Radiation distribution in a private neurological theatre during invasive back pain management procedures

Belinda vd Merwe
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Supervisor: Dr. H. Friedrich-Nel
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Belinda van der Merwe

DECLARATION OF INDEPENDENT WORK

I, BELINDA VAN DER MERWE, do hereby declare that this project submitted for the degree MAGISTER TECHNOLOGIAE; RADIOGRAPHY: DIAGNOSTIC in the SCHOOL OF HEALTH TECHNOLOGY at the CENTRAL UNIVERSITY OF TECHNOLOGY, FREE STATE, is my own independent work. It has not been submitted before to any institution or anyone else as part of any qualification by me.

_____ _____

Signature of student Date

Dedicated to David vd Merwe.

I wish he could have celebrated the end result with me.

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LIST OF ACRONYMS AND ABBREVIATIONS

µ	**micro**
AAPM	**American Association of Physicists in Medicine**
ALARA	**As-Low-As-Reasonably-Achievable**
AP	**Anterior-posterior**
BMI	**Body Mass Index**
CT	**Computed Tomography**
DAP	**Dose Area Product**
DoH	**Department of Health**
DRL	**Diagnostic reference levels**
ERCP	**Endoscopic Retrograde Cholangiopancreatography**
ESE	**Entrance Skin Exposure**
Gy	**Gray**
ICRP	**International Commission of Radiological Protection**
II	**Image Intensifier**
kV	**Kilo Volt**
LAT	**Lateral**
mA	**milliampere**
mR	**milliroentgen**
mrad	**millirad**
mrem	**millirem**
mSv	**millisievert**
NCRP	**National Council on Radiation Protection**
NRPB	**National Radiation Protection Board**
PA	**Posterior-anterior**
Pb	**Lead**
R	**Roentgen**
rad	**radiation absorbed dose**
rem	**radiation equivalent man, now person**
RSA	**Republic of South Africa**

RSF	**Relative Sensitivity Factor**
s	**seconds**
SAAPMB	**South African Association of Physicists in Medicine and Biology**
SAS	**SAS 9.1.3 Service Pack 3 computer software package**
SID	**Source to Image Receptor Distance**
Sv	**Sievert**
TLD	**Thermoluminescent Detector**
TLDs	**Thermoluminescent Detectors**
UFS	**University of the Free State**
UK	**United Kingdom**
US	**United States**

SUMMARY

The aim of the study was to determine radiation dose levels around the theatre table, on either side of the C-Arm, in order to establish if the radiation dose received by staff during back pain procedures fell within the limits set by the International Commission of Radiological Protection (ICRP). The question that arose from this goal was whether the stance of staff, in relation to the x-ray tube side of the C-Arm, influenced radiation dose levels. In order to apply the ALARA principle, the possibility of lowering the radiation dose in the neurological theatre was explored.

The measurement methodology of the study was twofold: measurements were executed by means of TLD meters, as well as with an ionisation chamber. TLD meters were placed on the patient, the neurosurgeon and the radiographer during back pain procedures, and, more specifically, during fluoroscopy, to record the doses with the Image Intensifier (II) above the table as well as with the x-ray tube above the table, at the pelvis and the chest height of the staff. Ionisation chamber measurements were recorded in 25cm intervals around the theatre table with a phantom and the C-Arm positioned in the PA, oblique and lateral positions at 110cm and 133cm heights from the floor.

The TLD results indicated that, when compared to the Image Intensifier side, the radiation dose was higher on the x-ray tube side of the C-Arm. The radiation dose was higher at the height closest to the x-ray source. The radiation dose received by the patient was higher with the x-ray tube positioned above the table (PA). The radiation dose to the surgeon's hand and body was higher with the x-ray tube positioned above the table (PA). Radiation dose levels with the x-ray tube above the table during back pain procedures in the current theatre exceeded the occupational annual recommendation of 500mSv to the neurosurgeons hands, as recommended by the ICRP. The opposite is true with the II positioned above the table. The research question was answered positively in that the x-ray tube under couch orientation has the potential to limit dose levels during back pain

procedures.

The measurement values resulted in a proposed protocol in terms of positioning of staff and orientation of the C-Arm in order to apply the ALARA principle during back pain procedures. Constant revision of protocols is the responsibility of the radiographer in order to guarantee that the ALARA principle is implemented in every unique situation.

OPSOMMING

Die doel van die studie was om die stralingsvlakke rondom die teatertafel, aan weerskante van die C-Arm te bepaal, om sodoende vas te stel of die bestralingsdosis waaraan die personeel tydens rugpynbehandelings blootgestel word, binne die bestralingslimiet is soos bepaal deur die ICRP (International Commission of Radiological Protection). Die vraag wat dus ontstaan, is of die posisionering van die personeel, in verhouding met die buiskant van die C-Arm, dosisvlakke beïnvloed. Om aan die ALARA-beginsel (As Low as Reasonably Achievable) te voldoen, is die moontlikheid ondersoek om die bestralingsdosis waaraan die personeel in die neurologiese teater blootgestel is, te verlaag.

Die metingsmetodologie van hierdie studie het TLD-meters sowel as ’n ionisasiekamerinstrument ingesluit. TLD-meters is tydens rugpynbehandelings (veral met fluoroskopie) op die pasiënt, die neurochirurg en die radiograaf geplaas om die dosisvlakke te bepaal met beide die beeldversterker en die X-straalbuis bokant die tafel geposisioneer, op pelvis- en borskashoogtes van die personeel. Ionisasiekamermetings is geneem rondom die teatertafel in intervalle van 25cm met ’n fantoom en die C-Arm in die PA posisie, skuins en lateraal op 110cm en 133cm van die vloer af.

Metingsresultate toon dat die bestralingsdosis hoër is naaste aan die buiskant van die C-Arm as aan die beeldversterkerkant. Die dosis was hoër op die hoogte naaste aan die X-straalbron. Die bestralingsdosis aan die pasiënt was hoër met die x-straalbuis bokant die tafel (PA). Die dosis waaraan die neurochirurg se hand en liggaam blootgestel was, was hoër met die X-straalbuis bokant die tafel. Die bestralingsdosisvlakke het met die buis bokant die tafel tydens rugpynbehandelings in diè spesifieke teater die jaarlikse beroepslimiet van 500mSv waaraan die neurochirurg se hande blootgestel mag word soos deur die ICRP bepaal, oorskry. Die teenoorgestelde is waar wanneer die beeldversterker bokant die tafel geposisioneer word. Die antwoord op die navorsingsvraag is dus positief deurdat bewys is dat die beeldversterker bokant die teatertafel moontlik

die bestralingsdosisvlakke tydens rugpynbehandelings kan beperk.

Die metingswaardes het daartoe aanleiding gegee dat ’n protokol voorgestel is vir die posisionering van die personeel en die oriëntasie van die C-Arm sodat die ALARA-beginsel tydens rugpynbehandelings toegepas kan word. Dit is die radiograaf se verantwoordelikheid om protokols deurlopend te hersien en te verseker dat die ALARA-beginsel in elke unieke situasie toegepas word.

CHAPTER 1

OVERVIEW OF THE STUDY

1.1 INTRODUCTION

Back pain management procedures include radio frequency neuroablation (nerves are destroyed by means of heat, generated by an electrical current), caudal, facet joint and sacroiliac joint injection. During these procedures the x-ray machine, that combines the x-ray source and a fluorescent screen to enable direct observation of structures and movement (fluoroscopy), is utilised. The major purpose of fluoroscopy in the theatre, where the above-mentioned neurological procedures are performed, is to ensure the correct needle placement for target specificity and the accurate delivery of the injectate during back pain management procedures (Manchikanti, Cash, Moss & Pampati, 2003).

The use of fluoroscopy with mobile C-Arm x-ray machines - so named because of their configuration - is associated with doses of radiation to the neurosurgeon, the radiographer, the scrub nurse, the patient and others in the theatre. The scatter levels from the patient emitted during exposure are the main source of the radiation doses received by staff during fluoroscopy (Raubenheimer, Spangenberg, Van Jaarsveld, Koller, De Vries, Willemse, Joubert and Herbst, 2004). The levels of the radiation doses staff and patients are exposed to during radio frequency neuroablation and injection procedures are also subject to the expertise of the neurosurgeon, as well as the complexity of the case. The procedure routines differ for each neurosurgeon, to include facet, sacroiliac and epidural caudal injections in different combinations. The difference in duration of fluoroscopy that is recorded among different surgeons will be explored in Chapter 2.

Due to the cumulative effect of radiation, staff members who are chronically exposed to low doses of radiation are vulnerable to the stochastic effect of

radiation (Zhou, Singh, Abdi, Wu, Crawford and Furgang, 2005). The current study was conducted to determine the ionising radiation level distribution during fluoroscopy and to obtain confirmation that, in accordance with international standards, the C-Arm operation keeps radiation doses to staff and patients within a safe limit. The standards, as set by the International Commission of Radiological Protection (ICRP), were considered for the purposes of this study.

This chapter provides an explanation of the initial investigation, the research objectives, and pinpoints the protocol for the research.

1.2 INITIAL INVESTIGATION

Protection against radiation is mandatory. The South African Department of Health (DoH), Directorate Radiation Control, accepted the conditions stated by the ICRP as law. The ICRP Publication 57, paragraph 174 (1989) states that any person within one metre of the x-ray source or patient - in our situation, the neurosurgeon and the radiographer - when the C-Arm is operated at 100kV, should wear a protective apron of at least 0.35mm lead (Pb) equivalence (DoH, s.a.a.:1 of 3). The policy further recommends that other staff in theatre should wear at least 0.25mm Pb equivalent aprons as a means of protection during fluoroscopy procedures.

The duty of a radiographer is to be prudent so as to minimise radiation exposure to the patient and staff because the basis of modern radiation protection is to keep the level of exposure “As-Low-As-Reasonably-Achievable” (ALARA) (Bushberg, 2001). The report of the American Association of Physicists in Medicine (AAPM) confirms that staff members, as well as the patient, will be exposed to radiation; the level of exposure will depend on their proximity to the x-ray source (AAPM, 1998). The question was whether those a few metres from the x-ray source and, on the other hand, whether the neurosurgeon who is standing in close proximity to it, received the lowest possible exposure during back pain management procedures.

1.3 PILOT STUDY

Motivated by the ALARA principle, the researcher initiated and conducted a study in a specific neurological theatre of a private hospital with the support of a neurosurgeon and the Department of Medical Physics, Faculty of Health Sciences and the University of the Free State (UFS). The initial study, approved by the Ethics Committee of the UFS (ETOVS NR 84/05), acted as the groundwork for this investigation. The aim of the study was to determine the radiation levels received by the patient, the neurosurgeon, the radiographer and the scrub nurse while in the theatre. Determining the radiation dose levels to the neurosurgeon's hand was a primary objective. Due to his position in relation to the C-Arm, the neurosurgeon's hand is exposed directly to the main radiation beam.

Apart from the background levels, the results of this initial investigation indicated that the radiographer's eyes and thyroid, as well as the scrub nurse's thyroid under the shield, did not receive any noticeable dose levels. However, for example, the neurosurgeon's thyroid received, per patient, a dose value of 0.001mSv and his hand 0.014mSv (refer to Appendix IX – page 1). The measuring instruments were placed outside the thyroid lead protection collar. During facet injections, an average dose of 9.26mSv per patient to the neurosurgeon's hand was recorded (refer to Appendix IX – page 2). According to the ICRP 60 Annual Report (1991) paragraph A 10, the effective dose limit to radiation workers is 20mSv per year, whilst the value for the hands of a radiation worker should be less than 500mSv (ICRP, 1990). The maximum value that was recorded to the neurosurgeon's hand during the initial investigation may be an unreliable peak value, but it was nevertheless of concern. It was imperative to determine that the radiation dose values to the hands in the current environment remain within the recommended limit of 500mSv, as set by the ICRP and accepted by the South African Radiation Control Board.

This initial study included 30 patients. However, the investigation was extended to include an additional 40 patients receiving back pain fluoroscopic interventions, providing the required evidence on the radiation dose levels that the neurosurgeon and theatre staff received.

1.4 PROBLEM STATEMENT

The following questions needed to be answered:

- Does the position of the neurosurgeon's stance in relation to the C-Arm Affect the radiation dose he receives?
- How can the radiation dose in this neurological theatre be lowered in order to comply with the ALARA principle?

Thus, we need to confirm that radiation levels to theatre staff during back pain fluoroscopy procedures are within the acceptable limits, in accordance with the international standards recommended by the ICRP (1991).

1.5 RESEARCH AIM AND OBJECTIVES

The aim of the study was to establish whether the radiation levels that staff in theatre 4, Universitas Annex were exposed to during back pain management procedures were within the accepted international limits of the ICRP (1991). The following objectives were guiding the research:

- Determine the radiation doses the neurosurgeon receives when standing on either side of the C-Arm, the x-ray tube or image intensifier (II).
- Determine working areas for the theatre staff to maximise radiation protection during fluoroscopy in the theatre.
- Apply the ALARA principle by proposing protocols with regard to the position of the C-Arm in relation to the neurosurgeon and other staff during back pain management procedures.

1.6 STUDY DESIGN

This study was an action enquiry and investigation into current practice (McNiff & Whitehead, 2006:5). Quantitative measurements of radiation dose levels received from fluoroscopy by the radiographer, the neurosurgeon and the patient during back pain procedures were recorded with the aim to propose a protocol in order to optimise radiation protection during fluoroscopy. The researcher's personal goal for this study was to be part of the new scholarship of enquiry (McNiff and Whitehead, 2006:67), in which practice becomes the object of research. The claim to knowledge will therefore be that, while investigating with the ultimate goal of maximizing radiation protection in mind, one's own theory of practice is improved in the current work environment.

1.7 METHODOLOGY

The main focus of the study was the gathering of quantitative information related to exposure by measuring the radiation levels at the patient; the neurosurgeon and the radiographer were exposed to on each side of the C-Arm during fluoroscopic procedures. Thermoluminescent detectors (TLDs) were used to determine the dose. The radiation levels other staff members were exposed to in the theatre (at various distances from the radiation source, at different heights from the floor) were determined by means of an ionisation chamber instrument. A phantom was used to simulate the patient.

Sampling

Staff members exposed to radiation included two neurosurgeons, two nurses, two nursing assistants, two anaesthetists and two radiographers. To limit variables to the minimum, the original plan was that only one experienced and skilled neurosurgeon should participate in the study. However, due to unforeseen circumstances the TLD measurements had to be conducted with the assistance of an additional neurosurgeon.

The aim was to include 40 patients undergoing treatment for back pain by means of fluoroscopic interventions in the study. The duration of the study depended on the availability of patients. It was possible to test 10 patients per month. 10 patients composed a cycle of patients on each side of the C-Arm and four cycles concluded the study. The ionisation chamber measurements were determined without patients by means of a phantom.

1.8 STATISTICAL ANALYSIS

Biostaticians from the Department of Biostatistics, UFS, analysed data according to Appendix II and Appendix III by means of the computer software package, SAS 9.1.3 Service pack 3. A comparison between the doses received by the radiographer and neurosurgeon on each side of the C-Arm (x-ray tube or II) was analysed by means of the Mann-Whitney nonparametric test. A medical physicist analysed and calibrated the ionisation chamber measurements.

Quantitative information

The layout of the quantitative measurements is given in Table 3.1 (see page 36). The measurements were twofold. TLDs were utilised to measure the dose that the neurosurgeon and the radiographer received. The exposure factors, as well as the patient's size were recorded. The second set of measurements was conducted with an ionisation chamber and a phantom. The ionisation chamber was exposed to 10 seconds of radiation at known exposure parameters.

Measurement data was presented and included as values according to the blank format captured in Appendices II and III. The TLD measurements were analysed and presented in comparison tables and graphs with the difference in dose to the staff between the x-ray tube and II side of the C-Arm. The ionisation chamber measurements were interpreted and calculated to present values in millisievert per hour (mSv/h), milliroentgen per hour (mR/h) and millisievert per minute (mSv/min) in the grid format, according to Appendix III.

Graphs presented the dose distribution of the ionisation chamber measurements.

1.9 ETHICAL ASPECTS

Consent from the patient was not required for the following reasons:

- All patient-related information was confidential.
- No specific patient information was required for the project.
- The study did not influence the radiation dose to patients in any way, as the standard imaging protocols were adhered to.
- The customary patient treatment procedures were not jeopardised by the study.
- No complications, due to the performance of fluoroscopy, were expected.

The Ethics Committee of the UFS confirmed that the ethical principles of the extended study fell within the accepted standards (ETOVS NR 155/06). Permission from the hospital management, the theatre management as well as the neurosurgeon and staff in the specific theatre was obtained [Appendices I(a) and I(b)].

1.10 ARRANGEMENT OF THE DISSERTATION

Chapter 1: *Overview of the study*

Confirmation that the ionising radiation dose limits in this specific theatre were within the limits set by the ICRP merited the investigation of dose distribution.

Chapter 2: *Situation assessment*

The various aspects of radiation protection were presented, based on literature.

Chapter 3*:* *Methodology*

Radiation dose was determined by means of measurements with TLDs and an ionisation chamber.

Chapter 4: *Measurement results*
The difference in radiation dose on either side of the C-Arm was presented.

Chapter 5: *Proposed protocol*
The radiographer was furnished with a protocol for C-Arm orientation and staff placing in theatre during back pain management procedures to optimise the ALARA principle.

Chapter 6: *Conclusion and recommendations*
Research has no purpose if it does not become common knowledge in the field of interest. Although radiation protection is mandatory by law, policing remains the responsibility of the operator.

1.11 SUMMARY

Fluoroscopy during back pain management procedures is associated with radiation doses to staff. Laws are formulated to protect radiation workers against ionising radiation and limits are set on effective doses that staff may receive. The ultimate goal of protection is to keep the dose levels setout by the ALARA principle.

The study was based on determining the radiation levels that staff receive during back pain management procedures. The objective was to propose specific protocols for these procedures involving the position of the C-Arm in relation to the staff. The ultimate goal was to apply the ALARA principle.

In the next chapter the complexity of radiation protection and possible biological effects of radiation will receive attention. Responsibility towards personal radiation protection will only be nurtured if radiographers fully comprehend the fundamental terms, as well as the risks, of radiation. The terms, definitions and dose units regarding radiation that may confuse the

radiographer who is not necessarily familiar with radiation physics, are described in the following chapter.

CHAPTER 2

SITUATION ASSESSMENT

2.1 INTRODUCTION

Working as a radiographer in an operating theatre of a private hospital, the observation was made that the neurosurgeons preferred different orientations of the C-Arm during back pain management procedures. Some preferred the x-ray tube side above the table while others preferred the II side above the table. The orientation of the C-Arm, together with other factors such as position of the neurosurgeon in relation to the x-ray tube and the pilot study measurements, initiated the current study, namely: to determine the radiation distribution levels in this specific theatre. As a non-physicist the description of radiation terminology in plain terms became a goal for personal clarity. In this chapter, the researcher points out the complexity of radiation protection aspects, the global radiation safety standards that have been set, and focuses on the rationale behind protective measures. The radiation dose values of other relevant studies are mentioned to act as a benchmark for the values of the current study.

The literature review was conducted via articles found on the World Wide Web with the use of search engines Ebscohost and Science Direct. The keywords used for the search were: “radiation protection”, “radiation exposure”, “x-ray exposure”, “x-ray dose”, “x-ray protection”, “radiation safety”, “radiation physics”, “radiation distribution”, “radiation levels”, “iso dose lines”, “Berthhold”, “TLD”, “fluoroscopy dose”, “diagnostic reference levels (DRL)”, “C-Arm fluoroscopy” and “ionising radiation safety”. Articles published in journals relating to radiation dose were consulted, for example *Pain Physician* and *SA Journal of Radiology,* handbooks on radiological protection and the Annals of the IRCP. Papers presented at the 11th International Congress of the International Radiation Protection Association in Madrid, Spain, in May 2004, which are available on CD-ROM, provided valuable information. The

attendance of the 46th Annual Congress of the South African Association of Physicists in Medicine and Biology (SAAPMB) on Radiological Protection: Diagnostic Reference Levels, June 2007, concluded the search for relevant resources.

The descriptions of the different units and terms referring to dose levels and absorption of radiation can sometimes be confusing and thus require clarification, which is what the next section will focus on.

2.2 AN OCEAN OF UNITS AND DEFINITIONS

The literature reviewed made us aware of various terms (i.e. exposure, absorbed dose, effective dose, dose equivalent, radiation dose or absorption of radiation) some of which can be confusing. Units such as sievert, grays, roentgen, rem and rad add weight to the conundrum. Since the terms and units form a backdrop to the study, the aim of this section is to clarify these units of radiation and explain the terms that the radiographer should be familiar with.

Exposure refers to the x-ray beam and measure the amount of radiation (ionisation in air) at any particular point. Exposure is measured in roentgen or Coulomb/kg. The roentgen is only a unit for x- or gamma rays. Exposure is a property of the beam and is not measuring absorbed energy (Meredith and Massey, 1977). Air kerma (kinetic energy released in a mass of air) is numerically equal the to absorbed dose in air. The units for air kerma are the gray (Gy) or milligray (mGy) (IRCP, 2001).

Three different dosimetric quantities (ICRP, 1991) are used in radiological protection namely the mean absorbed dose (energy absorbed per unit mass), the equivalent dose (formed by weighting the absorbed dose using the radiation weighting factor) and the effective dose (formed by weighting the equivalent dose using the tissue weighting factor).

The amount of energy that the beam deposits is referred to as the Absorbed Dose and is measured with the unit rad or gray (Gy) as the S.I. unit. (1 gray = 1 joule per kilogram = 100rad). The roentgen can be regarded as the amount of radiation incident to the material and the rad as the amount of energy absorbed as the result of this exposure (Meredith, 1977).

The biological effectiveness of radiations varies – equal absorbed doses of different radiation levels do not produce biological effects of the same extend – thus it is necessary to describe a quality factor for each radiation. This proper term for the specific unit is Equivalent Dose. The dose equivalent (in rem) is the product of the absorbed dose in rads and the quality factor (Meredith, 1977). Dose limits for occupational exposure is expressed in equivalent doses for specific tissues and expressed as effective dose for stochastic effects throughout the body. The SI unit for equivalent dose and effective dose is sievert (Sv) [ICRP, 2000].

The ICRP (1991) uses the term “detriment” to represent the combination of the likelihood of a harmful health effect to occur and a judgement of the severity of that effect. The distribution of the detriment in tissue is determined by taking into account fatal cancer probability, a factor for non-fatal cancer, probability of hereditary effects and relative length of life lost. The distribution of the combined detriment is represented by the tissue weighting factors. The Effective Dose is the sum of the weighted equivalent doses in all the tissues and organs in the body. Effective dose can also be expressed as the sum of the doubly-weighted absorbed dose in all the tissues and organs in the body (ICRP, 1991).

In summary, absorbed dose imparted per unit mass by ionising radiation to matter at a specific point is expressed as gray (Gy) and equivalent dose quantity used for radiation protection purposes is expressed in sievert (Sv). The absorbed dose (in gray) and the dose equivalent (in sievert) are proportional to each other and are related by a quality factor Q, where dose equivalent (Sv) = Q x absorbed dose (Gy) (Wilks, 1981:441). The quality factor indicates the biological effect and is useful in radiation protection

purposes to assess staff doses. Absorbed dose differs from equivalent dose, since absorbed dose quantifies the amount of energy transferred to tissue without reflecting the biological damage that potentially occurred (Miller, Balter, Wagner, Cardella, Clark, Neithamer, Schwartzberg, Swan, Towbin, Rholl and Sacks, 2004).

The difference between the radiation exposure, absorbed dose, dose equivalent and effective dose terms described above is expressed in the following flowchart (see Figure 2.1).

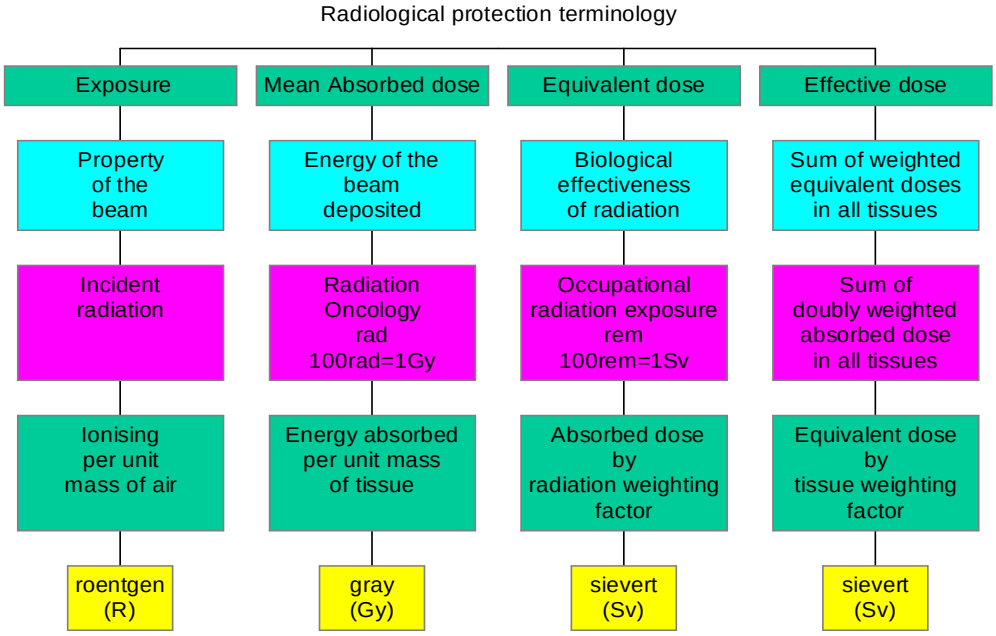

Fig. 2.1 Flow-chart illustrating radiation exposure and radiological protection quantities

Radiation workers in South Africa are monitored by means of a monthly dosimeter (Regulation 247, 1993) issued by a radiation protection service such as that of the South African Bureau of Standards (SABS). The equivalent dose received by registered workers is relevant for this study. The equivalent doses are expressed in mSv. As far as possible, the measurements of the present study will also be expressed in terms of mSv for the purpose of allowing uncomplicated comparisons to be made.

The researcher utilised a Berthold ionisation chamber and Thermo Luminescent Detectors (TLDs) for the measurements of the present study.

The two types of measurement instruments will receive attention before the radiation protection aspects are addressed.

2.2.1 Measurement instruments

TLDs and an ionisation chamber were used for measurements of ionising radiation dose in the present study. The Berthold radiation protection dose rate meter apparatus (Berthold, 1975) is an ionisation chamber consisting of a central electrode in a probe. The cap of the probe behaves the same as a mass of air. Electrons produced in the cap by ionising radiation can penetrate the surrounding air and are attracted to the positively charged electrode because of the potential difference between the cap and the probe (Wilks, 1981). The specific model (TOL/E) utilised during the current study has an aluminium probe with an energy range of 8keV and higher, with a wide measuring range from background to 3000R/h. The probe collected charge that is displayed in milliroentgen on the console of the apparatus.

TLDs are lithium fluoride dosimeters with phosphorescent characteristics. Phosphorescence is caused by the presence of electron traps in the crystal. The number of electrons trapped is proportional to the irradiation dose (Wilks, 1981). Within the phosphor traps, electrons must be re-energized to escape. After irradiation, when the lithium fluoride material is heated in a specially designed oven, a photo-multiplier instrument detects the luminescence. The trapped electrons take part in luminescence referred to as thermoluminescence because of the heating process necessary to give the electrons energy to escape the traps. The photo multiplier instrument displays the luminescence as counts that can be converted to radiation dose after suitable calibration. The counts in the present study were converted to dose values in millisievert (mSv). After the reading of the thermoluminescence count, the dosimeter is raised to a higher temperature and then cooled down – a process known as annealing - to empty the phosphor traps for re-use by the TLDs (Wilks, 1981).

The average atomic number of the TLD is close to that of soft tissue and will therefore be a coefficient with similar absorption qualities. The small

dosimeters are ideal for measuring ionising radiation when placed over soft tissue and seem invisible on the displayed monitor image. The size of the TLD makes it a convenient ionising radiation measurement tool when placed, for example, on the finger of the neurosurgeon during back pain management procedures (Wilks, 1981).

The rationale behind radiation protection must be explained and will be discussed next.

2.3 RADIATION PROTECTION

Staff will not necessarily heed safety limits if they are ignorant of the biological effects of radiation. Every radiation worker requires knowledge of the biological effects of ionising radiation, safety limits, ways to reduce radiation levels and the underlying principles of radiation protection. The effects of radiation will be the focus of attention in the following paragraphs.

2.3.1 Effects of radiation

The radiographer requires a thorough knowledge of the risks involved with the use of x-rays to educate all staff involved in order to compile responsible protocols regarding the ALARA principle. Laws to protect against radiation and knowledge of ionising radiation dose limits will not guarantee safety against radiation exposure (Touzet, 2004a).

The average person receives a radiation dose from natural radiation sources such as cosmic rays (27mrem), terrestrial radioactivity (soil, rock, housing material) (28mrem), inhaled radon (200mrem) and potassium 40 in the body (39 mrem). This natural radiation dose adds up to a rough total of 3mSv (300mrem) per year (Health Physics Society, 2006). The focus of this discussion will however, be on the biological effects caused by ionising radiation doses that are controlled and produced by the human race. X-rays are classified as electromagnetic radiation that may vary in energy, wavelength and frequency. It is ionising radiation because it contains more energy than radio waves or microwaves or visible light (its high energy may

cause ionisation of atoms). The energy can cause biochemical changes that may lead to radiation damage (Henry Ford Health System, 2001). Two main biological effects described by the ICRP, Publication 73 (1996) are deterministic (non-stochastic) and stochastic effects of radiation. The main difference between stochastic and deterministic effects is that stochastic effects MAY occur while deterministic effects ALWAYS occur above a certain dose level (Wilks, 1981).

Deterministic effects appear when many cells in tissue or an organ are killed and, if the dose is large enough, may cause cell loss and impairment of tissue or organ function (ICRP, 1991). The effect is only clinically visible above a certain threshold dose (ICRP, 1996). Above a threshold dose it may present symptoms of skin injury, hair loss and cataracts (Miller *et al*., 2004). Above the threshold, the severity of the effect will increase with dose (ICRP, 1991).

In both patients and medical personnel, exposure of the skin may lead to the development of erythema or a reddening of the skin. An early response (early transient erythema) is seen a few hours after a dose above 2Gy. Cataract-forming may also be caused above the threshold of 2Gy. In fluoroscopically guided procedures, with a short source skin distances and long exposure times, patient skin doses may approach the doses experienced in some cancer radiotherapy fractions (ICRP, 2000). These levels will only be reached after long periods of gross negligence. In such cases, according to the ICRP Publication 85 (ICRP 2000) injuries (such as erythema), to physicians and staff performing interventional procedures have been observed. The skin injuries occur in patients due to poor operational technique during lengthy procedures.

Stochastic (probabilistic) effects cannot be ruled out at low levels of exposure. This statement implies that there is no safe dose below which the stochastic effect cannot appear. It means that any radiation dose will amplify the cancer risk, thus all radiation must be kept to a minimum (Wilks, 1981). Stochastic effects may result when irradiated cells are modified rather than killed. The modified cells may develop into a cancer (ICRP, 1991). There are two stochastic effects namely: carcinogenesis and hereditary effects.

Ionising radiation may cause the chemical change in molecules to form free radicals. The free radicals may damage the DNA of the cell. High doses may kill cells, resulting in damage such as erythema, but low doses, although without observable changes, may produce cells that behave differently and cause them to become malignant (AAPM, 1998). The carcinogenesis effect is also referred to as a somatic effect (ICRP, 1996). An example of the stochastic effect of ionising radiation was induced cancer (Miller *et al.*, 2004). Cancers may appear many years after the radiation was received (Wilks, 1981), which is referred to as the latent period. The average latent period for cancer induction is 20 years, and for leukemia, seven years after radiation (AAPM, 1998). Occupational disease among dentists, before the carcinogenic properties of x-rays were understood, was cancer of the finger that was used to hold the dental x-ray film in the mouths of patients while x-raying their teeth (Henry Ford Health System, 2001). Carcinogenic effects for doses of 1Gy or more radiation delivered at high dose rates are well documented, consistent and definitive (NDT Resource Center, s.a.a). Malignancy may occur even at low doses, but the exact dose-response relationship is not accurately known (ICRP, 2000). The most frequent induced cancers are the female breast, thyroid, lung, bronchus and the alimentary tract (Bushberg *et al*., 2001). There is an increased probability of a future malignancy in organs that are irradiated, especially the breast and bone marrow, “and particularly in children” (ICRP, 2000). The following statement explains the potential extent of the stochastic effects of radiation exposure: “If a population of one million is irradiated with 10mSv effective dose, it will cause 200 more cancers (AAPM, 1998).”

The second stochastic effect is the genetic or hereditary effect (ICRP, 1996). Ionising radiation may damage the genes and chromosomes of the germ cells. Although lower ionising radiation doses result in lower occurrence of genetic changes, slight physical or functional impairment may be passed on to future generations. Reducing man-made ionising radiation is imperative because the chance of occurrence of genetic and carcinogenic effects “is always higher than zero” (Wilks, 1981).

The effects of radiation on the unborn fetus deserve mention since pregnant women my require back pain treatment if they suffer from back pain. At most diagnostic levels this would include risk of childhood cancer, while at doses in excess of 100–200mGy risks related to nervous system abnormalities, malformations, growth retardation, and fetal death should be considered. The magnitude of these latter risks differs quite considerably between the various stages of pregnancy. The above-mentioned dose is higher than the amount reached in most diagnostic radiology or diagnostic nuclear medicine procedures. As an example, a fetal dose of 100mGy is not likely to be reached with 3 pelvic Computed Tomography (CT) scans, nor with 20 conventional diagnostic x-rays of the abdomen or pelvis. At 100–200mGy, the risk of malformations is low, but the risk does increase with increasing dose (ICRP, 2000b). The estimation of fetal dose after fluoroscopy is more difficult than for routine radiographic examinations. Even when fluoroscopy time or useful factors are known, because of the fluoroscopic beam being moved, the exact time of the fetus in the beam is uncertain. However, medically indicated procedures involving ionising radiation are appropriate for pregnant women, but should be avoided if alternate techniques are available. Alternatively measures should be taken to minimise patient/fetal exposure (ICRP 2000b). The effects of ionising radiation substantiate the existence of the radiation protection law.

2.3.2 Why protect against radiation?

The significance of protection against radiation is emphasised. The goal of modern radiation protection is to keep exposures set in accordance with ALARA. The reason is based on the assumption that risks of radiation increase with dose and “there is no threshold dose below which risks cease to exist” (Bushberg, Seibert, Leidholdt and Boone, 2001).

The existence of global and local ionizing radiation protection regulations attempts to ensure protection against radiation (IAEA, 1996) because protection against radiation is mandatory. There are several advisory bodies that issue recommendations regarding radiation protection. The two most widely known agencies are the National Council on Radiation Protection

(NCRP) and the ICRP (Fishman, Smith, Meleger and Seibert, 2002). The South African Department of Health (DoH), Directorate Radiation Control, accepted the conditions, stated by the ICRP regarding the policy on protective clothing (DoH, s.a.a). The conditions stated by the ICRP Publication 57, paragraph 174 (1998), dictated that workers shall wear a protective apron of at least 0.25mm lead equivalence when in the area where the x-ray machine is operated. Additionally, any person standing within one metre of the x-ray tube when the machine is operated at tube voltages above 100 kV should wear a protective apron of at least 0.35mm lead equivalence. More than 90% of the scattered radiation incident on the lead apron is attenuated by the 0.25mm thickness at tube voltages less than 100kVp (Bushberg *et al*., 2001).

The neurosurgeon who monitors injections with fluoroscopy cannot avoid ionising radiation during back pain management procedures because of the proximity from the x-ray source and patient. Every radiation worker should, however, concentrate to lower the absorption by biological tissues because adverse biological effects of long-term low dose radiation exposure remain unclear at this point in time. As mentioned previously, malignant as well as genetic change after radiation exposure is a possibility (Zhou *et al.*, 2005).

Since more than 20 years have passed in technology development that accelerated the widespread use of many image-guided interventions, the potential risk of occupational radiation exposure may be difficult to establish (Haku, Hosoya, Ito, Eguchi, Watanabe and Nishina, 2002). Pain management procedures are an example of an intervention relatively new in reporting issues related to radiation exposure (Manchikanti *et al*., 2003). Although the widespread use of fluoroscopy contributes about 90% of the annual collective dose to staff in diagnostic radiology, the interventional and fluoroscopy procedures have not yet reached a level of optimised protection comparable to general radiology and CT (Al-Haj, Lagarde and Lobriguito, 2004).

Analysis of occupational doses should be part of a continuous radiation safety programme. Risks and benefits must, however, always be balanced (ICRP, 1991). According to Vetter (2004), the safety of the patient should be a

continued effort to balance lowest diagnostic x-ray dose with increasing quality diagnostic information: “Field based research is essential in the emerging field of patient safety to create the evidence as to which technologies actually improve patient safety and those that may well increase the potential for harm”.

Although it is law to wear the prescribed thickness of lead apron as radiation protection, the researcher is of the opinion that the safety aspect of radiation protection must be reiterated to all role players involved in fluoroscopic procedures. Radiation is potentially dangerous, and more so because its presence cannot be perceived with human senses (Vetter, 2004). The uncertainty of the cumulative effect of radiation on staff members who are chronically exposed to low doses of radiation, such as during back pain fluoroscopic procedures, boils down to the one concern, namely the stochastic effect of radiation (Zhou *et al.*, 2005). The daily challenges for a radiographer remains to consistently keep radiation levels ALARA.

All radiation workers or staff exposed to radiation should be familiar with the safety limits set for radiation dose.

2.3.3 Safety limits

Ionising radiation causes both deterministic and stochastic effects in irradiated tissue. Radiological protection aims to avoid the deterministic effect by setting dose limits below the thresholds and to limit risks of stochastic effects (Bushberg *et al*., 2001). The stochastic effects that are believed to occur with low doses, below 2Gy, have been taken into account at all dose limits (ICRP, 1991).

The effective dose limit for non-radiation workers is set at 1mSv per year, and is not to exceed 5mSv over five years. The recommended effective dose limit for radiation workers differs from the allowed public dose and is set at 20mSv per year, not to exceed 100mSv over five years. A further provision is that the effective dose should not exceed 50mSv in one year. Specific higher dose limits for radiation workers are determined for the lens of the eye at

150mSV/year, with the skin and hands at 500mSv/year respectively (ICRP, 1991). In South Africa the DoH recommends that restrictions on the effective dose of 20mSv per annum are sufficient to ensure an acceptable risk of stochastic effects (DoH, 2001), except for the skin and the eyes. Specific higher dose limits are indicated for the lens of the eye at 150mSv/year, with the skin and hands at 500mSv/year respectively (Regulation 247, 1993).

The ICRP 73 Report introduced the term “Diagnostic Reference Levels” (DRL) in order to advise local authorities to investigate unusually high levels and not to constrain dose levels (ICRP, 1996). DRL applies to medical exposure, with the goal of achieving diagnostic information on doses to the patient. DRL’s are then used to manage the dose (ICRP, 2007). The dose levels act as a reference to compare values in one’s own environment with previous recorded values. It is important to realise that, while the radiographer aims to lower the radiation dose to the patient, it will facilitate to control the dose to staff (Herbst, 2007). Fishman *et al.,* (2002) explained that staff would receive roughly 0.1 % of the patient entrance exposure if at a distance of 1m from the patient. DRL’s are then also managing the doses to the staff. For fluoroscopically-guided procedures, the observed distribution of patient doses is extensive because the complexity and duration of the procedure is dependent on clinical circumstances such as placing of stents or injecting contrast into disc spaces. It is important to monitor in real time if threshold for deterministic effects is approached for the specific procedure (ICRP, 2001). “At doses higher than 100mSv, there is an increased likelihood of deterministic effects and a significant risk of cancer. For these reasons, the Commission considers that the maximum value for a reference level is 100mSv incurred either acutely or in a year. Exposures above 100mSv incurred either acutely or in a year would be justified only under extreme circumstances, either because the exposure is unavoidable or in exceptional situations such as the saving of life or the prevention of a serious disaster. No other individual or societal benefit would compensate for such high exposures” (ICRP, 2007).

2.3.4 Radiation protection aspects

The available studies regarding protection against radiation brings one to the realisation that the radiation protection concept is complex because it involves various aspects, such as the fundamental principles of protection, the distance from the source, scattering of radiation in- and outside the lead rubber aprons, the position of the neurosurgeon in relation to the C-Arm and the experience of the neurosurgeon to execute procedures. All of these aspects are discussed in the following paragraphs.

According to Manchikanti *et al*., (2003), the primary source of radiation is scatter from the patient. Scattered radiation occurs due to the Compton effect, when an incident x-ray interacts with a loosely bound outer-shell electron of an atom deflecting the x-ray from its original path. The protection from the scattered x-rays emanating out of the patient is therefore necessary (Fishman *et al*., 2002). Applying certain principles during fluoroscopy can lower scatter, for example: maintaining maximum distance from the source of x-rays; utilising shielding material; minimising exposure time; applying intermittent fluoroscopy; applying last image holding and applying electronic collimation and adjustment of beam quality (Manchikanti *et al*., 2003). These principles are discussed as recommendations in Chapter 6.

Maximum distance from the source of radiation varies according to every unique situation. During back pain procedures in the current environment, it is observed by the researcher that the neurosurgeon needs to be very close to the x-ray source in order to administer the injectate. The neurosurgeon visualises the placement of the needle by means of fluoroscopy and his hand holding the needle is directly in the beam. The opinion of the researcher is that although applying the fundamental principles previously mentioned that may reduce the dose, such as intermittent fluoroscopy and last image holding, the exposure of the neurosurgeon's hands cannot be totally eliminated.

Every individual physician influences radiation levels. The experience of the neurosurgeon in the current situation, the visualisation in multiple views and the number of regions treated (Manchikanti *et al*., 2003) are variables. It is

therefore impossible to estimate exposure to the individual neurosurgeon in the current environment based solely on dose levels reported in literature. It is imperative to take the variables of each unique environment into account and to put measures into place so as to adhere to the ALARA principle in every specific situation.

There are global and local regulations to ensure protection against radiation (IAEA, 1996) but the challenge for a radiographer is to consistently keep ionising radiation levels in accordance with ALARA. It is a daily task that must be reviewed regularly because, due to the cumulative effect of radiation, staff members - who are chronically exposed to low doses of radiation - are vulnerable to the stochastic effect of radiation (Zhou *et al.*, 2005).

To complicate matters even further, one must bear in mind that lead rubber jackets used as shielding material do not protect every part of the body (Niklason, Marx and Chan, 1993). Lead jackets with a minimum 0.25mm Pb equivalent do protect most of the 12 most sensitive organs in the body. The 12 protected organs are the gonads, bone marrow, the colon, the lungs, the stomach, the bladder, the breast, the liver, the oesophagus, the thyroid, the skin and the bone surface (Niklason *et al*., 1993). However, the area of the head and limbs that are generally not covered by the lead rubber apron may receive a higher annual dose.

The effectiveness of protective measures to reduce scatter in the upper and lower parts of the body was evaluated during fluoroscopically guided intervention techniques (Machicanti *et al*., 2003). Scatter radiation exposure was higher outside the lead aprons compared to inside the apron. Extra shielding around the fluoroscopy table decreased scattered radiation outside and inside the protective apron at all levels, except for inside the groin area. Scatter radiation inside the apron in the groin area was similar with or without shielding from the floor. In the current study, investigation of the doses received at the upper and lower levels of the body needs to be addressed to complete the radiation distribution picture (Manchikanti *et al*., 2003).

Rules governing the use of the C-Arm in the United Kingdom (UK) suggest that the radiation source should be placed below the patient (under the couch x-ray tube) and the image intensifier above. The inverted C-Arm technique with the image intensifier under the patient (over the couch x-ray tube and an under the couch image intensifier) can, however, reduce the radiation to the surgeon and the patient during surgical procedures on upper extremities (Tremains, Georgiadis and Dennis, 2001). With the inverted C-Arm technique of the Tremains study, the distance between the x-ray tube and the phantom (upper extremity) was doubled. This increase in distance led to lower exposure of the phantom-hand that follows the inverse square law (which describes the reduction in radiation intensity with increasing distance from the x-ray source).

Lower radiation levels were recorded at the groin area of the surgeon (closest to the II) when compared to the head, although the groin and head were equidistant from the source (x-ray tube). The reduction in radiation levels to the groin may be due to the housing of the II, that acts as a radiation barrier between the scattering source and the surgeon. The chest area of the surgeon, with the C-Arm inverted, received the highest radiation values because of the proximity of the chest to the scattering source. With the tube above the table in upper extremity surgery, the dose rate to the patients hand was reduced and the radiation exposure to the surgeons hands and body was reduced (Tremains *et al*., 2001). Although pain procedures differ from protocols regarding extremities, the above-mentioned study measured lower radiation levels with the C-Arm configuration inverted (II under). Thus, the configuration of the C-Arm needs planning for every unique situation. It was important to determine radiation dose levels in this current theatre because the inverted C-Arm technique was used routinely during back pain procedures (see Figure 2.2).

Fig. 2.2: Inverted C-Arm with the Image Intensifier under the table

A study to design a radiation protection system for extra shielding around an x-ray tube and II during interventional procedures of the upper extremities (Haku *et al*., 2002) measured doses at different body heights to ensure the exact information of radiation distribution on all levels of radiosensitive organs. Measurements were taken at 50, 100 and 150 cm heights from the floor. Dosimetry of the scattering dose rate around the angiographic table was measured at intervals of 25cm. The ideas used in the Haku study, where dosimetry is measured at different heights and intervals occur at 25cm, were applied in the current study.

In this specific neurological theatre, the x-ray tube is positioned above the patient to satisfy the preference of the neurosurgeon for various reasons - effortless visualisation of the C-Arm monitor and increased distance of the x-ray apparatus from the sterile area without overmagnification of the x-ray image on the monitor (Van der Merwe, 2005: personal communication). The main reason, however, is to speedily alter the C-Arm position over the patient from a vertical PA position into a horizontal lateral position. Most theatre tables do not accommodate the movement of the C-Arm through the arc

underneath the table. A specially designed screening table utilised in the current study (refer to Figure 2.2) however, can accommodate this movement.

Although the AAPM Report (AAPM, 1998) indicates that the operator should stand closer to the II side of the C-Arm (in the lateral position) to lower radiation doses, it is not always practically possible or comfortable to position the neurosurgeon on the II side or to place the II above the table. The placement of the needle in a sterile environment often requires that the x-ray tube be positioned above the table to minimise magnification of the vertebra, especially with an overweight patient. However, if radiation dose distribution of the present study confirms that the dose levels are higher with the x-ray tube positioned above the table, the change in position of the neurosurgeon in relation to the C-Arm can be proposed.

The expertise of the surgeon seems to influence the radiation dose received by the patient during back pain procedures. In a study by Zhou *et al.,* (2005), lower fluoroscopic exposure times for various interventional procedures were recorded for private practice when compared to university academic environments due to different experience levels. The mean fluoroscopic time for lumbar epidural injections was 46.6s ± 4.2s at teaching hospitals. Studies by Botwin and other individuals confirmed that the radiation exposure was higher in a university setting (Botwin, Freeman, Gruber, Torres Rames, Bouchlas, Sarelli and Hanna, 2001), with average exposure times of 12.55s on caudal epidural injections in a private setting. This current study was conducted in a private practice environment with the assistance of two neurosurgeons with more than five years of experience in back pain injections. The neurosurgeons of the current study are considered skilful because average exposure times of 16.1s per patient for the epidural injections (recorded prior to the current study) compare to the epidural injection fluoroscopic time of 12.55 -15.16 seconds reported by Botwin (Zhou, 2005). The experience factor of the two neurosurgeons should result in the lowest possible exposure dose to the patient and the environment.

The various above-mentioned aspects, with human efforts added to the equation, are perfectly suited to be investigated by means of practitioner-based research. The radiographer-practitioner aims at a way of more effective protection against radiation, takes stock of the outcomes; and then modifies current radiation protection protocols in the light of the findings (McNiff, 2002). The various factors that influence radiation dose levels make it impossible to address all the issues about radiation protection in the same study.

It is essential to treat ionising radiation with care rather than fear. One needs to keep a balanced perspective by taking other risks into account and consciously heed against illogical thoughts about ionising radiation. Comparing radiation doses with other studies will give an indication of the uniqueness of the dose levels within a specific theatre.

2.4 COMPARISON AND PERSPECTIVE OF AVAILABLE DOSE MEASUREMENTS

Diagnostic reference levels (DRL), in principle, can be used to promote management of patient doses in order to avoid stochastic radiation risk (ICRP, 2001). Reference levels give professionals worldwide values of comparison and are not linked to limits or constraints. The idea is to help avoid radiation doses to the patient that do not contribute to the clinical purpose of a medical imaging task (ICRP, 1996). The patient's effective dose was measured in this neurological theatre study for future referencing purposes. The focus of this study, however, was on the effective dose received by the radiographer and neurosurgeon closest to the theatre table during back pain management procedures. Some of the radiation values that radiation workers are exposed to during fluoroscopy, that were found in literature, are mentioned in the following paragraphs. Although the references are not all specifically related to back pain procedures, it may add perspective to the radiation dose levels staff are exposed to.

Manchikanti *et al*. (2003) measured doses of 3.13mSv and 0.006mSv outside and inside the lead apron respectively and, of radiation workers at chest level for an average irradiation time, 8.9 ± 0.4s per patient. The corresponding

doses at the groin level were 1.76mSv and 0.0035mSv. This study showed that protective measures (i.e. lead shielding from the table to the floor) lowered scatter radiation exposure at all levels, outside and inside the apron, except for inside the groin.

Another study that included 35 interventional radiologists calculated an annual radiation dose and converted it to an effective dose to relate the risk associated with non-uniform dose to that associated with an equivalent uniform whole body dose. The mean annual effective dose of 3.16mSv (0.37-10.1mSv) was measured by means of a dosimeter inside and outside the apron (Niklason *et al*., 1993). The dose for these interventional radiologists is equal to the background dose of 3mSv per year from natural sources. The National Council on Radiation Protection and measurements recommended that the effective dose should be used instead of a single dosimeter reading. The annual radiation risk of fatal cancer, according to the above authors, would be one in 10 000 for the entire career of an interventional radiologist. The reader is reminded that interventional radiologists do not necessarily position themselves close to the x-ray source, compared to neurosurgeons performing back pain procedures who use a short needle for injection purposes. The highest annual over collar dose received by an interventional radiologist during a five-year study in Saudi Arabia was 24.1mSv (Al-Haj *et al*., 2004).

Data was collected from 165 spinal injection procedures including transforaminal caudal and interlaminar epidurals (Zhou *et al*., 2005) showing an average exposure of 46.6± 4.2 seconds.

The U.S.A. patient typically receives radiation to the skin at a rate of 2R per minute and as high as 30R per minute when using a high dose rate mode if the patient skin is close to the collimator (AAPM, 1998). The AAPM report further indicates that exposure rates to staff involved in fluoroscopy are lower because staff standing 1 m away from the patient would receive 1/1000 of the patient's exposure. The maximum legal exposure rate for normal dose rate fluoroscopy to the patient is 10R/min (Bushberg *et al*., 2001). The typical staff

exposure at the tableside during fluoroscopy is 2mGy/hr and, at the thyroid level, 2-5mGy/hr (AAPM, 1998).

The aim of the Haku study (Haku *et al.,* 2002) was to test a specific radiation protection system (made up of acrylate with a 0.50 Pb equivalent and lead curtain with a 0.35mm Pb equivalent), namely a x-ray tube cover and II hood cover, by measuring the dose rate at different heights from the floor during fluoroscopy of the upper extremities. Although higher exposure factors are necessary for imaging of the spine when compared to extremities, the values obtained in the Haku *et al.* study (2002) are worth mentioning for comparison purposes. Values of 116μR/min (1.16μSv/min) at a height of 50cm from the floor, 86μR/min at 100cm and 59μR/min at 150cm from the floor were recorded. For the measurements, the x-ray tube was positioned under the table. Maximum dose levels estimated were: 938μR/min to the hands, 82μR/min to the lens and 312μR/min to the lower extremities.

Higher dose levels of 600μSv/min (0.6mSv/min) to the hand of the surgeon holding the needle during back pain management procedures were recorded whilst positioning a pedicle screw (Zeiller, Lee, Lim and Vaccaro, 2005). The difference in dose values to the hands between the Zeiller and Haku studies can be explained by the thicker anatomical part of the spine compared to upper extremities and the closer proximity of the hands placing screws in the radiation field. In the Haku and co-worker study (2002), the manual injection of contrast is mostly avoided with the use of auto injectors. The hand of the neurosurgeon in the current study is placed directly in the x-ray beam whilst positioning the needle during back pain procedures. Gloves with the recommended 0.35mm lead equivalent (DOH, s.a.a) are heavy and, due to the non-flexibility, not used during injections.

At the Florida Spine Institute, radiation exposure was monitored performing fluoroscopically-guided lumbar injections. For one hundred consecutive patients, the average fluoroscopy time per procedure was 15.16 seconds. The average exposure per procedure was 0.7mrem (0.007mSv) at the ring badge, 0.004mSv at the glasses badge, and 0.003mSv at the outside apron badge (Botwin, Thomas, Gruber, Torres, Bouchlas and Rittenberg, 2002).

Although the interventional procedure studies of Vano (Vano, Gonzalez, Fernandez, Prieto and Guibelalde, 2005) and Paulson (Paulson, Sheafor, Enterline, Page Mc Adams and Yoshizumi, 2001) differ from fluoroscopy in theatre, it is mentioned to put the measurements of the current study in perspective. In the Radiological Department of the Complutense University, the scatter dose rates at the cardiologist's position, ranged from 1 to 14mSv per hour for fluoroscopy (Vano *et al*., 2005). The dose to the radiologist during CT Fluoroscopy-guided procedures was 2.5mrem (0.025mSv) per procedure (Paulson *et al*., 2001). The individual finger doses during the CT procedure ranged from 0.66 to 4.75mrem (0.0007- 0.047mSv).

The DoH in South Africa recommends that non-radiation workers two metres away from x-ray tube head during operation do not need extra shielding "provided that scattered radiation at a distance 30cm from any point from the source is less than 20mR/h" (DoH, s.a.b). The conversion calculates 0.2mSv per hour and 0.0003mSv per minute. It is, however, not referring to the registered radiation worker close to the x-ray source. The determination of the specific dose equivalent for the neurosurgeon during back pain management procedures with a C-Arm was conducted to evaluate the ionising radiation risk close to the table.

The exposure values and duration time of the above mentioned procedures are summarised with mSv conversion for comparison purposes in Table 2.1 (see Table 2.1).

Table 2.1 Comparison of studies in literature with reference to procedures, exposure time,

radiation dose values and mSv conversion

Reference	Procedures	Fluoroscopy duration	Radiation dose levels	mSv conversion
AAPM 1998	Tableside fluoroscopy in the U.S.A		Typical patient exposure of 2R/min (Staff 1/1000) Typical staff exposure at the table side is 2 mGy/hr and at thyroid level 2-5 mGy/hr	20mSv/min- patient 0.02mSv/min- staff 2mSv/h 2-5mSv/h
Botwin *et al.*, 2002	Fluoroscopically-guided lumbar injections	Average fluoroscopy time per procedure was 15.16 seconds	Average exposure per procedure 0.7mrem ring badge, 0.4mrem glasses 0.3mrem outside apron No radiation inside apron.	0.007mSv/patient at the finger 0.03mSv/ minute 0.003mSv/patient outside the apron (0.012mSv/min)
Bushberg *et al.*, 2001	Maximum legal exposure rate to the patient for normal dose rate fluoroscopy		10R/min to the patient	100mSv/min
DoH 1973	Scatter radiation at distance of 30cm from any point from the source		Must be less than less than 20mR/h	0.2mSv per hour or 0.0003mSv/min
Haku *et al.*, 2002	Angiography-extremities With automatic injector		Staff dose: 938µR/min hands 82 µR/min eye lens 312 µRv/min- lower extremities.	9.83 Sv/min 0.00983mSv/min to the hands 0.003mSv/min to extremities
Manchikanti *et al.*, 2003	Back pain management	8.9 ± 0.4per patient	0.629 mREM outside apron - chest - per patient Highest 313mREM Thus 3.13mSv (21mSv/minute) 0.352 mREM outside apron - groin - per patient	0.006mSv outside apron per patient chest (0.04mSv/minute) 0.003mSv outside per patient groin 0.02mSv/min groin per patient
Niklason *et al.*, 1993	Interventional radiologists		Mean annual effective dose of 3.16mSv Predicts mean annual over collar dose of 4.8 rem and mean annual under apron dose of 88mREM	0.003mSv/patient 48mSv 0.88mSv
Vano *et al.*, 2005	Cardiology		1-14mSv/hr	
Zeiller *et al.*, 2005	Placement pedicle screw		600 µSv/min to the hand of the surgeon	0.6mSv/min - hand
Zhou *et al.*, 2005	Fluoroscopically-guided pain procedures	Average of 46.6±4.2 seconds		

Table 2.1 indicates the following: As reference to the current study, the typical tableside fluoroscopy mentioned in the AAPM report of 20mSv/min to the patient may indicate that staff will receive 1% of the dose to the patient, (i.e 0.02mSv /minute). In the Botwin *et al.* (2002) study, with 15s exposure times, the dose measured outside the apron was 0.012mSv/ minute. The Manchikanti *et al.,* (2003) study, measured outside the apron at the chest level, measured 0.006mSv per patient. With the 8.9s average exposure per patient, the dose will be 0.04mSv/minute to the chest and 0.02mSv/minute to the groin area. In the Zeiller study (Zeiller *et al*., 2005) the dose recorded to the hands placing a pedicle screw was 0.6mSv/minute and, in the Botwin study (2002), 0.03mSv/min to the ring badge was recorded. The fluoroscopy duration during back pain procedures varied between 46.6 seconds (Zhou *et al*., 2005) and 8.9s (Manchikanti *et al*., 2003).

2.5 SUMMARY

Terms regarding radiation were explained, such as that the absorbed dose does not reflect biological damage and paves the way for the use of the term “equivalent dose”. The equivalent dose is calculated by multiplying the absorbed dose in Rad or Gray by a specific weighting factor for ionising radiation. The equivalent dose is expressed in Sievert (Sv). Reference levels and radiation limits globally aim to protect radiation workers against radiation. Monitoring of the dose that radiation workers receive is policy in most countries. In South Africa, the equivalent dose received by registered workers is expressed in mSv. The stochastic risks that are associated with low dose fluoroscopy reflect the uncertainty of damage caused by x-ray exposure and radiation protection is thus compulsory.

One way to control radiation risks is to set occupational dose limits that apply to occupational and public exposures. Radiation dose can be lowered by applying certain fundamental principles such as maintaining maximum distance from the source of x-rays, utilising shielding material and minimising exposure time to maintain the concept of keeping radiation levels “as low as reasonably acceptable” (ALARA).

The fact that the radiation workers implement all these guidelines does not eliminate the exposure of radiation to staff members. It should be realised that lead rubber aprons used as shielding material do not protect every part of the body against ionising radiation. It is imperative to take the variables during fluoroscopy of back pain procedures of each unique environment, in different settings with different neurosurgeons into account and to put measures into place to reduce scatter radiation for every specific procedure.

Various studies to design radiation protection systems reiterate the difference in radiation values at different body heights. The above-mentioned values tabled from the studies consulted in literature will be compared with the measurements recorded during the present study and listed in Chapter 4. The highest equivalent dose recorded in the above-mentioned literature per patient, for lumbar injections, was 3.13mSv outside the apron on the chest level (Manchikanti *et al*., 2003). The highest radiation dose to the hands was 0.6mSv/min (Zeiller *et al*., 2005).

The specific methods utilised to measure the radiation levels received by the staff in this specific theatre are explained fully in Chapter 3.

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

It was imperative to confirm the ionising radiation levels staff, assisting with back pain management procedures in the fluoroscopic neurological theatre, was exposed to. Radiation levels recorded in literature may not just be randomly linked to procedures in the theatre under discussion because, due to variables every situation is unique. These variables, as previously mentioned, namely skill of the surgeon, specific injection protocols and positioning of staff around the table, are unique in every situation and may influence radiation doses.

The aim of the study was to determine the radiation doses to the neurosurgeon close to the theatre table and the x-ray source; the radiographer on the opposite side of the theatre table; and assisting staff present in the room in this specific theatre. The dose levels were measured on both sides of the C-arm, x-ray tube or II side, as well as at different body heights.

The objective of the study was to determine areas for the theatre staff to maximize radiation protection during fluoroscopy. The research will be futile if the results are not implemented so as to apply with the ALARA principle. Thus, the foundational objective is to propose protocols with regard to the position of the C-Arm in relation to the neurosurgeon and other staff during back pain management procedures.

The methodology will be described in detail in this chapter, followed by the recorded measurement data in Chapter 4. Measurements were twofold, namely TLDs and an ionisation chamber. The two sets of measurements were correlated to confirm distribution of dose. The methodology sequence flow chart (refer to Figure 3.1) presents the twofold layout of the study.

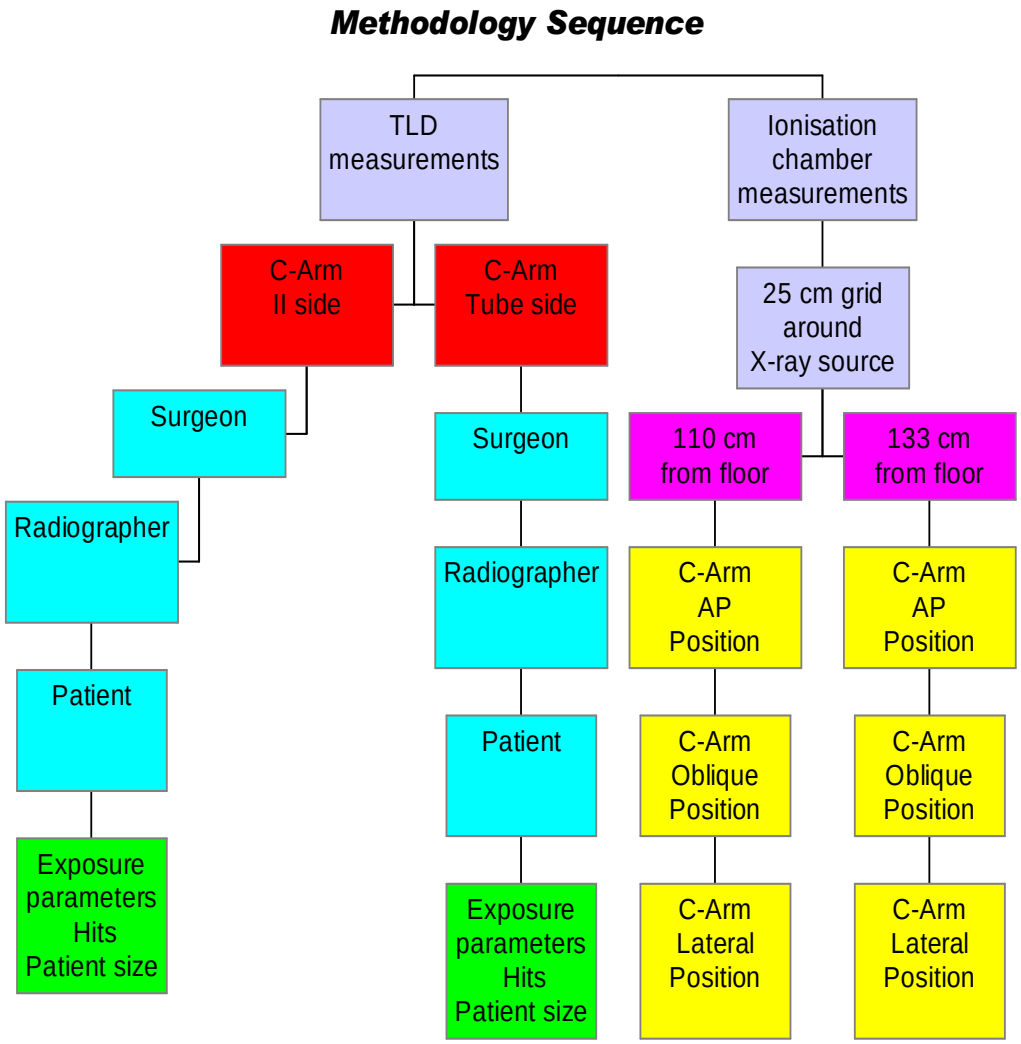

Fig 3.1: Flow-chart illustrating the layout of methodology

3.1.1 Configuration of the C-Arm

The C-Arm orientation throughout the study was depicted taking into account the assumption that the patient or phantom was in the prone position. The tube positioned above the theatre table with the x-ray beam in a vertical position, was described as posterior anterior (PA). During the PA position, the x-ray tube side was closest to the neurosurgeons chest area. The x-ray tube under the table was described as the anterior-posterior (AP) position. When the x-ray tube was above the table, the C-Arm in 45-degree angles from the vertical position was referred to as posterior oblique (PO). This meant that the neurosurgeon was closest to the x-ray tube side with the x-ray beam directing

away from him in the right posterior oblique (RPO). The lateral (LAT) position of the C-Arm implied that the x-ray beam was horizontal and that the staff could be positioned on either the x-ray tube side or II side of the C-Arm.

3.2 MEASUREMENTS

The Department of Medical Physics, National Hospital, Bloemfontein made the Berthold ionisation chamber apparatus available. The x-ray Department of the Universitas Academic Hospital made the phantom available for the ionisation chamber measurements. The phantom consists of human bone retrieved from the lower body and spine covered in Perspex to represent the thickness of a human body. The researcher purchased 14 new TLDs for the measurements of staff and patient radiation dose equivalent.

The first part of the measurement entailed TLD measurements to determine the dose that the neurosurgeon, the radiographer and the patient receive. The difference in dose to the neurosurgeon when standing on either side of the C-Arm, x-ray tube side or II side, was compared. The x-ray tube was routinely placed above the table (over couch x-ray source) during the procedures. Another set of measurements was conducted with the x-ray tube under the table. TLDs were placed on the pelvis, chest and finger in the beam of the neurosurgeon during back pain procedures. TLDs on the chest and pelvis of the radiographer determined radiation levels close to the x-ray source opposite the neurosurgeon. TLDs on the patient recorded the radiation dose to the area of the patient which was irradiated, whilst exposure factors, patient size and the number of injections (hits) were recorded for future reference.

3.2.1 TLD measurements (see Appendix II)

TLDs were used to collect data in the form of counts, which could be translated into radiation dose. The principal researcher marked the period number and C-Arm side (Tube or II) on the blank form (refer to Appendix II). During the x-ray tube side period, the neurosurgeon stood on the x-ray tube side of the C-Arm during the lateral view of the procedure and remained on that side. The x-ray tube was above the prone patient during the PA

injections. During the II side period, the II side of the C-Arm was positioned above the theatre table.

Once the patient was sedated and the procedure started, the radiographer and the neurosurgeon placed the TLDs in the anatomical positions indicated on the TLDs (i.e. Doctor Chest, Patient). The TLDs all remained in position for the entire duration of the procedure. The radiographer operated the x-ray unit by positioning the x-ray tube to display the anatomical part (facets) and the neurosurgeon placed the needle into the joint or space to inject the appropriate injectate. On completion of the procedure, the radiographer placed all the TLDs back into the appropriate containers so as to be kept away from the x-radiation.

The radiographer recorded the following data automatically available from the fluoroscopic unit: the screening time (s), the kilo Voltage (kV) and the x-ray tube current (mA). The weight and height of the patient was available from the patient file to calculate the body mass index (BMI) of each patient for future studies (refer to Appendix II – Procedure measurements).

Before commencing with the measurements, the distances from the neurosurgeon's pelvic and chest TLDs to the x-ray centre point on the patient were determined. The radiographer measured the distance of the neurosurgeon's TLDs from the x-ray tube to explore the possibility of a routine distance for future reference. The distance was observed to be a distance that was comfortable for the neurosurgeon, making injections into the facet possible. It was also observed that this distance of about 38cm was not fixed because the neurosurgeon had to adjust his stance according to the anatomy of each individual patient. The purpose of this measurement was to locate the neurosurgeon's position on the grid relating to the ionisation chamber measurements. The neurosurgeon and the scrub nurse counted the number of injections of injectate per patient (Hits). The radiographer recorded the data (refer to Appendix II - Procedure measurements).

After a batch of 10 patients on the specific side of the C-Arm, the radiographer, under supervision of a physicist, read out the counts collected

by means of TLDs and the physicist calculated the values to present the radiation doses in mSv (see Appendix IV a-d). The TLDs were then annealed to erase all dose memory so that they were ready for use on the 10 patients to follow. The procedure was then repeated for the alternating side of the C-Arm according to the next period until an equal number of cycles for each side of the C-Arm were completed. TLD measurements with the x-ray tube under the theatre table completed the current measurements.

Specific procedure for TLD measurements

19 TLDs were needed in the operating theatre for each procedure:

a) Seven TLDs were calibrated (kV values between 64-110kV) to ensure accurate measurements as well as for background radiation measurement purposes. The TLD's were calibrated to determine the sensitivity calibration factor, which was used for the sensitivity correction of each TLD. Each group of TLDs was initially annealed in an oven and irradiated with a 90Sr/90Y radioactive source to the same dose. It was read out in a TLD reader (Toledo 654, Vinten Instruments). The annealing and irradiation procedures were repeated five times to determine the reproducibility and the standard deviation of each TLD within the group. Individual reproducibility was better than 5% and the standard deviation less than 1%. The sensitivity uncertainty of the total set of the TLDs was estimated to be 1% (see Appendix VIII). The calibration factor per batch was obtained by irradiating four TLD's from each batch in a 100kV orthovoltage beam that had been calibrated against a secondary standard dosimeter. The TLDs were calibrated at 100kV, as this was the nearest available energy to the average kilovoltage for the LAT projection in this study.

b) TLDs were marked and placed in protective sachets. Each TLD had a specific number allocated to the anatomical part, as indicated in Appendix II – TLD measurements.

   Neurosurgeon: (Five TLDs): Two were placed in the pelvis area, opposite the umbilicus, two on the right upper corner of the theatre shirt pocket; and one on the proximal phalanges of the index finger holding the needle in the

x-ray beam. The distance from the floor to this specific surgeon's umbilicus was 110cm and 133cm to the chest. It was noted that the neurosurgeon did not face the patient directly, but because he is left-handed, his right side was closer to the x-ray tube. The chest TLDs were placed on his right side rather than the left pocket to be closer to the x-ray source during the injection (see Figure 3.2).

Fig 3.2: Placement of TLDs on the surgeon's finger, chest and pelvis area

Radiographer (Four TLDs): Two on the left upper corner of the lead apron and two opposite the umbilicus on the outside of the apron (refer to Figure 3.3).

Fig. 3.3: Placement of TLDs on the radiographer's chest and pelvis area

Patient: (Three TLDs) TLDs were placed in each beam field with the surgeon's field of view - for example, anterior on the patient when the x-ray tube was under the theatre table (AP) or posterior on the patient when the x-ray tube is positioned above the theatre table (PA). The TLDs were changed to the side of the patient, to be closest to the x-ray tube side of the C-Arm, during lateral views (see Figure 3.4).

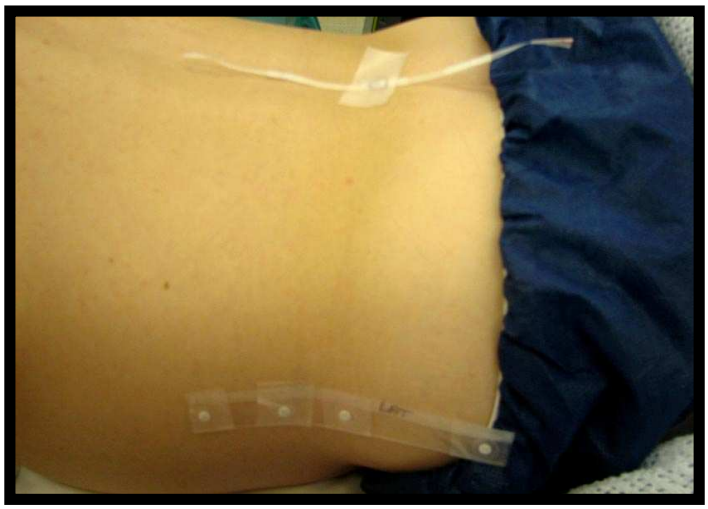

Fig. 3.4: TLD placement on the patient in the lateral and PA positions

c) The TLDs were placed in the sachets on the edges and in the centre of a 15cm narrow ruler. The ruler was sterilised with 90% alcohol spray every time before use. The doctor cleaned the injection area before the radiographer placed the ruler on the patient's area of interest. The PA TLDs were placed in the middle of the spine with the center of the strip on the level of the 4^{th} lumbar vertebra, opposite the upper margin of the iliac crest. The lateral marker strip centre was placed in the centre of the side of the patient at the level of the coccyx. For the lateral view, the bottom part of the 15cm strip with the TLDs, was placed on the level of the femoral greater trochanter. No sterility was needed in the lateral region because the injection occurred in the middle of the spine and the lateral TLDs were placed on the side of the patient (refer to Figure 3.4).

d) The C-Arm side period was indicated (refer to Appendix I) and the following information was recorded on the form: kV and mA in the PA position, kV and mA in the lateral position, weight of patient, height of the

patient, BMI, number of injections (hits), and exposure time during the procedure.

e) Between procedures the TLD's were placed into containers to ensure protection from ionising radiation.

f) After each batch of 10 patients, the TLDs were taken to the laboratory in order to count the doses accumulated during examination and the deduction of values. The TLD counts were recorded on the form (refer to Appendix IV a-d) so as to be analysed by the biostatistician.

3.2.2 Ionisation chamber (see Appendix III)

The second sets of measurements utilised an ionisation chamber and a phantom to simulate the patient. The researcher determined the radiation distribution around the theatre table by means of a radiation protection dose rate meter (Berthold TOL/E, model Berthold LB1310). Radiation dose was measured around the x-ray source and fluoroscopic table by placing the ionisation chamber at fixed 25cm intervals around the table in accordance with the grid (refer to Figure 3.5), altering the height of the chamber from the floor to 110cm and 133cm respectively. The specific surgeon's umbilicus was 110cm from the floor and the chest area, specifically the left pocket, 133cm from the floor. The ionisation measurements were conducted with the C-Arm in the PA, PO and LAT positions. The phantom, simulating the patient, was positioned in a prone position.

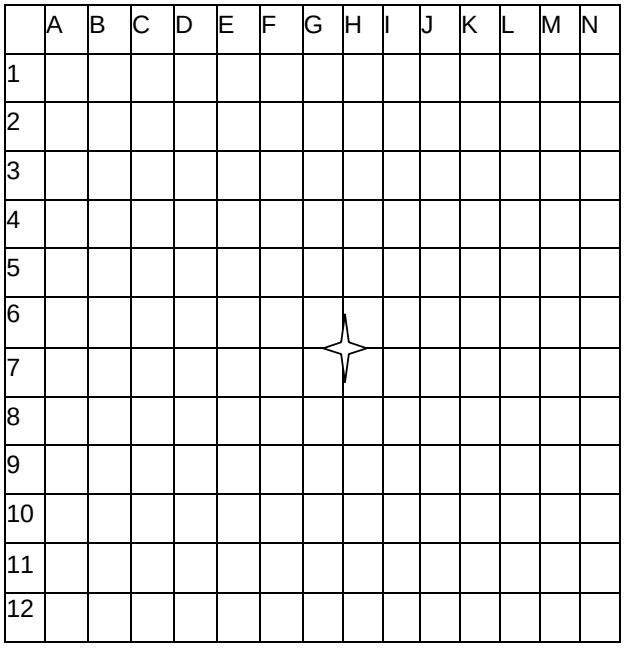

Fig. 3.5: Floor plan grid for measurements with the Berthold ionisation chamber

* Point of reference, H 7

The researcher's original methodology idea was improved after reading about a study to design a radiation protection system for lead shielding during interventional procedures of the upper extremities (Haku *et al*., 2002). The methodology of the Haku study was to measure doses at three different body heights, with a grid of 25cm intervals around the x-ray source.

Specific procedure for ionisation chamber measurements

The measurements with an ionisation dosimeter (model Berthold LB1310) took place during a time when the theatre was available.

a) The Berthold ionisation apparatus was calibrated with the calibration probe A (refer to Figure 3.6). At the start of every session, the calibration process was repeated three times before commencing with the measurements. The apparatus was sensitive in terms of needle movement. The calibration process required patience because the needle took time to stabilise on the required reading of three. The radiographer made sure not to take the reading before the needle rested at the required setting after altering the needle knob. After the calibration, during measurements when the fluoroscopy started, the needle reacted slowly and stabilised after the 10 seconds of set exposure. The needle never started exactly at zero for measurements (refer to Figure 3.7).

Fig. 3.6: Berthold ionisation chamber with calibration probes

Fig. 3.7 Berthold dose rate selection

b) C-Arm features: The Mini C-Arm (Instrumentarium Imaging, Ziehm 8000) with a half value layer of 3.2mm Al at 80kV, was operated under continuous fluoroscopy in an automatic brightness control mode, with an over the couch x-ray tube and an under the bed II. The cesium iodide input II with an irradiation area diameter of 23cm was attached to a high-resolution television system. The following selections were made on the Ziehm 8000 Mini C-Arm to simulate the work environment (refer to Figure 3.8): spine exposure, automatic programme, half dose and continuous fluoroscopy.

Fig. 3.8: Exposure factors during PA and Oblique measurements

The fluoroscopic parameters displayed were 64kV, 5.8mA and 0.1s for the PA orientation and 74kV and 6mA for the lateral orientation. The exposure factors remained constant by adjusting the position of the phantom in relation to the x-ray beam. The phantom was irradiated during every measurement with an exact duration of 10 seconds. It was possible to repeat the set duration with the fluoroscopic timer displaying the countdown of the seconds during screening.

c) Positioning of the phantom and C-Arm: Grid lines were pasted on the floor in 25cm blocks with masking or isolation tape after permission was obtained from the nursing authorities in the operating theatre. A point of reference was clearly marked in the centre of the grid for future recognition. The fluoroscopy table was parked in the centre of the grid. A centre point of reference was marked, with masking tape on the tabletop in the centre region of the patient's field. The tape markers remained on the table and floor for the entire measurement procedure that lasted for weeks, due to the dependence on the availability of the C-Arm. The reference point on the table was matched with the reference point on the floor. A lead marker hung from a string attached with tape under the centre of the table to correlate with the reference point on the floor (refer to Figure 3.9 and Figure 3.5). The markers guaranteed similar placement of the fluoroscopy table and phantom, since it was impossible to carry out all the readings during one session.

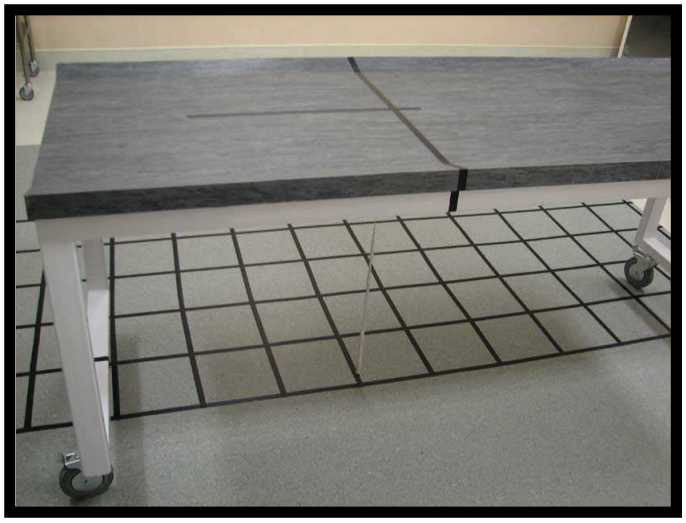

Fig. 3.9: Screening table with marked point of reference and grid on the floor

The exercise was conducted with a Perspex phantom in order to simulate a patient. A suitable centre point was determined and marked on the phantom with isolation tape for future reference. An anatomical marker was placed on that specific point (refer to Figure 3.10).

Fig. 3.10: Perspex phantom for measurements to simulate a patient

The centre of the phantom was placed on the tabletop to correspond with the marked point of reference. The phantom was irradiated to confirm the centre placement on the TV monitor of the C-Arm unit (refer to Figure 3.11). The phantom marked with the C-Arm x-ray source centring point resulted in a point of reference, H7 on the grid of measurements (refer to Figure 3.5 & 3.9).

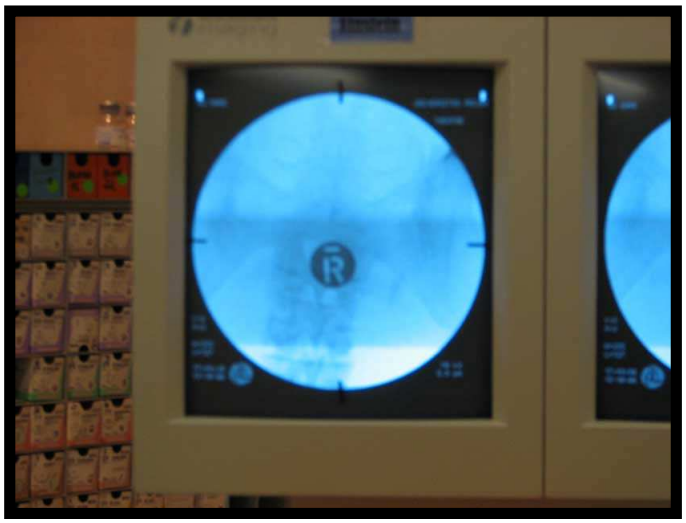

Fig. 3.11: Anatomical marker in mid-radiation field

d) Placement of Berthold apparatus

The ionisation probe was fixed on the pole of a mobile drip stand (refer to Figure 3.12) in order to maintain a constant height. The positions were marked on the drip stand at heights measured in centimeters of 110cm and 133cm from the floor in order to ease adjustments between the two heights. The bottom part of the ionisation probe was opposite the measured height, extending upwards. The marks were permanently visible during the weeks of measurement – a single drip stand was dedicated to the project. The dosimeter was set at each measuring point by moving the stand on the coordinate lines and the height adjusted along the pole. The ionisation chamber was placed with the probe in the upward direction to limit differences in positioning.

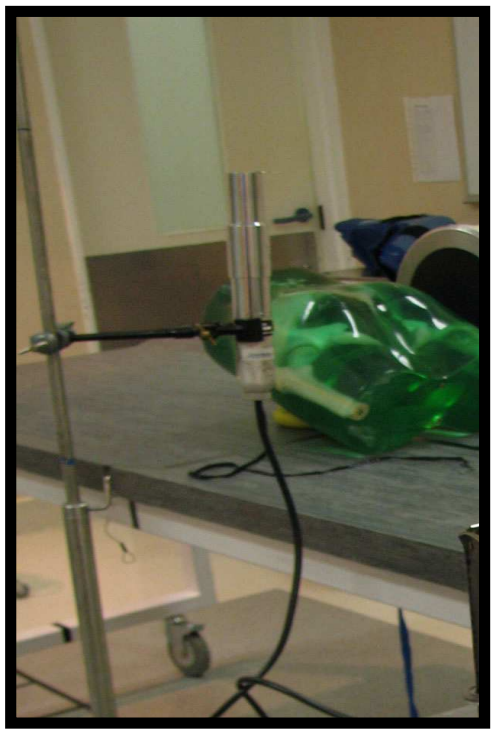

Fig. 3.12: Drip stand with ionisation probe

e) The drip stand was placed on each corner of the grid (see Figure 3.13) starting as close as possible to the centre and marked point of reference as the width of the table would allow.

Fig. 3.13: Drip stand and grid orientation

f) A 10s exposure duration, at the repeated exposure parameters of 64kV and 5.8mA, was executed. The reading of the Berthold instrument was recorded in the appropriate space on the grid and then cancelled. The height of the probe was changed to 133cm. After the phantom was exposed for 10 seconds, the reading was recorded and cancelled again. The position of the drip stand was changed to the next position of the grid on the floor and repeated at the different heights at each point. This procedure was repeated until obstacles (theatre equipment) were reached. The obstacles resulted in spaces without values on the grid. The procedure was repeated with the C-Arm in a vertical (PA) as well as a 45-degree (oblique) and a horizontal (lateral) position. The recorded value of the C-Arm orientation is displayed in Appendix V (a- f).

3.2.2.1 PA position of the C-Arm

The C-Arm was placed in position over the table with the middle of the beam centred on the point of reference. The II was positioned under the table, as close as possible to the underside of the table (refer to Figure 3.14).

Fig. 3.14: C-Arm in PA position

The height of the fluoroscopy tabletop was fixed at 82cm. The height of the C-Arm was fixed at 17cm as indicated on the C-Arm pole. The height of the x-ray tube was 82cm from the table, 148.5cm from the floor, II top part was 72cm from the floor; the distance of the phantom upper margin to the x-ray tube was 62.5cm and from the phantom upper top to the II top part was 20cm.

3.2.2.2 *Oblique position of the C-Arm*

For the oblique views the C-Arm height was set at a distance measurement of 12cm on the C-Arm pole in order to make space for the C-Arm to be tilted up to 50 degrees (refer to Figure 3.15) through the arc for the display of the Scotty dog view (see Figure 3.16) of the facets without altering the height of the C-Arm. This simulates practical procedures so as to be able to change the position of the arc without wasting time. The height of the table was 82cm from the floor, x-ray tube 152.5cm from the floor, II top part was 76.5cm from the floor; distance of the phantom upper margin to the x-ray tube was 45cm and from the phantom upper top to the II top part, 28cm. The exposure parameters were exactly the same as for the PA positioning.

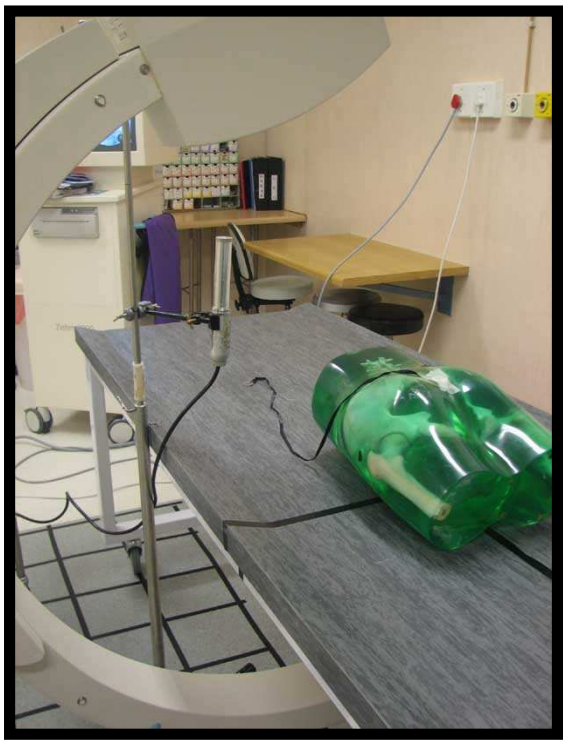

Fig. 3.15 C-Arm in Oblique position with the Berthold probe on a drip stand

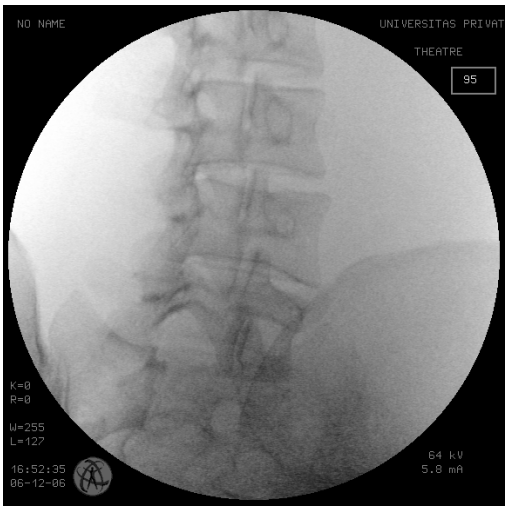

Fig. 3.16 Scotty dog view of facets obtained with the C-Arm in the Oblique position

3.2.2.3 *Lateral position of the C-Arm*

For the lateral view the fixed height of the table determined the height of the C-Arm (see Figure 3.17) since the height was fixed at 26cm as the II of the C-Arm touched the tabletop. The fluoroscopic parameters displayed with the phantom in the lateral position were 74 kV, 6mA and 0.1s, with 10s exposure

time. The phantom under side to floor distance was 86cm and the x-ray tube to phantom distance was 5cm. The centring point in the centre of the phantom is the point of reference on the grid at position H7. The neurosurgeon's position is estimated to be in the region of I6 or J6 (refer to Figure 3.5).

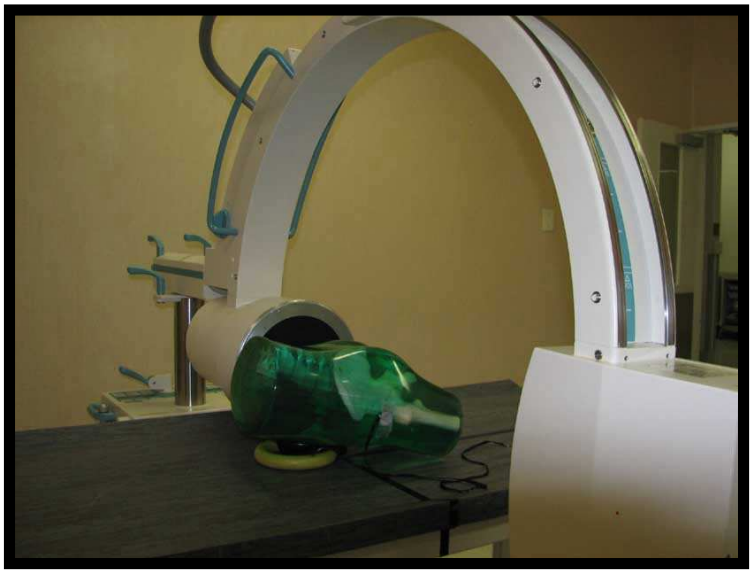

Fig. 3.17: C-Arm in lateral position with phantom position on the fluoroscopic table

Quantitative Information

Table 3.1 provides a summary of the sequence of the measurements with the TLDs and the ionisation chamber.

Table 3.1: Summary of all measurements for statistical analysis

EXPOSURE FACTORS AND PATIENT SIZE DURING TLD MEASUREMENTS	
Average exposure	KV, mA Screening time
Average patient size	Height Weight
Patient Body Mass Index	BMI
Number of injections per patient	"Hits"

TLD MEASUREMENTS	
Median dose received (patient) (Three TLDs)	PA and Lateral positions
Median dose received (neurosurgeon) (Five TLDs)	Upper body Lower body Finger
Median dose received (Radiographer) (Four TLDs)	Upper body Lower body
Background exposure measurement (Three TLDs)	
Calibration (Three TLDs)	

IONISATION CHAMBER MEASUREMENTS (milliroentgen per hour)	
Average dose (Constant kV and mAs and exposure time of 10s)	25cm intervals from the source
Height from the floor with the C-Arm in PA, Oblique and Lateral positions	110cm 133cm

3.3 COMPARISON BETWEEN TLD AND IONISATION CHAMBER MEASUREMENTS

To establish the correlation between the two types of measurements, the physicist advised the radiographer to compare the ionization chamber values with the TLD values. The ionization chamber attached to the drip stand was positioned and calibrated at grid position I6. The C-Arm orientation and phantom position was repeated to simulate the previously recorded ionization chamber measurements in the lateral position. The exposure factors and duration time of 10s were repeated. The aim was to duplicate the Berthold measurement value in the grid position I6 as recorded in Appendix V. When the satisfactory close value was recorded, the plastic cover of the ionization probe was placed over the probe. Six TLD's were kept in a lead container to be protected from the radiation. The TLD's were attached to the upper part of the ionization probe on top of the plastic probe cover to face the x-ray tube. The TLD's were exposed to radiation for duration of eight minutes. The TLD's were taken to the laboratory for counting of the dose accumulated and deduction of the values (refer Appendix VII).

3.4 SUMMARY

This chapter described the methodology of the TLD and ionisation chamber measurements. The specific placement of the TLDs, C-Arm orientations and positioning of the ionisation chamber instrument were explained. The specific exposure parameters were described in detail. In the next chapter, the separate results of the TLD and the ionisation chamber measurements will be expressed utilizing the table format as well as figures. The TLD measurements on both sides of the C-Arm and the ionisation chamber results are presented for each of the three positions of the C-Arm at the two different heights respectively.

CHAPTER 4

MEASUREMENT RESULTS

4.1 INTRODUCTION

The objectives that guided the research were to determine the radiation doses of the neurosurgeon when standing on either side of the C-Arm and to pinpoint working areas for the theatre staff to maximize radiation protection during fluoroscopy. The first part of the measurement entailed TLD measurements to determine the dose that the neurosurgeon, the radiographer and the patient received and specifically to compare the dose on either side of the C-Arm, on the x-ray tube side or II side. The second set of measurements utilised an ionisation chamber, a phantom to represent the patient and the C-Arm in PA, PO and LAT positions (see section 3.1.1) in order to determine areas of lower exposure to radiation around the table that would enhance the ALARA principle.

The TLD and ionisation chamber measurement results were recorded in table format. The original data, is provided for referencing purposes and future comparisons as Appendix IV (a-d) for the TLD measurements and as Appendix V (a-f) for the ionisation chamber measurements.

The TLD measurements were interpreted by calculating the median dose that staff and the patient received on the x-ray tube and the II side of the C-Arm respectively. The difference in doses on the opposite sides of the C-Arm is displayed as figures for the neurosurgeon's finger, chest and pelvis as well as for the chest and pelvis areas of the radiographer.

The ionisation chamber measurements were recorded in the PA, PO and LAT positions of the C-Arm at the two different heights from the floor [see Appendix V (a-f)]. The ionisation chamber results were interpreted as surface

graphs to represent the radiation exposure in mR/h at each point on a grid (Figures 4.5 to 4.10).

4.2 TLD MEASUREMENT RESULTS

39 patients with back pain were included in the study. The patients were referred by the neurosurgeon for back pain management procedures in the theatre with the procedures being done under general anaesthetic. The TLD measurements, with the x-ray tube side of the C-Arm above the table (PA), included 20 patients and the TLD measurements with the II side of the C-Arm above the table (AP) included 19 patients.

The procedures of this current study mostly consisted of lumbar facet injections with the C-Arm in the PA and both oblique positions combined with a lateral position during the caudal injection. However, the injections differ for each patient. The neurosurgeon, for instance, may determine that, for the specific patient's pathology, the radio frequency option is the procedure of preference. During radio frequency procedures for neurosurgeon 1, no caudal injection was administered. The C-Arm was only positioned in the PA position because no LAT view was necessary. The radio frequency routine of neurosurgeon 2 comprised of PA, oblique and lateral projections routinely combined with SI joints injections. This work routine resulted in more hits (3 for each SI joint and 1 for the caudal) per patient. The exposure factors during the TLD measurements were recorded for each procedure namely kV, mA and screening time. The exposure factors were recorded for the PA and LAT views as indicated automatically by the C-Arm console after irradiation (screening). The patient size (Body Mass Index - BMI) and the number of injections (hits) executed per patient were also recorded. The median of the exposure factors, BMI and hits with the x-ray tube side of the C-Arm above the table are indicated in Table 4.1.

Table 4.1: Exposure factors, patient size and hits during TLD measurements with the x-ray tube side of the C-Arm above the table (PA)

Variable	n	Lower quartile	Median	Upper Quartile
kV PA	20	64	72	77
mA PA	20	5.8	6	6
kV LAT	20	79	84	98
mA LAT	20	5.8	6	6
Screening time (minute)	20	2.0	2.4	4.2
BMI	20	25	28	32
Hits	20	5	11	15.5

kV PA=kilo Volt Posterior Anterior **mA PA= milliampere Posterior Anterior view**
Hits=injections **BMI= Body Mass Index** **LAT=lateral view**

The median of the exposure factors, BMI and hits with the II side of the C-Arm above the table are indicated in Table 4.2.

Table 4.2: Exposure factors, patient size and hits during TLD measurements with the II side of the C-Arm above the table (AP)

Variable	N	Lower quartile	Median	Upper Quartile
KV AP	19	64	66	73
mA AP	19	4.5	6	6
KV lateral	19	60	63	77
mA lateral	19	3.9	5.3	6
Screening Time (minute)	19	1.41	2.14	2.48
BMI	19	21.6	26	28.3
Hits	19	6	13	16

kV AP=kilo Volt Anterior Posterior view **mA AP= milliampere Anterior Posterior view**
Hits=injections **BMI= Body Mass Index** **LAT=lateral view**

The median screening time for the AP and PA sides was 2.1 and 2.4 minutes per patient. The median BMI values of the patients were 26 and 28. The median value of the “hits” were 11 and 13, indicating the number of injections per procedure. The kV values for the PA and the lateral views were higher

with the x-ray tube side of the C-Arm positioned above the patient. For both sides of the C-Arm, the kV was lower than 100kV. The C-Arm used in the study records only a maximum value of 6mA; the median mA values during the procedures were above 5.3mA.

The median radiation exposure time of 2.4 minutes recorded in this study is longer than the 15.6s for the transforaminal injections recorded by Botwin *et al*., (2002) and the 8.9±0.4 seconds exposure per patient described by Manchikanti *et al*., (2003). Mean fluoroscopic times for lumbar facet injections were 81.5±12.8 seconds in University teaching hospitals (Zhou *et al*., 2005). From the above-mentioned studies, it is clear that there is a difference in fluoroscopic exposure time amongst surgeons. The current study did not separate caudal epidurals, facet joint block or sacroiliac injections, but the pain injection routines consisted of a combination of the above-mentioned injections and could explain the longer fluoroscopic times. The median number of hits (11-13) per procedure indicated the length of the procedure compared to a single caudal epidural injection (hit). The surgeons in the current operating theatre utilised the C-Arm during fluoroscopy in the PA, oblique and lateral positions and not only the lateral, as associated with a caudal epidural. The 2.4 minutes radiation exposure time is longer than the duration times mentioned above and should be lowered if possible (Zhou, *et al*., 2005). Pulsed fluoroscopy is an option to consider because continuous fluoroscopy was selected during the back pain procedures in the current operating theatre.

The next section represents the results of the median dose values of the TLD measurements of both surgeons with the x-ray tube side of the C-Arm above the theatre table.

4.2.1 Median dose values of TLD measurements that the staff/patient received with the x-ray tube above the theatre table (PA)

Table 4.3 represents the median values of the measurement results pertaining to the 20 procedures done by both neurosurgeons, with the x-ray tube side of the C-Arm positioned above the table. The TLDs were measured

after a batch of 10 patients for each of the surgeons on either side of the C-Arm. The following table represents a summary of the readings for each doctor (N=2) as well as for the doctors combined (N=4). Also the three sets of two patients each and the six patients combined. For the doctors, the values represent the dose for 10 patients. Two TLDs were used to measure doses to the radiographer and neurosurgeon's pelvis and chest areas respectively. Three TLDs were used for the patient (see Figures 3.2 to 3.4).

Table 4.3: TLD values of staff and the patient with the X-ray tube above the theatre table (n=20)

TLD placement	N	Minimum (mSv)	Median value (mSv)	Maximum (mSv)
R pelvis	2	0.470	0.548	0.626
R pelvis	2	- 0.022	0.043	0.110
R pelvis	4	-0.022	0.290	0.626
R chest	2	0.024	0.137	0.250
R chest	2	- 0.028	0.351	0.730
R chest	4	-0.028	0.137	0.730
Dr finger	2	9.170	65.684	122.199
Dr pelvis	2	1.664	2.332	3
Dr pelvis	2	1.679	2.274	2.870
Dr pelvis	4	1.664	2.275	3
Dr chest	2	2.110	2.214	2.318
Dr chest	2	1.900	1.916	1.932
Dr chest	4	1.900	2.021	2.318
Patient	2	365	433.9	502.9
Patient	2	265.8	431.9	598
Patient	2	209	283.6	358.3
Patient	6	209	361.7	598

R=radiographer **Dr=neurosurgeon**

The table above indicates that, with the x-ray tube above the patient, the radiographer received the highest dose at the pelvis with a median value of 0.29mSv. That means 0.03mSv per patient (0.29 divided by 10). The pelvis of the neurosurgeon received the highest dose 0.23mSv per patient compared to

the chest with a highest median value of 0.20mSv per patient. The patient received a median dose of 36.1mSv with the x-ray tube positioned above the table. The median dose to the neurosurgeon's finger was 6.6mSv per patient. Should the neurosurgeon treat 300 patients per year, it is possible that the annual ICRP limit of 500mSv may be exceeded, as the dose to the skin can then be estimated as 1980mSv (6.6 x 300) per year should he not make use of lead rubber gloves to protect his hands from radiation.

4.2.2 Median dose values of the TLD measurements that the staff/patient received with the x-ray tube under the theatre table (AP)

Table 4.4 represents the median values of the measurement results pertaining to the 19 procedures done by both neurosurgeons with the II side of the C-Arm positioned above the table. The TLD's were measured after a batch of 10 patients for each of the surgeons on either side of the C-Arm. The following table represents a summary of the readings for each doctor (N=2) as well as for the doctors combined (N=4). Also the three sets of two patients each and the six patients combined. For the doctors, the values represent the dose for 10 patients.

Table 4.4: TLD values of staff and the patient with the II above the theatre table (n=19)

TLD placement	N	Minimum (mSv)	Median value (mSv)	Maximum (mSv)
R pelvis	2	- 0.018	0.350	0.720
R pelvis	2	0.007	0.279	0.552
R pelvis	4	-0.018	0.280	0.720
R chest	2	- 0.005	0.763	1.531
R chest	2	- 0.018	0.281	0.581
R chest	4	-0.018	0.288	1.531
Dr finger	2	0.371	0.842	1.313
Dr pelvis	2	0.462	0.962	1.462
Dr pelvis	2	0.384	0.975	1.566
Dr pelvis	4	0.384	0.962	1.566

Dr chest	2	0.176	0.475	0.774
Dr chest	2	0.163	0.585	1.007
Dr chest	4	0.163	0.475	1.007
Patient	2	13.4	70.7	127.9
Patient	2	18.7	95.2	171.6
Patient	2	7.8	53.9	99.8
Patient	6	7.8	59.3	171.6

R=radiographer **Dr=neurosurgeon**

Table 4.4 indicates that the radiographer received a median dose of 0.28mSv at the pelvis area – comparable with the value of the x-ray tube side. The chest of the radiographer received a median dose of 0.29mSv (0.03mSv/patient) - a higher value than with the x-ray tube positioned above the table. The neurosurgeon's pelvis area received a higher dose than the chest but lower if the x-ray tube were to be positioned above the table, namely 0.09mSv per patient. The median dose to the neurosurgeon's finger is lower per patient at a value of 0.08mSv compared to the x-ray tube side value of 6.6mSv per patient. Should the neurosurgeon treat 300 patients per year, the annual ICRP limit of 500mSv to the hands will be not be exceeded, as the skin dose can then be estimated (300 x 0.08mSv) as 24mSv per year.

4.2.3 Median dose values of the patient and the staff with the x-ray tube and the II respectively above the theatre table

TLD dose values of the pelvis and chest areas of the neurosurgeons, measured with the C-Arm positioned with the II above the patient, seem lower than with the x-ray tube positioned above the patient. Figure 4.1 is an indication of the difference in the median values of the doses that the two neurosurgeons' pelvis and chest areas received. The difference in radiation dose on the x-ray tube and II side of the C-Arm is displayed.

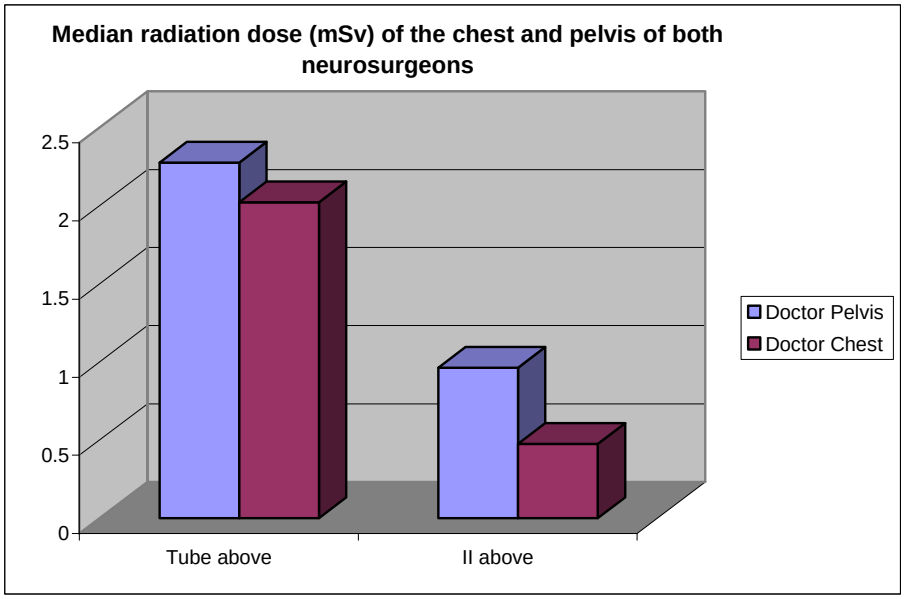

Fig. 4.1: The pelvis and chest dose values of the neurosurgeons with x-ray tube and II respectively above the table

The median values of the radiation doses to the neurosurgeon's chest were 2.02mSv (0.2mSv per patient), with the x-ray tube positioned above the table and 0.48mSv (0.04mSv per patient) with the II above the table (p-value=0.02). The median radiation doses to the pelvis areas were 2.3mSv (0.23mSv per patient) with the x-ray tube above and 0.96mSv (0.09mSv per patient) with the II above the theatre table (p-value=0.12).

The radiation dose values to the radiographer's pelvis and chest areas, on both sides of the C-Arm, are indicated in Figure 4.2. The radiation dose to the chest of the radiographer is higher with the x-ray tube positioned under the table. The radiographer was positioned on the console side of the C-Arm. The median value of the radiation dose to the radiographer's chest area was 0.14mSv with the x-ray tube side above the table and 0.29mSv with the II above the table (p-value=0.77). The median value of the radiation dose to the radiographer's pelvis was 0.29mSv with the x-ray tube above the table and 0.28mSv with the II above the table (p-value=0.7).

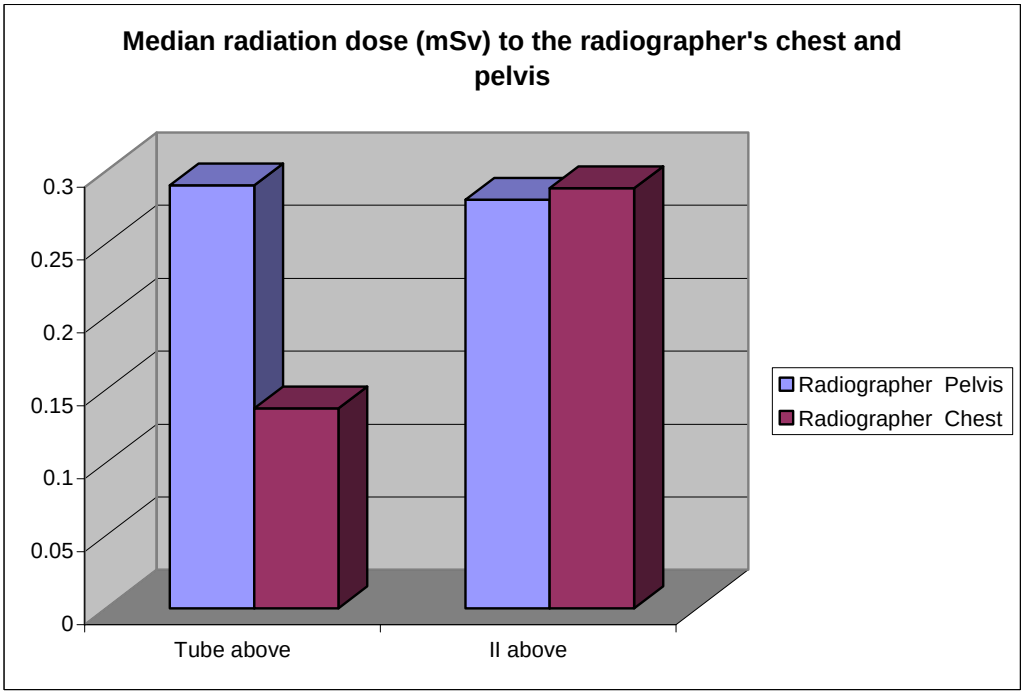

Fig. 4.2: The chest and pelvis dose values received by the radiographer with the x-ray tube and II respectively above the table

The dose to the neurosurgeon's hand, as indicated in Figure 4.3, confirmed a lower dose on the II side of the C-Arm.

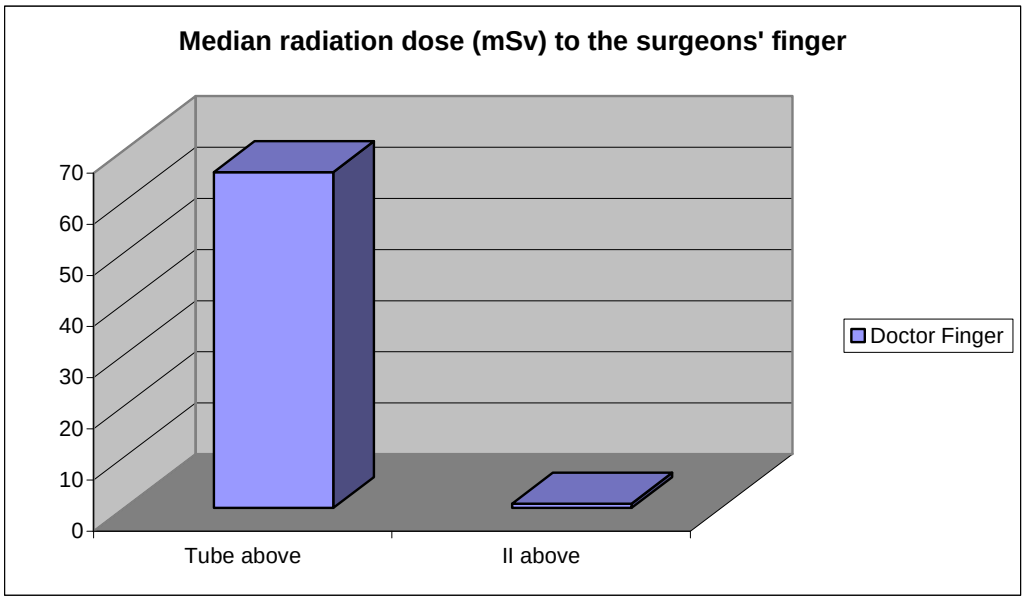

Fig. 4.3: The finger dose values of the neurosurgeons with the x-ray tube and II respectively above the table

The median value of the radiation dose to the finger of the neurosurgeons was 65,68mSv with the x-ray tube positioned above the theatre table and 0.84mSv with the II positioned above the table (p-value=0.12).

In all instances, placement of the TLDs on the patient (prone) was on the skin facing the x-ray tube. For example, with the x-ray tube above the table, the TLDs were placed on the patient's back at the level of the third lumbar vertebra. When the C-Arm was positioned with the II above the table, the patient TLDs were placed on the patient's stomach. The TLDs were moved from the back or stomach positions and placed on the side of the patient during the lateral views so as to be on the side of the x-ray tube. According to Tables 4.3 and 4.4, the radiation dose to the patient with the x-ray tube above the table is five times higher than with the II positioned above. The highest median values of the dose that the patient received on either side of the C-Arm are displayed in the following figure (refer to Figure 4.4).

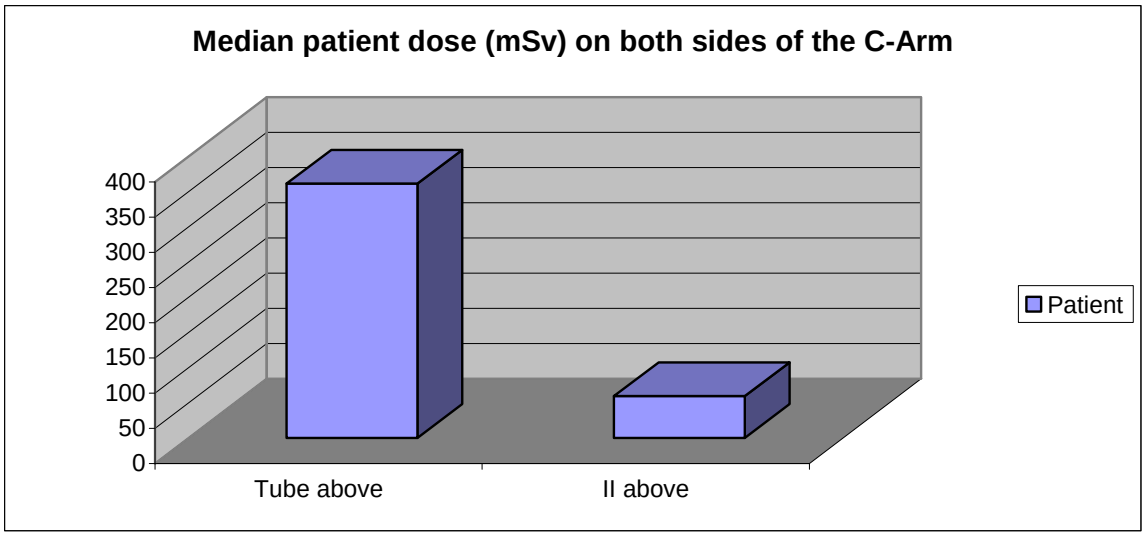

Fig. 4.4: The radiation dose values of the patient with the x-ray tube and II respectively above the table

The highest median values of the radiation dose to the patient were 361.7 mSv with the x-ray tube positioned above the theatre table and 59.3mSv with the II positioned above the table (p-value=0.0039).

The second set of measurements was conducted using a phantom and an ionisation chamber with the C-Arm in the PA, lateral and oblique positions. The measurements, according to the 25cm grid positions, will be discussed under the following heading.

4.3 IONISATION CHAMBER MEASUREMENT RESULTS

The position of the C-Arm and the width of the fluoroscopic table determined the closest possible distance between the ionisation chamber and the centring point. The blank areas in the center of the measurement result grid are due to the table taking up space (see Appendix V(a) rows 6 and 7). The C-Arm side of the measurement grid has blank areas, since it is not possible to position the drip stand closer to the C-Arm wheels. The blank areas were of no importance, with reference to the dose measurements, for the reason that no staff member can be positioned in those areas due to the equipment taking up floor space. The measurements were taken up to a point where the drip stand could not be positioned further because of the positioning of the theatre equipment, fixed furniture or the theatre wall.

The measurement values, which were recorded on the blank form shown in Appendix III, were the values displayed on the ionisation chamber console. The measurements were executed with the x-ray tube above the table because the C-Arm x-ray tube side was routinely placed above the patient (PA) in this theatre during back pain management procedures before the current study. In the following figures, namely 4.5 to 4.10, the recorded measurements are displayed with the C-Arm in the PA, PO and LAT positions, each at the height of 110cm and 133cm respectively. In the radiation distribution figures of each C-Arm orientation, both the heights are displayed for comparison purposes.

The values of the ionisation chamber were compared on the grid as included in the different C-Arm positions and the two heights under Appendix V. For the PA position of the C-Arm (see Appendix V b), grid positions H4 and G9 were compared because H4 was located more or less on the neurosurgeons

side of the fluoroscopic table opposite the console of the C-Arm. The measurement values (mR/10s) in the proximity of the x-ray source indicated that values were higher on the neurosurgeons side (H4 = 8.2mR/10s), which was opposite the console side of the C-Arm (G9 = 6.6mR/10s). The sum of the measurement values closest to the source (row 4 and row 9, between E and I) were higher on the neurosurgeons side (row 4=33.5mR/10s and row 9=23.9mR/10s). The 110cm height, appendix V(a) indicated less difference in the measurement values closest to the x-ray source (row 4= 15.1mR/10s and row 9 =16mR/10s). The measurement values closest to the source were higher at the 133cm height (value 33.5mR/10s) from the floor than at the 110cm height (value 15.1mR/10s).

The following two figures, namely Figures 4.5 and 4.6 respectively, display the radiation distribution with the C-arm in the PA position [refer to Appendix V (a and b)] on the two different heights from the floor.

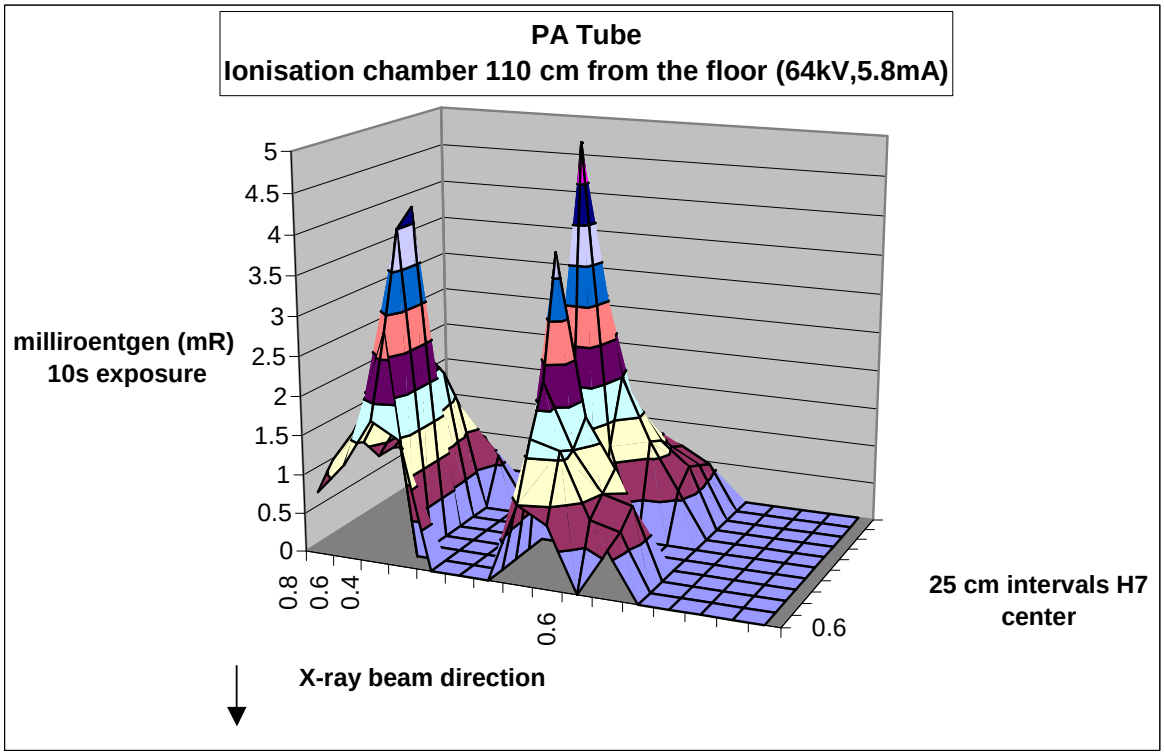

Fig. 4.5: C-Arm in PA position (Ionisation chamber height 110cm)

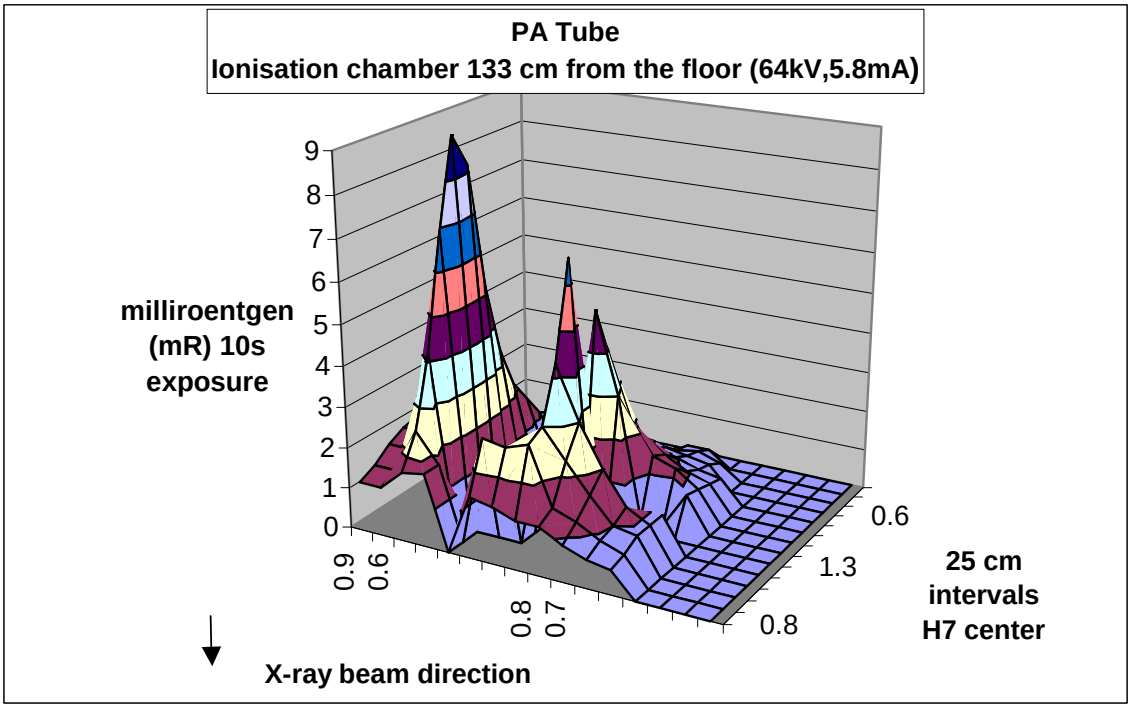

Fig. 4.6: C-Arm in PA position (Ionisation chamber height 133cm)

If a comparison is made between the PA values in grid position row four, where the neurosurgeon was positioned (Sum of E-I), it is clear that the dose values (33.5mR/10s) were higher at the 133cm height than at the 110cm height (15.1mR/10s) when the PA positioning of the C-Arm was used. The reason for the higher (33.5mR/10s) dose value was may be due to the angle of scatter. With the TLD measurements, however, the dose was higher at the pelvic height. This can be ascribed to more scatter from the patient because the lateral views were included in the TLD measurements.

The oblique positioning of the C-Arm resulted in dose values as displayed in Figures 4.7 and 4.8 respectively [Refer to Appendix V (c and d) for the data measurements of the dose values with the C-Arm in the oblique position]. For a comparison of the oblique values, positions H4 and H9 were compared.

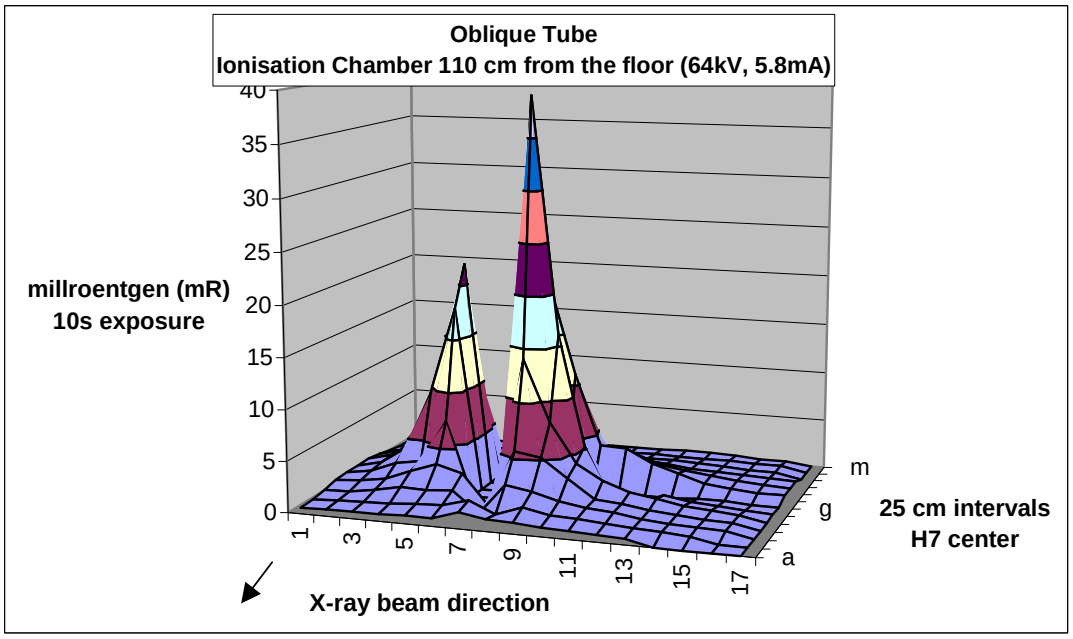

Fig. 4.7: C-Arm in Oblique position (Ionisation chamber height 110cm)

In a comparison between the heights the sum of the measurement values recorded on row four and row nine (sum of E-I) were considered on the grid. Row 4 measured a sum value of 30.9mR/10s at the 110cm height and at the 133cm height, a value of 29.4mR/10s. (The blank area on the grid due to the space taken up by the apparatus was given the value of the adjacent block).

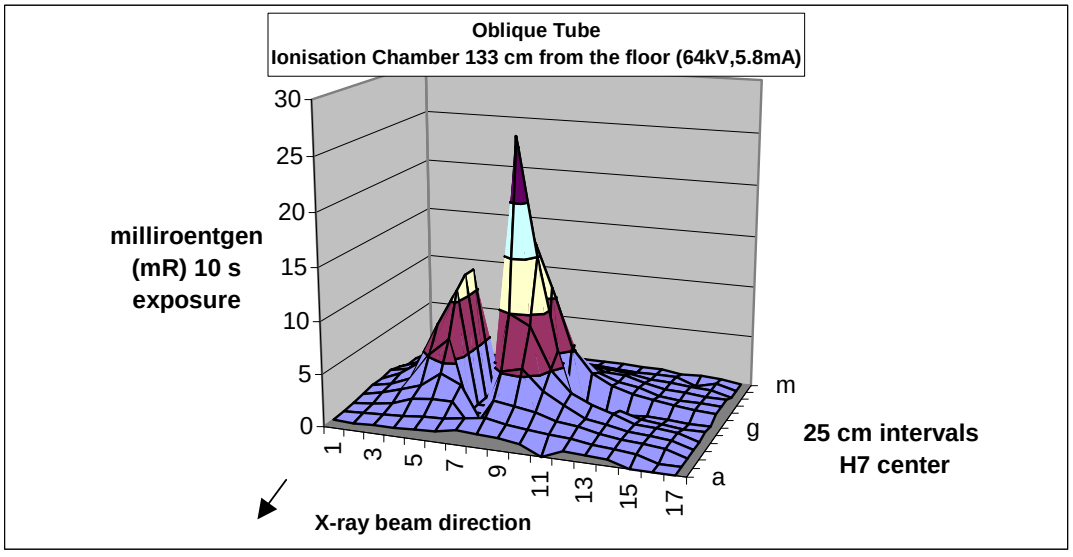

Fig. 4.8: C-Arm in Oblique position (Ionisation chamber height 133cm)

There was only a slight difference in the values between the two heights when the C-Arm was positioned in the oblique position (29.4mR/10s versus 0.9mR/10s).

The difference between the II and x-ray tube side of the C-Arm, with the oblique position of the C-Arm, was also explored (refer Appendix V c and d). When the centre values on the II side of row 4 (value 30.9mR/10s) on the grid were compared to the x-ray tube side of row nine (value 52.9mR/10s), the dose values with the C-Arm at the 110cm height were higher latter. The higher dose values on the x-ray tube side were repeated at the 133cm height.

The data measurements for the lateral positioning of the C-Arm were recorded in Appendix V (e and f). The lateral values on both sides of the C-Arm grid, positions J6 on the x-ray tube side and J8 on the II side of the C-Arm, were compared. The grid on the 133cm height (Appendix V (f)) indicated in block J8 (value 5.6mR/10s) and J6 (value 12mR/10s) that higher dose values were recorded on the x-ray tube side of the C-Arm. The dose values on the 110cm height were also higher on the x-ray tube namely J6=44mR/10s compared to J8=8.2mR/10s on the II side.

Figures 4.9 and 4.10 display the radiation distribution on both heights with the C-Arm in the lateral position.

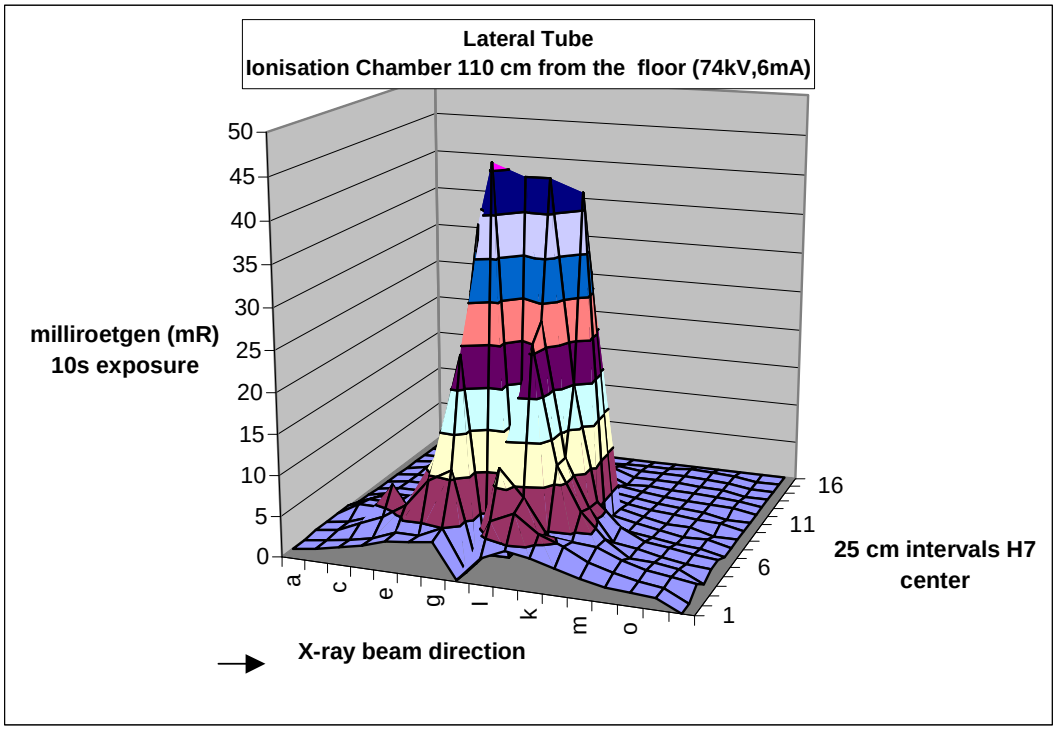

Fig. 4.9: C-Arm in Lateral position (Ionisation chamber height 110cm)

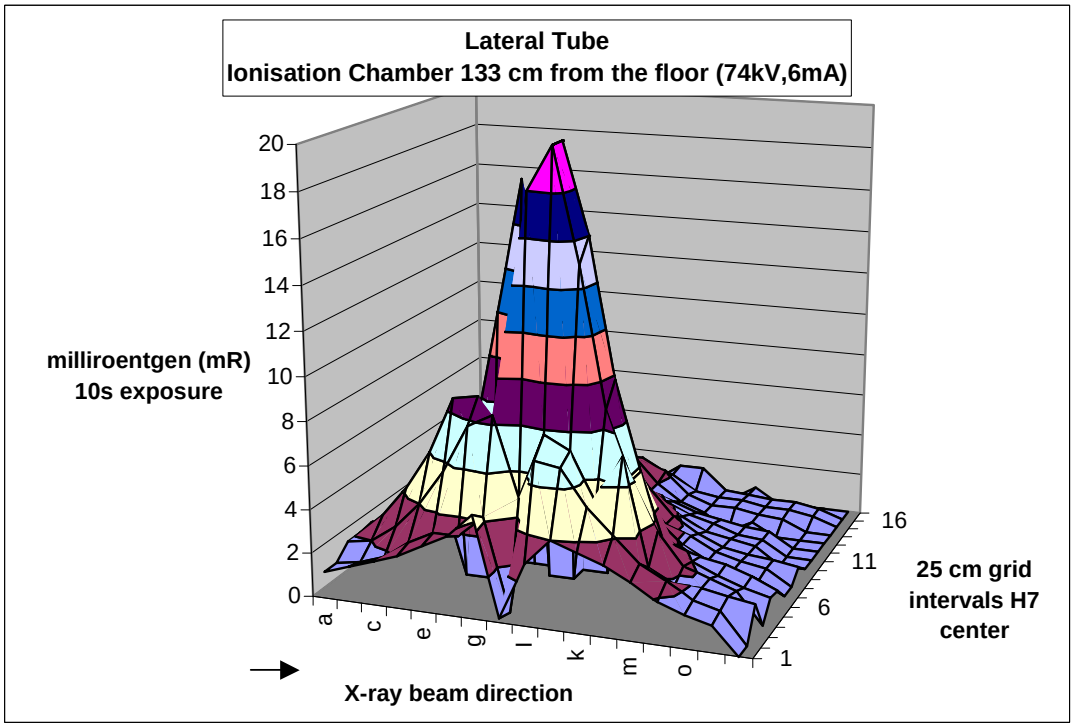

Fig. 4.10: C-Arm in Lateral position (Ionisation chamber height 133cm)

In the above displayed graphs, with the C-Arm in the lateral position, indicated that the dose values on the 110cm height (J6=44mR/10s) were higher than on the 133cm height (J6=12mR/10s). The reason for this is that the pelvis of the neurosurgeon at the 110cm height was positioned closer to the horizontal x-ray tube as well as the patient (table height 82cm).

4.4. COMPARISON OF THE IONISATION AND TLD MEASUREMENT RESULTS

A comparison between the TLD and the ionisation chamber measurements needs to be mentioned at this stage of the study. To establish the correlation between the two types of measurements, the physicist advised the radiographer to compare the ionisation chamber values with the TLD values. The values of the ionisation chamber were verified by means of an eight-minute TLD exposure at a grid point pre-selected by the researcher and the physicist. On the lateral grid [refer to Appendix V(e)], at a height of 110cm in position I6 a grid value of 44 (simulated as a value of 43) converts to 4,3mR per 10s of exposure or 0.43mR/s. This total dose of 2.1mSv in 8 minutes was documented in Appendix VII. This is a comparison of about 60%, with the value of 3.5mSv determined with the TLDs in the same area.

4.5 CONCLUSION

The objective to determine the radiation doses of the neurosurgeon when standing on either side of the C-Arm was executed by means of TLD and ionisation chamber measurements. The radiation distribution indicated working areas for the theatre staff to maximize radiation protection during fluoroscopy.

The TLD measurements for the neurosurgeons indicated that the radiation dose values to the neurosurgeon's hands, pelvis and chest were higher with the x-ray tube over couch position compared to the II over couch position of the C-Arm. The significant difference in the median values of the radiation

doses to the neurosurgeon's chest were 2.02mSv, with the tube positioned above the table and 0.48mSv with the II above the table (p-value=0.02).

The median values of the radiation dose to the patient were 361.7mSv with the x-ray tube positioned above the theatre table and 59.3mSv with the II positioned above the table (p-value=0.0039). The large difference between the entrance doses to the patients was unexpected because of the automatic exposure control. The difference may be ascribed to an inconsistent positioning of the TLD's on the stomach of the patient, especially when overweight. Other factors that require consideration are the wooden table between the patient and the x-ray tube with the x-ray tube positioned under the theatre table and the distance from the x-ray source.

The pelvis of the radiographer received a comparable median dose on the II and tube side of the C-Arm. Although the radiation dose to the radiographer's chest measured with the TLDs was unexpectedly higher with the II side positioned above the table, a maximum median value of 0.08mSv per patient was recorded for all orientations of the C-Arm.

The median radiation doses to the pelvis areas of the neurosurgeons were 2.3mSv with the x-ray tube above and 0.96mSv with the II above the theatre table (p-value=0.12). The median value of the radiation dose to the finger of the neurosurgeons was 65.68mSv with the x-ray tube positioned above the theatre table and 0.84mSv with the II positioned above the table (p-value=0.12). Due to the sample size, the p-values < 0.15 could be an indication of statistical significance. The radiation dose to the hand is of importance during the PA and oblique views because, with the lateral view, the hand was not directly positioned in the x-ray beam, as was the case with the PA and oblique views. The median ionising radiation dose to the neurosurgeon's hands was 78 times less on the II side if values of 6.6mSv per patient on the x-ray tube side of the C-Arm, were compared to 0.08mSv to the hand on the II side of the C-Arm.

The median dose values of the neurosurgeon's finger, pelvis and chest area are a confirmation that, during back pain management procedures, the x-ray tube side of the C-Arm must be positioned under the theatre table to lower radiation to the neurosurgeon. The radiation dose to the patient was also lower with the II positioned above the table.

The ionisation chamber measurements with the C-Arm in the PA position, indicated that the values were higher closer to the x-ray source at the 133cm height from the floor than at the 110cm height. The radiation dose measured on the x-ray tube side during the oblique views was higher at the x-ray tube side of the C-Arm compared to the II side. Because the x-ray tube was positioned above the table, the higher values were recorded at the 133cm height, when the x-ray tube was closer to the neurosurgeon's chest with the C-Arm in the oblique position. The reader is reminded that the dose values will change when the C-Arm is adjusted through the arc to the other side.

The ionisation chamber measurements, with the x-ray tube in the LAT position, indicated a five times less difference on the II side. For the lateral views, the values were higher on the height 110cm from the floor compared to the 133cm height.

In order for the neurosurgeon to be able to execute injections into the facet or SI joints he is positioned close to the x-ray tube and the patient during back pain management procedures. Application of the ALARA principle grounds the placement of the neurosurgeon in relation to the II side of the C-Arm and is a matter of meticulous thought and planning.

The next chapter will compare the doses measured by means of TLDs and the ionisation chamber with radiation doses recorded in literature, to determine if the doses are within the limits set by the ICRP. The results were analysed to facilitate the design of protocols for positioning of the C-Arm while applying the ALARA principle during back pain management procedures for this specific theatre.

CHAPTER 5

INTERPRETATION OF RESULTS AND PROPOSED PROTOCOL

5.1 INTRODUCTION

The aim of the study was to optimise the dose to the neurosurgeon, the radiographer and the patient applying the ALARA principle in a specific theatre by determining the radiation dose levels around the theatre table. The measured radiation distribution, together with guiding principles from literature, were used to propose a protocol for C-Arm orientation and staff positioning during back pain management procedures.

This chapter will focus on the orientation of the C-Arm and positioning of staff in relation to the C-Arm according to the doses measured with TLDs and the ionisation chamber. The remainder of this chapter is dedicated to the comparisons of the measurement results with literature findings. The proposed protocol for positioning of the x-ray tube and staff during the PA, oblique and lateral positions of the C-Arm is visually displayed at the end of this chapter.

5.2 DISCUSSION AND INTERPRETATION OF THE MEASUREMENT RESULTS

The TLD and the ionisation chamber measurements were considered in order to interpret the radiation distribution in relation to the C-Arm orientation and positioning of staff around the theatre table. The C-Arm orientation referring to the PA, AP and LAT positions will be discussed first.

5.2.1 C-Arm orientation

Fluoroscopy training recommends positioning of the x-ray tube with the II above the table (AAPM, 1998). The AAPM report also indicated that the

radiation dose on the II side during the lateral view might have a five times lower value than on the x-ray tube side. The difference can be ascribed to the three times higher scatter radiation from the patient on the entrance surface than from the exit surface of the patient (Fishman *et al*., 2002). Thus, positioning of the x-ray tube during fluoroscopic procedures needs meticulous focus. It is also important that the II is positioned as close to the table and thus to the patient, as possible (Herbst, 2007). In the theatre that was utilised for the current study, however, the theatre table did not accommodate the x-ray tube positioning under the table comfortably during back pain management procedures. The main reason was that, with the available theatre table, the x-ray tube was close to the patient if positioned under the table, causing a magnified view of the spine. To address the magnification, the table had to be elevated. However, due to the increased bed height, it became rather challenging for the neurosurgeon to administer spinal injections. The bulkiness of the II above the table then obscured comfortable viewing of the monitor. The II was not positioned close to the patient because the neurosurgeon preferred the space for the sterile needle placement with resulting magnification of the spinal image. The C-Arm adjustment from the AP position to the lateral position was time-consuming due to the fact that the C-Arm had to slide through the arc under the table. The table had to be raised to an even higher level to make adjustment under the table possible for the lateral position. Adjustment of the C-Arm over the patient into the lateral position as a second option meant that the C-Arm had to be removed from under the table and the table had to be lowered again. Besides the fact that this maneuver was time consuming, the sterile area was, as a result of this, a point of concern. These circumstances resulted that the x-ray tube was routinely positioned directly against recommendations, above the table (over couch) before the current study.

According to the TLD measurements recorded in Table 4.2 and Table 4.3 and displayed in Figures 4.1 to Figures 4.5 (see Chapter 4), the potential of higher doses to the staff and the patient was a reality. The measurements pointed out, with the x-ray tube above the table, that the median kV values were higher with the x-ray tube side positioned above the table. The higher BMI recorded

on the x-ray tube side, however, could have had an influence. The chest and pelvis of the neurosurgeon received a higher median dose with the x-ray tube positioned above the table. The median pelvis dose to the radiographer was comparable on both sides of the C-Arm. The median chest dose to the radiographer was, however, lower with the x-ray tube above the table. The median dose to the patient was higher with the x-ray tube above the table. According to the TLD values determined in the current study, the median difference of the radiation dose to the neurosurgeon's hands was 78 times higher (66.5mSv compared to 0.84mSv) with the x-ray tube side positioned above the theatre table in the PA position. All of these measurements suggested the AP position of the C-Arm should apply to the ALARA principle, since the hand is placed close to the beam in order to place the needle in the anatomical area of interest.

The potential higher doses on the x-ray tube side were confirmed by the ionisation chamber measurements, according to Figure 4.5 to Figure 4.10. Compared to the II side, the dose values were higher on the x-ray tube side in the PA, OBL and LAT positions. In the PA position of the C-Arm the dose values were higher on the 133cm height than on the 110cm level. The reason for this can be the angle of scatter from the x-ray source for scattered radiation, the phantom. The lateral values also indicated higher dose levels on the x-ray tube side of the C-Arm with a specifically bigger difference at the 110cm height. The difference is recorded because of the higher scatter radiation from the patient on the entrance surface than from the exit surface of the patient (Fishman *et al*., 2002).

The positioning of staff around the theatre table in relation to the C-Arm will be discussed next.

5.2.2 Positioning of the staff

It is important to note that it was difficult for the neurosurgeon to position himself close enough to the patient on the console side of the C-Arm in the AP/PA or oblique position due to the space occupied by the arc of the C-Arm on the console side. The neurosurgeon preferred to stand opposite the

radiographer, away from the console side of the C-Arm, because there was more space on the opposite side for the sterile trolley with the syringes and needles to be positioned close to him. According to theatre protocol, the radiographer also needed space to alter the C-Arm position and had to be at a distance of 30cm from the sterile trolley. It was thus not only more comfortable, but practical to have the neurosurgeon opposite the console side.

The measurements with the C-Arm in the PA position, 133cm height [refer to Appendix V (b)] indicated that the radiation dose was higher opposite the console side of the C-Arm close to the x-ray source where the neurosurgeon will be positioned during the injection. The value opposite the console side on H4 is 8.2mR/10s compared to the lower value of 6.6mR/10s at position G9 on the console side of the C-Arm. The values at distances of one metre or more were closer on either side of the C-Arm.

If one compares H4, with a value of 5.8mR/10s, to H9, with a value of 11mR/10s on the II side, the radiation dose measured is higher during the oblique view at 133cm [refer to Appendix V(d)]. The normal procedure for back pain management in this theatre included both oblique views to inject in the left and right facets. The reader is reminded that the dose values would change should the C-Arm be adjusted through the arc to the alternative side for the other PO view. The neurosurgeon remains standing on one side of the patient as it seem impractical (time-consuming) to position the neurosurgeon on the alternative side during the procedure for the other PO.

While the x-ray tube is in the lateral position, the ionization chamber measurements indicated a difference five times lower on the side and in the position, that the neurosurgeon had positioned himself in order to administer the injection [refer to Appendix V (e)]. For the lateral views, the values were higher at the height 110cm from the floor compared to the 133cm height. The higher values on the 110cm level can be ascribed to the neurosurgeon being in closer proximity to the scatter from the patient.

Although the ionisation chamber measurements indicated a lower dose on the

console side of the C-Arm compared to the side where the neurosurgeon was positioned, the measurements of the dose distribution were only executed with the x-ray tube positioned above the table. The TLD values confirmed that the neurosurgeon opposite the console side received a higher dose than the radiographer with the x-ray tube positioned above the table. On the other hand, the dose to the chest areas of the radiographer and the neurosurgeon, with the II above the table were almost similar. This implied that the neurosurgeon may operate opposite the console side of the C-Arm in the AP and oblique positions of the C-Arm.

The custom-manufactured screening table accommodated the movement of the C-Arm through its arc underneath the table. With the placement of the II above the table during the AP view, the x-ray tube side was altered to the lateral position underneath the table – this means that the x-ray tube was on the neurosurgeon's side during the lateral view. For the duration of the study, the neurosurgeon remained on the x-ray tube side of the C-Arm without walking around to the II side when the x-ray tube was adjusted in the lateral position. The TLD dose to the neurosurgeon's hand and body was still lower, considering his position close to the x-ray tube in the lateral position, than with the x-ray tube above the patient during the PA views. It would, however, be ideal to minimise the dose to the neurosurgeon in total by changing his position to the other side of the table during the single injection in the lateral position. The dose is lower in the LAT position on the II side, as confirmed by the lateral measurements of the ionisation chamber, (Refer to Appendix V(e), where the difference in grid position I6 has a value of 44mR/10s compared to I8 with a value of 8.4mR/10s on the II side of the C-Arm).

The ionisation chamber measurements confirmed that the radiation dose decreases the further one moves away from the x-ray source. According to the layout of the PA view in the mR/h table (refer to Appendix VI - PA 133cm), the staff around the table must be positioned at the furthest distance possible from the x-ray tube. Position H4 recorded a dose value of 295mR/h and at 25cm further, a value of 75.6mR/h. In the mSv/minute table at grid position A7, the measurements recorded that even staff 1.75m from the source were

exposed to a radiation value of 0.004mSv/min. Staff must be positioned as far as possible from the x-ray tube and must make use of lead aprons during back pain management procedures.

5.2.3 Factors that influence radiation distribution

The positioning of the C-Arm and the staff in relation to the C-Arm is not the only factor that influences radiation dose to staff. Other factors must be mentioned in the same breath, namely lead rubber protective wear, exposure times and image quality. The above-mentioned factors will be addressed under recommendations in the final chapter. A comparison with the literature findings will be addressed in the following paragraphs.

5.3 BENCHMARKING THE STUDY WITH LITERATURE REVIEW FINDINGS

A comparison of the radiation doses measured in the current environment with other studies that performed fluoroscopic procedures will indicate if the radiation doses measured in this specific theatre are within the expanse of other studies. If the doses measured in this theatre are higher than the doses received in other back pain procedure environments, a scrutinisation of the current theatre's protocols may reveal that adjustments are needed in order to adhere to the ALARA principle. One of the aims of this study was to determine if the doses received by the staff fell within the acceptable limits set by the ICRP. The following section compares some of the values in studies, as mentioned in Chapter 2, with the findings of the TLD and Ionisation chamber measurements of the present study.

The policy of the South African Department of Health (DoH, s.a.b.) states that no lead rubber apron shielding is required if non-radiation workers are at a distance of 2m away from the x-ray tube head, provided that scattered radiation at a distance of 30cm at any point from the source is less that 20mR/h. The PA ionisation chamber values of this study recorded scatter from the phantom at a distance of 50cm (Grid position H4) as 295mR/h and values next to the theatre table between 97mR/h and 324mR/h (refer to Table 5.1).

The LAT measurements on the x-ray tube side of the C-Arm at grid J8 measured a dose value of 295mR/h and, closer to the reference point J6, a value of 1584mR/h (refer to Appendix VI – LAT 110cm). The Berthold mR/h measurements of the current study were confirmed by a physicist to be acceptable by means of a Fluke Radiation Monitor instrument. [According to Appendix VI (LAT 110cm), on position C9, the 39.6mR/h value was confirmed with the Fluke monitor as 345uSv/h – calculated as 34mR/h (Willemse, 2007)]. Thus, should the staff classified as non-radiation workers (cleaners, assistants) in this theatre, have no other option but to be present during fluoroscopy procedures, they are obliged to wear 0.25mm Pb rubber aprons so as to adhere to the requirements of the DoH and the ICRP.

Table 5.1: Ionisation chamber measurements with the C-Arm in the PA position representing mR/h values.

PA position grid, representing radiation dose distribution in mR/h													
	A	B	C	D	E	F	G	H	I	J	K	L	M
1			28.8	36.0	39.6	43.2	50.4	46.8	43.2	36.0	28.8	25.2	21.6
2	21.6	32.4	43.2	50.4	61.2	68.4	72.0	75.6	64.8	50.4	43.2	28.8	28.8
3	28.8	36.0	43.2	50.4	61.2	68.4	72.0	75.6	64.8	50.4	43.2	28.8	28.8
4	28.8	43.2	61.2	90.0	151.2	248.4	324.0	295.2	187.2	118.8	79.2	57.6	36.0
5	28.8	43.2	64.8	64.8									
6													
7	28.8	43.2	54.0	97.2				*					28.8
8	28.8	36.0	50.4	93.6									21.6
9	21.6	28.8	43.2	100.8	108.0	154.8	237.6		180.0	136.8	79.2	50.4	32.4
10	25.2	28.8	43.2	50.4	82.8	108.0			108.0	79.2	57.6	36.0	28.8
11	21.6	28.8	32.4	43.2	57.6	72.0				50.4	43.2	32.4	25.2
12			25.2	32.4	36.0	43.2				43.2	32.4	25.2	21.6
13			21.6	25.2	32.4	32.4	32.4		32.4	28.8	25.2	21.6	

* Point of Reference H7

Blank areas due to theatre table, C-Arm and fixed theatre equipment

Manchikanti *et al*. (2003) recorded, with a radiation time of 8.9 ± 0.4s, the exposure doses to the staff per patient at 0.629mRem (0.006mSv) outside the apron at the chest area and, at the groin level, 0.352mRem (0.003mSv). According to the TLD measurements of the current study outside the apron (see Tables 4.3 and 4.4), the lowest dose to the neurosurgeons at chest level was 0.04mSv per patient (0.176 + 0.77mSv divided by 19) and the highest dose at 0.22mSv per patient. At the pelvis level, the highest dose to the neurosurgeons was 0.23mSv and the lowest 0.09mSv per patient. These

doses were recorded for a 2.4-minute average exposure duration. To compare the measurement of the current study with the Machicanti 8.9s exposure times mentioned above, the calculation would be as follows:

144s (2.4 minutes) divided by 8.9s =16.17

16.17 x 0.006mSv = 0.09mSv outside the apron at chest level for 2.4 minutes applies. The 0.09mSv is higher than the lowest chest value of 0.04mSv for the neurosurgeon in the current study but lower than the 0.22mSv value. For the pelvis area the Machicanti 0.003mSv (0.04mSv/2.4 min) value is lower than the current study's values of 0.23mSv and 0.09mSv.

According to the 1998 AAPM Report (AAPM, 1998), the typical effective dose equivalent rate next to the table during fluoroscopy, without an extra lead drape from the table to the floor, is 2mSv/hr (2mGy/hour). The conversion of millisievert per minute will result in a radiation dose value of 0.03mSv per minute. The specific details of the type of fluoroscopic equipment or source skin distances are not available from the AAPM report so as to compare similarities between the current study and other back pain fluoroscopy procedures but it may give an indication as to dose rates. If we compare the dose in mSv/minute with the ionisation chamber PA measurements of the current study (refer to Appendix VI - PA 133cm), the dose at grid position H4 is higher during back pain procedures at 0.05mSv/minute (refer to Table 5.2) but the lower height (refer to Appendix VI-PA 110cm) at grid position measured a lower dose of 0.01mSv/min.

Table 5.2: Ionisation chamber measurements with the C-Arm in the PA position representing mSv/minute values

PA position grid, representing radiation dose distribution in mSv/minute								
	C	D	E	F	G	H	I	J
1	0.0048	0.006	0.0066	0.0072	0.0084	0.0078	0.0072	0.006
2	0.0072	0.0084	0.0102	0.0114	0.012	0.0126	0.0108	0.0084
3	0.0072	0.0084	0.0102	0.0114	0.012	0.0126	0.0108	0.0084
4	0.0102	0.015	0.0252	0.0414	0.054	**0.0492**	0.0312	0.0198
5	0.0108	0.0108						
6								
7	0.009	0.0162				* X		
8	0.008	0.0156						

* Point of Reference H7 -Blank areas due to theatre table, C-Arm and fixed theatre equipment

The radiation doses in the lateral view of the current study at grid position J6 (refer to Table 5.3) measured a higher dose at 0.3mSv/minute when compared to the AAPM value of 0.03mSv/minute (Appendix VI –Lateral 110cm).

Table 5.3: Ionisation chamber measurements with the C-Arm in the lateral position at 110cm height, representing mSv/minute values

LAT position grid, representing radiation dose distribution in mSv/minute at the 110cm height										
	E	F	G	H	I	J	K	L	M	N
1	0.0222	0.024	0.026	0.0012	0.0192	0.027	0.024	0.0192	0.0144	0.0108
2	0.0222	0.0222	0.03		0.0396	0.0474	0.0348	0.0282	0.0192	0.0144
3	0.036	0.0564	0.066		0.072	0.0528	0.027	0.0252	0.024	0.0168
4	0.0072	0.072	0.144			0.156	0.072	0.0408	0.0228	0.0114
5				**0.276**		**0.168**	0.072	0.0372	0.0144	0.012
6	0.0384	0.084	0.228		0.264	**0.264**	0.12	0.036	0.0192	0.0108
7	0.0288	0.0348		* X			0.252	0.0156	0.0096	0.0072
8	0.0192	0.0276	0.228		0.0504	0.0492	0.192	0.0132	0.0096	0.0066
9	0.015	0.0192	0.051		0.057	0.0288	0.018	0.012	0.0084	0.0048
10	0.0132	0.144	0.052		0.0468	0.0192	0.144	0.0096	0.0072	0.006

* Point of Reference H7

Blank areas due to theatre table, C-Arm and fixed theatre equipment

The hand of the neurosurgeon holding the needle was directly exposed to the x-ray beam and requires definite focus during back pain management procedures. Whilst positioning a pedicle screw in a cadaveric model, the average hand dose rate recorded was 58.2mrem per minute (0.6mSv/minute) (Zeiller *et al*., 2005). The TLD measurements of the current study confirmed the radiation dose value to the neurosurgeon's hands per patient as between 0.084mSv (II above the patient) and 6.5mSv (x-ray tube above the patient). Considering the median exposure time of 2.4 minutes per patient, it means an average of 0.03mSv per minute per patient with the II above the table and 2.7mSv/minute on the x-ray tube side. In the current study the doses on the x-ray tube side were higher than those recorded in the study done by Zeiller and others (2005) and may be ascribed to the hand of the neurosurgeon directly in the beam during the PA and PO views. The procedure of the current study was executed by altering the C-Arm in the PA, Oblique and lateral positions. Most

of the back pain management hits (injections) take place in the PA views. During the lateral view, the hand was not placed directly in the path of the x-ray beam. With the II side above the table in the current study, lower doses were recorded than in the mentioned study because the hand of the neurosurgeon was not placed in the position closest to the x-ray tube side. Another possible reason is that, during the screw placement of the Zeiller study, mostly lateral views were required and that is associated with higher levels of radiation exposure “due to greater soft tissue penetration required to obtain images.” (Zeiller *et al*., 2005).

At the Florida Spine Institute, the average exposure per procedure, with an average duration of 15s was 0.7mrem at the ring badge (0.007mSv) and 0.003mSv at the outside apron badge (Botwin *et al*., 2002). The median exposure per procedure, in this current study to the hand of the neurosurgeon with the II positioned above the table, was 0.084mSv per 2.4 minutes. Thus 0.035mSv/min (0.084mSv divided by 2.4min). The ring badge dose of 0.007mSv in 15s implies 0.028mSv/min (0.007 x 4). These two values to the hands are comparable. Outside the apron on the chest level the highest median dose was 0.06mSv per patient for 2.4 minutes, thus 0.025mSv/minute. The Botwin (Botwin *et al*., 2002) study measured a value of 0.012mSv per minute outside the apron - lower than the current study.

The aim of the Haku study (Haku *et al*., 2002) was to test shielding material and the dose rate was measured at different heights from the floor during fluoroscopy of the upper extremities. Higher exposure factors were necessary in the current study for imaging of the spine compared to extremities because of the difference in the thickness of the human anatomy. It was not possible to compare the dose values because of the difference in fluoroscopic parameters (52kV and 20mA versus 74kV and 6mA), the phantom used (6cm acrylic plate versus Perspex body phantom) and the orientation of the C-Arm. In the Haku study, the x-ray tube was closest to the table versus the II close to the table in the current study. Dose levels measured to the hands, however, are worth mentioning. Dose levels estimated were as follows: 938µR/min (0.00983 mSv/min) to the hands, 82µR/min to lens and 312µR/min to the lower

extremities (Haku *et al*., 2002). The 0.00983mSv/min are lower than the 0.035mSv/min (0.084 divided by 2.4 minutes) recorded in the current study.

In the Radiological Department of Complutense University, the scatter dose rates at the cardiologist's position, with no radiation protective tools, ranged from 1-14mSv per hour for fluoroscopy (Vano *et al*., 2005). In the lateral ionization chamber, this current study calculated a measurement of 0.3mSv/min (refer to Table 5.2). The PA measurements indicated that the radiation dose close to the reference point at grid H4 was 0.049mSv/minute (3mSv/h) and, according to the lateral measurements (refer Table 5.3), 0.168mSv/minute (10mSv/h). The fluoroscopy dose of the current study is comparable with the cardiology study.

Variables in the environment and differences in the pain procedure protocols of individual surgeons made it impossible to compare exactly the different studies. The fact remains, however, that the TLD measurements of this study represent the dose that the neurosurgeon received during the back pain management in this specific theatre.

The study confirmed the rationale behind radiation protection laws. The II positioned above the patient lowered the dose to the neurosurgeon's hand substantially. As indicated, higher dose values were recorded at the 110cm height (see Figure 4.10) during the lateral view and during the PA view at the 133cm height (see Figure 4.7). It is incorrect for staff to deduce that half body aprons will provide sufficient protection when operating close to the x-ray source because, during different orientations of the C-Arm, the x-ray tube is at different heights.

The ideal protocol design during back pain management procedures regarding positioning on the x-ray tube side of the C-Arm and stance of staff in the theatre will be addressed in the next section.

5.4. PROTOCOL DESIGN

Based on the measurements of the TLDs and the ionisation chamber, the researcher proposed a protocol for orientation of the C-Arm and placing of staff during back pain management procedures in this specific theatre. The fact that this theatre customised a screening table dedicated for the use of back pain management procedures needs to be taken into consideration by the reader. A special screening table specifically for back pain procedures, was manufactured as an initiative by the nursing staff in this theatre. This table allowed effortless movement of the C-Arm arc under the table and undemanding positioning of the x-ray tube under the patient. The table height was fixed throughout the procedure, saving time while adjusting positions for the purpose of this study. The sterile area was not compromised. The table made it possible to position the x-ray tube under the table during back pain procedures.

No additional pads for patient comfort were placed between the patient and the table, except sponge pillows. The proposed protocol gives attention to the position of the C-Arm, recommended areas for staff in theatre and radiation protection measures.

5.4.1`Position of the C-Arm

The position of the C-Arm refers to the x-ray tube over couch (PA) or x-ray tube under couch position (AP). The II must be positioned above the patient during back pain management procedures for the AP and Oblique positions. The neurosurgeon should be placed on the II side of the C-arm during the lateral positioning of the C-Arm. Other staff, namely nurses, assistant nurses and anaethetists should be encouraged to position themselves on the II side during lateral views.

AP Position

The ideal is to position the II above the patient, as close as possible to the patient without hampering needle placement into the facets of the spine. It is important to make sure that the x-ray tube is at a distance of 30cm from the

patient under the table. Because of the height of the customized table in this specific theatre, the x-ray tube can be placed at a 30cm distance from the patient. Figure 5.1 is a display of the position of the II above the patient and the x-ray tube at least 30cm from the patient. The photograph indicates the position of the neurosurgeon, the monitor and the C-Arm position. The nurse is not close to the table.

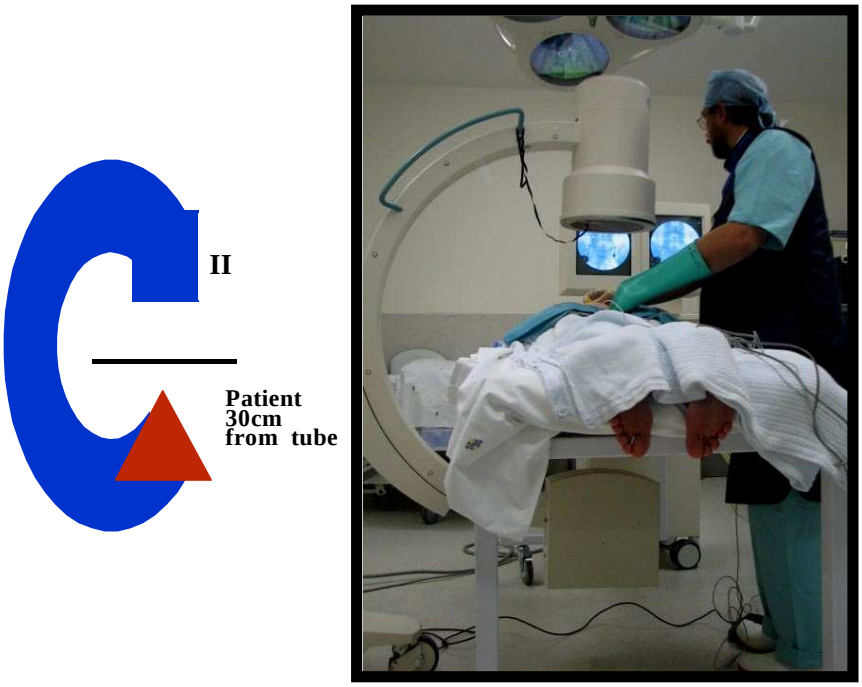

Fig. 5.1: Ideal AP positioning of the C-Arm with the II above the theatre table

Oblique position

The ideal is to position the II above the patient, as for the AP view. The neurosurgeon stands as close to the II as possible. In this specific theatre both oblique views were used during the procedure. It was impractical to make the neurosurgeon move over to the opposite side when the II was altered so as to be further away from the neurosurgeon. The neurosurgeon in this specific theatre remained on one side but the dose values were still lower than with the x-ray tube above the table. Figure 5.2 is a visual presentation of the oblique position of the C-Arm, as well as the positions of the neurosurgeon, the radiographer and the monitor. The II is positioned as close to the patient as possible.

Fig. 5.2: Ideal oblique positioning of C-Arm with the II above the theatre table

Lateral position

During back pain management procedures in the specific theatre the II was placed above the table. The neurosurgeon was placed opposite the radiographer so that they faced each other. The adjustment of the C-Arm into the lateral position meant that the neurosurgeon was placed at the x-ray tube side of the C-Arm. The measurement results for the TLD indicated a lower dose to the neurosurgeon, although he was on the x-ray tube side. The hand of the neurosurgeon is not directly in the beam with the x-ray tube in the lateral position. The ideal will be to have the neurosurgeon and the radiographer on the console side of the C-Arm so that the neurosurgeon will be closest to the II during the lateral view (see Figure 5.3). This statement was confirmed with the ionisation chamber measurements where the dose was five times lower on the II side of the C-Arm during lateral views. The ideal position of the radiographer and the neurosurgeon in relation to the C-Arm during lateral views is displayed in Figure 5.3. The neurosurgeon must be on the II side of the C-Arm so as to adhere to the ALARA principle.

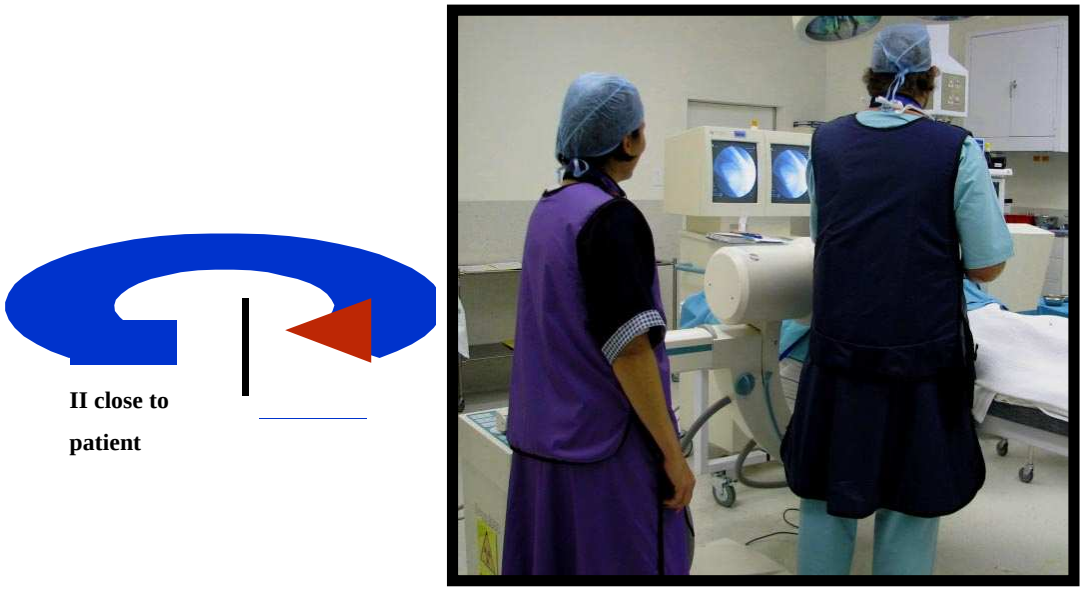

Fig. 5.3: Ideal lateral positioning of the C-Arm with staff on the II side

During procedures such as laminectomy or spinal fusion operations, fluoroscopy is utilised to determine the level of operation or screw placement. Only lateral views are normally required and the radiographer must plan in advance to position the C-Arm with the II side closest to the neurosurgeon and the scrub nurse.

5.4.2 Recommended areas for staff in theatre

Although the ideal is to place the radiographer and the surgeon on the console side of the C-Arm, the sterile trolley and arc of the C-Arm, however, made this positioning impractical (as discussed previously). The neurosurgeon may operate on the side opposite the console side in the AP and oblique views and, during the time taken for the radiographer to position the C-Arm in the lateral from the AP, the neurosurgeon can walk around for the lateral injection. The anaesthetist is normally placed at the head of the table in order to monitor the patient. It is possible to position the anaethetist and corresponding equipment closer to the II side of the C-Arm during back pain management procedure lists. Another idea is to position the anaesthetist behind the ventilation machine or to place an extra lead barrier - in the form of a lead apron hanging over a drip stand - between the anaesthetist and the x-ray source for utmost shielding

from the x-ray radiation.

Nurses in the room must be positioned on the II side during the lateral view and also at a distance not closer than 2m to the x-ray source with a 0.25mm lead equivalent apron. The nurse closest to the table should make use of a lead apron with a 0.35mm Pb equivalent during back pain management procedures.

5.4.3 Radiation protection measures

Radiographers should encourage only the necessary staff to be present during the fluoroscopy procedures in theatre. The staff present should wear full body lead rubber aprons (0.25mm Pb equivalent) and thyroid shields, as stipulated by law. Since a difference in dose measured to different heights varied with the altering of the C-Arm position, half-body protection is not recommended. Each permanent worker in the theatre must be issued with a dosimeter badge. Lead gloves will give extra protection to the hand close to the x-ray field but may not be practical to use due to the weight of the lead or the need for sterility of the injection area during the procedure. Pulsed fluoroscopy can be considered during placement of the needle to lower the dose to the hand.

5.4.4 Implementation of the protocol

In the present study, the difference in radiation dose measured to the hands and the body of the neurosurgeon with the x-ray tube under the table compared to the doses with the x-ray above the table, already played a role in convincing the neurosurgeons to modify the C-Arm positioning protocol for back pain procedures in this specific theatre. The enforcement of the C-Arm positioning protocol (II above) for back pain management procedures during the course of the study was implemented and accepted in the specific theatre with minor adjustments needed. The special screening table made the positioning of the II above the table and the application of the ALARA principle practical. The customised screening table eased positioning of the arc of the C-Arm. The theatre layout was changed to position the C-Arm monitor above the patient's head to in order to make visualisation effortless. The anaethetist equipment was moved slightly to the side. The II is positioned closer to the

sterile area compared to the distance with the x-ray tube above the table, but the distance between the II and the patient gave the neurosurgeon enough space to work in a sterile environment. The magnification due to the II patient distance was accepted and preferred above the higher dose levels of the PA view. Magnification of the image due to the II distance from the patient so as to provide space to the injection area is only applicable with overweight patients. The neurosurgeon accepted that, due to the magnification, both sides of the facet joints are not visible simultaneously. Slight movement of the II from the left to the right include visualisation of the facets.

5.5 CONCLUSION

The measurement values recorded with the TLD and ionisation chamber instrument were compared with values of studies found in literature. The dose levels measured with the TLDs and the ionisation chamber were within the range of the identified studies. Comparisons of values, measured at specific points by means of an ionisation chamber, confirmed that dose values were lower on the II side of the C-Arm. The TLD measurements confirmed that the dose to the neurosurgeon were lower with the C-Arm positioned with the II above the table. The TLD measurements indicated that the radiation dose to the patient was lower with the II positioned above the table.

The radiation distribution measured in the specific theatre, with the x-ray tube positioned above the table, confirmed that the hands of the neurosurgeon executing injections during back pain management fluoroscopy was at risk to exceed the radiation dose limit as set by the ICRP. In this chapter, a protocol in terms of positioning of staff and orientation of the C-Arm was proposed so as to comply with the ALARA principle.

The protocol indicated that the current C-Arm orientation had to be changed to position the II above the theatre table during back pain management procedures. The neurosurgeon must be positioned at the II side of the C-Arm during the lateral views. Full body lead protection of 0.35mm lead equivalent is mandatory. The assisting permanent staff in the theatre must be positioned at

the furthest distance possible from the x-ray source and must wear a full body protective apron (0.25mm Pb) with a dosimeter badge.

In the next chapter, the promotion of a safety culture in terms of radiation levels in this specific theatre will receive attention. Additionally, shortcomings of the study and possible future studies will be identified.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

Radiation distribution during back pain management procedures prompted the research concerning the ionising radiation levels in this specific theatre. The current study was led by the need to find answers to the questions stated in the first chapter, namely: Does the position of the neurosurgeon's stance in relation to the C-Arm affect the radiation dose he receives. The second question that needed to be answered was whether it was possible to lower the radiation dose to the staff in a neurological theatre. The research objectives of the study were formulated to answer these questions. The objectives of the study were thus to determine the radiation doses that the neurosurgeon receives when standing on either side of the C-Arm, x-ray tube side or image intensifier side and, further, to determine working areas for the theatre staff to maximize radiation protection during fluoroscopy in the theatre. These objectives were then to be used in order to propose protocols with regard to the position of the C-Arm, in relation to the neurosurgeon and other staff during back pain management procedures in this neurological theatre, which would promote the ALARA principle.

Measurements by means of TLDs placed on the neurosurgeon and the radiographer close to the x-ray source indicated the radiation dose to the pelvis, the chest areas and to the hand of the neurosurgeon. Measurements with an ionisation chamber and a phantom indicated the ionising radiation distribution pattern around the fluoroscopy table (mR) in order to answer questions regarding the positioning of staff in relation to the C-Arm.

The shortcomings of the study will receive focus before possible future studies are identified. The researcher discusses recommendations regarding radiation protection in the theatre, made possible by utilising the knowledge and insight

gathered over three years of observation. The research is concluded in the final remarks.

6.2 CONCLUSION OF MEASUREMENTS

The occupational dose limits that were important for this study (as mentioned in Chapter 2) were 20mSv per year, with a limit of 500mSv for the hands. The research objective was to investigate the possibility of lowering the radiation dose during back pain management procedures.

The TLD and ionisation measurements indicated that the dose was less on the II side of the C-Arm. The mean TLD radiation dose measured per patient (refer to Tables 4.4 and 4.5) with the II above the table was 0.04mSv for the neurosurgeon's chest, 0.09mSv for the neurosurgeon's pelvis and 0.08mSv for the neurosurgeon's hands. The measurements for the radiographer's pelvis were 0.03mSv on both sides of the C-Arm. The radiation dose measured to the radiographer's chest was also 0.03mSv per patient with the II of the C-Arm positioned above the table but unexpectedly lower with the x-ray tube positioned above the theatre table. This could be investigated in future.

Protocols for back pain management procedures were recommended according to the TLD and ionising radiation measurements. It is imperative that the II is positioned above the table during the AP and oblique views. The surgeon and staff should always be positioned at the II side of the C-Arm, especially during lateral views of the spine. The anesthetist and other staff should be positioned at least two metres away, guarded by 0.25mm Pb equivalent aprons. The surgeon close to the table must make use of whole body lead protection the equivalent of 0.35mm Pb. Lead protection gloves should be considered due to the fact that protecting remains a matter of urgency because injury to the hands of fluoroscopists still occurs involving radio dermatitis with unknown long-term malignant potential (Fishman *et al*., 2002).

Implementation of this protocol in the current theatre was accepted after communication of the confirmation regarding the dose difference on either side of the C-Arm. The change in the orientation of the C-Arm required minor adjustments. The neurosurgeon had to tolerate the II closer to the sterile injection area in order to limit magnification of the anatomy on the image. The II was positioned especially close to the working area when overweight patients were treated. The radiographer had to move the monitor into the neurosurgeon's comfortable viewing area, especially during the oblique view. The anesthetic apparatus had to be repositioned so as to accommodate the C-Arm monitor directly at the head of the patient. The radiographer must move the monitor back to the wall after the procedure to make room for the anaethetist so that he/she can have access to the subsequent patient. The proposed protocol was accepted completely during back pain procedures in this specific theatre.

The shortcomings of the study will be discussed under the following heading.

6.3 SHORTCOMINGS OF THE STUDY

In this section, measurement and methodology errors were identified and described. The shortcomings and errors of the current study will be addressed under two headings, namely TLD errors and ionisation chamber error considerations. The ideal of limiting variables could not be attained due to the death of the major role-player in the current study. Half of the TLD measurements were still outstanding at the time of death. Although the routines of the two neurosurgeons were different in terms of number of injections and exposure times, the average dose provided valuable and reliable information as confirmed in discussions with the biostatistician and the medical physicist.

6.3.1 TLD errors

The calibration process limited the error in dose values recorded by the TLDs. The shortcomings of the measurements in terms of placement of the TLDs will subsequently be addressed.

6.3.1.1 Neurosurgeon TLD distance from the radiation source

The distance of the neurosurgeon's TLDs from the x-ray source may vary. The investigator determined the average distance of the TLDs from the source by measuring the distance of the TLDs on the neurosurgeon's body from the source with the treatment of the first two patients. It was not practical to maintain an exact distance due to the anatomy difference of each patient but it was observed that the doctor normally stood close to the table as well as the patient so as to inject the medicine comfortably. The table height was fixed. The distance varied slightly because the neurosurgeon was not focused on standing in the same position with every case. The distance of the TLDs from the x-ray source was thought to be of the utmost importance, however, the radiographer determined an average distance from the patient and the x-ray tube due to the fact that the distance did not alter more than a few centimeters. The radiation levels were a true reflection of this specific neurosurgeon's environment because of the fact that the importance of the measurements was to focus on the dose received, irrespective of the distance from the source during real life procedures.

6.3.1.2 Placing of TLDs

Placing of the TLDs on the radiographer and neurosurgeon was centered in the pelvis area. The first neurosurgeon in this study was left-handed and turned his body slightly to the right. The TLD's on the chest level were placed on the right pocket but his rotation during injections may have had an influence on the dose measurements.

6.3.1.3 TLDs on the patient

The TLDs were placed in the centre of the anatomical area of interest, in other words between the third lumbar and fifth sacral vertebrae (L1-S1). It was not possible to move the TLDs during the examination in the centre of the beam due to the sterility of the area. The TLDs were placed on a 15cm strip exactly 5cm apart, to cover the region normally injected between L1-S1. The centre of the TLD-strip was placed exactly opposite the fourth lumbar vertebra, above the margin of the crest ileac. The strip could not be fixed with plaster in the PA

view because of the sterility of the area. It was observed that the strip was sometimes moved millimetres by the neurosurgeon so as to inject in some facets. For the II above the table measurements, the TLDs were placed on the patient's stomach to measure the entrance dose from the x-ray tube under the table.

The lateral TLDs were placed on the level of the coccyx, with the center on the bigger trochanter of the femur on the side of the x-ray tube. The TLDs that were placed in the middle of the back were not in the neurosurgeon's area of injection because needles are placed just off centre to reach the facet. In overweight patients, the bigger trochanter was not palpable and the strip was not necessarily placed with the centre in the exact area. The lateral TLDs measured the dose to the side of the patient during an epidural injection, which was in the centre of the spine. It was also decided that because of availability, two TLDs per region (in other words, two on the neurosurgeon's chest and two on the radiographer) were utilised to detect spurious values of a specific TLD.

6.3.2 Ionisation chamber errors

6.3.2.1 Berthold ionization chamber instrument

To eliminate error, the physicist recommended exposing TLDs simultaneously with the Berthold measurement in order to observe the difference in measurements between the two measuring instruments. The six TLDs were exposed on top of the ionisation probe for 60 seconds at (64kV and 5.8mA) on position E9 on the grid (refer Figure 3.5). The researcher checked the ionisation chamber measurements in the PA as well as the posterior oblique positions. It was exactly the same as measured at the previous session. The reading on the Berthold apparatus was 5mR. The TLD values were higher but comparable with the ionisation chamber measurement values at the position on the grid, namely position I6, within about 60% (compare the verification process in Appendix VII).

6.3.2.2 The C-Arm

The C-Arm operates automatically according to anatomical thickness at kV values between 60kV and 110kV. The phantom was selected in order to draw exposure factors as close as possible to these two extremes. During the measurements, the C-Arm tends to overheat after 30 minutes of 10 second screening times. A thicker phantom will draw higher kV and mA values, which is not feasible in terms of overheating, since the C-Arm must be ready for theatre use at all times. The measurements had to be done when theatres were available. The number of readings per C-Arm position (250 per position, thus 1500 in total) was time-consuming and made it impossible to finish all the measurements during one session. The researcher repeated, for example, previous known and recorded measurements each time at the beginning of the session to make sure the readings at a specific point were similar compared with previously recorded readings.

6.3.2.3 The height of the C-Arm

During the ionisation chamber measurements with the phantom, the C-Arm was set at fixed distances from the fixed table, as well as the phantom, to limit variables. During examinations with patients, the distance of the x-ray source depended on the anatomy of the patient and was impossible to set at a pre-selected fixed distance, although the radiographer kept the II as close to the patient and the table as possible. During PA views, the II also touched the table under the patient and was as close to the patient as possible so as to limit magnification of the anatomical structures. With the oblique views the distance varied according to the thickness of the patient's body so as to correctly include the spine facet for the injection. The angle was not always fixed at 45 degrees due to the difference in anatomy. The distance of the II during lateral views was dependant on the thickness of the patient - the patient was prone on the table and the body thickness determined the distance of the spine from the table. The diameter of the C-Arm's II is 30cm, which influences the distance to the patient. The radiographer kept the distance between the patient side and the II as short as possible.

The study revealed the need of staff to be informed about radiation protection aspects that will be addressed with information sheets and possible future studies.

6.4 FUTURE STUDIES

The dose measurements confirmed that the II should be placed above the fluoroscopy table. The difference in the radiation dose to the hand convinced the staff to accept the implementation of a different C-Arm orientation. Investigation into the situation in other theatres and pain management clinics in South Africa, as well as abroad, will confirm appropriate orientation of the C-Arm during back pain procedures in other facilities. Questionnaires can be distributed both at congresses and electronically, to investigate the circumstances.

The findings of this study must be communicated widely, not only in this theatre, but also to other facilities. The researcher's next step will be to inform the staff of the results in a user-friendly way with the use of simple explanations. Ways to communicate the findings in this theatre will be in the form of information sheets, posters, and workshops.

The researcher is of the opinion that there is an urgent need to have more information available regarding protocols with every C-Arm manual. The information sheets, that are planned to influence protection positively, can be distributed to manufacturers so as to be included in the C-Arm manuals. Since back pain management procedures are widely used, it is necessary to train radiography students appropriately. Such procedures should therefore specifically be included as part of the curriculum for radiography students. Articles, seminars and congresses are ways to distribute information, but distance training is an area that should become part of thinking processes for the remote areas of our continent.

The focus of this study was the neurological theatre, but the bigger picture of radiation distribution will be concluded when ionising radiation dose levels are

determined in the Urology and Orthopedic theatres as well. Another concern is the dose received by gastro-enterologists during ERCP procedures, where exposure duration times of 30 minutes per session is recorded when placing stents into the bile system. The gastro-enterologists are also positioned close to the patient and x-ray source due to the length of the scope. TLDs placed on the surgeon can determine the dose levels received during procedures. It will also be noteworthy to determine the effectiveness of radiation protection gloves for the neurosurgeon during the back pain management injections. This can assist theatre management in making an informative choice between the different providers of lead gloves. The above-mentioned enquiries will provide a comprehensive analysis of radiation distribution in a modern theatre.

In order to ensure radiological protection and safety, the implementation of a quality system is an obvious requirement (Touzet, 2004). Touzet further recommends the implementing of a "safety culture that is absolutely essential" by using a structured programme. The importance of a safety culture is imperative where specialists who have no prior training in radiological protection increasingly use fluoroscopically guided techniques. It is possible that a radiographer may encounter an individual who may refuse to make use of protection. People may be vulnerable to mistakes, not only because of a lack of knowledge and motivation, but also absent-mindedness, conflicts, or "just because it does not suit them to work well on that day" (Touzet, 2004b: 2). It may happen that an individual just does not feel the need to make use of physical protection against radiation. This quality system and safety culture will be the focus of study in this current theatre to conclude the radiation distribution during back pain procedures. Establishing of a safety culture in this theatre is a personal goal for the future.

Some of the other factors that need consideration in the radiation protection scenario will be addressed in the following section under recommendations during fluoroscopy.

6.5. RECOMMENDATIONS

Protection against ionising radiation should be a lifelong challenge. The basic principles of radiation safety is time, distance and shielding (Bushberg *et al*., 2001). The most effective way to reduce patient exposure is to use less fluoroscopic time. This will bebefit all because the dose to the staff is reduced when the dose to the patient is reduced (Bushberg *et al*., 2001). Fluoroscopy machines are equipped with a timer and an alarm which sound at the end of every five minute fluoroscopic use (Henry Ford Health System, 2001). Radiation dose can be lowered by limiting exposure times (Fishman *et al*., 2002)

Exposure rate from a point source or radiation decreases as the distance from the source squared (Bushberg *et al*., 2001). The Inverse Square Law is of the utmost importance during fluoroscopy since doubling the distance from the radiation source decreases the radiation level by a factor of four. Scattered radiation from the patient and tabletop are also sources of radiation exposure. The radiation intensity is 0.1% when the neurosurgeon is placed one metre from the patient at 90 degrees to the incident beam. The staff should be located as far as possible from the x-ray source. Communicate a warning in a loud voice that fluoroscopy is in progress before the fluoroscopy button is activated.

Many factors should be mentioned simultaneously with the proposed protocol in order to lower the fluoroscopy radiation dose during back pain management procedures. Image detail, for example, can be improved by increasing kV, decreasing the distance between the patient, the II and the x-ray beam collimation. Higher kV values produce brighter fluoroscopy pictures. The radiographers should remember that the clearest images may produce the highest doses, but with an increase in kV with lower mA, the same quality may be produced at a lower dose. Radiographers and surgeons must learn to work with imperfections which still allow the needed clinical outcome. “Noise is good!” (Gray, 2007). High kV and low mA are preferred in fluoroscopy to produce reasonable images with low patient radiation exposure (Fishman *et*

al., 2002). The x-ray tube current (mA setting) controls the quantity of x-rays produced per unit of time. When mA is doubled, the exposure to the patient and the staff will double. Patient size should be taken into account, as larger patients receive higher doses (ICRP, 2000). All fluoroscopic parameters and radiation duration must be recorded at all times.

One should calibrate the monitor conditions for the specific environment due to the fact that good lighting for surgical needs must be balanced with imaging considerations (Henry Ford Health System, 2001). The patient dose can also be reduced by other factors, i.e. filtration in the unit. The filtration can remove the low energy x-rays before they reach the patient since the low energy x-rays do not contribute to the image (Fishman *et al.,* 2002).

All radiographerss and staff present in the theatre during back pain management procedures must wear a dosimeter badge, as issued monthly by the Radiation Protection Service. In theatre, workers must be identified for whom individual monitoring is needed - all full-time staff must be monitored (ICRP,1990). Even low doses during fluoroscopy must be kept in accordance with the ALARA principle because radiation dose to the equivalent of 0.25Sv or 25rem may lead to measurable haematological depression (Fishman *et al*., 2002). This also provides an opportunity to communicate the effects of radiation and to encourage protection against x-rays. The researcher views the dosimeter badge as an open door to campaign for protective measures during fluoroscopy.

Prudent use of collimators lowers the radiation that the patient receives, since less patient tissue is in the radiation beam. Collimation restricts the field size (Bushberg *et al*., 2001). With collimation, workers receive less radiation since there is less radiation available to scatter towards staff. Scatter will reduce image quality and decrease contrast.

Last image hold avoids unnecessary patient and staff exposure due to the image being available for reference. Intermittent, or pulsed fluoroscopy will

reduce exposure when compared to continuous fluoroscopy (Manchikanti *et al*., 2003).

C-Arm fluoroscopic units may cause problems for patients, especially when the radiographer allows the x-ray tube to be positioned very close to the patient's skin. This should be avoided. The radiographer should make sure that the x-ray tube is as far from the patient as possible with the image intensifier as close as possible (ICRP, 2000).

Attention to detail, increased kV, increased filtration and the tabletop transmission (silicon pads on the tabletop) can result in a 78% reduction in patient dose (Gray, 2007). In summary, time, distance and shielding are the best ways to protect against radiation (AAPM, 1998). Implementing all these factors is a constant challenge for any radiographer.

It is law that staff should wear physical protection. The aprons may be experienced as a heavy burden during lenghty procedures and should be as comfortable as possible. The aprons “must comprise of a well-designed, tailored lead apron, which distributes the weight across the individual's shoulders, or hangs the skirt on the bony pelvis, sparing the spine from the full weight of the apron (ICRP, 2000).

One of the ICRP recommendations (ICRP, 2000) is that all departments performimg interventional procedures should record the typical doses delivered to patients and staff and, therefore, equipment manufacturers should provide inicators of delivered doses. Useful diplays are the air kerma (in mGy or Gy) and the air kerma rate (mGy per minute) during fluoroscopy that have accumulated at the same reference location to the current point of the procedure. Other recommendations include training of staff on potential radiation injuries, as well as the methods to reduce dose to the patient and staff.

6.6 CONCLUDING REMARKS

Tableside fluoroscopy receives among the highest occupational radiation exposures within the health system (Radiation Office, 2001c:9). The culprit is scatter. Scatter radiation is highest near its source, the beam entry point on the patient. Because of tissue attenuation, radiation doses are significantly lower on the II side than on the x-ray tube side of the C-Arm. The current study indicated, with the protocols previously used during back pain management procedures (x-ray tube above table), that the ionising radiation dose values received by the hand of the neurosurgeon are higher than the dose received during the proposed protocol. The Berthold measurement values, with the C-Arm in different positions, confirmed that the C-Arm orientation should be with the II above the table and the staff positioned at the II side at all times during back pain management procedures.

The median values of the radiation doses, measured with the TLDs, did indicate statistical significance for the neurosurgeons chest when compared on either side of the C-Arm. The median values to the neurosurgeon's pelvis and finger may indicate statistical significance if the sample size is taken in consideration. A larger study group to include more measurement periods will address the statistical data, but repetition of the cycles to include more patients will imply measurements with the x-ray tube positioned above the table. This will suggest that the ALARA principle is not applied. The TLD values indicated that the radiographer would receive radiation dose values below the annual dose limit of 20mSv, provided that the II is placed above the table. The II above table orientation will limit the skin dose to the hands of the neurosurgeon within the annual 500mSv recommendation.

Orientation of the C-Arm and positioning of staff on the II side are not the only radiation protection measures that need to be put into place during fluoroscopy so as to adhere to the ALARA principle as mentioned before. The good news is that the radiation dose can be lowered during fluoroscopy.

6.7 FINAL CONCLUSION

The study was initiated out of concern due to the dose levels that the neurosurgeon received during back pain procedures. The possibility to lower the radiation dose to the neurosurgeon needed investigation. The objectives of the study were completed by determining the radiation dose to the neurosurgeon on the x-ray tube side and II side of the C-Arm, as well as pointing out working areas for the theatre staff so as to maximize radiation protection during fluoroscopy. TLD and ionisation chamber measurements at two heights as well as different distances from the x-ray tube provided a clear picture of the radiation distribution during back pain management procedures. The final objective was achieved with the implementation of the proposed protocol.

The protocol during back pain procedures changed the C-Arm orientation from the PA view to the AP view. The special screening table was manufactured due to the initiative taken by the nursing staff who made the change a reality. The staff accepted a change in the theatre layout, motivated by the benefit of lower doses. The neurosurgeon positioned himself on the II side of the C-Arm during the LAT views. Nurses were aware of radiation distribution and focused to be positioned at further distances from the source. The resentment of the neurosurgeon to implement the protocol in terms of the magnification of the image and bulky II disappeared with the understanding of the reduction in radiation doses to all staff and the patient. The prominent perception that stood out among the staff in this specific theatre prior to the study was that fluoroscopy dose levels are low compared to the dose of conventional x-ray films. The radiation levels recorded changed this perception. The implementation of the protocol during back pain procedures confirmed the possibility to lower the radiation dose and thus made a significant contribution to the application of the ALARA principle in the current theatre.

Although the goals of the study were achieved and questions answered, the work is not completed. Three steps are planned for the way forward. The first

will be to install lead shielding from the table to the floor on the customised theatre table in order to incorporate this protective measure so as to reduce radiation exposure to the legs of the staff, since the x-ray source is positioned under the theatre table. A lead shield (non-solid) will only be attached to the theatre tableside closest to the neurosurgeon in order not to affect the ease of change in tube orientation. The second step entails obtaining advice from a medical physics expert regarding patient dosimetry; appropriate indicators of delivered doses quality assurance. This will address the need for the local clinical protocol of the interventional procedures in this current environment. The comprehensive clinical protocol statement includes fluoroscopy times, air kerma rates, and the resulting cumulative skin doses associated with the various parts of the interventional procedure. The third issue to address is to purchase a device (e.g. cumulative air kerma indication) so as to help assess the magnitude of skin dose (ICRP, 2000). Dose Area Product (DAP) meters provide an estimation of the radiation dose (absorbed dose to air times the x-ray beam across asectional area at the point of measurement) expressed in $Gycm^2$ (Kocinaja, Cioppa, Ambrosinia, Tesorioa, Salemmia, Sorropagoa, Rubinoa, and Picano, 2006).

According to Professor Joel Gray, however, fluoroscopy is more widely used in modern medicine and has the potential of unlimited exposure (Gray, 2007). When we put ionising radiation exposure into perspective, in a population of one million radiated with 10mSv equivalent, effective dose will cause only 200 extra cancers (AAPM, 1998). It is argued that smoking and accidents cause more deaths. The researcher's opinion is that 200 cancer patients are 200 too many. The radiographer's duty is to lower the statistics to an absolute minimum. It will remain a constant challenge to review practices and protocols in order to ensure that the ionising radiation doses during back pain management procedures are as low as reasonably possible.

One needs to constantly look for quality and to improve through learning (McNiff, 2002). In order to improve the workplace or ourselves, radiographers should have the right to explain why extra attention is given to this study. To ask the question: "How can I improve what I am doing?" is the only way to

influence social change (McNiff and Whitehead, 2006). The researcher agrees with Zhou and others (2005) in that it is necessary to implement continuing education programmes regarding radiation safety for fluoroscopy users. The awareness of radiation values contributes to the awareness of protection. The research resulted in the changing of the protocol (x-ray tube above table) in this current theatre, with improved ionising radiation protection during fluoroscopy. Lower radiation levels to staff imply lower radiation levels to the patient. Thus, the creation of a safer work environment for staff and patients in this specific neurological theatre has the possibility to improve the quality of life for the patient as well as the staff.

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APPENDIX I (a)

Dr. David J. van der Merwe

Neurosurgeon / Neurochirurg

M.B.Ch.B. (UOVS) M.Med. (Neurochir) (UOVS)
Pr. No: 2400995

Mediese Sentrum
G–03 Universitas Private Hospitaal
Logeman Str 1
BLOEMFONTEIN
9301

Posbus 29469
Danhof
9310

Tel: (051) 444 3736/7
Faks: (051) 444 0261

26 April 2006

VIR WIE DIT MAG AANGAAN

Hiermee gee ek toestemming dat bestralingsdosisse in my teater gemeet mag word. Daar sal geen verandering in my prosedures wees nie, aangesien dit gemeet is in die lig van die normale prosedure, so pasiënt toestemming behoort nie nodig te wees nie.

Die meting van sodanige bestraling sal van waarde wees om bestralingsblootstelling in teater te bespreek.

.....

DR. DAVID J. VAN DER MERWE

APPENDIX I (b)

Community Hospital Management Limited
t/a Universitas Private Hospital

Reg. 2000/022215/06
1 Logeman Street, Universitas, Bloemfontein, 9301.
P.O. Box 11595, Universitas, 9321
Tel: 051-5063 500 Fax: 051-444 5499

18 Julie 2006

Mev. R. van der Merwe
Posbus 26719
Langenhovenpark
9330

Faks: 051 – 446 2441

Geagte mevrou van der Merwe

M. STUDIE: "RADIATION AWARENESS IN THEATRE"

Hiermee wil die Kliniese Advieskomitee u laat weet dat bogenoemde studie goedgekeur is en dat u mag voortgaan daarmee in die Netcare hospitaal.

Vriendelike groete.

Dr. H. Smallberger
Algemene Bestuurder: Netcare Private Hospitaal

APPENDIX II

APPENDIX II

Period number 1 2 3 4 5 6

Side of C-Arm: Tube / Image Intensifier side

TLD procedure measurements

Patient	KV AP	MA AP	KV LAT	MA LAT	Screening time	Weight	Height	BMI	Hits
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

TLD measurements

	PERIOD	TLD RP	TLD RP	TLD RC	TLD RC	TLD DF	TLD DP	TLD DP	TLD DT	TLD DT	TLD 1 AP		TLD 2 AP	TLD 3 AP
TLD no.		**12**	**5**	**11**	**4**	**10**	**8**	**9**	**6**	**7**	**1**		**2**	**3**
10PT	1 TUBE													
10PT	1 II													

TLD calibration

Dose Calculation:													
Relative sensitivity factor (RSF):													
Corrected Readings													
Dose (cGy):													
Dose (mSv):													

APPENDIX III

APPENDIX III

Ionization chamber measurements in milli-Roentgens/h (mR/h)

Position of C-Arm_____

Berthold apparatus height from the floor _____cm

1. Berthold probe from the floor _____m
2. Fluoroscopic parameters: ___ kV, ___mA and ___s
3. 10s exposure
4. Berthold measurement in mR (milli-Roentgens)
5. Table height fixed at ___cm from the floor
6. Phantom bottom to floor ___cm
7. II UNDER TABLE top to floor ___cm
8. Tube to floor ____cm
9. Phantom upper to II ___cm
10. Phantom upper to tube ___cm
11. C-Arm arm distance fixed at 17cm
12. X-ray source position is the point of reference
13. On the grid at position 7H
14. Grid = 25cm blocks

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														

APPENDIX IV

Appendix IV (a)

TLD results for 10 patients with tube over couch Surgeon 1

Preiod 1 2 3 4 5 6 7 8 9 10
Side of C-Arm
Tube

	PERIOD	TLD RP	TLD RP	TLD RC	TLD RC	TLD DF	TLD DP	TLD DP	TLD DT	TLD DT	TLD 1 AP	TLD 2 AP	TLD 3 AP
TLD no.		**12**	**5**	**11**	**4**	**10**	**8**	**9**	**6**	**7**	**1**	**2**	**3**
10PT	T1	213	76	87	75	25713	414	422	556	492	104722	55335	74402
10PT	I2												
10PT	T3												
10PT	I4												
Dose calculation:													
Relative Sensitivity Factor (RSF):													
		0.988	1.009	0.991	1.007	0.983	1.025	1.013	1.006	0.975	0.991	0.992	0.994
Corrected values		210.44	76.684	86.217	75.525	25276	424.35	427.486	559.336	479.7	103779.5	54892.32	73955.59
Dose(cGy):		0.0627	-0.0022	0.0024	-0.0028	12.22	0.1664	0.167942	0.231892	0.193266	50.29572	26.58447	35.83053
Dose (mSv):		**0.627**	**-0.022**	**0.024**	**-0.03**	**122.2**	**1.664**	**1.6794**	**2.31892**	**1.93266**	**502.957**	**265.84**	**358.31**
Calibration:		Dosis 50 cGy by 100 kV,20mA						**Background**					
TLD no.		13	14	15	16			17	18	19			
RSF		0.997	1.003	1.037	0.961			0.998	1.01	1.025			
Value		101675	101428	99478	110737			77	84	80			
Corrected value		101370	101732	103159	106418			76.846	84.84	82			
Average:		**103170**						**81.22867**					

Appendix IV (b)

TLD results for 10 patients with II over couch Surgeon 1

Preiod 1 2 3 4 5 6 7 8 9 10
Side of C-Arm
Image Intensifier

	PERIOD	TLD RP	TLD RP	TLD RC	TLD RC	TLD DF	TLD DP	TLD DP	TLD DT	TLD DT	TLD 1 AP	TLD 2 AP	TLD 3 AP
TLD no.		**12**	**5**	**11**	**4**	**10**	**8**	**9**	**6**	**7**	**1**	**2**	**3**
10PT	T1	213	76	87	75	25713	414	422	556	492	104722	55335	74402
10PT	I2	7	9	8	7	37	44	38	22	21	1043	1450	613
10PT	T3	167	90	121	218	2019	678	659	506	477	77127	126099	43960
10PT	I4												
Dose (mSv)	I2	-0.02	0.01	-0	-0.02	0.37	0.46	0.384	0.176	0.163	13.45	18.73	7.857
TLD Calibration (100 kV, 50 cGy)													
TLD No	Value	R.S.F.	Corrected value		Average								
13	40577	0.997	40455.3										
14	39678	1.003	39797		38483								
15	35363	1.037	36671.4										
16	38509	0.961	37007.1										
Background													
17	9	0.998	8.982										
18	8	1.01	8.08		8.4207								
19	8	1.025	8.2										

Appendix IV (C)

TLD results for 10 patients with tube over couch Surgeon 2

Preiod 1 2 3 4 5 6 7 8 9 10
Side of C-Arm
Tube

	PERIOD	TLD RP	TLD RP	TLD RC	TLD RC	TLD DF	TLD DP	TLD DP	TLD DT	TLD DT	TLD 1 AP	TLD 2 AP	TLD 3 AP
TLD no.		**12**	**5**	**11**	**4**	**10**	**8**	**9**	**6**	**7**	**1**	**2**	**3**
10PT	T1	213	76	87	75	25713	414	422	556	492	104722	55335	74402
10PT	I2												
10PT	T3	167	90	121	218	2019	678	659	506	477	77127	126099	43960
10PT	I4												
5PT	T5												
5PT	I6												
											365		
Dose (mSv)		0.47	0.11	0.25	0.73	9.17	3	2.87	2.11	1.9	365	598	209

Appendix IV (d)

TLD results for 10 patients with II over couch Surgeon 2

Preiod 1 2 3 4 5 6 7 8 9 10
Side of C-Arm
Image Intensifier

	PERIOD	TLD RP	TLD RP	TLD RC	TLD RC	TLD DF	TLD DP	TLD DP	TLD DT	TLD DT	TLD 1 AP	TLD 2 AP	TLD 3 AP
TLD no.		**12**	**5**	**11**	**4**	**10**	**8**	**9**	**6**	**7**	**1**	**2**	**3**
10PT	T1	213	76	87	75	25713	414	422	556	492	104722	55335	74402
10PT	I2	7	9	8	7	37	44	38	22	21	1043	1450	613
10PT	T3	167	90	121	218	2019	678	659	506	477	77127	126099	43960
10PT	I4	183	149	347	155	303	333	354	194	241	25886	34724	20208
Dose (mSv)	I2	0.72	0.55	1.53	0.58	1.31	1.46	1.566	0.775	1.007	127.9	171.6	99.78
TLD Calibration (100 kV, 50 cGy)													
TLD No	Value	R.S.F.	Corrected value		Average								
13	99904	0.997	99604.3										
14	103590	1.003	103901		101110								
15	97079	1.037	100671										
16	104335	0.961	100266										
Background													
17	37	0.998	36.926										
18	36	1.01	36.36		37.412								
19	38	1.025	38.95										

APPENDIX V

APPENDIX V (a)

Ionization Chamber measurement results with the C-Arm in the PA position – height 110cm

1. Berthold probe from the floor 110cm
2. Fluoroscopic parameters: 64 kV, 5.8mA and 0.1s
3. 10s exposure
4. Berthold measurement in mR (milli roentgen)
5. Table height is fixed at 82 cm from the floor
6. Phantom bottom to floor 86 cm
7. II UNDER TABLE top to floor 72 cm
8. Tube to floor 148.5cm
9. Phantom upper to II 20cm
10. Phantom upper to tube 62.5cm
11. C-Arm arm distance fixed at 17cm
12. X-ray source position is the point of reference
13. On the grid at position 7H
14. Grid = 25cm blocks

OPERATOR SIDE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				0.6	0.7	0.7	0.7							
2	0.4	0.6	0.8	0.8	1.1	1.2	1.1	0.8	0.8	0.7	0.6			
3	0.6	0.7	0.9	1.2	1.6	1.8	1.8	1.4	1.2	0.9	0.7			
4	0.6	0.8	1.2	1.8	2.8	4	4.2	2.2	1.9	1.4	0.9	0.7		
5	0.60	0.6	1.1	1.6							0.6			
6														
7														
8		0.6	0.8	1.4										
9			0.8	1	1.7	2.3	3.8		5	3.7	2.4	1.6	1.2	
10			0.6	0.8	1.6	1.5	1.8		1.2	2	1.6	1.2	0.9	
11					0.8	1	1.2			1.2	1.1	0.9	0.8	
12				0.6	0.7	0.9				0.6	0.8	0.7	0.6	

C-ARM CONSOLE SIDE

Appendix V (b)

Ionization Chamber measurement results with the C- Arm in the PA position – height 133cm

1. Berthold probe from the floor 1.33m
2. Fluoroscopic parameters: 64 kV, 5.8mA and 0.1s
3. 10s exposure
4. Berthold measurement in mR (milli roentgen)
5. Table height is fixed at 82 cm from the floor
6. Phantom bottom to floor 86 cm
7. II UNDER TABLE top to floor 72 cm
8. Tube to floor 148.5cm
9. Phantom upper to II 20cm
10. Phantom upper to tube 62.5cm
11. C-Arm arm distance fixed at 17cm
12. X-ray source position is the point of reference
13. On the grid at position 7H
14. Grid = 25cm blocks

OPERATOR SIDE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1			0.8	1	1.1	1.2	1.4	1.3	1.2	1	0.8	0.7	0.6	
2	0.6	0.9	1.2	1.4	1.7	1.9	2	2.1	1.8	1.4	1.2	0.8	0.8	
3	0.8	1	1.2	1.8	2.8	3.8	4.8	2.5	2.4	1.7	1.2	0.9	0.8	
4	0.8	1.2	1.7	2.5	4.2	6.9	9	8.2	5.2	3.3	2.2	1.6	1	0.8
5	0.8	1.2	1.8	1.8										
6														
7	0.8	1.2	1.5	2.7										0.8
8	0.8	1	1.4	2.6										0.6
9	0.6	0.8	1.2	2.8	3	4.3	6.6		5	3.8	2.2	1.4	0.9	0.4
10	0.7	0.8	1.2	1.4	2.3	3			3	2.2	1.6	1	0.8	0.5
11	0.6	0.8	0.9	1.2	1.6	2				1.4	1.2	0.9	0.7	0.6
12	4		0.7	0.9	1	1.2				1.2	0.9	0.7	0.6	0.4
13			0.6	0.7	0.9	0.9	0.9		0.9	0.8	0.7	0.6		

C-ARM CONSOLE SIDE

Appendix V (c)

Ionization Chamber measurement results with C-Arm in the OBLIQUE position - height 110cm

1. Berthold probe from the floor 1.10m
2. Fluoroscopic parameters: 64 kV, 5.8mA and 0.1s
3. 10s exposure
4. Berthold measurement in mR (milli roentgen)
5. Maximum tube tilt (45 degrees)
6. Table height is fixed at 82 cm from the floor
7. Phantom bottom to floor 86 cm,
8. II UNDER TABLE top to floor 76.5 cm
9. Tube to floor 152.5cm, Phantom upper to II 28cm
10. Phantom upper to tube 45cm
11. C-Arm arm distance fixed at 12cm
12. X-ray source position is the point of reference
13. On the grid at position 7H
14. Grid = 25cm blocks

IMAGE INTENSIFIER SIDE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	0.6	0.7	0.9	1.2	1.3	1.3	1.4	1.2	0.9	0.7	0.6			
2	0.7	0.8	1	1.4	1.7	1.9	2	1.8	1.2	0.8	0.7			
3	0.7	0.9	1.4	1.8	2.7	3.6	3.7	3	1.6	1	0.7			
4	0.7	1	1.9	2.8	3.1	9.4	10	6	2.4	1.4	0.8			
5	0.8	1.2	1.8	3.7	7.3	18	22	12	3	1.2	0.8			
6	0.8	1.3	2	3										
7	1.6	2								1.8	1	0.7	0.5	
8	1.2	0.9	3	5.6	14	39		20	6.3	2.3	1.2	0.7	0.5	
9	1.1	1.8	2.6	5.2	8	16		11	6.1	2.3	1.3	0.7	0.5	
10	0.9	1.3	1.9	3.4	4.2	5.2		4	2.5	1.7	1	0.6	0.5	
11	0.8	1.2	1.5	1.6	2.7			3.9	2.8	1.4	0.9	0.7	0.5	
12	0.7	1	1.3	1.4	1.8			2.6	1.8	1.2	0.9	0.6	0.6	
13	0.6	0.8	0.9	1	1.4	1		1.8	1.4	0.9	0.8	0.6	0.6	
14		0.7	0.7	0.8	0.9	0.6	0.2	1	1.1	0.8	0.7	0.6	0.5	
15		0.5	0.6	0.6	0.7	0.4	0.2	0.7	0.8	0.7	0.5	0.5	0.3	
16			0.5	0.5	0.5	0.2	0	0.5	0.6	0.6	0.5	0.5	0.3	

TUBE SIDE

Appendix V (d)

Ionization Chamber measurement results with the C-Arm in the OBLIQUE position - height 133 cm

1. Berthold probe from the floor 1.33m
2. Fluoroscopic parameters: 64 kV, 5.8mA and 0.1s
3. 10s exposure
4. Berthold measurement in mR (milli roentgen)
5. Maximum tube tilt (45 degrees)
6. Table height is fixed at 82 cm from the floor
7. Phantom bottom to floor 86 cm
8. II UNDER TABLE - top to floor 76.5 cm
9. Tube to floor 152.5cm
10. Phantom upper to II 28cm
11. Phantom upper to tube 45cm
12. C-Arm arm distance fixed at 12cm
13. X-ray source position is the point of reference
14. On the grid at position 7H
15. Grid = 25cm blocks

IMAGE INTENSIFIER SIDE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	0.8	0.9	1	1.2	1.4	1.4	1.6	1.3	0.9	0.9	0.6			
2	0.7	1	1.2	1.6	1.8	2.2	2	2	1.4	1	0.7			
3	0.8	1.1	1.5	2.2	2.6	3.5	3.8	3.3	1.8	1.2	0.8			
4	0.8	1.2	2.2	2.8	5.2	7.5	8	5.8	2.9	1.6	1			
5	0.9	1.4	2.4	4.2	6.9	11	12	12	4	2.5	1.2			
6	1	1.5	2.4	3.3										
7	1.4	1.8								2.5	1.5	0.9	0.5	
8	1.3	2.1	3	5.1	10	26		16	6.3	3.1	1.4	1.1		0.7
9	1.2	1.7	2.7	5.6	9	15		11	5.1	2.8	1.6	1		0.7
10	0.9	1.5	2.4	3.7	5.1	6.2		5.3	3.6	2.5	1.5	0.9		0.7
11	0	1.3	1.8	2.6	3.1			3	2.4	1.8	1.4	0.8		0.7
12	0.8	1.2	1.6	1.6	2.2			2	1.7	1.7	1.2	0.7		0.6
13	0.7	0.9	1.2	1.3	1.6	1.2		1.4	1.4	1.2	0.9	0.7		0.6
14	0.6	0.8	0.9	0.9	0.9	0.6	0.2	1.1	0.8	0.8	0.8	0.7		0.3
15		0.6	0.8	0.8	0.8	0.4	0.1	0.8	0.6	0.7	0.6	0.5		0.4
16			0.6	0.6	0.6	0.2	0	0.6	0.6	0.5	0.5	0.5		0.3

Appendix V (e)

Ionization Chamber measurement results with the C- Arm in the LATERAL position - height 110cm

1. Berthold probe from the floor 1.10m
2. Fluoroscopic parameters: 74 kV, 6mA and 0.1s
3. 10s exposure
4. Berthold measurement in mR (milli roentgen)
5. Table height is fixed at 82 cm from the floor
6. Phantom bottom to floor 86 cm
7. Tube to phantom 5cm
8. C-Arm arm height distance fixed at 26cm
9. C-Arm and tube to touch table
10. X-ray source position is the point of reference
11. On the grid at position 7H
12. Surgeon position I 4 or G 4

TUBE SIDE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	1.2	1.6	2.2	2.8	3.7	4	4.4	0.2	3.2	4.5	4	3.2	2.4	
2	1.2	1.6	2	2.6	3.7	3.7	5	0	6.6	7.9	5.8	4.7	3.2	
3	1.4	1.8	3	4.2	6	9.4	11	0	12	8.8	4.5	4.2	4	
4	1.4	1.8	2.8	7.2	1.2	12	24			26	12	6.8	3.8	
5	1.4	3	3	4.2				46		28	12	6.2	2.4	
6	1.4	2.6	2.6	3.6	6.4	14	38		44	44	20	6	3.2	
7	0.9	2	2	2.8	4.8	5.8					42	2.6	1.6	
8	0.8	1.4	1.4	2.8	3.2	4.6	38		8.4	8.2	3.2	2.2	1.6	
9	0.6	1.1	1.1	1.6	2.5	3.2	8.5		9.5	4.8	3	2	1.4	
10	0.6	1	1	1.4	2.2	2.4	8.8		7.8	3.2	2.4	1.6	1.2	
11	0.6	0.9	0.9	1.2	1.8	2.4	9.8			2.4	1.8	1.4	1	
12	0.5	1	1	1.4	1.3	2.8	5.2		5.1	2.2	1.6	1.2	0.9	
13	0.5	0.8	0.8	0.9	1.4	2.8	0	0.1	0.1	2	0.8	1	0.8	
14	0.4	0.5	0.5	0.7	0.8	2.4	0	0	0.1	1.8	0.8	0.8	0.8	
15	0.4	0.5	0.5	0.5	0.6	0.6			0.1	1	0.7	0.7	0.7	
16	0.4	0.5	0.5	0.5	0.1	0.1			0.1	0.3	0.4	0.4	0.7	
17						0.1								

IMAGE INTENSIFIER SIDE

Appendix V (f)

Ionization Chamber measurement results with the C-Arm in the LATERAL position – height 133cm

1. Berthold probe from the floor 1.33m
2. Fluoroscopic parameters: 74 kV, 6mA and 0.1s
3. 10s exposure
4. Berthold measurement in mR (milli roentgen)
5. Table height is fixed at 82 cm from the floor
6. Phantom bottom to floor 86 cm
7. Tube to phantom 5cm
8. C-Arm arm height distance fixed at 26cm
9. C-Arm and tube to touch table
10. X-ray source position is the point of reference
11. On the grid at position 7H
12. Surgeon position I 4 or G 4

TUBE SIDE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	1.2	1.6	2	2.4	3	3.6	4.7	0.2	2.8	4	3.6	3.2	2.6	1.9
2	1.2	1.4	1.8	2.6	3.2	3.2	4.2		7	6.8	5.2	4.1	3	2.4
3	1.8	2	2.8	4	5.6	7.8	8.4	4.8	7.8	7.2	5	7.2	2.4	1.8
4	1.8	2.8	4.2	6	8.6	8.8	4	18	20	15	8.8	5.8	3.6	2.2
5	1.9	2	2.4	3.8				16	20	16	9.8	5.8	2.4	2
6	1.4	2	2.6	4	6.3	12	18			12	5.9	3.2	2.2	1.8
7	1	1.5	2.4	3.2	5.2						4.8	2.8	1.8	1.2
8	0.8	1.2	1.4	2.6	3.5	5.4	9.2		9.8	5.6	3.4	2.2	1.8	1.2
9	0.7	0.9	1.2	1.8	2.8	4.5	6.4		6.4	4.9	3.4	2.2	1.5	1
10	0.6	0.9	1.2	1.6	2.4	3.6	4.3		4.4	3.6	2.5	1.8	1.2	1
11	0.6	0.8	0.9	1.4	1.9	2.4	3.6			2.7	2	1.5	1.2	0.8
12	0.6	0.7	0.8	1	1.4	2	3.2		2.6	2	1.6	1.2	1	0.8
13	0.5	0.6	0.8	1	1.4	1.8	3.8	0.1	3.2	2	1.2	0.8		0.6
14	0.5	0.6	0.7	0.9	1.2	1.8	3.4	0.1	2.8	2.2	1.2	0.8	0.8	0.6
15	0.4	0.4	0.7	0.8	1.2	2.4	1.2	0	1.8	1.7	1	0.8	0.8	0.6
16	0.4	0.6	0.6	0.6	1.2	2.4	0.1	0	1	1.8	1.8	0.8	0.7	0.6

IMAGE INTENSIFIER SIDE

APPENDIX VI

C-Arm PA position – 110cm

Ionization chamber mesurements expressed in mR and mSv

PA_110 (Dose rate: milliSv / minute)

	a	b	c	d	e	f	g	h	l	j	k	l	m	n	
1				0.0036	0.0042	0.0042	0.0042								
2	0.0024	0.0036	0.0048	0.0048	0.0066	0.0072	0.0066	0.0048	0.0048	0.0042	0.0036				Operator side
3	0.0036	0.0042	0.0054	0.0072	0.0096	0.0108	0.0108	0.0084	0.0072	0.0054	0.0042				
4	0.0036	0.0048	0.0072	0.0108	0.0168	0.024	0.0252	0.0132	0.0114	0.0084	0.0054	0.0042			
5	0.0036	0.0036	0.0066	0.0096							0.0036				
6															
7															patient leg side
8		0.0036	0.0048	0.0084											
9			0.0048	0.006	0.0102	0.0138	0.0228		0.03	0.0222	0.0144	0.0096	0.0072		
10			0.0036	0.0048	0.0096	0.009	0.0108		0.0072	0.012	0.0096	0.0072	0.0054		
11					0.0048	0.006	0.0072			0.0072	0.0066	0.0054	0.0048		C-Arm side
12				0.0036	0.0042	0.0054				0.0036	0.0048	0.0042	0.0036		
13															
14															
15															
16															
17															

PA_110 (Dose rate: milliSv / 3 minute)

	a	b	c	d	e	f	g	h	l	j	k	l	m	n	
1				0.0108	0.0126	0.0126	0.0126								
2	0.0072	0.0108	0.0144	0.0144	0.0198	0.0216	0.0198	0.0144	0.0144	0.0126	0.0108				Operator side
3	0.0108	0.0126	0.0162	0.0216	0.0288	0.0324	0.0324	0.0252	0.0216	0.0162	0.0126				
4	0.0108	0.0144	0.0216	0.0324	0.0504	0.072	0.0756	0.0396	0.0342	0.0252	0.0162	0.0126			
5	0.0108	0.0108	0.0198	0.0288							0.0108				
6															
7															patient leg side
8		0.0108	0.0144	0.0252											
9			0.0144	0.018	0.0306	0.0414	0.0684		0.09	0.0666	0.0432	0.0288	0.0216		
10			0.0108	0.0144	0.0288	0.027	0.0324		0.0216	0.036	0.0288	0.0216	0.0162		
11					0.0144	0.018	0.0216			0.0216	0.0198	0.0162	0.0144		C-Arm side
12				0.0108	0.0126	0.0162				0.0108	0.0144	0.0126	0.0108		
13															
14															
15															
16															
17															

PA_110 (milliRoentgen / hour)

	a	b	c	d	e	f	g	h	l	j	k	l	m	n	
1				21.6	25.2	25.2	25.2								
2	14.4	21.6	28.8	28.8	39.6	43.2	39.6	28.8	28.8	25.2	21.6				Operator side
3	21.6	25.2	32.4	43.2	57.6	64.8	64.8	50.4	43.2	32.4	25.2				
4	21.6	28.8	43.2	64.8	100.8	144.0	151.2	79.2	68.4	50.4	32.4	25.2			
5	21.6	21.6	39.6	57.6							21.6				
6															
7															patient leg side
8		21.6	28.8	50.4											
9			28.8	36.0	61.2	82.8	136.8		180.0	133.2	86.4	57.6	43.2		
10			21.6	28.8	57.6	54.0	64.8		43.2	72.0	57.6	43.2	32.4		
11					28.8	36.0	43.2			43.2	39.6	32.4	28.8		C-Arm side
12				21.6	25.2	32.4				21.6	28.8	25.2	21.6		
13															
14															
15															
16															
17															

PA_110 (Original values)															
	a	b	c	d	e	f	g	h	I	j	k	l	m	n	
1				0.6	0.7	0.7	0.7								
2	0.4	0.6	0.8	0.8	1.1	1.2	1.1	0.8	0.8	0.7	0.6				Operator side
3	0.6	0.7	0.9	1.2	1.6	1.8	1.8	1.4	1.2	0.9	0.7				
4	0.6	0.8	1.2	1.8	2.8	4	4.2	2.2	1.9	1.4	0.9	0.7			
5	0.6	0.6	1.1	1.6							0.6				
6															
7															patient leg side
8		0.6	0.8	1.4											
9			0.8	1	1.7	2.3	3.8		5	3.7	2.4	1.6	1.2		
10			0.6	0.8	1.6	1.5	1.8		1.2	2	1.6	1.2	0.9		
11					0.8	1	1.2			1.2	1.1	0.9	0.8		C-Arm side
12				0.6	0.7	0.9				0.6	0.8	0.7	0.6		
13															
14															
15															
16															
17															

PA_110(Dose rate: microSv / second OF milli- Roentgen / 10 seconds)															
	a	b	c	d	e	f	g	h	I	j	k	l	m	n	
1				0.06	0.07	0.07	0.07								
2	0.04	0.06	0.08	0.08	0.11	0.12	0.11	0.08	0.08	0.07	0.06				Operator side
3	0.06	0.07	0.09	0.12	0.16	0.18	0.18	0.14	0.12	0.09	0.07				
4	0.06	0.08	0.12	0.18	0.28	0.4	0.42	0.22	0.19	0.14	0.09	0.07			
5	0.06	0.06	0.11	0.16							0.06				
6															
7															patient leg side
8		0.06	0.08	0.14											
9			0.08	0.1	0.17	0.23	0.38		0.5	0.37	0.24	0.16	0.12		
10			0.06	0.08	0.16	0.15	0.18		0.12	0.2	0.16	0.12	0.09		
11					0.08	0.1	0.12			0.12	0.11	0.09	0.08		C-Arm side
12				0.06	0.07	0.09				0.06	0.08	0.07	0.06		
13															
14															
15															
16															
17															

PA_110 (Dose rate: mikroSv per second)															
	a	b	c	d	e	f	g	h	I	j	k	l	m	n	
1				0.00006	0.00007	0.00007	0.00007								
2	0.00004	0.00006	0.00008	0.00008	0.00011	0.00012	0.00011	0.00008	0.00008	0.00007	0.00006				Operator side
3	0.00006	0.00007	0.00009	0.00012	0.00016	0.00018	0.00018	0.00014	0.00012	0.00009	0.00007				
4	0.00006	0.00008	0.00012	0.00018	0.00028	0.0004	0.00042	0.00022	0.00019	0.00014	0.00009	0.00007			
5	0.00006	0.00006	0.00011	0.00016							0.00006				
6															
7															patient leg side
8		0.00006	0.00008	0.00014											
9			0.00008	0.0001	0.00017	0.00023	0.00038		0.0005	0.00037	0.00024	0.00016	0.00012		
10			0.00006	0.00008	0.00016	0.00015	0.00018		0.00012	0.0002	0.00016	0.00012	0.00009		
11					0.00008	0.0001	0.00012			0.00012	0.00011	0.00009	0.00008		C-Arm side
12				0.00006	0.00007	0.00009				0.00006	0.00008	0.00007	0.00006		
13															
14															
15															
16															
17															

APPENDIX VI

C-Arm PA position – 133cm

Ionization chamber mesurements expressed in mR and mSv

PA_133 (Dose rate: milliSv / minute)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
1	0	0	0.0048	0.006	0.0066	0.0072	0.0084	0.0078	0.0072	0.006	0.0048	0.0042	0.0036				
2	0.0036	0.0054	0.0072	0.0084	0.0102	0.0114	0.012	0.0126	0.0108	0.0084	0.0072	0.0048	0.0048				Operator side
3	0.0048	0.006	0.0072	0.0084	0.0102	0.0114	0.012	0.0126	0.0108	0.0084	0.0072	0.0048	0.0048				
4	0.0048	0.0072	0.0102	0.015	0.0252	0.0414	0.054	0.0492	0.0312	0.0198	0.0132	0.0096	0.006	0.0048	0.0036	0.0024	
5	0.0048	0.0072	0.0108	0.0108													
6													0.0048				Patient leg side
7	0.0048	0.0072	0.009	0.0162									0.0036	0.0024			
8	0.0048	0.006	0.0084	0.0156									0.0054	0.0024			
9	0.0036	0.0048	0.0072	0.0168	0.018	0.0258	0.0396		0.03	0.0228	0.0132	0.0084	0.0048	0.003	0.0024		
10	0.0042	0.0048	0.0072	0.0084	0.0138	0.018			0.018	0.0132	0.0096	0.006	0.0042	0.0036	0.0024		C-Arm side
11	0.0036	0.0048	0.0054	0.0072	0.0096	0.012				0.0084	0.0072	0.0054	0.0036	0.0024			
12			0.0042	0.0054	0.006	0.0072				0.0072	0.0054	0.0042					
13			0.0036	0.0042	0.0054	0.0054	0.0054		0.0054	0.0048	0.0042	0.0036					
14																	
15																	
16																	
17																	

× 3

PA_133 (Dose rate: milliSv / 3 minute)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
1			0.0144	0.018	0.0198	0.0216	0.0252	0.0234	0.0216	0.018	0.0144	0.0126	0.0108				
2	0.0108	0.0162	0.0216	0.0252	0.0306	0.0342	0.036	0.0378	0.0324	0.0252	0.0216	0.0144	0.0144				Operator side
3	0.0144	0.018	0.0216	0.0252	0.0306	0.0342	0.036	0.0378	0.0324	0.0252	0.0216	0.0144	0.0144				
4	0.0144	0.0216	0.0306	0.045	0.0756	0.1242	0.162	0.1476	0.0936	0.0594	0.0396	0.0288	0.018	0.0144	0.0108	0.0072	
5	0.0144	0.0216	0.0324	0.0324													
6													0.0144				Patient leg side
7	0.0144	0.0216	0.027	0.0486									0.0108	0.0072			
8	0.0144	0.018	0.0252	0.0468									0.0162	0.0072			
9	0.0108	0.0144	0.0216	0.0504	0.054	0.0774	0.1188		0.09	0.0684	0.0396	0.0252	0.0144	0.009	0.0072		
10	0.0126	0.0144	0.0216	0.0252	0.0414	0.054			0.054	0.0396	0.0288	0.018	0.0126	0.0108	0.0072		C-Arm side
11	0.0108	0.0144	0.0162	0.0216	0.0288	0.036				0.0252	0.0216	0.0162	0.0108	0.0072			
12			0.0126	0.0162	0.018	0.0216				0.0216	0.0162	0.0126					
13			0.0108	0.0126	0.0162	0.0162	0.0162		0.0162	0.0144	0.0126	0.0108					
14																	
15																	
16																	
17																	

20 / milliSv per 3 minute

× 6 × 60

PA_133 (milliRoentgen / hour)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
1			28.8	36.0	39.6	43.2	50.4	46.8	43.2	36.0	28.8	25.2	21.6				
2	21.6	32.4	43.2	50.4	61.2	68.4	72.0	75.6	64.8	50.4	43.2	28.8	28.8				Operator side
3	28.8	36.0	43.2	50.4	61.2	68.4	72.0	75.6	64.8	50.4	43.2	28.8	28.8				
4	28.8	43.2	61.2	90.0	151.2	248.4	324.0	295.2	187.2	118.8	79.2	57.6	36.0	28.8	21.6	14.4	
5	28.8	43.2	64.8	64.8													
6													28.8				Patient leg side
7	28.8	43.2	54.0	97.2									21.6	14.4			
8	28.8	36.0	50.4	93.6									32.4	14.4			
9	21.6	28.8	43.2	100.8	108.0	154.8	237.6		180.0	136.8	79.2	50.4	28.8	18.0	14.4		
10	25.2	28.8	43.2	50.4	82.8	108.0			108.0	79.2	57.6	36.0	25.2	21.6	14.4		C-Arm side
11	21.6	28.8	32.4	43.2	57.6	72.0				50.4	43.2	32.4	21.6	14.4			
12			25.2	32.4	36.0	43.2				43.2	32.4	25.2					
13			21.6	25.2	32.4	32.4	32.4		32.4	28.8	25.2	21.6					
14																	
15																	
16																	
17																	

PA_133 (Original values)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
1			0.8	1	1.1	1.2	1.4	1.3	1.2	1	0.8	0.7	0.6				
2	0.6	0.9	1.2	1.4	1.7	1.9	2	2.1	1.8	1.4	1.2	0.8	0.8				Operator side
3	0.8	1	1.2	1.4	1.7	1.9	2	2.1	1.8	1.4	1.2	0.8	0.8				
4	0.8	1.2	1.7	2.5	4.2	6.9	9	8.2	5.2	3.3	2.2	1.6	1	0.8	0.6	0.4	
5	0.8	1.2	1.8	1.8													
6													0.8				Patient leg side
7	0.8	1.2	1.5	2.7									0.6	0.4			
8	0.8	1	1.4	2.6									0.9	0.4			
9	0.6	0.8	1.2	2.8	3	4.3	6.6		5	3.8	2.2	1.4	0.8	0.5	0.4		
10	0.7	0.8	1.2	1.4	2.3	3			3	2.2	1.6	1	0.7	0.6	0.4		C-Arm side
11	0.6	0.8	0.9	1.2	1.6	2				1.4	1.2	0.9	0.6	0.4			
12			0.7	0.9	1	1.2				1.2	0.9	0.7					
13			0.6	0.7	0.9	0.9	0.9		0.9	0.8	0.7	0.6					
14																	
15																	
16																	
17																	

÷ 10

PA_133 (Dose rate: microSv / second OF milli- Roentgen / 10 seconds)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
1			0.08	0.1	0.11	0.12	0.14	0.13	0.12	0.1	0.08	0.07	0.06				
2	0.06	0.09	0.12	0.14	0.17	0.19	0.2	0.21	0.18	0.14	0.12	0.08	0.08				Operator side
3	0.08	0.1	0.12	0.14	0.17	0.19	0.2	0.21	0.18	0.14	0.12	0.08	0.08				
4	0.08	0.12	0.17	0.25	0.42	0.69	0.9	0.82	0.52	0.33	0.22	0.16	0.1	0.08	0.06	0.04	
5	0.08	0.12	0.18	0.18													
6													0.08				Patient leg side
7	0.08	0.12	0.15	0.27									0.06	0.04			
8	0.08	0.1	0.14	0.26									0.09	0.04			
9	0.06	0.08	0.12	0.28	0.3	0.43	0.66		0.5	0.38	0.22	0.14	0.08	0.05	0.04		
10	0.07	0.08	0.12	0.14	0.23	0.3			0.3	0.22	0.16	0.1	0.07	0.06	0.04		C-Arm side
11	0.06	0.08	0.09	0.12	0.16	0.2				0.14	0.12	0.09	0.06	0.04			
12			0.07	0.09	0.1	0.12				0.12	0.09	0.07					
13			0.06	0.07	0.09	0.09	0.09		0.09	0.08	0.07	0.06					
14																	
15																	
16																	
17																	

÷ 1000

AP_133 (Dose rate: milliSv / second)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
1			0.00008	0.0001	0.00011	0.00012	0.00014	0.00013	0.00012	0.0001	0.00008	0.00007	0.00006				
2	0.00006	0.00009	0.00012	0.00014	0.00017	0.00019	0.0002	0.00021	0.00018	0.00014	0.00012	0.00008	0.00008				Operator side
3	0.00008	0.0001	0.00012	0.00014	0.00017	0.00019	0.0002	0.00021	0.00018	0.00014	0.00012	0.00008	0.00008				
4	0.00008	0.00012	0.00017	0.00025	0.00042	0.00069	0.0009	0.00082	0.00052	0.00033	0.00022	0.00016	0.0001	0.00008	0.00006	0.00004	
5	0.00008	0.00012	0.00018	0.00018													
6													0.00008				Patient leg side
7	0.00008	0.00012	0.00015	0.00027									0.00006	0.00004			
8	0.00008	0.0001	0.00014	0.00026									0.00009	0.00004			
9	0.00006	0.00008	0.00012	0.00028	0.0003	0.00043	0.00066		0.0005	0.00038	0.00022	0.00014	0.00008	0.00005	0.00004		
10	0.00007	0.00008	0.00012	0.00014	0.00023	0.0003			0.0003	0.00022	0.00016	0.0001	0.00007	0.00006	0.00004		C-Arm side
11	0.00006	0.00008	0.00009	0.00012	0.00016	0.0002			0	0.00014	0.00012	0.00009	0.00006	0.00004			
12			0.00007	0.00009	0.0001	0.00012			0	0.00012	0.00009	0.00007					
13			0.00006	0.00007	0.00009	0.00009	0.00009		0.00009	0.00008	0.00007	0.00006					
14																	
15																	
16																	
17																	

× 60

APPENDIX VI

C-Arm Oblique position – 110cm

Ionization chamber mesurements expressed in mR and mSv

PAO_110 (Dose rate: milliSv / minute)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	0.0036	0.0042	0.0054	0.0072	0.0078	0.0078	0.0084	0.0072	0.0054	0.0042	0.0036				
2	0.0042	0.0048	0.006	0.0084	0.0102	0.0114	0.012	0.0108	0.0072	0.0048	0.0042				ii side
3	0.0042	0.0054	0.0084	0.0108	0.0162	0.0216	0.0222	0.018	0.0096	0.006	0.0042				
4	0.0042	0.006	0.0114	0.0168	0.0186	0.0564	0.06	0.036	0.0144	0.0084	0.0048				
5	0.0048	0.0072	0.0108	0.0222	0.0438	0.108	0.132	0.072	0.018	0.0072	0.0048				
6	0.0048	0.0078	0.012	0.018											
7	0.0096	0.012								0.0108	0.006	0.0042	0.003		patient leg side
8	0.0072	0.0054	0.018	0.0336	0.084	0.234		0.12	0.0378	0.0138	0.0072	0.0042	0.003		
9	0.0066	0.0108	0.0156	0.0312	0.048	0.096		0.066	0.0366	0.0138	0.0078	0.0042	0.003		
10	0.0054	0.0078	0.0114	0.0204	0.0252	0.0312		0.024	0.015	0.0102	0.006	0.0036	0.003		
11	0.0048	0.0072	0.009	0.0096	0.0162			0.0234	0.0168	0.0084	0.0054	0.0042	0.003		tube side
12	0.0042	0.006	0.0078	0.0084	0.0108			0.0156	0.0108	0.0072	0.0054	0.0036	0.0036		
13	0.0036	0.0048	0.0054	0.006	0.0084	0.006		0.0108	0.0084	0.0054	0.0048	0.0036	0.0036		
14		0.0042	0.0042	0.0048	0.0054	0.0036	0.0012	0.006	0.0066	0.0048	0.0042	0.0036	0.003		
15		0.003	0.0036	0.0036	0.0042	0.0024	0.0012	0.0042	0.0048	0.0042	0.003	0.003	0.0018		
16			0.003	0.003	0.003	0.0012		0.003	0.0036	0.0036	0.003	0.003	0.0018		
17						0.0006		0.003	0.003	0.003					

PAO_110 (Dose rate: milliSv / 3 minute)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	0.0108	0.0126	0.0162	0.0216	0.0234	0.0234	0.0252	0.0216	0.0162	0.0126	0.0108				
2	0.0126	0.0144	0.018	0.0252	0.0306	0.0342	0.036	0.0324	0.0216	0.0144	0.0126				ii side
3	0.0126	0.0162	0.0252	0.0324	0.0486	0.0648	0.0666	0.054	0.0288	0.018	0.0126				
4	0.0126	0.018	0.0342	0.0504	0.0558	0.1692	0.18	0.108	0.0432	0.0252	0.0144				
5	0.0144	0.0216	0.0324	0.0666	0.1314	0.324	0.396	0.216	0.054	0.0216	0.0144				
6	0.0144	0.0234	0.036	0.054											
7	0.0288	0.036								0.0324	0.018	0.0126	0.009		patient leg side
8	0.0216	0.0162	0.054	0.1008	0.252	0.702		0.36	0.1134	0.0414	0.0216	0.0126	0.009		
9	0.0198	0.0324	0.0468	0.0936	0.144	0.288		0.198	0.1098	0.0414	0.0234	0.0126	0.009		
10	0.0162	0.0234	0.0342	0.0612	0.0756	0.0936		0.072	0.045	0.0306	0.018	0.0108	0.009		
11	0.0144	0.0216	0.027	0.0288	0.0486			0.0702	0.0504	0.0252	0.0162	0.0126	0.009		tube side
12	0.0126	0.018	0.0234	0.0252	0.0324			0.0468	0.0324	0.0216	0.0162	0.0108	0.0108		
13	0.0108	0.0144	0.0162	0.018	0.0252	0.018		0.0324	0.0252	0.0162	0.0144	0.0108	0.0108		
14		0.0126	0.0126	0.0144	0.0162	0.0108	0.0036	0.018	0.0198	0.0144	0.0126	0.0108	0.009		
15		0.009	0.0108	0.0108	0.0126	0.0072	0.0036	0.0126	0.0144	0.0126	0.009	0.009	0.0054		
16			0.009	0.009	0.009	0.0036		0.009	0.0108	0.0108	0.009	0.009	0.0054		
17						0.036		0.18	0.18	0.18					

PAO_110 (milliRoentgen / hour)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	21.6	25.2	32.4	43.2	46.8	46.8	50.4	43.2	32.4	25.2	21.6				
2	25.2	28.8	36.0	50.4	61.2	68.4	72.0	64.8	43.2	28.8	25.2				ii side
3	25.2	32.4	50.4	64.8	97.2	129.6	133.2	108.0	57.6	36.0	25.2				
4	25.2	36.0	68.4	100.8	111.6	338.4	360.0	216.0	86.4	50.4	28.8				
5	28.8	43.2	64.8	133.2	262.8	648.0	792.0	432.0	108.0	43.2	28.8				
6	28.8	46.8	72.0	108.0											
7	57.6	72.0								64.8	36.0	25.2	18.0		patient leg side
8	43.2	32.4	108.0	201.6	504.0	1404.0		720.0	226.8	82.8	43.2	25.2	18.0		
9	39.6	64.8	93.6	187.2	288.0	576.0		396.0	219.6	82.8	46.8	25.2	18.0		
10	32.4	46.8	68.4	122.4	151.2	187.2		144.0	90.0	61.2	36.0	21.6	18.0		
11	28.8	43.2	54.0	57.6	97.2			140.4	100.8	50.4	32.4	25.2	18.0		tube side
12	25.2	36.0	46.8	50.4	64.8			93.6	64.8	43.2	32.4	21.6	21.6		
13	21.6	28.8	32.4	36.0	50.4	36.0		64.8	50.4	32.4	28.8	21.6	21.6		
14		25.2	25.2	28.8	32.4	21.6	7.2	36.0	39.6	28.8	25.2	21.6	18.0		
15		18.0	21.6	21.6	25.2	14.4	7.2	25.2	28.8	25.2	18.0	18.0	10.8		
16			18.0	18.0	18.0	7.2		18.0	21.6	21.6	18.0	18.0	10.8		
17						3.6		18.0	18.0	18.0					

PAO_110 (Original values)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	0.6	0.7	0.9	1.2	1.3	1.3	1.4	1.2	0.9	0.7	0.6				
2	0.7	0.8	1	1.4	1.7	1.9	2	1.8	1.2	0.8	0.7				ii side
3	0.7	0.9	1.4	1.8	2.7	3.6	3.7	3	1.6	1	0.7				
4	0.7	1	1.9	2.8	3.1	9.4	10	6	2.4	1.4	0.8				
5	0.8	1.2	1.8	3.7	7.3	18	22	12	3	1.2	0.8				
6	0.8	1.3	2	3											
7	1.6	2								1.8	1	0.7	0.5		patient leg side
8	1.2	0.9	3	5.6	14	39		20	6.3	2.3	1.2	0.7	0.5		
9	1.1	1.8	2.6	5.2	8	16		11	6.1	2.3	1.3	0.7	0.5		
10	0.9	1.3	1.9	3.4	4.2	5.2		4	2.5	1.7	1	0.6	0.5		
11	0.8	1.2	1.5	1.6	2.7			3.9	2.8	1.4	0.9	0.7	0.5		tube side
12	0.7	1	1.3	1.4	1.8			2.6	1.8	1.2	0.9	0.6	0.6		
13	0.6	0.8	0.9	1	1.4	1		1.8	1.4	0.9	0.8	0.6	0.6		
14		0.7	0.7	0.8	0.9	0.6	0.2	1	1.1	0.8	0.7	0.6	0.5		
15		0.5	0.6	0.6	0.7	0.4	0.2	0.7	0.8	0.7	0.5	0.5	0.3		
16			0.5	0.5	0.5	0.2	0	0.5	0.6	0.6	0.5	0.5	0.3		
17						0.1	0	0.5	0.5	0.5					

PAO110 (Dose rate: mikroSv / second OF milliRoentgen / 10 seconds)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	0.06	0.07	0.09	0.12	0.13	0.13	0.14	0.12	0.09	0.07	0.06				
2	0.07	0.08	0.1	0.14	0.17	0.19	0.2	0.18	0.12	0.08	0.07				ii side
3	0.07	0.09	0.14	0.18	0.27	0.36	0.37	0.3	0.16	0.1	0.07				
4	0.07	0.1	0.19	0.28	0.31	0.94	1	0.6	0.24	0.14	0.08				
5	0.08	0.12	0.18	0.37	0.73	1.8	2.2	1.2	0.3	0.12	0.08				
6	0.08	0.13	0.2	0.3											
7	0.16	0.2								0.18	0.1	0.07	0.05		patient leg side
8	0.12	0.09	0.3	0.56	1.4	3.9		2	0.63	0.23	0.12	0.07	0.05		
9	0.11	0.18	0.26	0.52	0.8	1.6		1.1	0.61	0.23	0.13	0.07	0.05		
10	0.09	0.13	0.19	0.34	0.42	0.52		0.4	0.25	0.17	0.1	0.06	0.05		
11	0.08	0.12	0.15	0.16	0.27			0.39	0.28	0.14	0.09	0.07	0.05		tube side
12	0.07	0.1	0.13	0.14	0.18			0.26	0.18	0.12	0.09	0.06	0.06		
13	0.06	0.08	0.09	0.1	0.14	0.1		0.18	0.14	0.09	0.08	0.06	0.06		
14		0.07	0.07	0.08	0.09	0.06	0.02	0.1	0.11	0.08	0.07	0.06	0.05		
15		0.05	0.06	0.06	0.07	0.04	0.02	0.07	0.08	0.07	0.05	0.05	0.03		
16			0.05	0.05	0.05	0.02		0.05	0.06	0.06	0.05	0.05	0.03		
17						0.01		0.05	0.05	0.05					

PAO_110 (Dose rate: mikroSv per second)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	0.00006	0.00007	0.00009	0.00012	0.00013	0.00013	0.00014	0.00012	0.00009	0.00007	0.00006				
2	0.00007	0.00008	0.0001	0.00014	0.00017	0.00019	0.0002	0.00018	0.00012	0.00008	0.00007				ii side
3	0.00007	0.00009	0.00014	0.00018	0.00027	0.00036	0.00037	0.0003	0.00016	0.0001	0.00007				
4	0.00007	0.0001	0.00019	0.00028	0.00031	0.00094	0.001	0.0006	0.00024	0.00014	0.00008				
5	0.00008	0.00012	0.00018	0.00037	0.00073	0.0018	0.0022	0.0012	0.0003	0.00012	0.00008				
6	0.00008	0.00013	0.0002	0.0003											
7	0.00016	0.0002								0.00018	0.0001	0.00007	0.00005		patient leg side
8	0.00012	0.00009	0.0003	0.00056	0.0014	0.0039		0.002	0.00063	0.00023	0.00012	0.00007	0.00005		
9	0.00011	0.00018	0.00026	0.00052	0.0008	0.0016		0.0011	0.00061	0.00023	0.00013	0.00007	0.00005		
10	0.00009	0.00013	0.00019	0.00034	0.00042	0.00052		0.0004	0.00025	0.00017	0.0001	0.00006	0.00005		
11	0.00008	0.00012	0.00015	0.00016	0.00027			0.00039	0.00028	0.00014	0.00009	0.00007	0.00005		tube side
12	0.00007	0.0001	0.00013	0.00014	0.00018			0.00026	0.00018	0.00012	0.00009	0.00006	0.00006		
13	0.00006	0.00008	0.00009	0.0001	0.00014	0.0001		0.00018	0.00014	0.00009	0.00008	0.00006	0.00006		
14		0.00007	0.00007	0.00008	0.00009	0.00006	0.00002	0.0001	0.00011	0.00008	0.00007	0.00006	0.00005		
15		0.00005	0.00006	0.00006	0.00007	0.00004	0.00002	0.00007	0.00008	0.00007	0.00005	0.00005	0.00003		
16		0	0.00005	0.00005	0.00005	0.00002		0.00005	0.00006	0.00006	0.00005	0.00005	0.00003		
17						0.00001		0.00005	0.00005	0.00005					

APPENDIX VI

C-Arm Oblique position – 133cm

Ionization chamber mesurements expressed in mR and mSv

PAO_133 (Dose rate: milliSv / minute)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	0.0048	0.0054	0.006	0.0072	0.0084	0.0084	0.0096	0.0078	0.0054	0.0054	0.0036				
2	0.0042	0.006	0.0072	0.0096	0.0108	0.0132	0.012	0.012	0.0084	0.006	0.0042				
3	0.0048	0.0066	0.009	0.0132	0.0156	0.021	0.0228	0.0198	0.0108	0.0072	0.0048				ii side
4	0.0048	0.0072	0.0132	0.0168	0.0312	0.045	0.048	0.0348	0.0174	0.0096	0.006				
5	0.0054	0.0084	0.0144	0.0252	0.0414	0.066	0.072	0.072	0.024	0.015	0.0072				
6	0.006	0.009	0.0144	0.0198											
7	0.0084	0.0108													
8	0.0078	0.0126	0.018	0.0306	0.06	0.156				0.015	0.009	0.0054	0.003		patient leg side
9	0.0072	0.0102	0.0162	0.0336	0.054	0.09		0.096	0.0378	0.0186	0.0084	0.0066	0.0042		
10	0.0054	0.009	0.0144	0.0222	0.0306	0.0372		0.066	0.0306	0.0168	0.0096	0.006	0.0042		
11		0.0078	0.0108	0.0156	0.0186			0.0318	0.0216	0.015	0.009	0.0054	0.0042		
12	0.0048	0.0072	0.0096	0.0096	0.0132			0.018	0.0144	0.0108	0.0084	0.0048	0.0042		tube side
13	0.0042	0.0054	0.0072	0.0078	0.0096	0.0072		0.012	0.0102	0.0102	0.0072	0.0042	0.0036		
14	0.0036	0.0048	0.0054	0.0054	0.0054	0.0036	0.0012	0.0084	0.0084	0.0072	0.0054	0.0042	0.0036		
15		0.0036	0.0048	0.0048	0.0048	0.0024	0.0006	0.0066	0.0048	0.0048	0.0048	0.0042	0.0018		
16			0.0036	0.0036	0.0036	0.0012		0.0048	0.0036	0.0042	0.0036	0.003	0.0024		
17						0.0012		0.0036	0.0036	0.003	0.003	0.003	0.0018		
								0.003	0.003	0.003					

PAO_133 (Dose rate: milliSv / 3 minute)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	0.0144	0.0162	0.018	0.0216	0.0252	0.0252	0.0288	0.0234	0.0162	0.0162	0.0108				
2	0.0126	0.018	0.0216	0.0288	0.0324	0.0396	0.036	0.036	0.0252	0.018	0.0126				
3	0.0144	0.0198	0.027	0.0396	0.0468	0.063	0.0684	0.0594	0.0324	0.0216	0.0144				ii side
4	0.0144	0.0216	0.0396	0.0504	0.0936	0.135	0.144	0.1044	0.0522	0.0288	0.018				
5	0.0162	0.0252	0.0432	0.0756	0.1242	0.198	0.216	0.216	0.072	0.045	0.0216				
6	0.018	0.027	0.0432	0.0594											
7	0.0252	0.0324													
8	0.0234	0.0378	0.054	0.0918	0.18	0.468				0.045	0.027	0.0162	0.009		patient leg side
9	0.0216	0.0306	0.0486	0.1008	0.162	0.27		0.288	0.1134	0.0558	0.0252	0.0198	0.0126		
10	0.0162	0.027	0.0432	0.0666	0.0918	0.1116		0.198	0.0918	0.0504	0.0288	0.018	0.0126		
11		0.0234	0.0324	0.0468	0.0558			0.0954	0.0648	0.045	0.027	0.0162	0.0126		
12	0.0144	0.0216	0.0288	0.0288	0.0396			0.054	0.0432	0.0324	0.0252	0.0144	0.0126		tube side
13	0.0126	0.0162	0.0216	0.0234	0.0288	0.0216		0.036	0.0306	0.0306	0.0216	0.0126	0.0108		
14	0.0108	0.0144	0.0162	0.0162	0.0162	0.0108	0.0036	0.0252	0.0252	0.0216	0.0162	0.0126	0.0108		
15		0.0108	0.0144	0.0144	0.0144	0.0072	0.0018	0.0198	0.0144	0.0144	0.0144	0.0126	0.0054		
16			0.0108	0.0108	0.0108	0.0036		0.0144	0.0108	0.0126	0.0108	0.009	0.0072		
17						0.0036		0.0108	0.0108	0.009	0.009	0.009	0.0054		
								0.009	0.009	0.009					

PAO_133 (milliRoentgen / hour)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1	28.8	32.4	36.0	43.2	50.4	50.4	57.6	46.8	32.4	32.4	21.6				
2	25.2	36.0	43.2	57.6	64.8	79.2	72.0	72.0	50.4	36.0	25.2				
3	28.8	39.6	54.0	79.2	93.6	126.0	136.8	118.8	64.8	43.2	28.8				ii side
4	28.8	43.2	79.2	100.8	187.2	270.0	288.0	208.8	104.4	57.6	36.0				
5	32.4	50.4	86.4	151.2	248.4	396.0	432.0	432.0	144.0	90.0	43.2				
6	36.0	54.0	86.4	118.8											
7	50.4	64.8													
8	46.8	75.6	108.0	183.6	360.0	936.0				90.0	54.0	32.4	18.0		patient leg side
9	43.2	61.2	97.2	201.6	324.0	540.0		576.0	226.8	111.6	50.4	39.6	25.2		
10	32.4	54.0	86.4	133.2	183.6	223.2		396.0	183.6	100.8	57.6	36.0	25.2		
11		46.8	64.8	93.6	111.6			190.8	129.6	90.0	54.0	32.4	25.2		
12	28.8	43.2	57.6	57.6	79.2			108.0	86.4	64.8	50.4	28.8	25.2		tube side
13	25.2	32.4	43.2	46.8	57.6	43.2		72.0	61.2	61.2	43.2	25.2	21.6		
14	21.6	28.8	32.4	32.4	32.4	21.6	7.2	50.4	50.4	43.2	32.4	25.2	21.6		
15		21.6	28.8	28.8	28.8	14.4	3.6	39.6	28.8	28.8	28.8	25.2	10.8		
16			21.6	21.6	21.6	7.2		28.8	21.6	25.2	21.6	18.0	14.4		
17						7.2		21.6	21.6	18.0	18.0	18.0	10.8		
								18.0	18.0	18.0					

PAO_133 (Original values)																
	a	b	c	d	e	f	g	h	I	j	k	l	m	n		
1	0.8	0.9	1	1.2	1.4	1.4	1.6	1.3	0.9	0.9	0.6					
2	0.7	1	1.2	1.6	1.8	2.2	2	2	1.4	1	0.7					ii side
3	0.8	1.1	1.5	2.2	2.6	3.5	3.8	3.3	1.8	1.2	0.8					
4	0.8	1.2	2.2	2.8	5.2	7.5	8	5.8	2.9	1.6	1					
5	0.9	1.4	2.4	4.2	6.9	11	12	12	4	2.5	1.2					
6	1	1.5	2.4	3.3												
7	1.4	1.8								2.5	1.5	0.9	0.5			patient leg side
8	1.3	2.1	3	5.1	10	26		16	6.3	3.1	1.4	1.1	0.7			
9	1.2	1.7	2.7	5.6	9	15		11	5.1	2.8	1.6	1	0.7			
10	0.9	1.5	2.4	3.7	5.1	6.2		5.3	3.6	2.5	1.5	0.9	0.7			
11	0	1.3	1.8	2.6	3.1			3	2.4	1.8	1.4	0.8	0.7			tube side
12	0.8	1.2	1.6	1.6	2.2			2	1.7	1.7	1.2	0.7	0.6			
13	0.7	0.9	1.2	1.3	1.6	1.2		1.4	1.4	1.2	0.9	0.7	0.6			
14	0.6	0.8	0.9	0.9	0.9	0.6	0.2	1.1	0.8	0.8	0.8	0.7	0.3			
15		0.6	0.8	0.8	0.8	0.4	0.1	0.8	0.6	0.7	0.6	0.5	0.4			
16			0.6	0.6	0.6	0.2	0	0.6	0.6	0.5	0.5	0.5	0.3			
17						0.2	0	0.5	0.5	0.5						

PAO_133 (Dose rate: mikroSv / second OF milliRoentgen / 10 seconds)																
	a	b	c	d	e	f	g	h	I	j	k	l	m	n		
1	0.08	0.09	0.1	0.12	0.14	0.14	0.16	0.13	0.09	0.09	0.06					
2	0.07	0.1	0.12	0.16	0.18	0.22	0.2	0.2	0.14	0.1	0.07					ii side
3	0.08	0.11	0.15	0.22	0.26	0.35	0.38	0.33	0.18	0.12	0.08					
4	0.08	0.12	0.22	0.28	0.52	0.75	0.8	0.58	0.29	0.16	0.1					
5	0.09	0.14	0.24	0.42	0.69	1.1	1.2	1.2	0.4	0.25	0.12					
6	0.1	0.15	0.24	0.33												
7	0.14	0.18								0.25	0.15	0.09	0.05			patient leg side
8	0.13	0.21	0.3	0.51	1	2.6		1.6	0.63	0.31	0.14	0.11	0.07			
9	0.12	0.17	0.27	0.56	0.9	1.5		1.1	0.51	0.28	0.16	0.1	0.07			
10	0.09	0.15	0.24	0.37	0.51	0.62		0.53	0.36	0.25	0.15	0.09	0.07			
11		0.13	0.18	0.26	0.31			0.3	0.24	0.18	0.14	0.08	0.07			tube side
12	0.08	0.12	0.16	0.16	0.22			0.2	0.17	0.17	0.12	0.07	0.06			
13	0.07	0.09	0.12	0.13	0.16	0.12		0.14	0.14	0.12	0.09	0.07	0.06			
14	0.06	0.08	0.09	0.09	0.09	0.06	0.02	0.11	0.08	0.08	0.08	0.07	0.03			
15		0.06	0.08	0.08	0.08	0.04	0.01	0.08	0.06	0.07	0.06	0.05	0.04			
16			0.06	0.06	0.06	0.02		0.06	0.06	0.05	0.05	0.05	0.03			
17						0.02		0.05	0.05	0.05						

PAO_133 (Original values)																
	a	b	c	d	e	f	g	h	I	j	k	l	m	n		
1	0.00008	0.00009	0.0001	0.00012	0.00014	0.00014	0.00016	0.00013	0.00009	0.00009	0.00006					
2	0.00007	0.0001	0.00012	0.00016	0.00018	0.00022	0.0002	0.0002	0.00014	0.0001	0.00007					ii side
3	0.00008	0.00011	0.00015	0.00022	0.00026	0.00035	0.00038	0.00033	0.00018	0.00012	0.00008					
4	0.00008	0.00012	0.00022	0.00028	0.00052	0.00075	0.0008	0.00058	0.00029	0.00016	0.0001					
5	0.00009	0.00014	0.00024	0.00042	0.00069	0.0011	0.0012	0.0012	0.0004	0.00025	0.00012					
6	0.0001	0.00015	0.00024	0.00033												
7	0.00014	0.00018								0.00025	0.00015	0.00009	0.00005			patient leg side
8	0.00013	0.00021	0.0003	0.00051	0.001	0.0026		0.0016	0.00063	0.00031	0.00014	0.00011	0.00007			
9	0.00012	0.00017	0.00027	0.00056	0.0009	0.0015		0.0011	0.00051	0.00028	0.00016	0.0001	0.00007			
10	0.00009	0.00015	0.00024	0.00037	0.00051	0.00062		0.00053	0.00036	0.00025	0.00015	0.00009	0.00007			
11		0.00013	0.00018	0.00026	0.00031			0.0003	0.00024	0.00018	0.00014	0.00008	0.00007			tube side
12	0.00008	0.00012	0.00016	0.00016	0.00022			0.0002	0.00017	0.00017	0.00012	0.00007	0.00006			
13	0.00007	0.00009	0.00012	0.00013	0.00016	0.00012		0.00014	0.00014	0.00012	0.00009	0.00007	0.00006			
14	0.00006	0.00008	0.00009	0.00009	0.00009	0.00006	0.00002	0.00011	0.00008	0.00008	0.00008	0.00007	0.00003			
15		0.00006	0.00008	0.00008	0.00008	0.00004	0.00001	0.00008	0.00006	0.00007	0.00006	0.00005	0.00004			
16			0.00006	0.00006	0.00006	0.00002		0.00006	0.00006	0.00005	0.00005	0.00005	0.00003			
17						0.00002		0.00005	0.00005	0.00005						

APPENDIX VI

C-Arm Lateral position – 110cm

Ionization chamber mesurements expressed in mR and mSv

Lat_110 (Dose rate: milliSv / minute)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p		
1	0.0072	0.0096	0.0132	0.0168	0.0222	0.024	0.0264	0.0012	0.0192	0.027	0.024	0.0192	0.0144	0.0108	0.0096	0.0084		
2	0.0072	0.0096	0.012	0.0156	0.0222	0.0222	0.03		0.0396	0.0474	0.0348	0.0282	0.0192	0.0144	0.0108	0.0084		
3	0.0084	0.0108	0.018	0.0252	0.036	0.0564	0.066		0.072	0.0528	0.027	0.0252	0.024	0.0168	0.012	0.0096	0.0072	
4	0.0084	0.0108	0.0168	0.0432	0.0072	0.072	0.144			0.156	0.072	0.0408	0.0228	0.0114	0.0108	0.0084		Tube side
5	0.0084	0.018	0.018	0.0252				0.276		0.168	0.072	0.0372	0.0144	0.012	0.0084	0.0054	0.0042	
6	0.0084	0.0156	0.0156	0.0216	0.0384	0.084	0.228		0.264	0.264	0.12	0.036	0.0192	0.0108	0.0084	0.006	0.0042	
7	0.0054	0.012	0.012	0.0168	0.0288	0.0348					0.252	0.0156	0.0096	0.0072	0.0048	0.0036		
8	0.0048	0.0084	0.0084	0.0168	0.0192	0.0276	0.228		0.0504	0.0492	0.192	0.0132	0.0096	0.0066	0.0036	0.0042		
9	0.0036	0.0066	0.0066	0.0096	0.015	0.0192	0.051		0.057	0.0288	0.018	0.012	0.0084	0.0048	0.0048			
10	0.0036	0.006	0.006	0.0084	0.0132	0.0144	0.0528		0.0468	0.0192	0.0144	0.0096	0.0072	0.006	0.0042	0.0036		
11	0.0036	0.0054	0.0054	0.0072	0.0108	0.0144	0.0588		0	0.0144	0.0108	0.0084	0.006	0.0048	0.0036			
12	0.003	0.006	0.006	0.0084	0.0078	0.0168	0.0312		0.0306	0.0132	0.0096	0.0072	0.0054	0.0042	0.0036	0.003		
13	0.003	0.0048	0.0048	0.0054	0.0084	0.0168		0.0006	0.0006	0.012	0.0048	0.006	0.0048	0.0042	0.0036	0.0024		II side
14	0.0024	0.003	0.003	0.0042	0.0048	0.0144			0.0006	0.0108	0.0048	0.0048	0.0048	0.0036	0.003			
15	0.0024	0.003	0.003	0.003	0.0036	0.0036			0.0006	0.006	0.0042	0.0042	0.0042	0.0036	0.0024			
16	0.0024	0.003	0.003	0.003	0.0006	0.0006			0.0006	0.0018	0.0024	0.0024	0.0042	0.0036	0.0024			
17						0.0006												

Lat_110 (Dose rate: milliSv / 3 minute)

	a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p		
1	0.0216	0.0288	0.0396	0.0504	0.0666	0.072	0.0792	0.0036	0.0576	0.081	0.072	0.0576	0.0432	0.0324	0.0288	0.0252		
2	0.0216	0.0288	0.036	0.0468	0.0666	0.0666	0.09		0.1188	0.1422	0.1044	0.0846	0.0576	0.0432	0.0324	0.0252		
3	0.0252	0.0324	0.054	0.0756	0.108	0.1692	0.198		0.216	0.1584	0.081	0.0756	0.072	0.0504	0.036	0.0288	0.0216	
4	0.0252	0.0324	0.0504	0.1296	0.0216	0.216	0.432			0.468	0.216	0.1224	0.0684	0.0342	0.0324	0.0252		Tube side
5	0.0252	0.054	0.054	0.0756				0.828		0.504	0.216	0.1116	0.0432	0.036	0.0252	0.0162	0.0126	
6	0.0252	0.0468	0.0468	0.0648	0.1152	0.252	0.684		0.792	0.792	0.36	0.108	0.0576	0.0324	0.0252	0.018	0.0126	
7	0.0162	0.036	0.036	0.0504	0.0864	0.1044					0.756	0.0468	0.0288	0.0216	0.0144	0.0108		
8	0.0144	0.0252	0.0252	0.0504	0.0576	0.0828	0.684		0.1512	0.1476	0.576	0.0396	0.0288	0.0198	0.0108	0.0126		
9	0.0108	0.0198	0.0198	0.0288	0.045	0.0576	0.153		0.171	0.0864	0.054	0.036	0.0252	0.0144	0.0144			
10	0.0108	0.018	0.018	0.0252	0.0396	0.0432	0.1584		0.1404	0.0576	0.0432	0.0288	0.0216	0.018	0.0126	0.0108		
11	0.0108	0.0162	0.0162	0.0216	0.0324	0.0432	0.1764		0	0.0432	0.0324	0.0252	0.018	0.0144	0.0108			
12	0.009	0.018	0.018	0.0252	0.0234	0.0504	0.0936		0.0918	0.0396	0.0288	0.0216	0.0162	0.0126	0.0108	0.009		
13	0.009	0.0144	0.0144	0.0162	0.0252	0.0504		0.0018	0.0018	0.036	0.0144	0.018	0.0144	0.0126	0.0108	0.0072		II side
14	0.0072	0.009	0.009	0.0126	0.0144	0.0432			0.0018	0.0324	0.0144	0.0144	0.0144	0.0108	0.009			
15	0.0072	0.009	0.009	0.009	0.0108	0.0108			0.0018	0.018	0.0126	0.0126	0.0126	0.0108	0.0072			
16	0.0072	0.009	0.009	0.009	0.0018	0.0018			0.0018	0.0054	0.0072	0.0072	0.0126	0.0108	0.0072			
17						0.0018												

Lat_110 (milliRoentgen / hour)

	a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p		
1	43.2	57.6	79.2	100.8	133.2	144.0	158.4	7.2	115.2	162.0	144.0	115.2	86.4	64.8	57.6	50.4		
2	43.2	57.6	72.0	93.6	133.2	133.2	180.0		237.6	284.4	208.8	169.2	115.2	86.4	64.8	50.4		
3	50.4	64.8	108.0	151.2	216.0	338.4	396.0		432.0	316.8	162.0	151.2	144.0	100.8	72.0	57.6	43.2	
4	50.4	64.8	100.8	259.2	43.2	432.0	864.0		0.0	936.0	432.0	244.8	136.8	68.4	64.8	50.4		Tube side
5	50.4	108.0	108.0	151.2				1656.0	0.0	1008.0	432.0	223.2	86.4	72.0	50.4	32.4	25.2	
6	50.4	93.6	93.6	129.6	230.4	504.0	1368.0		1584.0	1584.0	720.0	216.0	115.2	64.8	50.4	36.0	25.2	
7	32.4	72.0	72.0	100.8	172.8	208.8		#			1512.0	93.6	57.6	43.2	28.8	21.6		
8	28.8	50.4	50.4	100.8	115.2	165.6	1368.0		302.4	295.2	1152.0	79.2	57.6	39.6	21.6	25.2		
9	21.6	39.6	39.6	57.6	90.0	115.2	306.0		342.0	172.8	108.0	72.0	50.4	28.8	28.8	0.0		
10	21.6	36.0	36.0	50.4	79.2	86.4	316.8		280.8	115.2	86.4	57.6	43.2	36.0	25.2	21.6		
11	21.6	32.4	32.4	43.2	64.8	86.4	352.8			86.4	64.8	50.4	36.0	28.8	21.6	0.0		
12	18.0	36.0	36.0	50.4	46.8	100.8	187.2		183.6	79.2	57.6	43.2	32.4	25.2	21.6	18.0		
13	18.0	28.8	28.8	32.4	50.4	100.8		3.6	3.6	72.0	28.8	36.0	28.8	25.2	21.6	14.4		II side
14	14.4	18.0	18.0	25.2	28.8	86.4			3.6	64.8	28.8	28.8	28.8	21.6	18.0			
15	14.4	18.0	18.0	18.0	21.6	21.6			3.6	36.0	25.2	25.2	25.2	21.6	14.4			
16	14.4	18.0	18.0	18.0	3.6	3.6			3.6	10.8	14.4	14.4	25.2	21.6	14.4			
17						3.6												

Lat_110 (Original values)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p		
1	1.2	1.6	2.2	2.8	3.7	4	4.4	0.2	3.2	4.5	4	3.2	2.4	1.8	1.6	1.4		
2	1.2	1.6	2	2.6	3.7	3.7	5	0	6.6	7.9	5.8	4.7	3.2	2.4	1.8	1.4		
3	1.4	1.8	3	4.2	6	9.4	11	0	12	8.8	4.5	4.2	4	2.8	2	1.6	1.2	
4	1.4	1.8	2.8	7.2	1.2	12	24			26	12	6.8	3.8	1.9	1.8	1.4		Tube side
5	1.4	3	3	4.2				46		28	12	6.2	2.4	2	1.4	0.9	0.7	
6	1.4	2.6	2.6	3.6	6.4	14	38		44	44	20	6	3.2	1.8	1.4	1	0.7	
7	0.9	2	2	2.8	4.8	5.8					42	2.6	1.6	1.2	0.8	0.6		
8	0.8	1.4	1.4	2.8	3.2	4.6	38		8.4	8.2	32	2.2	1.6	1.1	0.6	0.7		
9	0.6	1.1	1.1	1.6	2.5	3.2	8.5		9.5	4.8	3	2	1.4	0.8	0.8			
10	0.6	1	1	1.4	2.2	2.4	8.8		7.8	3.2	2.4	1.6	1.2	1	0.7	0.6		
11	0.6	0.9	0.9	1.2	1.8	2.4	9.8			2.4	1.8	1.4	1	0.8	0.6			
12	0.5	1	1	1.4	1.3	2.8	5.2		5.1	2.2	1.6	1.2	0.9	0.7	0.6	0.5		
13	0.5	0.8	0.8	0.9	1.4	2.8	0	0.1	0.1	2	0.8	1	0.8	0.7	0.6	0.4		II side
14	0.4	0.5	0.5	0.7	0.8	2.4	0	0	0.1	1.8	0.8	0.8	0.8	0.6	0.5			
15	0.4	0.5	0.5	0.5	0.6	0.6			0.1	1	0.7	0.7	0.7	0.6	0.4			
16	0.4	0.5	0.5	0.5	0.1	0.1			0.1	0.3	0.4	0.4	0.7	0.6	0.4			
17						0.1												

Lat_110 (Dose rate: mikroSv / second OF milliRoentgen / 10 seconds)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p		
1	0.12	0.16	0.22	0.28	0.37	0.4	0.44	0.02	0.32	0.45	0.4	0.32	0.24	0.18	0.16	0.14		
2	0.12	0.16	0.2	0.26	0.37	0.37	0.5		0.66	0.79	0.58	0.47	0.32	0.24	0.18	0.14		
3	0.14	0.18	0.3	0.42	0.6	0.94	1.1		1.2	0.88	0.45	0.42	0.4	0.28	0.2	0.16	0.12	
4	0.14	0.18	0.28	0.72	0.12	1.2	2.4			2.6	1.2	0.68	0.38	0.19	0.18	0.14		Tube side
5	0.14	0.3	0.3	0.42				4.6		2.8	1.2	0.62	0.24	0.2	0.14	0.09	0.07	
6	0.14	0.26	0.26	0.36	0.64	1.4	3.8		4.4	4.4	2	0.6	0.32	0.18	0.14	0.1	0.07	
7	0.09	0.2	0.2	0.28	0.48	0.58					4.2	0.26	0.16	0.12	0.08	0.06		
8	0.08	0.14	0.14	0.28	0.32	0.46	3.8		0.84	0.82	3.2	0.22	0.16	0.11	0.06	0.07		
9	0.06	0.11	0.11	0.16	0.25	0.32	0.85		0.95	0.48	0.3	0.2	0.14	0.08	0.08			
10	0.06	0.1	0.1	0.14	0.22	0.24	0.88		0.78	0.32	0.24	0.16	0.12	0.1	0.07	0.06		
11	0.06	0.09	0.09	0.12	0.18	0.24	0.98			0.24	0.18	0.14	0.1	0.08	0.06			
12	0.05	0.1	0.1	0.14	0.13	0.28	0.52		0.51	0.22	0.16	0.12	0.09	0.07	0.06	0.05		
13	0.05	0.08	0.08	0.09	0.14	0.28		0.01	0.01	0.2	0.08	0.1	0.08	0.07	0.06	0.04		II side
14	0.04	0.05	0.05	0.07	0.08	0.24			0.01	0.18	0.08	0.08	0.08	0.06	0.05			
15	0.04	0.05	0.05	0.05	0.06	0.06			0.01	0.1	0.07	0.07	0.07	0.06	0.04			
16	0.04	0.05	0.05	0.05	0.01	0.01			0.01	0.03	0.04	0.04	0.07	0.06	0.04			
17						0.01												

Lat_110 (Dose rate: milliSv per second)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p		
1	0.00012	0.00016	0.00022	0.00028	0.00037	0.0004	0.00044	0.00002	0.00032	0.00045	0.0004	0.00032	0.00024	0.00018	0.00016	0.00014		
2	0.00012	0.00016	0.0002	0.00026	0.00037	0.00037	0.0005		0.00066	0.00079	0.00058	0.00047	0.00032	0.00024	0.00018	0.00014		
3	0.00014	0.00018	0.0003	0.00042	0.0006	0.00094	0.0011		0.0012	0.00088	0.00045	0.00042	0.0004	0.00028	0.0002	0.00016	0.00012	
4	0.00014	0.00018	0.00028	0.00072	0.00012	0.0012	0.0024			0.0026	0.0012	0.00068	0.00038	0.00019	0.00018	0.00014		Tube side
5	0.00014	0.0003	0.0003	0.00042				0.0046		0.0028	0.0012	0.00062	0.00024	0.0002	0.00014	0.00009	0.00007	
6	0.00014	0.00026	0.00026	0.00036	0.00064	0.0014	0.0038		0.0044	0.0044	0.002	0.0006	0.00032	0.00018	0.00014	0.0001	0.00007	
7	0.00009	0.0002	0.0002	0.00028	0.00048	0.00058					0.0042	0.00026	0.00016	0.00012	0.00008	0.00006		
8	0.00008	0.00014	0.00014	0.00028	0.00032	0.00046	0.0038		0.00084	0.00082	0.0032	0.00022	0.00016	0.00011	0.00006	0.00007		
9	0.00006	0.00011	0.00011	0.00016	0.00025	0.00032	0.00085		0.00095	0.00048	0.0003	0.0002	0.00014	0.00008	0.00008			
10	0.00006	0.0001	0.0001	0.00014	0.00022	0.00024	0.00088		0.00078	0.00032	0.00024	0.00016	0.00012	0.0001	0.00007	0.00006		
11	0.00006	0.00009	0.00009	0.00012	0.00018	0.00024	0.00098			0.00024	0.00018	0.00014	0.0001	0.00008	0.00006			
12	0.00005	0.0001	0.0001	0.00014	0.00013	0.00028	0.00052		0.00051	0.00022	0.00016	0.00012	0.00009	0.00007	0.00006	0.00005		
13	0.00005	0.00008	0.00008	0.00009	0.00014	0.00028		0.00001	0.00001	0.0002	0.00008	0.0001	0.00008	0.00007	0.00006	0.00004		II side
14	0.00004	0.00005	0.00005	0.00007	0.00008	0.00024			0.00001	0.00018	0.00008	0.00008	0.00008	0.00006	0.00005			
15	0.00004	0.00005	0.00005	0.00005	0.00006	0.00006			0.00001	0.0001	0.00007	0.00007	0.00007	0.00006	0.00004			
16	0.00004	0.00005	0.00005	0.00005	0.00001	0.00001			0.00001	0.00003	0.00004	0.00004	0.00007	0.00006	0.00004			
17						0.00001												

APPENDIX VI

C-Arm Lateral position – 133cm

Ionization chamber mesurements expressed in mR and mSv

Lat_133 (Dose rate: milliSv / minute)

	a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p		
1	0.0072	0.0096	0.012	0.0144	0.018	0.0216	0.0282	0.0012	0.0168	0.024	0.0216	0.0192	0.0156	0.0114	0.009	0.0072		Tube side
2	0.0072	0.0084	0.0108	0.0156	0.0192	0.0192	0.0252	0	0.042	0.0408	0.0312	0.0246	0.018	0.0144	0.0102	0.0084		
3	0.0108	0.012	0.0168	0.024	0.0336	0.0468	0.0504	0.0288	0.0468	0.0432	0.03	0.0432	0.0144	0.0108	0.0108	0.0096	0.0084	
4	0.0108	0.0168	0.0252	0.036	0.0516	0.0528	0.024	0.108	0.12	0.09	0.0528	0.0348	0.0216	0.0132	0.0108	0.0084		
5	0.0114	0.012	0.0144	0.0228				0.096	0.12	0.096	0.0588	0.0348	0.0144	0.012	0.009	0.0066	0.0048	
6	0.0084	0.012	0.0156	0.024	0.0378	0.072	0.108			0.072	0.0354	0.0192	0.0132	0.0108	0.0096	0.0072	0.0042	
7	0.006	0.009	0.0144	0.0192	0.0312						0.0288	0.0168	0.0108	0.0072	0.0054	0.0036		
8	0.0048	0.0072	0.0084	0.0156	0.021	0.0324	0.0552		0.0588	0.0336	0.0204	0.0132	0.0108	0.0072	0.0054	0.0042		
9	0.0042	0.0054	0.0072	0.0108	0.0168	0.027	0.0384		0.0384	0.0294	0.0204	0.0132	0.009	0.006	0.0048	0.0042	0.003	
10	0.0036	0.0054	0.0072	0.0096	0.0144	0.0216	0.0258		0.0264	0.0216	0.015	0.0108	0.0072	0.006	0.0048			
11	0.0036	0.0048	0.0054	0.0084	0.0114	0.0144	0.0216			0.0162	0.012	0.009	0.0072	0.0048	0.0042			
12	0.0036	0.0042	0.0048	0.006	0.0084	0.012	0.0192		0.0156	0.012	0.0096	0.0072	0.006	0.0048	0.0042			
13	0.003	0.0036	0.0048	0.006	0.0084	0.0108	0.0228	0.0006	0.0192	0.012	0.0072	0.0048		0.0036				II side
14	0.003	0.0036	0.0042	0.0054	0.0072	0.0108	0.0204	0.0006	0.0168	0.0132	0.0072	0.0048	0.0048	0.0036	0.003			
15	0.0024	0.0024	0.0042	0.0048	0.0072	0.0144	0.0072		0.0108	0.0102	0.006	0.0048	0.0048	0.0036	0.0036	0.0024		
16	0.0024	0.0036	0.0036	0.0036	0.0072	0.0144	0.0006		0.006	0.0108	0.0108	0.0048	0.0042	0.0036	0.0036	0.0024		
17																		

Lat_133 (Dose rate: milliSv / 3 minute)

	a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p		
1	0.0216	0.0288	0.036	0.0432	0.054	0.0648	0.0846	0.0036	0.0504	0.072	0.0648	0.0576	0.0468	0.0342	0.027	0.0216		Tube side
2	0.0216	0.0252	0.0324	0.0468	0.0576	0.0576	0.0756	0	0.126	0.1224	0.0936	0.0738	0.054	0.0432	0.0306	0.0252		
3	0.0324	0.036	0.0504	0.072	0.1008	0.1404	0.1512	0.0864	0.1404	0.1296	0.09	0.1296	0.0432	0.0324	0.0324	0.0288	0.0252	
4	0.0324	0.0504	0.0756	0.108	0.1548	0.1584	0.072	0.324	0.36	0.27	0.1584	0.1044	0.0648	0.0396	0.0324	0.0252		
5	0.0342	0.036	0.0432	0.0684				0.288	0.36	0.288	0.1764	0.1044	0.0432	0.036	0.027	0.0198	0.0144	
6	0.0252	0.036	0.0468	0.072	0.1134	0.216	0.324			0.216	0.1062	0.0576	0.0396	0.0324	0.0288	0.0216	0.0126	
7	0.018	0.027	0.0432	0.0576	0.0936						0.0864	0.0504	0.0324	0.0216	0.0162	0.0108		
8	0.0144	0.0216	0.0252	0.0468	0.063	0.0972	0.1656		0.1764	0.1008	0.0612	0.0396	0.0324	0.0216	0.0162	0.0126		
9	0.0126	0.0162	0.0216	0.0324	0.0504	0.081	0.1152		0.1152	0.0882	0.0612	0.0396	0.027	0.018	0.0144	0.0126	0.009	
10	0.0108	0.0162	0.0216	0.0288	0.0432	0.0648	0.0774		0.0792	0.0648	0.045	0.0324	0.0216	0.018	0.0144			
11	0.0108	0.0144	0.0162	0.0252	0.0342	0.0432	0.0648			0.0486	0.036	0.027	0.0216	0.0144	0.0126			
12	0.0108	0.0126	0.0144	0.018	0.0252	0.036	0.0576		0.0468	0.036	0.0288	0.0216	0.018	0.0144	0.0126			
13	0.009	0.0108	0.0144	0.018	0.0252	0.0324	0.0684	0.0018	0.0576	0.036	0.0216	0.0144		0.0108				II side
14	0.009	0.0108	0.0126	0.0162	0.0216	0.0324	0.0612	0.0018	0.0504	0.0396	0.0216	0.0144	0.0144	0.0108	0.009			
15	0.0072	0.0072	0.0126	0.0144	0.0216	0.0432	0.0216		0.0324	0.0306	0.018	0.0144	0.0144	0.0108	0.0108	0.0072		
16	0.0072	0.0108	0.0108	0.0108	0.0216	0.0432	0.0018		0.018	0.0324	0.0324	0.0144	0.0126	0.0108	0.0108	0.0072		
17																		

Lat_133 (milliRoentgen / hour)

	a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p		
1	43.2	57.6	72.0	86.4	108.0	129.6	169.2	7.2	100.8	144.0	129.6	115.2	93.6	68.4	54.0	43.2		Tube side
2	43.2	50.4	64.8	93.6	115.2	115.2	151.2		252.0	244.8	187.2	147.6	108.0	86.4	61.2	50.4		
3	64.8	72.0	100.8	144.0	201.6	280.8	302.4	172.8	280.8	259.2	180.0	259.2	86.4	64.8	64.8	57.6	50.4	
4	64.8	100.8	151.2	216.0	309.6	316.8	144.0	648.0	720.0	540.0	316.8	208.8	129.6	79.2	64.8	50.4		
5	68.4	72.0	86.4	136.8				576.0	720.0	576.0	352.8	208.8	86.4	72.0	54.0	39.6	28.8	
6	50.4	72.0	93.6	144.0	226.8	432.0	648.0			432.0	212.4	115.2	79.2	64.8	57.6	43.2	25.2	
7	36.0	54.0	86.4	115.2	187.2						172.8	100.8	64.8	43.2	32.4	21.6		
8	28.8	43.2	50.4	93.6	126.0	194.4	331.2		352.8	201.6	122.4	79.2	64.8	43.2	32.4	25.2		
9	25.2	32.4	43.2	64.8	100.8	162.0	230.4		230.4	176.4	122.4	79.2	54.0	36.0	28.8	25.2	18.0	
10	21.6	32.4	43.2	57.6	86.4	129.6	154.8		158.4	129.6	90.0	64.8	43.2	36.0	28.8			
11	21.6	28.8	32.4	50.4	68.4	86.4	129.6			97.2	72.0	54.0	43.2	28.8	25.2			
12	21.6	25.2	28.8	36.0	50.4	72.0	115.2		93.6	72.0	57.6	43.2	36.0	28.8	25.2			
13	18.0	21.6	28.8	36.0	50.4	64.8	136.8	3.6	115.2	72.0	43.2	28.8		21.6				II side
14	18.0	21.6	25.2	32.4	43.2	64.8	122.4	3.6	100.8	79.2	43.2	28.8	28.8	21.6	18.0			
15	14.4	14.4	25.2	28.8	43.2	86.4	43.2		64.8	61.2	36.0	28.8	28.8	21.6	21.6	14.4		
16	14.4	21.6	21.6	21.6	43.2	86.4	3.6		36.0	64.8	64.8	28.8	25.2	21.6	21.6	14.4		
17																		

Lat_133 (Original values)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p		
1	1.2	1.6	2	2.4	3	3.6	4.7	0.2	2.8	4	3.6	3.2	2.6	1.9	1.5	1.2		Tube side
2	1.2	1.4	1.8	2.6	3.2	3.2	4.2		7	6.8	5.2	4.1	3	2.4	1.7	1.4		
3	1.8	2	2.8	4	5.6	7.8	8.4	4.8	7.8	7.2	5	7.2	2.4	1.8	1.8	1.6	1.4	
4	1.8	2.8	4.2	6	8.6	8.8	4	18	20	15	8.8	5.8	3.6	2.2	1.8	1.4		
5	1.9	2	2.4	3.8				16	20	16	9.8	5.8	2.4	2	1.5	1.1	0.8	
6	1.4	2	2.6	4	6.3	12	18			12	5.9	3.2	2.2	1.8	1.6	1.2	0.7	
7	1	1.5	2.4	3.2	5.2						4.8	2.8	1.8	1.2	0.9	0.6		
8	0.8	1.2	1.4	2.6	3.5	5.4	9.2		9.8	5.6	3.4	2.2	1.8	1.2	0.9	0.7		
9	0.7	0.9	1.2	1.8	2.8	4.5	6.4		6.4	4.9	3.4	2.2	1.5	1	0.8	0.7	0.5	
10	0.6	0.9	1.2	1.6	2.4	3.6	4.3		4.4	3.6	2.5	1.8	1.2	1	0.8			
11	0.6	0.8	0.9	1.4	1.9	2.4	3.6			2.7	2	1.5	1.2	0.8	0.7			
12	0.6	0.7	0.8	1	1.4	2	3.2		2.6	2	1.6	1.2	1	0.8	0.7			
13	0.5	0.6	0.8	1	1.4	1.8	3.8	0.1	3.2	2	1.2	0.8		0.6				II side
14	0.5	0.6	0.7	0.9	1.2	1.8	3.4	0.1	2.8	2.2	1.2	0.8	0.8	0.6	0.5			
15	0.4	0.4	0.7	0.8	1.2	2.4	1.2	0	1.8	1.7	1	0.8	0.8	0.6	0.6	0.4		
16	0.4	0.6	0.6	0.6	1.2	2.4	0.1	0	1	1.8	1.8	0.8	0.7	0.6	0.6	0.4		
17													0.7					

Lat_133 (Dose rate: mikroSv / second OF milliRoentgen / 10 seconds)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p		
1	0.12	0.16	0.2	0.24	0.3	0.36	0.47	0.02	0.28	0.4	0.36	0.32	0.26	0.19	0.15	0.12		Tube side
2	0.12	0.14	0.18	0.26	0.32	0.32	0.42	0	0.7	0.68	0.52	0.41	0.3	0.24	0.17	0.14		
3	0.18	0.2	0.28	0.4	0.56	0.78	0.84	0.48	0.78	0.72	0.5	0.72	0.24	0.18	0.18	0.16	0.14	
4	0.18	0.28	0.42	0.6	0.86	0.88	0.4	1.8	2	1.5	0.88	0.58	0.36	0.22	0.18	0.14		
5	0.19	0.2	0.24	0.38				1.6	2	1.6	0.98	0.58	0.24	0.2	0.15	0.11	0.08	
6	0.14	0.2	0.26	0.4	0.63	1.2	1.8			1.2	0.59	0.32	0.22	0.18	0.16	0.12	0.07	
7	0.1	0.15	0.24	0.32	0.52						0.48	0.28	0.18	0.12	0.09	0.06		
8	0.08	0.12	0.14	0.26	0.35	0.54	0.92		0.98	0.56	0.34	0.22	0.18	0.12	0.09	0.07		
9	0.07	0.09	0.12	0.18	0.28	0.45	0.64		0.64	0.49	0.34	0.22	0.15	0.1	0.08	0.07	0.05	
10	0.06	0.09	0.12	0.16	0.24	0.36	0.43		0.44	0.36	0.25	0.18	0.12	0.1	0.08			
11	0.06	0.08	0.09	0.14	0.19	0.24	0.36			0.27	0.2	0.15	0.12	0.08	0.07			
12	0.06	0.07	0.08	0.1	0.14	0.2	0.32		0.26	0.2	0.16	0.12	0.1	0.08	0.07			
13	0.05	0.06	0.08	0.1	0.14	0.18	0.38	0.01	0.32	0.2	0.12	0.08		0.06				II side
14	0.05	0.06	0.07	0.09	0.12	0.18	0.34	0.01	0.28	0.22	0.12	0.08	0.08	0.06	0.05			
15	0.04	0.04	0.07	0.08	0.12	0.24	0.12		0.18	0.17	0.1	0.08	0.08	0.06	0.06	0.04		
16	0.04	0.06	0.06	0.06	0.12	0.24	0.01		0.1	0.18	0.18	0.08	0.07	0.06	0.06	0.04		
17	0																	

Lat_133 (Dose rate: mikroSv per second)

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p		
1	0.00012	0.00016	0.0002	0.00024	0.0003	0.00036	0.00047	0.00002	0.00028	0.0004	0.00036	0.00032	0.00026	0.00019	0.00015	0.00012		Tube side
2	0.00012	0.00014	0.00018	0.00026	0.00032	0.00032	0.00042		0.0007	0.00068	0.00052	0.00041	0.0003	0.00024	0.00017	0.00014		
3	0.00018	0.0002	0.00028	0.0004	0.00056	0.00078	0.00084	0.00048	0.00078	0.00072	0.0005	0.00072	0.00024	0.00018	0.00018	0.00016	0.00014	
4	0.00018	0.00028	0.00042	0.0006	0.00086	0.00088	0.0004	0.0018	0.002	0.0015	0.00088	0.00058	0.00036	0.00022	0.00018	0.00014		
5	0.00019	0.0002	0.00024	0.00038				0.0016	0.002	0.0016	0.00098	0.00058	0.00024	0.0002	0.00015	0.00011	0.00008	
6	0.00014	0.0002	0.00026	0.0004	0.00063	0.0012	0.0018			0.0012	0.00059	0.00032	0.00022	0.00018	0.00016	0.00012	0.00007	
7	0.0001	0.00015	0.00024	0.00032	0.00052						0.00048	0.00028	0.00018	0.00012	0.00009	0.00006		
8	0.00008	0.00012	0.00014	0.00026	0.00035	0.00054	0.00092		0.00098	0.00056	0.00034	0.00022	0.00018	0.00012	0.00009	0.00007		
9	0.00007	0.00009	0.00012	0.00018	0.00028	0.00045	0.00064		0.00064	0.00049	0.00034	0.00022	0.00015	0.0001	0.00008	0.00007	0.00005	
10	0.00006	0.00009	0.00012	0.00016	0.00024	0.00036	0.00043		0.00044	0.00036	0.00025	0.00018	0.00012	0.0001	0.00008			
11	0.00006	0.00008	0.00009	0.00014	0.00019	0.00024	0.00036			0.00027	0.0002	0.00015	0.00012	0.00008	0.00007			
12	0.00006	0.00007	0.00008	0.0001	0.00014	0.0002	0.00032		0.00026	0.0002	0.00016	0.00012	0.0001	0.00008	0.00007			
13	0.00005	0.00006	0.00008	0.0001	0.00014	0.00018	0.00038	0.00001	0.00032	0.0002	0.00012	0.00008		0.00006				II side
14	0.00005	0.00006	0.00007	0.00009	0.00012	0.00018	0.00034	0.00001	0.00028	0.00022	0.00012	0.00008	0.00008	0.00006	0.00005			
15	0.00004	0.00004	0.00007	0.00008	0.00012	0.00024	0.00012		0.00018	0.00017	0.0001	0.00008	0.00008	0.00006	0.00006	0.00004		
16	0.00004	0.00006	0.00006	0.00006	0.00012	0.00024	0.00001		0.0001	0.00018	0.00018	0.00008	0.00007	0.00006	0.00006	0.00004		
17																		

APPENDIX VII

APPENDIX VII

Comparison between ionization chamber and TLD measurements

Comparison between Berthold values and TLD readings					
Grid Position I6	Berthold measurements:				
	Average of 4.3 mR in 10 seconds		**Thus a dose rate of 4.3 micro Sievert per seconds**		
TLDs exposed for eight minutes	Thus a total dose (according to Berthold) of 8x60x4.3 = 2064 mikroSv = 2.1 mSv				
TLD number	**Reading**	**Corrected reading**			
2	859	852			
3	658	654			
4	624	628	Average:	731	
Calibration dose 50 cGy:					
13	97875	97581			
14	100231	100532			
15	96767	100347			
16	104736	100651	Average:	99778	
Background: 17	34	34			
18	39	39			
19	37	38	Average:	38	Dose 3.5 mSv

APPENDIX VIII

TLD CALIBRATION

GROUP: **BvdM** New TLDs purchased November 2006

Calibrated by: A.Nordin Apparatus: Toledo

Cycle:	1		2		3			
	Date:	23-Nov-06	Date:	24-Nov-06	Date:	27-Nov-06	MEAN	%
TLD #	Reading	CF	Reading	CF	Reading	CF	CF	STD
1	5965	0.999938	6338	0.980726	6105	0.993422	0.991362	0.985544
2	6069	0.982803	6252	0.994217	6062	1.000469	0.992496	0.902541
3	5976	0.998098	6278	0.990099	6099	0.994399	0.994199	0.402641
4	5945	1.003302	6166	1.008083	6006	1.009797	1.007061	0.334246
5	5959	1.000945	6157	1.009557	5962	1.01725	1.009251	0.808183
6	5927	1.006349	6206	1.001586	6000	1.010807	1.006247	0.458277
7	6089	0.979575	6299	0.986798	6334	0.957506	0.974626	1.56576
8	5749	1.037508	6086	1.021335	5966	1.016568	1.025137	1.070647
9	5839	1.021516	6095	1.019826	6079	0.997671	1.013004	1.313518
10	6022	0.990474	6375	0.975034	6160	0.984552	0.983353	0.792112
11	5932	1.005501	6399	0.971377	6093	0.995379	0.990752	1.768962
12	6044	0.986868	6305	0.985859	6114	0.99196	0.988229	0.3309
13	6022	0.990474	6253	0.994058	6020	1.007449	0.997327	0.897136
14	5993	0.995266	6143	1.011858	6052	1.002122	1.003082	0.831161
15	5804	1.027676	5927	1.048733	5862	1.034603	1.037004	1.034906
16	6185	0.964371	6470	0.960717	6331	0.95796	0.961016	0.334631
17	6034	0.988504	6173	1.00694	6073	0.998657	0.998034	0.925223
18	5948	1.002796	6133	1.013508	5989	1.012664	1.009656	0.589861
19	5826	1.023795	6046	1.028092	5925	1.023602	1.025163	0.247582
Average	5964.6		6215.8		6064.8			
STD	1.784939		2.157084		1.96347			

APPENDIX IX

PILOT STUDY

Pilot Study

Patient No: **1**

		Counts	Corr. Factors	Corr. Counts	mGy	mSv		Dose Cal.
								472174
1. Physician	Finger	432.14	0.828010967	357.82				
		318.57	1.264966591	402.98	**mSv**			523139
	Average			**380.40**	**0.014**	0.014	0.13927	583079
								635126
	Thyroid	15.51	1.1117896	17.24				547330
		14.08	1.184893808	16.68	**mSv**			
	Average			**16.96**	**0.001**			
2. Radiographer	Thyroid	4.69	1.323056857	6.21				
		13.02	0.867822322	11.30	**mSv**			
	Average			**8.75**	**0.000**			
	Lower Body	8.78	0.845680972	7.43				
		5.37	1.049542339	5.64	**mSv**			
	Average			**6.53**	**0.000**			

3. Sister		**Counts**	**Corr. Factors**	**Corr. Counts**	
	Lower Body	7.96	0.847834099	6.75	
		13.82	1.137992546	15.73	
		4.90	1.470550561	7.21	**mSv**
	Average			**9.89**	**0.000**

4. Patient

	Posterior				**Lateral**	
	Counts	**Corr. Factors**	**Corr. Counts**		**Counts**	**Corr. Factors**
1	134.69	1.024431765	137.98	1	1200	0.975895139
2	210.14	0.780024391	163.91	2	1820	0.834500398
3	174.29	0.835819872	145.68	3	1810	0.807892171
4	379.89	1.02207164	388.27	4	1610	0.939655043
5	420.41	0.954181307	401.15	5	1960	0.815442797
6	393.28	1.16563772	458.42	6	1430	1.129040383
Average			**282.57**	Average		

mSv **0.010**

Patients	**30**				
	N	**Projection**	**Range of exposure time p**	**Doc fingers**	**Doc thyriod**
			for both projections	**for both projections (cGy)**	**for both projections (cGy)**
Fascets	**20**	**PA**	**2.04-300**	**0.1-2.9 (100-2900mRem)**	**0.002-0.02 (2-0mRem)**
Epidural	**20**	**LAT**			
Radiofrequency	**6**	**PA**	**3.24 -420**	**0.1-10.8(100-10800mRem)**	**0.01-0.09(10-90mRem)**
epidural		**LAT**			
Sacroiliac joint	**4**	**PA**	**60-145**	**0.022-5.4(22-5400mRem)**	**0.001-0.06(1-60mRem)**
epidural		**LAT**			

Average for facets- Dr Finger 0.926 cGy per patient (926mRem) 9.26 mSv/patient