Measurement of Absorbed Dose for Peadiatric patients for the purpose of developing dose guidelines in Peadiatric Radiology

Dissertation submitted in fulfilment of the requirements for the degree Masters in Technology (M.Tech: Radiography) to the Department of Health Sciences in the Faculty of Science at Peninsula Technikon.

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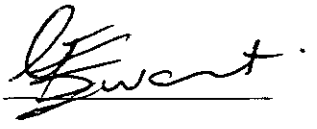
Dissertation Contents

Declaration

Measurement of absorbed doses for Paediatric patients for the purpose of developing dose guidelines in Paediatric Radiology

I, Gillian Edith Swart, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise), and that neither the whole work nor any part of it has been, is being or is submitted for another degree at this or any other Technikon or University.

December 2004



Gillian Edith Swart

Acknowledgements

I would like to extend my heart-felt gratitude to the following persons who have inspired and assisted me during this research.

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Dr .WA Groenewald, my external supervisor who greatly assisted me with his expertise, constructive and positive influence.

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Prof. Scher, Mrs VA Meyer and all Radiographers of the Diagnostic Radiology Department for making their department available.

The Department of Medical Physics for making this research possible.

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Allan, for always delivering and collecting.

To those I have not personally mentioned thank-you for the words of encouragement.

THERE ARE MANY THINGS IN LIFE

THAT WILL CATCH YOUR EYE,

BUT ONLY A FEW WILL CATCH

YOUR HEART...PURSUE THOSE.
Passion

Abstract

The radiation risks associated with children are higher than the risk for adults. Children have growing organs and they have a longer life expectancy than that of adults. As a consequence the effects of damage from radiation could be greater than in adults. Children who receive radiation damage may pass genetic damage onto future generations.

This study was carried out to investigate the optimal effective x-ray dose young children need to receive who have radiographic examination to the chest at Tygerberg Hospital, South Africa. Chest radiographs are documented as being the most common radiographic examination done on children. The age groups of children participating in this study were 0-1 year, 1-5 years and 5-10 years. A total of 67 children were involved and the absorbed doses for 134 views of the anterior-posteria (AP) chest and lateral chest were measured.

Entrance surface dose (ESD) values were determined, and measured mean ESD (mGy) and the ESD range was reported for each age group. This was done by attaching thermoluminescent dosimeters (TLD pellets) to the patients skin at the entrance point of the x-ray beam. The results were compared to similar studies done in Ireland and Nigeria. From the ESD values obtained the absorbed doses of the eyes, heart, liver, thyroid and genitals could be calculated by using the "Childdose" programme of the NRPB.

The ESD dose levels for South Africa compare favourably with Ireland. However the Nigerian values differed greatly from those of Ireland and South Africa. It was very encouraging to note the comparative results achieved at Tygerberg Hospital especially due to the fact that this was the first time such study had been conducted in the Tygerberg Hospital Radiology Department. The results also compare favourable with that achieved by a group working in the United Kingdom. This group does similar surveys every five years as part of their radiation protection programme. The results were also in line with the UNSCEAR document of 2000.

This study could serve as a valuable source of reference to radiographers and radiologists when performing paediatric radiology especially as the radiation absorbed dose could be used as a baseline to create awareness of size of dose received, and to limit deleterious radiation doses to patients and to prevent unnecessary exposures.

A second significant outcome of the study was the effect that added filters had on the x-ray beam generated. Experiments were done in which the filtration filters were added sequentially. It was found that if the filtration was increased to 2mmAl the dose to the patient decreased by more than 20%. At 50 and 60 kV the density of the x-ray image on film only increased by 2%. From these results it may be concluded that an increase in filtration thickness used for paediatric chest x-rays should be giving reduced dose readings and assisting with radiation protection of the patient.

Key words: *thermoluminescent dosimeters, entrance surface dose (ESD), absorbed dose.*

List of Abbreviations

ALARA	As Low As Reasonably Achievable
Al	Aluminum
AP	Anterior-posteria
CV	Co-efficient of variation
CTDI	Computed Tomography Dose Index
DAP	Dose area product
ESD	Entrance surface dose
FFD	Field focus distance
kV	Kilo Voltage
IRPA	International Radiologic Protection Association
Lat	Lateral
LiF	Lithium fluoride
mAs	milliAmperes per second
mGy	milliGray
mSv	milliSieverts
NCRP	National Council on Radiation Protection and measurements
NRPB	National Radiological Protection Board.
PMT	Photo multiplier tube
SFD	Surface focus distance
STDEV	Standard deviation
TL	Thermoluminescence
TLD	Thermoluminescent Dosimeters
UNSCEAR	United Nations Scientific Committee on the Effect of Atomic Radiation

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Chapter 1:
INTRODUCTION

1.1 The research problem and its' setting

Living things have evolved in an environment that has significant levels of ionising radiation. Many of us owe our lives and health to radiation that is artificially produced. However medical x-rays have hidden problems. Radiation is used to diagnose ailments and also to treat patients thus people benefit from a multitude of products and services made possible by the careful use of radiation (Hall, 1980).

Diagnostic Radiology is an accepted imaging modality for the diagnosis of pathological conditions in both children and adults. However, x-rays have inherent hazards that are of special concern when applied to young children. Studies have shown that children less than ten years of age are more sensitive to ionizing radiation than middle aged adults (Mooney et al., 1998). This is because ionizing radiation can cause genetic mutations and congenital malformations in the foetus. Furthermore the risk of inducing malignancy is greater in growing organs and tissues. In general, children have a longer life expectancy than adults and are therefore at a greater risk to the long-term side effects of radiation. The risk of movement during x-ray procedure is greater with children and this can lead to repeating of the x-ray procedure. This in turn, leads to an increase of the absorbed dose of radiation to the patient (NCRP, 1980).

Given the above statements it is important for the radiographer, radiologist and referring doctor to have a sound knowledge of the radiation dose received by their patients, particularly when these patients are children. The aim of this project was therefore, to measure the absorbed doses that children receive when undergoing diagnostic radiology procedures. With the data obtained, it is intended to develop guidelines for radiographers, radiologists and referring doctors to use as reference

levels when managing their patients and the radiographic modalities with which they work.

1.1.1 Statement of the problem

To determine what the expected absorbed dose of radiation that children between the ages of 0 to10 years of age, known as a paediatric patients, will receive to the radiosensitive tissues of the eyes, heart, thyroid, liver and gonads when undergoing conventional diagnostic radiography of the chest. In order to develop guidelines for radiographers, radiologists and referring doctors to use as reference levels when managing their patients and the radiographic modalities with which they work.

1.1.2 Statement of the sub-problems

First sub-problem:

To investigate the use of radiation dose meters and thermoluminecent dosimeters, for the purpose of measuring absorbed doses of radiation in paediatric patients in Diagnostic radiology. In order to establish an accurate calibration procedure for TLD dosimeters and the calibration parameters needed for the x-ray tube potentials to be applied to the procedure studied.

Second sub-problem:

To investigate the effective dose delivered to the children, and then to calculate absorbed doses of individually exposed organs using 16 TLD pellets to assist in the measurement and calculation of the radiation dose. It has been shown that children less than 10 years of age are more sensitive to ionising radiation than adults (Mooney et al., 1998).

Third sub-problem:

To analyse and interpret the processed data as captured from TLD pellets in order to establish a database of effective dose(s) for children with reference to procedures followed at Tygerberg Hospital. This will assist the radiologist to reliably predict the effective dose to be received by the individual patient.

1.2 Hypothesis

1. It is hypothesised that the children participating in the study will at no time be receiving radiation dose other than that which is required to produce a diagnostic image.
2. It is hypothesised that all radiographers, radiologists and referring doctors are aware at all times of the radiation dose received by a patient when they request examinations and administer radiation.

1.3 Delimitations

The study was limited to surveying only the "in-patient" (the child who has been admitted to hospital for medical care) children at Tygerberg hospital. Children x-rayed at other hospitals were excluded as well as children attending Tygerberg hospital on an outpatient basis.

The study did not focus on children with a specific health conditions but it did, however, take into account the age, height and weight of the 67 children randomly chosen from those who presented to the x-ray department. The study did not make a profile of children's social backgrounds.

1.4 Assumptions

1.4.1.The first assumption

The first assumption was that Tygerberg Hospital was a prototype of Hospitals in the Western Cape and that a good representation of age groups will be covered from the children admitted to the paediatric department of Tygerberg Hospital.

1.4.2.The second assumption

The second assumption was that the radiological examinations at Tygerberg Hospital have an impact on the rest of the hospitals and clinics of the Western Cape.

1.5 Glossary

Absorbed dose: Refers to the amount of energy imparted by ionising radiation to a given mass of matter. Measured in gray (Gy), with subunits milligray (mGy)(1mGy=1/1000Gy) (1 Gy =1J / kg) (Greening, 1981).

Children: A young human being below the age of puberty. (The Concise Oxford Dictionary).

Diagnostic Radiology: The observation of images of the internal organs of the human body are achieved with the use of ionising and non-ionising radiation and specialised detectors (viz. radiographic film) for the purpose of medical diagnosis. (NCRP Report no. 68)

Dose area product: (DAP) is the integral of the absorbed dose to air over the area, A, of the x-ray beam perpendicular to the beam axis (Wall, 1996).

Effective dose: The sum of the products of the equivalent dose to each organ or tissue irradiated (H_T) and the corresponding weighting factor (W_T) for that organ or tissue is called the effective dose (E). The effective dose is expressed in the units of sievert ($1Sv = 1J\ kg^{-1}$) (Bushberg, p57).

In-patient: A patients who lives in hospital whilst under treatment (The Concise Oxford Dictionary).

Lithium Flouride(LiF): Crystal used in the makeup of TLD pellets. LiF has the ability to emit light when heat is applied to the crystal (McKinlay, 1981).

Out-patient: A hospital patient who is resident at home but attends hospital for regular appointments (The Concise Oxford Dictionary).

Organ dose: The absorbed dose of radiation, which the underlying organ receives.

Entrance surface dose: ESD is the adsorbed dose to air on the x-ray beam axis at the point where the x-ray beam enters the patient or phantom. The contribution of back-scattered radiation is to be included. The entrance surface dose is related to the incident absorbed dose (ID), by the backscatter factor(BSF). Thus ESD = ID. BSF
The backscatter factor depends on the x-ray spectrum, the x-ray field size, the thickness of the patient or phantom and the distance between the effective center of the dosimeter and the surface (Wall, IRPA 9,1996).

Thickness variation: Thickness differences of the patient i.e. from anterior to posteria of the chest (cm).

Thermoluminescence: The ability that specific phosphors have to emit light when subjected to heat after it has been exposed to radiation.

Whole body dose: The total dose of radiation, which the body receives.

1.6 Importance of the study

The importance of this study is to increase awareness of medical personal of the importance of the radiation dose received and to always also consider the absorbed dose when irradiating a young patient. Radiation workers, i.e. radiographers, radiologist should always take into account that, although the absorbed dose for one individual is small, but when seen in context with a number of children then this absorbed dose could increase could dramatically increase the population load dose. This in-turn could have an influence on the possible genetic mutations of future generations of the population. Thus protection of the child and dose accountability of the radiographer, radiologist and referring clinicians, is of utmost importance.

It is hoped that this study will assist with the calculation of absorbed dose, the use of measuring equipment and be able to recommend a more user-friendly system for dose

determination and the establish the absorbed dose levels to paediatric patients undergoing radiological procedures at Tygerberg Hospital.

1.7 Objective(s)

The objectives of the study are:

1.7.1. To establish absorbed doses to selected radiosensitive organs, i.e. eyes, heart, thyroid, liver, and gonads in three groups of children between the ages of 0-1 year, 1-5 years and 5-10 years. The doses are measured during their radiation examinations at the in- patient radiological division at Tygerberg Hospital.

1.7.2. To establish effective doses levels of individuals having x-ray examinations of the chest. It was the plan initially to measure also the abdomen but due to the insufficient number of children with abdominal x-ray request the study was unable to include such measurements.

1.7.3. To develop absorbed dose guidelines for use in paediatric radiology.

1.8 Ethics

It must be noted that children in this study were not exposed to any other doses of radiation other than the dose that was required for their respective radiographic examinations, requested by referring doctors.

The LiF detectors were 4.5 mm x 0.89 mm in size, and are also tissue equivalent as LiF has a Z atomic of 8.2 that is near equivalent to tissue. Their use did not influence the quality of resultant radiographic images. The placement of the pellets did not harm or hurt the child in any way.

Parents and nursing personnel accompanying patients were informed of the placement of the detectors. This was done in the form of an information pamphlet, explaining

what the study was about, without alarming them. Appendix 1 is an example of the letter given to each patient. The letter was only in English but interpretation in Afrikaans or Xhosa was offered when requested. Utmost care was taken to ensure that the patient was comfortable and not stressed at any time during the examination. As indicated in Appendix 1 the parent/ guardian could refuse the application of TLD pellets to the child's chest by indicating this to the radiographer (Appendix 1).

Radiographers were instructed as to the placement of the detectors, so as not to increase the time, the patient spent in the x-ray department. A letter was sent to the reporting radiologist explaining the research study and also lithium fluoride detectors (Appendix 2).

The project was fully supported by Professor A. Scher, Head of the Radiology Department Tygerberg Hospital (Appendix 3). Written approval was received from Tygerberg Hospital Research Committee (Appendix 4). Peninsula Technikon Higher Degrees committee also gave approval for the study to proceed.

1.9 Dissertation plan

When reading this dissertation the reader will, in Chapter 1, be given some insight into the problem of radiation dose measurements and reasons why and how the dissertation topic came about.

In Chapter 2 the relevance of dose measurements in Diagnostic Radiology will become clear and the impact of the historical impact of ionizing radiation on medical history.

Chapter 3 discusses the methods used to calibrate TLD pellets and how we were able to extract usable data for radiation dosimetry measurements.

Chapter 4 answers some of the questions concerning exposure factors and the outside influences on radiation dose we also look at filtration of the x-ray beam.

Chapter 5 will interpret the data recorded and inform the reader of the results achieved and also how these results were analysed. In this chapter we also try to discuss and compare our results with that which was achieved locally and internationally.

In Chapter 6, this thesis is concluded and recommendations made concerning the radiation doses of paediatric patients at Tygerberg Hospital, South Africa are put forward.

It is hoped that the reader will find the pages of this dissertation interesting and informative and that you will be able to use the knowledge generated during the study.

Chapter 2:

Literature Review

2.1 Historical Background to Radiation

Wilhelm Conrad Roentgen at the Physical Institute of the University of Würzburg, Germany (1895) observed that platino-barium cyanide fluorescent material smeared on thin cardboard and lying near heated tubes that were covered with black light tight paper, glowed. He found that the newly discovered rays also penetrated wood, books and metals sheets. More startling observations were made when he interposed his hand between the source of the rays and the luminescent cardboard he saw his hand silhouette on the screen. Thus these new rays, which Roentgen called "X-rays" were discovered (Mould et al., 1995).

The development of the radiology discipline, from the discovery of x-rays in a laboratory in Germany, to their implementation in medical practice, for diagnostic purposes is according to Hall (2002), one of the most rapid and remarkable examples of transitional research.

The medical fraternity quickly realised the benefit of this "new ray". However, not before long did they realise that the x-rays also had deleterious side effects. They became aware of skin damage, loss of fingers and also Leukaemia, in persons working with the "new rays" (Mould et al., 1995).

Thus dawned the era of radiation measuring devices. Over the years a number of designs for radiation measuring devices were developed. As early as 1896 the measurement of the penetration of x-rays started. Kassabian called the early devices "Skiameters" in 1907. Demonstrated in Figure 2.1, these devices were used to measure the penetrating power of x-rays (Mould et al., 1995).

In 1896, Benoist and Hurmuzeescu designed the gold leaf electrometer by which they measured the absorption of x-rays by various substances. Also, in November 1896, Parisian Jean Perrin published drawings shown in Figure 2.2 of the principle of a free –in air chamber (Mould et al., 1995).

Very little appears to have happened again up until 1920's when the "Wulf electrometer", was designed by Kronig and Friedrich in 1922. Mould et al., also tells us that in 1920 Williams designed an instrument call a "Densitometer". Its purpose was to measure the density of a patient's thorax. A picture is seen in Figure 2.3 (Mould et al., 1995).

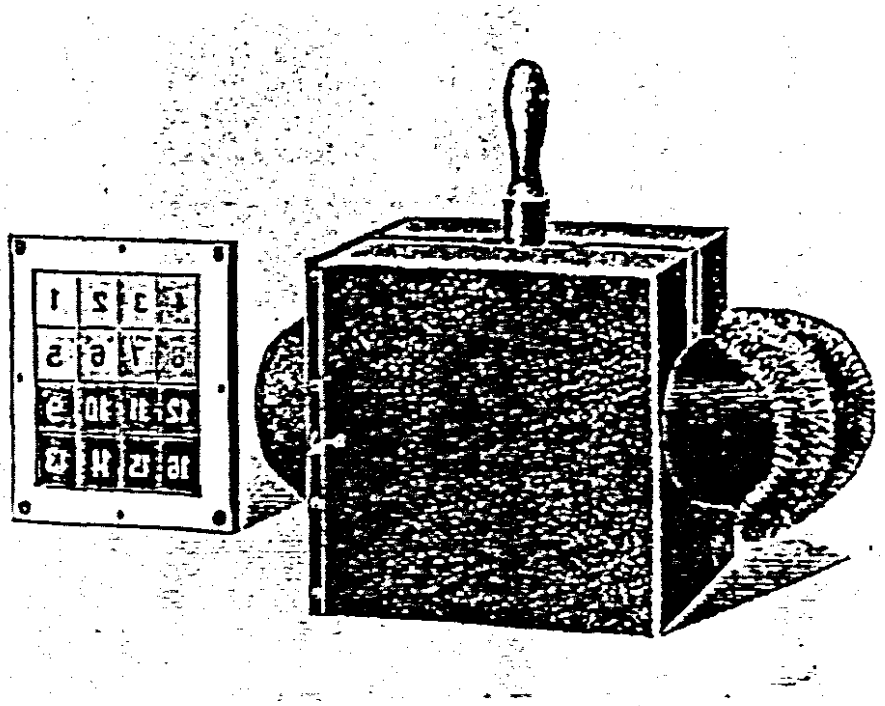

Figure 2.1. A Skaimeter used to measure penetrative power of x-rays (Mould et al., 1995).

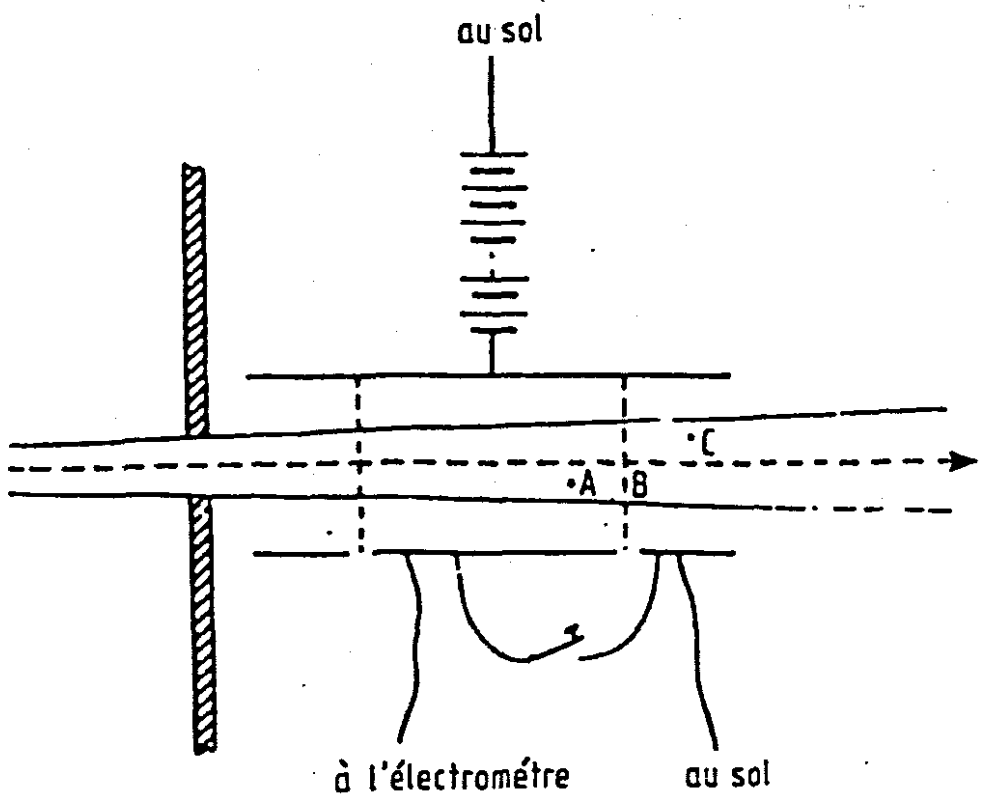

Figure 2.2. Illustration of the principle of the free-air ionization chamber by Perrin 1896 (Mould, 1995).

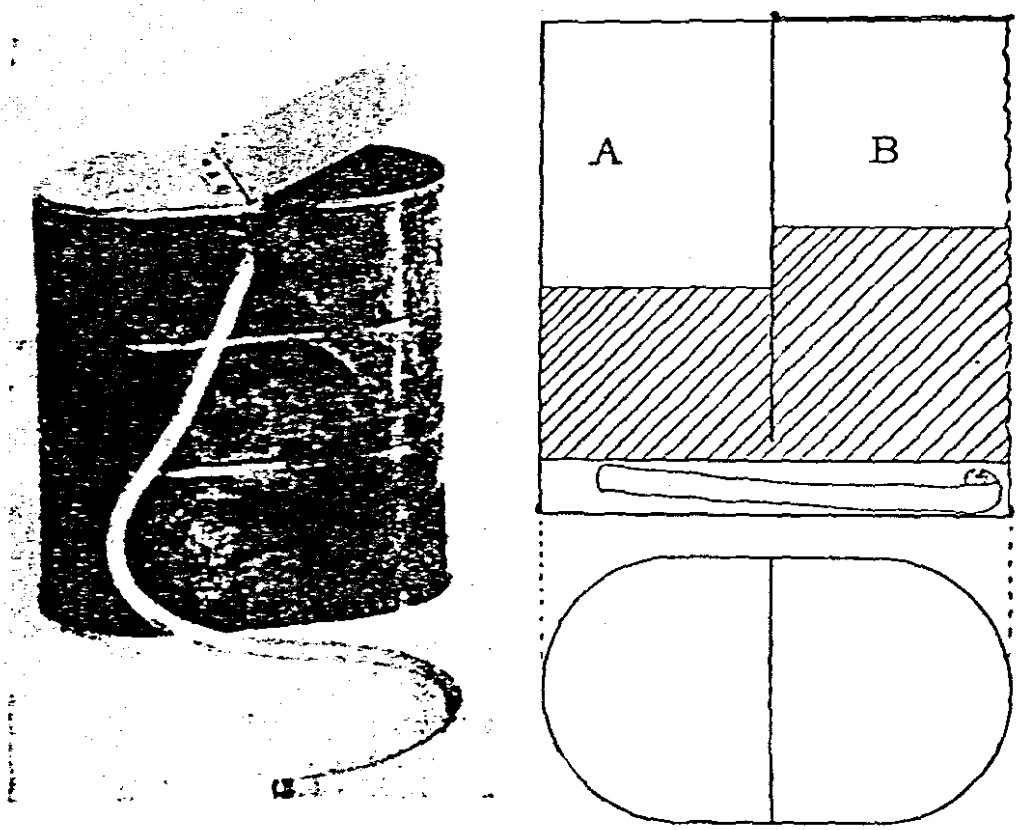

Figure 2.3. The thorax densitometer of Williams 1902(Mould, 1995)

2.1.1 The Twentieth Century

As early as 1940 the thermoluminescence was used to make quantitative measurements of radiation exposure. Lif was obtainable in small crystals. These where used for internal radiation measurements and radiotherapy. They were found to have large variations in sensitivity. It was found that grinding the crystal into powder and then mixing into pellets could lessen this. In 1960 Harshaw produced a material is today regarded as the "standard" TL phosphor. It became available in other forms, viz: discs, tapes and rods. Over the years investigation of thermoluminescence has expanded and they be came commercially available and their use increased. (McKinley, 1981)

In the Twentieth century radiation dose apparatus evolved rapidly and instruments used today either detect or measure radiation or both. In Figure 2.4 a modern dose meter is illustrated. These instruments accumulate the radiation received and are able to give the total exposure. The techniques of measuring radiation is referred to as "Dosimetry"

The following types of radiation detection devices are available. Panosonic® dosimeters used for personal radiation monitoring. The TLD pellets monitors measure patient dose and personnel dose (Bushong 2002).

There is also gas- filled radiation detectors of which there is three types: ionisation chambers, proportional counters and Geiger-Muller detectors. These instruments detect and measure radiation intensity. The modern radiation meters as the " Diodose" shown in Figure 2.4 are able to measure multiple values for example dose and dose rate measurements. Most are able to read in uGy, mGy and Gy.

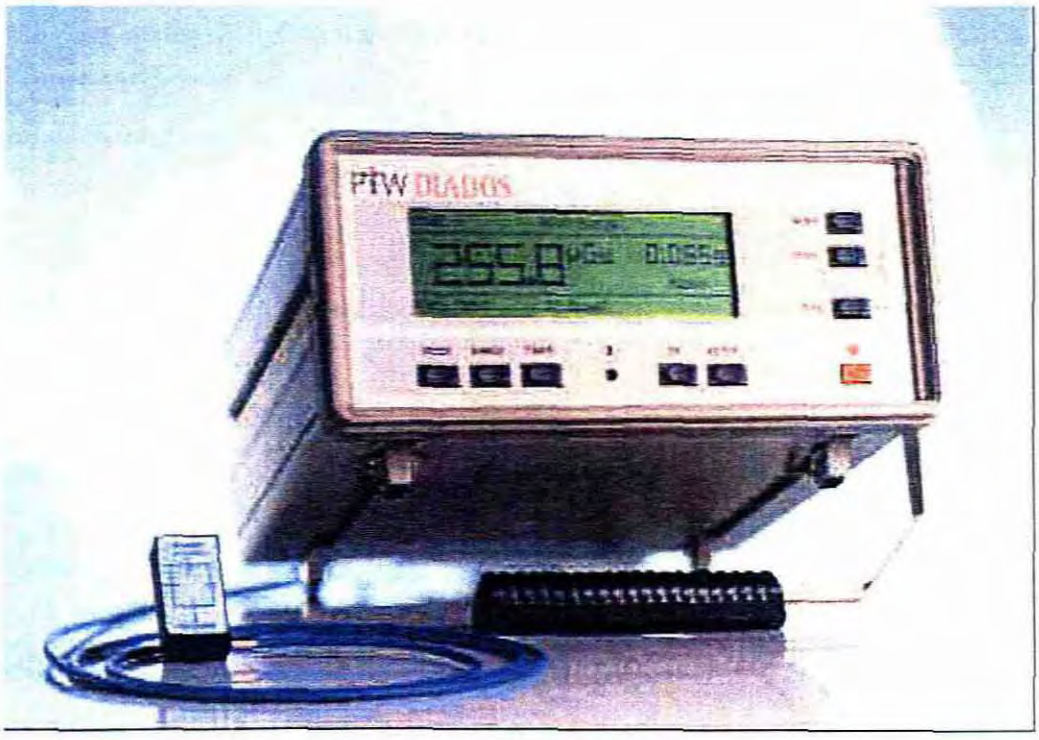

Figure 2.4. A "Diodose" dose meter by PTW as the one used in the study.

2.2 Radiation Effects

2.2.1 Biological Effects of Radiation

According to McKinlay (1981), the collective dose to the population of the United Kingdom resulting from medical exposure has been estimated to represent the largest single man-made contribution to both the somatic and the genetically significant dose equivalent. A similar distribution was found in other developed countries. The largest contribution being from Diagnostic Radiology, which is estimated at ten times the sum of contributions from nuclear medicine and radiotherapy.

It is desirable to reduce the patient exposure to radiation from diagnostic x-rays to a minimum consistent with a good diagnosis. It's therefore the goal of modern radiation protection to keep exposures as low as reasonably achievable. This is referred to as the ALARA principle (Bushberg et al, 1997).

Ionising radiation damages living tissue; the extent of damage may vary. If this damage is limited to a small number of insignificant cells the effect on the body may be insignificant. However if a large amount of cells or if only one cell vital to the functioning of the body is damaged, this may be harmful to the patients' health/ and well being (Ball & Moore, 1994).

Biological effects may occur in the exposed individual as somatic radiation damage to the cell or alternatively this genetic damage could be passed on to the individuals' descendants. The effects are classified into Stochastic and Deterministic effects

(a) Stochastic effects

Short-term effects may arise soon after a person is exposed to radiation. The effect may subside quickly. The skin appears red, like sunburn, which fades quickly. Long-term effects may manifest years after the radiation exposure has occurred. These effects may include skin tumours and cataracts to the eyes. If the whole body is irradiated leukaemia may develop (Van Rooyen et al., 1995).

Stochastic effects occur when the cell is not killed by radiation but, due to radiation, changes occur in their genetic material. These changes also referred to as genetic mutations are passed from parents' to their children, which may be harmful to them. The genetic mutations can cause for example congenital blindness, deafness, mental and physical abnormalities and also fetal death. The term "stochastic" (stochastic - governed, by the laws of probability; Greek: "to aim" or "to guess") implies that the seriousness of the effect is independent of the dose received, but by the probability of the effect occurring depends on the magnitude of the dose. No dose threshold applies to the occurrence of stochastic effects (Van Rooyen et al., 1995).

The risk of damage to cells or radiation effects occurring increases with the increase in absorbed dose of radiation. It is difficult to prove that radiation exposure is the cause of stochastic effects unless a number of persons are exposed (Van Rooyen et al., 1995).

(b) Deterministic effects

In this group there is a threshold dose of radiation below, which the affect does not occur. Doses significantly above the threshold will produce effects of which the severity is proportional to the absorbed dose received. Short-term effects are: radiation erythema, gastro-intestinal syndrome where the cell renewal system of the bowel is damaged (Van Rooyen et al., 1995). The human body has repair mechanisms in its cells and in many cases it may be able to restore a damaged cell to its pre-irradiated state (Bushberg et al., 1997).

In Figure 2.5 a schematic diagram is presented which shows the process of cell damage from the time of irradiation (Bushberg et al., 1997). It must be noted that humans are not only exposed to man made radiation directly, for example medical irradiation, but also indirectly from radiation that occurs naturally, eg. cosmic rays of the sun.

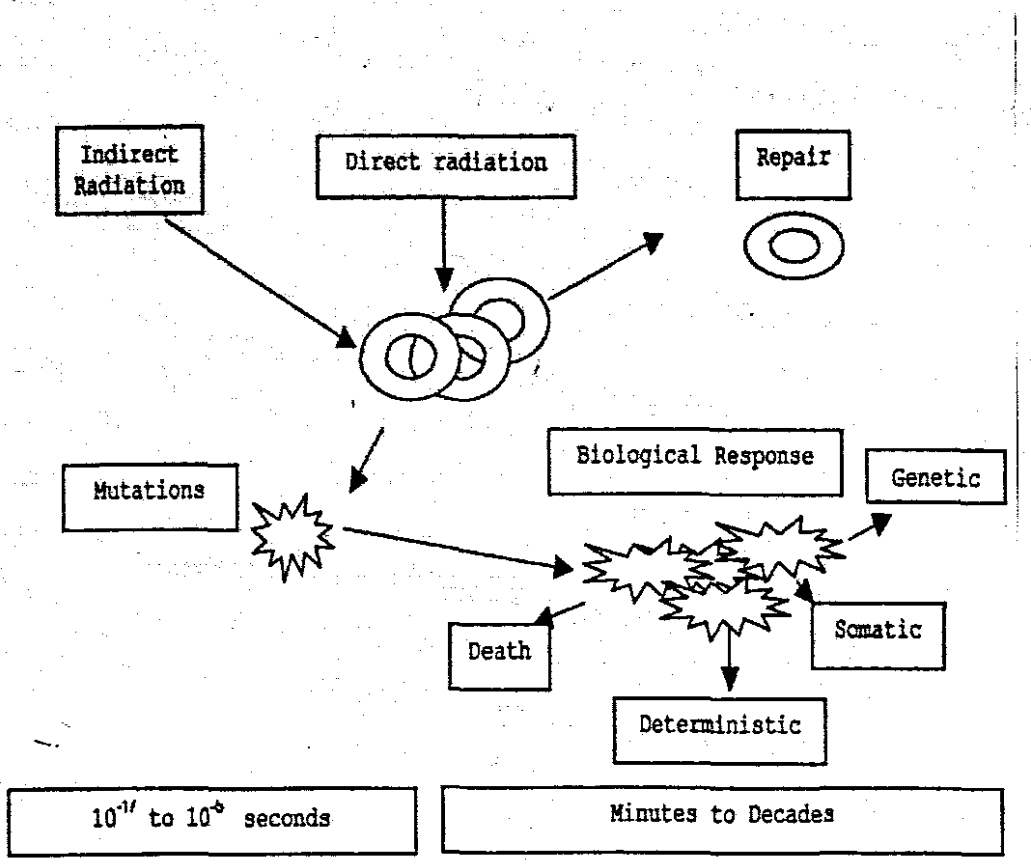

Figure 2.5. Diagram showing how a cell is damaged (extracts from Bushberg et al., 1997).

2.3 Radiation Protection

In 1928 at the second Congress of Radiology held in Stockholm two commissions were set-up to prepare x-ray protection guidelines. These two commissions are still functioning today: The International Commission on Radiological Protection (ICRP) and the International Commission on Radiological Units and Measurements. These two commissions control set rules and have regulations in place that control radiation dose to patients and staff and public.

The main aim of radiation protection is to substantially reduce the exposure to radiation that patients receive due to diagnostic x-rays, but to remain consistent with good diagnosis. Thus NCRP Report no. 68 "Radiation Protection in Paediatric Radiology" guides us to the following criterion when using medical diagnostic radiation:

2.3.1. The introduction of new equipment should produce a benefit that is expected to outweigh the risk of radiation.

2.3.2. Exposure should be kept to the minimum necessary to gain the required diagnostic information.

2.3.3. There are no maximum permissible dose for medical radiation.

2.3.4. Exposure should be kept as "Low as Reasonably Achievable" (ALARA).

2.4 Dose Assessment

In the United Kingdom, since the 1960's dose assessments where widely and routinely performed over a five year period at out patient hospitals. The purpose was to keep records of radiation doses received, to work on the reduction of dose and also to improve radiographic techniques.

The article by Mooney & Thomas, (1998), "Dose reduction in a paediatric X-ray department following optimisation of radiographic technique", covered a similar study to that of this research topic. In their article they stated that in Ireland reference dose surveys had been carried out, but no reference levels had been set. The Irish study used TLD pellets and a dose area product (DAP) meter to measure radiation dose. In this study at Tygerberg hospital the use TLD pellets was made for measurements directly on patients, a radiation dosimeter (PTW) and ionization chamber to read radiation dose outputs from the x-ray tube. The dose readings were then verified by using the "Nero" radiation measuring equipment.

The method to determine effective dose for the purpose of assessing stochastic risks of radiation is complex. This is verified in the article by Theocharopoulos (2002), where he and colleagues compared four methods of assessing effective dose. The methods compared was firstly, direct measurement of dose with the use of TLD pellets within a phantom. This they found to be labour intensive but did allow reliable estimation of radiation dose. The other methods all made use of entrance surface dose measurements or dose area product measurements to estimate patient effective dose.

The method of effective dose estimation using direct organ dose measurements with the assistance of TLD pellets was considered to be the "gold standard" against which indirect methods are compared (Theocharopouos, 2002).

Literature consulted has also assisted in finding out more about TLD pellets, their use, sensitivity and methods of calibrations. The notes of a refresher course of the NRPB by Wall (1996), "How to assess the dose to the patient in Diagnostic Radiology" was used to assist in this study with many of the set-up procedures and to help in evaluating the data received.

During this study a continual search for literature was done that could assist in answering questions occurring whilst data collection was in progress. Ogundare et al. (1999), of the University of Ibadan, Nigeria, published one such paper. The authors studied radiological doses pertaining to children undergoing diagnostic radiology in Nigeria. For their study they employed the use of one TLD pellet that they attached to the patients skin to read ESD. However their results differed greatly from set

standards of their reference source of the UNSCEAR 2000. This they state is due to different radiographic equipment, in many cases much older than that of the United Kingdom and also different imaging apparatus such as film and processing.

In contrast to the Tygerberg hospital study, they only used one TLD pellet per x-ray view for measurements at the entrance point. The study at Tygerberg hospital used eight TLD pellets per view, placed on the entrance point of position. The reason for this increased use of TLD pellets was that according to Mckinlay (1981), all TLD pellets do not contain the same amount of LiF phosphors. Consequently the sensitivity to radiation differs for each pellet.

By using more TLD pellets at measurement points a better average dose could be calculated. It is thought that this could have a large influence and be the reason for the difference between the Nigerian results and results of referenced sources coupled with that which was measured at Tygerberg Hospital, South Africa.

A tabulation of the outcome of the Irish and the Nigerian studies appear on page 21, Table 2.6. The difference between the values of these two studies is again demonstrated in the histogram on page 21, Figure 2.7. Both presentations demonstrate that the Nigerian values for mean entrance surface dose (ESD) far exceed that of Ireland. It was with this in mind that the South African study was undertaken for the purpose of measuring and setting South African standards against published international studies.

Table 2.6. Tabulation of Mean ESD (mGy) measured in Ireland and Nigeria.

Country	Age group (yrs.)	Mean ESD (mGy)
Ireland	< 1	0.060 (± 0.02)
Mooney et al., 1998	1-5	0.053 (± 0.019)
	5-10	0.054 (± 0.029)
Nigeria	< 1	0.350 (± 0.15)
Ogundare et al., 2004	1-5	0.520 (± 0.47)
	5-10	0.490 (± 0.21)

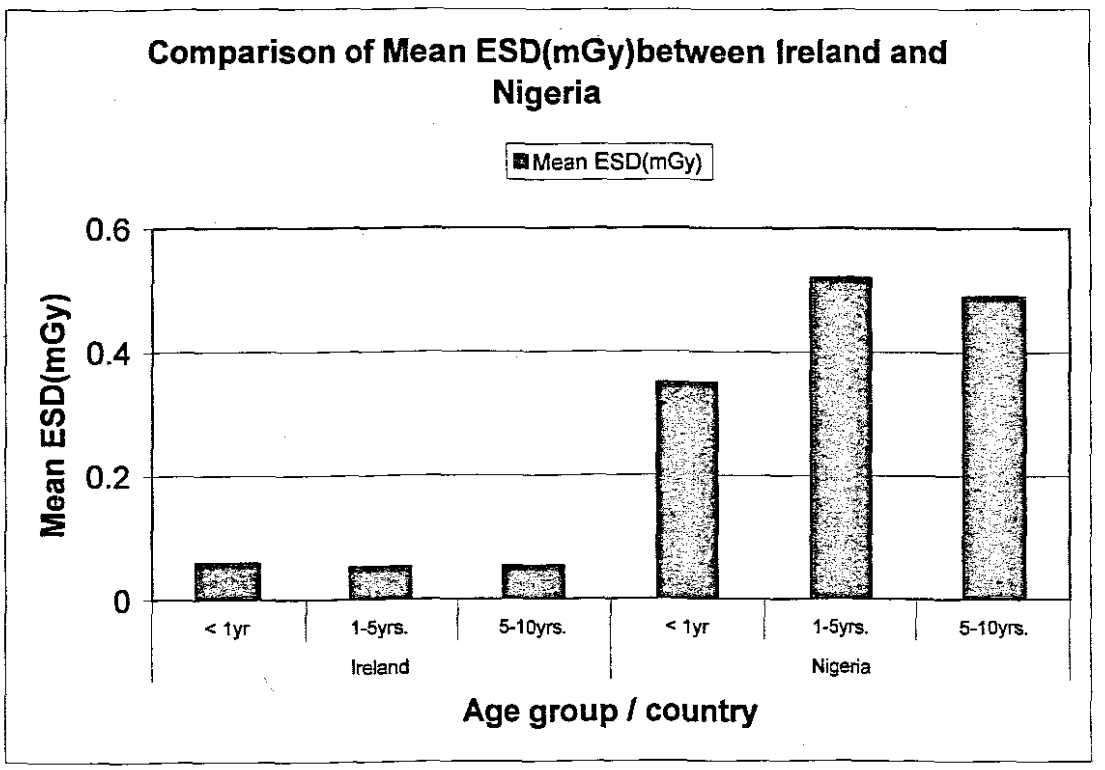

Figure 2.7. Histogram demonstrating the differing Mean ESD (mGy) between Ireland and Nigeria.

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Ogundare et al., 2004	1-5	0.520 (± 0.47)
	5-10	0.490 (± 0.21)

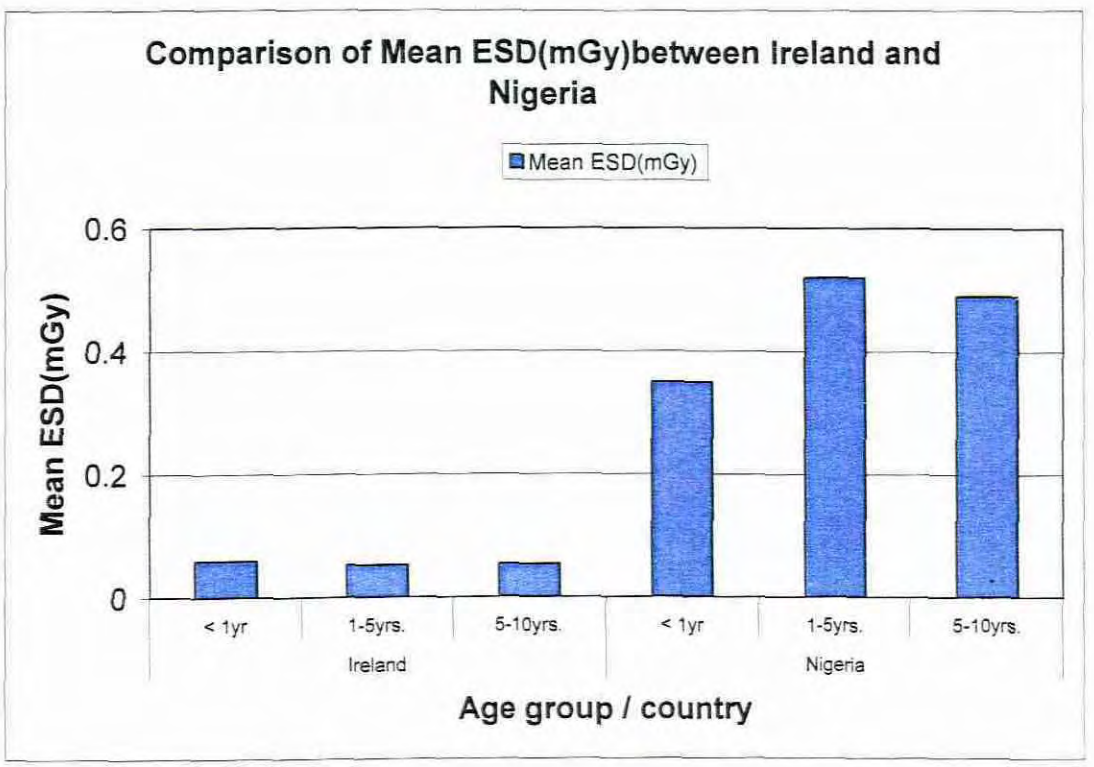


Figure 2.7. Histogram demonstrating the differing Mean ESD (mGy) between Ireland and Nigeria.

2.5 Radiation and Dosimetery

2.5.1 The production of x-rays

In this section ionising radiation and the form of radiation measured is clarified. This clarification is required as ionising radiation comes in several forms (x-rays, gamma rays, etc). In this study electromagnetic radiation produced in an x-ray tube and which are called x-rays was used.

The following is a brief description of the production of man-made x-rays. The production of man-made x-rays has evolved rapidly since x-rays were discovered in 1895.

X-rays are produced when high-speed electrons are decelerated on collision with a high atomic number (Z number) material. This process occurs in an x-ray tube, which is an evacuated glass tube containing two electrodes see Figure 2.8. The one terminal, which is called the "Cathode", is a filament made of tungsten alloy. The other terminal the "Anode" is a tungsten alloy target set in a copper disc. The cathode is heated so that it glows with heat and releases free electrons in a process called thermionic emission. When a high voltage is applied across the two terminals, the electrons are electrostatically accelerated towards the anode, collide with the tungsten target, x-rays and heat are produced. A beam of x-rays is emitted through the opening in the metal casing called the primary collimator. Figure 2.8 shows a schematic diagram the x-ray tube and the production of x-rays.

2.6 Radiation Dosimetry units

Diagnostic Radiology Departments are becoming increasingly aware that radiation doses to patients vary from facility to facility and that dose monitoring of patients is important (Wall,1996). Furthermore, staff and patients become more aware that radiation doses must be controlled. These aspects were discussed at the International Congress on Radiation Protection held in 1996. Wall (1996) subsequently published a

"refresher course" on assessment of radiation doses. In this course Wall explained the source quantities and field quantities, which are useful in radiation dosimetry.
Due to the nature of this study, and the availability of equipment, the emphasis during the survey was only to obtain measurements of certain radiation quantities that could be measured on patients or on a phantom.

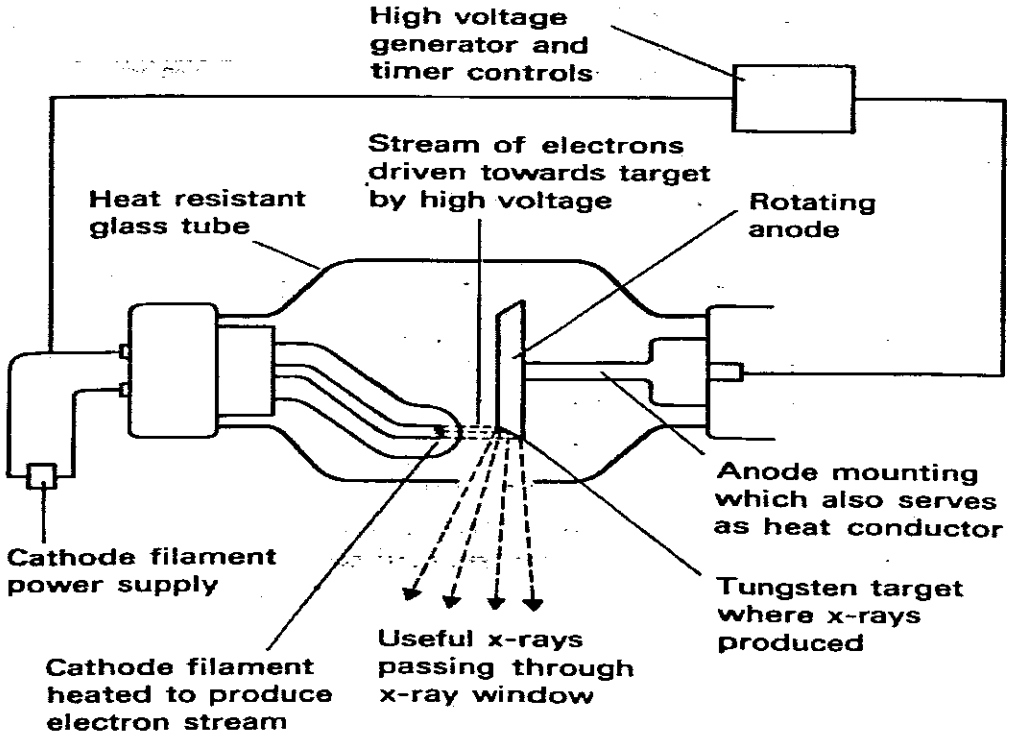


Figure 2.8. Diagram of an x-ray tube (Armstrong & Wastie, 1995).

2.6.1 Radiation Source Quantities

The intensity and quality of the radiation beam delivered is a function of the tube current, exposure time, applied potential and the filtration used. The number of photons emitted over a certain time is controlled by the tube current (mA) whereas the applied potential (kVp), inherent and added filtration (mm Al) determine the spectral distribution of the photons in the path of the x-ray beam (Wall, 1996).

The photons ionise the air through which they pass and the ionization process leads to measurable values of absorbed dose to air, at any point in the x-ray beam.

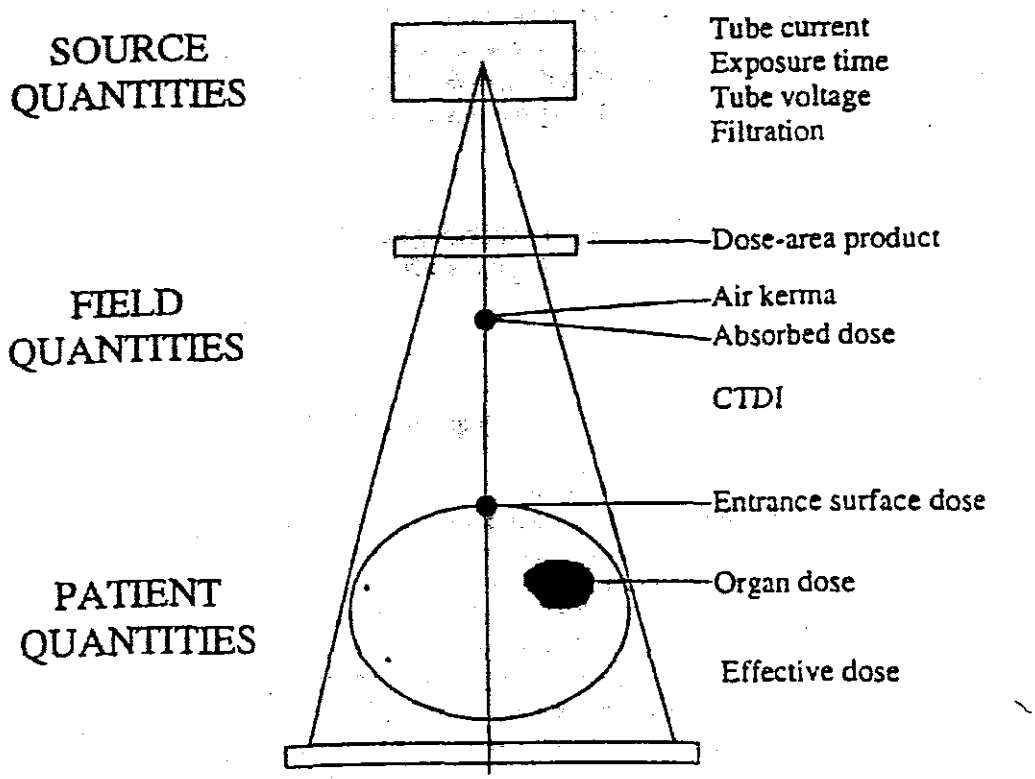


Figure 2.9. Radiation quantities for describing exposures in Diagnostic Radiology (Wall, 1996).

2.6.2 Entrance surface dose (ESD)

ESD is the absorbed dose to air on the x-ray beam axis at the point where the x-ray beam enters the patient. The backscattered radiation must be included. The ESD is related to the incident absorbed dose, ID, by the backscatter factor, BSF.

$$ESD = ID \times BSF \qquad \text{(eq. 1)}$$

ESD - Entrance surface dose
ID - Incident absorbed dose
BSF - Backscatter factor

The backscatter factor depends on the x-ray spectrum, the field size, thickness of the patient and distance between the effective centre of the dose measurement point and the surface. The influence of the latter factor can be minimised by using a dosimeter of small volume directly attached to the patients skin. The TLD pellets used in this study were of a volume small enough so as to minimise the effects on the backscatter factor (Wall, 1996).

2.6.3 Mean absorbed dose to organ or tissue (D_T)

Absorbed dose is measured in joules per kilogram with 1J/kg = 1gray(Gy). The ICRP 60 recommendation: "The average absorbed dose over a tissue or organ is the appropriate dosimetric indicator for the probability of stochastic radiation effects. Knowledge of the dose distribution, throughout relevant tissues and organs can rarely be obtained by direct measurement in patients. Either physical phantom or computer models have been used to measure or calculate organ and tissue doses" (Wall, 1996).

For the calculation of organ dose publications concerning organ dose calculation using Monte Carlo Techniques, which is a mathematical model for calculating dose, was purchased. This included the NRPB R189 (Johns & Cunningham 1983) and the software package NRPB-SR279 (Hart, et al., 1996). The software package "Childdose" written to run as a Microsoft Dos program by Le Heron of the National Radiation Laboratory New Zealand was also purchased for use in conjunction with NRPB-SR279.

The "Childdose" programme was written to simplify the calculation of organ and tissue doses. They are 3 separate publications but were written to be used in conjunction with each other one.

2.6.4 Effective dose (E)

Organ doses can be combined to account for their relative contribution to the total radiation harm. Not all tissues or organs are equally sensitive to the effects caused by ionizing radiation. Effective dose can provide a single measure of dose that is directly related to damage. Effective dose is measured in joule per kilogram and named the sievert (Sv) (Wall, 1996).

In 1991 the IRCP 60 published tissue-weighting factors (W_T) that were established to assign a dose equivalent to a particular organ or tissue (T). Each weighting factor can be considered a proportion of the risk of stochastic effects, which results from the irradiation of the body.

The effective dose is calculated as follows:

Effective Dose (E) is taken to be the sum of: -

2.6.4.1. The organ doses to the 12 specified organs multiplied by their radiosensitive tissue weighting factor (W_T) and either

2.6.4.2. The average dose to the remainder organs multiplied by 0.05 or

2.6.4.3. If one of the remainder organs receives a dose higher than any other organ for which tissue weighting factor are specified, half of the remainder weighting factor (i.e. 0.025) multiplied by the dose for that organ and the other half (0.025) multiplied by the mean dose to the rest of the remainder organs. (NRPB –R279). Tissue weighting factors are indicated in Table 2.10.

Table 2.10. Tissue weighting factors for the 12 specified organs and 10 remainder organs specified by the IRCP (NRPB-R279, 1996).

Organ	Tissue weighting Factor
Gonads	0.20
Bone marrow	0.12
Lower large intestine	0.12
Lungs	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Bone surface	0.01
Skin	0.01
Remainder Organs	0.05

Note:

Remainder organs are adrenals, brain, kidney, muscle, pancreas, small intestine, spleen, thymus, upper large intestine and uterus.

2.7 Thermoluninescent dosimeters

Thermoluminescence is the property that a crystal has to absorb energy and when subsequently subjected to heat, to release this energy in the form of visible light. It is this release of light that can be measured by a Photomultiplier tube in a TLD reader (McKinlay, 1981).

TLD pellets are solid dosimeters, made of Lithium Fluoride (LiF), which is an inorganic crystal. They exhibit the property to absorb radiation and then emit light

when heated. By measuring these light emissions one can determine the radiation dose that the TLD has been subjected to.

Johns & Cunningham (1983), explains that Lithium fluoride (LiF) has a regular crystalline structure, or lattice formation. When the material is irradiated and energy is absorbed from the radiation beam; some of the electrons of the crystals of LiF are raised to higher energy levels. Most of these electrons immediately return to their ground state, but a few remain in the impurity levels. With heating of the LiF, these electrons are elevated to higher levels from which they return to ground level with the emission of light. The total amount of light emitted will be proportional to the number of electrons that were trapped; this in turn is proportional to the amount of energy absorbed from the radiation (Johns & Cunningham, 1983). See Figure 2.11 for a schematic diagram.

TLD pellets used for this project were "TLD100", manufactured by FIMEL, France, for integrated dose measurements in health physics and medical radiology. They were 4.5 mm x 0.89 mm in size, thus making placement easier. LiF has an atomic number of 8.2 and it has x-ray absorption properties similar to soft tissue. It is thus considered to be a tissue equivalent dosimeter. LiF can measure doses as low as 0.1 mGy and as high as 100 mGy, with a accuracy better than 5%. These characteristics all make the phosphor suitable for radiation dosimetry (Bushong, 2002).

Care must be taken when handling the TLD pellets. To obtain optimal results the following should be abhered to:

- Handle lightly with a clean tweezer;
- Avoid touching with hands or dirty objects as oil and dust affect the sensitivity of the pellet;
- Keep the pellets away from non-radiation induced humidity and organic atmosphere;
- Store tightly closed in a cool dry place away from food and drink; and
- Do not allow Lif to get into the eyes, on the skin or clothing as LiF is considered a toxic substance (PTW handbook, 2002).

The energy, which is absorbed by the TLD is only released as visible light when it is subsequently heated to about 300°C. Figure 2.12 is a simple representation of the apparatus for measuring the light output from thermoluminescent material (Johns & Cunningham, 1983).

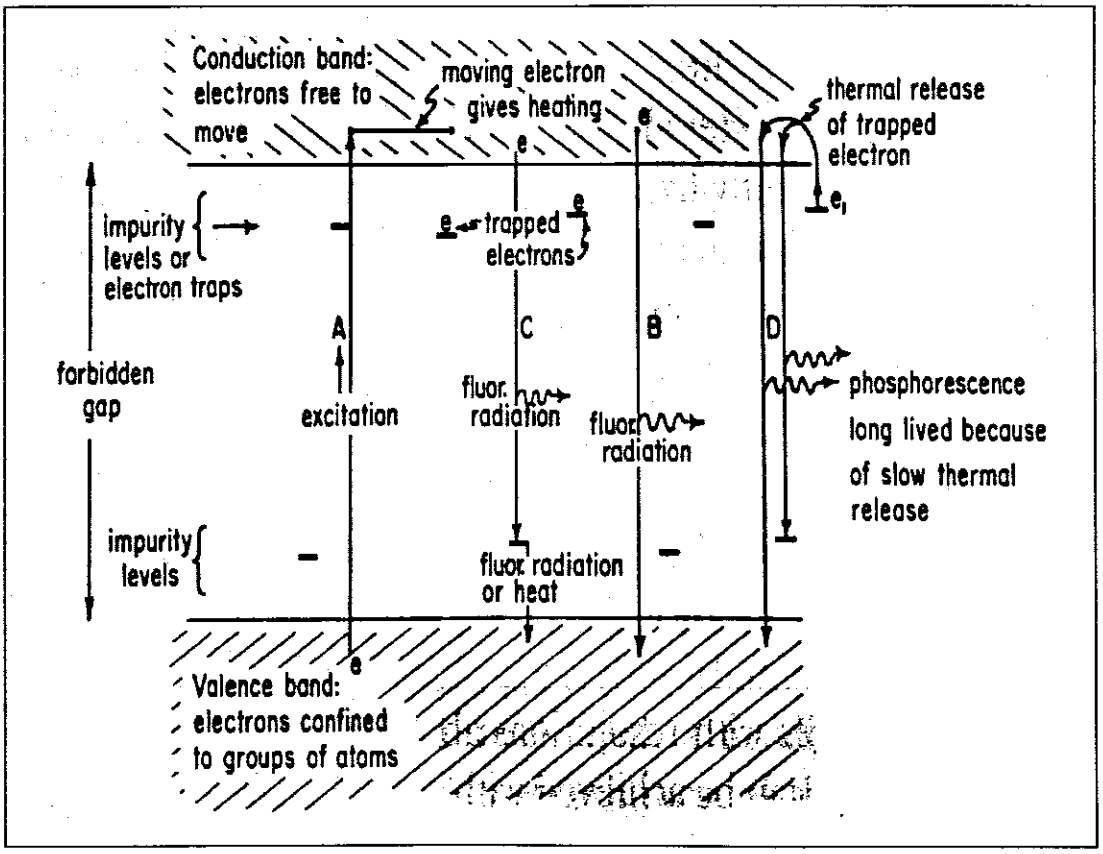


Figure 2.11. Illustrates what occurs when ionising radiation is absorbed in the material and free electrons are produced (Johns & Cunningham, 1983).

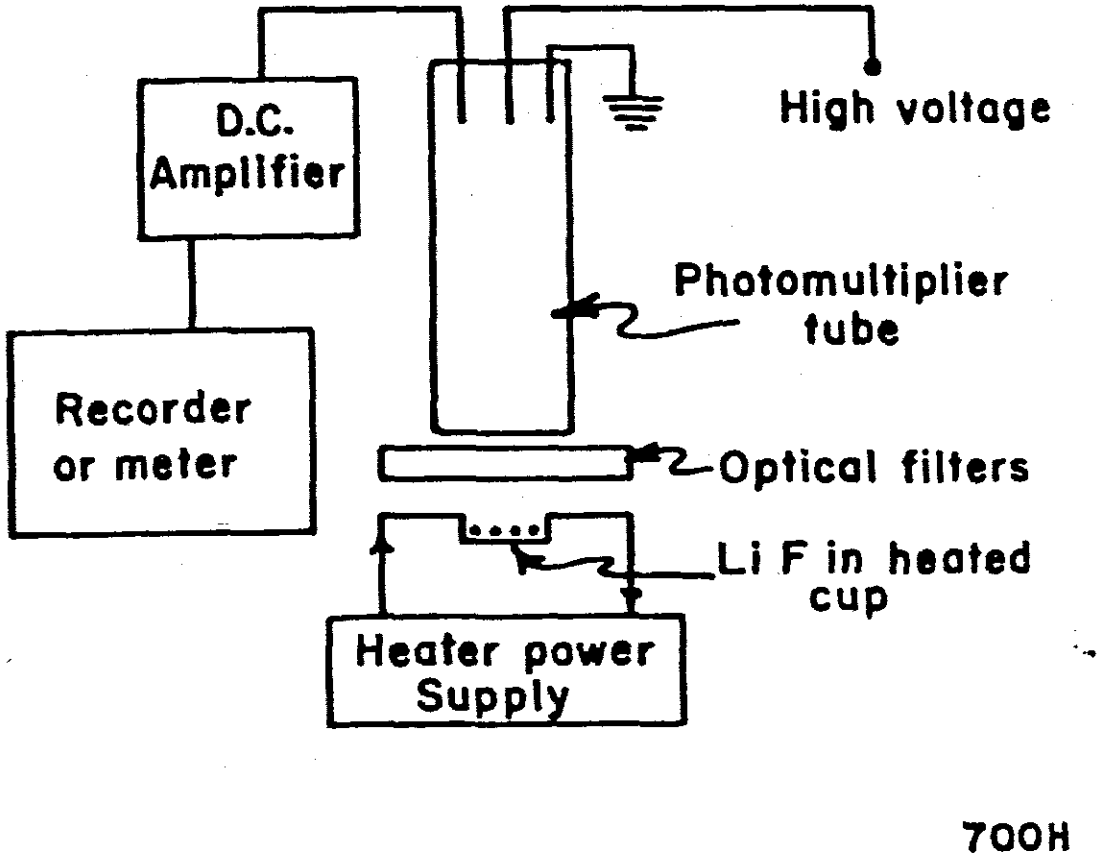


Figure 2.12. *Schematic diagram showing the apparatus for measuring light output from thermoluminescent material (Johns & Cunningham, 1983).*

After irradiation the TLD pellet is placed on a planchet, which is a specially indented stainless steel plate. The temperature of this planchet is controlled in the TLD analyser /reader. As the temperature of the planchet is increased the light emitted from the TLD pellet increases in a regular manner. This is called a "Glow curve" (Johns, 1983).

Figure 2.13 shows the light output from Lithium Fluoride with temperature increase.

LiF pellets are annealed in a special oven heated to 400°C and followed by heating for a further 16 hours at 80°C. This is called "zeroing" the crystal (Stanton, 1996). Thus heating restores the crystal to its original form, ready for reuse.

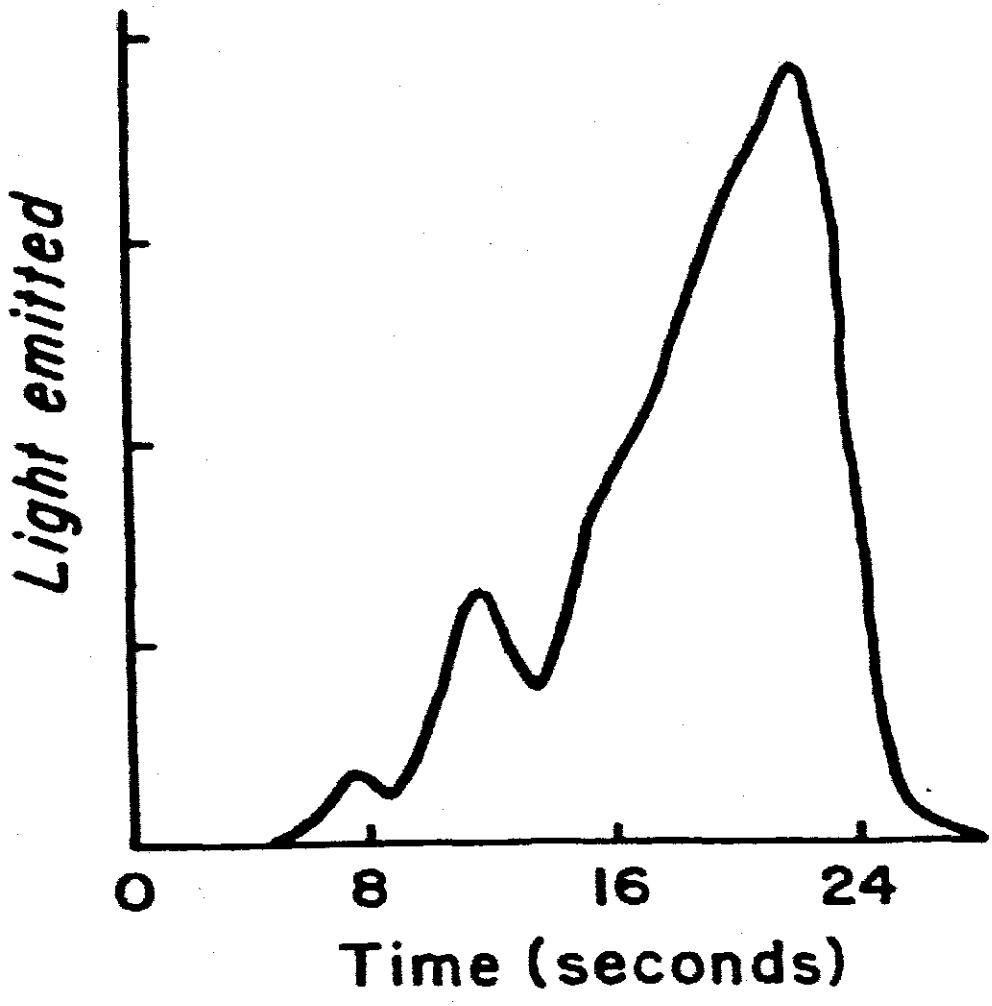


Figure 2.13. Glow curve of LiF (Johns & Cunningham, 1983).

Chapter 3:

Methodology

3.1 The Data

Before the data collection part of the study commenced measurements were done on a control group of 10 children in the age groups of 1 year to 5 years, to clarify the following:

3.1.1. TLD pellets do not show up on the x-ray image. As TLD pellets have a effective atomic number of 8.2 which resembles human soft tissue.

3.1.2. The response of the person accompanying the child to positioning of the TLD pellet on the child's skin

3.1.3. How stressful it is for the child.

3.1.4. Whether or if due to the placement of the TLD pellets, the radiographer takes longer to x-ray the child.

3.1.5. The method of placement of TLD pellets

3.1.6. To check if the method used for the calibration of TLD pellets was correct and sensitive enough to measure the low doses of radiation delivered.

3.1.7. To check formulas and calculations that will be used for dose calculations.

In the actual study three groups of randomly chosen children were measured. They were divided into specific groups by virtue of the body mass, body surface and age. The ages of each group were as follows: group (i): 0 to 1 year, group (ii): 1 to 5 years, group (iii): 5 to 10 years, a distinction was made between males and females.

3.2 Equipment

The Table 3.1 is a list of the most important equipment which was used in the process of data acquisition during this study:

Table 3.1. Equipment required for TLD pellet calibration.

Equipment	Make	Model	Manufacture
TLD pellets	Li – Fi chips	100	"Fimel'
Annealing Tray	Al tray		" Vinten"
Annealing Oven		DB – 4 Volt	" Vinten"
TLD Reader	Toledo	654	" Vinten"
Electrometer	Diodos	11003-1105	PTW Feiburg
Phantom	Polystyrene Slab Phantom	Water equivalent	Departmental apparatus
Tweezer	Chrome	Solinger	" Vinten"
Plastic Pockets	Black		Departmental apparatus
Suction Apparatus	Vacuum Suction unit	DA7-C.VAT/T	Charlse Austin Pumps Ltd.

Figure 3.2. TLD reader Toledo "Model 654" Serial no. 22-5.Used for all TLD pellet readings done in this project.

3.3 Calibration of TLD's

McGhee et al.,(1993), states: that "Present day procedures for performing thermoluminescece (TL) dosemitry can achieve a high degree of accuracy but are typically labour intensive"and involves a number of stages.

McKinlay (1981), furthermore states "that to ensure a complete readout of the stored signal and repeated use of the phosphor without significant change in its thermoluminescence sensitivity a thermal anneal is required". This must occur before making radiation measurements and it is advised that all pellets are annealed under identical conditions to standardize their sensitivities and backgrounds. Before the TLD pellets are ready for capturing of data they require calibration at different x-ray beam energies. In the calibration procedure a relationship is determined between the light output and absorbed dose delivered to the TLD pellets.

Firstly TLD pellets are packed into individual depressions in a specially prepared aluminum, annealing tray. The annealing process is achieved by heating the pellets in an annealing oven for 1 hour at 400°C and followed by heating for a further 16 hours at 80°C. The annealing process is important to eliminate low temperature glow peaks (McKinlay, 1981). Figure 3.3 represents a flow diagram indicating the processes which TLD pellets were subjected to for the purpose of dose readings and evaluations.

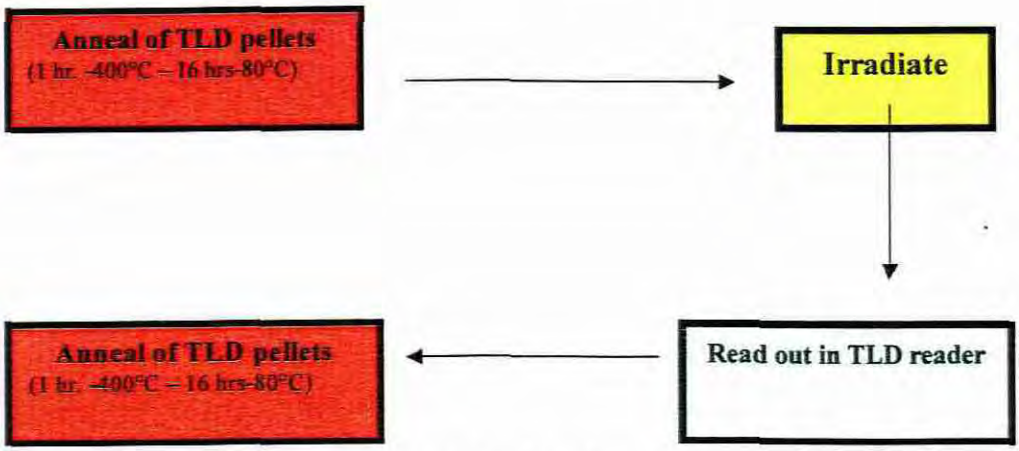


Figure 3.3. A flow diagram showing the process, to which TLD pellets are subjected to.

After the annealing process has been completed the TLD pellets are transferred to a Perspex tray, similar in construction to the aluminum (Al) tray as shown in Figure 3.4. Use was made of a tray number system from 1 to 110. Each pellet in an indentation was linked to a specific number. This numbering system was kept constant thoughout the study. Pellets in the Perspex tray were placed on a 38 x 38 cm^2, 6 cm high polystyrene phantom block simulating a child's chest age 0 –1 year. The x-ray tube was positioned at a distance of 100 cm from the surface of the pellets which where placed on the centrally on the phantom at the central axis of the x-ray beam. A field size of 10 x 10 cm^2 was coned which covered all the pellets, leaving a border of 14 cm around the coned field size.

The pellets were irradiated using a Philips three phase x-ray generator unit, (model: Super 80 CP) with 2.5 mm of aluminum (Al) filtration at an FFD of 100cm from the surface of the perspex holder. Exposure values of 50 kV and 5 mAs were used. This procedure was repeated four times and each time 110 TLD pellets were calibrated. See Figure 3.5 for a schematic drawing of TLD irradiation and the phantom set up.

The purpose of redoing the calibration was to achieve the lowest possible standard deviation (SDEV). After the 4th set of calibrations, a coefficient of variation (CV) of 3% was achieved.

Figure 3.4. The aluminium annealing tray showing TLD pellets, tray indents and suction apparatus.

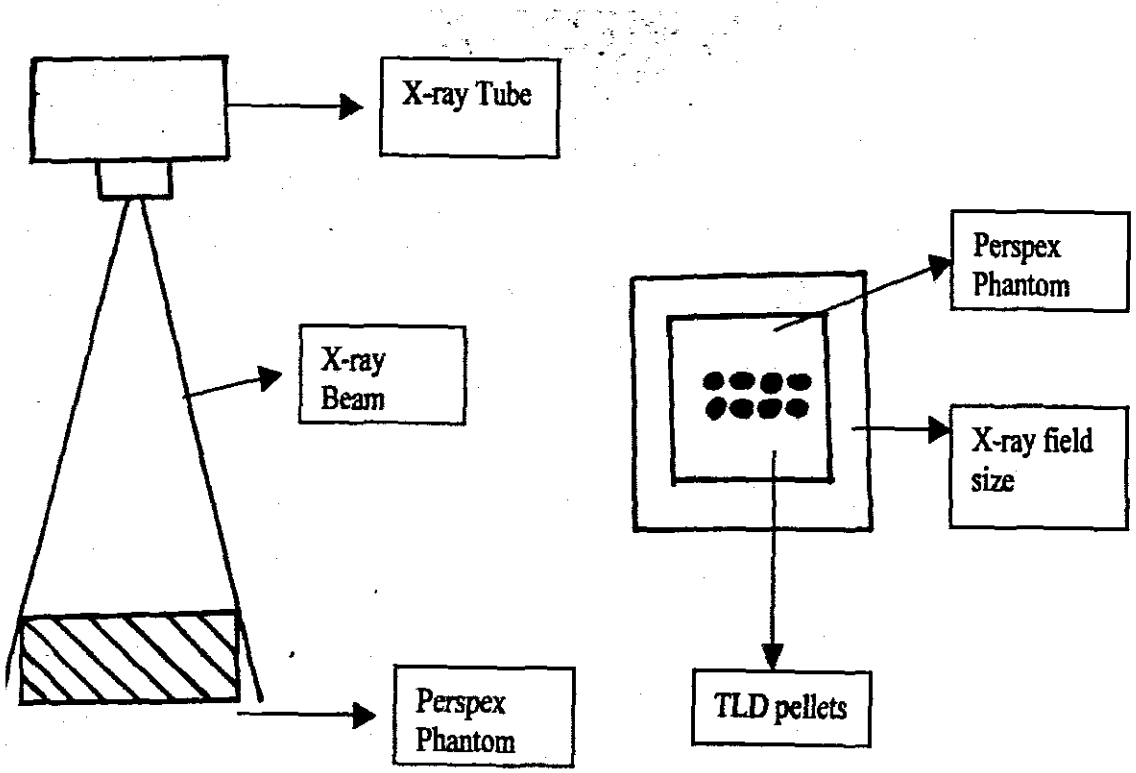


Figure 3.5. A schematic diagram showing the Perspex Phantom and the positioning of the TLD pellets.

After the TLD pellets were exposed to radiation they were heated in a TLD reader. For the purpose of this study a "Toledo" TLD Reader, Model 654, Serial no. 22-5 manufactured by "Vinten" Instruments Limited of Surrey, England was used (See Figure 3.2).

3.3.1 Toledo reader

The irradiated pellets were read using the "Toledo" TLD reader see (Figure 3.2). The light detector was a photomultiplier tube (PMT), which generates a pulse proportional to the light input. The pulse from the PMT is converted into a digital signal. For the calibration and read-out a sensitivity factor of 7000 to the 4^{th} digital point was used. The Toledo reader allows the digital point to be altered thus the assisting the unit to give more accurate readings. The sensitivity factor of 7000/4 refers to the sensitivity of the light measurement system of the TLD reader. This factor was used after repeated attempts at setting the readers sensitivity to read diagnostic radiation dose measurements.

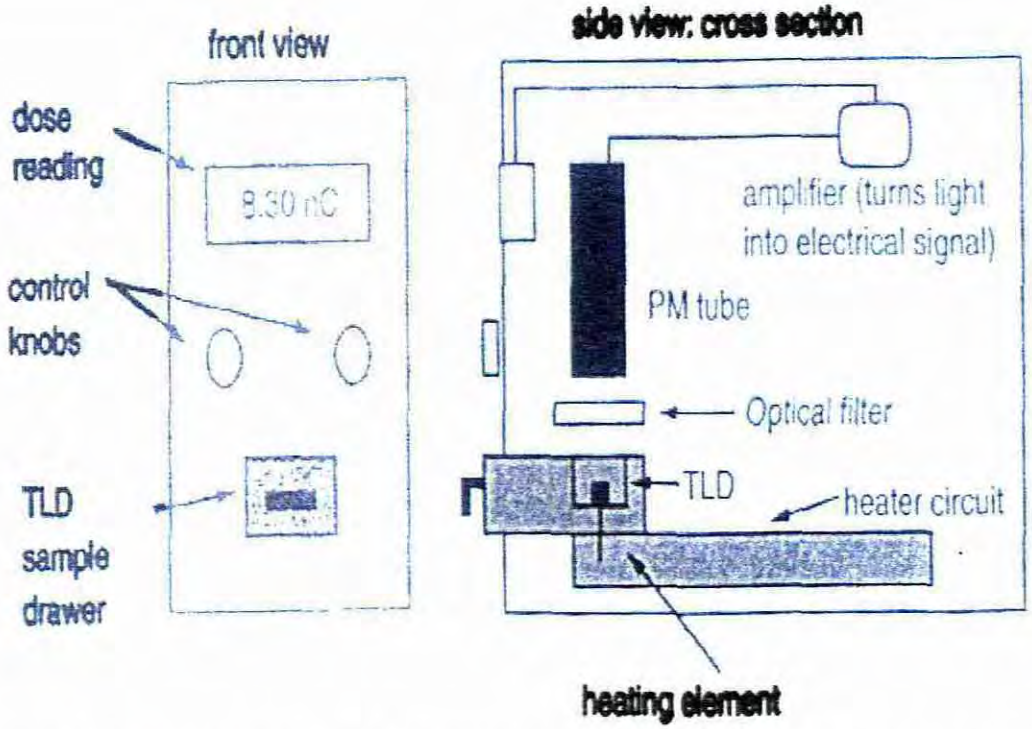


Figure 3.6. Schematic drawing showing the parts within a TLD reader (Stanton & Stinson, 1996).

3.4 The Calibration Factor

Before the dosimeters could be used for measurement, a sensitivity factor for each individual dosimeter had to be determined. This was necessary since the sensitivity varies from pellet to pellet mainly due to variation in the exact amount of phosphor in the specific pellet and its surface characteristics. McKinlay (1981) states "All real crystals contain lattice defects of various kinds and these play and important role in the thermoluminecent process." As shown in Figure 3.7 (b) the lattice defects are shown as squares. The crystal during measurement and the annealing process IS subjected to constantly to variations in temperature, which changes the surface characteristics. This will thus change its calibration factor thus recalibration of sensitivity is necessary in-order to keep pellets readings constant.

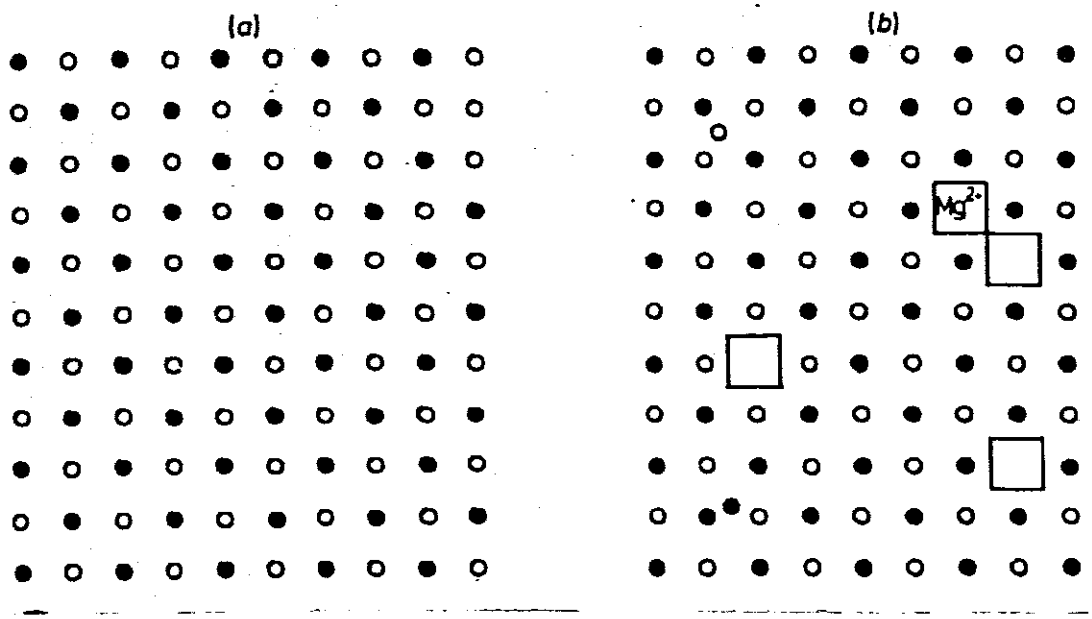


Figure 3.7. Illustrated (a) A perfect crystal structure (b) an imperfect crystal structure or what is also known as a real crystal (Mckinlay, 1981).

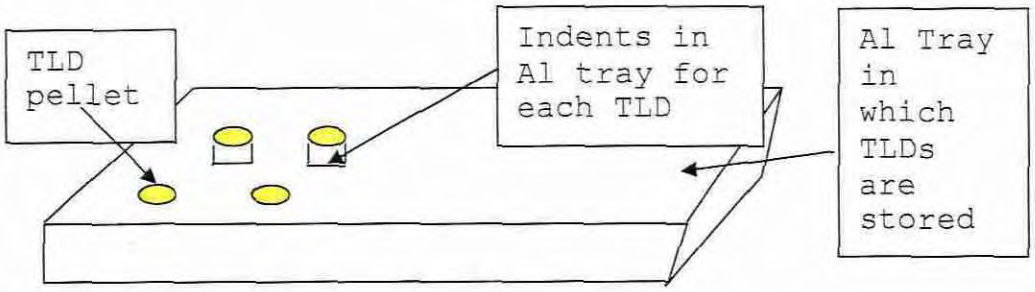


Figure 3.8. Illustration of heating tray with numbered indents.

The first column of 11 TLD's viz. No's 1,11,21, --- 101 were used to get average TLD readings (Eq. 2). This average reading was then used in the equation 3, (p.42) in order to calculate an individual calibration factor for each individual TLD.

$$\mathbf{R} = \frac{R\,1 + R11 + \text{--------} R101}{11} \qquad \text{(Eq. 2)}$$

Where: R = Average TLD reading

R_1-R_{101} = Irradiated TLD readings

11 = Number of TLD's used to calculate average

The sensitivity of each individual pellet is obtained by dividing the TLD reading of the pellet by **R**. Sensitivity $\mathbf{S_i} = \frac{R_i}{R}$ (Eq. 3)

Where: S_i = Sensitivity factor of pellet i

R_i = Individual TLD reading

R = Average TLD reading

S_i corrects the reading subsequently obtained in dose measurement for sensitivity of the pellet by dividing the dose reading by S_i.

The sensitivity factor of each TLD was used together with all TLD Readings.

Table 3.9. A table to illustrate sensitivity factors (F) calibrated for the first set of LiF pellets.

TLD No	1	2	3	4	5	6	7	8	9	10	
1	.07	.857	.714	1.000	.714	1.000	1.000	1.000	.289	.857	10
11		1.000	.714	.714	.429	.714	.714	1.000	1.571	1.000	20
21		1.143	.0857	1.286	.857	1.000	1.143	1.429	1.000	.0857	30
31		1.000	.714	.571	1.286	1.000	1.286	1.000	.714	1.000	40
41		.714	.714	.714	.714	1.714	.857	1.286	.285	1.143	50
51		.714	1.000	.286	.857	.857	.857	.714	.857	.857	60
61		.286	.714	.857	.857	.857	1.143	.857	.714	.714	70
71		1.000	1.143	1.000	1.143	.857	.857	.857	1.286	1.000	80
81		1.143	1.143	1.000	1.286	.857	.857	.857	1.143	1.143	90
91		1.143	.714	1.143	1.143	1.143	1.143	.857	1.143	1.143	100
101		1.143	1.143	.857	1.143	.857	.429	.285	1.286	1.143	110

3.5 The calibration curve

From the sensitivity factor calculations TLD calibration curves could be constructed. This was achieved by the following procedure: A "Diados" electrometer manufactured by PTW Freiburg, (Model: APP, Serial number: 11003-1105,calibration certificate number IEC 61010-1, calibrated 03/02) and ionization chamber (detector number: 1720 12 with calibration certificate number: 02–1698, and model number 60004–1027 CE 0124). The "Diados" was factory calibrated and is traceable to the German Standards Laboratory. It was used to determine the output of the x-ray beam on the phantom surface.

The ionization chamber was set-up on a Perspex block phantom of the following dimensions; surface area 38 X 38 cm^2 and a height of 6 cm. The phantom was positioned at a distance of 100 cm from the x-ray tube with a field size of 10 x 10 cm^2 on the surface of the phantom and the ionisation chamber was placed on the central axis of the beam. See Figure 3.5 for a diagrammatic illustration. The TLD pellets were removed from the surface of the phantom and replaced by the ionisation chamber of the "Diodos". Applied voltages of 40 kV, 50 kV, 60 kV and 70 kV with mAs values of 1.5, 2, 2.5, 5, 10 and 20 respectively were used.

The dose received for each set of parameters was measured by means of the PTW electrometer and the ionization chamber. Four TLD pellets were simultaneously exposed for each set of parameters. The average reading for the four TLD pellets was then calculated. Care was taken to include the sensitivity factor of each pellet within the final reading. This was repeated for each set of exposures.

The average TLD reading was plotted against the mAs value measured using the PTW "Diados" dose meter. The results are shown in Figure 3.10

The average TLD reading measured using measured using the PTW "Diados" dose meter was plotted against the mAs values

The histogram shown in Figure 3.10 is a combination of the calibration curves for the initial TLD calibration. The histogram shows that the fitted lines follow a constant pattern with little or no deviation.

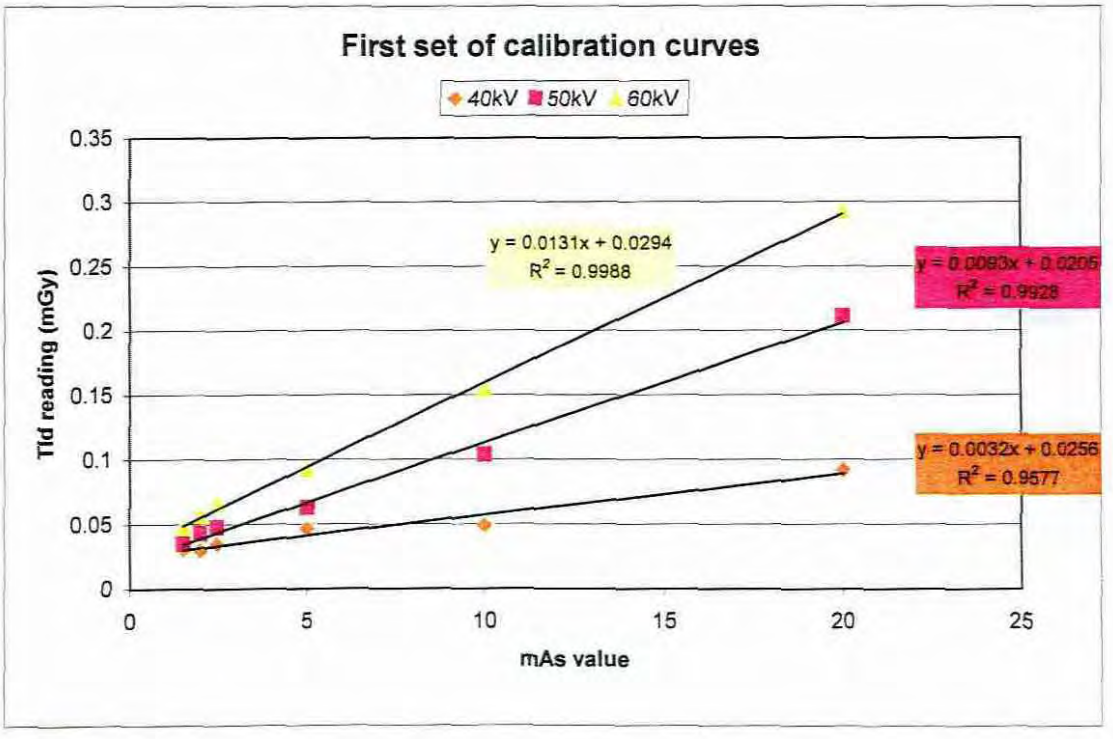


Figure 3.10. A combination of the calibration curves achieved after the first TLD calibrations. Pellets were exposed at 40 kV, 50 kV and 60 kV respectively. The solid lines are the lines fitted through the experimental data points. The equation of the fitted straight line with respective parameter values are shown for each curve.

When continuously subjecting TLD pellets to radiation and heating for the dose readout and then to heating again for annealing and reuse, the TLD pellets tend to loose sensitivity (McKinley 1981). In order to overcome this and to keep sensitivity consistent the pellets are re-calibrated in order to establish new sensitivity factors. The pellets were recalibrated after the first set of testing had been completed. Figure 3.11. shows the calibration curves with solid fitted lines through the experimental points. Calibration had now been repeated for the 2nd time and a calibration curve for 70kV was included. From this histogram the 40 kV curve is illustrated to be considerably lower than those of 50 kV, 60 kV and 70 kV. Thus indicating change in TLD sensitivity.

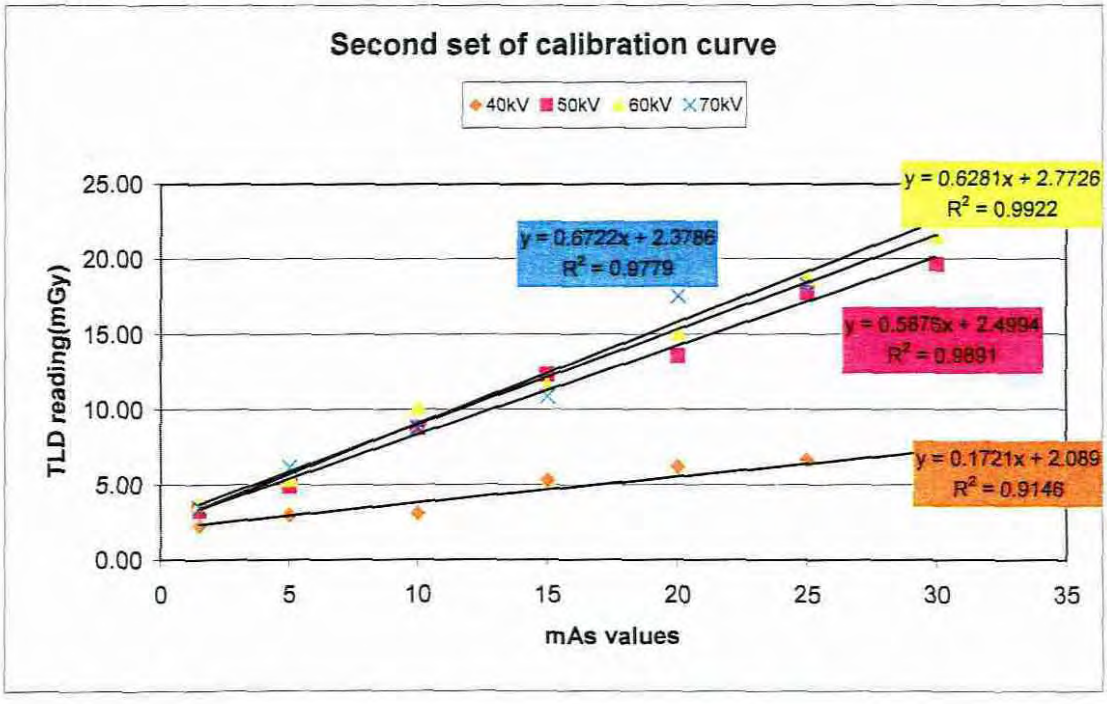


Figure 3.11. A combination of the calibration curves achieved after the second TLD calibrations. Pellets were exposed at 40 kV, 50 kV, 60 kV and 70 kV respectively. The solid lines are the lines fitted through the experimental data points. The equation of the fitted straight line with respective parameter values are shown for each curve.

Testing on patients had now started and after 30 patients had been completed the pellets where again recalibrated. The pellets have now undergone calibration for the 3rd time.

In Figure 3.12 the 3rd set of calibration curves are demonstrated. TLD pellets were calibrated in order to keep sensitivity factors as near as possible to that which was used after the 2nd calibration. The reason is as explained together with the 2nd calibration curve. TLD pellets loose sensitivity with added use.

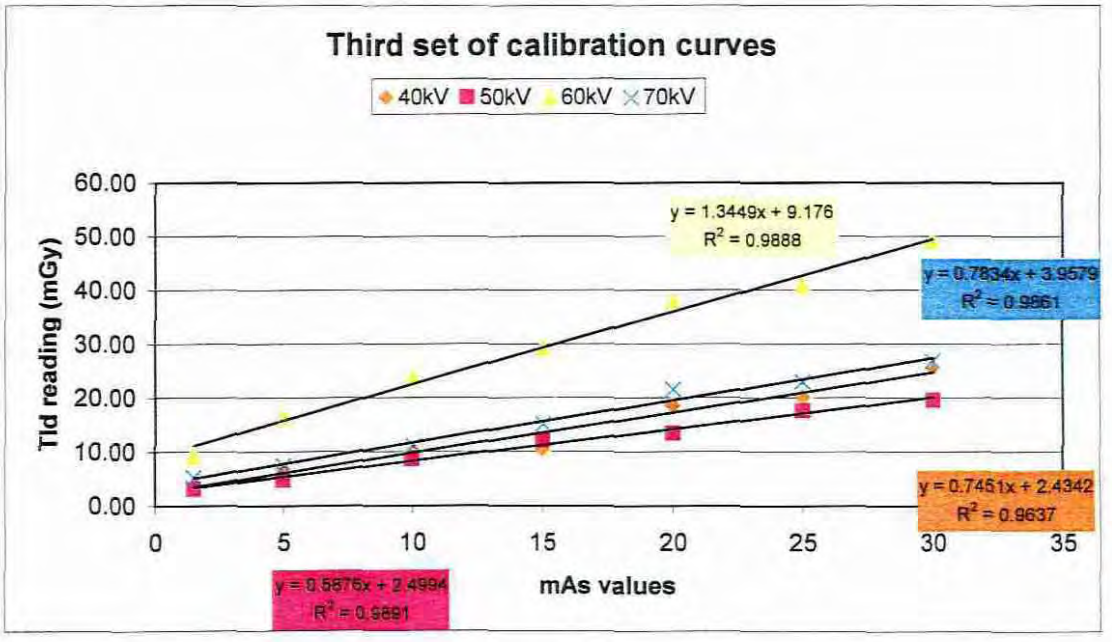


Figure 3.12. A combination of the calibration curves achieved after the third TLD calibrations. Pellets were exposed at 40 kV, 50 kV, 60 kV and 70 kV respectively. The solid lines are the lines fitted through the experimental data points. The equation of the fitted straight line with respective parameter values are shown

The sensitivity changes are again show however this time the 70 kV curve appears more sensitive than those of the other kVs plotted.

McKinlay states "when constantly subjecting TLD pellets to radiation and heating for dose readout and then to heating again for annealing and reuse the Pellets loose sensitivity".

Testing on patients had now started and after 30 patients had been completed the pellets where again recalibrated. The pellets have now undergone calibration for the 3rd time. In figure 3.12 the 3rd set of calibration curves are demonstrated. TLD pellets were calibrated in order to keep sensitivity factors as near as possible to that which was used after the 1st and 2nd calibration. The reason is as explained together with the 2nd calibration curve. TLD pellets loose sensitivity with added use. The equation of the fitted straight line with the respective parameter values are shown for each curve.

3.6 Primary Data

After completion of the TLD calibrations, measurements on patients commenced. It was decided firstly to do a test experiment using TLD pellets. The TLD pellets were checked for sensitivity by making use of a test experiment. The method is outlined below.

The experiment was done in the paediatric x-ray room in the Radiology Department at Tygerberg Hospital. A three phase x-ray generator with an over couch x-ray tube was used. The tube was positioned central to a Perspex phantom with the dimensions 38 cm x 38 cm, 6 cm high at a surface to focus distance (SFD) of 100 cm. The radiation field was collimated to cover an area of 15 cm x 15 cm. The exposure was made at a voltage of 50 kVp and mAs of 2.5 with added filtration of 0.5 mm Al. The placement of the pellets is graphically shown in Figure 3.13.

A summary of the surface doses measured using TLD pellets are indicated in Table 3.14. The experiment was done to see if the TLD pellets would read radiation dose at low radiation levels. Only one pellet was placed at each marked point and the surface dose (mGy) measured.

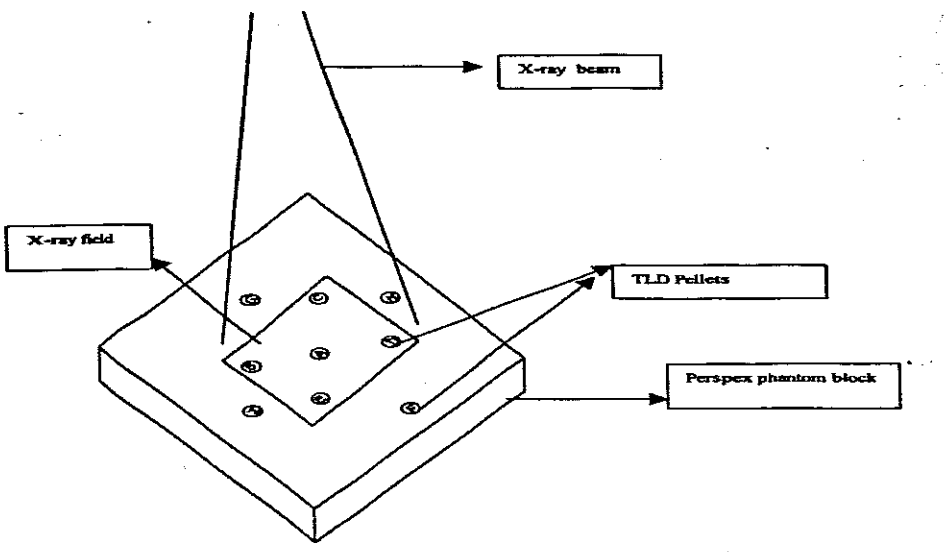


Figure 3.13. Schematic drawing of TLD pellet placements.

Table 3.14. Tabulation of the absorbed dose results.

TLD position	Surface dose (mGy)	Comment
A	0.055	At point of entry
B	0.050	At edge of radiation field
C	0.050	At edge of radiation field
D	0.045	At edge of radiation field
E	0.045	At edge of radiation field
F	0.020	5 cm outside of radiation field
G	0.030	5 cm outside of radiation field
H	0.035	5 cm outside of radiation field
I	0.030	5 cm outside of radiation field

The TLD results tabulated in Table 3.14 give a clear indication that the TLD was sensitive enough to read diagnostic radiation doses at low radiation levels. Furthermore, the experiment also demonstrated that the pellets where sensitive enough to pick up scatter radiation. This experiment thus assisted me in testing the TLD pellets for calibration levels and sensitivity to diagnostic doses.

TLD measurements was then performed on actual patients as follows:
The patient was positioned in the Antero-posterior (AP) position either sitting in the erect (upright) position against the x-ray cassette holder or lying supine in the specially designed child, restraining device similar to that pictured in Figure 3.15.

Anteria-posteria views were done with the patient facing the x-ray tube. The radiographer immobilised the patient with immobilisation devices available in the x-ray room.

The radiographer placed Lead rubber (Pb) protection on the gonad area of the patient. A film focus distance (FFD) of 100cm was used.

Eight TLD pellets in separate plastic protective bags were positioned on the patient's skin, at the point of entry of the radiation beam on the central axis. With all parameters checked and the patient reassured the exposure switch was depressed allowing the radiation exposure. See placement of TLD pellets for the AP. chest view in Figure 3.16.

This procedure was repeated for the lateral view of the chest; care was however taken to remove the first set of TLD pellets from the anterior of the patients' chest. A new set of 8 TLD pellets in separate plastic coverings was placed on the patients' skin, secured with adhesive tape at the entrance point of the Lateral chest view. See placement of TLD pellets for the lateral chest view in Figure 3.17.

Figure 3.15. Immobilization chair similar to that used at Tygerberg hospital (NRPC Report No.68, 1980).

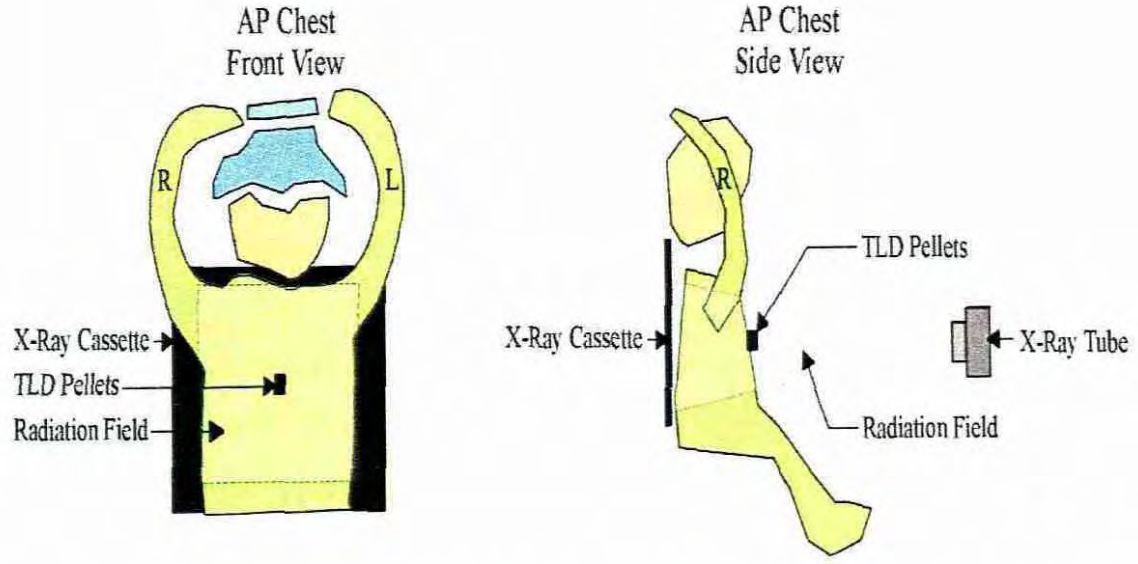


Figure 3.16. Schematic representation of the placement of TLD pellets for the AP. chest view.

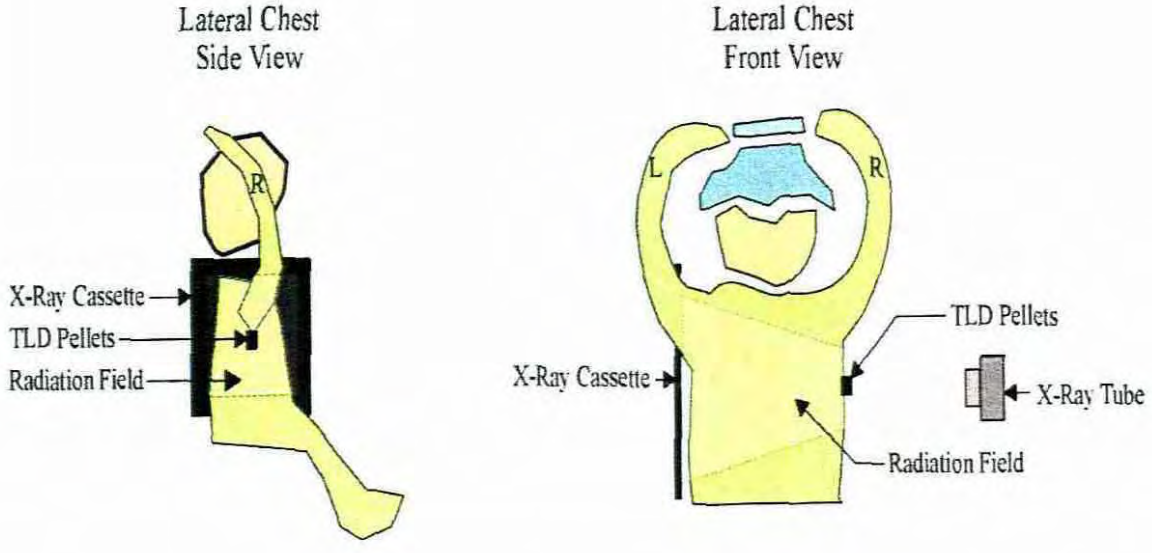


Figure 3.17. Schematic representation of the placement of TLD pellets for the lateral chest view.

Once both the required exposures were completed and the radiographer entered exposure parameters and data required on the patient information form. A sample of the form is demonstrated in Appendix 5.

The exposed TLD pellets where stored away from any further radiation sources. Pellets were kept in their protective bags and only removed from these coverings in the dosimetry laboratory of the Medical Physics department at Tygerberg Hospital. A total of 6 patients were measured at each session and a total of 16 pellets from both views were read for each patient. The read out time after each session was kept at a constant 30 minutes after the measuring session taking into account that TLD sensitivity fades with time. McGee et al., 1993 did investigation into TLD fade and he said "pellets not used for a long time (more than a month) demonstrate a degraded response".

On removal of the protective covering each pellet was individually placed in the TLD reader, where it was heated and the photomultiplier tube was able to read the amount of light it emitted. From the values read off the TLD reader the absorbed dose (D), received by the patient was calculated by using the equation 4.

$$D = \frac{R-B}{A} \qquad \text{(Eq.4)}$$

Where: R = Average TLD reading

A = Slope of calibration curve

B = Intersect on calibration curve

The Effective Dose (E), was calculated by multiplying the absorbed dose (D), by a conversion coefficient(C):

$$\mathbf{E} = D \, X \, C \ (mSv) \qquad \text{(Eq.5)}$$

Where: E - Effective Dose

D - Absorbed Dose

C - Conversion coefficient

The conversion coefficients were obtained from the Publication NRPB-R279 (Hart et al 1996), Given in Table 3.18.

Table 3.18. Conversion coefficients used to calculate effective dose (Courtesy of Hart, 1996).

Age (yrs.)	kV	Filtration (mm Al)	AP Chest	Lat. Chest
0	50	2.5	1.590	1.180
	60	2.5	1.790	1.365
1	50	2.5	0.131	0.087
	60	2.5	0.146	0.101
5	50	2.5	0.120	0.071
	60	2.5	0.138	0.084
	70	2.5	0.152	0.099
10	50	2.5	0.249	0.139
	60	2.5	0.298	0.180
	70	2.5	0.339	0.209

Table 3.19 shows the parameters required to calculate results. Reasons for the low exposure parameters of 50kV and 1.6mAs, was to see if TLD pellets where sensitive to low exposures of radiation and 50 kV and 1.6mAs was the lowest values that could be set. However a bigger field size was used as apposed to the calibration in order to simulate a typical patient set up. The change in field size was not investigated.

Table 3.19. Parameters required too calculate Effective Dose.

View	AP. Chest
Tube potential	50 kV
Tube current / time	1.6 mAs
A	0.0093
B	0.0205
R	TLD reading
FFD (cm)	100
Field size (cm^2)	15 cm × 15 cm

In Table 3.20 the results of an Anterior posterior (AP) chest exposure done on a simulation of a patient, illustrating the calculation procedure described above.

Table 3.20. Example of TLD readings and the calculations of Absorbed dose (mGy) and Effective dose (mSv).

TLD	Reading (R)(mGy)	Sensitivity Factor (F)	R/F	Mean Corrected Reading	SDEV.	CV
73	0.080	1.200	0.06	0.058	0.008	14
74	0.060	1.000	0.060			
75	0.070	1.143	0.061			
76	0.050	0.891	0.056			
77	0.060	0.891	0.067			
78	0.040	0.892	0.045			
79	0.80	1.290	0.062			
80	0.050	1.050	0.048			

$$D = \frac{0.059 - 0.0204}{0.0093}$$

Absorbed Dose: *4.032 mGy*

: $E = 4.0321 \times 0.120$

Effective Dose *0.48 mSv*

With the parameters listed in Table 3.18 the TLD mean reading for the Absorbed Dose (D) was calculated to be 4.032 mGy and the Effective dose was calculated by multiplying the absorbed dose by the conversion coefficient (see Table 3.20). An AP Chest for a 5 year old the conversion coefficient is 0.120 thus we calculated an effective dose of 0.48 mSv.

3.6.1. Re-calibration of TLD Pellets

It was mentioned in earlier (Chapter 3) that due to the composition of Lithium Fluoride the TLD pellet had to be re-calibrated after frequent use in order to maintain its maximum sensitivity. As the pellets were being frequently used and also at times subjected to a higher radiation dose. It was thus fitting to anneal them and re-calibrate sooner. Thus the 4^{th} set of calibrations where done after a further 20 patients had been exposed. Figure 3.21 demonstrated graphical representations of data plotted after the 4^{th} calibration of TLD pellets was successfully completed. We see a change in the slope of the curve, suggesting that TLD pellets also loose sensitivity with repeated use.

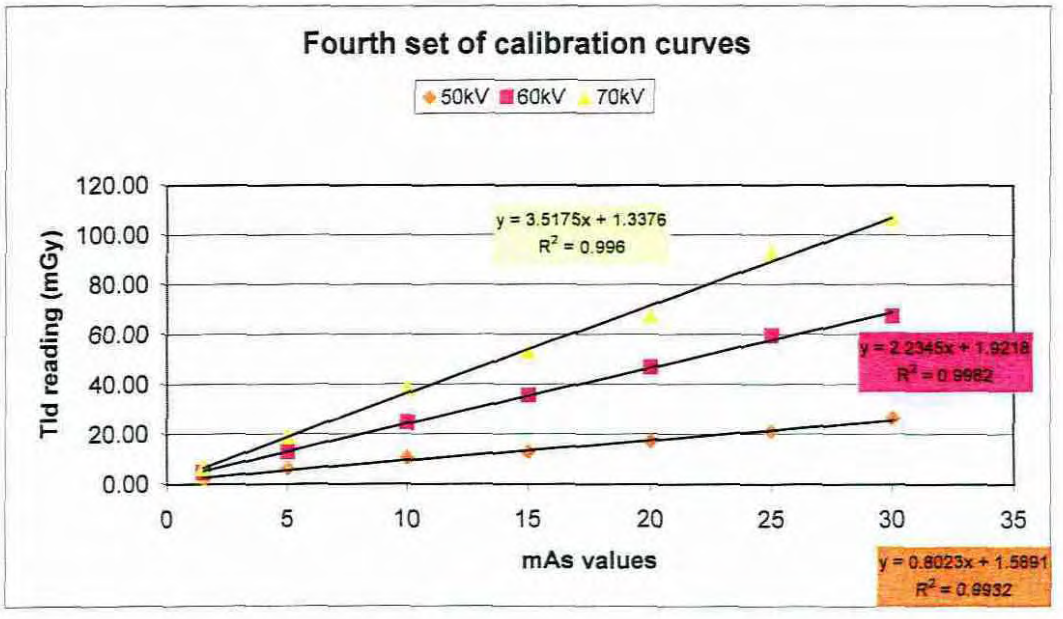


Figure 3.21. A combination of the calibration curves achieved after the fourth TLD calibrations. Pellets were exposed at 50 kV, 60 kV and 70kV respectively. The solid lines are the lines fitted through the experimental data points. The equation of the fitted straight line with respective parameter values are shown.

Chapter 4

Experiments

4.1 Introduction

A review of the literature indicates that radiation technicians do not vary filtration settings and they use only exposure parameters documented on technique charts. A technique chart is a set of exposure parameters and factors relevant to a certain area of the body. Radiographers use technique charts as guides as to which x-ray parameters to use (Bushong, 1997).

A study by Bushong (1997) indicates that radiation equipment was placed into service at the lowest allowed added filtration of 2,5 mm Al. Radiographic technique charts are formulated at this filter position. If different filter thicknesses are used new technique charts should be developed. This may therefore explain why radiation workers are reluctant to use different filter settings. It was decided that the possibility of added filtration should be investigated as this could influence patient radiation dose. Department of Health regulation is for kV up to and including 70 kV, the addition filtration should not exceed 1.5mm Al.

The question was asked, whether filtration of the x-ray beam, influences the resultant radiation dose the patient receives. Leading from the above it was also questioned whether additional Aluminium (Al) filtration over and above the standard filtration of all x-ray units, influences the dose of radiation to the patient? Are there any density changes in the final radiographic image?

The researcher thus undertook to do the experiments which are explained below.

4.2. Experiment 1

Effects of Filtration on Radiation doses.

4.2.1 Purpose of experiment

The Purpose was to test whether the radiation dose measured after exposure changes with a change in the filtration of the x-ray beam.

4.2.2 Materials and Methods

Equipment used included a Philips three-phase x-ray generator; model SUPER 80 CP (serial number 863267) installed at the diagnostic x-ray suite in the Gene Louw building, Tygerberg Hospital. A "PTW" x-ray dose meter and ionisation chamber, reading in mGy at a high range setting was used to measure radiation dose from the exposures made. The ionisation chamber was positioned on a polystyrene phantom block with dimensions of 38 cm x 38 cm x 6 cm high. The field size of the x-ray beam used was 10 cm x 10 cm at an FFD equalling 100 cm.

In this experiment the filtration settings were changed and the radiation dose measured. The experiment was performed as follows: The phantom with the above dimensions, was positioned on the x-ray couch. The ionisation chamber was positioned in the centre of the surface of the phantom, with this surface at an SFD of 100 cm. The collimator was adjusted to 10 cm x 10 cm field size. Radiation dose readings were taken at 45 kV, 50 kV, 60 kV and 70 kV and at 1.6, 2.5, 10, 15, 20 mAs for each kV setting. The filtration wheel was set to 1mm added Al, which is the amount of filtration normally used when x-raying patients at Tygerberg Hospital.

The above measurements were repeated with the filtration wheel changed to read 2 mm added filtration. The results of the measurements are summarised and tabulated in Table 4.1 and graphically represented in Figure 4.2.

4.2.3 Results

Table 4.1 shows the measured surface dose (mGy) received with 1 mm Al added filtration. Table 4.2 and shows a decrease in the dose to the phantom with increase in the added filtration from 1 to 2 mm Al. Figure 4.3 is a histogram of the dose differences. The dose decrease with increased filtration is observed for every kV range selected. The histogram shows smooth curves with no overlapping for each parameter measured, suggesting the absence of scatter and the clear changes with increase of kV and filtration indicates that the uncertainties in measurements are insignificant. Table 4.4 gives an indication of the percentage reduction in dose that is achieved with the increase in filtration of the x-ray beam.

Table 4.1. A tabulation of surface dose (mGy) received with 1 mm Al added filtration.

	Measured surface dose (mGy) with 1 mm Al filtration			
mAs	**45kV**	**50kV**	**60kV**	**70kV**
1.6	0.020	0.024	0.040	0.060
2.0	0.028	0.032	0.052	0.076
5.0	0.044	0.068	0.116	0.188
10.0	0.096	0.148	0.228	0.372
15.0	0.144	0.220	0.340	0.564
20.0	0.188	0.300	0.448	0.740

Table 4.2. A tabulation of Doses received with 2 mm Al added filtration.

	Measured surface dose(mGy) with 2 mm Al filtration			
mAs	**45kV**	**50kV**	**60kV**	**70kV**
1.6	0.012	0.016	0.032	0.052
2.0	0.016	0.020	0.036	0.068
5.0	0.032	0.048	0.084	0.148
10.0	0.068	0.104	0.172	0.298
15.0	0.096	0.160	0.256	0.444
20.0	0.132	0.212	0.344	0.588

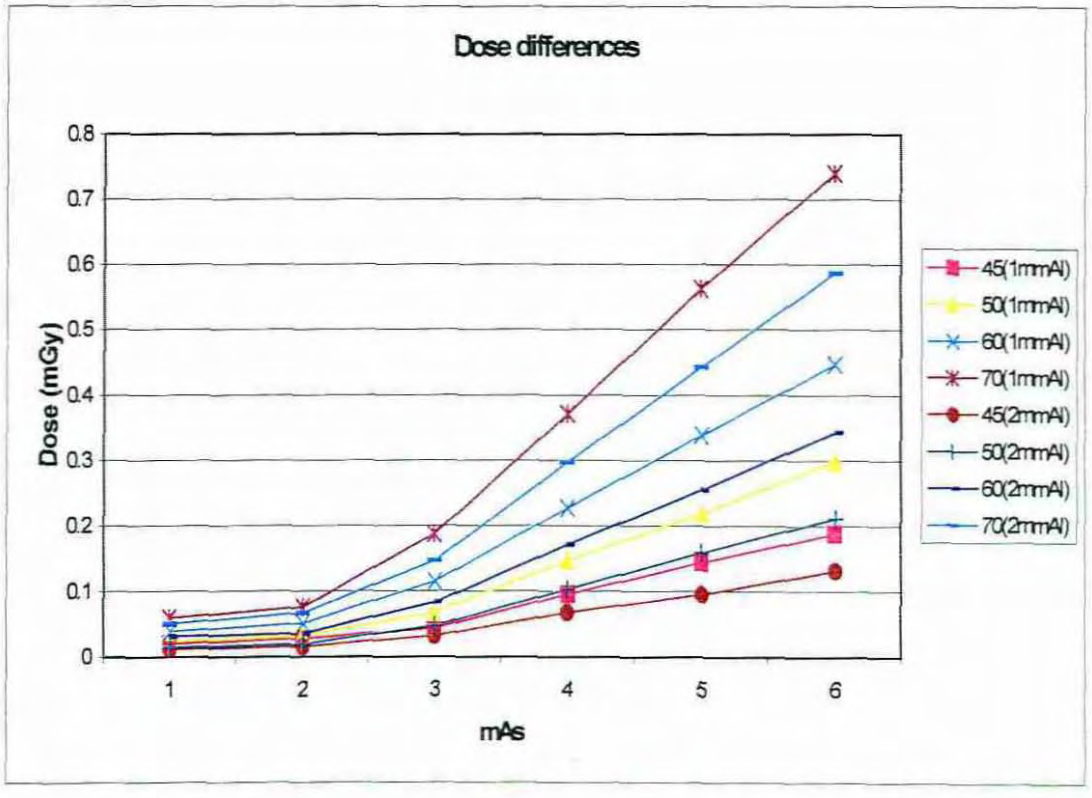


Figure 4.3. Graphical representation of doses received.

Table 4.4. A tabulation of the Percentage Decrease in Dose with the increase in filtration (all values are percentage).

	% Decrease in Surface dose (mGy) if 2 mm Al filtration is used .			
mAs	**45kV (%)**	**50kV (%)**	**60kV (%)**	**70kV (%)**
1.6	40	33	20	13
2.0	43	38	30	11
5.0	27	29	28	21
10.0	29	30	25	20
15.0	33	27	25	18
20.0	30	29	23	21

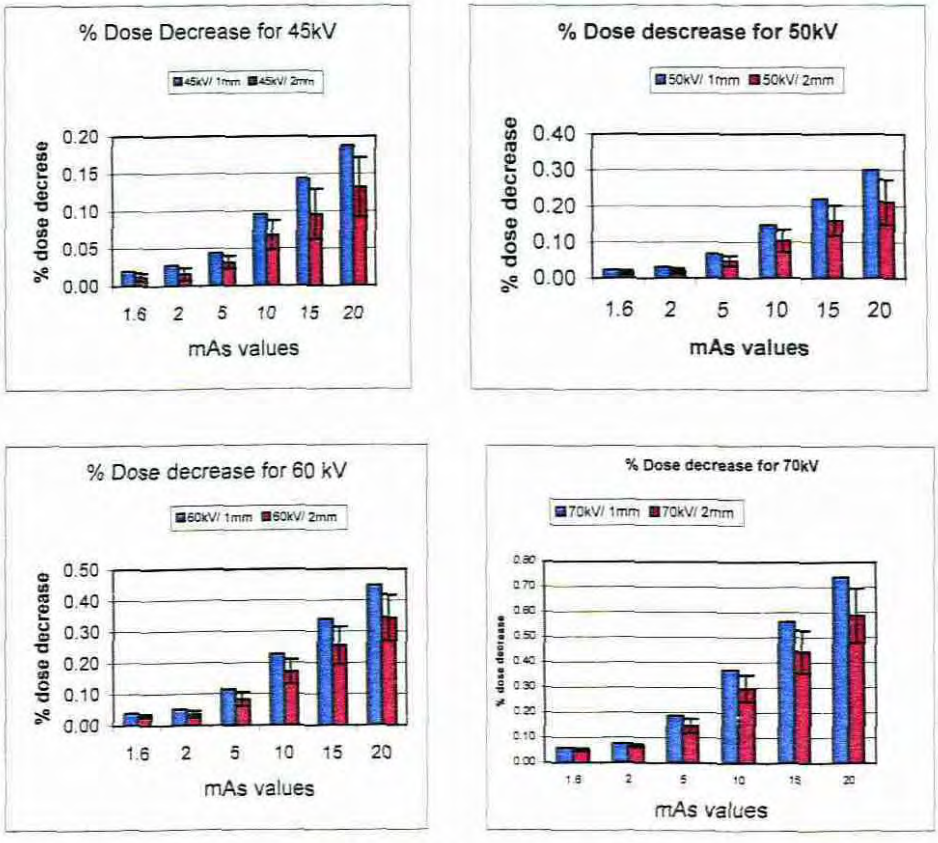


Figure 4.5. Demonstrates the % dose reduction achieved with an increase in filtration and also the standard deviation.

Figure 4.5 is a histogram of the percentage dose reduction achieved with an increase of Al filtration. Example: for the exposure parameters of 50kV and 5 mAs and added filtration of 2 mm Al there was a reduction of up to 29% in dose as apposed to using the same parameters with an added filtration of only 1 mm Al.

The experiment was repeated with TLD pellets as detectors and the results are indicated in Figure 4.6. These results also indicate a reduction to phantom dose with an increase in filtration. For an exposure of 50 kV and 5 mAs with 2 mm Al added filtration a decrease in dose measured with TLD pellets was 9%. This could be attributed to the high variation of 14% that seen with TLD dose calibrations.

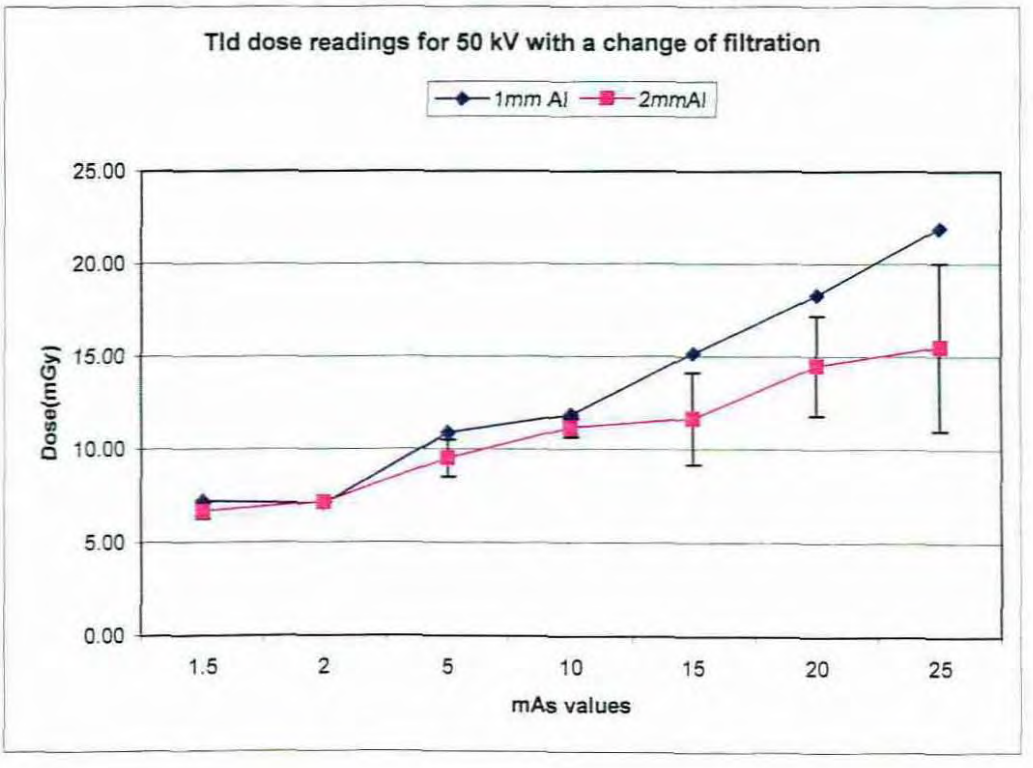


Figure 4.6. Absorbed dose (mGy) readings measured with TLD pellets.

4.3 Experiment 2

Density and Filtration

4.3.1 Purpose of experiment

The results of experiment 1 showed that with the added filtration to the x-ray beam the dose to the patient is decreased (Mooney & Thomas, 1998). The next question to answer would be whether an increase in the beam filtration would influence the film density of the resulting x-ray image.

4.3.2 Method

The same x-ray parameters as for experiment 1 were used.
Films used were blue sensitive "Agfa" 400 speed with quanta fast detail screens irradiated at 50kV and the following mAs values: 1.6, 2, 2.5, 5, 10, 15, and 20 mAs. The added filtration used was 1 mm Al.

A second set of x-ray films was irradiated, using the same exposure parameters but with the filtration wheel setting changed to 2 mm Al.

Film density readings were done using a Digital Densitometer II, model 07-424 I manufactured by "Victoreen" instruments. Densities were read at 5 positions within the 10 cm x 10 cm irradiated area of the x-ray film The same positions where used when reading each film which was reproducible to within a millimetre of each other. An average reading was calculated for each radiograph.

4.3.3 Results

From the tabulated results of dose readings appearing in Table 4.7 a reduction in dose with added filtration is observed. However Table 4.8 shows minimal changes in film density with change in filtration from 1 mm Al to 2 mm Al. There was however an exception with the parameters of 50 kV, 2 mm Al and 5 mAs, where the film was

fogged. The fogged film was only discovered when density readings where taken and thus could not be repeated. Figure 4.9 graphically represents the above results.

However all other density differences were below 3% thus indicating that doubling the filtration will not substantially influence the image quality but will however filter the soft rays which influences the radiation dose received. Thus the resultant entrance surface dose (ESD) with an increase in the filtration will be lower but there will not be a noticeable difference in the image quality achieved on the resultant radiograph.

Table 4.7. Table of Absorbed dose (mGy) and density reading with 1 mm Al and 2 mm Al.

mAs	Absorbed dose (mGy)	Absorbed dose (mGy)	Density	Density
	50kV + 1mm Al	50kV + 2mm Al	50kV + 1mm Al	50kV + 2mm Al
1.6	0.024	0.016	2.462	2.494
2.0	0.032	0.020	2.692	2.698
5.0	0.068	0.048	2.974	2.896
10.0	0.148	0.104	2.984	2.990
15.0	0.220	0.160	3.000	3.016
20.0	0.300	0.212	3.020	3.042

Table 4.8. Table of % Dose reduction and % of density increase with 2 mm Al added filtration.

mAs	% Dose reduction	% Density increase
1.6	33	1
2.0	38	0
5.0	29	-3
10.0	30	0
15.0	27	0
20.0	29	1

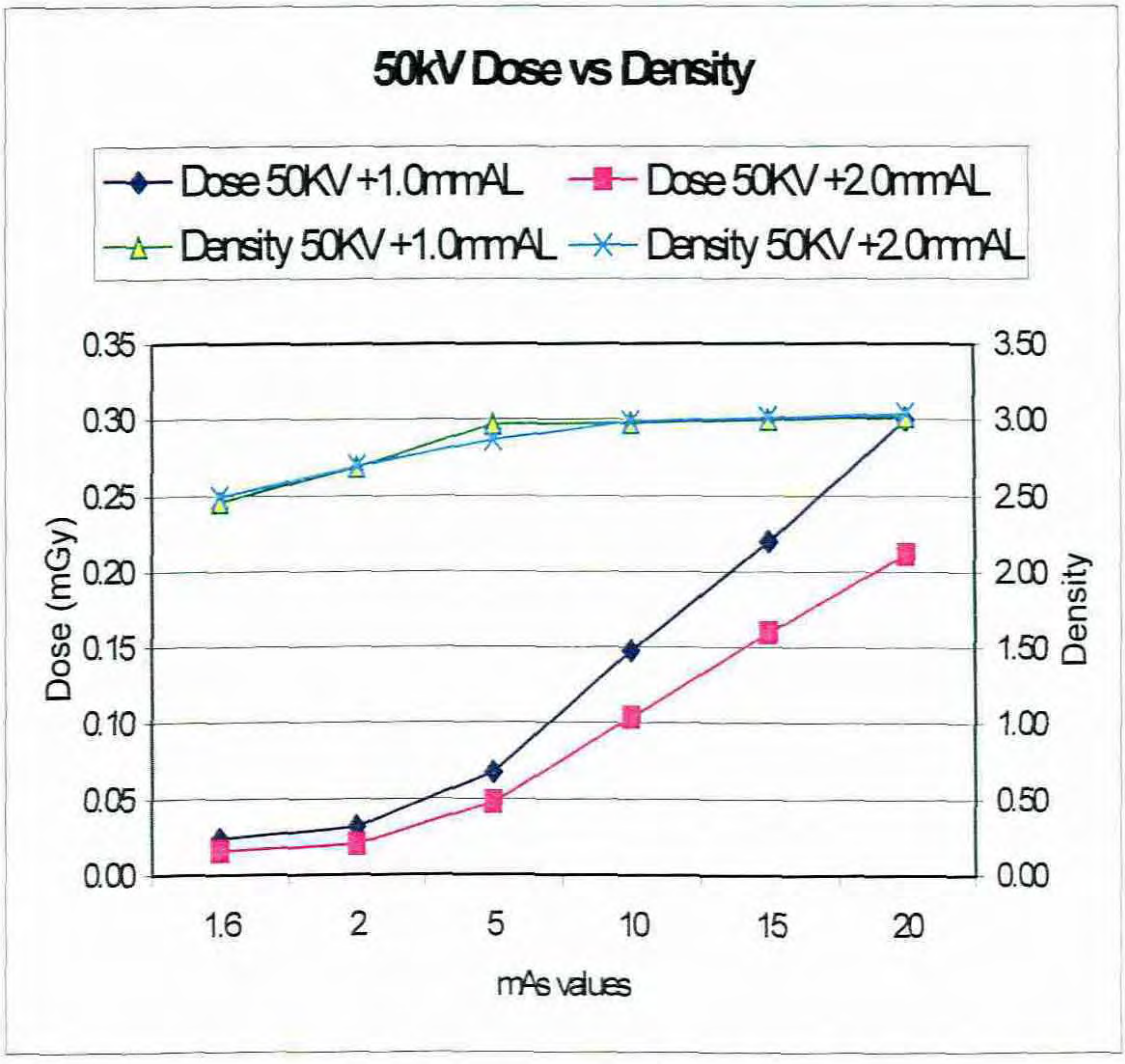


Figure 4.9. Graphical representation of the results from table 4.7 & 4.8.

Experiment 3

4.4 Paediatric x-ray room

All measurements were done on the x-ray unit that was used to irradiate the majority of children visiting Tygerberg hospital. The x-ray generator is a three-phase generator made by "Shimadzu", model UD 150 B-10 with serial number 0262235106.

The x-ray tube is suspended from the ceiling. On investigation of the filtration possibilities it was found that only 0.5 mm Al was used as added filtration when irradiating children in this particular x-ray facility. The Department of Health regulation is for up to and including 70kV not more than 1.5 mm Al should be used.

It was then undertaken to test the filtration capabilities as done before. However minor changes had to be incorporated into the testing procedure due to differences in construction features between the "Philips" and the "Shimadzu" x-ray tube assemblies. The differences are tabulated in Table 4.10.

Table 4.10. The machine differences used in experiment 3.

X-ray Apparatus	Tube mounting	Filter construction	Available Filter settings
Philips 3-phase, 12-pulse	Ceiling suspended	Filter wheel	1 mm Al 2 mm Al 1 mm + 1 mm Cu
Shimadzu 3-phase, 12-pulse	Ceiling suspended	Filter Slot	0.5 mm Al

The "Philips" ceiling suspended x-ray tube, has a filter wheel built into the tube housing, for changing filter settings ranging from 1 mm Al, 2 mm Al and 1 mm Al + 1 mm Cu (Figure 4.11). The "Shimadzu" tube assembly has a slot for Aluminium filters (Figure 4.12,) of which only 0,5 mm Al was available. Thus when higher filtration was required separate Al filter plates of 0.5 mm Al thicknesses were stuck to the beam collimator housing. This was done to see if there were density changes.

Figure 4.11. Photograph demonstrates a Philips x-ray unit with filter wheel (Bushong, 1993).

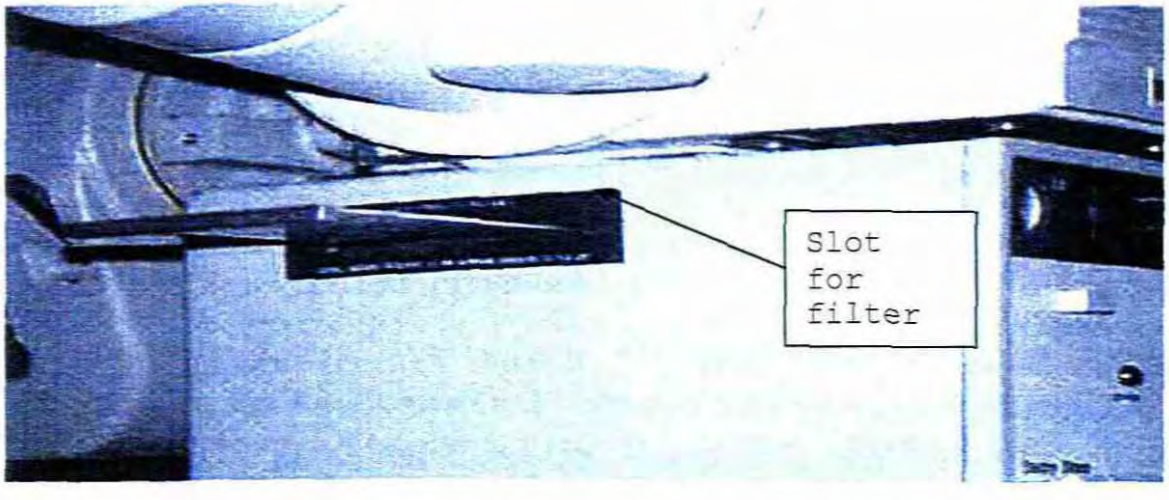


Figure 4.12. Photograph demonstrates a Shimadzu x-ray unit with slot in filter (Bushong, 1993).

4.4.1 Method

Films were irradiated using 50 kV with mAs values 1.6, 2, 2.5, 3.2, 4, & 5 and 0.5 mm Al filtration. These exposures were repeated keeping parameters the same but adding another 0.5 mm Al. Absorbed dose reading and density readings were again obtained and plotted graphically as before. The results are presented below in Table 4.13 and Figure 4.14.

4.4.2 Results

As represented in Figures 4.15 and 4.16, for increased filtration a reduction in dose is observed. This correlates to the tests on the "Philips" x-ray unit. The density of the resultant image is greater indicating that with an increase in filtration, lower exposure parameters can be used which in turn will result in lowering of the ESD to patients.

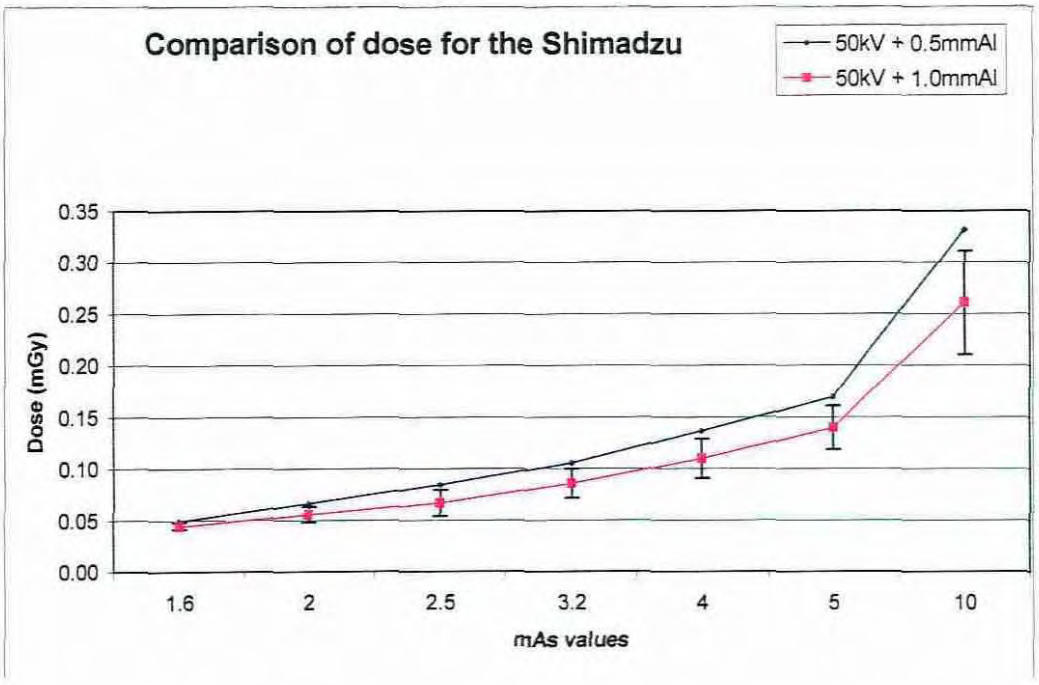
A similar tendency was observed when the measurements were repeated for tube voltages of 60 kV. The similarities are shown in Table 4.17 and Figure 4.18.

Mooney et al., (1998), in a study to reduce paediatric dose also investigated increasing added filtration to the x-ray beam. Mooney et al., as in the study at Tygerberg Hospital, discovered that an increase in filtration reduced the ESD. They introduced 3 mm Al for a pelvic x-ray and found the ESD to be reduced by 38%. At Tygerberg Hospital for exposure factors of 60 kV and 3.2 mAs there is a reduction in absorbed dose of 18% if the filtration is increased from 1mmAl to 2mmAl. The image quality remained as with 1 mm Al.

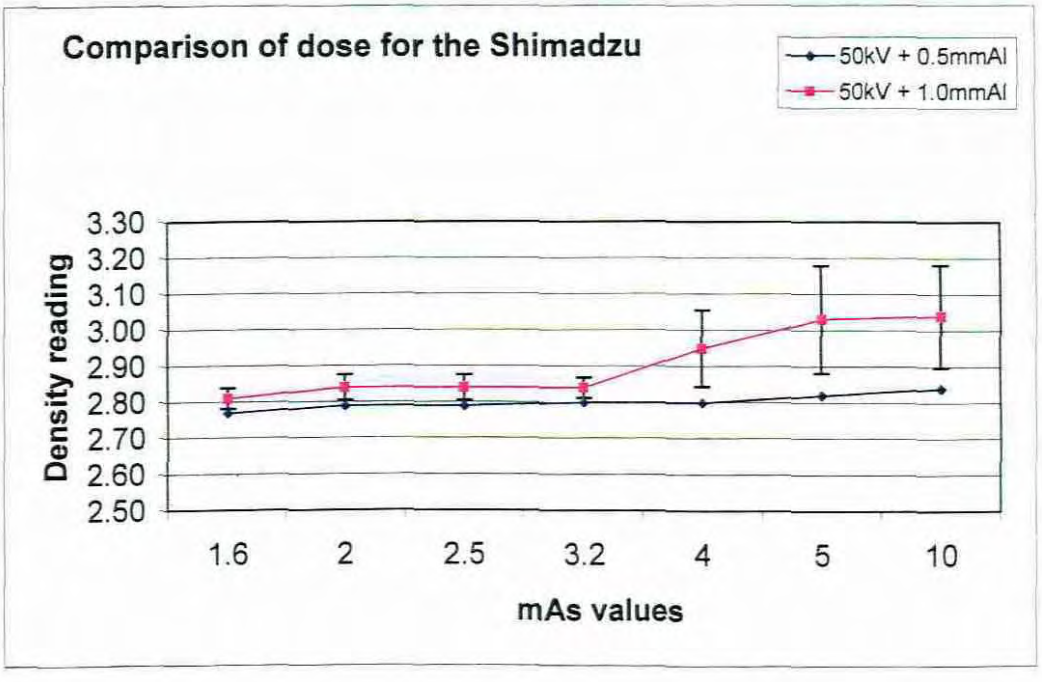
The current study as well as the study of Mooney & Thomas, (1998), shows that increasing the added Al filtration on the x-ray tube can significantly reduce the dose to infants during radiography. Care must however be taken when increasing filtration as an increase in the filtration may shorten the life span of the tube. Table 4.19 and Figure 4.20 compares the decrease in absorbed dose in comparison with density increase of the x-ray image (mGy) at Tygerberg Hospital.

Table 4.13. A table showing Absorbed dose (mGy) vs Density for 50kV for the Shimadzu x-ray unit.

mAs	Absorbed dose (mGy) 50kV + 0.5mm Al	Absorbed dose (mGy) 50kV + 1mm Al	Density 50kV + 0.5mm Al	Density 50kV +1mm Al
1.6	0.050	0.045	2.77	2.81
2.0	0.067	0.056	2.79	2.84
2.5	0.085	0.067	2.79	2.84
3.2	0.106	0.086	2.80	2.84
4.0	0.137	0.110	2.80	2.95
5.0	0.170	0.140	2.82	3.03
10.0	0.332	0.261	2.84	3.04



(a) Absorbed dose (mGy) at 50 kV



(b) Density at 50kV

Figure 4.14 (a & b). Graphical representation of Dose and Density at 50kV.

Table 4.15. Table of the comparison of the reduction in Dose (mGy) vs the increase in density of the x-ray image with an increase in filtration.

mAs	% Absorbed dose reduction	% Density increase
1.6	10	1
2.0	16	2
2.5	21	2
3.2	19	1
4.0	20	5
5.0	18	7
10.0	21	7

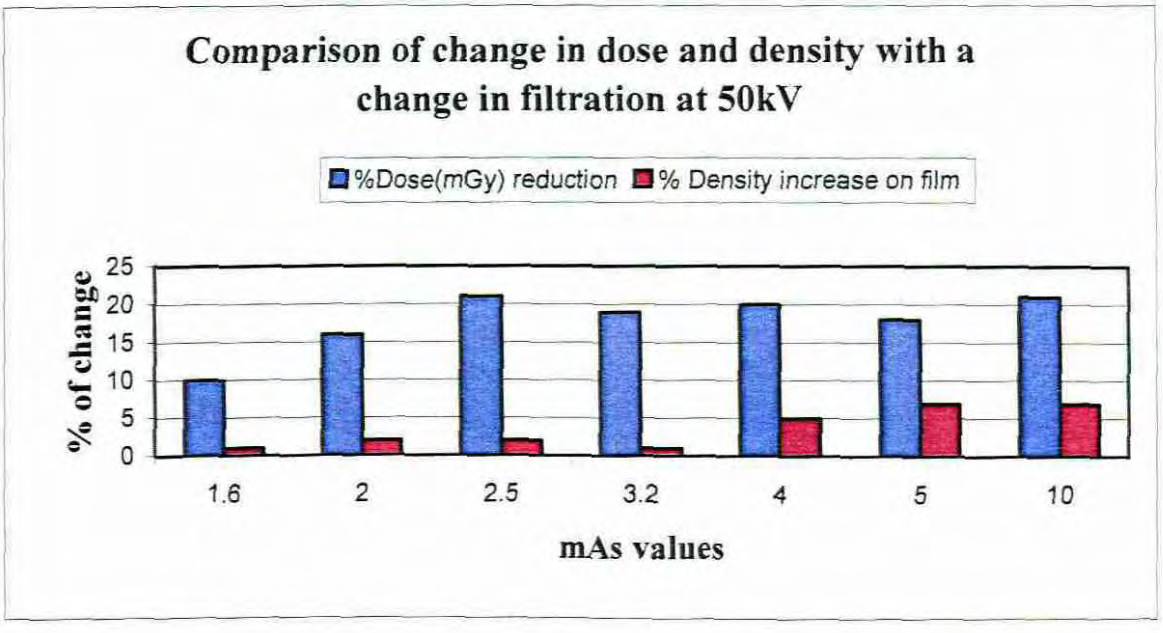
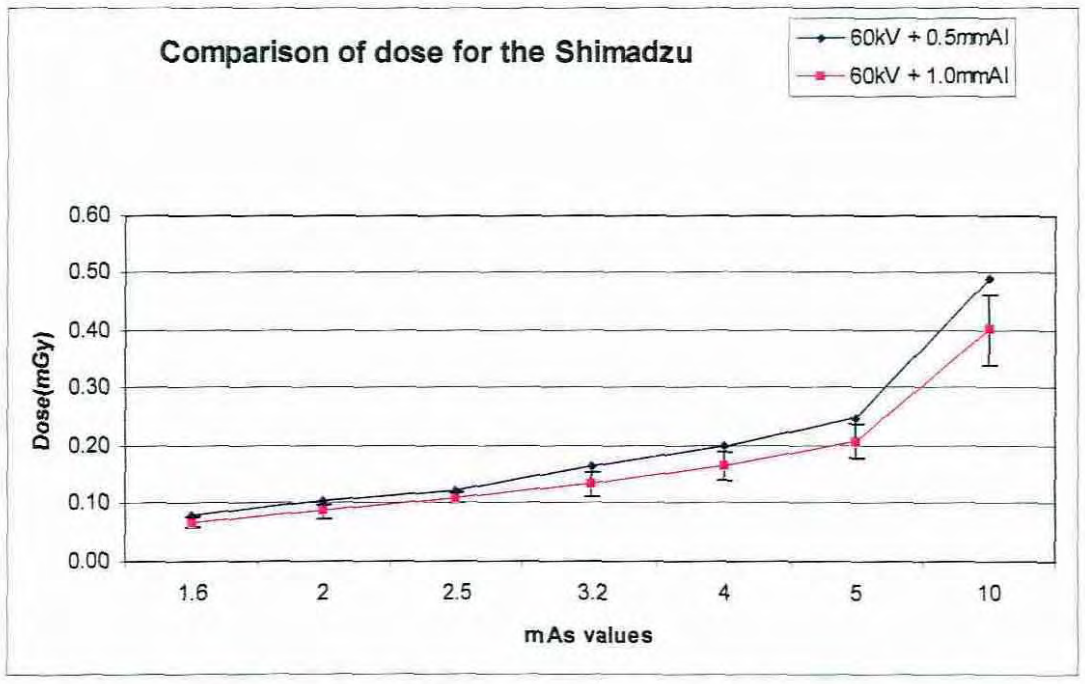


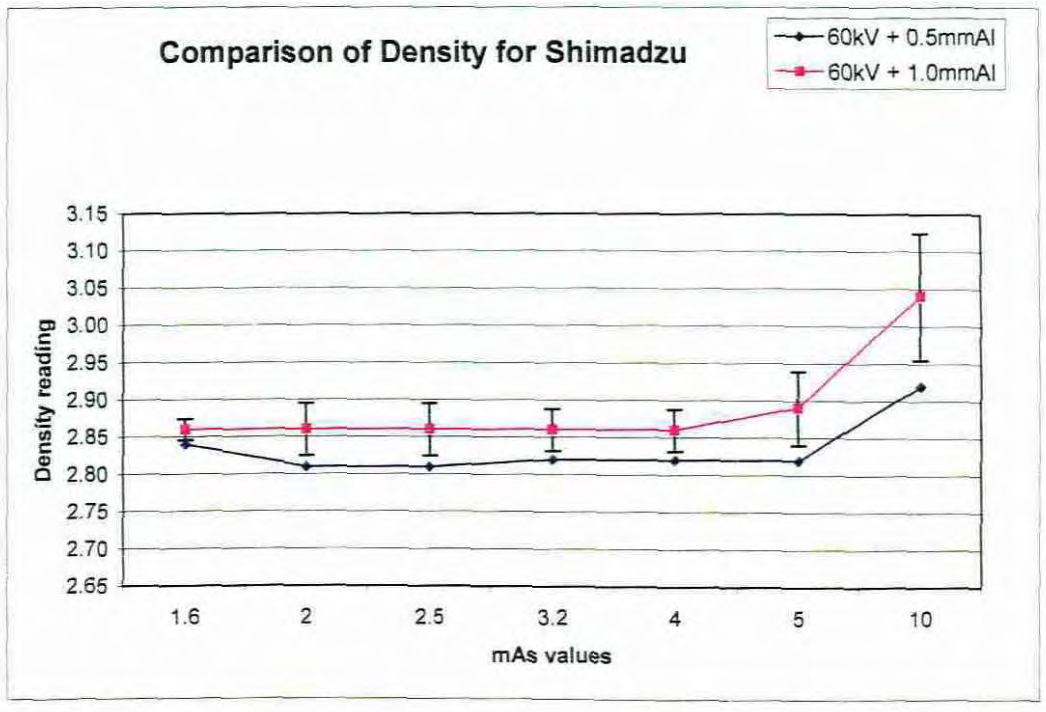
Figure 4.16. Comparison of the change in dose (mGy) and the film density with a change in filtration at 50kV.

Table 4.17. A table of Absorbed dose vs Density for 60kV at Shimadzu x-ray unit.

mAs	Absorbed dose (mGy) 60kV + 0.5mm Al	Absorbed dose (mGy) 60kV + 1mm Al	Density 60kV + 0.5mm Al	Density 60kV +1mm Al
1.6	0.080	0.068	2.84	2.86
2.0	0.104	0.086	2.81	2.86
2.5	0.124	0.110	2.81	2.86
3.2	0.164	0.134	2.82	2.86
4.0	0.200	0.166	2.82	2.86
5.0	0.249	0.208	2.82	2.89
10.0	0.490	0.402	2.92	3.04



(a) Dose at 60 kV



(b) Density at 60 kV

Figure 4.18 (a & b). Graphical representation of (a) Dose and (b) Density at 60kV.

Table 4.19. Table of the comparison of the reduction in Absorbed dose (mGy) vs. the increase in density of the x-ray image with an increase in filtration.

mAs	% Absorbed dose reduction	% Density increase
1.6	15	1
2.0	17	2
2.5	11	2
3.2	18	1
4.0	17	1
5.0	16	2
10.0	18	4

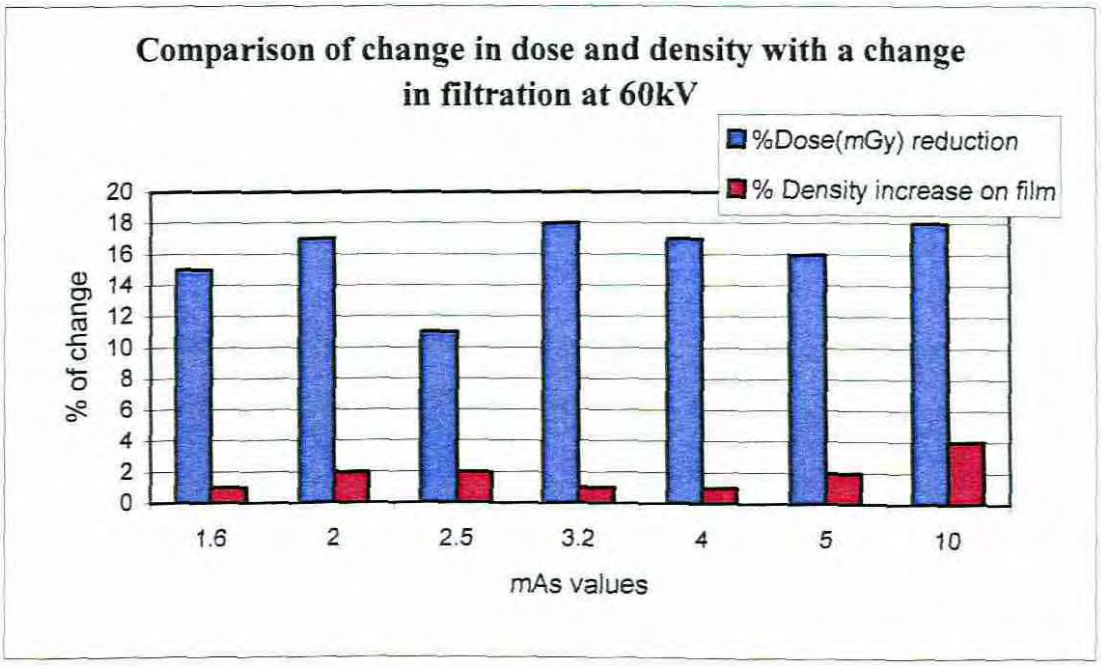


Figure 4.20. Histogram of the comparison of in Dose reduction vs. the density increase of the x-ray image with an increase of filtration.

Chapter 5

Results and Discussion

5.1 Entrance Surface Dose (ESD) Range

In order of the objectives of the research the results of the study conducted at Tygerberg hospital are reported. The results are for ESD readings for a total of 67 paediatric patients with a total of 134 x-ray views of the chest.

On consultation of the radiology department at Tygerberg Hospital, departmental statistical data (2001-2002), it was found that the chest x-ray was the examination most commonly done on children. Scheider et al., (1998), in the publication "Dose values for paediatric radiography" also reported that the chest x-ray was the most common radiographic examination performed on children. The study at Tygerberg Hospital focused on ESD measurements of the Paediatric chest.

The children were divided into three age groups, namely 0-1 yr., 1-5 yrs and 5-10 yrs. The distribution of patients in each age group is indicated in Table 5.1.

Table 5.1. Distribution of patients in each age group at Tygerberg Hospital
Key: yrs: years, AP.: Anterior- posteria, Lat.: Lateral

Age group (yrs.)	Chest (AP.)	Chest (Lat.)
< 1	17	17
1 - 5	32	32
5 - 10	18	18
Total	**67**	**67**

The AP chest view was the examination of choice, as most children under the age of 3 years did not sit still and where restrained in a baby-restraining device. The child was either x-rayed supine or erect, always facing the x-ray tube. For the lateral view the child was again restrained and turned with the left lateral side of the chest in contact with the x-ray cassette. No grid was used. Most children between 4 and 5 years did not stand still and were thus positioned sitting facing the x-ray tube.

The rest of the children could understand instructions and all other chest x-rays were done with the child standing and facing the x-ray tube (AP) and standing for the left sided lateral view as well.

The results of this study indicate good correlation with the literature. The similarity in number is demonstrated in Table 5.2. Comparison was made, concerning patient numbers and distributions with the studies of (Ogudae et al., 2004) of the University of Ibiden, Nigeria and (Mooney & Thomas, 1998) of the Royal Belfast Hospital who both did similar studies for their respective countries. Sample numbers of the United Kingdom and the UNSCEAR groups are not compared in Table 5.3 as the size of groups are not listed in these publications. Comparison of mean ESD of Tygerberg Hospital is also made the with mean ESD reading of studies done in the United Kingdom and the mean ESD values of the UNSCEAR group.

It is important to remember that no two sets of published data will agree exactly. This is due to different film screen combinations, different equipment and different radiographic techniques. Our study confirms this and it is also confirmed in the publication "Radiation dose in Diagnostic Radiology" produced and distributed by the Royal Prince Alfred Hospital, Australia. They state "it is important to note that dose calculation is an estimate only with a wide range of accuracy".

However, it is vitally important for diagnostic departments to have a good idea of the dose(s) that they render to patients. Dose indicators and reference levels can also serve as a means of reducing high radiation doses to patients. Individual diagnostic radiation doses are not high but numerous radiographs and scans which patients receive cause the radiographic dose received by the patient and public pool to accumulate. This could have long term damaging effects for generations to come.

Table 5.2. Comparison of the distribution of patients measured in the three countries listed.

Country	Age group (yrs.)	Sample size
Tygerberg Hospital	**< 1**	**17**
South Africa	**1 - 5**	**32**
(Current study).	**5 - 10**	**18**
Ireland	< 1	16
Mooney *& Thomas*,1998	1 - 5	16
	5 - 10	30
Nigeria	< 1	30
Ogundare *et al.*,2004	1 - 5	30
	5 - 10	21

ESD measurements for the AP chest was the only view compared. The reason being in literature consulted it was the only view for which ESD's were reported.(Mooney & Thomas,1998),(Ogundare *et al.*,2004).

In Table 5.3 the ESD results of AP chest and the range is tabulated. The table indicates that the mean ESD range in the age group < 1 year at Tygerberg Hospital is in the range of (0.05-0.091 mGy) this compares favourably with studies conducted in Ireland for the same age group where the range is (0.040 - 0.100 mGy). United Kingdom studies only give a mean ESD of 0.090 mGy which still falls with in the two ranges discussed above. However Table 5.3 shows the Nigerian ESD range for the same age to be (0.200 - 0.500mGy), which is much higher than other studies compared in Table 5.3. Comparative results for other age groups also appear in Table 5..3.

Table 5.3. Comparison of mean ESD measurements for the AP chest view.

Country	Age group (yrs.)	Mean ESD (mGy)	ESD range (mGy)
Tygerberg Hospital South Africa (Current study).	**< 1**	**0.070**	**0.05-0.09**
	1 - 5	**0.072**	**0.05-0.09**
	5 - 10	**0.065**	**0.04-0.09**
Ireland Mooney & Thomas, 1998	< 1	0.060	0.04-0.10
	1 - 5	0.053	0.03-0.12
	5 - 10	0.054	0.03-0.09
Nigeria Ogundare *et al.*, 2004	< 1	0.350	0.20-0.50
	1 - 5	0.520	0.05-0.10
	5 - 10	0.490	0.28-0.70
United Kingdom Mooney & Thomas, 1998	< 1	0.090	
	1 - 5	0.090	
	5 - 10	0.060	
UNSCEAR 2000 Ogundare *et al.*, 2004	< 1	0.020	
	1 - 5	0.030	
	5 - 10	0.040	

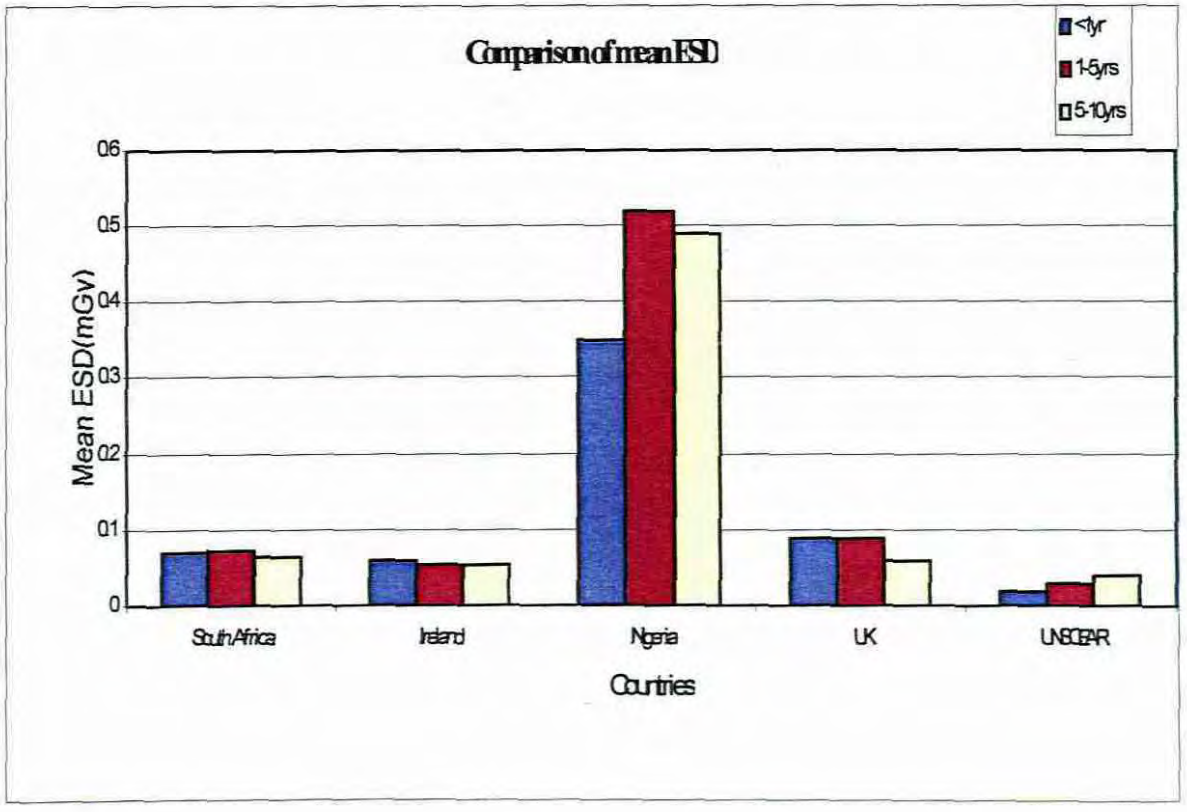


Figure 5.4. Histogram showing mean ESD comparison.

The Histograms in Figures 5.4 shows the mean ESD values of all groups. As demonstrated South Africa, unlike Nigeria, compares favourable with Ireland, the United Kingdom and the UNSCEAR group ESD measurements. Ogundare *et al.*, 2004 cite the increased dose readings in Nigeria are due to the use of inappropriate parameters, lack of information on recent developments in the field of radiology coupled with the non-availability of Nigerian national guidance criteria that can serve as a guide for radiographers may be responsible for the use of inappropriate techniques. They also refer to the contribution of low kVs and high mAs and low filtration as a reason for the high doses reported in their work (Ogundare *et al.*,2004)..

In the study at Tygerberg Hospital ESD measurements were done for the lateral chest. However there was no international work to compare them with. The lateral chest results will be discussed further on in the study.

In the study at Tygerberg Hospital ESD measurements were done for the lateral chest. However there was no international work to compare them with. The lateral chest results will be discussed further on in the study.

5.1.1. ESD Range at Tygerberg Hospital

Table 5.5 and Figure 5.6 (a, b & c) demonstrates the mean ESD results of the AP and lateral chest measured at Tygerberg Hospital. The range is tabulated. The lateral chest dose is higher for all age groups. For example, for the age group 1-5 years there is the mean kV increase from 51 to 57 (12%) and the mAs values from 1.6 to 2.3 (43%). The mean dose for the AP chest is 0.072 mGy and the lateral chest 0.090 mGy which is an increase of 25%. The histograms of Figure 5.6 show each individual age groups mean ESD the standard deviation with in each group is demonstrated.

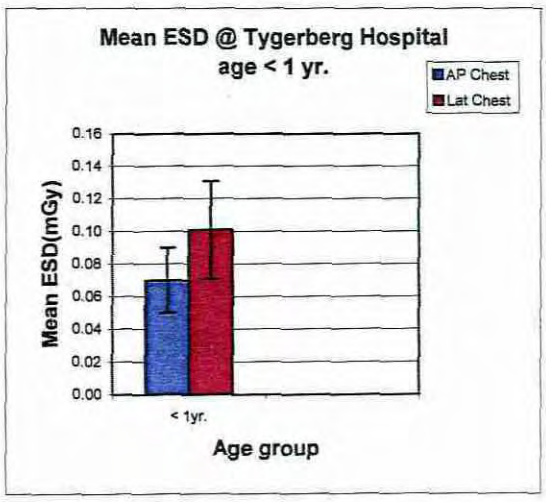
Table 5.5. A tabulation of the ESD measurements for Tygerberg Hospital .

Key:

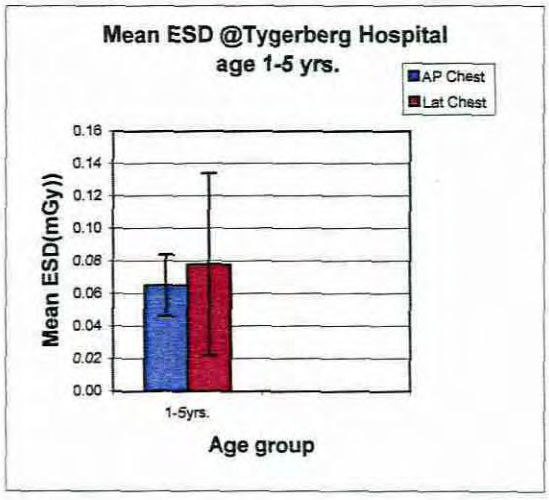
AP = Anterior-posteria

Lat. = Lateral

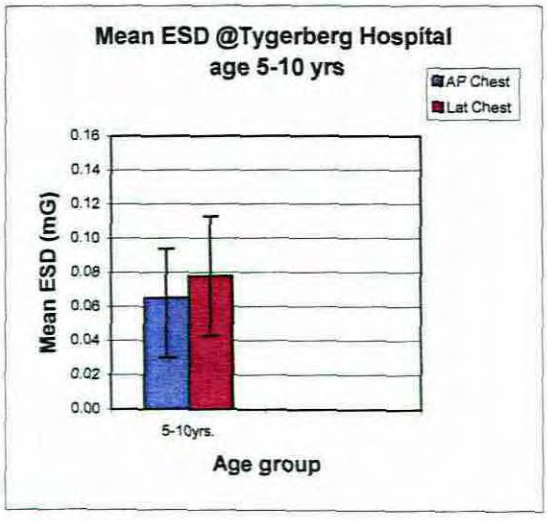
Exam.	View	Age group (yrs.)	Mean kVp	Mean mAs	Mean ESD (mGy)	ESD Range (mGy)
Chest	AP.	< 1	49	1.6	0.070	0.050-0.091
	Lat.	< 1	54	1.8	0.101	0.071-0.132
Chest	AP.	1-5	51	1.8	0.072	0.530-0.091
	Lat.	1-5	57	2.3	0.090	0.034-0.146
Chest	AP.	5-10	56	2.0	0.065	0.036-0.094
	Lat.	5-10	63	2.3	0.078	0.043-0.113



(a) Age group < 1 yr.



(b) Age group 1 - 5 yrs.



(c) Age group 5 - 10 yrs.

Figure 5.6 (a, b & c). Mean ESD measurements at Tygerberg Hospital.

5.2 Organ dose

Here I have used of the "Childdose" computer program, written by Le Heron (1996), of the National Radiation Laboratory New Zealand. This program enables the calculation of organ doses and dose indices for paediatric radiographic projections and examinations using Monte Carlo calculations. The software package was developed at the National Radiological protection Board in the UK. "Childdose" uses 5 sets of data files for children of ages 0, 1, 5, 10 and 15 years respectively.

Table 5.7 is an example of a typical set of output data for a 5-year-old. The first set of output data (A) gives the age of the child, the projection, the kVp, filtration, incident radiation and the frequency of the projection. The data is followed by organ doses in milligray(mGy) for the 13 organs with IRCP specified weighting factors, 10 remainder organs and 6 additional organs or body regions, and the effective dose equivalent for each projection.

The second set of output data (B) is for the complete examination of a child of a specific age. The first column is of organs or tissues with IRCP 60 specified tissue-weighting factors. The second column gives the organ doses for the IRCP 60 specified remainder organs, The third column gives additional organs of interest (Le Heron, 1996). This data set gives individual doses for the organs mentioned and then indicates the average dose that the remaining organs receive and then also gives indication of the average total body dose.

The third set of output data (C) presents dose indices, effective dose and effective dose equivalents for the complete examination.

Table 5.7. A sample of the "Childdose" printout for 2 projections of the chest.

ORGAN DOSE & DOSE CALCULATED USING NRPB-SR270 MONTE CARLO DATA.

(A)

	Mean organ dose (mGy) for a child of 5 yrs.	
	Chest (AP)	**Chest (Lat.)**
kVp	53	63
Filtration mm Al	2.50	2.50
Filtration mm Cu	0.00	0.00
Incident radiation	0.07 mGy	0.08 mGy
Projection frequency	1	1
Adrenals	0.004	0.008
Brain	0.000	0.000
Breasts	0.051	0.025
Eye lens	0.000	0.000
G bladder	0.006	0.003
Stomach	0.015	0.002
Small int.	0.000	0.000
ULI	0.001	0.001
LLI	0.000	0.000
Heart	0.028	0.012
Kidneys	0.002	0.003
Liver	0.014	0.016
Lungs	0.023	0.022
Ovaries	0.000	0.000
Pancreas	0.011	0.005
Shin	0.006	0.007
Spleen	0.006	0.002
Testis	0.000	0.000
Thymus	0.042	0.011
Thyroid	0.003	0.002
U bladder	0.000	0.000
Uterus	0.00	0.000
Oesophagus	0.009	0.012
Muscle	0.005	0.004
Head reg.	0.000	0.000
Trunk reg.	0.011	0.009
Leg reg.	0.000	0.000
Tot. bone	0.012	0.011
RBM	0.003	0.003
Effective dose	0.009	0.006
Eff. Dose equiv.	0.016	0.010

(B). Total mean Organ dose (mGy) for chest x-ray of a 5yr. old child.

IRCP Organs	Dose (mGy)	Remainder Organs	Dose (mGy)	Other Organs	Dose (mGy)
Ovaries	0.000	Brain	0.001	Eye lens	0.000
Testis	0.000	Thymus	0.053	Heart	0.040
Lungs	0.045	Adrenals	0.012	G bladder	0.009
Stomach	0.018	Pancreas	0.016	Head Reg.	0.001
LLI	0.000	Spleen	0.008	Trunk Reg.	0.021
RBM	0.006	Kidneys	0.005	Leg Reg.	0.000
Thyroid	0.005	Small int.	0.001		
Breast	0.075	ULI	0.001		
Esophagus	0.021	Uterus	0.000		
Liver	0.031	Muscle	0.001		
U bladder	0.000				
Skin	0.012				
Tot. bone	0.022	Average Rem.	0.002	Ave. Tot. Body	0.003

(C).

DOSE INDEX	ICRP 60	ICRP 26
E or ESD (mSv)	0.015	0.026
Remainder (mSv)	0.000	0.008
Remainder organs used	Mean rem.	Thymus Liver Stomach Pancreas Adrenals

NB*. ESD was calculated using a mass weighted mean remainder and a greater than test on the highest remainder organ dose.

5.2.1. Organ dose range for Tygerberg Hospital

In Table 5.8 a tabulation of the absorbed doses per age group for the eyes, heart, liver, thyroid and genitals is presented. These absorbed dose measurements where measured at Tygerberg Hospital. This was achieved by measuring the ESD using TLD pellets. The effective dose was calculated as explained in Chapter 3. The effective dose was entered into the "Childdose" programme which, by using Monte Carlo calculations, calculates the absorbed dose for each organ. In Table 5.8 no distinction is made as to gender of the child.

Table 5.9 and Figure 5.10 illustrates the absorbed dose for children in the 0 - 1 year age group. The dose results are tabulated for gender x-ray view for the following organs: eyes, heart, liver, thyroid and genitals. The dose ranges for both views of the chest is tabulated for the above- mentioned organs.

Table 5.11 and Figure 5.12 illustrates the absorbed dose for children aged 1 - 5 year age group. The dose results are tabulated for gender, x-ray view and for the following organs: eyes, heart, liver, thyroid and genitals.

Table 5.13 and Figure 5.14 give the values of absorbed dose for children in the 5 - 10 year age group. The dose results are tabulated for gender, x-ray view AP chest and the lateral view, for the following organs: eyes, heart, liver, thyroid and genitals.

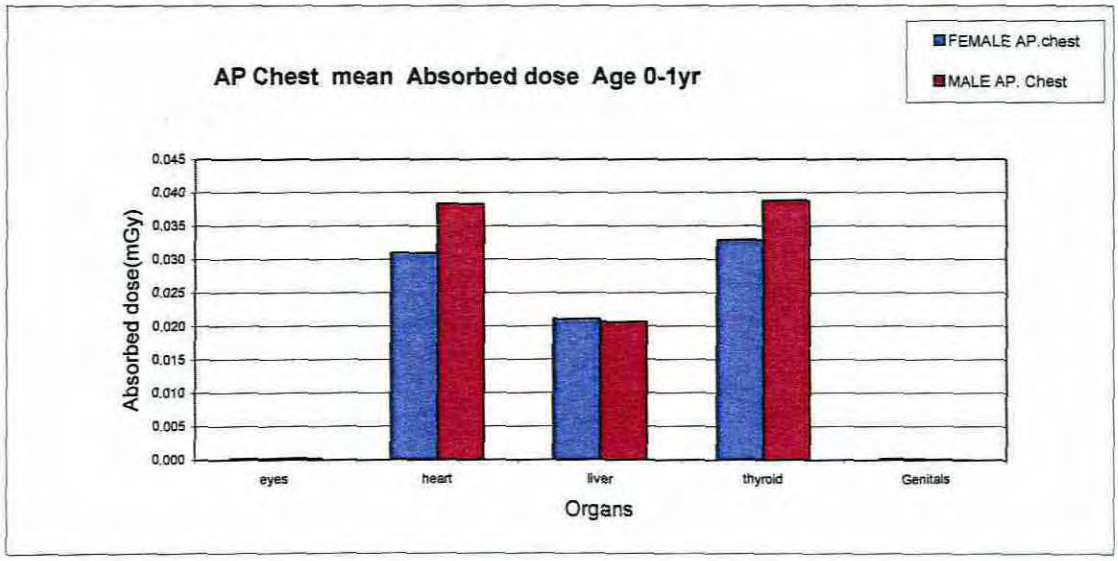
All dose ranges are reflected in the Tables 5.9, 5.11, and 5.14. The total deviation of results are illustrated in the histograms of Figures 5.10, 5.12 and 5.13.

Table 5.8. Tabulation of mean Absorbed dose (mGy) per organ measured at Tyberberg Hospital.

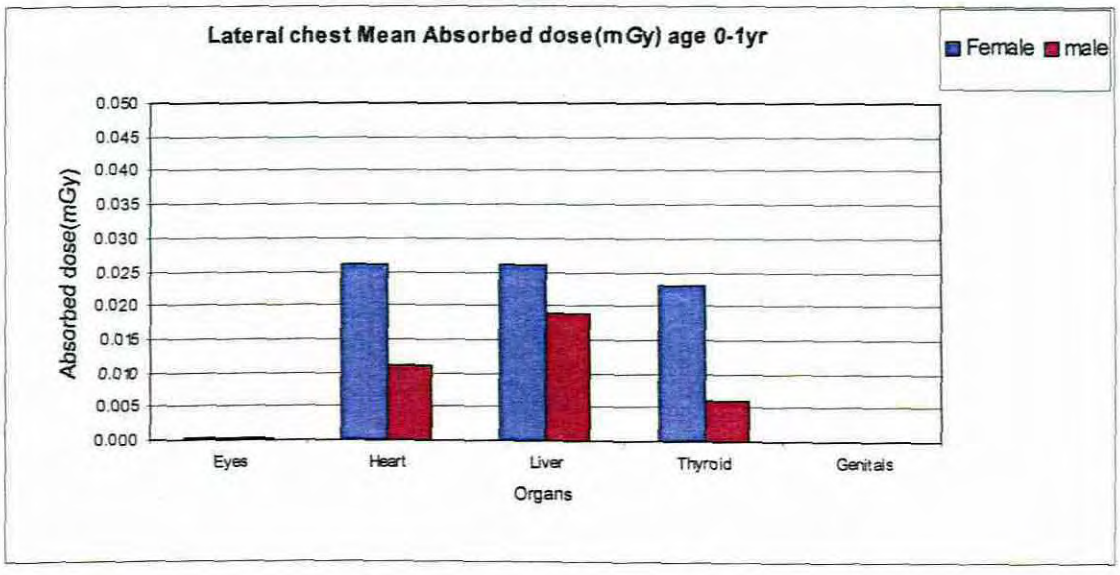
		Effective dose (mGy) for organs:									
Age group(yrs)	View	Eyes	Range	Heart	Range	Liver	Range	Thyroid	Range	Genitals	Range
< 1	AP	1.9×10^{-4}	3×10^{-4} - 2.5×10^{-4}	0.033	0.022 –0.044	0.020	0.009 - 0.032	0.034	0.024 - 0.043	1.7×10^{-4}	1.0×10^{-4} - 2.3×10^{-4}
	Lat.	1.8×10^{-4}	6.6×10^{-4} - 3.0×10^{-4}	0.015	-0.055 - 0.156	0.025	0.013 - 0.037	0.023	0.013 - 0.032	4.0×10^{-4}	1.1×10^{-4} - 2.9×10^{-4}
1-5	AP	3.0×10^{-5}	-1.5×10^{-5} – 7.9×10	0.027	0.016 - 0.037	0.011	0.007 - 0.011	0.011	-0.002 - 0.025	9.0×10^{-5}	6.0×10^{-5} - 1.2×10^{-4}
	Lat.	3.0×10^{-4}	-0.001 - 0.002	0.016	-0.008 - 0.024	0.017	0.006 - 0.027	0.006	-0.001 - 0.013	1.0×10^{-4}	2.4×10^{-5} - 1.7×10^{-4}
5-10	AP	6.6×10^{-5}	-1.6×10^{-4} - 3.0×10^{-4}	0.025	0.006 - 0.021	0.014	0.008 - 0.021	0.0051	-0.002 - 0.012	1.0×10^{-4}	8.0×10^{-5} - 7.5×10^{-5}
	Lat.	1.7×10^{-5}	-4.0×10^{-5} - 7.0×10^{-5}	0.011	2.1×10^{-4} - 0.023	0.019	0.007 - 0.042	0.002	-3.0×10^{-4} - 0.005	9.2×10^{-5}	-1.1×10^{-5} - 1.9×10^{-4}

Table 5.9. Tabulation of mean Absorbed dose (mGy) organ for age group 0 – 1 yr. measured at Tyberberg Hospital.

		Effective dose (mGy) for organs:									
Gender)	View	Eyes	Range	Heart	Range	Liver	Range	Thyroid	Range	Genitals	Range
Female	AP.	1.7×10^{-4}	1.0×10^{-4} - 2.3×10^{-4}	0.031	0.018 –0.044	0.021	0.007 - 0.032	0.033	0.023 - 0.043	1.7×10^{-4}	1.0×10^{-4}- 2.3×10^{-4}
Male	AP.	2.4×10^{-4}	1.8×10^{-4}- 2.9×10^{-4}	0.038	-0.035 - 0.047	0.021	0.015 - 0.025	0.039	0.030 - 0.048	4.0×10^{-4}	0.00 –1.2×10^{-4}
Female	Lat	2.0×10^{-4}	0.00 – 3.3×10^{-4}	0.026	0.015 - 0.038	0.026	0.012 - 0.035	0.023	-0.012 - 0.034	4.3×10^{-5}	1.3×10^{-5} - 0.001
Male	Lat.	2.0×10^{-4}	1.2 – 2.7. $\times10^{-4}$	0.011	0.019 - 0.033	0.019	-0.020 - 0.034	0.006	-0.018 - 0.03	1.0×10^{-4}	0.00 - 2.9×10^{-4}



(a) AP chest age 0 - 1yr.



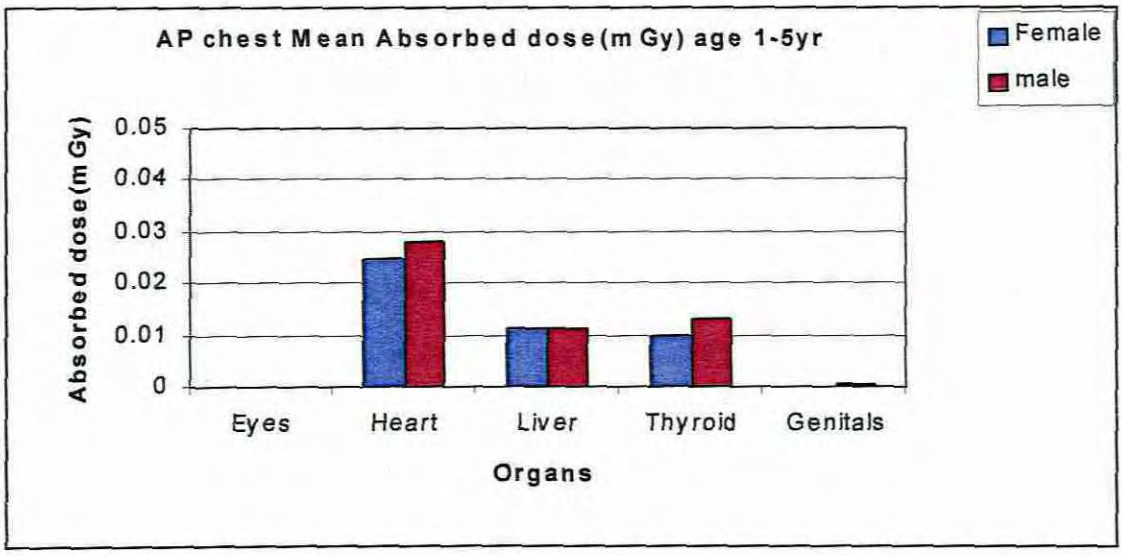
(b) Lateral chest age 0 - 1yr.

Figure 5.10 (a & b). Histogram demonstrating the mean organ dose calculated with the "Child dose" programme for children in the 0 - 1 year age group x-rayed at Tygerberg Hospital

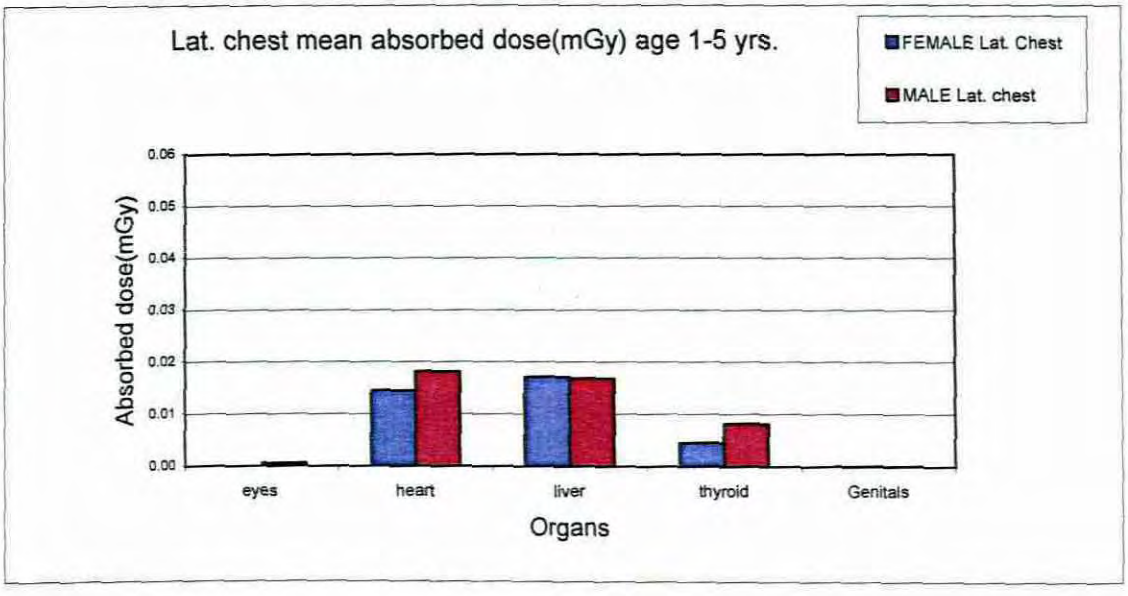
The histogram of the AP chest for male and female children shows how minimal the dose to the eyes and the genitals is, virtually nothing at (1.0×10^{-4} - 2.3×10^{-4}). The heart (0.018 –0.044), the liver (0.007 - 0.032) are shown as well as the thyroid (0.023 - 0.043) which is in the range similar to that of the heart. Similar tendencies are shown for the lateral view. However, doses for males appear higher in the lateral view.
There is no explanation for the male dose being higher than the female, this was not investigated as it fell outside the margins of the study but further investigation is suggested.

Table 5.11. Tabulation of mean Absorbed dose (mGy) organ for age group 1-5 yrs. measured at Tyberberg Hospital.

		Effective dose (mGy) for organs:									
Gender)	**View**	**Eyes**	**Range**	**Heart**	**Range**	**Liver**	**Range**	**Thyroid**	**Range**	**Genitals**	**Range**
Female	**AP.**	**2.0×10^{-5}**	$0.00 - 9.0\times10^{-5}$	**0.025**	0.017 –.033	**0.011**	0.008 -0.014	**0.010**	-0.003 - 0.023	**9.0×10^{-5}**	6.0×10^{-5} - 1.1×10^{-4}
Male	**AP.**	**4.0×10^{-5}**	$0.00 – 9.0\times10^{-5}$	**0.028**	-0.015 - .04	**0.011**	0.005 - 0.018	**0.013**	-0.002 - 0.028	**4.0×10^{-4}**	0.00
Female	**Lat**	**2.0×10^{-4}**	$0.00 – 6.0\times10^{-5}$	**0.014**	0.005 - .020	**0.017**	0.004 - 0.029	**0.004**	-0.00 - 0.028	**4.3×10^{-5}**	2.4×10^{-5} - 1.7×10^{-4}
Male	**Lat.**	**0.001**	$0.00 – 0.002^{4}$	**0.018**	0.011 -0.025	**0.016**	-0.009 - 0.020	**0.008**	-0.0002 - 0.016	**0.00**	0.00



(a) AP. chest age 1 - 5yrs.



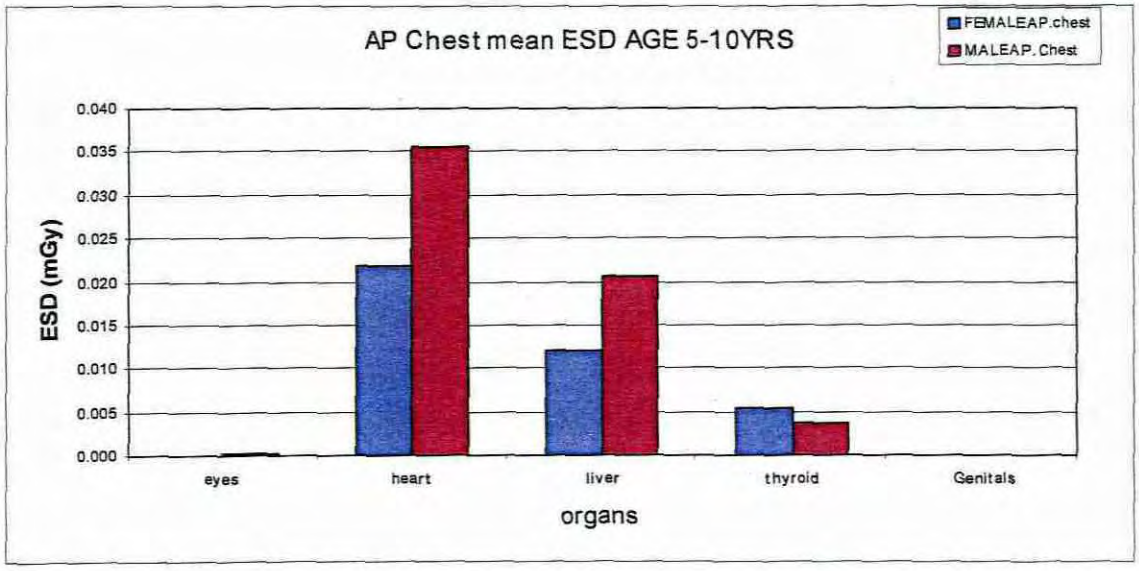
(b) Lat. chest age 1 - 5yrs

Figure 5.12 (a & b). Histogram demonstrating the mean organ dose calculated with the "Child dose" programme for children in the 1 - 5 years age group x-rayed at Tygerberg Hospital.

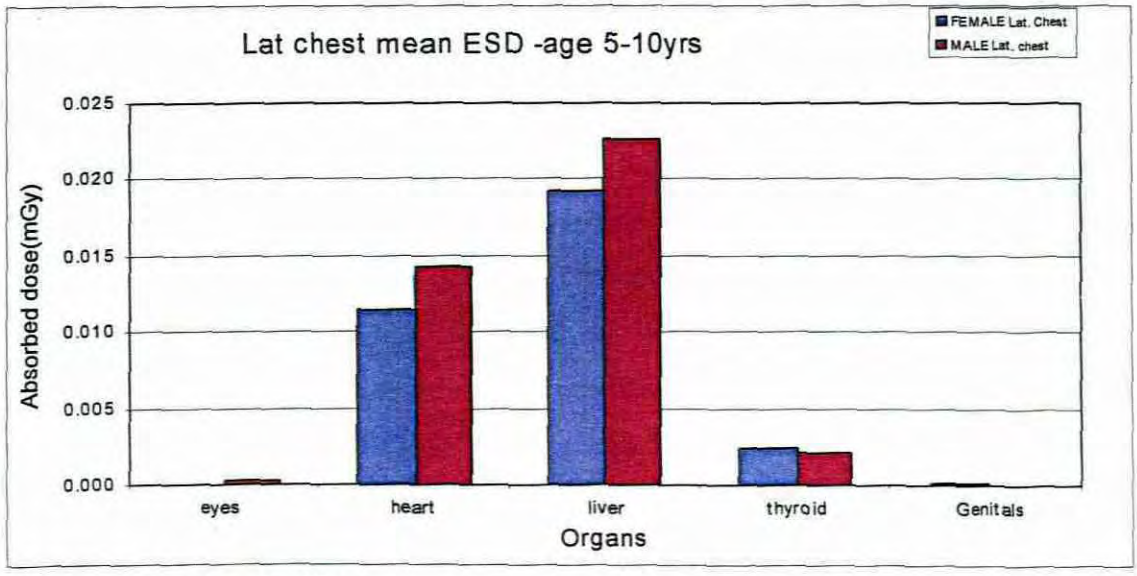
The histogram of the AP chest for male and female children show how minimal the dose to the eyes and the genitals is, virtually nothing at (0.00 - 9.0×10^{-4}). The heart (0.017 –0.033), the liver (0.008 - 0.014) are shown as well as the thyroid (-0.003 - 0.023). Similar tendencies are shown for the lateral view however doses for heart and thyroid appear lower, the dose to the liver is only slightly higher in the lateral view for both male and female. There is no explanation for the male dose being higher than the female, this was not investigated as it fell outside the margins of the study but further investigation is suggested.

Table 5.13. Tabulation of mean Absorbed dose (mGy) organ for age group 5 - 10yrs.measured at Tyberberg Hospital.

		Effective dose (mGy) for organs:									
Gender)	View	Eyes	Range	Heart	Range	Liver	Range	Thyroid	Range	Genitals	Range
Female	AP.	7.0×10^{-6}	0.00 - 3.3×10^{-5}	0.020	0.017 – 0.026	0.011	0.006 - 0.017	0.005	0.003 - 0.010	9.0×10^{-5}	8.0×10^{-5} - 1.3×10^{-4}
Male	AP.	2.7×10^{-4}	0.00 – 0.001^{5}	0.035	0.018 - 0.05	0.020	0.010 - 0.030	0.003	-0.001 - 0.005	2.5×10^{-5}	0.00 - 7.5×10^{-5}
Female	Lat	1.5×10^{-5}	$0.00 – 7.0\times10^{-5}$	0.011	-0.001 - 0.024	0.020	-0.006 - 0.040	0.004	-0.001 - 0.005	4.3×10^{-5}	0.00 - 1.0×10^{-4}
Male	Lat.	2.5×10^{-5}	0.00 – 7.5×10^{-5}	0.014	-0.007 - 0.020	0.017	-0.013 - 0.030	0.002	-0.001 - 0.003	0.00	0.00 - 7.5×10^{-5}



(a) AP. Chest age 5 - 10yrs.



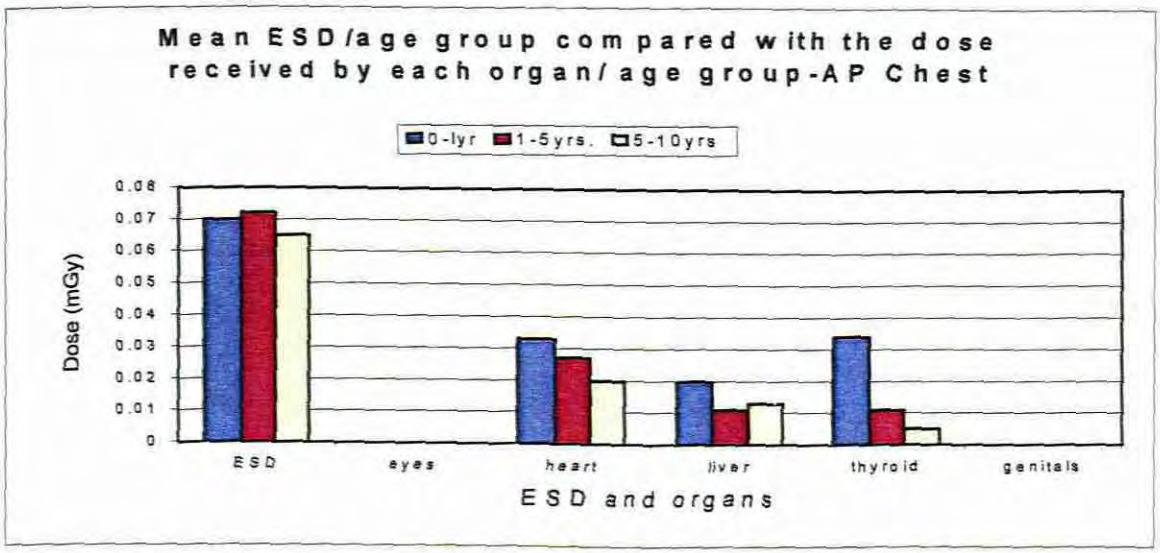
(b) Lateral chest age 5 - 10yrs.

Figure 5.14 (a & b). Histogram demonstrating the mean organ dose calculated with the "Child dose" programme for children in the 5 -10 years age group x-rayed at Tygerberg Hospital.

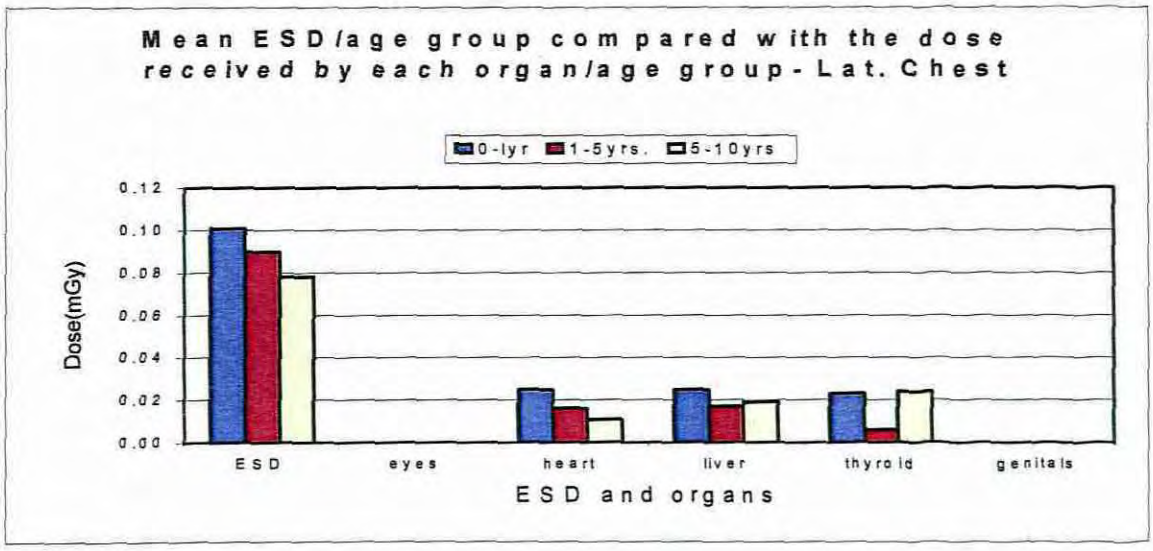
The histogram of the AP chest for male and female child show how minimal the dose to the eyes and the genitals is, virtually nothing at (0.00 - 3.3×10^{-5}). The dose to the heart (0.017- 0.026) is highest, the liver follows at (0.006 - 0.017) and the thyroid (0.003 - 0.010) in a lower dose range to the heart. For the lateral view however doses for heart is lower at (-0.001-0.024), the dose to the liver (-0.006-0.040) is higher for the lateral view the thyroid dose range at (-0.001-0.005) is lower. The overall tendency of this group is that male children receive a higher dose in both views. There is no explanation for the male dose being higher than the female, this was not investigated as it fell outside the margins of the study but further investigation is suggested

5.2.2 The mean ESD compared with the organ dose for each age group.

The histograms in Figure 5.15 (a & b) demonstrate the distribution of the mean organ dose as well as the mean ESD dose per age group at Tygerberg Hospital. Both histograms show a tendency that children 0 - 1 year receive a higher total average dose. This could be attributed to the exposure parameters used by radiographers for 0-1year age group are similar to the 1 - 5 year group. If the differing surface areas of the groups are considered the 0 – 1 year group being smaller, then as our results confirm this group should receive a higher ESD.



(a.) Mean ESD / age group AP chest.



(b) Mean ESD / age group Lat. Chest.

Figure 5.15 (a & b). Mean ESD / age group compared with the dose received by each organ / age group.

5.2.3. Total Dose per examination at Tygerberg Hospital

Thus, for an examination of the chest that would consist of an AP view and a lateral view the patient will receive and average total ESD (mGy) the values are tabulated in Table 5.16. The total absorbed dose that received per organ listed per examination can be read from Table 5.17.

Table 5. 16. Total ESD (mGy) measure at Tygerberg Hospital.

Age group (yrs.)	**Total ESD/ Examination** (mGy)
< 1	0.171
1-5	0.162
5-10	0.143

Table 5.17. Total Absorbed dose (mGy) per organ at Tygerberg Hospital.

Age group (yrs)	Eyes	Heart	Liver	Thyroid	Genitals
<1	3.7×10^{-4}	0.058	0.045	0.057	5.7×10^{-4}
1-5	6.0×10^{-4}	0.043	0.028	0.017	2.7×10^{-4}
5-10	2.2×10^{-4}	0.031	0.032	0.025	1.0×10^{-4}

The tabulated doses of Table 5.16 and 5.17 are minimal but it does serve to give the radiation worker a clear indication of the dose per examination. It also serves as a consideration when repeated x-rays are done which increases the patients' total absorbed dose. This increase of radiation dose to unnecessary exposure is minimal to the patient but in time will increase the population dose, which in latter years may have a significant influence on the genetic pool of the population. Thus it must be stress that radiographers make use of proper techniques in order to keep radiation dose to patients as low as possible.

Chapter 6:

Conclusion and Recommendations

6.1 *Conclusion*

"Diagnostic radiology is the greatest source of public exposure to radiation. Although these investigations are medically justifiable, it is important to limit the dose per examination" (Basson & Swiegers, 1999).

Thermoluminecent dosimeter (TLD) pellets provided a means of measuring ESD. directly on paediatric patients. The software package "Childdose" allowed conversion of ESD to organ-absorbed doses. Measurements were done for the age groups of 0 - 1 yr., 1 - 5 yrs. and 5 - 10 yrs. The results obtained compared favourably to those measured in Ireland, United Kingdom and also that of the working group UNSCEAR 2000. This is illustrated in Table 5.3 and the histogram in Figure 5.4. The measurements At Tygerberg Hospital tend to be in line with Ireland and the United Kingdom. The amount of improvement between Nigeria was not investigated but difference in samples size between South Africa and Nigeria could be an attributing factor (Ogudae et al., 1999). This difference in sample size is shown in Figure 5.2. Figure 5.2 also compares the distribution of patients for Tygerberg Hospital with the Ireland. They have similar sample sizes.

However, it must be noted that measuring with TLD pellets is a long and tedious and labour intensive process (McGee et al.,1993). The time is extended by the requirement that before work can commence using the TLD pellets the sensitivity to radiation must be determined. TLD pellets are sensitive to handling and thus require very specific handling processes. Each TLD pellet was numbered individually and a sensitivity factor was determined for each pellet (McKinlay, 1981).

The outcome of the study provided Tygerberg hospital with a reference table of ESD values for the chest x-ray of children 10 years of age and younger. In addition a table of effective doses was calculated and tabulated to absorbed doses for the eyes, heart, liver, thyroid and genitals for children aged 10 years and younger who have chest x-rays.

6.2 Recommendations

On completion of the study it can be recommended that further such studies should be done to include more radiographic examinations of regions other than those concentrated on in this study. The regions of the abdomen, skull and long bones should be considered.

The study recommends future experiments concerning filtration of the x-ray beam. It showed that radiation dose to the patient are considerably reduced if a higher filtration is used. The results of this study indicate that density changes when the filtration of the beam is increased from 1mmAl to 2mmAl are minimal in regard to the final image quality. Thus it is recommended that filtration be increased especially when considering that with added filtration the exposure parameters require little or no adjustment but the reduction in dose to the patient is considerable. However before changes are made, testing of the half value layer should also be considered to check if the x-ray machines are performing as required in the conditions set concerning licencing requirements of the Department of Health commissioned in 2000.

Recommendation is made that the reference radiation dose tables formulated in this study becomes part of the available reference radiation dose data material in the Diagnostic Radiology department of Tygerberg Hospital. Lastly this study should be seen as a basis for further investigations where more samples are measured over a variety of radiographic regions.

6.3 Limitations

Limiting factors were the number TLD pellets available, the time it took for the readout and annealing processes of the TLD pellets. Each pellet had to be individually numbered in order to calibrate the specific pellet. Thus the number of children within the study was limited largely by the availability of TLD pellets. However, when compared with international data, a comparative result was achieved.

6.4 Summary

The study had three main objectives: (1) to measure absorbed dose (mGy) values for children at Tygerberg Hospital, (2) to establish the ESD levels and match them with internationally published data and (3) to compile reference dose tables.

All of the above objectives have been successfully met as documented in Chapter 5. A sub problem was the mastering of TLD pellets, and as the literature indicated and the researcher discovered, the use of the pellets was a long and tedious process involving many man-hours (McGhee et al., 1993). However, the use of TLD pellets was mastered as a tool for dose measurements.

With this study it was concluded that Tygerberg hospital dose references are in line with international standards but could still be improved. (Ogudae et al., 2004).
On the aspect of added Al filtration for paediatric patients, further investigation is required to investigate whether increased filtration will assist in reducing the ESD (mGy) without greatly influencing the radiographic image.

A user-friendly tabulation of ESD and absorbed dose values for Tygerberg Hospital was established.

In conclusion the study confirms the hypothesis that the radiation dose(s) delivered to chests at Tygerberg Hospital are in line with and comparative to international data, thus concluding that patients are not receiving unnecessarily high doses of radiation. With the formulation of dose tables and ranges for Tygerberg Hospital there is method for radiation workers to be made aware of radiation dose(s) received by their patients.

Lastly the department now has a set of usable reference dose levels for paediatric radiology chest x-rays. It is hoped that measuring of radiation dose at Tygerberg Hospital will become standard practice and that improvements will be shown in relation to this study. The new knowledge gained will be of assistance to the radiation worker and make them more aware of radiation dose(s) imparted to patients and to keep in mind the "ALARA" principles especially when working with children.

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Appendices

APPENDIX . 1 Information letter to person accompanying patient

Paediatric Radiology Dosimetry Project

Dear Nurse, Parent, Guardian

The child in your care will be taking part in a research project for the Department of Medical Physics at Tygerberg Hospital.

The child will not receive any extra radiation, only that which is required for the radiographer to produce a x-ray image.

A patch, which contain measuring pellets, a device that will assist with measuring the radiation dose. It will be carefully place on the child's chest or abdomen.

This patch will be replaced on the chest for each view by the radiographer .

It will not harm or hurt the child in any way and it will also not be visible on the x-ray image.

If you do not wish to allow the child in you care to take part in the project please fell free to indicate your wish to the Radiographer on duty.

Thank you for your co-operation.

Yours sincerely
Mrs. G. SWART
Chief Radiographer
Medical Physics
Tygerberg Hospital

APPENDIX. 2. Information Letter to Radiologist.

Paediatric Radiology Dosimetry Project.

Dear Radiologist.

Mrs. G Swart in conjunction with Medical Physics, wishes to inform you about a project to be undertaken in the Diagnostic Radiology Department at Tygerberg Hospital. The project will cover the following topic: **Measurement of adsorbed doses for Paediatric Patients for the purpose of developing adsorbed dose guidelines in Paediatric Radiology.**

As you are aware, Diagnostic Radiology is an accepted tool for the diagnosis of childhood illnesses and diseases. However, the application of x-rays on children has inherent hazards. Children have growing organs and the risk of inducing tumours to growing organs at an early age is greatly increased with the use of x-rays.

Radiation exposure can cause genetic mutations and congenital malformations. The absorbed dose may however be small for one individual but when seen in context with a number of children, the dose to the population could increase dramatically. Children have a longer life expectancy than adults thus they are a greater risk to the damaging effects of radiation.

Thus our aim with this project is to assess the absorbed doses to the eyes, thyroid, liver and gonads of children undergoing diagnostic x-ray examinations of the chest and abdomen. At the end of this project a set of dose guideline for use in Paediatric Radiology which would have been developed.

Dr.JP.Muller together with the Ethical committee of Tygerberg Hospital and Prof. A. Scher, Head of the Diagnostic Radiology Department, have given full consent for the go ahead of this project.

The Radiographer will place Lithium Fluoride pellets (TLD) on specific predetermined areas on the anatomy of the child, before he/she proceeds with the x-ray. The flouride detectors are small 4.5mm x 0.89mm pellets and will not interfere with or influence your x-ray image in anyway. The Radiographer will be required to fill out a form for each chest and abdomen x-rayed. This form will give an indication of how and where the pellets have been placed.

Only inpatient children will take part in the study. The children will be divided into age groups,.viz. Birth to 1 year, 1 to 5 years and 5 to 10 years. The irradiation of these pellets will involve no extra radiation doses to the child.

Medical Physics would ask that you to be aware of the project when reporting on chest and abdomen x-rays. Radiation protection of the child and dose accountability of the radiographer, radiologist and referring doctor is of utmost importance to future generations.

Thank you for you assistance.

Mrs. G. Swart
Chief Radiographer
Medical Physics
Tygerberg Hospital.
October 2002

APPENDIX. 3. Letter from Professor Scher.

Prof A T Scher
Department of Radiology, 4th Floor, C-Block, Tygerberg Hospital
***Tel.** (021) 938-5622 **(Fax)** (021) 938-5903*
E-Mail :** aj@gerga.sun.ac.za **(University of Stellenbosch)
**** E-Mail :** ascher@pawc.wcape.gov.za **(Tygerberg Hospital)** **

28 June 2002

Ms Gillian Swart
Dept. Medical Physics
TYGERBERG ACADEMIC HOSPITAL

Dear Ms Swart

Re: RESEARCH PROJECT ON PAEDIATRIC RADIATION DOSAGES

The Department of Radiology would be most happy to make available our Imaging equipment for you to pursue your studies. I understand that this research project has been approved by the Ethics Committee and I am sure that by strict adherence to the protocol, no unnecessary irradiation to patients will be caused.

Please contact me should you require any further assistance or advise and I look forward to seeing the result of your study.

Yours sincerely

A T Scher

PROF A T SCHER

HEAD: DEPARTMENT OF RADIOLOGY

Prof 97 g Swart - Dept Medical Physics

APPENDIX. 4. Letter from Ethical Committee.

TYGERBERG AKADEMIESE HOSPITAAL

LêER : 24/1

NAVRAE : Dr J P Müller

TELEFOON : 938-4141

DATUM : 24 April 2002

Mev G E Swart
Hoof Radiografis
Mediese Fisika
GENE LOUW GEBOU
TYGERBERG HOSPITAAL

Geagte Mev Swart

STRALING NAVORSING

U skrywe gedateer 13 Maart 2002 verwys.

Die projek word ondersteun. Dit word voorgestel dat die deelnemers gepaste toestemming verleen nadat hulle breedvoerig ingelig is oor die doelwitte van die studie.

Vriendelike groete

DR J P MÜLLER
SENIOR KLINIESE UITVOERENDE BEAMPTE: NAVORSING

APPENDIX. 5. Form for Capturing patients' x-ray parameters.

PAEDIATRIC RADIOLOGY DOSIMETRY PROJECT.

Please complete a form for each Paediatric inpatient – requiring Chest / Abdomen x-rays.

Patient information: *Date:* / /

Age: | 0 –1yr | 1 –5yrs | 5- 10yrs |

Gender: | Male | Female | *Weight:* .....

K V ..... *Height:* ..... *Thickness:* .....

mAs: ..... *Film size:* .....

Field size: .....

Area: | Chest. | Abdomen. |

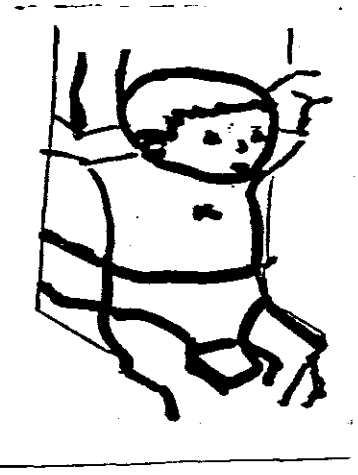
Position: | Supine | Erect |

Views: | AP. | PA | LAT. |

TLD. Positions:

AP /PA: Point of entry:

Lat : Point of entry



Pb.rubber shielding.

Gonad: | yes | no |

Thyroid: | yes | no |

Radiographer: _____

All forms will be collected by : G.Swart, Medical Physics
Contact no.:938 6074

Appendix: 6

Samples in the age 0-1year group Antero-posteria and Lateral chest x-ray examinations.

Sample	Chest view	Age	kV	mAs	ESD
1	AP	3wks.	50	1.6	0.06
	Lat	3wks.	50	1.6	0.04
2	AP	1mth	50	1.6	0.08
	Lat	1mth	50	2.0	0.16
3	AP	2mths	50	1.6	0.07
	Lat	2mths	56	2.0	0.12
4	AP	3mths	51	1.6	0.11
	Lat	3mths	60	2.0	0.15
5	AP	10mths	50	1.6	0.06
	Lat	10mths	50	2.0	0.08
6	AP	6mths	50	2.0	0.06
	Lat	6mths	56	1.6	0.11
7	AP	3mths	50	1.2	0.09
	Lat	3mths	50	1.2	0.11
8	AP	4mths	50	1.6	0.08
	Lat	4mths	54	2.0	0.11
9	AP	7mths	50	2.0	0.10
	Lat	7mths	54	2.5	0.12
10	AP	4mths	50	1.6	0.07
	Lat	4mths	58	2.0	0.11
11	AP	8mths	48	1.6	0.09
	Lat	8mths	54	1.6	0.09
12	AP	6mths	48	1.6	0.06
	Lat	6mths	58	1.6	0.10
13	AP	6mths	49	1.6	0.06
	Lat	6mths	53	1.6	0.10
14	AP	4mths	48	1.6	0.08
	Lat	4mths	53	2.0	0.09
15	AP	12mths	50	1.6	0.05
	Lat	12mths	52	1.6	0.08
16	AP	12mths	50	1.6	0.03
	Lat	12mths	54	2.0	0.05
17	AP	12mths	50	1.6	0.06

Appendix: 7

Samples in the age group 1- 5year Antero-posteria and Lateral chest x-ray examinations

Sample	Chest view	Age(yrs/ mths)	kV	mAs	ESD
1	AP	1.2	50	2.0	0.11
	Lat		50	5.0	0.05
2	AP	1.2	50	2.0	0.06
	Lat		54	2	0.09
3	AP	1.3	50	2.0	0.05
	Lat		53	2.0	0.09
4	AP	1.8	50	1.6	0.05
	Lat		54	2.0	0.09
5	AP	2.6	50	2.0	0.06
	Lat		53	2.0	0.09
6	AP	2.7	50	1.6	0.05
	Lat		56	1.6	0.06
7	AP	2.10	50	2.0	0.03
	Lat		67	2.5	0.08
8	AP	2.11	58	1.6	0.14
	Lat		64	1.6	0.14
9	AP	3.2	51	1.6	0.02
	Lat		59	2.0	0.06
10	AP	3.11	55	2.5	0.08
	Lat		60	2.5	0.14
11	AP	3.11	54	2	0.06
	Lat		64	2.5	0.14
12	AP	4	52	1.6	0.04
	Lat		58	2	0.07
13	AP	4.7	52	2	0.06
	Lat		60	2.5	0.14
14	AP	1.4	51	1.6	0.09
	Lat		57	2	0.14
15	AP	3.10	52	2	0.08
	Lat		62	2	0.00
16	AP	2.4	50	1.6	0.10
	Lat		60	2	0.24
17	AP	3.9	50	1.6	0.06
	Lat		60	1.6	0.06
18	AP	3.8	52	2.0	0.05
	Lat		60	2.5	0.052
19	AP	1.2	50	2.0	0.108
	Lat		58	2.5	0.14
20	AP	2	54	2.0	0.05
	Lat		60	1.6	0.037
21	AP	1.7	50	1.6	0.052
	Lat		53	2.0	0.087

Sample	Chest view	Age(yrs/ mths)	kV	mAs	ESD
22	AP	2.8	50	1.6	0.06
	Lat		55	2.0	0.037
23	AP	2.8	55	2.0	0.047
	Lat		65	2.0	0.057
24	AP	1.2	55	1.6	0.08
	Lat		50	5.0	0.10
25	AP	1.2	50	1.6	0.09
	Lat		53	2.0	0.11
26	AP	2.9	52	2.0	0.07
	Lat		52	2.0	0.10
27	AP	3.0	50	1.6	0.07
	Lat		56	2.0	0.13
28	AP	3.2	53	1.6	0.05
	Lat		56	1.6	0.06
29	AP	3.8	50	1.6	0.06
	Lat		55	1.6	0.11
30	AP	3.9	50	2.0	0.10
	Lat		60	2.0	0.14
31	AP	4.0	52	1.6	0.07
	Lat		60	2.0	0.12
32	AP	4.5	55	1.6	0.07
	Lat		50	5.0	0.02

Appendix: 8

Samples in the age group 5- 10 years Antero-posteria and Lateral chest x-ray examinations

Sample	Chest view	Age(yrs/ mths)	kV	mAs	ESD
1	AP	5.5	53	2.0	0.077
	Lat		63	2.0	0.04
2	AP	5.5	53	2.0	0.054
	Lat		63	2.0	0.16
3	AP	5.6	53	1.6	0.109
	Lat		57	1.6	0.12
4	AP	7.4	54	1.6	0.053
	Lat		66	2.5	0.15
5	AP	8.6	64	1.6	0.159
	Lat		77	1.6	0.08
6	AP	5.4	52	2.0	0.049
	Lat		62	2.0	0.11
7	AP	6.4	55	2.0	0.062
	Lat		64	2.5	0.11
8	AP	8.5	54	2.0	0.058
	Lat		62	2.5	0.11
9	AP	6.10	56	2.0	0.059
	Lat		62	2.0	0.12
10	AP	10	68	2.5	0.060
	Lat		72	2.0	0.11
11	AP	10	62	1.6	0.034
	Lat				
12	AP	5.5	56	2.0	0.064
	Lat		58	2.5	0.10
13	AP	9.7	60	2.5	0.050
	Lat		68	2.5	0.10
14	AP	5.11	53	2.0	0.065
	Lat		63	2.0	0.09
15	AP	8.4	54	2.0	0.046
	Lat		62	2.0	0.08
16	AP	5	50	2.0	0.081
	Lat		53	2.0	0.05
17	AP	5	54	2.0	0.041
	Lat		66	2.0	0.05
18	AP	5	56	2.0	0.053
	Lat		60	2.5	0.05

Equations

$$ESD = ID.BSF \qquad \textit{(Eq.1)}$$

$$R = \frac{R1 + R11 + \text{———} R101}{11} \qquad \textit{(Eq.2)}$$

$$Si = \frac{Ri}{R} \qquad \textit{(Eq.3)}$$

$$D = \frac{R-B}{A} \qquad \textit{(Eq.4)}$$

$$E = D X C \ (mSv) \qquad \textit{(Eq.5)}$$