the other unit. The kV values for fluoroscopy ranged from 80 to 115 kV on both machines, and for radiographic exposures a lower range of about 65 – 90 kV was used. Other information recorded included the screening times and numbers of films and their
sizes for each patient. The same film-screen combinations and the same type of automatic processors were used in the 2 departments. Gonad shielding was considered impractical for both types of examination.

The distribution of patients examined in the 2 departments by sex and examination type is shown in Table 13. Barium enema examinations were performed only with the overcouch tube facility. Patients included in the survey were not specially selected. The age of patients ranged from 19 to 88 years, with most of them over 45. The mean age of patients examined at the inpatients' department was higher than that of patients at the outpatients' department by 7.7 years, and the general condition of patients at the latter department was judged to be better. Some follow-through examinations of barium meal were carried out at the inpatients' department only. Eight of the 19 male and 11 of the 28 female patients underwent this investigation. A different x-ray set was sometimes used to take the late radiographs. For all barium meal investigations, a quick examination of the oesophagus was done, even when barium swallow was not specifically requested.

The measurement of radiation doses was undertaken using thermoluminescent LiF:Mg:Ti in the form of loose powder contained in plastic sachets.
<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba enema</td>
<td>44</td>
<td>144</td>
<td>188</td>
</tr>
<tr>
<td>Ba meal</td>
<td>25</td>
<td>43</td>
<td>68</td>
</tr>
<tr>
<td>180</td>
<td>101</td>
<td>18</td>
<td>119</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>127</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTALS**

19

(Outpatient's dept.)

(Overcouch tube)

**TABLE 13. THE NUMBER OF PATIENTS UNDERGOING BARIUM MEAL AND BARIUM ENEMA**

Examinations by sex and type of equipment used.
Each sachet contained 30mg of powder, enough for 2 sample measurements using 12mg aliquots each during dose read-out. A manual powder volume dispenser was used to measure the quantity of powder.

For male patients, the dose meters were positioned on the scrotum to monitor the testicular dose directly, while in female patients the skin dose was monitored on the abdominal surface at the level of the iliac crests, 5 cm on either side of the median plane (Figure 11). This position was chosen to facilitate evaluation of ovary doses from the measured skin doses. In some of the female patients, 4 dose meters were used - 2 each in anterior and posterior positions, but in others only 2 dose meters were used on one side.

Dose meters were not re-used by transferring them from one patient to another, but the criterion for the lower limit of dose detectability was set conservatively to include some of the lowest doses. Doses were considered significant if they satisfied the relation:

\[ S - B \geq \sqrt{S + B} \quad \text{Eq. 7.1.} \]

where \( S \) was the measured TL signal from an irradiated dose meter, and \( B \) the mean background signal from 3 control dose meters. The powder dose meters
FIG. 11. Positions of TL dose meters (arrowed) on female patients during GIT examinations.
showed lower background signals than the PTFE-based discs used for the studies in Chapters 4-6. This was partly due to the higher temperature at which the powder was annealed (see Chapter 3), and also because of the absence of spurious TL effects of PTFE origin. In practice, the sensitivity of the LiF:Mg:Ti powder and the background levels at the times of read-out were such that the threshold dose for significance was about $6 \times 10^{-2}$ mGy. Insignificant doses were recorded as zero.

7.2.1. Calibration of the LiF powder/TLD Reader system.

The TLD system comprising the LiF powder aliquots and the Toledo 654 TLD Reader was calibrated at the Radiation Protection Laboratories of the Christie Hospital & Holt Radium Institute, Manchester, where all the TLD measurements were made.

Following the standard pre-irradiation anneal and sieving for optimum particle size range (see Chapter 3), samples of the dispensed powder aliquots were calibrated using a $^{90}\text{Sr} / ^{90}\text{Y}$ irradiator. This special irradiator consists of a circular turntable with many holes near the rim for accommodating dose meters. The turntable is rotated at constant speed
about its centre by means of an electric motor. All
dose meter compartments are equidistant from the
centre of rotation, and pass under a $^{90}$Sr/$^{90}$Y
source in a fixed position at the same radius as the
holes. Dose meters are exposed to beta radiation as
they pass under the source. The amount of radia­
tion they receive will depend on the number of times
they pass under the radiation source. This number
is chosen and pre-set at the beginning of the calib­
ration, while the turntable is stationary. Rotation
is initiated by pressing a button, and stops automa­
tically after the pre-set number of revolutions.
Typically, 6 sachets of powder would be used for
calibrating a batch of powder before use.

The absorbed dose per revolution of the turn­
table was determined by calibration against a
reference $^{226}$Ra gamma ray source. The output of the
$^{226}$Ra source was determined using a 35 cc tertiary
standard ionization chamber whose calibration was
traceable to the National Physical Laboratory,
Teddington. Dose meters irradiated to a known dose
with the $^{226}$Ra source and those irradiated through
a known number of revolutions in the $^{90}$Sr/$^{90}$Y
irradiator were read using the same settings on the
Toledo Reader. This exercise was performed about
twice a year, while for routine calibrations after
every powder batch anneal, the $^{90}$Sr/$^{90}$Y irradiations
were considered adequate.

The response of the LiF:Mg:Ti powder to diagnostic x-rays relative to its response to $^{226}$Ra gamma rays was taken to be 1.20. The response varies by about 30% in the equivalent photon energy range 30-100keV (from about 1.4 relative to $^{226}$Ra gamma rays at 30keV to about 1.1 at 100keV). The radiation quality used necessarily varied widely during the examinations, but with fluoroscopy probably having a greater influence than radiography, a quality of 100kV, HVL 3 mm Al was taken to be reasonably representative of the radiation from both machines.

7.3. Results

7.3.1. Skin-entry and male gonadal doses

The mean values of the measured skin-entry doses for barium meal and barium enema examinations in female patients, and the gonadal doses in male patients, are shown in Table 14. Dose data for patients whose examinations were discontinued before completion have not been included in the results. The skin doses in female patients were obtained by averaging the doses recorded by anteriorly-positioned dose meters for the overcouch tube machine, and posterior dose meters for the undercouch tube equipment. Coefficients of variation given with the
<table>
<thead>
<tr>
<th>Tube</th>
<th>Overcouch tube</th>
<th>Partum enema</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.49</td>
<td>1.49 (65%)</td>
<td></td>
</tr>
<tr>
<td>65%</td>
<td>33.5 (80%)</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>33.5 (80%)</td>
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</tr>
<tr>
<td>2.0</td>
<td>9.6 (14.7%)</td>
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</tr>
<tr>
<td>2.0</td>
<td>9.6 (14.7%)</td>
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</tr>
<tr>
<td>2.0</td>
<td>9.6 (14.7%)</td>
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</tr>
<tr>
<td>2.0</td>
<td>9.6 (14.7%)</td>
<td></td>
</tr>
</tbody>
</table>

Weighted hospital mean

<table>
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<tr>
<th>Tube</th>
<th>Overcouch tube</th>
<th>Undercouch tube</th>
<th>Partum meal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.32</td>
<td>0.32 (102%)</td>
<td>0.32 (102%)</td>
<td></td>
</tr>
<tr>
<td>1.51</td>
<td>9.71 (151%)</td>
<td>9.71 (151%)</td>
<td></td>
</tr>
<tr>
<td>2.91</td>
<td>9.71 (151%)</td>
<td>9.71 (151%)</td>
<td></td>
</tr>
<tr>
<td>2.90</td>
<td>9.66</td>
<td>9.66</td>
<td></td>
</tr>
</tbody>
</table>

Table 14. Means of skin-entry and gonadal doses during CT studies. Coefficients of variation are shown in brackets.

Female gonads | Female skin | Male gonads

*Table 14: Means of skin-entry and gonadal doses during CT studies. Coefficients of variation are shown in brackets.*
measured values indicate the variability of doses among individual patients.

The dosimetric uncertainties associated with individual skin-entry and male gonadal dose values arose mainly from the energy-dependence of LiF:Mg:Ti, which were within $\pm$ 20%. In addition, the measuring technique introduced further errors not exceeding $\pm$ 10% at the 95% confidence level for doses greater than about 0.1 mGy.

The most striking feature of the data for the barium meal examination is the difference in the male gonad doses measured on the 2 x-ray machines. The mean values differ by a factor of about 9, and statistical analysis by Student's method showed the difference to be highly significant ($p<0.01$). It is noteworthy that the skin-entry doses for the same examination in female patients showed no significant difference (with $p>0.9$). A majority of the male patients examined on the undercouch tube equipment recorded insignificant doses, according to the criterion in Eq. 7.1, while all those examined on the overcouch tube machine received significant doses.

Doses recorded during barium enema examinations with the overcouch tube machine were higher than those for the barium meal examinations. This
reflects comparatively more screening of the lower abdomen in investigations of the colon, the use of generally larger films, and the fact that the lower margin of the radiation field lies closer to the male gonads, which therefore receive more scatter radiation. Direct-beam exposure of the male gonads can be avoided, but the possibility remains during radiography for full-size AP, PA, or lateral decubitus views when the largest films are used. The doses recorded at this hospital showed no evidence of direct-beam irradiation of the testes.

The skin-entry doses recorded in female patients, taken together with the average screening times (see Table 15), give some indication of the skin-entry dose rate from fluoroscopy. This is seen to be approximately 10 mGy min⁻¹. However, the skin-entry dose rate cannot be accurately assessed in this manner because:

(i) some of the recorded dose was due to radiographic exposure (which tends to increase the dose rate), and

(ii) the shifting fluoroscopic beam was incident on the skin at the dose meter positions for only part of the total screening time (which reduces the dose rate considerably).
For x-radiation of diagnostic quality, the incident skin dose gives an indication of the maximum dose received by any cell population of the body, and the rate at which it is delivered has previously been used to prescribe safety standards for fluoroscopic equipment (ICRP, 1970).

7.3.2. Estimates of female gonadal doses

The mean skin-entry doses in female patients were used to estimate doses to the ovaries. The positioning of the TL dose meters in relation to the ovaries (Fig. 11) facilitated this. An ovary-to-skin dose ratio of 0.30 ± 0.15 was used for both barium meal and barium enema examinations on each machine. The initial choice of this factor (Tole, 1984) was influenced largely by the findings of Stanford & Vance (1955), who performed intracavitary measurements in human cadavers and tissue-equivalent phantoms. The large margin of uncertainty in the value of this ratio, amounting to ± 50%, was attributed to radiographic factors such as beam quality, and the relative proportions of scatter versus direct beam exposure of the ovaries. An even larger uncertainty is associated with the variability in the position of the ovaries from one patient to another. The ovaries can be expected to be situated at a depth of approximately 10 cm from the surface dose meter.
measuring the skin dose, but, due to wide variations in physique, the range could probably extend from 7 to 14 cm. in different beam projections. Reference to depth dose data, such as those published by Harrison (1981), show that for a radiation quality of 100kV, HVL 3 mm Al, the variation in percentage depth dose corresponding to the extreme ovarian positions in this range is from about 50 to 100% of the value at 10 cm depth for the range of FSDs and field sizes used in the present work. This uncertainty, amounting to as much as ± 100%, is predominant in the translation of skin-entry doses to ovary doses. The dosimetric errors are much smaller in comparison.

Some recent studies have produced data which tend to support the use of the chosen ovary-to-skin dose ratio of 0.30. Rosenstein (as cited by Gray et al (1981)), in a Monte Carlo calculation assuming exposure parameters similar to those used in these studies, obtained normalized ovary doses of 357 mrad and 286 mrad per roentgen skin-entry exposure (free-in-air) for the AP and PA projections, respectively, in gastro-intestinal colon examinations, assuming an ovary position of 10 cm depth from the anterior skin surface and 6 cm lateral from the midline. Gray et al (1981), in phantom measurements using the same exposure factors as Rosenstein, but assuming an ovary position of 12 cm depth and 3 cm lateral from the
midline, obtained corresponding normalized organ doses of 185 mrad/R and 355 mrad/R. These ratios are based on radiographic examinations. A critical analysis of the relationship between skin and organ doses during fluoroscopic examinations appears in Chapter 8 of this thesis.

The values of the female gonadal doses derived from the skin-entry doses are shown in Table 14. Values for the barium enema examinations were higher than those for barium meal due to more direct-beam exposure of the ovaries during barium enema.

7.3.3. Screening times and film consumption

Average screening times and numbers of films used for each type of examination are shown in Table 15. Spoilt films were also counted, but the incidence of retakes at this centre was very low. In general, the number of radiographic exposures exceeded the number of films used because some films were split into 2 or 4. The difference can be quite big in barium meal examinations. At this hospital, the ratio of the number of radiographic exposures to the number of films consumed was 1.0 for barium enema and 1.5 for barium meal examinations. This ratio is increased by extensive examinations of the duodenal cap and the oesophagus, and kept close to 1 by small
Follow-through examinations of barium meal were carried out using the overcouch tube equipment only.

<table>
<thead>
<tr>
<th>Sex</th>
<th>F</th>
<th>M</th>
<th>F</th>
<th>M</th>
<th>F</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undercouch tube</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9.6</td>
<td>9.6</td>
</tr>
<tr>
<td>Overcouch tube</td>
<td>3.3</td>
<td>4.1</td>
<td>7.5</td>
<td>10.0</td>
<td>3.4</td>
<td>6.8</td>
</tr>
</tbody>
</table>

**TABLE 15. AVERAGE SCREENING TIMES AND NUMBERS OF FILMS USED IN BARIUM MEAL AND BARIUM ENEMA EXAMINATIONS.**
bowel follow-through examinations. Differences in the departmental ratios (1.7 for the outpatients' and 1.3 for the inpatients' department) reflect this (follow-through investigations were performed at the inpatients' department only).

7.3.4. **Effects of small bowel follow-through investigations**

Patients who underwent follow-through examinations of the barium meal recorded higher doses and a larger number of films consumed than those who did not. These effects are shown in Table 16, which also shows the influence on average screening times.

It is common in dose survey reports to classify barium meal investigations as a single type of examination. When detailed analysis of intra-hospital variations is desired, perhaps it would be appropriate to consider the data for those examinations extended to include small bowel follow-through separately from those for the dedicated barium meal examination.

7.3.5. **Patient dose versus age classification**

A breakdown of the mean doses recorded
The dose data for female patients refer to skin-entry doses.

<table>
<thead>
<tr>
<th>SEX</th>
<th>NO FOLLOW-THROUGH</th>
<th>FOLLOW-THROUGH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>p</td>
<td>0.18</td>
<td>0.50</td>
</tr>
<tr>
<td>m</td>
<td>8.2</td>
<td>12.1</td>
</tr>
<tr>
<td>f</td>
<td>5.9</td>
<td>6.1</td>
</tr>
<tr>
<td>w</td>
<td>3.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

**TABLE 16. THE EFFECT OF SMALL BOWEL FOLLOW-THROUGH EXAMINATIONS DURING BARIUM MEAL INVESTIGATIONS ON RADIATION DOSE, SCREENING TIME, AND NUMBER OF FILMS USED**
according to 2 broad age groups (≤45y, >45y) is shown in Table 17 for those examinations in which data on 5 or more patients were available. For this comparison, barium meal with follow-through was classified separately from barium meal without follow-through. The results do not reveal any clear pattern relating patient dose to age class.

7.4. Discussion

Some recent surveys of patient dose during GIT examinations, undertaken at about the same time as the present work, have been reported in the literature. Leibovic & Caldicott (1983), using indirect methods to determine the skin-entry exposure, recorded much higher patient doses. However, their data for male gonad doses, which were determined by direct TLD measurements, are similar to those recorded here. Harrison et al (1983), also using indirect methods, recorded higher skin-entry doses. Faulkner & Bramall (1985), using direct TLD measurements at several abdominal skin positions during barium meal examinations, recorded data which are more in agreement with the results of the present work. As emphasized by Leibovic & Caldicott (1983), data from indirect methods do not take into account the effects of moving the radiation beam over different areas of the skin during fluoroscopic examinations. Measuring
TABLE 17. RADIATION DOSES RECEIVED BY YOUNGER AND OLDER PATIENTS FROM DIFFERENT

<table>
<thead>
<tr>
<th>No. of Patients (mgY)</th>
<th>No. of Patients (mgY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 45 Years</td>
<td>≥ 45 Years</td>
</tr>
</tbody>
</table>

- Female inpatients, Barium enema
  - 7
  - 48.33
  - 6
  - 14.22
  - 0.048
  - 6
  - 4.28
  - 11.98

- Female inpatients, Barium meal with follow-through
  - 7
  - 9.53
  - 5
  - 14.22
  - 0.019
  - 14
  - 0.048

- Male inpatients, Barium meal,
- Male inpatients, Barium meal,
devices which integrate the total dose at some position between the x-ray tube target and the patient's entrance skin surface therefore overestimate the skin-entry dose at those positions not covered by the radiation field for some time during the scanning beam movement.

It was pointed out in the introduction to this chapter that the present study was undertaken shortly after the publication of the findings of the 1977 NRPB national survey of patient doses in Great Britain. During that survey, dose data for barium meal examinations were collected from 61 male and 27 female adult patients in 21 hospitals. In this among other examinations, the numbers of patients of either sex from any one hospital were too small to enable dose variations within, or between, hospitals to be analysed.

The large difference observed between the mean male gonadal doses recorded at the 2 departments during barium meal examinations in the present study demonstrates that mean values obtained for a particular hospital are considerably affected by intrahospital variations. Even for the comparatively large numbers of patients included in the study, the weighted hospital mean (Table 14) apparently bears little relation to the mean values for each depart-
ment. To obtain a truly representative mean value for the hospital, the data must be collected from a sufficiently large number of patients from each department, and weighting between departments should take into account departmental workloads. The effort required and the resources available for national surveys make it difficult to collect sufficient data for each type of examination for accurate inter- or intra-hospital comparisons. For this reason, small-scale institutional or regional surveys have an important supplementary role to play.

It is interesting to consider the possible reasons for the large difference in male gonadal doses at the 2 facilities, since no significant difference was observed in the doses for female patients. Exposure of the testes during barium meal investigations in adults arises exclusively from radiation outside the useful beam. It has been demonstrated that small bowel follow-through examinations (performed only on the overcouch tube equipment) cause a substantial increase in the radiation dose (Table 16). However, an interdepartmental comparison of doses from those patients who did not undergo the follow-through part of the barium meal studies still leaves the mean values for male gonad doses differing by a factor of 5. Differences in age and condition of patients cannot account for
this large difference, since neither the dose data for female patients nor for age-dependence lend support to this hypothesis. The dose variation was therefore most likely due to differences in equipment. Faulkner & Moores (1982) have reported the results of dose-rate measurements around overcouch and undercouch tube fluoroscopy machines, with special reference to radiation exposure of the staff. Their data showed much higher radiation levels around the overcouch tube machine, which they attributed to a combination of tube leakage and the absence of the protection afforded by the lead-rubber screens around the image-intensifier in undercouch tube fluoroscopy equipment. Patient doses measured in the normal course of diagnostic investigations in this study support their findings. Leakage radiation is, in general, specific to individual x-ray tubes. Whether other aspects contribute to higher radiation levels around overcouch tube machines generally, and whether this leads to increased patient doses in organs outside the useful beam needs to be further investigated. Some of the other equipment factors which have been identified as affecting patient dose during fluoroscopic examinations include the image intensifier input dose rate (Faulkner & Bramall, 1985) and the sizes of the sensor for automatic brightness control and the aperture iris of the TV camera (Leibovic & Caldicott, 1983).
It has been common practice in patient dose surveys, including the NRPB survey (Darby et al., 1980; Wall et al., 1980) to attempt breakdowns of radiation dosage from given types of radiological examination by age of the patient. There is need to exercise caution in the interpretation of the quantitative data, as the age-dependence among adult patients has not always shown consistency. The data in Table 17 reflect this inconsistency, and point to the likelihood that the medical condition of the patient is a more important factor than age.
CHAPTER 8

SOME OBSERVATIONS ON THE RELATION BETWEEN SKIN AND ORGAN DOSES DURING X-RAY FLUOROSCOPIC EXAMINATIONS.

8.1. Introduction

Knowledge of the skin dose from radiodiagnostic investigations enables the calculation of doses to other organs. The measurement of skin doses and their subsequent translation to organ doses by application of appropriate organ-to-skin dose ratios is less cumbersome, more generally applicable, and more acceptable to the patient than direct estimations of organ dose using intracavitary measurements. Although organ doses can alternatively be calculated from recorded beam characteristics in conjunction with tissue-air ratios, or by employing Monte Carlo photon transport models, it is not always possible to obtain all the necessary physical data for such calculations during fluoroscopy using equipment with automatic brightness control, or with falling-load generators. Actual dose measurement is indicated in such situations.

Fluoroscopic examinations present unique problems in the assessment of skin doses due to continual changes in beam direction, field size, and patient positioning during the course of the investigations. On some types of fluoroscopic equip-
ment, the exposure factors will also vary automatically in response to changes in tissue thickness or tissue structure.

Radiation monitoring devices which intercept the radiation beam throughout the course of an examination (for example, parallel plate exposure-area ionization chambers) have been found most useful for the indirect assessment of patient dose during fluoroscopy. However, they are inadequate for purposes of estimating the doses at particular sites on the skin, or to any individual organ, because they do not take into account the scanning pattern of the fluoroscopic beam.

Attempts to measure the magnitude and distribution of skin doses during fluoroscopic examinations by using film dosimetry have been made in a number of studies. Blatz & Epp (1961) first suggested a method based on the use of industrial x-ray film jackets to monitor the incident skin exposure during fluoroscopy. Researchers of the Atomic Bomb Casualty Commission in Japan (later replaced by the Radiation Effects Research Foundation) tested the suitability of the method in phantom studies and reported good agreement between doses measured at several bone-marrow and gonadal sites within the phantom using ionization chambers, on the one hand, and those
obtained from surface dose mapping with film jackets and converted to doses at corresponding phantom sites using x-ray attenuation curves, on the other hand.

While the incident exposure side of the patient is not in doubt during radiographic examinations, it is pertinent to pose the questions: does the distribution of skin doses during fluoroscopic examinations lend itself to a clear division between incident and exit sides, and can the pattern be readily delineated with reasonable effort and accuracy? In this chapter, some data which are relevant to these problems are presented and analysed.

8.2. Measurements of "incident" and "exit" doses during barium meal examinations

As part of the studies reported in Chapter 7, skin doses were monitored in 40 women patients undergoing barium meal examinations, using 4 LiF powder dose meters for each patient. Two of the dose meters were placed on the anterior skin surface in the anatomical position illustrated in Figure 11, and the other 2 on the posterior surface directly opposite. The dose meters were marked "anterior" or "posterior" before positioning to avoid mix-up. Twenty two of the patients were examined using an undercouch tube fluoroscopy unit with overcouch image intensifier,
while 18 were examined with overcouch tube equip-
ment.

After the complete examination, including both fluoroscopy and spot-filming, radiation doses were read out and the mean skin doses in anterior and posterior positions calculated for each patient.

8.3. Results

Table 18 shows the arithmetic means of the skin doses measured at each position (anterior or posterior) for the 2 types of machine, and their standard errors.

8.3.1. Statistical analysis

A separate analysis of variance (ANOVAR) was performed for the dose data from the undercouch tube and overcouch tube examinations. The distributions of doses were highly skewed (for example, Figure 12a), so for the statistical analysis the data were transformed logarithmically. The logarithms of patient doses are much less variable than the doses themselves, and the log-dose frequency distribution is therefore much less affected by extreme dose values. An example of this effect is illustrated by comparing Figures 12a and 12b, which show, respectively, the dose and log-dose
<table>
<thead>
<tr>
<th>(mGy)</th>
<th>(mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean posterior dose</td>
<td>Mean anterior dose</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.53 + 0.72</th>
<th>9.03 + 1.93</th>
<th>Overcouch tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.61 + 2.14</td>
<td>2.35 + 0.79</td>
<td>Undercouch tube</td>
</tr>
</tbody>
</table>

Fluoroscopic Equipment. Standard errors are shown.

Table 18. Arithmetic means of skin doses by position of dose meter and type of
Fig. 12 a. Frequency distribution of doses recorded in the posterior position for 22 female patients undergoing barium meal examinations on an undercouch tube machine.
FIG. 12 b. Frequency distribution of log doses in the posterior position for 22 female patients during barium meal examinations on an undercouch tube machine.

NUMBER OF PATIENTS PER LOG DOSE INTERVAL

<table>
<thead>
<tr>
<th>LOG DOSE</th>
<th>Number of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
</tr>
</tbody>
</table>

N 0 1 2 3 4 5 6 7 8 9 10 11
frequency distributions for the posterior position among patients examined with the undercouch tube x-ray unit.

Terms for the main effects of subjects and positions, and the two-way interactions between subjects and positions, were included in the linear model for log dose. ANOVAR tables for the undercouch and overcouch tube dose data are shown in Tables 19 and 20, respectively. Plots of the residuals against normal equivalent deviates indicated that the statistical model was adequate (The computer printouts of these plots are shown in Appendix D).

Table 21 shows the mean log doses from the model, and the geometric mean ratios between the 2 positions.

8.3.2. *Inferences from the statistical analysis*

Analysis of variance revealed that differences in log dose between anterior and posterior positions were highly significant (*p < 0.001*) for both machines (Tables 19 & 20). Interaction between subjects and positions was found to be insignificant (with *p > 0.1*) on one of the facilities, but highly significant on the other (the overcouch tube equip-
<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>Variance Ratio</th>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>Variance Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>87</td>
<td>0.68</td>
<td>29.99</td>
<td>44</td>
<td>Residual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients</td>
<td>21</td>
<td>0.59</td>
<td>53.7</td>
<td>78.79**</td>
<td>Patients X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>5.62</td>
<td>117.94</td>
<td>8.24**</td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Using an Undercooch Tube X-Ray Machine.

Table 19. Analysis of Variance for Doses Measured on 22 Patients Examined.
## TABLE 20. ANALYSIS OF VARIANCE FOR DOSES MEASURED ON 18 PATIENTS EXAMINED USING AN OVERCOUCH TUBE X-RAY MACHINE

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Variation</th>
<th>Freedom</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>R Ratio</th>
<th>Total</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td></td>
<td>17</td>
<td>11.04**</td>
<td>0.67</td>
<td>1.33**</td>
<td>17</td>
<td>0.56</td>
</tr>
<tr>
<td>Positions x</td>
<td></td>
<td></td>
<td>40.24</td>
<td>2.25</td>
<td></td>
<td>17</td>
<td>14.68</td>
</tr>
<tr>
<td>Positions</td>
<td></td>
<td></td>
<td>49.72</td>
<td>2.82</td>
<td></td>
<td>17</td>
<td>14.96</td>
</tr>
<tr>
<td>Patients</td>
<td></td>
<td></td>
<td>2.92</td>
<td>0.17</td>
<td></td>
<td>17</td>
<td>0.56</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>224.6</td>
<td>13.2</td>
<td></td>
<td></td>
<td>71</td>
</tr>
<tr>
<td>Position</td>
<td>Log dose Mean Ratio</td>
<td>Log dose Mean Difference in Geometric</td>
<td>Log dose Posterior</td>
<td>Log dose Anterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>--------------------------------------</td>
<td>-------------------</td>
<td>------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.490</td>
<td>1.245</td>
<td>0.356</td>
<td>0.225</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.560</td>
<td>1.335</td>
<td>0.225</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 21. ESTIMATES OF THE MAIN EFFECT OF POSITION ON NATURAL LOG DOSE.
ment). The implications of a significant interaction here are that although patients examined using the overcouch tube equipment recorded higher doses in anterior positions than posteriorly, and although the dose differences between positions were highly significant as revealed by ANOVAR, the mean log dose may not have been higher in the anterior position for some individual subjects. This was indeed the case in 2 of the 18 patients examined on this facility. In the undercouch tube examinations, 2 of the 22 patients also recorded higher doses in anterior positions, contrary to expectation. These findings show that during GIT fluoroscopy it is not possible to predict which is the predominantly incident skin side for the x-ray beam in individual patients. Unexpected dose relationships will be dictated by the circumstances of individual patients, and considerably influenced by the examining techniques preferred by the radiologist. That a significant interaction between subjects and positions was found in one of the x-ray facilities and not in the other is not in itself of significance; it is most likely a consequence of the size of the statistical sample and variations in doses between patients.

8.3.3. Calculation of percent "exit doses"

The relationship between dose and position
was further examined by calculating the percentage "exit doses" for each of the 40 patients individually to test whether they were representative of beam transmission as expected from depth dose data. The anterior/posterior dose ratios from the undercouch tube examinations and the posterior/anterior dose ratios for the overcouch tube investigations were computed. Their frequencies in various percentage ranges are presented in Table 22. Depth dose data by Harrison (1981) show that for an adult patient whose AP thickness in the lower abdomen is assumed to be greater than the conservative value of 16 cm, the exit dose does not exceed 10% of the incident skin dose over the widest possible range of beam qualities, field sizes, and source-to-skin distances used in diagnostic radiology. Only a quarter of the patients in this study recorded dose ratios less than 10%, while in 4 of the patients, already referred to above, the expected dose relationships between anterior and posterior positions were actually reversed (ratios > 100%). It can be inferred from the data in both Tables 18 and 21 that the mean exit dose for all the patients was in the range 20-30% for both machines. These observations lead to the conclusion that doses measured on patients at the "far side" of the x-ray tube may be generally un-representative of exit doses during GIT fluoroscopy.
<table>
<thead>
<tr>
<th>Range (%)</th>
<th>No. of Patients</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>10 - 20</td>
<td>13</td>
<td>90</td>
</tr>
<tr>
<td>20 - 50</td>
<td>13</td>
<td>57</td>
</tr>
<tr>
<td>51 - 100</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>5</td>
<td>12</td>
</tr>
</tbody>
</table>

TABLE 22. THE FREQUENCIES OF PERCENTAGE "EXIT DOSE" AMONG 40 PATIENTS DURING BARIUM MEAL EXAMINATIONS.
8.4. Discussion

Ideally, organ doses from fluoroscopic examinations should be calculated by integrating the products of measured skin doses with organ-to-skin dose ratios for all beam projections. Because of the large number of measurements and physical parameters required for this exercise, it is necessary in practice to simplify the procedure. It is common for this purpose to assume that, for undercouch tube x-ray machines, the posterior surface of the patient constitutes the incident skin side of the x-ray beam, with the position reversed when overcouch tube equipment is used. A limited number of measurements is then made on the assumed incident side, which are then converted to doses in other organs. The analysis in this study has shown that these assumptions amount to approximations which may provide estimates of average skin doses in a large number of patients, but which cannot be applied to individual patient dose determinations.

From the observation that doses monitored on the patient's far side with respect to the x-ray tube may be unrepresentative of exit doses during GIT examinations, it may be inferred that organ-to-skin dose ratios are also likely to be affected in a complex and perhaps unpredictable manner. There
is need to be cautious in applying organ-to-skin dose ratios obtained under radiographic conditions of exposure, or from depth dose tables, in calculating organ doses for fluoroscopic procedures.

Deviations from the expected relationships between incident and exit doses for the fluoroscopy component in GIT examinations can be expected to be even more marked than revealed by the data in this analysis, because the spot-filming component has a moderating effect. Bearing in mind that, in terms of radiation dose, a radiographic exposure of 60 mAs at a given kV is equivalent to screening over the same body area at a tube current of 1 mA for 1 minute at the same kV, the contribution of spot-filming to the radiation dose in barium meal examinations is substantial. Experimental determinations of the relative contributions of radiography and fluoroscopy to the total radiation dose during this examination have yielded wide-ranging results. Leibovic & Caldicott (1983), in measurements involving a small sample of young patients at one hospital attributed only 10% of the total skin-entry exposure to spot-filming. Harrison et al (1983), in a more extensive survey covering 10 hospitals, reported contributions from fluoroscopy in the range 26-78% of the total dose, with a weighted mean of 51%.
Monitoring of skin doses using dose meters in lateral positions may provide much useful information on the magnitudes of patient exposures arising from lateral oblique projections. During GIT studies, it is these exposures which are largely responsible for upsetting the antero-posterior dose ratios as expected from true AP or PA views.

The role of film dosimetry in mapping the distribution of skin doses during fluoroscopy has been mentioned. However, the value of elaborate determinations of skin dose distributions needs to be re-examined in the light of the effort required and the uncertainties as to whether the positions at which the doses are measured represent the incident skin side. The effort required in the film jacket technique is demonstrated in one study (Liuzzi et al, 1964) in which over 200 measurements of absorbance (optical density) were made for the calculation of average bone marrow dose from a barium enema examination in one subject. Apart from such an effort, the necessity of changing film jackets during fluoroscopic investigations has not made this technique acceptable during actual examinations of patients. As a result, most of the available data in which this method has been used are based on laboratory phantom studies. But phantom studies of patient doses during fluoroscopic examinations suffer
from certain drawbacks. In attempting to perform a fluoroscopic examination of an inanimate object, the radiologist's attention and commitment are reduced. The absence of dynamic motion of anatomical parts and contrast media influences the extent to which the examiner manipulates the phantom, and the time it takes him to perform the simulated examination. The extent to which these considerations affect the results of patient dosimetry deserves further attention.

The problem of assessing organ doses from fluoroscopic examinations with a degree of accuracy comparable to that of radiographic dose estimates remains unresolved. It appears, moreover, that the uncertainties attributed to current methods are probably larger than believed.
CHAPTER 9

AN ESTIMATE OF THE FREQUENCY OF DIAGNOSTIC X-RAY EXAMINATIONS IN KENYA, 1986.

9.1. Introduction

The annual frequency of radiological examinations in any country is an important indicator of the general scope of radiological services in that country. Frequency survey data provide health planners with valuable information which may form an objective basis for resource allocation, especially when considering further expansion of radiological services. From the point of view of radiation protection, the collection of data on the frequencies of different types of radiological examination is one of the essential steps in the process of estimating the collective health risks to the general population from x-ray diagnosis.

The frequencies of radiological examinations in the industrialized countries range from about 300 to over 1,000 examinations per thousand inhabitants per year. Only scarce information is available from the developing countries, but crude estimates indicate that the frequencies in these countries are about 1/10th of those in the industrialized countries (UNSCEAR, 1982).
During 1977/78, Cockshott (1979) made a records-based survey of radiological coverage in many tropical countries, Kenya included. He concluded that radiology was used about 30 times less often per capita in developing than in industrialized countries. His estimate of the frequency of radiological examinations in Kenya was 36 examinations per thousand population per year. Whittaker (1980) and Raja (1982) have also previously reported data from a prospective survey conducted at a few x-ray centres in Kenya, but the scope of their studies was too limited to enable national estimates of annual workload.

In this chapter, the methodologies employed in frequency surveys are briefly reviewed. A retrospective survey of the number of diagnostic x-ray examinations performed in Kenya during 1986 is described. The relative frequencies of different types of examination are analysed.

9.2. Review of frequency survey methodologies.

9.2.1. Prospective surveys

Prospective surveys are normally organized to take place simultaneously at a sample of radiological institutions representative of the x-ray facilities in the population of interest. The
relevant information concerning all the radiological examinations performed over a set period of time (for example, type of examination, numbers of examinations performed, sex and age of patient, etc.) is recorded. Logistical problems limit both the number of institutions included in the sample and the time period over which the survey is conducted. Rigorous statistical methods have to be applied to obtain reasonably accurate estimates of the frequency of examinations in the population.

The 1977 NRPB survey in Great Britain (Kendall et al, 1980) is a good example of a prospective survey. A sample of 112 hospitals was selected from among more than 1,400 hospitals. Eighty one consented to take part. Data collection was carried out over a period of 7 consecutive days. Returns from 77 of the hospitals met the survey criteria and formed the basis of the frequency analysis.

9.2.2. Retrospective surveys

Two general approaches have been followed in retrospective surveys. The more common one is based on examining the records of examinations previously performed over a specified period of time. A less accurate variation of this method has been to
examine records of the numbers of x-ray films consumed over a known period of time. The advantages of the records-based survey methods are that they require less resources than prospective surveys, and, in general, data can be collected from larger numbers of institutions and over longer periods of time.

The second method is based on household interviews and has been the basis of national frequency surveys in the U.S.A. (PHS, 1962; Gitlin & Lawrence, 1966; DHEW, 1973). In this method, a representative sample of the population is interviewed concerning possible visits to x-ray centres during a fixed period of time prior to the date of interview (the preceding 3 months in the case of the U.S. national surveys). This initial house-to-house exercise is then followed by enquiries at x-ray facilities named by those respondents who had undergone x-ray examinations during the relevant period. The purpose of the x-ray facility follow-up is to obtain details of the examinations performed.

The household interview method is perhaps the most demanding in terms of resources and logistics. The inevitable constraints have usually led to data analyses being eventually based on very low proportions of the annual radiological workloads. For example, the number of patient visits to x-ray
facilities on which the frequency of radiological examinations for the 1964 U.S. national survey was based represented a mere 0.002% of the annual workload (UNSCEAR, 1972). The method also suffers from the disadvantage of being suitable only among populations in which the general level of education is high.

9.3. Methods in the current survey

This survey was based on the retrospective collection of data using a questionnaire. Between July and August, 1987, a questionnaire was mailed out to 115 medical institutions, representing government, missionary, and private hospitals and clinics, and radiologists' practices. Each centre was requested to provide data on the numbers of radiological examinations performed during the calendar year 1986, if these were available, or during an earlier year, if data for 1986 were not available. Centres were also requested to state the numbers of x-ray units they had. The medical institutions were all those known or believed to have x-ray facilities, and for which addresses were readily available. No sampling methods were employed in selecting centres.

A simple breakdown of types of radiological examination was designed to suit the majority of
x-ray centres in the country, namely government district and sub-district hospitals, missionary hospitals, and small private clinics. The questionnaire format and the covering letter accompanying it are shown in Appendix B. An assurance was given that the information which a responding centre may provide would be treated in confidence. It was hoped that this assurance would help increase the response rate.

The institutions to which the questionnaire was dispatched were classified into various categories under the broad groups of government and private institutions. These categories are shown on the first column in Table 23.

Reminders were sent out to 24 of the non-respondents as at the end of September, 1987. In addition, a few personal contacts were made with non-respondents up to April, 1988.

The data provided by respondents up to the end of April, 1988, form the basis of the present estimates of the annual frequency of radiological examinations in Kenya during 1986.
<table>
<thead>
<tr>
<th>Category</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Private Clinics</td>
<td>172</td>
</tr>
<tr>
<td>Missionary Hospitals</td>
<td>4</td>
</tr>
<tr>
<td>Radio-Logical Practices</td>
<td>2</td>
</tr>
<tr>
<td>Large Private Hospitals</td>
<td>11</td>
</tr>
<tr>
<td>Private Institutions</td>
<td>8</td>
</tr>
<tr>
<td>Others</td>
<td>4</td>
</tr>
<tr>
<td>District &amp; Sub-District Hospitals</td>
<td>7</td>
</tr>
<tr>
<td>Provincial Hospitals</td>
<td>7</td>
</tr>
<tr>
<td>National Hospitals</td>
<td>1</td>
</tr>
<tr>
<td>Government Institutions</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Were Sent</td>
<td></td>
</tr>
<tr>
<td>Were Used</td>
<td></td>
</tr>
<tr>
<td>Questionnaires</td>
<td></td>
</tr>
</tbody>
</table>
| Centres to Which REPLYING NUMBER
| Per CENT PERCENT                  |        |
| Category of INSTITUTION          |        |
|                                   |        |

**TABLE 2. DISTRIBUTION OF FREQUENCY SURVEY QUESTIONNAIRES**

AND RESPONSE RATES FOR DIFFERENT CATEGORIES OF MEDICAL INSTITUTION.
9.4. Results

9.4.1. Response to questionnaire

Of the 115 institutions contacted, 74 sent replies. Sixty seven of these provided data for annual workloads within the period 1985-1987 (1985 - 3 centres; 1986 - 62 centres; 1986/87 - 1 centre; 1987 - 1 centre). Returns from these 67 centres (representing a response rate of 58%, and about 50% of the estimated number of all x-ray institutions in the country) have been used to estimate the national radiological workload during 1986. Of the remaining 7 institutions, 5 reported that they did not have functioning x-ray facilities during 1986, 1 promised to send data for calendar year 1987 at a later date but did not subsequently do so, and 1 sent data covering a one-year period during 1982/83, data which were considered too old for the purposes of this work.

A breakdown of the response rates by category of institution is shown in Table 23. The response rates varied widely, with government hospitals recording very high response rates, while the small private clinics and private radiologists' practices showed poor response rates.
9.4.2. Estimates of the total numbers of examinations performed

The total volume of x-ray examinations performed was calculated separately for each category of x-ray institution, and the category totals were then added up to provide the national total. The general approach was to calculate the arithmetic mean of the totals for each category from the responding centres and multiply the mean value by the estimated number of institutions of that category in the whole country (shown in Table 24). This was done for the categories of government district and sub-district hospitals, and missionary hospitals. Slight modifications of this method were applied for the remaining categories.

Among the "other government hospitals" were 3 specialized centres (2 dental departments and 1 chest clinic) and 8 centres performing general radiological work. All 3 specialized centres provided data. The total number of examinations for the general x-ray departments was calculated using the mean of the 4 responding centres in this sub-category, rather than from all the 7 respondents.

Six of the 7 provincial hospitals in the country were served by radiologists by 1986. The remaining 1, situated in a low population-density
province, had never had a radiologist. This 1 hospital and 4 others sent their returns. The mean value of the 4 hospitals served by radiologists was used to represent the workload for each of the 2 non-respondents. The data provided by the 1 less privileged provincial hospital showed that its separate treatment was justified: the total number of examinations performed at this hospital was more than 7 times less than that from any of the other 4 respondents.

In calculating the total workload for the category of large private hospitals, a similar distinction was made between the 3 hospitals served by full-time radiologists (out of which 2 responded) and the 8 which had only part-time access to a radiologist (out of which 4 responded). Here also, the respondents' returns showed large differences in the workloads between the 2 sub-groups.

Two x-ray centres responded in the category of private radiologists' practices. These were 1 well-established group practice and 1 comparatively smaller practice. In the absence of any other returns under this class of institution, data from the smaller x-ray centre were taken to be representative of the remaining 8 centres in the country, all of which were operated by single radiologists.
The resulting total for the category should be regarded as a crude estimate.

Another crude estimate was that for the small private clinics. Only 1 of the 12 institutions contacted in this category provided data. The category total in this case was estimated by assuming identical workloads with the missionary hospitals, which recorded the lowest average category workload, but from a satisfactory response rate of 50%. (The single responding centre among institutions classified as small private clinics reported a total number of examinations which was much lower than the average for missionary hospitals).

The calculated category totals for the year 1986 are shown in the last column of Table 24, rounded off to the nearest thousand. The most important attributes in estimating the total numbers of examinations performed were the large sample sizes and very high response rates among the government hospitals. These parameters were also satisfactory among the large private hospitals and the missionary hospitals. The precision of individual category totals is indicated by the standard errors shown against the corresponding category or sub-category sample means from which the totals were calculated.
<table>
<thead>
<tr>
<th>Category of Institution</th>
<th>No. of Examinations (1986)</th>
<th>Mean No. of Examinations</th>
<th>Estimated No. of Examinations</th>
<th>Estimated Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government Hospitals</td>
<td>112,070</td>
<td>1525</td>
<td>7,200</td>
<td>10,650</td>
</tr>
<tr>
<td>Other Health Institutions</td>
<td>10,888</td>
<td>1573</td>
<td>7,200</td>
<td>10,650</td>
</tr>
<tr>
<td>Other Districts</td>
<td>42,000</td>
<td>10,000</td>
<td>7,200</td>
<td>10,650</td>
</tr>
<tr>
<td>Private Institutions</td>
<td>50,000</td>
<td>10,000</td>
<td>7,200</td>
<td>10,650</td>
</tr>
<tr>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
</tr>
<tr>
<td>177,000</td>
<td>177,000</td>
<td>177,000</td>
<td>177,000</td>
<td>177,000</td>
</tr>
</tbody>
</table>

Crude estimate: Mean values in brackets indicate 1 respondent.
There were some uncertainties regarding the estimated numbers of x-ray centres in the country (Table 24). One official source (KAR, 1987) put the total number of x-ray centres in Kenya at 117 as of 1987, out of which 61 were governmental and 56 non-governmental. The number of governmental institutions concurs with the present estimates, which, however, give a higher figure for the private institutions. The estimates in Table 24 were arrived at after examining various official records and license applications. The uncertainties were highest for the small private clinics (probably as high as + 50%) and the missionary hospitals (of the order of + 30%). However, these considerable uncertainties in the numbers of centres did not seriously affect the estimate for the total volume of radiological workload country-wide, since these 2 categories were associated with comparatively low workloads. The numbers of government institutions, large private hospitals, and radiologists' practices were known quite accurately. For example, the number of functional x-ray departments at district and sub-district hospitals was within + 2 (i.e. about 5%) of the stated number.

The grand total for all categories of institution shows that about 643,000 radiological examinations were performed in Kenya during 1986.
The overall uncertainty associated with this estimate is about ±20%, with individual category total estimates having uncertainties ranging from about ±10% among the government institutions to as much as ±100% for the small private clinics.

The population of Kenya in 1986 was estimated as 20 million. It is concluded from the results of this survey that the annual frequency of all radiological examinations combined was 32 examinations per thousand population.

9.4.3. The most commonly performed examinations

Sixty one of the centres making returns conformed with the questionnaire format in reporting their data. In order to obtain an indication of the most commonly performed radiological examinations in Kenya, data from these 61 institutions were used to calculate the relative frequencies of individual types of examination. The sums of the total numbers of investigations performed for individual types of examination were computed and expressed as percentages of the grand total of all examinations of all types in these 61 institutions.
The results, shown in Table 25, indicate that examinations of the limbs predominate, followed by chest examinations. Special radiological examinations, involving the use of contrast media and requiring the expertise of specially-trained physicians, were performed with relatively low frequency. Among these, examinations of the gastrointestinal tract, urological examinations, and hysterosalpingography were the most common. The special examinations were performed with a higher frequency among the radiologists' practices, the large private hospitals, and the government provincial hospitals (the national hospital did not provide a breakdown), which had screening equipment and regular access to the services of radiologists, than in the remaining categories of institution in this survey.

Dental examinations have been included in the data analysed here. Facilities for dental x-ray examinations were available at 2 government-managed specialized departments, most of the provincial hospitals, some district hospitals, some large private hospitals, and a few private dentists' clinics. Unfortunately, there was no specific provision for dental examinations on the survey questionnaire that would have enabled an accurate assessment of the workload for this type of examination. However, some useful deductions may be made.
TABLE 25. RELATIVE FREQUENCIES OF DIFFERENT TYPES OF RADIOLOGICAL EXAMINATION.

<table>
<thead>
<tr>
<th>Type of examination</th>
<th>Relative frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>28.9</td>
</tr>
<tr>
<td>Skull &amp; mandible</td>
<td>8.9</td>
</tr>
<tr>
<td>Lower &amp; upper limbs</td>
<td>39.0</td>
</tr>
<tr>
<td>Spine</td>
<td>5.0</td>
</tr>
<tr>
<td>Plain abdomen</td>
<td>3.5</td>
</tr>
<tr>
<td>Pelvis &amp; hips</td>
<td>3.5</td>
</tr>
<tr>
<td>Other plain x-rays</td>
<td>5.6</td>
</tr>
<tr>
<td>GIT (with contrast)</td>
<td></td>
</tr>
<tr>
<td>HSG</td>
<td></td>
</tr>
<tr>
<td>IVU</td>
<td>5.7</td>
</tr>
<tr>
<td>Other special exams</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.1</strong></td>
</tr>
</tbody>
</table>
from data provided by a few of the respondents. The 2 specialized departments, believed to be the busiest dental centres in the country, reported a total of 27,100 examinations during 1986. Six other centres, comprising 2 provincial and 4 district hospitals indicated their dental workloads, either as a separate item or under "other plain x-rays" or "skull & mandible" (Table 25), with an explanation. The sum total from these 6 centres was 2,700 examinations, with the district hospitals reporting 100-300 examinations each. Most of the missionary hospitals had only one general purpose x-ray machine each, and so did not perform any dental examinations. It was not possible to assess the volume of dental radiography among the large private hospitals, the radiologists' practices, and private dentists' clinics, but only a few such institutions had dental x-ray sets, and their combined workload should be considerably lower than that for government hospitals. It would appear from the few available data that dental radiography constituted some 5-10% (32,000-64,000 examinations) of the total number of examinations performed in 1986. The relative frequencies of examinations classified as "skull & mandible" or "other plain x-rays" were both \(\leq 10\%\). Data for centres which may have reported their dental examinations under one of these classes would therefore seem not to contradict the estimated
upper limit for the frequency of dental examinations.

Computed tomography had only just been introduced into Kenya in 1986. Data for CT scans have therefore not been included in this work, but the number of such examinations performed was negligible in comparison to the total national workload.

9.5. Discussion

Some of the major obstacles in obtaining data on the frequencies of radiological examinations from the developing countries include the unavailability of proper records in the case of retrospective surveys, and large fluctuations in workload at different times in the case of prospective surveys. Such fluctuations are caused by equipment breakdown and irregular supplies of films, processing chemicals, and contrast media. This feature is illustrated in Figure 13, which shows the variation in the numbers of contrast examinations of the gastro-intestinal tract performed at Kenya's national referral hospital during 1984. The retrospective approach to frequency surveys is to be preferred where such large fluctuations in workload are to be expected, because it lends itself more readily to data collection over long periods of time. To facilitate records-based data collection, good record keeping
FIG. 13. Variation in the number of contrast examinations of the gastro-intestinal tract performed at Kenyatta National Hospital, Nairobi, during 1984 (Courtesy of Mr. S. Karbuki, X-ray Department, KNH).
is essential. In this respect, the high response rates recorded from government institutions during this survey reflect an established system of record keeping which should be encouraged in the other institutions as well.

Although the volume of radiological work in this survey was assessed on the basis of the number of radiological examinations performed, without applying workload factors to account for differences in complexity between different procedures, the estimates presented here provide an adequate indication of workloads for most hospitals in Kenya, and for the country as a whole, because of the low frequency of the specialized contrast examinations.

The results of this survey indicate that Kenya is one of those countries in which the annual frequency of radiological examinations is at least one order of magnitude lower than that typical for the industrialized nations. The estimated frequency of 32 examinations per thousand population per year is similar to the data reported from India during the early 1970s (Supe et al, 1974). Other sources of data show lower frequencies in a few countries, but also reveal that some other developing countries record annual frequencies in the range 100-400 examinations per thousand inhabitants (Cockshott,
1979; UNSCEAR, 1982). For Kenya, the close agreement between the present result and Cockshott's estimate for 1976/77 does not imply that radiological services have not undergone expansion during the intervening decade. The explanation lies in Kenya's fast population growth rate of about 4% per annum, a recognized problem which imposes constraints on the provision of most social amenities.

Although about a half of all x-ray centres in Kenya are managed by private institutions, the results of this study show that about 70% of the total number of examinations were performed in government institutions during 1986. One unfortunate aspect of the geographical distribution of radiological services within the developing countries has been the tendency to have most facilities concentrated in the major urban areas, while the vast majority of their populations live in the rural areas. This disparity is still evident in Kenya, but it is encouraging to note that the district and sub-district hospitals now take a substantial proportion of the radiological workload.

Reasons for the predominance of radiological examinations of the limbs in Kenya have previously been identified as trauma arising from a high incidence of traffic accidents, and assault
(Raja, 1982). The high frequency for chest examinations is attributed largely to infections of the lung. A majority of chest examinations were performed using photofluorographic equipment of the Odelca camera type (Philips Co., Netherlands). It was shown in Chapter 4 of this thesis that the patient doses associated with this equipment are high. Chest examinations are therefore likely to be a major contributor to the collective population dose from medical exposure in Kenya.

The low frequency recorded for the special radiological procedures reinforces the view that efforts to spread radiological services to the majority of the people among the developing countries should be directed mainly at providing basic radiographic services, using simple and appropriate equipment.

All x-ray departments in government hospitals in Kenya are manned by qualified radiographers and formally-trained film processing staff. Some of the reported workloads at individual centres raise some questions concerning manpower utilization. Fifteen of the 31 hospitals in the category of district and sub-district hospitals whose data were used in this study reported annual workloads of \( \leq 3,000 \) examinations performed (i.e. an average of \( \leq 10 \) examinations
per day). The reasons for such low workloads need to be studied to help avoid under-utilization of professionally trained manpower.

Some district hospitals and a few missionary hospitals and private clinics have direct fluoroscopy units as part of their equipment. Fluoroscopy without image intensification has the potential for delivering some of the highest patient doses in x-ray diagnosis, especially when the examinations are performed by non-radiologists. Fortunately, the findings of the frequency survey suggest that most of the direct screening units in Kenya are either not used, or used very little, as only a few district and missionary hospitals reported the performance of fluoroscopic examinations. The use of direct screening units should not be encouraged, and should probably be stopped altogether at those x-ray departments not served by specialist radiologists.
CHAPTER 10

AN APPRAISAL OF COLLECTIVE POPULATION HAZARDS FROM DIAGNOSTIC X-RAY EXPOSURE IN KENYA

10.1. Scope of x-ray diagnosis in Kenya

The history of x-ray diagnosis in Kenya may be traced to 1936 when the first x-ray department in government service was opened (ISRRT, 1972). Major expansion took place during 1950/51 when x-ray departments were opened at provincial hospitals outside the city of Nairobi, and the training of radiographers was started. The following three decades saw a steady growth of radiological facilities in both government and private institutions. The survey reported in Chapter 9 of this thesis indicates that by 1986, there were about 130 x-ray establishments in the country, performing an estimated 643,000 examinations annually. The trained personnel in that year included 27 qualified radiologists and about 300 radiographers, serving a population of 20 million.

The following ratios are implied:

Population per radiologist, 740,000 : 1
Population per radiographer, 67,000 : 1

These ratios, taken together with the estimated annual frequency of 32 radiological examinations per thousand population (see Chapter 9), place Kenya among those countries in which radiological coverage is regarded as inadequate (Racoveanu, 1980: Brederhoff &
Racoveanu, 1982). Therefore, when considered as an isolated factor, the scope of x-ray diagnosis would suggest that the absolute contribution to the collective population exposure from this source is quite low.

10.2. Patient dose per examination

The collective population dose from a given type of radiological examination is a function of both the frequency of that examination and the mean dose per examination. In Chapter 1, some unfavourable conditions prevailing in many of the developing countries, and which have the potential for leading to the delivery of high patient doses per examination, were reviewed. The studies of patient dose reported in Chapters 4 - 6 were conducted at Kenyan hospitals under the conditions prevailing at the survey centres. Limitations in the scope of these studies do not allow one to make estimates of collective population dose indices such as per caput mean bone marrow dose, or genetically-significant dose. However, a few relevant observations may be made.

Enhanced doses were recorded for chest imaging using photofluorographic techniques, but not for full-size radiography. In the light of the high frequency for chest examinations, as reported in Chapter 9, the extensive use of photofluorography
needs to be reviewed.

Although examinations of the limbs were performed more frequently than those of the chest, the former are unlikely to be as important as the latter from the point of view of collective hazards to the population. This is because during chest examinations a larger proportion of the bone marrow is irradiated by the direct beam, other important organs such as the breasts, the lungs, and the thyroid are exposed, and the patient doses recorded during photofluorography were considerably higher than those to be expected from limb examinations.

Both hysterosalpingography and pelvimetry using CaWO$_4$ intensifying screens delivered generally high patient doses. Further studies are indicated to assess levels of patient exposure from other potentially high-dose examinations, or from those examinations performed with high relative frequencies. Among the contrast examinations, investigations of the gastro-intestinal tract, urological studies, and myelography deserve particular attention. Plain examinations which may be important with regard to patient dose include those of the skull, the pelvis, and dental examinations.
10.3. **Possible effects of population characteristics on collective risks**

Kenya's population is characterised by a large proportion of young people, and high fertility rates resulting in a rapidly increasing population. These features are illustrated by data from the Central Bureau of Statistics (CBS, 1981a, 1981b), shown in Tables 26 and 27.

The average risk factor for hereditary effects in the first two generations has been estimated by the ICRP (1977) as being about $4 \times 10^{-3} \text{Sv}^{-1}$. This estimate is based on the assumption that some 40% of the collective gonad dose in the population is genetically significant. The percentage figure originates from the assumption that 40% of the model population is below the age of 30 yr., taken to be the approximate median age of child-bearing (Pochin, 1979).

Examination of Kenya's population characteristics reveals considerable differences with the model population. The median age of conception for females falls in the age bracket 25 - 29 yr. (Table 27), and interpolation suggests a mean age of child-bearing of about 27 yr. Table 26 shows that about 70% of Kenyans are below age 27 yr., while 75% are below age 30 yr. The average genetic risk in the population per unit dose equivalent in Kenya is
<table>
<thead>
<tr>
<th>Age Group (yr)</th>
<th>Per cent in population</th>
<th>Cumulative percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 4</td>
<td>18.6</td>
<td>18.6</td>
</tr>
<tr>
<td>5 - 9</td>
<td>16.3</td>
<td>34.8</td>
</tr>
<tr>
<td>10 - 14</td>
<td>13.5</td>
<td>48.3</td>
</tr>
<tr>
<td>15 - 19</td>
<td>11.4</td>
<td>59.7</td>
</tr>
<tr>
<td>20 - 24</td>
<td>8.7</td>
<td>68.4</td>
</tr>
<tr>
<td>25 - 29</td>
<td>6.9</td>
<td>75.2</td>
</tr>
<tr>
<td>30 - 39</td>
<td>9.4</td>
<td>84.6</td>
</tr>
<tr>
<td>40 - 49</td>
<td>6.4</td>
<td>91.0</td>
</tr>
<tr>
<td>50 +</td>
<td>8.8</td>
<td>99.8</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>

TABLE 27. AGE SPECIFIC FERTILITY RATES FOR KENYA WOMEN: ANNUAL BIRTHS PER 1,000 WOMEN IN EACH AGE GROUP (INTERCENSAL DECADE 1969-1979).

<table>
<thead>
<tr>
<th>Age group (yr)</th>
<th>Age specific fertility rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 14</td>
<td>3</td>
</tr>
<tr>
<td>15 - 19</td>
<td>179</td>
</tr>
<tr>
<td>20 - 24</td>
<td>368</td>
</tr>
<tr>
<td>25 - 29</td>
<td>372</td>
</tr>
<tr>
<td>30 - 34</td>
<td>311</td>
</tr>
<tr>
<td>35 - 39</td>
<td>226</td>
</tr>
<tr>
<td>40 - 44</td>
<td>105</td>
</tr>
<tr>
<td>45 - 49</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total (x 5)</strong></td>
<td><strong>7,890</strong></td>
</tr>
</tbody>
</table>

therefore about 1.8 times higher than that for the ICRP model population.

The average number of children borne alive by a Kenyan woman who lives to the age of 50 yr. is about 8 (Table 27). The genetically significant dose per unit gonadal dose is enhanced by this high fertility rate because, on average, the subsequent child-expectancy at the time of exposure is high. The generally young population, the prevalence of some types of infectious diseases common among children in the tropics which may require radiological investigation, and physicians' tendencies to subject the younger patient to comparatively more extensive investigations, all combine to make the average age at diagnostic x-ray exposure quite low.

Somatic risks are also adversely affected by the population age distribution, because exposure at an early age implies an extended period for possible delayed stochastic effects to become clinically manifest during subsequent life.

In summary, the population characteristics of Kenya suggest an enhanced risk per average unit dose of radiation. In assessing the collective risks of radiation to the population, this factor must be
considered along with the amount of exposure received by the population.
11.1. Summary of the main findings

Radiation doses received by patients during the performance of a few types of radiological examination have been measured at a number of x-ray departments in Kenya and in the United Kingdom. The doses recorded at Kenyan institutions provide a data base which should serve as a useful reference for comparisons with similar studies in the future. A survey of the annual frequency of radiological examinations in Kenya has been conducted, providing an insight into the extent of current radiological services in the country.

Patient doses during chest photofluorography at Kenyan departments were found to be generally high, with wide variations between different centres. During full-size chest radiography, however, the measured doses were found to be comparable to those reported from other countries. Calculation of patient doses from recorded technical parameters used during chest examinations showed reasonable agreement with direct TLD measurements. This suggests that indirect methods of dose determination are a feasible approach to patient dosimetry studies in Kenya.

Maternal skin-entry doses measured during erect lateral pelvimetry were found to be high when
CaWO$_4$ intensifying screens were used, but the use of Y$_2$O$_2$S : Tb rare-earth screens reduced these doses by a large factor. The risk of inducing childhood leukaemia from irradiation in utero during ELP using CaWO$_4$ screens at the Kenyatta National Hospital, Nairobi, was crudely estimated to be 200 cases per million pelvimetries. Referal criteria for pelvimetry examinations were found not to have changed over a long period of time, despite previous findings that a large proportion of such examinations might have been unnecessary.

Fluoroscopy was shown to contribute a large proportion of the patient dose during hysterosalpingography.

Other causes which may have been responsible for elevated levels of patient exposure were identified as the use of inefficient image receptors, inadequate beam filtration, collimation without light-beam indication, and inadequate maintenance of equipment.

Patient doses during gastro-intestinal radiology at a busy hospital in the United Kingdom revealed large intra-hospital variations in male gonad doses, with doses recorded on an overcouch tube fluoroscopy unit being several times higher than those measured on an undercouch tube unit, for
identical abdominal skin-entry doses. The study suggests that overcouch tube fluoroscopy equipment may deliver higher patient doses to organs outside the useful beam [The ICRP (1985) has previously expressed its reservations concerning the use of such equipment, on the basis of enhanced radiation doses to radiological staff].

The large intrahospital dose variations observed in the GIT study leads to the conclusion that institutional dose surveys conducted over extended periods of time offer better opportunities for detailed studies of intrahospital dose variations than do national surveys, at any rate for radiological examinations of relatively low frequency.

The frequency survey revealed that, during 1986, 32 radiological examinations were performed per thousand population in Kenya. The most common types of examination were plain x-rays of the limbs and the chest.

11.2. **Limitations of the present studies**

The general scope of these studies was limited by various resource constraints. Dose measurements could only be made for a few types of
radiological examination. Data for some types of examination were collected from only one or two hospitals; therefore, the resulting data in such cases did not necessarily reflect mean values on a wider scale. The size of the patient sample for a given type of examination at some hospitals was sometimes rather small.

The survey of the annual frequency of radiological examinations did not seek to obtain the age and sex distributions of the patients examined. For one or two categories of x-ray facility, the response rates were too low to enable an accurate estimation of the corresponding radiological workloads.

It was not feasible within the resources at the disposal of this study project to diversify the scope of the dose measurements and the frequency survey to the extent that would have enabled evaluations to be made of population indices of radiation-induced detriment, such as genetically significant dose, or collective effective dose equivalent.

11.3. Recommendations

The discussions appearing in the various chapters of this thesis have, on the bases of the
observations made, suggested a number of measures relevant to the protection of the patient from the hazards of ionizing radiation during diagnostic radiology. The following is a summary of the major recommendations.

(1) Restrictions should be introduced into the use of photofluorographic cameras for chest imaging in Kenya. It is suggested that pregnant women, children under the age of 15 years, and patients whose follow-up management may require frequent chest examinations should be examined by full-size screen-film radiography, despite the higher costs involved.

(2) The feasibility of replacing conventional CaWO$_4$ intensifying screens with the more efficient rare-earth screens at radiology departments in Kenya should be studied. The evaluation should consider the costs involved, the benefits in terms of patient dose reduction, and the possible effects on image quality.

(3) The professional medical associations representing various specialities should, in collaboration with diagnostic radiologists, be actively involved in the formulation of guidelines for patient referral criteria for those radiological
examinations most frequently requested by members of their respective medical specialities.

(4) All X-ray Departments in Kenya should be required to make annual returns of the radiological examinations they perform. The returns should be made using standard formats designed with the help of professional radiological organizations, and sent to a central authority such as the Radiation Protection Board.

(5) An active quality assurance programme for diagnostic radiology should be established in Kenya, along the guidelines proposed by the World Health Organization (WHO, 1982), to help achieve acceptable standards of equipment performance, reduce patient dose variability, and improve the quality of diagnostic images.

(6) Radiological equipment repair services in Kenya should be given much more support than at present.

(7) The use of overcouch tube fluoroscopy equipment should be discouraged worldwide, in the interests of the radiation protection of both patients and radiological personnel.
11.4. **Suggestions for further research**

Further studies are indicated in the following areas:

(i) More studies of patient dose at Kenyan hospitals to provide data for those examination types not covered in this thesis. In this regard, gastro-intestinal, urological, and dental examinations deserve preferential consideration.

(ii) A separate study of radiological workloads in private clinics, and an evaluation of the standards of radiographic practice at such institutions.

(iii) Studies of the correlation between the radiological manpower deployed at government district and sub-district hospitals and their annual workloads.

(iv) Quality assurance research to investigate the performance of x-ray equipment, film processors, and image receptors to optimise patient dose with image quality.
<table>
<thead>
<tr>
<th>No.</th>
<th>Serial</th>
<th>Age</th>
<th>Sex</th>
<th>KY</th>
<th>m/s</th>
<th>No. of exposures</th>
<th>Position</th>
</tr>
</thead>
</table>

**DATE:**

**TYPE OF EXAMINATION:**

**STATION:**

*A: FORM FOR RADIOGRAPHIC EXAMINATIONS*

EXAMINATION DETAILS DURING RADIATION MONITORING

TECHNICAL DATA FORMS USED FOR RECORDING INDIVIDUAL PATIENTS.

APPENDIX A
<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Age</th>
<th>Sex</th>
<th>kV</th>
<th>mA</th>
<th>Screening time</th>
<th>(or range)</th>
<th>Film size</th>
<th>Dosemeter position</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>73</td>
<td></td>
<td>7</td>
<td>30</td>
<td>73</td>
<td>&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

- DATE:
- TYPE OF EXAMINATION:
- STATION:

**All forms for FLUOROSCOPIC EXAMINATIONS**
APPENDIX B

QUESTIONNAIRE USED FOR FREQUENCY OF RADIOLOGICAL EXAMINATIONS IN KENYA, AND COVERING LETTER ACCOMPANYING THE QUESTIONNAIRE.

B1. LETTER SENT OUT TO X-RAY CENTRES

UNIVERSITY OF NAIROBI
COLLEGE OF HEALTH SCIENCES
DEPARTMENT OF DIAGNOSTIC RADIOLOGY

KENYATTA NATIONAL HOSPITAL
P.O. Box 30888
NAIROBI
KENYA


(Addresssee)

Dear Sir,

ANNUAL FREQUENCY OF RADIOLOGICAL EXAMINATIONS.

I am collecting data on the number of radiological examinations performed annually at different X-ray Centres in Kenya for the purpose of assessing collective radiation dose to patients. I would be most appreciative if you would kindly supply me with the latest complete data from your hospital, preferably the data for 1986, but if these are not available, data from an earlier year will be appreciated. Please use the attached questionnaire. The information you supply will be treated in confidence. Details of individual hospitals will not be revealed.

Yours faithfully,

MR. H.M. Tole,
SENIOR LECTURER,
DEPT. OF DIAGNOSTIC RADIOLOGY.

Encl.
### QUESTIONNAIRE

#### ANNUAL FREQUENCY OF RADIOLOGICAL EXAMINATIONS.

**HOSPITAL**

**YEAR**

<table>
<thead>
<tr>
<th>EXAM TYPE</th>
<th>NO. OF EXAMS PERFORMED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td></td>
</tr>
<tr>
<td>Skull &amp; Mandible</td>
<td></td>
</tr>
<tr>
<td>Lower &amp; Upper Limbs</td>
<td></td>
</tr>
<tr>
<td>Spine</td>
<td></td>
</tr>
<tr>
<td>Plain abdomen</td>
<td></td>
</tr>
<tr>
<td>Pelvis &amp; Hips</td>
<td></td>
</tr>
<tr>
<td>Other plain X-rays</td>
<td></td>
</tr>
<tr>
<td>GIT (with contrast)</td>
<td></td>
</tr>
<tr>
<td>HSG</td>
<td></td>
</tr>
<tr>
<td>IVU</td>
<td></td>
</tr>
<tr>
<td>Other Special Exams</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL NUMBER OF EXAMS**

**Number of X-ray Units in hospital**
APPENDIX C

ENERGY RESPONSE FACTOR FOR 0.4mm THICK LiF (PTFE) DISCS: DIAGNOSTIC X-RADIATION RELATIVE TO $^{60}\text{Co}$ GAMMA RADIATION.

Procedure

Two sets of LiF (PTFE) discs were exposed to 500mR exposure using $^{60}\text{Co}$ radiation for one set and 100kV, 4 mm AL HVL X-radiation for the other. The exposures were carried out at the Dosimetry Laboratories of the International Atomic Energy Agency in Vienna. A third set of unirradiated discs served as controls.

After 3 weeks the discs were read out in Nairobi using the Toledo 654 TLD Reader. The Reader sensitivity was adjusted to give a nett reading of 1 digit/mR for discs exposed to $^{60}\text{Co}$ radiation. All the three sets of discs were then read out using this same sensitivity setting.

Results

Mean reading of 2 control discs = 116 digits
Mean reading of 3 discs exposed to $^{60}\text{Co}$ radiation = $614 \pm 12(1SD)$ digits
Mean reading of 4 discs exposed to X-rays = $825 \pm 34(1SD)$ digits
Response factor \( \frac{\text{X-rays}}{\text{60}\text{Co radiation}} \) = Nett x-ray reading

\[
\frac{\text{Nett 60Co reading}}{\text{Nett 60Co reading}} = \frac{825 - 116}{614 - 116} = 1.42
\]
APPENDIX D

COMPUTER PRINTOUTS (D1, D2, D3) OF PLOTS TO CHECK THAT ANOVAR STATISTICAL MODEL WAS ADEQUATE (REMARKS BY STATISTICIAN).


