RADIATION EXPOSURE O PATIENTS AND

ASSOCIATED HEALTH RISKS IN SOME

DIAGNOSTIC X-RAY EXAMINATIONS

BY

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A thesis submitted in fulfilment
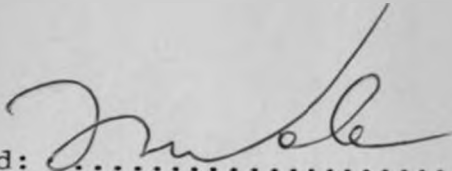
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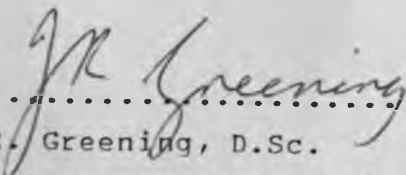Doctor of Philosophy

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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 assess-
ments 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 magni-
tudes 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 photo-fluorography, 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,

1984, 1985, 1987, 1988).

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_2O_2S : 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 gastro-intestinal radiology, with special reference to intra-hospital 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 re-
commendations touch on restrictions in the use of
photofluorographic equipment, the use of sensitive
image receptors, wider dissemination of knowledge on
patient referal criteria for radiological investi-
gations, 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 diag-
nostic 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 occuring, 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 pro-
portionality 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 observa-
tions. This latter model relates an effect, E, to
the radiation dose, D, causing it, through the expres-
sion:

$$E = aD + bD^2 \quad \text{------------Eq. 1.1.}$$

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 chil-
dren 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 syner-
gistic 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 carci-
nogenesis 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 2.5×10^{-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 malig-
nancies. 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 (Mar-
shall, 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 malfor-
mations. 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 eva-
        luations 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 gene-
        ration, 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 $10^{-2}Gy^{-1}$, 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 x $10^{-3}Gy^{-1}$ 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 inter-
preted 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 child-
hood malignancies among those pre-natally exposed
during diagnostic x-ray examinations claimed a signi-
ficant association between low dose in utero exposure
and childhood malignancy, especially leukaemia (Stewart
& Kneale, 1970), but this study has remained contro-
versial. 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 abnor-
malities. Sensitivity to a particular organ malfor-
mation 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 retar-
dation, 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 retarda-
tion 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, experi-
mental 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 quanti-
tative 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 $(20-25) \times 10^{-3} Gy^{-1}$, 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 $400 \times 10^{-3} Gy^{-1}$ 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 $300 \times 10^{-3} Gy^{-1}$ 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 correspon-ding 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 refer-
ences for future epidemiological studies.

In conjunction with quality assurance studies,
patient dosimetry research offers the possibility for
optimizing patient dose with image quality in diag-
nostic 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 photo-fluorography without image intensification are good examples of potentially high-dose techniques. The lack of proper maintenance facilities for radio-logical 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 exami-nations 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 radio-
logical services, and consequently increases in popu-
lation 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 diag-
nostic 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 radio-
logical 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. Insti-
tutional 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 gene-
tic 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;   Beentjes, 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 dosi-
metry 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 ioni-
zation 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 measure-
ment 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 fluoro-
scopic 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 $Li_2B_4O_7$, 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 re-used 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 determined by direct measurement, or estimated indirectly from recorded equipment factors and irradiation geometry.

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, per cent 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 end-point of interest for purposes of dose determination. The absorbed dose (or some related quantity) to a particular organ in the subject undergoing a radio-logical 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 deter-
mination 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 calcu-
lated 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 exminations 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 popu-
lation, 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

case of the GSD) and the active bone marrow (CMD).

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 recom-
mended 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 radio-
      logical 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 diag-
nostic radiology has ben 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 instru-
mentation for measuring the exposure-area product
were developed by Reinsma (1959), Morqan (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 (Bengt-
sson 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 indivi-
dual organs.

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

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CHAPTER 3

TECHNICAL ASPECTS OF THERMOLUMINESCENCE DOSIMETRY

Throughout this work, absorbed doses to
patients were measured using thermoluminescence dosi-
metry (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 crystal-
line 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 radia-
tion upon thermal stimulation. The emission of optical
radiation takes place at a temperature below that of
incandescence of the TL material: this is the distin-
guishing 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

(1981). 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 ΔE is given by:

$$p = s. \exp(-\Delta E/kT) \quad \ldots\ldots\ldots Eq. 3.1.$$

where s is a constant characteristic of the trap centre,

k is the Boltzmann constant,

and T is the absolute temperature.

The trap depth ΔE is effectively the energy difference
between the metastable state and the free-electron
energy state.

Thermoluminescent materials are characterized
by large values of ΔE 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
emmission 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 ΔE) 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 characteris-
tics 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 $Li_2B_4O_7$ in various physical forms. The important character- istics of these and other phosphors have been exten- sively 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 pre- dominantly 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 $Li_2B_4O_7$ 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 $Li_2B_4O_7$, 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, $Li_2B_4O_7$, 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 inten-
sity 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 - impreg-
nated 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 thermo-
luminescence 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 compart-
ment 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 polytetrafluoro-
ethylene (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 $\pm$ 0.2 mm, a thickness
of 0.40 $\pm$ 0.02 mm, and lithium isotopic concentrations
of 99.99% ^{7}Li and 0.01% ^{6}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
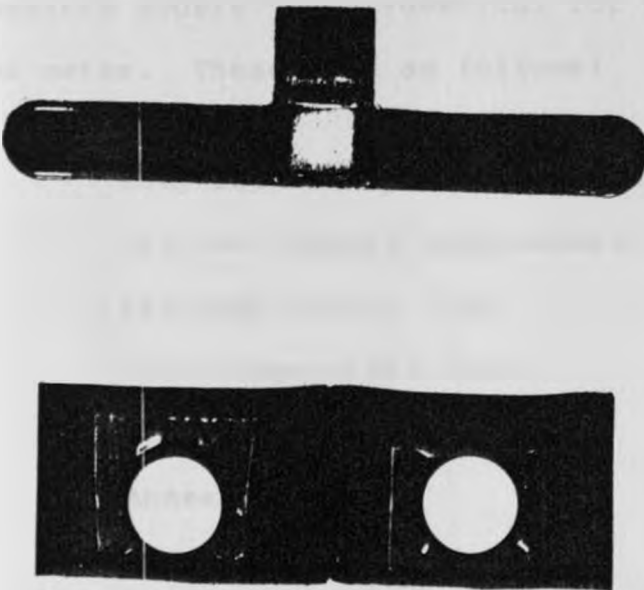
Fig. 2.   Thermoluminescent LiF:Mq:Ti dose meters; top,
LiF powder in plastic sachet, and bottom, LiF (PTFE)
discs.

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

RELATIVE TEMPERATURE/RELATIVE TL EMISSION

RELATIVE TIME

—————— TL emission

— — — Temperature
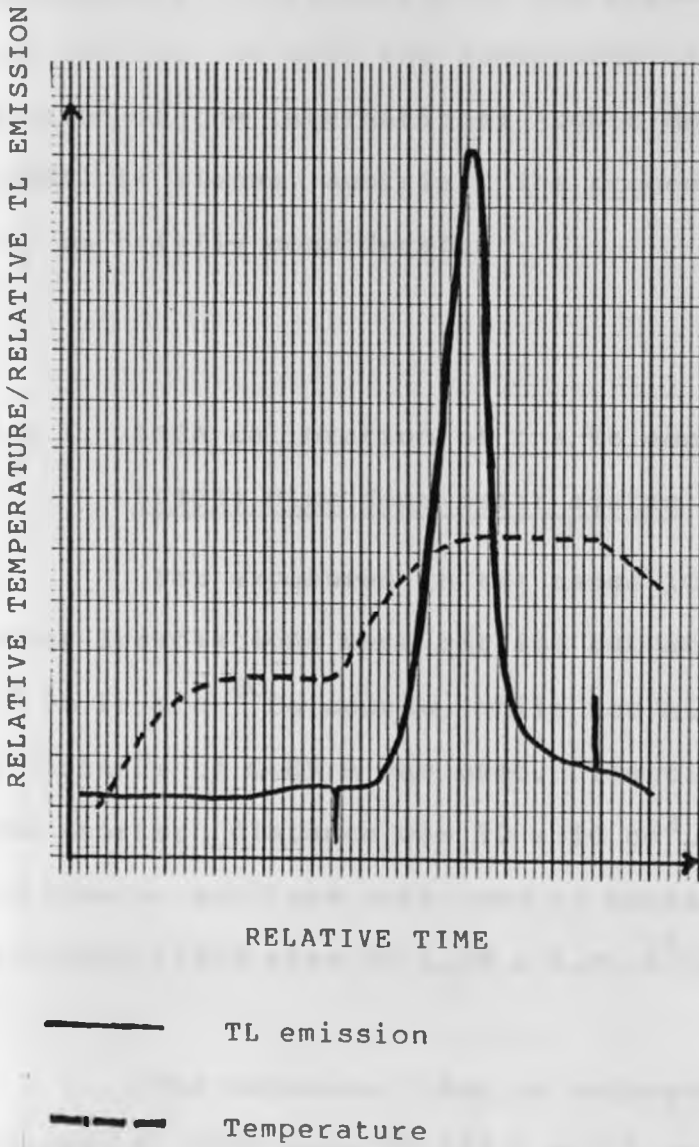
Fig. 3. Glow curve obtained with LiF (PTFE) disc,
showing TL emission from dosimetry peaks 4 & 5.

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 ^{60}Co source, while for higher exposures

a distance of 0.85 m was used. The field size at

the shorter distance was 10 x 10 cm^2. The same

collimator settings were used at 9m distance, giving

a larger field size of 1.06 x 1.06 m^2 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-

tories. 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 Inter-
national 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}Co gamma rays and 0.11-0.15%
for X-rays.

For ^{60}Co calibrations, the discs were
irradiated in a perspex phantom at a depth of 5 mm,
with a backscatter depth of at least 10mm. 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 1mR for calibration discs receiving
exposures up to 1R, and 1 digit per nett exposure of
10mR for discs receiving exposures > 1R. The 2 sen-
sitivity scales showed very good agreement - an
important factor when reading out unknown exposures.
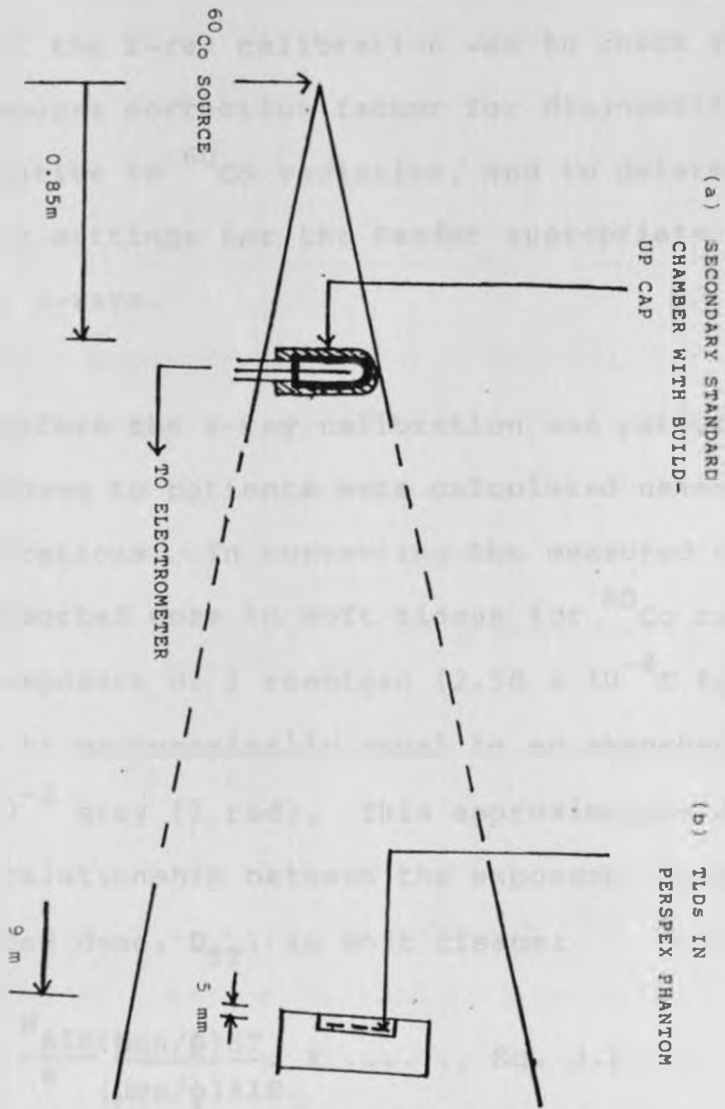
FIG. 4. CALIBRATION GEOMETRY. (a) Exposure rate determination with secondary standard ionization chamber. (b) Exposure of LiF (PTFE) discs in perspex phantom.

During the period covering these studies,
IAEA calibrations were made twice for ^{60}Co radiation
and once with x-rays of quality 100kVp, 4 mm Al HVT.
The second ^{60}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}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}Co calibrations. In converting the measured expo-
sure to absorbed dose in soft tissue for ^{60}Co radia-
tion, an exposure of 1 roentgen (2.58×10^{-4} 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:

$$D_{ST} = \frac{W_{AIR}}{e} \frac{(\mu en/\rho)ST}{(\mu en/\rho)AIR}. \; X \; \dots\dots \; Eq. \; 3.2.$$

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 $\dfrac{(\mu en/\varrho)ST}{(\mu en/\varrho)AIR}$ 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:

$$D_{LIF} = D_{ST} \frac{(\mu en/\varrho)LiF}{(\mu en/\varrho)ST} \text{------- Eq. 3.3.}$$

The mass energy absorption coefficient ratio in Eq. 3.3.

varies considerably between ^{60}Co radiation and diag-

nostic x-ray quality. Water is commonly used as a

dosimetric substitute for soft tissue. The varia-

tion of the ratio $\dfrac{(\mu en/\varrho)LiF}{(\mu en/\varrho) H_2O}$ 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 Rudén (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 varia-
tion 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 ^{60}Co radiation
immediately after the standard pre-irradiation
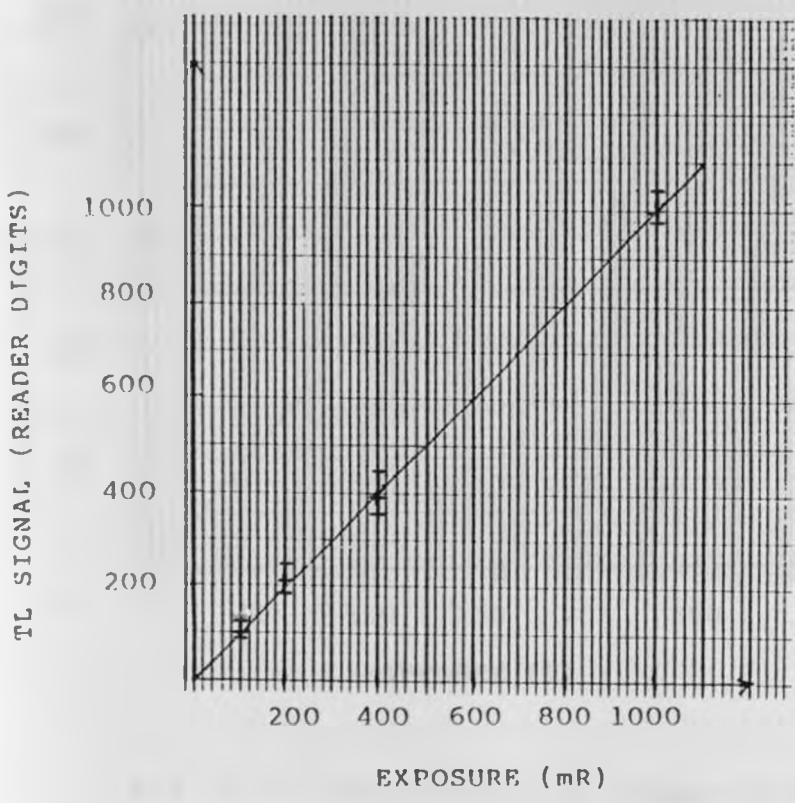
Fig. 5 a.   Variation of TL signal with exposure
(100—1000 mR).
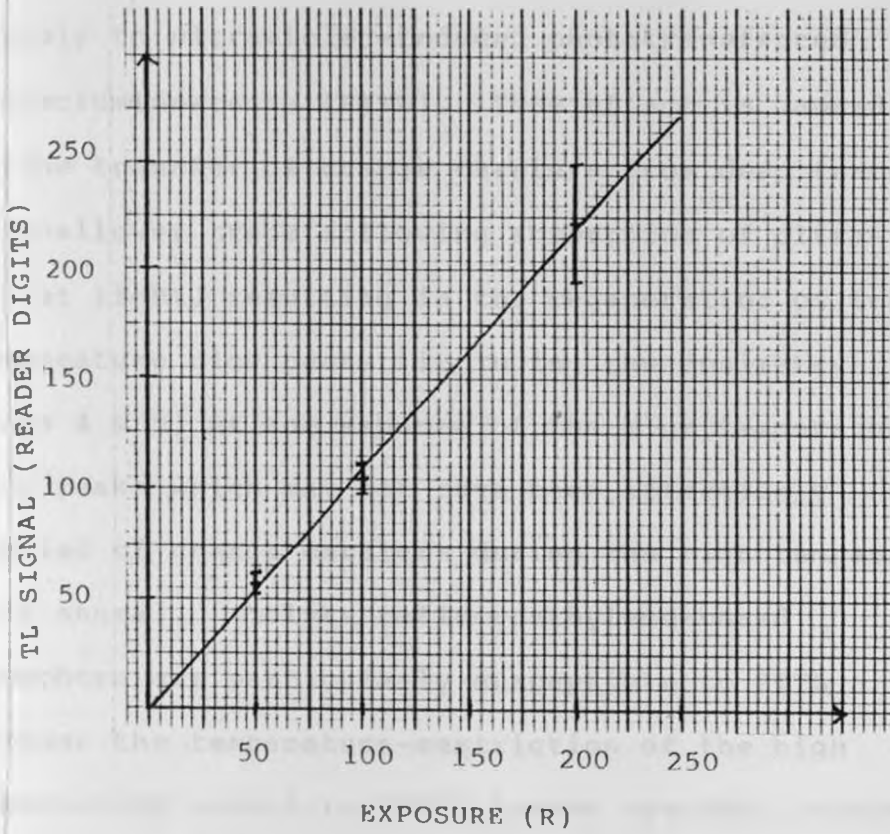
Fig. 5 b. Variation of TL signal with exposure (50 - 200 R)

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 ultra-violet 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 tempera-ture 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 tempera-ture 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 con-
tamination.

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.

Storage time (days)	Measured TL Signal (TLD Reader digits)				
	Ambient lighting			Dark Storage		
	Mean	S.D.	n	Mean	S.D.	n
0	10.5	4.4	10	10.5	4.4	10
40	67.8	8.1	30	47.7	3.6	29

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

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

	ILS		ELS	
	Min	Max	Min	Max
Absolute Reading (Reader digits)	9911	9981	17843	19060
Coefficient of Variation (%)	0.02	0.06	0.04	0.42

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. Interdisc 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.

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

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.

CHAPTER 4

PATIENT EXPOSURES DURING CHEST IMAGING

4.1.   Introduction

Radiological examinations of the chest con-
stitute 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 col-
lective 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 exami-
nations 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 intensi-
       fication, 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 cm^2 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 tung-
       state 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 4: TECHNICAL SPECIFICATIONS OF EQUIPMENT AND EXPOSURE FACTORS.

CENTRE	FACILITY	GENERATOR TYPE	TUBE TYPE	TOTAL TUBE FILTRATION (mm Al)	SID(cm)*	RADIO-GRAPHIC VIEW	kV RANGE ADULTS	kV RANGE CHILDREN	mAs RANGE ADULTS	mAs RANGE CHILDREN
1. RHO	Odelca	GEC Roentgen 301	Machlett Dynamax-40	0.7	92	PA	66-83	60-63	AUTO.	AUTO.
2. KNH	Odelca	Phillips Medio 20	Mullarc Guardian 125	2.7	96	PA	66-83		25-80	
						LAT	80-86		63-100	
3. KIS	Odelca	Phillips Rotapractix	Phillips Rotalix	2.8	90	PA	65-80		10-20	
4. ELD	Odelca	GEC MX 4	Watson VX 4	2.7	93	PA	78-94		30-60	
	GPU	GEC Roentgen 301	Machlett Dynamax 40	2.7	156	PA	83-91		8-10	
5. MSA	GPU(A)	GEC Roentgen 301	Machlett Dynamax 40	1.7	150	PA	75-95		7.5-12.5	
	GPU(B)	GEC Roentgen 301	Machlett Dynamax 40	1.7	150	PA	75-95		6.0-12.5	
6. IDH	GPU	Phillips Medio 20	Phillips Rotalix	2.8	120	AP	60-72		12-16	
						LAT	63-76		12-25	

*SID = SOURCE-TO-IMAGE RECEPTOR DISTANCE.

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 radio-
graphy 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 back-
ground. 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. Indivi-
dual 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., Faulkner
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 exami-
nation 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-

TABLE 5: MEAN SKIN-ENTRY DOSES DURING CHEST EXAMINATIONS

CENTRE	FACILITY	RADIOGRAPHIC VIEW	NO. OF PATIENTS	MEAN DOSE (mGy)	S.D.
1. RHO	Odelca	PA	Ad, 207	5.87	2.23
		PA	Ch, 20	3.18	0.55
2. KNH	Odelca	PA	Ad, 153	5.68	1.81
		LAT	Ad, 9	16.10	4.30
3. KIS	Odelca	PA	Ad, 36	2.15	0.81
4. ELD	Odelca	PA	Ad, 45	3.20	1.41
	GPU	PA	Ad, 17	0.29	0.037
5. MSA	GPU(A)	PA	Ad, 62	0.27	0.056
	GPU(B)	PA	Ad, 27	0.33	0.085
6. IDH	GPU	AP	Ch, 58	0.20	0.038
		LAT	Ch, 55	0.36	0.063

Ch, children (under 15 years); Ad, adults; S.D., standard deviation.
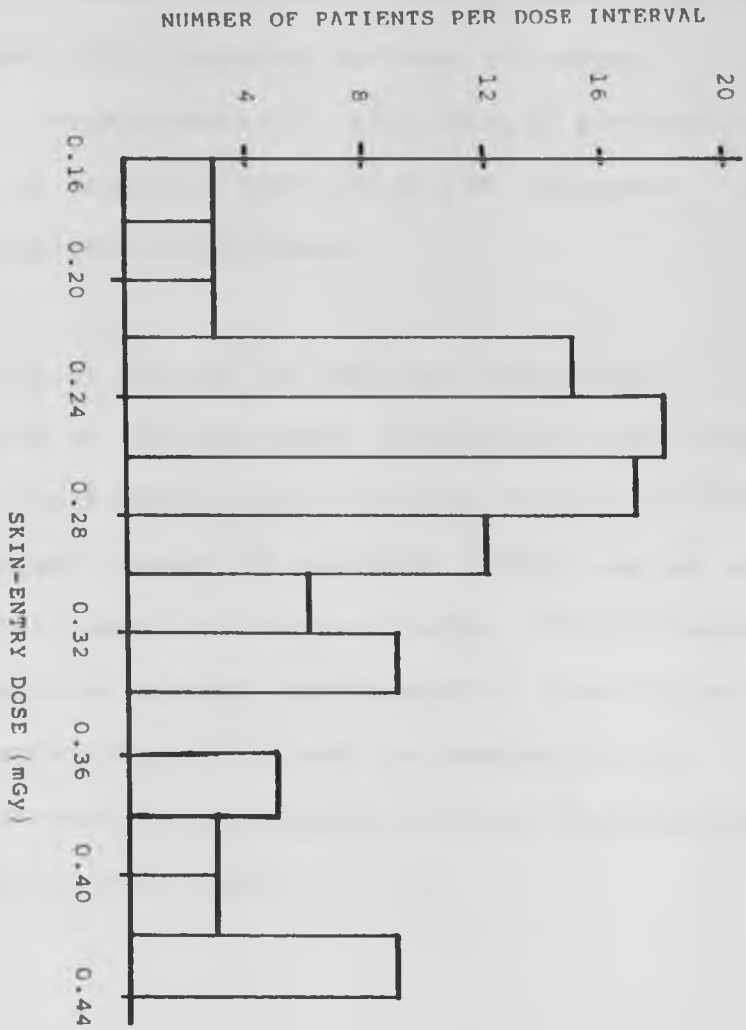
Fig. 6. Frequency distribution of skin-entry doses during full size chest radiography.

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 6: REFERENCES ON SKIN-ENTRY DOSES DURING CHEST PHOTO-FLUOROGRAPHY.

Authors	Country	Mean dose (or dose range) (mGy)
Bushong et al, 1973	U.S.A.	(a) 2.36
		(b) 6.01
Gaeta & Burnett, 1975	U.S.A.	1.54 - 3.82
Jain et al, 1979	India	1.50 - 3.30
Wall et al, 1980	U.K.	1.20
Jankowski, 1984	Poland (Female)	5.80
	(Male)	6.30
Kumamoto, 1985	Japan	1.50
Padovani et al, 1987	Italy	2.64
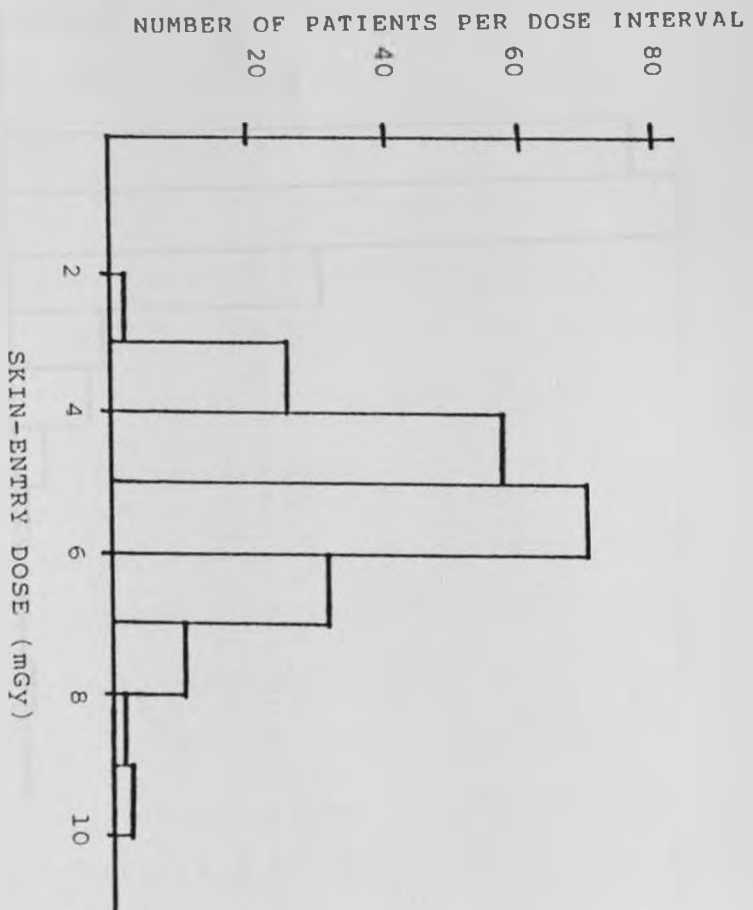
Fig. 7 a. Frequency distribution of skin-entry doses during chest photofluorography: adult patients at centre RHO.

NUMBER OF PATIENTS PER DOSE INTERVAL
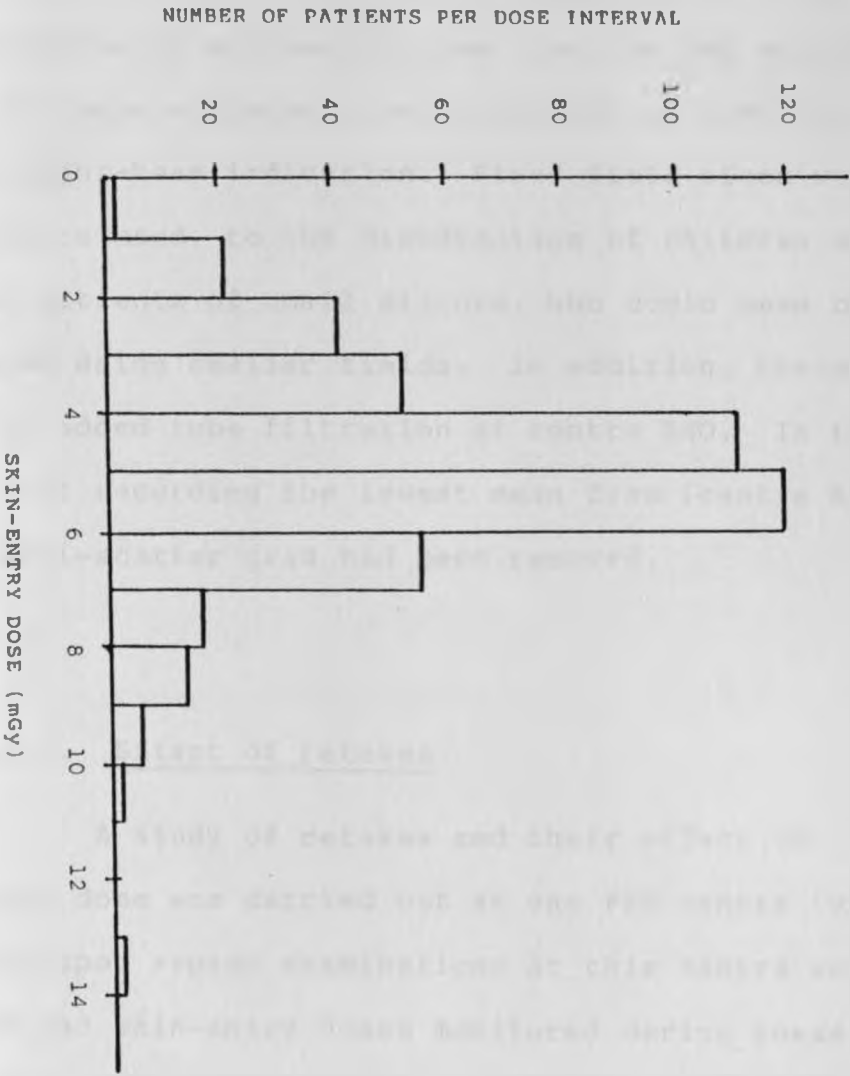
SKIN-ENTRY DOSE (mGy)

Fig. 7 b. Frequency distribution of skin-entry doses during chest photofluorography: adult patients at all centres surveyed.

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 7: PROBABILITY THAT THE OVARIES WERE IRRADIATED BY THE DIRECT BEAM DURING CHEST PHOTOFLUOROGRAPHY

PERCENTAGE RANGE	PROBABILITY CLASSIFICATION	NO. OF PATIENTS	PERCENT OF TOTAL
> 30%	Most probable	10	9.3
10 - 30%	Possibly	10	9.3
< 10%	Unlikely	87	81.3
		107	100

the useful beam (anode heel effect).

4.5. Discussion

It has already been observed that the skin-
entry doses recorded from full-size chest radio-
graphy 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 colli-
mation (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 awarenes 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 equip-
ment.

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 tech-
nique 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.

ADDENDUM

4.6.   Estimates of skin-entry dose by indirect methods.

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
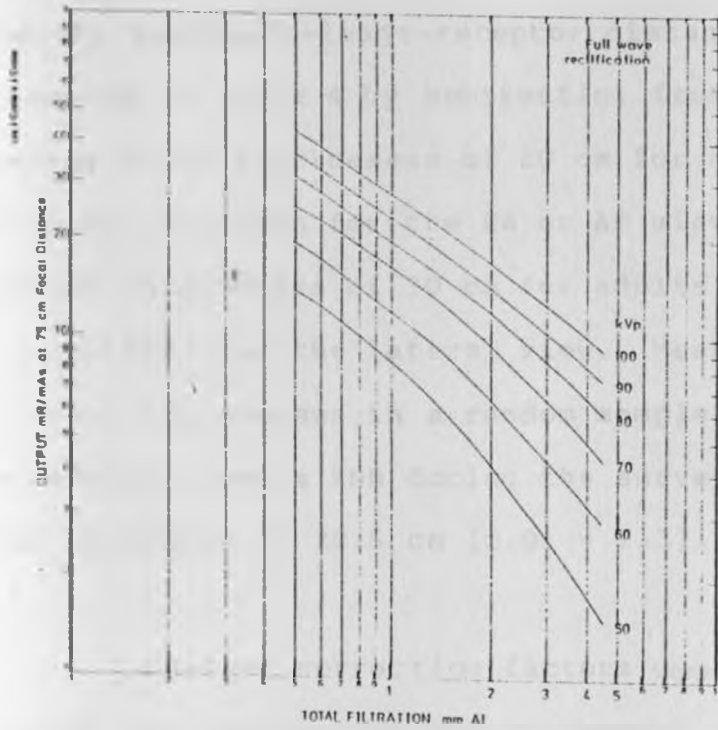
Fig. 8. Output of x-ray tubes as a function of kVp and total tube filtration (HPA, 1977).

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 cm^2. 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 cm^2. For purposes of the present estimates,
a single BSF of 1.30 is applied in each calculation.

A correction factor,

$f = 0.88$ 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

$$S.E.D. = X_{75} \cdot \frac{(75)^2}{(SSD)^2} \quad BSF. \quad f \quad \text{---------Eq. 4.1.}$$

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 8: MEAN SKIN-ENTRY DOSES DURING CHEST EXAMINATIONS, AS CALCULATED FROM TECHNICAL PARAMETERS. THE LAST COLUMN SHOWS THE RATIO OF CALCULATED TO MEASURED DOSES.

FACILITY/PROJECTION	MEAN kVp	MEAN mAs	MEAN SKIN-ENTRY DOSE (mGy)		RATIO (a)/(b)
			(a) CALCULATED	(b) MEASURED	
KNH, Odelca, PA	76.6	40	3.74	5.68	0.66
KNH, Odelca, LAT	82.2	73	10.34	18.10	0.57
KIS, Odelca, PA	72.8	14.9	1.46	2.15	0.68
ELD, Odelca, PA	83.4	40	4.83	3.20	1.51
ELD, GPU, PA	86.3	9.1	0.33	0.29	1.14
MSA, GPU(A), PA	85.3	8.7	0.48	0.27	1.78
MSA, GPU(B), PA	85.4	9.4	0.52	0.33	1.58
IDH, GPU, AP	65.6	12.1	0.37	0.20	1.85
IDH, GPU, LAT	70.3	17.8	0.73	0.36	2.02
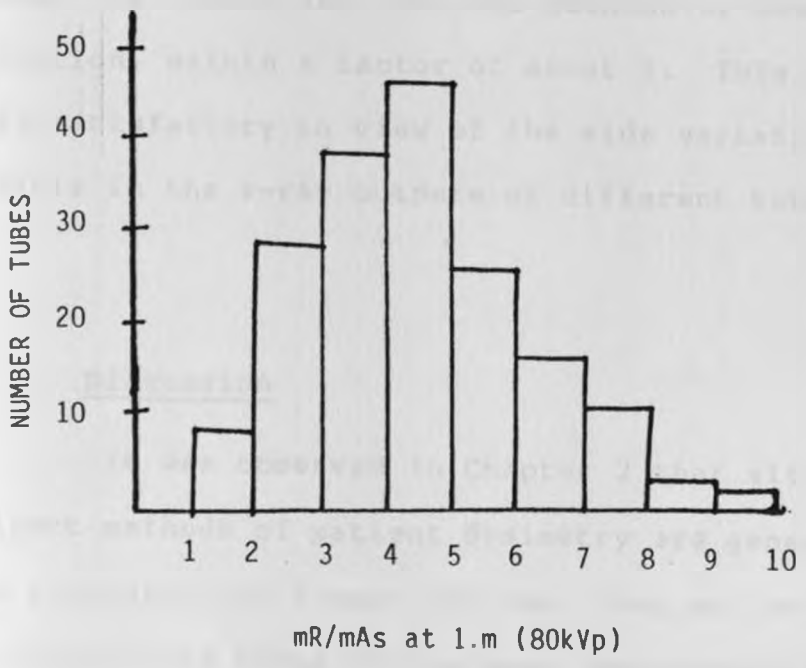
Fig. 9. Variation in the output of x-ray tubes from
181 single phase units (HPA, 1980).

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 parti-cularly 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
referal 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 radia-
tion 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_2O_2S:Tb rare-earth screens
(Dr. Goos-Suprema, Heidelberg), with a blue-green
emission, were used in conjunction with the same
type of films.

TABLE 9. REASONS WHY PATIENTS WERE REFERRED FOR PELVIMETRY

Indications	No. of patients	Percent of patients
Previous caesarian section	59	71.1
Breech presentation	18	21.7
Other (specified)	4	4.8
Not stated	2	2.4
	83	100.0

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 indi-
vidual 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 effec-
tiveness 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 10. MATERNAL SKIN-ENTRY DOSES, AND CRUDE ESTIMATES OF THE MATERNAL AND FETAL BONE MARROW DOSES, DURING ERECT LATERAL PELVIMETRY USING 2 TYPES OF INTENSIFYING SCREENS.

Intensifying screens	Maternal skin-entry dose (mGy)			Maternal bone marrow dose (mGy)	Fetal bone marrow dose (mGy)
	Mean	Median	Range of middle quartiles		
$CaWO_4$	130	128	88-166	7.1	21.3
$Y_2O_2S:Tb$	21.5	23.0	18.0-24.0	1.3	3.8
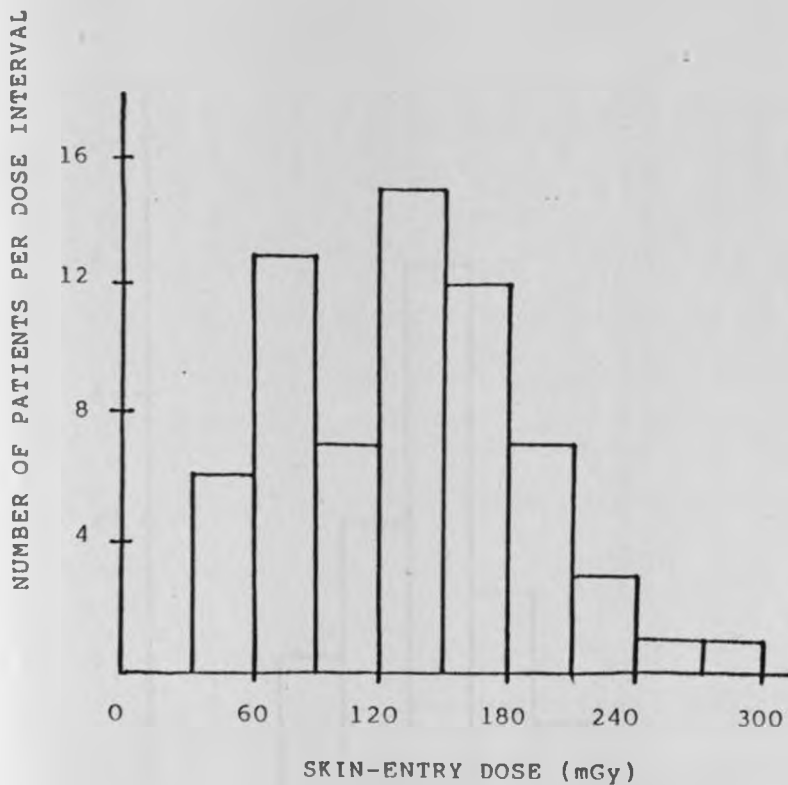
Fig. 10 a.   Frequency distribution of skin-entry doses during erect lateral pelvimetry: $CaWO_4$ intensifying screens.
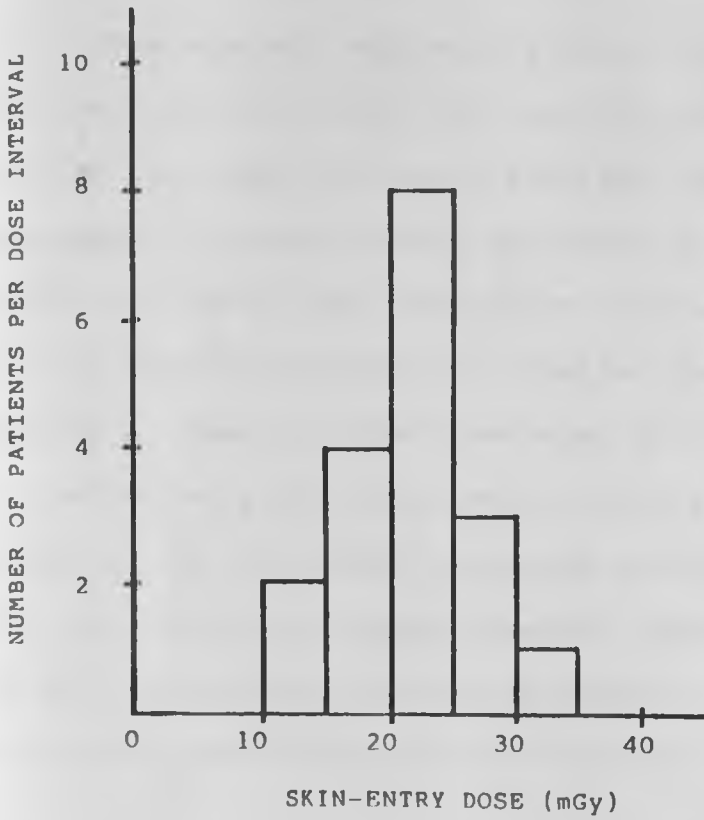
Fig. 10 b.   Frequency distribution of skin-entry doses during erect lateral pelvimetry: Y_2O_2S:Tb intensifying screens.

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 deter-
mined 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 ($1.54 \times 10^{-3} CKg^{-1}$)

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 mater-
nal 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. <u>Estimates of the risks of leukaemogenesis</u>

It was mentioned in Chapter 1 that the
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} Gy^{-1}
(20 cases per million exposed to 1 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 rad
(2 - 200 mGy), some 200-250 fatal childhood malig-
nancies can be expected per million exposed per rad
[(200 - 250) x 10^{-4} Gy^{-1}] during the first ten
years of life, about a half of which would be
leukaemia. A risk coefficient of 100 x $10^{-4}Gy^{-1}$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 11. THE RISK OF RADIATION-INDUCED LEUKAEMIA FROM A SINGLE PELVIMETRY EXAMINATION, USING $CaWO_4$ INTENSIFYING SCREENS.

	Estimated mean bone marrow dose per examination (mGy)	Risk coefficient $(x \ 10^{-4} Gy^{-1})$	Estimated risk of leukaemia
Maternal	7.1	20(ICRP, 1977)	14×10^{-6}
Fetal	21.3	100(UNSCEAR, 1977)	213×10^{-6}

pelvimetry examination. In both cases, the estimates
represent excess cases, over and above normal
incidence. The estimated figures incorporate un-
certainties 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 $CaWO_4$
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 sub-
stantial. The data in Table 11 imply a total fatal
malignancy risk of about 40 cases per million pelvi-
metries per year (twice the annual leukaemia risk).
This may be put into clearer perspective by compari-
son 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 referal
criteria to match current policy guidelines on radio-
logical 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 exami-
nation 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 compa-
ratively high frequency. Together with the gastro-
intestinal 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 radio-
logist 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 12. SKIN-ENTRY DOSES DURING HYSTEROSALPINGOGRAPHY.

	Centre	No. of patients	Mean dose (mGy)	Standard deviation
Screening + Radiography	KNH	36	64.70	42.71
Radiography only	KNH	10	21.54	4.12
	MSA	12	41.38	14.92
Late film	KNH	28	6.95	3.44

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 under-
going 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 gastro-intestinal 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 13. THE NUMBER OF PATIENTS UNDERGOING BARIUM MEAL AND BARIUM ENEMA
EXAMINATIONS, BY SEX AND TYPE OF EQUIPMENT USED.

	Ba meal			Ba enema			TOTAL
	Male	Female	All	Male	Female	All	
Undercouch tube (Outpatients' dept.)	22	32	54	-	-	-	54
Overcouch tube (Inpatients' dept.)	19	28	47	18	25	43	90
TOTALS	41	60	101	18	25	43	144

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 trans-
fering 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
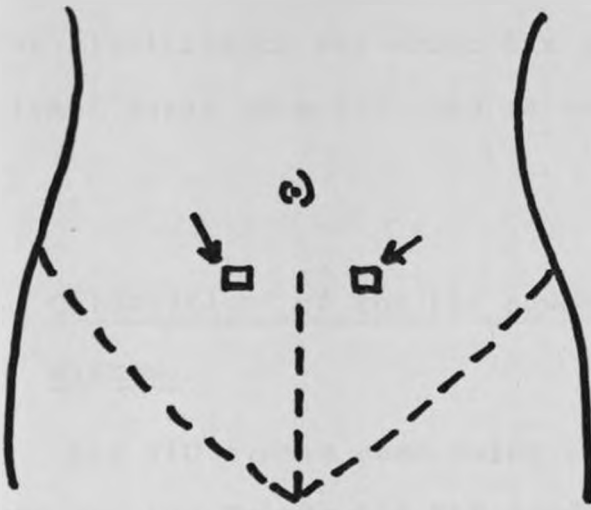
FIG. 11.   Positions of TL dose meters (arrowed)
on female patients during GIT examinations.

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 x 10^{-2}mGy. In-
significant 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}Sr/^{90}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 14. MEANS OF SKIN-ENTRY AND GONADAL DOSES DURING GIT STUDIES. COEFFICIENTS OF VARIATION ARE SHOWN IN BRACKETS.

	Male gonads (mGy)	Female skin (mGy)	Female gonads (mGy)
Barium meal			
Undercouch tube	0.036 (211%)	9.61 (147%)	2.88
Overcouch tube	0.32 (102%)	9.71 (151%)	2.91
Weighted hospital mean	0.17	9.66	2.90
Barium enema			
Overcouch tube	1.49 (65%)	33.5 (80%)	10.0

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 radio-
graphic 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 $\pm$ 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

TABLE 15. AVERAGE SCREENING TIMES AND NUMBERS OF FILMS USED IN BARIUM MEAL AND BARIUM ENEMA EXAMINATIONS.

		Barium meal				Barium enema			
		Screening time (min)		No. of films		Screening time (min)		No. of films	
	Sex	M	F	M	F	M	F	M	F
Undercouch tube		4.6	3.4	7.3	6.7	–	–	–	–
Overcouch tube*		6.8	3.4	10.0	7.5	4.1	3.3	9.4	9.6
Weighted mean		5.6	3.4	8.5	7.1	–	–	–	–

*Follow-through examinations of barium meal were carried out using the overcouch tube equipment only.

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 examina-tions 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

TABLE 16. THE EFFECT OF SMALL BOWEL FOLLOW-THROUGH EXAMINATIONS DURING
BARIUM MEAL INVESTIGATIONS ON RADIATION DOSE, SCREENING TIME, AND NUMBER OF
FILMS USED.

Sex	No. of patients		Dose (mGy)		Screening time (min)		No. of films	
	M	F	M	F*	M	F	M	F
Follow-through	8	11	0.50	12.1	8.1	3.4	12.7	9.0
No follow-through	11	17	0.18	8.2	5.9	3.4	8.0	6.5

*The dose data for female patients refer to skin-entry doses.

according to 2 broad age groups ($\leq$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. <u>Discussion</u>

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 agree-
ment 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 GIT EXAMINATIONS.

	≤ 45 years		> 45 years	
	No. of patients	Dose (mGy)	No. of patients	Dose (mGy)
Barium meal, female outpatients	6	4.28	14	11.98
Barium meal, male outpatients	7	0.019	14	0.048
Barium meal with follow-through, female inpatients	6	14.22	5	9.53
Barium enema, female inpatients	7	48.33	18	27.64

devices which integrate the total dose at some
position between the x-ray tube target and the
patient's entrance skin surface therefore over-
estimate 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 depart-
ments 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 examina-

tions (performed only on the overcouch tube equip-

ment) 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 out-
side the useful beam needs to be further investigated.
Some of the other equipment factors which have been
identified as affecting patient dose during fluoro-
scopic 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 quanti-
tative 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 radio-
diagnostic 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 estima-
tions 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 exami-
nations, 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 under-
going 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 distri-
butions 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 18. ARITHMETIC MEANS OF SKIN DOSES BY POSITION OF DOSE METER AND TYPE OF
FLUOROSCOPIC EQUIPMENT. STANDARD ERRORS ARE SHOWN.

	Mean anterior dose (mGy)	Mean posterior dose (mGy)
Undercouch tube	2.35 + 0.79	9.61 + 2.14
Overcouch tube	9.03 + 1.93	2.53 + 0.72
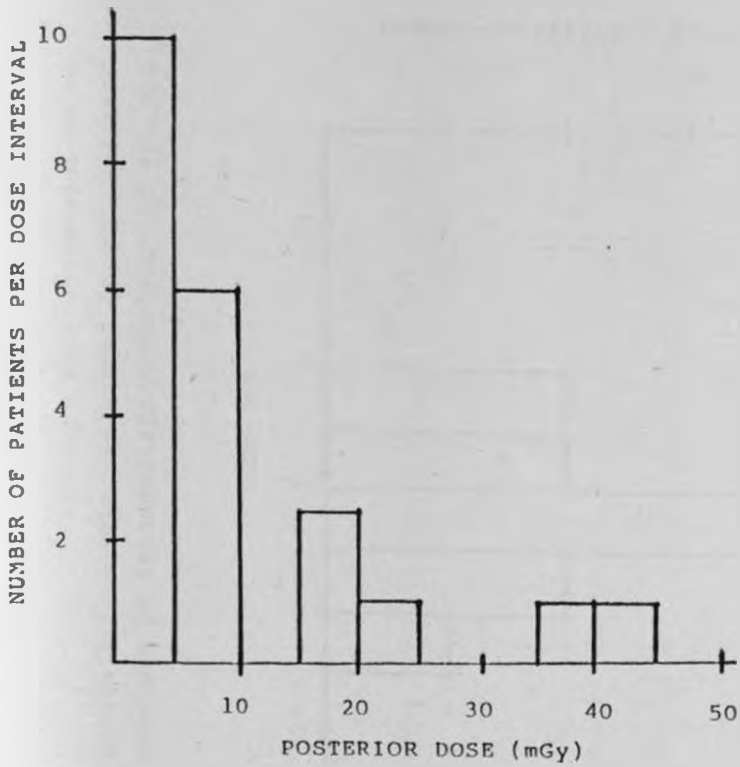
Fig. 12 a. Frequency distribution of doses recorded in the posterior position for 22 female patients undergoing barium meal examinations on an undercouch tube machine.
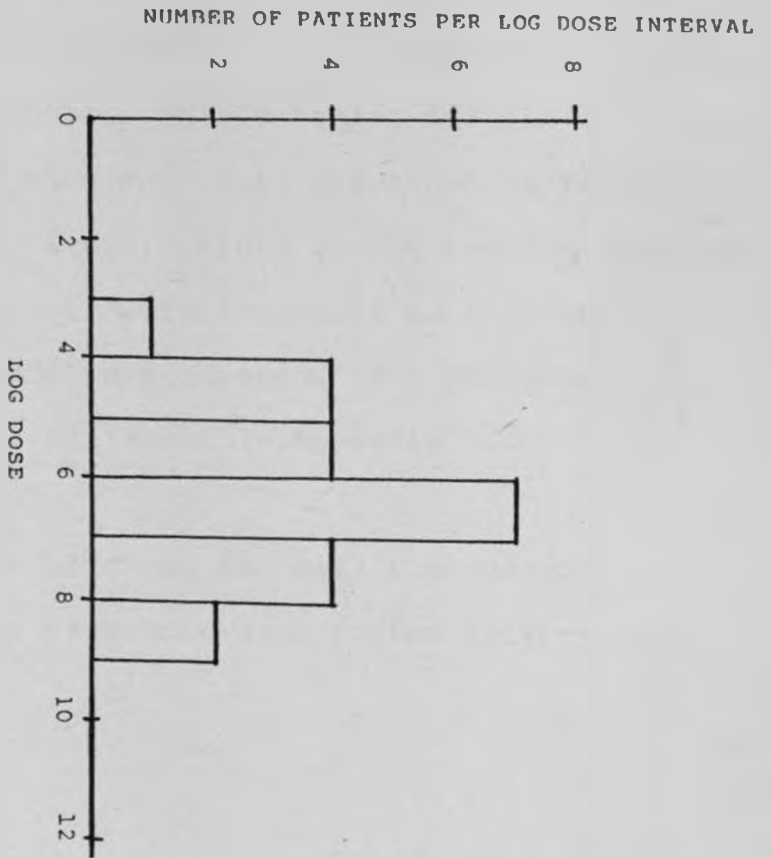
FIG. 12 b. Frequency distribution of log doses in the posterior position for 22 female patients during barium meal examinations on an undercouch tube machine.

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 19. ANALYSIS OF VARIANCE FOR DOSES MEASURED ON 22 PATIENTS EXAMINED
USING AN UNDERCOUCH TUBE X-RAY MACHINE.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean of Squares	Variance Ratio
Patients	21	117.94	5.62	8.24***
Positions	1	53.7	53.7	78.79***
Patients X Positions	21	12.37	0.59	0.86
Residual	44	29.99	0.68	
Total	87	214		

TABLE 20. ANALYSIS OF VARIANCE FOR DOSES MEASURED ON 18 PATIENTS EXAMINED

USING AN OVERCOUCH TUBE X-RAY MACHINE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean of Squares	Variance Ratio
Patients	17	114.54	6.74	12.04***
Positions	1	40.24	40.24	71.93***
Patients X Positions	17	49.72	2.92	5.23***
Residual	36	20.14	0.56	
Total	71	224.6		

TABLE 21. ESTIMATES OF THE MAIN EFFECT OF POSITION ON NATURAL LOG DOSE BY EQUIPMENT TYPE. THE LAST COLUMN SHOWS THE RATIOS OF THE GEOMETRIC MEAN DOSE IN THE 2 POSITIONS, OBTAINED BY ANTI-LOGGING THE DIFFERENCES IN LOG DOSE.

	Anterior log dose	Posterior log dose	Difference in log dose	Geometric mean ratio
Undercouch tube	-0.225	1.335	1.560	4.7
Overcouch tube	1.245	-0.245	1.490	4.4

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. Un-

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

"Exit dose" range (%)	No. of patients	Cumulative frequency (%)
< 5	5	12
5 - 10	5	25
10 - 20	13	57
20 - 100	13	90
> 100	4	100

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 infor-
mation 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 cal-
culation 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 exami-
nations 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 protec-
tion, 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 radio-
logical 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 work-
load.

In this chapter, the methodologies employed
in frequency surveys are briefly reviewed. A retro-
spective 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. <u>Review of frequency survey methodologies.</u>

9.2.1. <u>Prospective surveys</u>

Prospective surveys are normally organized
to take place simultaneously at a sample of radio-
logical 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 insti-
tutions 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 pros-
pective 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 res-
pondents 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 propor-
tions 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 work-
load (UNSCEAR, 1972). The method also suffers from
the disadvantage of being suitable only among popu-
lations 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 question-naire 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 23. DISTRIBUTION OF FREQUENCY SURVEY QUESTIONNAIRE, AND RESPONSE RATES FOR DIFFERENT CATEGORIES OF MEDICAL INSTITUTION.

CATEGORY OF INSTITUTION	NUMBER OF CENTRES TO WHICH QUESTIONNAIRES WERE SENT	NUMBER REPLYING	NUMBER WHOSE DATA WERE USED	PER CENT RESPONSE
Government institutions				
National hospital	1	1	1	100
Provincial hospitals	7	5	5	71
District + sub-district hospitals	41	34	31	75
Others	8	8	7	87
Private institutions				
Large private hospitals	11	6	6	54
Radiologists' practices	7	2	2	28
Missionary hospitals	28	16	14	50
Small private clinics	12	2	1	8
Totals	115	74	67	58

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 represen-
tative 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 24. ESTIMATED NUMBERS OF X-RAY CENTRES IN KENYA, AND TOTAL NUMBERS OF RADIOLOGICAL EXAMINATIONS PERFORMED DURING 1986, BY DIFFERENT CATEGORIES OF MEDICAL INSTITUTION

CATEGORY OF INSTITUTION	ESTIMATED NO. OF CENTRES IN KENYA (1986)	MEAN NO. OF EXAMINATIONS PERFORMED (1986)	STANDARD ERROR	ESTIMATED TOTAL NO. OF EXAMINATIONS PERFORMED (1986)
Government hospitals				
National	1	(112,017)	-	112,000
Provincial				
(with radiologists)	6	19,849	1,888	121,000
(no radiologist)	1	(2,367)	-	
District & sub-district	42	3,876	488	163,000
Others				
(specialized depts.)	3	11,565	-	53,000
(general depts.)	8	2,304	689	
Private institutions				
Large private hospitals				
(full-time radiologists)	3	15,303	-	74,000
(part-time radiologists)	8	3,496	653	
Radiologists' practices				
(group practice)	1	(17,160)	-	53,000*
(single radiologists)	9	(3,961)	-	
Missionary hospitals	30	1,335	215	40,000
Small private clinics	20	(570)	-	27,000*
All	132			643,000

*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 $\pm$ 50%) and the missionary hospitals (of the order of $\pm$ 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 $\pm$ 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 exami-
nations, 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 gastro-
intestinal 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 examina-
tion. However, some useful deductions may be made

TABLE 25.   RELATIVE FREQUENCIES OF DIFFERENT TYPES
OF RADIOLOGICAL EXAMINATION.

Type of examination	Relative frequency (%)
Chest	28.9
Skull & mandible	8.9
Lower & upper limbs	39.0
Spine	5.0
Plain abdomen	3.5
Pelvis & hips	3.5
Other plain x-rays	5.6
GIT (with contrast))	
HSG)	
IVU)	5.7
Other special exams)	
Total	100.1

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 exami-
nations, 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 < 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 referal 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
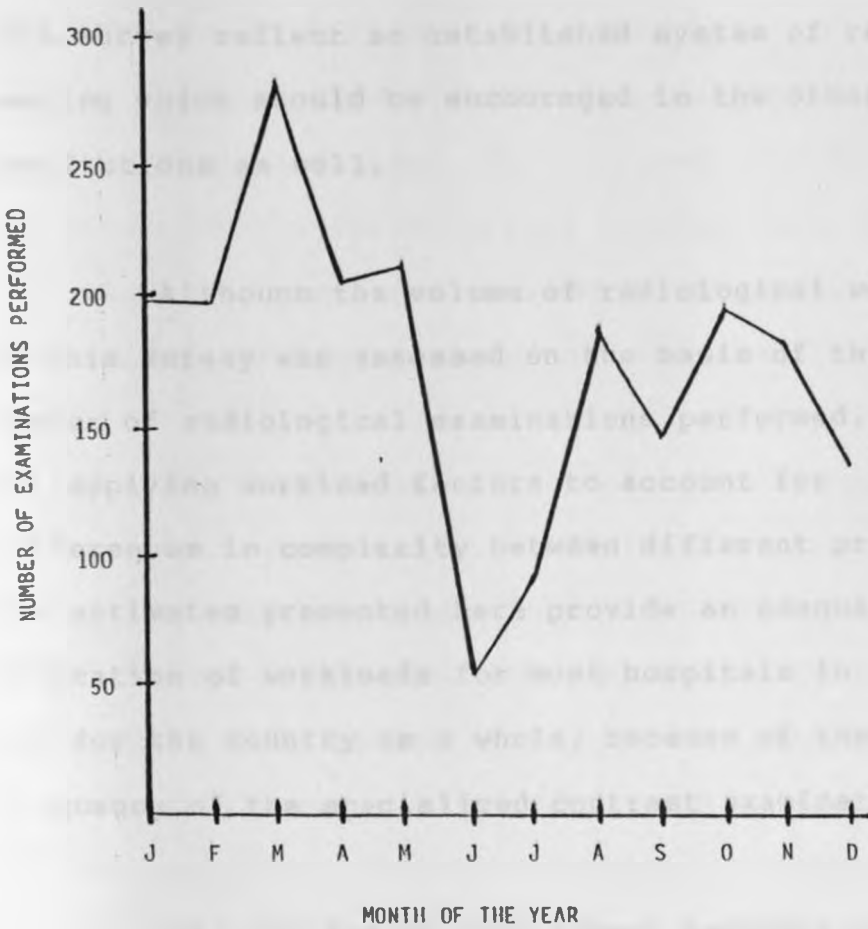
FIG. 13. Variation in the number of contrast examinations
of the gastro-intestinal tract performed at Kenyatta National
Hospital, Nairobi, during 1984 (Courtesy of Mr. S. Kariuki,
X-ray Department, KNH).

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, with-
out 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 agree-
ment between the present result and Cockshott's
estimate for 1976/77 does not imply that radio-
logical 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 radio-
logical services within the developing countries
has been the tendency to have most facilities con-
centrated 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 radio-
logical 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 exami-
nations 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 radio-
graphic 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 $<$ 3,000 exami-
nations performed (i.e. an average of $<$ 10 examinations

per day). The reasons for such low workloads need to
be studied to help avoid under-utilization of profes-
sionally 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 depart-
ments 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 exami-
nations 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 col-
lective 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 esti-mated by the ICRP (1977) as being about $4 \times 10^{-3} Sv^{-1}$. 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 charac-teristics 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 26. DISTRIBUTION OF THE POPULATION OF KENYA
ACCORDING TO DIFFERENT AGE GROUPS (1979 CENSUS)

Age Group (yr)	Per cent in population	Cummulative percentage
0 - 4	18.6	18.6
5 - 9	16.3	34.8
10 - 14	13.5	48.3
15 - 19	11.4	59.7
20 - 24	8.7	68.4
25 - 29	6.9	75.2
30 - 39	9.4	84.6
40 - 49	6.4	91.0
50 +	8.8	99.8
Unknown	0.2	100.0

Data source : CBS, 1981 a.

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

Age group (yr)	Age specific fertility rate
10 - 14	3
15 - 19	179
20 - 24	368
25 - 29	372
30 - 34	311
35 - 39	226
40 - 44	105
45 - 49	14
Total (x 5)	7,890

Data source : CBS, 1981 b.

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 investi-
gation, 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.

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

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_2O_2S : 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 hysterosal-pingography.

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 radio-
logical 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 measure-
ments 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 some-
times rather small.

The survey of the annual frequency of radio-
logical 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 referal 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 per-
      formance, 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. <u>Suggestions for further research</u>

Further studies are indicated in the following areas:

(i)   More studies of patient dose at Kenyan
        hospitals to provide data for those examina-
        tion 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 radio-
        logical 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.

APPENDIX A

TECHNICAL DATA FORMS USED FOR RECORDING INDIVIDUAL PATIENTS'
EXAMINATION DETAILS DURING RADIATION MONITORING

A1. FORM FOR RADIOGRAPHIC EXAMINATIONS

STATION:

TYPE OF EXAMINATION:

DATE:

Serial No.	Age	Sex	kV	mAs	No. of exposures	Dosemeter position

A2. FORM FOR FLUOROSCOPIC EXAMINATIONS

STATION:

TYPE OF EXAMINATION:

DATE:

Serial No.	Age	Sex	kV screening (or range)	mA screening (or range)	Screening time	kV Rad.	mAs Rad.	No. of Rad. exposures	Film sizes	Dosemeter position

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

Telephone 726300
Extn. 2223
Telegrams
"Medhan" Nairobi

KENYATTA NATIONAL HOSPITAL
P O Box 30588
NAIROBI
KENYA

8th July, 1987.

(Addressee)

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. N.M. TOLE.
SENIOR LECTURER,
DEPT. OF DIAGNOSTIC RADIOLOGY.

NMT/mao

Encl.

B2. QUESTIONNAIRE

ANNUAL FREQUENCY OF RADIOLOGICAL EXAMINATIONS.

HOSPITAL ....

YEAR ....

EXAM TYPE	NO. OF EXAMS PERFORMED
Chest	....
Skull & Mandible	....
Lower & Upper Limbs	....
Spine	....
Plain abdomen	....
Pelvis & Hips	....
Other plain X-rays	....
GIT (with contrast)	....
HSG	....
IVU	....
Other Special Exams	....
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}Co

GAMMA RADIATION.

Procedure

Two sets of LiF (PTFE) discs were exposed to
500mR exposure using ^{60}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}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}Co radiation   = 614 $\pm$ 12(1SD) digits

Mean reading of 4 discs exposed

   to X-rays   = 825 $\pm$ 34(1SD) digits

Response factor $\dfrac{\text{X-rays}}{^{60}\text{Co radiation}}$ $= \dfrac{\text{Nett x-ray reading}}{\text{Nett }^{60}\text{Co reading}}$

$$= \frac{825 - 116}{614 - 116}$$

$$= \underline{1.42}$$

APPENDIX D

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

D1

points should fall
along a straight
line if model is
adequate

Points should be similarly dispersed along two lines if model is adequate

D3

these of the plot suggest the model is inadequate
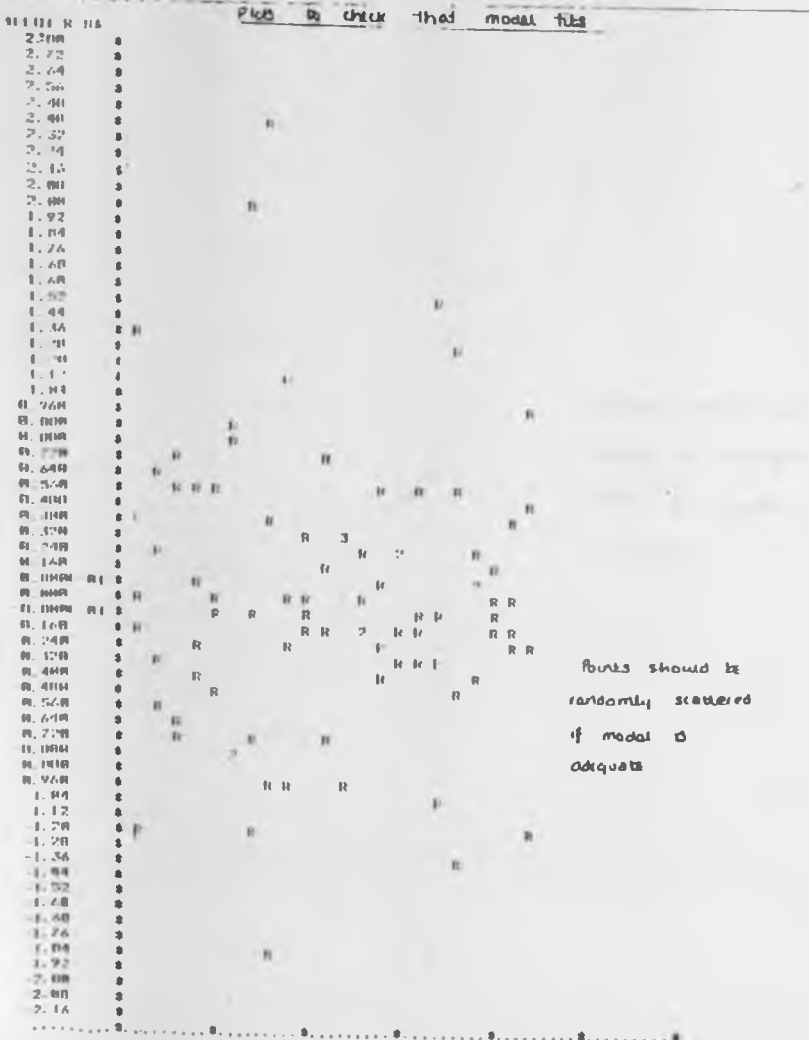
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