Chest radiography: optimising the dose at industrial mines in the Northern Cape

Leandré Toüa

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Department of Clinical Sciences

Faculty of Health and Environmental Sciences

Central University of Technology, Free State

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Supervisor: Dr B van der Merwe Co-supervisor: Mrs B van der Linde

DECLARATION

I, the undersigned, hereby declare that *Chest radiography: optimising the dose at industrial mines in the Northern Cape* is my own work and that it has not been submitted before by me or any other person to any university for the obtainment of a qualification, and that all the sources I have used have been indicated and acknowledged as references.

LM Toüa

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When the attitude of the mind is enthusiastic, research provides countless opportunities.

SUMMARY

Occupational medical testing requires an employee to perform certain medical tests before he/she can be classified as fit for duty. A chest x-ray is part of such medical tests. Contracted employees are employed over different periods of time to complete a contract on a mine. When they enter and leave the site, a medical examination is required, which includes a chest x-ray (CXR).

The aim of the study was to establish whether certain contracted employees receive more than one CXR per annum, and to determine a baseline for dose reference level (DRL) for a posterior-anterior (PA) CXR for the four clinics that participated in the study and ensures the researcher and the study collaborates with radiation protection. The research questions that were addressed were: (1) are contracted employees referred for more chest imaging than permanent employees, and (2) are contracted employees receiving a higher than necessary radiation dose compared to permanent employees, due to unnecessary repetition of chest imaging at the different clinics contracted by mining companies.

A (1) technical parameters sheet, a (2) checklist of x-rays and a (3) formulae and calculations sheet were compiled in order to approach the research questions. (1) was the part of data collection the radiographer had to complete, with the permission of the employee, due to the fact that they interact with the employees when medical testing is done. (2) was done by the researcher where a search was done for previous CXRs, other x-rays and rejects/repeats. (3) was done by the researcher with the assistance of a medical physicist to calculate the Entrance Surface Dose (ESD) of each employee and ultimately determine DRL for that clinic. A univariate procedure was used to test

for normality for the ESD by utilising the Schapiro-Wilk test, and presented with a statistic of 0.907037, all four clinics combined.

Firstly, the researcher conducted a pilot study to determine the research instruments' credibility, and they proved to be user friendly. The large scale study started after all required permissions were granted and the technical parameter information were recorded by the radiographer on duty. The study found that the median patient thickness was between 21 to 25 cm. With this information the (1) ESD and DRL were calculated. The results of the checklist showed that there were no employees who had x-ray examinations at the other three clinics. (2) Clinic 1, 2 and 4 reported contracted employees only had one chest x-ray done per annum, whilst clinic 3 had 5 contracted employees who had more than one chest x-ray done per annum. The total of all four clinics combined that had only one chest x-ray done per annum were 54.25 % (217 employees) of the study population (n = 400), 2 chest x-rays = 22.50 % (89 employees), 3 chest x-rays = 8.50 % (34 employees), 4 chest x-rays = 3.50 % (14 employees), 5 chest x-rays = 3.25 % (13 employees), 6 chest x-rays = 3.25 % (13 employees), 7 chest x-rays = 3.50 % (14 employees), 8 chest x-rays = 1.25 % (5 employees) and 10 chest x-rays = 0.25 % (1 employee). There was no specific employee identified who had x-rays at another participating clinic in one year, but it was evident that certain employees received multiple x-ray examinations.

Other projections of all four clinics combined were reported as employees that had one other anatomical projection AP/PA = 2.75 %, 2 other projections AP/PA = 0.50 %, and 1 other projections AP/PA = 0.25 %. One other projection lateral = 2 %, 2 other projections lateral = 0.50 %, and 3 other projections lateral = 0.25 %. One other

projection oblique = 0.50 %, and 2 other projections oblique = 0.25 %. Rejects/repeats for PA CXR for all four clinics combined reported as 1 repeat = 4.25 %, 2 PA CXR repeats = 0.25 %, and 3 PA CXR repeats = 0.50 %. There were no CXR lateral repeats. Other repeats of all four clinics combined for AP/PA were reported as 1 other repeat AP/PA = 0.50 %. Other repeats lateral was reported as 1 other repeat lateral = 0.50 %, and 2 other repeats as 0.25 %. Repeats for other projections oblique were 0.

Potential diagnostic reference levels (DRLs) for PA CXR established through research studies for an adult chest examination in four countries are included in this study, and the values were as follows: a study done in South Africa established a DRL: 0.10; Ireland a DRL: 0.16; Iran a DRL: 0.26; and Slovenia a DRL: 0.16. (3) The DRLs of this study of the four clinics were calculated and reported as Clinic 1: 0.204, Clinic 2: 0.292, Clinic 3: 0.391 and Clinic 4: 0.144.

The study results can be utilised to assist radiographers with a baseline DRL for chest imaging to optimise dose, and to assist the mines to focus on limiting unnecessary exposure to ionizing radiation by enforcing only one chest image per annum. It was evident that a DRL value assisted the radiographer to limit exposure and if mining clinics share the images, less annual imaging is needed per employee.

Key terms: chest image, industrial mine, entrance surface dose, dose reference level

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GLOSSARY OF TERMS

Accumulative dose: accumulative radiation dose is the total radiation dose that accrues over a period of time due to repetitive exposure to ionizing radiation (Carlton and Adler 2006:140).

Anterior: Sectional plane referring toward the ventral or front part of the body (Jones, 2018:Online).

Asbestoses: Pathologic condition caused by the inhalation of asbestos dust, (fibres) which results in pulmonary fibrosis. It may develop into lung cancer. Individuals who smoke have enhanced risks to developing lung cancer (Laney and Weissman 2014:18).

Bucky: Sliding metal tray under the radiographic table or in the wall stand, which holds the grid and image receptor. It is also called a Potter-Bucky tray (Bontrager and Lampignano 2010:465).

Costophrenic angle: The outermost lower corner of the lung where the diaphragm meets the ribs (Meseret 2015:8).

Dose reference level: A selected level of a radiation dose quantity for broadly defined types of equipment for typical examination groups of standardised patient sizes, or in specific circumstances a phantom (ICRP 2011:2).

Electrocardiogram: A recording produced for representation of the heart's electrical function. An action derived by amplification of the minutely small electrical impulses generated by the heart and captured by electrodes placed on the skin (Sattar and Chhabra, 2021:Online).

Entrance surface dose: The measurement of an ionizing radiation dose that is absorbed by the skin once it reaches the patient. The entrance surface dose (ESD) is measured by the unit Milligray (mGy) (Bell, Murphy *et al*. 2017:Online).

Fibrosis: A respiratory disease which involves scarring of the lung tissue leading to breathing problems (Bontrager and Lampignano 2010:87).

Millisievert: The metric system named Système Internationale d'Units (SI) as a weighing factor of the measurement of absorbed radiation dose (Carlton and Adler 2006:141).

Mine: A surface or underground setting that operates in the extraction, preparation or processing of minerals (U.S. Department of Labour 2015:2).

Opacities/pulmonary opacification: Represents the decrease in the ratio of gas to soft tissue in the lungs (International Labour Office 2011:6).

Parenchymal opacities: A lung opacity that is discrete and well margined. It is surrounded by lung parenchyma and does not touch the hilum and mediastinum (International Labour Office 2011:6).

Patient: An individual that is receiving medical tests and/or treatment, and with reference to this study the patient is the contracting employee.

Pleural plaque: Circumscribed areas of dense acellular collagenisation, which involves the parietal, diaphragmatic and visceral pleura (Nelson 2013:94).

Pleural thickening: Result scarring calcification and/or thickening of the pleura (Nelson 2013:94).

Pneumoconiosis: A disease of the lungs which is diagnosable, and is caused by the inhalation of dust over a period of time. This disease is visible on a chest x-ray as small, less circular, discrete and disseminated opacities (Martin 1953:582).

Posterior: Sectional plane referring toward the dorsal or back part of the body (Jones, 2018:Online).

Silicosis: A form of occupational lung disease, caused by the inhalation of crystalline silica dust. On a chest x-ray, silicosis is marked by inflammation and scarring in the form of nodular lesions in the upper lobes of the lungs (Laney and Weissman 2014:18).

Visceral pleura: One of the two membranes surrounding the lungs. The visceral pleura encloses the lungs. The other pleura is the parietal pleura, and this membrane lines the inner chest walls (Laney and Weissman 2014:18).

LIST OF ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
BMI	Body Mass Index
COP	Code of Practice
CXR	Chest x-ray
DRC	Directorate of Radiation Control
DRL	Dose Reference Level
ECG	Electrocardiogram
EEA	Employment Equity Act
ESD	Entrance Surface Dose
ESAK	Entrance surface air kerma
FEV	Forced Expiratory Volume
FVC	Forced Vital Capacity
GCP	Good Clinical Practice
ICRP	International Commission on Radiological Protection
ID	Identification Number
ILO	International Labour Office
IOD	Injury on Duty
IR	Image Receptor
MBOD	Medical Bureau of Occupational Disease
MCC	Medical Control Council
mGy	Milligray
MHS Act	Mine Health and Safety Act
mSv	Millisievert
NDoH	National Department of Health

NDRL	National Dose Reference Level
NIOSH	National Institute for Occupational Safety and Health
OHMP	Occupational Health Medical Practitioner
OSH Act	Occupational Safety and Health Act
PA	Posterior-Anterior
PoPIA	Protection of Personal Information Act
RED	Radiography Education Group
RPOP	Radiation Protection of Patients
RSA	Republic of South Africa
SAHPRA	South African Health Products Regulatory Agency
UFS	University of the Free State

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CHAPTER 1

INTRODUCTION AND BACKGROUND FOR THIS STUDY

1.1 INTRODUCTION

The Northern Cape mining industry consists of a large mining industry that mostly produces manganese and iron ore; apart from Kimberley De Beers, that produces diamonds (South32 Our Company 2015:Online). In the Northern Cape there are numerous occupational health clinics directed by different mining companies. In the mining industry of South Africa, the Mine Health and Safety Act (MHS Act) was amended for the purpose of the Department of Mineral Resources to safeguard the health and safety of mine employees and communities affected by mining operations (Mine Health and Safety Act No 29 of 1996). Thus, each individual employed by an industrial mine in the Northern Cape has to undergo a series of mandatory annual medical examinations at these clinics (Guild *et al*. 2001: 6).

These medical examinations consist of a series of diagnostic tests that includes a yearly chest x-ray (Guild *et al*. 2001: 6). The chest x-ray is an imaging procedure which results in an ionizing radiation dose administered for the patient, which in this case would be an employee of the mine (Carlton and Adler 2006:20). The medical examinations are based on the MHS Act, which is part of an occupational health and safety protocol of all operating industrial mines in the Northern Cape and South Africa (Mine Health and Safety Act No 29 of 1996). Occupational medical surveillance for contracted employees include examinations at initial employment (initial medical), throughout employment (periodic medical), transferring (pre-placement medical)

and/or ending of employment/contract (exit medical). The frequency of these medical examinations is to provide effective monitoring systems and inspections to improve health and safety as stipulated by the Mine Health and Safety Act No. 29 of 1996.

This motivated the researcher to determine if contracted employees are subjected to numerous x-rays (chest and other), and thus if the annual radiation dose is in compliance with the Act (Act 29 of 1996). One of the main objectives was to calculate/estimate a baseline DRL for chest imaging with the use of the calculated ESD of participating employees. The number of chest images that contract employees undergo annually was uncertain. This motivated the researcher to investigate the safety of the employees with regard to possible repetitive exposure to ionizing radiation associated with multiple chest imaging procedures. This research serves as a directive for protection against radiation, since the first and fundamental principle radiographers are taught and practice throughout their profession is the As Low As Reasonably Achievable principle (ALARA) (Bontrager and Lampignano 2010:59), and in addition to adhere to the MHS Act.

In South Africa the Occupational Health and Safety Act of 1993 (Act no. 6 of 1993) assures safe and healthy working conditions for every man and woman (LaDou 2007:1). The OSH Act has been implemented for more than four decades; from 1970 to present. Since the implementation of this act, occupational injuries and fatalities in South Africa have decreased by 60 (Occupational Health and Safety Act no.6 of 1993). By setting a baseline DRL for each clinic, the study adhered to the OSH Act by assisting in protecting employees from unnecessary exposure to ionizing radiation, and also ensures that occupational screening occurs in such a manner that

occupational diseases are not overlooked. The Bureau of Labour Statistics (2016:1-10) states that patients with possible occupational health diseases, as well as their physical performance, are essential aspects to evaluate before, during and at the end of employment.

This chapter provides a background to the study to familiarise the reader with the aim and overall goal of the study, the problem statement and the objectives of the study. The design of the research is discussed, which includes the research instruments used to accumulate data and to provide the significance, validity, reliability and trustworthiness of the study. This chapter is concluded with a view of the legislation of the occupational and mining industry, and provides an understanding to the layout of the following chapters as well as a summative conclusion.

1.2 BACKGROUND

There is a minimum amount of standards that exists for an individual to be employed at an industrial mine in South Africa. These standards are defined as Code of Practice (COP), and are a mandatory requirement of the MHS Act (The Mine, Health and Safety Act no 29 of 1996). COPs ensure that risks to employees are assessed, standards of fitness for certain job types are enforced, and that employees are monitored (Department of Mineral Resources, 2011:4). The MHS Act states that each employee should be categorised in relation to their health, in order to determine the amount of medical testing that should occur (The Mine, Health and Safety Act no 29 of 1996).

The Northern Cape province of South Africa consists of a large mining industry. There were four clinics included in the study. These occupational health clinics each consist of a radiography department. Each clinic is allocated to a certain worksite on a mine. Each clinic's medical records (patient files) are mandatorily stored separately from one another, due to adherence to the Protection of Personal Information Act (PoPIA). The PoPIA defines that all South African institutions must conduct themselves in a responsible manner when collecting, processing, storing and sharing individuals' personal information, by holding them accountable should they abuse or compromise personal information in any way (Workpool, 2015:Online).

The PoPIA further ensures that patient information is kept confidential at each clinic. Permanent employees' medical charts are included in the patient file, where the radiographer has also recorded the date of the last chest imaging procedure. Chest imaging is required one to every three years (teWaterNaude, 2018:43). However, for contract employees, the date is not included in the patient file, but is available on the chest image itself. Numerous contract employees have a patient file at all four clinics, due to location of their contracts. To conclude the background to the research problem, the researcher identified a possible communication gap between the four clinics, as chest imaging is performed at each clinic without taking into account that a chest image was acquired recently at one of the other clinics. According to Ochs (2000:1) the most important factor in reducing radiation exposure to patients is the elimination of clinical preventable procedures referring to unnecessary request for chest x-rays.

1.3 PROBLEM STATEMENT AND RESEARCH QUESTION

The problem that needed to be addressed is that the possibility existed that employees who are employed on a contract basis by private contractors were referred for more chest imaging procedures than permanent employees at the four clinics in the Northern Cape, and thus may experience unnecessary exposure to radiation, which results in a higher accumulative radiation dose.

The following research questions guided the investigation:

1. Are contract employees referred for more chest imaging than permanent employees?
2. Are contracted employees receiving a higher than necessary radiation dose (number of x-ray projections) compared to permanent employees due to unnecessary repetition of chest imaging at the different clinics contracted by mining companies?

1.4 OVERALL GOAL, AIM AND OBJECTIVES OF THE STUDY

The overall goal of the study was to assist mining clinics in optimising the dose of the chest imaging, so that the radiation dose of the employees is kept as low as reasonably possible (ALARA).

1.4.1 Aim

The aim of the study was to optimise the radiation dose for chest radiography by determining the DRL levels at four mining radiology departments and the annual number of chest x-rays requested.

1.4.2 Objectives

In order to achieve the set aim for the study, the following objectives were pursued:

- Establish through a literature study how to calculate the entrance surface dose (ESD) (see **section 2.9.2** and **Appendix A1-A4: sheet 3**) and diagnostic reference level (DRL) that an adult acquires for a chest x-ray (See **section 2.9.3** and **Appendix A1-A4: sheet 3**).
- Calculate the ESD for each employee with the technique parameter information recorded by the radiographer on duty (see section **2.9.2.1** and **Appendix A1-A4: sheet 1 and 3**).
- Determine an estimated baseline DRL for the selected population group (**Appendix A1-A4: sheet 3** and **Figure 27, page 116**).
- Establish the number of chest images received per annum by individuals who are employed by four contracting and private companies - thus four Radiology practices (**Appendix A1-A4: sheet 3** and **Table 14, page 100**).

1.5 RESEARCH METHODOLOGY

Methodology is one of the most important aspects in research (Kallet 2015:Online) and describes the methods a researcher will follow in order to plan and perform a research study (Sileyew, 2019:3). Research methodology is a method to observe something by investigating certain criteria on a matter called a research problem (Koh and Owen 2000:219). The study was considered descriptive because the researcher used specific and different criteria to solve and research the problem (Koh and Owen 2000:219). Strasser, Sweeney, Wiley, Benisch-Tolley, Palmer and Bruera (2004:481)

defined a descriptive study as an observational study where the researcher conducts the study at a specific time without making changes to the environment. The researcher acquired data that already existed such as the employee ID numbers, technical parameters and dates of previous x-rays. This was recorded from each clinic's archive in order to get results without making changes to the existing data.

1.5.1 Demarcation and scope of the study

The scope of this study is limited to the field of clinical diagnostic imaging science and occupational health and safety. The study also includes calculation of the entrance surface dose (ESD) that an individual receives during a Posterior-Anterior (PA) chest x-ray, as well as the dose reference levels with regard to chest radiography.

1.5.2 Design of the study

Quantitative data were obtained from the different selections made on the clinic checklist (Appendix A1 - A4: sheet 2) and the technical parameter checklist (Appendix A1 - A4: sheet 1). DeFranzo (2011:Online) defines a quantitative research method as the method used to quantify a problem by generating numerical data that can be used and transformed into usable statistics. Creswell (2013:Online) further elaborates that it is used to measure attitudes, opinions, behaviours and other defined variables, thus, generalising results from a larger sample population. The research design choice was made since the researcher required numerical data to answer the research question.

1.5.3 Study population

A target population is a large collection of individuals that forms the main focus of the study and shares certain characteristics (Explorable 2009:Online). It serves as a benefit to the population to conduct the research (Explorable, 2009:Online). However, due to large populations, researchers cannot test every individual in the population, as it becomes too expensive and time-consuming. Thus, researchers rely on sampling techniques known as a study population. The 400 participants who participated in the study were selected through stratified sampling, as all employees were divided into permanent employees and contracted employees, and participants were selected from the contacting employees group. Employees were pre-booked for medical testing, irrespective of their occupation in the mining industry.

The reason was that permanent employees undergo medical testing annually, as their work is stationary to one mining site. Referring to Chapter 2, section 2.3.1 to 2.3.4, a contracting employee can be moved and employed to various mining sites in one year, which requires medical testing. Thus, only contracted employees were included in the study. Contracted employees make up a large employee population of the mining industry, as there are various companies that provide services to the mining industry on a non-permanent basis. This was a reassurance that 100 contracted employees per clinic would be an adequate average estimation for data collection.

1.5.4 Participant selection (sampling)

All individuals selected to participate in the study were employed by contractors and

private companies. Employees who are employed with private contractors and private companies work on various industrial sites where certain work is required.

For the participant selection, a random sampling method was used. Thomas (2020: Online) define simple random sampling as utilising the members of the population that are numbered consecutively, so that each member is given a unique number. Four hundred (400) selected employed miners' identification numbers were divided into subgroups of 100 employees per clinic. The contracted employees were selected consecutively when they visited the clinic on the specific day that data collection occurred irrespective of their occupation, given that the employee were contract based.

The radiographer obtained informed consent and took the chest measurements. The researcher then used the ID number of each participant to complete the data collection. The radiographer provided the employee with an information and consent letter prior to the examination. The radiographer recorded 100 employees' ID numbers and technical parameters prior to the chest images of only contract mine employees specific to that clinic. These ID numbers were utilised to perform the annual search after it has been established that it fits the inclusion and exclusion criteria of this study, and they were then replaced by a unique number to protect each employee's identity. This continued until 400 participants were gathered to be used at all four clinics to perform the annual number search.

1.5.5 Inclusion and exclusion criteria

The participants in this study were contract miners employed at one of the participating

mines. Only individuals who are employed at the sites and by private contractors at the four clinics were included in the study, as these individuals work on various mines and industrial sites. Employees who are permanently employed on a mine itself were excluded from the study, since these individuals work on one industrial site only. Thus, they are referred for one medical examination annually. The inclusion and exclusion criteria relevant to each research instrument are discussed in section 3.3 of Chapter 3.

1.5.6 Research instruments

The research instruments were designed by the researcher, whilst the formulae sheet was designed with the assistance of a medical physicist, with the goal to achieve all the objectives set prior to the study. Before any calculations were done, the researcher had to establish through a quantitative literature study how to calculate the entrance surface dose (ESD) that an adult acquires with chest imaging. The research instruments are described briefly but in more depth in Chapter 3.

1.5.6.1 Clinics checklists

The clinic checklist (Appendix A1–A4: sheet 1) was used to achieve the objective to collect technical parameters (Appendix A1–A4: sheet 2) and to use the parameters to calculate the ESD and determine a DRL (Appendix A1–A4: sheet 3). The information was used to cross reference the identifiable number of the employees to determine if employees had imaging done at another clinic within one year.

1.5.6.2 Technical parameters and formulae

These two conversion calculation sheets (found as Appendix A1-A4: sheet 3) made the following objective achievable, which were how to calculate an ESD for each employee with information recorded on the technical data parameters sheet, and ultimately to determine an estimated baseline DRL for the selected population group. To achieve the fourth objective, the researcher had to establish the number of chest images received per annum for employees by cross referencing the identifiable number of employees.

1.6 ETHICAL CONSIDERATIONS

Ethics is a norm that focuses on the disciplines that study standards of conduct (Walton 2015:Online). Ethics is descriptive of norms for conduct that distinguish between acceptable and unacceptable behaviour and stated that an ethical committee/board can also help a researcher to address potential predicaments before the study commences, and to adhere to the ethical considerations prior to the study (David and Resnik 2011:Online).

1.6.1 Ethical approval

The proposal was submitted to the Health Sciences Research Ethics Committee of the University of the Free State (HSREC), and ethical approval was granted on 13 August 2019 (as per ethical approval number UFS-HSD2019/0520/2708) (Appendix E).

1.6.2 Permission from occupational health clinics

Permission was required from occupational health clinics to conduct the study at the four clinics (Appendix F1-F4). The request for permission was issued by the researcher to the clinics, upon which a confirmation letter was received from each operational manager of all four clinics, stating that permission is granted (Appendix F1-F4).

1.6.3 Informed consent

Informed consent is included with regard to the patients (contract miners) (Appendix C). The participating radiographers did not sign a consent document, as they were covered in the approval provided by the mine, and since patient/employee interaction was not permitted to the researcher. The researcher travelled to the clinics prior to data collection to explain the study to the radiographers and answer questions. By explaining the research aim, procedure and significance to the radiographer, it ensured that they understood what was expected and what information should be given to the employee before signing the consent form. The radiographer at each participating radiology department was requested to provide each patient with an information letter, as well as a written consent letter, to record their ID numbers as well as the technical parameters height (cm), weight (kg), kVp and mAs. (which includes the chest measurement) following the exposure of the chest image, and to do an annual search for previous chest x-ray images using the patients' ID numbers.

1.6.4 Project safety

The researcher collected the rest of the technical parameters that were not required from the radiographers and completed the clinic checklist after all the patients that were booked for the day, were x-rayed. In some cases, this was done after hours which is from 16h00 and over weekends. This ensured that the data collection did not affect the patient flow rate within the operating hours of the clinic. This also ensured the accuracy of data collection, as there was no interference.

1.6.5 Participant withdrawal and safety

Permission was granted by the management of the organisation(s) of the four clinics where the study was conducted. Although permission was granted, the institution and participants could withdraw from the study at any time without implications on the routine imaging.

As mentioned, patient safety did not apply to this study; the researcher did not interact with patients, but only with the radiology imaging data. No personal information or images of patients were collected or recorded as part of this study. The identification numbers were used strictly to access the patients' previous x-rays. The research instruments were designed to exclude personal information, as the ID numbers were replaced with numerical data before submission to the statistician (see Appendix A1-A3).

1.6.6 Confidentiality

Under no circumstances were or will the names of any of the clinics or ID numbers of the participants be published in any research outputs of this study, meaning the researcher did not include it in the research report, presentations or publication of any article. The researcher always protected the identity and integrity of the clinics and participants. The names of the clinics are therefore omitted in the Appendices. The study adhered to the Protection of Private Information Act (PoPIA).

1.7 VALIDITY, RELIABILITY AND TRUSTWORTHINESS

Validity is an important aspect that forms part of a research study, as it provides an indication to the design and methods a researcher uses in order to provide usable research for readers; thus meaning the data collection that took place truly represented the research question or the hypothesis of the study, and the results of the study can be perceived as valid results (Middelton 2019:Online). Anney (2014:272) states that it is of great importance that researchers take into consideration the reliability, objectivity and validity of the study taking place, to ensure the trustworthiness of the research.

1.7.1 Validity

Validity refers to how thorough and comprehensive a study, and to an evaluation of the quality of the study is in terms of the research design and methods used by the researcher. Validity can be derived as the accuracy of the study's measuring tools

(Middleton 2019:Online). Validity is assessed throughout a study by checking how well the results correspond to established theories and other studies or published material on the same topic (Middleton 2019:Online).

In this study the validity was assessed through the literature review that was done on previous national and international research related to the topic. A reliable research instrument is not always valid. The results might be reproducible but not necessarily correct (Middleton 2019:Online). The research instruments, namely the technical parameters sheets, clinic checklists, formulae and calculations were tested by means of a pilot study. This ensured that valid data were collected, as the researcher collected all of the data utilising the above-mentioned research instruments. The researcher consulted a medical physicist with regard to the ESD calculation, in order to ensure accurate, credible and valid data output. A valid research instrument is usually reliable if the study produces accurate results (Middleton 2019:Online), and the study topic should be reproducible for further research. This study's research instruments have the capability to expand for a larger scale study where more clinics and participants can be included.

1.7.2 Reliability

Reliability of a study is similar to validity, but focuses more on the consistency of the evaluation of the research tools. Reliability is assessed throughout the study by checking the consistency of the measuring tools with different observers (Middleton 2019:Online).

In this study the research tools were observed and approved by a medical physicist, the study supervisor and co-supervisor. The pilot study was sent to the physicist for scrutiny. The research instrument was designed in such a way that further research can be done on this topic. The researcher can expand the research by focusing on the ESD of other body parts if an employee is referred for more x-rays than chest images. The ultimate dose calculated will then not only be an estimated dose of a chest image, but will take into consideration all the radiation the employee has received. A larger scale study can be conducted by including all the mining clinics in the Northern Cape Province. The study can therefore be considered as reliable, since the results can be transferred into usable statistics (Mohamad, Sulaiman, Sern and Salleh 2015:164).

1.7.3 Trustworthiness

Trustworthiness is the truth or value of a study and is essential to the worth and integrity of the results (Connelly 2016:435). Trustworthiness or rigor of a study refers to the confidentiality of the participants that form part of the data, thus meaning the interpretation and methods used to ensure the quality of the research study (Connelly 2016:435). The radiographers were only expected to record the technical parameters and obtain informed consent, thus meaning accurate data collection techniques were followed and did not negatively influence the study, as the researcher did the rest of the data collection. The meeting between the researcher and radiographers prior to the study clarified what information and explanation was needed from radiographer to employee regarding the purpose and procedure of the study. The pilot study done ensured that necessary changes were made before the actual study, and ultimately showed that the study was trustworthy, and that all ethics and norms were taken into

consideration to provide a trustworthy output (Malmqvist, Hellberg, Mollas, Rose and Shevlin, 2019:Online). It proves that the results of this study is the truth.

1.8 VALUE AND SIGNIFICANCE OF THE STUDY

Occupational epidemiology can be defined as the systematic study of illnesses and injuries that are related to the workplace environment (Naidoo 2014:275). Thus, studies in occupational environments can be classified as useful to all individuals involved. The researcher informed the unit managers of the participating clinics, as well as the Occupational Health Medical Practitioner (OHMP), of the outcome of the study to raise awareness on the importance of protection against radiation. With this study the researcher provided guidance to management to implement a system where all the clinics in the province are allowed to access medical records of employees. This will ensure that the ALARA principle is adhered to. The findings of the study will be obtainable to other occupational health institutions. Presentations will be held at radiology-related meetings, which occurs annually, through paper presentations at radiography conferences and seminars, as well as via publication in applicable journals.

1.9 IMPLEMENTATION OF THE FINDINGS

The report and findings of the study will be presented to the participating institutions as agreed between these institutions and the researcher prior to study approval. In Chapter 5 the researcher made recommendations for implementation of changes according to the study outcome.

1.10 LAYOUT OF THE STUDY

This dissertation will serve as a report and provide information in terms of what was expected of the study, as well as methods used to complete and finalise results. The following layout can be expected.

Chapter 1: Introduction and background, provided a background to the research problem, the aim, goals, expected objectives, research methods and design of the study. The value, significance, validity, reliability and trustworthiness of the study were also briefly discussed.

Chapter 2: Conceptual framework for this study, provides the reader with a path to understanding the research question and problem in the form of a literature review relevant to the topic - thus including the policies, legislation and practical standards that are expected in terms of the medical screening and testing of mining employees. The chest x-ray examination was the main focus of these tests and is described in great detail. The entrance surface dose that was calculated for each selected participant is also described, and it is explained how the calculation was done to ultimately establish a dose reference level for that unit.

Chapter 3: Clinics' checklists, technical parameters and formulae and calculations, provides a profound insight on data collection methods used, and data analysis done on the clinics checklists. This chapter also includes how the technical parameters were designed and the reason for each parameter collected, and how data

were inserted from the technical parameters sheet to the formulae sheet in order to calculate an ESD and ultimately a DRL.

Chapter 4: Results, presentation and discussion on the clinics' checklists, technical parameters and formulae and calculations provides a report on the clinics' checklists - thus the number of x-ray images or examinations all contracted employees have had. A report on the technical parameters document that was completed by the radiographer of that clinic, and the values that were used to insert the data on the ESD and DRL calculation data sheet are provided, to supply the reader with a numerical value that serves as the ESD of each employee, and ultimately a DRL for the clinic.

Chapter 5: Conclusion, limitations and recommendations provides a summary of the study, the limitations that the researcher experienced, and recommendations about the study outcome that could be of value to the participating institutions.

1.11 CONCLUSION

This chapter clarified the importance of occupational medical screening, as well as the policies and legislation related thereto. Chapter 2 will provide a framework for the literature review of the study, and encloses a background to occupational medical testing; focusing on the incorporation of chest images with the ESD and DRLs, in relation to chest radiography.

CHAPTER 2

CONCEPTUAL FRAMEWORK FOR THIS STUDY

2.1 INTRODUCTION

As mentioned in Chapter 1, the Occupational Health and Safety Act of 1993 (Act no. 6 of 1993) has been implemented and has the same ideals and principles as the to ensure a safe working environment for all employees. Since the implementation, occupational screening became a requirement in the mining industry. Occupational screening complements the OHS Act by ensuring that occupational screening occurs in such a manner and according to certain standards that occupational diseases are not overlooked (Department of Mineral Resources 2011:6). The aim of this chapter is to provide a conceptual framework and a background to the study. Thus, it provides an insight on the policy and legislation of medical testing and screening as well as the practical standards that are expected of these tests, and all the factors pertaining to a chest x-ray image. These factors include positioning, projections, significance and the classification report of a chest x-ray image in occupational health. All x-ray procedures consist of a radiation dose administered to the patient. Finally, a discussion on dose implications and optimisation that includes entrance skin/surface dose, exposure index and the dose reference level thereof, is provided.

Before the researcher could decide if the chosen topic was relevant for research, a literature review had to be done. This included a background check and understanding of what the policy and legislation states and requires of occupational medical testing on industrial mines, as well as the code of practices that is a requirement of the OHS Act to ensure that an employee adheres to a minimum number of standards. The

researcher found that the reason that mining clinics did not share x-ray images was due to the several acts in place to protect the personal information of employees. For the researcher to give valid feedback to the mines on the possible unnecessary exposure of ionizing radiation, and to consider this research as useful for future improvement, a calculated value had to be added to this feedback. This made the researcher enquire about entrance surface dose and dose reference levels. It was found in previous/related studies that these values are usually measured by using a thermoluminescent dosimeter (TLD) (Abdelhalim 2010:115).

Investigation through several online search engines namely Science Direct, Refworks and European Diagnostic Reference Levels (Ofori, Gordon, Akrobortu, Ampene and Darko 2014:460; Marsden, Hardwick, Mencik, McLaren, Young and Mashford 2008:454; Nyathi, Nethwadzi, Mabhengu, Pule and Van der Merwe 2009:10) was done to obtain information on the various calculations available to determine the entrance surface dose. With the assistance and recommendation of the medical physicist (Sweetlove, A. 2019. Personal communication, 22 August), a calculation in the textbook of Bushberg, Seibert, Leidholdt and Boone (2012:379) was selected as the formula of choice for this study (Equation 1(a) and 1(b) in section 2.9.2). The researcher consulted with the physicist to accurately calculate the entrance surface dose and ultimately determine a dose reference level for the clinics.

2.2 POLICY AND LEGISLATION OF OCCUPATIONAL MEDICAL TESTING

The Mine Health and Safety Act 29 of 1996 (MHSA) is the principal law regulating occupational health practice in South Africa's mining industry. A number of other acts

regulate the practice of occupational health. The Employment Equity Act (EEA) are accountable for medical testing of employees and the provisions dealing with HIV testing (Guild, Ehrlich, Johnston and Ross, 2001:17). It is known that individuals employed by an industrial mine face great health risks, also known as occupational hazards (LaDou 2007:7). Each individual performing their occupational tasks is aware of the occupational and environmental exposures, as each individual undergoes induction before employment. The health, safety, occupational or environmental exposure protocols related to the industrial mine are discussed and assessed during induction (Guild, Ehrlich, Johnston and Ross, 2001:6).

Each mine's occupational health clinic has an appointed Occupational Health Medical Practitioner (OHMP). It is of significance that the clinic acquires a full medical history of an employee before employment. The reason is that the history of any present illness may suggest potential diagnostic possibilities that lead to specific etiologic hypotheses (LaDou 2007:7). Medical testing facilitates employer compliance with occupational health legislation, which states that all on-site workplaces are to be free from alcohol, tobacco, illegal drug abuse and the misuse of other substances as stated in regulation 2A of OHSA. The policy states that it is expected of all on-site employees and visitors to be alcohol and drug free. Thus, all employees and visitors to a mining company or industrial site may be subjected to drug and alcohol testing. The policy also states that if one has a drug or alcohol dependency, one is expected to seek help and undertake appropriate rehabilitation and treatment (Guild *et al*. 2001: 6).

The administrative requirements of the MHS Act include aspects such as occupational risk assessment, risk-based medical surveillance, biological monitoring, the

management of injuries on duty, absence management support, basic primary healthcare, and chronic disease management support (Guild *et al*. 2001: 4). This implies that the health and safety of employees are of great importance.

2.3 OCCUPATIONAL MEDICAL SURVEILLANCE

The Department of Mineral Resources (2011:11) states that there are standards to be set for the medical surveillance done by occupational medical practitioners. After these risk profiles are established, the OHMP should set medical standards for each occupation according to their risk profiles. The Department of Mineral Resources (2011:12) state that each individual who is initially employed, during employment, transferred or ending employment should undergo an annual medical surveillance. The following categories are for the purposes of establishing minimum standards. These categories include an initial examination, periodic examination, transfer/pre-placement examination and exit medical examination. Each examination consists of a series of tests done at an occupational health clinic. The following graphical presentation illustrates an initial medical examination route an employee follows when these tests are done.

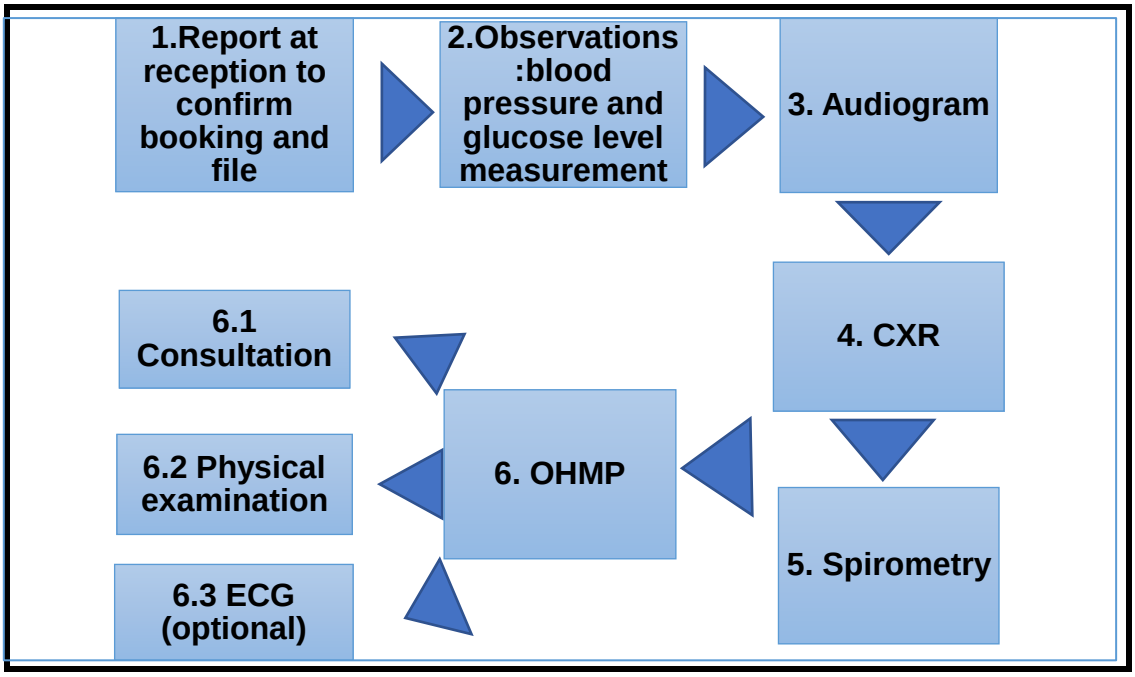


Figure 1: Pathway at an occupational health clinic during medical examinations (Compiled by researcher Leandré Toüa, 2019).

Figure 1 displays the route an employee follows when visiting an occupational health clinic for medical examinations. The figure is based on an initial medical examination, as it includes all the tests that are done on an employee upon start of employment. The individual will start at number one, where he/she reports at reception to receive a file. These medical examinations are booked in advance by the employees' company/contractor.

Secondly, the individual will be accompanied by a staff member from occupational health for observations, such as a blood pressure and blood glucose level test. Another occupational health professional will accompany the individual to the hearing test (audiogram), which will be followed by a chest x-ray in the x-ray department to be performed by a radiographer. The individual will then perform a lung function test (spirometry) at another location in the clinic. After completing all the tests, the OHMP

will review all the results, view the chest x-ray and call the individual to the consultation room. The OHMP will do a physical/clinical examination, discuss the results with the individual, and allow time for consultation and questions from the individual. If the OHMP decides to include an Electrocardiogram (ECG), it will be performed by the occupational nursing staff. After the process, the OHMP will issue a health certificate to the individual, stating whether the person is fit for work, or not (Department of Mineral Resources 2011: 11).

2.3.1 Initial medical examination

The baseline medical examination is applicable to an individual who is employed or visiting the mine for the first time. The observations are done first which includes a blood pressure, blood glucose level test and an ECG. An ECG is only performed if requested by the OHMP. An indication of whether it is required or not is the presence of chest pain, back, neck, jaw or arm pain without chest pain, palpitations, exertion dyspnoea, a feeling of weakness and anxiety (LaDou 2007:21). The following tests follow: a chest x-ray, lung function/spirometry test, audiogram, urine test, and eye test/vision screening.

2.3.2 Periodic medical examination

Each occupational health department will have specific requirements, determined by the occupational hazards one are exposed to, as well as the type of work that is required which provides an indication of the frequent needed medical testing needed, including a chest x-ray (Department of Mineral Resources 2011:22). Office staff are

not exposed to any risks, thus, only an initial and exit medical examination is required. Employees who work in dusty areas should get a chest x-ray every two years. A physical examination, urine test and lung function test is performed annually, and an eye test every three years. Employees who work in noisy areas should undergo an audiogram at intervals that are determined by the OHMP. However, it is recommended that these should be done annually.

2.3.3 Transfer medical examination

These medical tests include observations (blood pressure and glucose), urine test, audiogram, chest x-ray and spirometry. OHMP consultation must be undertaken when an employee is moved between different industrial sites. It should take into account hazards related to the specific site that will alter the medical surveillance of that particular employee (Department of Mineral Resources 2011:12).

2.3.4 Exit medical examination (certificate)

It is essential that this certificate is completed by the mine and issued to all employees when he/she is leaving an industrial site. The findings of the examination will be recorded on the patient's file. The exit medical examination includes a chest x-ray, lung function test, full physical examination and an audiogram (Department of Mineral Resources 2011:14).

Table 1 provides a visual presentation of medical examinations that are required when an employee is going through the process of medical testing before employment can start, resume or end.

Table 1: Medical examination categories with required medical tests as observed by the researcher

Medical examination category	Required medical tests
Initial	Observations (blood pressure & glucose) Urine test Eye/vision test Blood pressure measurement Audiogram Chest x-ray Spirometry OHMP consultation
Periodic	Observations (blood pressure & glucose) Urine test Audiogram Chest x-ray (for permanent employees: only excluded if done within one year). Spirometry OHMP consultation
Transfer/pre-placement	Observations (blood pressure & glucose) Urine test Audiogram Chest x-ray Spirometry OHMP consultation
	Observations (blood pressure & glucose) Audiogram

Exit	Chest x-ray Spirometry OHMP consultation

(Compiled by researcher Leandré Toüa, 2020)

2.4 PRACTICAL STANDARDS OF TESTS INCLUDED IN OCCUPATIONAL MEDICAL SURVEILLANCE: RESPIRATORY HEALTH ASSESSMENT

All medical testing is subjected to the appointed OHMP. The OHMP will view all the medical tests done on an employee and issue a medical certificate to the employee. The OHMP is responsible for signing off on an employee, with regard to their state of health, before and after employment (Department of Mineral Resources 2011:14). The tests which are included in the surveillance must be done according to a methodological standard. If an x-ray is of diagnostic standard, it supports the overall goal of the study which is to practice the ALARA principle.

2.4.1 Lung function testing

A chest image alone cannot determine healthy/unhealthy lungs. The measurement of lung volumes and diffusing capacity cannot be tested with a chest x-ray, thus, a pulmonary function or practical spirometry test is included in order to detect and quantitate abnormal lung function, to grade the extent of the functional impairment and to monitor the progression of the dysfunction of the lungs (Department of Mineral Resources 2011:20).

Lung function testing is also called spirometry and can be described as a standard test that is done to test and diagnose pathological lung conditions such as chronic obstructive pulmonary disease and asthma. It includes the use of an instrument named Spirolite where the patient blows into the device forcefully. The predicted values used are FEV1 and FVC. FEV1 is defined as Forced Expiratory Volume in one second. FVC is defined as Forced Vital Capacity, which refers to the maximum volume of air exhaled with force from maximum inspiration. These two readings are expressed in percentage (Department of Mineral Resources 2011:18). These parameters are used to provide the best possible way in detection of airway obstruction (LaDou 2007:311). Figure 2 below demonstrates the device that is used to perform a lung function test, and what will be expected of the patient during the test. Patient co-operation is essential during this test to prevent false or misleading results.

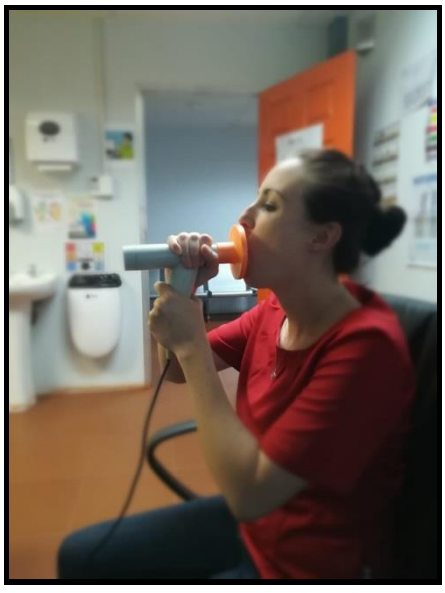


Figure 2: Lung function test device (Spirolite)

(Photo by researcher Leandré Toüa, 2019)

2.4.2 Chest x-ray examination

A chest x-ray examination consists of two projections, namely the posterior-anterior (PA) and lateral projections. However, only the one view (PA) is included in occupational health medical testing. LaDou (2007:310) states that the reason for only performing a PA chest x-ray is that these individuals undergo pre-, post- or periodical screening, as they are contracted at various working sites. The radiographer must ensure that the PA chest x-ray is performed on the image receptor size 35 X 42 cm or 25 X 30 cm, so that all chest anatomical structures are included and viewed at a reasonable size, in order for pneumoconiosis to be visualised. The chest x-ray image(s) that are available on the clinic's patient archive show(s) the patient's identification, which includes his/her name, surname, identification number, date of birth and gender (Mine Health and Safety Act 2011:Online). The chest images done by the radiographer at an occupational health clinic are only viewed by the OHMP and if for any diagnostic reason the employee will be referred for further intervention by the OHMP. There is no Radiologist intervention at the clinics. Figure 3 below demonstrates a typical PA chest x-ray image outlining a systematic approach of anatomical structures to establish in order for a chest x-ray to qualify as acceptable.

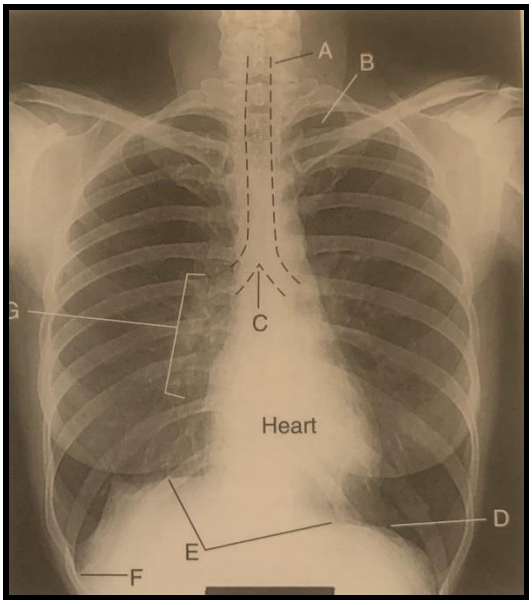


Figure 3: A typical chest x-ray image

(Image courtesy Bontrager and Lampignano 2010:76)

Table 2 provides a description of the radiographic appearance for each labelled anatomical description found on Figure 3 that is a typical chest x-ray. This image is only an example of the anatomical features present on a chest image, as each individual's features differ, and one may find a different appearance of another chest image and its anatomy, such as present pathology and/or other underlying conditions.

Table 2: The description of labels on Figure 2

Label	Anatomical description
A	Trachea which is the path or airway to the lungs
B	Lung apex which is the rounded upper part of the lungs
C	Carina is the point of bifurcation

D	Base of lungs with a concave shape and rests on the diaphragm
E	Diaphragm is the muscle that separates the upper respiratory system from the abdominal cavity
F	Costophrenic angle(s) are the most outer part of the lungs; this is where the diaphragm meets the lungs (important included anatomy on a chest image to exclude pathology)
G	Hilum (Hila/Hilus) is the root region in the central part of the lungs and is where the bronchi, blood vessels, lymph vessels and nerves exit the lungs

(Bontrager and Lampignano 2010:76)

The radiographer will check that the patient's information or image data are visible on the image. The image should be marked with a lead marker indicating right or left side, the image date and time and the image projection (PA or AP, standing, sitting or supine). The image gives the reader a pattern recognition approach that a radiographer uses when viewing a chest x-ray image. This is to ensure that all anatomical structures are included, and that the imaging technique (exposure parameters) that was used was sufficient. The correct exposure factors selected by the radiographer is evident in optimal image contrast when one can differentiate between bone, air and soft tissue (Carlton and Adler 2006:241).

Radiographic image quality is the radiographer's responsibility to produce optimal image quality that includes optimal diagnostic information. Thus, the radiographer will further critique the image before it is sent for reporting (Carlton and Adler 2006:714). The criteria utilised to evaluate the image quality includes over- and under exposure, rotation, tilt of the chest (lordotic), anatomical alignment of the chest to the image receptor, anatomy that should be included, centering of the main beam, motion unsharpness, collimation, patient artifacts and lead marker identification. The importance of optimal image quality is to prevent misinterpretation and/or incorrect diagnosis of pathologies (Radiology Masterclass 2015:1).

2.5 POSITIONING TECHNIQUE OF A CHEST X-RAY EXAMINATION

Routine chest examinations commonly consist of two images (projections), namely posterior-anterior (PA) and lateral (Bontrager and Lampignano 2010:89). The patient's chest is in contact with the image receptor (IR), also referred to as Bucky (Bontrager and Lampignano 2010:80). Meseret (2015:8) defined PA as referring to the patient standing and facing the upright Bucky, which means the central ray will enter the patient posterior and exit the anterior aspect of the patient in contact with the IR. The entrance point of the central ray, also named the centring point, is measured at 18-20cm from the vertebral prominence of thoracic vertebra one (T1) to enter posterior on the level of T7 (see Figure 4) and exit anterior to reach the IR (Bontrager and Lampignano 2010:83).

A radiographer uses different positioning techniques to acquire a chest image. Radiology Masterclass (2015:2) states that a chest examination is done PA, due to

the fact that the heart is situated anterior in the thorax. If the patient is in an AP position, it causes magnification of the heart. Erect chest radiographs are preferred, because gravity allows the liver and other abdominal organs to drop and the diaphragm to move down lower, and allows the lungs to fully aerate. It allows air and fluid levels to be visualised in the pleural space and lung cavities, and it prevents engorgement and hyperemia of the heart and blood vessels (Bontrager and Lampignano 2010:80). Ahmad (2001:Online) states that, during positioning, the legs are spread and weight is evenly distributed to prevent motion that can result in unsharpness. Hobbs (2007:502) elaborated that the patient's hands are placed on the hips and the shoulders are rolled forward until they are in contact with the Bucky, to prevent rotation of the thorax, as well as to prevent the scapulae from superimposing the lungs.

Hobbs (2007:502) explained that the radiographer should instruct the patient to inhale and make the exposure on full inspiration. Meseret (2015:7) elaborates that if the examination is not performed on inspiration, it causes the diaphragm to rise and leads to misinterpretation of the heart size (enlarged) and obstruction of the lung bases. In addition, the lung markings become crowded, and it can be misinterpreted as lung pathology. In occupational health practice, only a PA image is performed, unless the OHMP requests a lateral (Life Healthcare 2017:Online). By considering all the above, the radiographer should obtain a chest image that is of optimal diagnostic quality. By focusing on the correct positioning/centring point of a chest x-ray, means a lower repeat rate and supports the protection of patients from unnecessary radiation exposure. Figure 4 below demonstrates what the position of the patient looks like during the examination as well as the centring point.

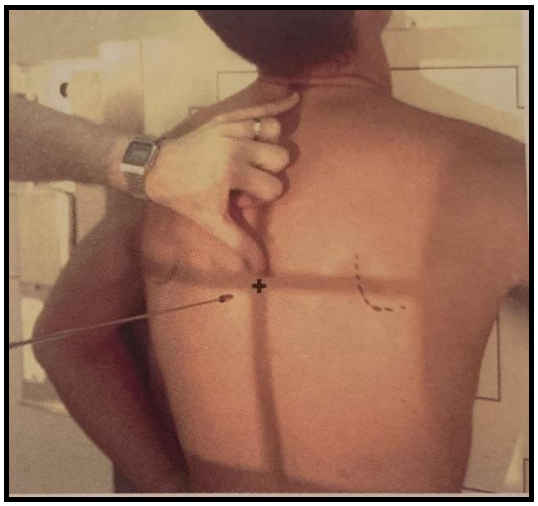


Figure 4: Positioning technique and centering point of a posterior-anterior chest x-ray

(Image courtesy Bontrager and Lampignano 2010:83)

2.6 CHEST X-RAY PROJECTIONS FREQUENCY IN OCCUPATIONAL HEALTH

Individuals who are employed by a private company or contractor will for this study be referred to as contracted employees. These employees undergo an entry, pre-placement, periodical or exit medical examination more than once a year, as the work they perform at a construction site is completed over a period of months and this can lead to undergoing medical testing at multiple occupational health clinics. These categories depend on a contract ending, retrenchment, re-hiring or replacement to another construction site. This category of medical examination for contracted employees excludes all employees that are permanently employed by a mining company (Guild *et al*. 2001: 5). The permanent employees' medical examinations are valid for a period of three years. The aim of periodical medical screening is to detect signs of illness and take corrective action before the individual develops other

occupational diseases (Myeni and Ngcobo, 2020:9). The requirements of the Occupational Safety and Health Branch of the Labour Department (2017:6) states that employees undergo medical screening depending on the individual's nature of hazardous exposure. For the most hazardous exposures, however, these examinations are conducted three yearly.

LaDou (2007:310) states that the reason for only performing a PA chest x-ray is that these individuals undergo pre-, post- or periodical screening as they are contracted at various working sites. As mentioned in section 1.2, each construction site consists of an occupational health clinic. Thus, the possibility exists that an individual at a mine is referred for more chest examinations annually, consisting of both positions, than the average permanent employee who undergoes chest examinations (see Table 1). The storage and tracking system do not involve any hardware copies of previous x-rays. Each individual's x-rays are stored under their unique identification number (ID) on the clinic's archive. Each clinic's x-ray department has an archive system (not linked to other clinics) where one can access all x-rays done from the date when the software was installed to present. Each chest image done is analysed by the OHMP. If any abnormalities are found and the pathology is outside the scope of practice of the OHMP, the patient will be referred to the nearest Medical Bureau of Occupational Disease (MBOD) of the Department of Health for treatment.

2.7 SIGNIFICANCE OF A CHEST X-RAY IN OCCUPATIONAL HEALTH

Chest imaging is still one of the most frequent examinations done, even though there are superior diagnostic imaging techniques available (Schaefer-Prokop, Neitzel,

Venema, Uffmann and Prokop 2008:1818). Thus, chest imaging plays an important role in the cycle of occupational health screening. Working Knowledge International (2017:Online) stated that for certain occupational industries, like mining and spray-painting, a chest x-ray is required. Cardinale, Volpicelli, Lamorte, Martino and Veltri (2012:398) state that chest images have great potential in the initial diagnosis of a variety of lung disorders, such as tuberculosis (TB), pneumo/hemo thorax, pleural effusion, pneumonia, asbestosis, silicosis, lung neoplasia and pneumoconiosis.

2.7.1 Occupational respiratory diseases in mining

Most occupations pose a health/danger risk when performing their duties. In the mining industry there are many hazardous risks in the profession. The relationship between mining and occupational lung diseases has been documented and researched since the 1500s (Murray, Davies and Reese 2011:S65). The focus on these risks are the respiratory diseases that employees are possibly subjected to over the long and short term. During the last thirty years, the occurrence of pneumoconiosis has declined steadily in the USA. The rates of underground miners included in the National Institute for Occupational Safety and Health (NIOSH) Coal workers' x-ray surveillance programme decreased from >10 % in the early 1970s to <2 % in the late 1990s, which is consistent with the estimated rates in South Africa that is 2.6 % (Laney and Weissman 2014:4).

Pneumoconiosis is one disease that is monitored closely amongst mine workers, and is defined as the term that is used to describe the parenchymal lung disease caused by the long-term inhalation of coal dust. Underground mine workers are at greater risk

to develop pneumoconiosis than above ground, and the condition is seen in mine workers who spent less than 20 years underground (LaDou 2007:328).

The mechanism or onset of pneumoconiosis is when the coal macule is the primary lesion in this condition, and is formed when the inhaled amount of dust exceeds the amount that can be removed by the alveolar macrophages and mucociliary clearance (LaDou 2007:328). The following illustration indicates the lung zones/lobes to provide a visual as to where pneumoconiosis starts and its progression through time.

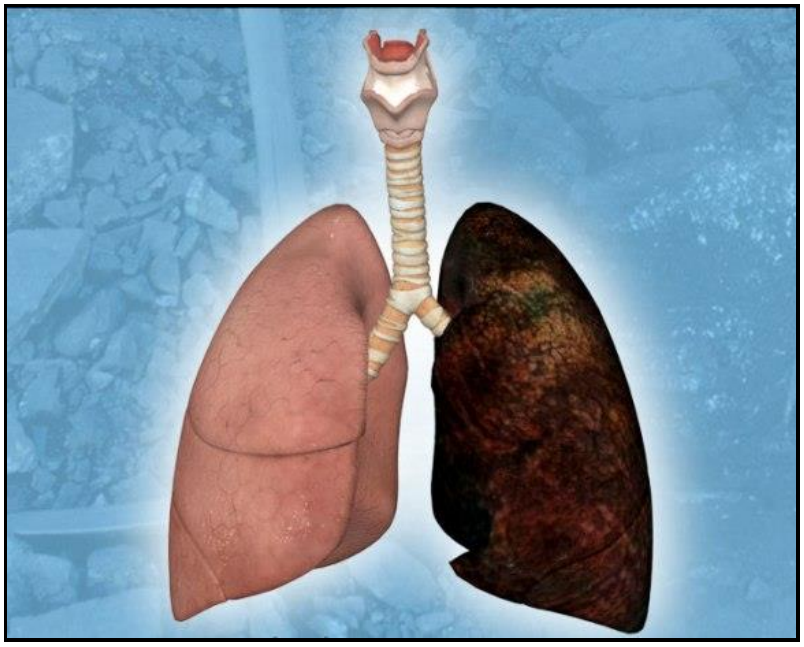


Figure 5: Illustration of pneumoconiosis

(Image courtesy Medifit, 2016:Online)

Silicosis, asbestosis, chronic obstructive pulmonary diseases (chronic bronchitis and bronchiolitis obliterans), pleural disorders (benign pleural effusions, pleural plaques and mesothelioma), lung cancer and pneumoconiosis are a small fraction of lung diseases amongst mine workers, and are mainly caused by coal dust inhalation

(LaDou 2007:332). Pneumoconiosis will be seen on a radiographic chest image clearly as the onset of the disease will be evident in the upper/superior lung zones, identified by small opaque and rounded opacities (lesion diameter size <10 mm) in the lung parenchyma, but with time and progression of the disease it may spread to lower lobes (LaDou 2007:329). This implicates that regular screening is necessary to track progression.

Pachman (2009:529) elaborates that a chest x-ray done as part of a pre-employment screening can be of great importance to ensure the health and safety of the employee, co-workers and all individuals the employee comes into contact with, as most lung diseases such as pneumonia, tuberculosis and influenza (flu) become contagious through droplets caused by coughing or sneezing. Thus, by including a chest image in the series of tests, one ensures that the employee is healthy and fit for work (Guild, Ehrlich, Johnston and Ross, 2001:6).

2.8 THE CHEST X-RAY REPORT

Each employee that visits these clinics has a hardcopy file that does not consist of the x-rays, but acts as a paper trail to the employee's time of employment and also include recordings of other medical tests done. All x-ray images are stored on the clinic's archive system, meaning all clinics are independent. This report acts as a date of the last chest image performed and an indication if any abnormalities were found.

The report consists of patient information such as name, surname, ID number, gender, date of birth, age, medical history (smoker/non-smoker/ex-smoker/exposure to silica

and asbestos). The category, namely initial, periodical, and follow-up or exit, needs to be completed by the radiographer. The exposure given as well as the EI for each for each x-ray performed are recorded by the radiographer on a separate booklet as part of the clinics protocol. The rest of the report needs to be completed by the OHMP, who has to state his/her findings in order to sign off on the individual as healthy and fit for work. The report is only completed after performing all the required medical tests. The OHMP completes the report by assessing the chest image, utilising the International Labour Office (ILO) classification as a guideline to what is normal and abnormal. The findings of the OHMP are recorded on the report itself, as well as on the software file on the archive of the clinic's database. This report acts as a trial that the OHMP uses to track progression of pathologic findings and in some cases may need more x-rays than once a year which add to the employee's annual dose.

2.8.1 International Labour Office classification

The International Labour Office (ILO) classification has prompted, promoted and published a series of guidelines on classification that is applicable to digital radiographic images. The use of the classification is to codify radiographic abnormalities in a simple, reproducible and accessible manner. It also provides a good clinical history and progress of the patient regarding pneumoconiosis. The goal of the classification is to utilise it for clinical purposes, thus, to standardise classification methods, facilitate international comparisons and act as a guideline to medical professionals on the diagnosis of pneumoconiosis. The protocol requires that appearances be described by using the appropriate symbols, and that comments be

reported on the patient's file to serve as a clinical history (International Labour Office 2011:1).

The utilisation of the classification is as follows: the OHMP will assess the technical quality of the image, which consists of four grades: good, acceptable with no technical defect to cause impairment of classification of pneumoconiosis, acceptable with some technical defect but adequate for optimal classification purposes or unacceptable for classification purposes. Secondly, the OHMP will scrutinise the image for parenchymal opacities, which include small and large opacities. The increased profusion of small opacities is recorded by categories (0, 1, 2 and 3) or subcategories (0/-, 0/0, 0/1, 1/0, 1/1, 1/2, 2/1, 2/2, 2/3, 3/2, 3/3 and 3/+). The 12 subcategories refer only to the profusion of small opacities. This is followed by the affected zones (upper, middle and lower zone). The shape and size of the opacities are recorded by the following symbols:

Table 3: Classification of size and shape of opacities

Symbol	Description
P	opacities with diameters up to 1.5 mm
Q	opacities with diameters exceeding 1.5 mm up to 3 mm
R	opacities with diameters exceeding 3 mm up to 10 mm
S	opacities with widths up to 1.5 mm
T	opacities exceeding widths 1.5 mm up to 3 mm
U	opacities exceeding widths 3 mm up to 10 mm

(International Labour Office 2011:5)

Thirdly, the OHMP will assess the image for any pleural abnormalities, such as pleural plaque which is represented by localised pleural thickening, as described in Table 4. Fourthly, the OHMP will assess the costophrenic angle obliteration either as present or absent on the left and right side. An evaluation of the thickening of the visceral pleura is recorded, which is called diffuse pleural thickening (International Labour Office 2011:8). After assessing all anatomy mentioned above, the OHMP's findings will be reflected by the symbols on the report. The last part of the report to be completed will be the summary of findings.

The bony chest cavity is the first category, and includes bilateral shoulders, ribs, sternum and the thoracic vertebrae. These subcategories must be marked normal or abnormal. The second category is the mediastinum, which includes the heart, great vessels, trachea, oesophagus, and the lymphatic glands. These subcategories must be marked normal or abnormal. The third category is the diaphragm that must be marked normal or abnormal (International Labour Office 2011:8).

Table 4: Measurement of pleural abnormalities

Symbol	Description
A	Abnormalities 3mm up to 5mm
B	Abnormalities 5 mm up to 10 mm
C	Abnormalities over 10 mm

(International Labour Office 2011:6)

Reflecting on all the measurements of the ILO classification, the frequency of medical testing depends on the nature of the occupational hazards one is exposed to (Myeni and Ngcobo, 2020:34). However, for most hazardous exposures, these examinations

(including a chest image) should be conducted annually. Statutory requirements recommend that individuals who are exposed to silica, arsenic, cadmium, manganese, lead, mercury, organophosphates, tar, benzene and raw cotton dust should undergo medical testing annually to detect and/or monitor pneumoconiosis and other pathological changes in the lungs (Myeni and Ngcobo, 2020:34). The Northern Cape Province mostly mines for manganese, which results in dust exposure for specifically contracted employees working at various mining sites in a year. This may potentially lead to more than one chest x-ray performed per year as the OHMP track different pathologies for example as a result of continuous dust exposure.

2.9 DOSE IMPLICATIONS AND OPTIMISATION

The International Commission on Radiological Protection (ICRP) is a non-governmental, registered charity institution created to serve as the primary protection against radiation. It was established in 1928 by the International Congress of Radiology to provide benefit to the public on the science of radiation protection, recommendation and guidance on protection and the risks associated with exposure to ionizing radiation (Valentine 2007:3). ICRP has revised the Recommendations for a System of Radiological Protection and replaced the Commission's previous recommendations released in 1990. These recommendations are an update and consolidate the additional guidance on the control of exposure from radiation sources issued in 1990 (Valentine 2007:4). The Commission describes three fundamental principles of radiation protection namely justification, optimisation and the application of dose limits or limitation.

Justification refers to when the exposure given or radiation dose is altered, the alteration must be beneficial to the patient, and these benefits must outweigh the deterministic effects (Valentine 2007:14). Limitation refers to the adherence of the ALARA principle and the total dose received by medical ionizing radiation, and this dose should not exceed the limits set by the Commission (Valentine 2007:14). This section will focus on optimisation of radiation protection.

Carlton and Adler (2006:34) state that within one year after the discovery of x-rays by the German physicist Wilhelm Conrad Roentgen, skin burns have been reported, and within seven years a case of cancer was observed. Thus, the dose a patient receives should be monitored closely to avoid irreversible effects. The dose of radiation received by a patient is an important aspect to contemplate due to its biological effects, namely stochastic and deterministic (non-stochastic) effects (Little 2003:259). Stochastic effects are described as genetic risks in offspring; somatic effects/malignant disease in a directly exposed population. Subsequently, described as the long-term effect of occurring radiation exposure without a threshold (Valentine 2007:33).

Deterministic effects are described as when the dose of radiation increases, so does the chance of reaction to the radiation an individual will experience such as cataracts, skin erythema and sterility (International Atomic Energy Agency 2010:5). The dose that an individual receives can be monitored and can affect the human physiology in various ways. Deterministic effects are also termed tissue reaction; therefore, certain deterministic effects are reversible or adaptable by post-irradiation procedures (Valentine 2007:20).

To avoid or limit these effects, dose optimisation must be taken in consideration. The main goal of diagnostic radiography is to produce the best image quality with the lowest possible dose (Bontrager and Lampignano 2010:60). Medical image quality is related to the subjective interpretation of visual data. It represents the clinical information contained in the image. In corporation with image quality, the lowest dose administration possible is wanted due to the ALARA principle, as discussed in section 1.2. This statement is defined as dose optimisation. There are several factors that influence the optimisation of the performance of radiographic equipment which is dependable on patient dose administration (Martin 2007:18).

The National Department of Health (NDoH) has a division named South African Health Products Regulatory Agency (SAHPRA), that was created by the South African government to ensure that the human and animal well-being is of fundamental standard; and to oversee the new medical device and pharmaceutical regulatory systems being developed in the Republic of South Africa (RSA) (EMERGO 2017:Online).

The historical trail to the creation of this unit is that SAHPRA undertakes the roles of the Medicine Control Council (MCC) as well as the Directorate of Radiation Control (DRC) which are contained at the NDoH. Subsequently, SAHPRA was recently established as an independent division that reports to the Minister of Health. The DRC ensures that a code is set for requirements and recommendations for radiation safety in relation to the use of medical x-ray equipment, and the licensee is responsible to take corrective action on matters that is of non-compliance to this Code according to the Department of Health Directorate.

2.9.1 Exposure Index (EI)

EI is a value available on the x-ray display screen. It is included to monitor relative speed and sensitivity of the digital image receptor in relation to the incident x-rays. Ultimately EI provides feedback to the radiographer on radiographic exposure parameters used to obtain the optimal diagnostic quality image, as ESD and DRL values do not serve as an indication of image quality (Skrk, Zdesar and Zontar 2006:190). EI is defined as the output value of a digital system which serves as an indication of the estimated amount of exposure the detector received after attenuation. It is not to be regarded as the radiation dose the patient received (Carlton and Adler 2006:342). This value is usually displayed on the image as numerical data, and is an indication of the signal-to-noise ratio and an indirect indication of image quality (Seibert and Morin 2011:573). The EI is recorded by the radiographer as part of the clinics administrative requirements but was excluded for this study.

Many manufacturers programme their software with mathematical algorithms to modify an image to get desired results such as images with high resolution, low contrast and rapid display (Carlton and Adler 2006:368). This is an optimisation process that manufacturers the need to be carried out regularly and to be communicated to the radiographers for it to be effective. The advantage of making use of EI is that it leads to improved radiographer performance in terms of uniformity and making use of optimised radiographic techniques which ultimately lead to the radiation protection of patients (Seibert and Morin 2011:573).

Since EI is not an indication of dose administration, the value fails to determine if a patient has been subjected to an unnecessary radiation dose. Nevertheless, this value can be used to indicate relative dose and image quality.

2.9.2 Entrance Surface Dose (ESD), absorbed and effective dose

ESD is defined by Bell, Murphy *et al*. (2017:Online) as the measurement of an ionizing radiation dose that is absorbed by the skin once it reaches the patient. The ESD is measured by the unit Milligray (mGy). Normally, the ESD is measured with a device named thermoluminescent dosimeter (TLD). This device is worn by a person and stores the received dose in a crystal, and then releases the radiation in a form of visible light. The intensity is measured when this crystal is heated. The intensity of light emitted is dependent on the radiation dose received and stored (Carlton and Adler 2006:140). The absorbed dose is defined by Carlton and Adler (2006:140) as the unit of absorbed energy, or dose, in any material. The International System of Units (SI) for exposure is expressed in coulomb per kilogram (C/kg), as Roentgen (R) has no specific SI unit. An effective dose is the sum of the weighted equivalent doses of all irradiated organs and tissues. An effective dose considers the fact that some organs and tissue are more sensitive to ionizing radiation than others (Carton and Adler 2006:141).

There are four ways described on how to calculate an ESD or incident air kerma of a PA chest x-ray of an adult to estimate dose (see **section 1.4.2, Objective 1**).

Using equation 1 to calculate ESD for an x-ray performed using 80 kVp and 100 mAs. The SSD is estimated to be 73 cm. Utilising Table 4, at 80 kVp the output of the x-ray system is 6.7mGy at 100 mAs at a distance of 100 cm from the source. The x-ray output is linearly proportional to the mAs. For the 82 kVp used in the example, the output kerma is calculated as illustrated in equation 1 (a):

Equation 1(a): (Bushberg *et al*. 2012:379)

$$K_{82mAs} = \frac{82}{100} K_{100mAs}$$

K_{100mAs} is determined from Table 5, where 80 kV is 6.7 mGy per 100 mAs, and therefore the kerma for this technique at 100 cm is 5.5 mGy. The inverse square law is required to calculate the entrance surface kerma (ESK) at 73 cm SSD, which is done as indicated in equation 1 (b):

Equation 1(b): (Bushberg *et al*. 2012:379)

$$ESK = \left[\frac{100\,cm}{73\,cm}\right]^2 K_{82\,mAs}$$

as calculated from equation 1 (a), K_{82mAs} at 100 mAs was 5.5 mGy. The inverse-square law calculation equates to a factor of 1.88, which results in an ESK of 10.3 mGy. Calculations 1 (a) and 1 (b) make use of the free-in-air measurements of kerma and, thus, backscatter in tissue does not influence the outcome, because the free-in-air

measurements are known as measurements without backscatter (Bushberg *et al*. 2012:379). Kerma and dose are equivalent terms; therefore ESK is equivalent to ESD.

Equation 2: (Ofori, Gordon, Akrobortu, Ampene and Darko 2014:460)

$$ESD = O \times \left(\frac{V}{80}\right)^2 \times \left(\frac{100}{d}\right)^2 CTf$$

Equation 2 is utilised to calculate the entrance surface dose (ESD), and the symbols are described as follows: O is the tube output; V is the tube voltage that is measured in kilo voltage (kV); D is the focus to skin distance measured in centimetre (cm); C is the current measured in milliampere (mA); T is the exposure time in seconds; and Ƒ is the backscatter factor (Ofori *et a*l. 2014:460).

Equation 3: (Marsden, Hardwick, Mencik, McLaren, Young and Mashford 2008:454)

$$D_{surface} = D_{air} \frac{(\mu_{en}/\rho)_{muscle}}{(\mu_{en}/\rho)_{air}} \left(\frac{L}{FSD}\right)^2 BSF$$

The symbols in Equation 3 are used to calculate as follows: L is the output measurement distance measured in cm; FSD is the focus to skin distance measured in cm; BSF is the backscatter factor; and $\mu_{en/p}$ is the mass energy absorption coefficient for the given medium (Marsden *et al*. 2008:454).

Equation 4: (Nyathi *et al*. 2009:10)

$$K_i = Y(d) * P_{It}\left(\frac{d}{d_{FTD} - t_p}\right)^2$$

Equation 4 is utilised to calculate the incident air Kerma (K_i), and the symbols are described as follows: Y(d) is the output of the x-ray tube (mAs) at a particular exposure setting; D is the focus to chamber distance measured in cm; P_{it} is the tube loading during exposure of the patient; d_{FTD} is the focus to table distance measured in cm; and t_P is the patient width at the irradiation site (Nyathi *et al*. 2009:10).

The best way to calculate precise ESD is to utilise radiographic exposure factors coupled with measurements of x-ray tube output (mGy/100mAs). The tube output, however, is not determined at the exact kVp during routine and quarterly Quality Control (QC) testing, thus the researcher will make use of a generic look-up table (Table 5) that is used to only give an estimate value of the tube output (mGy). The entrance surface dose (ESD)/entrance air kerma (ESK) was calculated utilising equation 1. Equation 1 calculated the ESD, which excludes the backscatter factor, therefore making the calculation efficient and easy to accomplish. Backscatter is scattered radiation that is projected backward from the primary beam when penetrating the patient, and this backscatter would measure 15% to 30% higher than in free air kerma (Bushberg *et al*. 2012:380). For equation 1, Table 5 is utilised to determine the output levels at certain kVp selections.

Table 5: Half-value layer and output levels as a function of kilovoltage (Kv) for a typical general diagnostic x-ray system measured at 100 cm.

HALF-VALUE LAYER AND OUTPUT LEVELS AS A FUNCTION OF kV FOR A TYPICAL GENERAL DIAGNOSTIC X-RAY SYSTEM		
kV	**HVL (mm Al)**	**OUTPUT (mGy per 100 mAs)**
40	1.15	1.1
45	1.36	1.7
50	1.57	2.3
55	1.79	2.9
60	2.00	3.5
65	2.22	4.3
70	2.43	5.0
75	2.65	5.8
80	2.86	6.7
85	3.08	7.5
90	3.29	8.5
95	3.50	9.5
100	3.71	10.5
105	3.92	11.6
110	4.12	12.7
115	4.32	13.9
120	4.51	15.1
125	4.71	16.4
130	4.89	17.8
135	5.08	19.2
140	5.25	20.6

(Bushberg, Seibert, Leidholdt and Boone 2012:378).

Most radiography projections are performed at 100 cm, which is the source to image distance (SID), while chest radiography is performed at 180 cm. The source to skin distance (SSD) can be estimated by knowing the width of the patient. For example, a patient with a width of 25 cm, with a 2 cm air gap between patient and IR, the SSD = 100 [25 + 2] = 73 cm (Bushberg *et al*. 2012:378).

Every patient that visits an x-ray department has a certain body type that is referred to as body habitus, as seen in Figure 7. Body habitus is defined by Shiel (2018:Online) as the human physique and physical characteristics of a body. Body habitus requires special consideration in chest radiography, when selecting kVp and mAs prior to exposure (Bontrager and Lampignano 2010:78). As seen in Figure 6, a PA chest is measured from posterior to anterior at the bust on the level of the centring point namely T7 to determine the thickness. The lateral chest is measured at the bust from one lateral side of the chest to the other (Bontrager and Lampignano 2010:82).

Figure 6: Measurement of posterior anterior and lateral chest projections (Photo by researcher Leandré Toüa, 2019).

There are four categories to describe the specific body habitus types, namely hypersthenic (5 % of population), sthenic (50 %), hyposthenic (35 %) and asthenic (10 %) as seen in Figure 7 (Bontrager and Lampignano 2010:78). This implies that the width/measurement and body habitus of each patient should be taken into consideration, as it differs and there is no specific assumed measurement one can

work with during the calculation of the ESD; thus each patient should be measured prior to the examination. These chest measurements, as well as selected kVp and mAs, is a technique chosen by the radiographer to calculate the ESD by utilising equation 1. See section 3.3.6.3, page 82, where it is described how equation 1 was utilised and values inserted in Microsoft Word Excel to calculate the ESD.

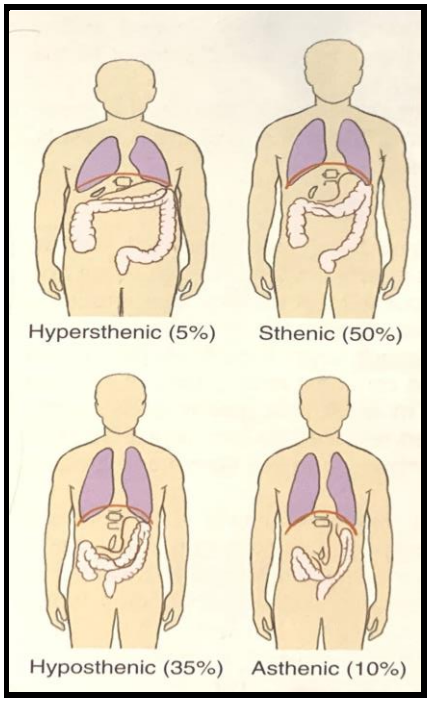


Figure 7: Body habitus of a human body

(Image courtesy: Bontrager and Lampignano 2010:78)

2.9.2.1 ESD calculation for the study

Taking all of the above into consideration, the researcher aimed to achieve the set objectives. The researcher worked with retrospective data to establish the annual number of x-ray images a period worker receives, but patient approval was needed before the radiographer could record his/her technical parameters. The researcher

provided each x-ray department with a document requesting these technical data or parameters, as well as a patient consent form, which had to be recorded by the radiographer for 100 patients at each clinic. The document included the patient thickness to be measured by the radiographer with a calliper. Every x-ray room should be equipped with a measuring calliper, if not; the researcher provided one but for this study three rulers were used to mimic a calliper as a calliper was not available. The measurement was done as seen in figure 6. The next parameter recorded was the kVp and mAs the radiographer selected for each patient (see Appendix A1-A4: sheet 1), as well as the Focus Film Distance (FFD) or Source Image Distance (SID), which is the distance from the x-ray source to the image receptor (IR) which should be recorded once the chest image is displayed (see Appendix A1-A4: sheet 1). The EI was not used for study purposes, but it is a requirement from certain mines to record it. Utilising all these parameters, the researcher was able to calculate an ESD for PA chest x-ray for each clinic by making use of equation 1 (a) and 1 (b) (see page 47 and 48).

Skrk, Zdesar and Zontar (2006:191) state that the backscatter factor ranges from 1.2 to 1.4 for the x-ray spectra and beam sizes used in diagnostic radiology. The researcher made use of the first equation to calculate the ESD at each clinic, as it was advised by the medical physicist for the reason that all the parameters are available to do the calculation without a TLD. DRLs are not dose values for an individual, but are values for a representative sample size, and to compare radiation dose distribution of a radiograph examination for a specific radiographic practice in a typical x-ray room; thus the establishment of baseline ESD calculations in a practical and easy way is of great significance to optimise dose, as it acts as a guideline for radiographers and all

health professionals to practice RPOP at all times (IAEA 2013:Online), as the four clinics can compare with each other.

2.9.3 Dose Reference Levels (DRL)

See **section 1.4.2, Objective 1.** The main objective of good practice in diagnostic radiology is to produce the best possible quality image that contains all the necessary diagnostic information needed to make an accurate diagnosis, while still resulting in the lowest radiation dose being administered to the patient (Skrk, Zdesar and Zontar 2006:189). Thus, diagnostic radiology is driven by principles of justification, limitation and dose optimisation, the latter by taking DRLs in consideration. From this statement, one can argue that the examination benefits the patient if it balances or outweighs the risk of exposure to the patient (IAEA 2018:Online). Once the examination is justified, it must be carried out with equipment and radiographers who practice and implement the ALARA principle.

Diagnostic Reference Levels are known as dose levels in medical radio-diagnostic practice, and were introduced by the International Commission of Radiological Protection (ICRP) in 1990 (Valentine 2007:3). Subsequently, these levels were recommended in greater detail from 1996 (McCollough 2010:1). DRLs are only applicable to medical radiation exposure, not to public and occupational exposure. DRLs are a selected level of a radiation dose quantity for broadly defined types of equipment for typical examination groups of standardised patient sizes, or in specific circumstances a phantom (Balonov and Shrimpton 2012:2). Thus, it should be the result of generic optimisation of the protection of the patient (McCollough 2010:1).

In diagnostic radiology, the existence of a radiation dose varies significantly. This led the Royal College of Radiologists (RCR) and the National Radiological Protection Board (NRPB) to recommend that regular patient-dose monitoring should become a component that forms part of the Quality Assurance (QA) programme (Nyathi, Nethwadzi, Mabhengu, Pule and Van Der Merwe 2009:9). DRLs are defined by Gray, Archer, Butler, Hobbs, Mettler, Pizzutiello, Scheuler, Strauss, Suleiman and Yaffe (2008:354) as an investigation level to be applied in an easily measured quantity, i.e. the absorbed dose in air or in tissue equivalent to surface of a patient. DRLs are set according to national standards (NDRL). NDRLs are set on wide-scale surveys of a median dose that represents a specific patient group to ultimately ensure radiation protection of patients (RPOP) (IAEA 2013:Online). RPOP refers to the radiation protection of patients. It is the most important foundation for health professionals to use medical radiation effectively and to protect patients and the public (IAEA 2013:Online). In relation to RPOP, DRLs are used in medical imaging to promote dose optimisation, even though DRLs do not refer directly to an individual, but only act as a guideline for radiographers and all health professionals to practice RPOP at all times (IAEA 2013:Online).

To establish DRLs in diagnostic imaging, it is expressed as dose quantities that are well defined and that can be easily measured with precision and accuracy (Skrk, Zdesar and Zontar 2006:190). Therefore, DRLs are used, primarily, as a dose optimisation tool for diagnostic imaging (McCollough 2010:2). Dose Reference Levels are defined as the optimisation dose level the patient receives during a radiographic examination, which is at entrance to skin exposure in air, without backscatter (Gray *et al*. 2008:355).

The reason for compiling DRLs is to observe and emphasise the variations on the different doses administered to patients in different health care facilities, but in similar patient groups. These set levels are expected not to be exceeded for standard procedures, when normal practice regarding diagnostic and technical performance is applied (European Diagnostic Reference Levels 2013:3). DRLs are set to monitor patient dosage and to achieve the lowest possible dose, but in the same effort to produce an optimal diagnostic quality image (IAEA 2013:Online). DRL values differ from each country, as imaging equipment differs globally, thus DRL values are calculated accordingly (McCollough 2010:2). See page 121 for this study's DRL values.

Table 6: Potential diagnostic reference levels (DRLs) established through research studies for an adult chest examination in four countries

Country	DRL PA chest (mGy)	DRL lateral chest (mGy)
South Africa (Nyathi *et al*. 2009:71)	0.10	0.22
Ireland (European Diagnostic Reference Levels 2013:4)	0.16	0.40
Iran (Shandiz, Toossi, Farsi and Yaghobi 2014:305)	0.26	0.96
Slovenia (Skrk, Zdesar and Zontar 2006:192)	0.16	0.40

Diagnostic radiology examinations are not the only tool that poses a risk to people's well-being due to exposure to ionizing radiation, but everyday life chores also result in a dose administered to humans. Referring to Table 7, the overall lifetime risk of developing an invasive cancer is 37.5% for women and 44.9% for men, regardless of previous exposure to a diagnostic radiology examination (X-Ray Risk 2018:Online). Individual risk factors (smoking, exercise and diet) also play a role in developing cancer, which excludes the exposure to ionizing radiation.

Table 7: Comparison doses: doses of everyday life compared to certain radiological examinations.

COMPARISON DOSES			
Natural background	3.1 mSv/year[10]	Domestic pilots	2.2 mSv/year[11]
Average overall environmental exposure	6.2 mSv/year[10]	7-hour airline flight	0.02 mSv/year[12]
Chest x-ray (2 views)	0.10 mSv/year[10]	Chest CT	7.0 mSv

(X-Ray Risk 2018:Online)

2.9.3.1 Absence of DRL values for the Northern-Cape mines

Literature showed that very little research has been done on this topic in the mining industry of the Northern Cape Province. One study was done by a researcher in 2018 that included only 3 of the 15 occupational mining clinics in the Northern Cape. The title of the study was "Establishing diagnostic reference levels for the Posterior-

Anterior chest image in Northern Cape radiology departments". The study's sample size for department 1 was 37, department 2 was 38 and department 3 was 34. The study was similar to this study, and encouraged the researcher to use this method (equation 1) and assistance of a medical physicist, and it proved to be reliable and provided valid results. The diagnostic reference levels were calculated for department 1 as 0.137 mGy, department 2 as 0.532 mGy and department 3 as 0.972 mGy (Lackay 2018:2).

2.9.3.2 Considerations for DRL calculations

When DRLs are utilised in a certain region, it is referred to as national DRLs (NDRLs). NDRLs are applied to wide scale surveys which represent certain groups, for example adults or children of different ages. NDRLs are not considered as optimum doses, but can be of assistance to prevent unnecessary dose to patients (IAEA 2018:Online). Nevertheless, DRLs can be established for a certain region or country as well. If there are no national or regional DRLs, it can be established in a local area or certain practice. DRLs can be updated as new technologies are introduced (IAEA 2018:Online). According to ICRP (2016:45) there are several factors to consider prior to calculating DRLs. To simplify these factors, Figure 8 from ICRP below is utilised.

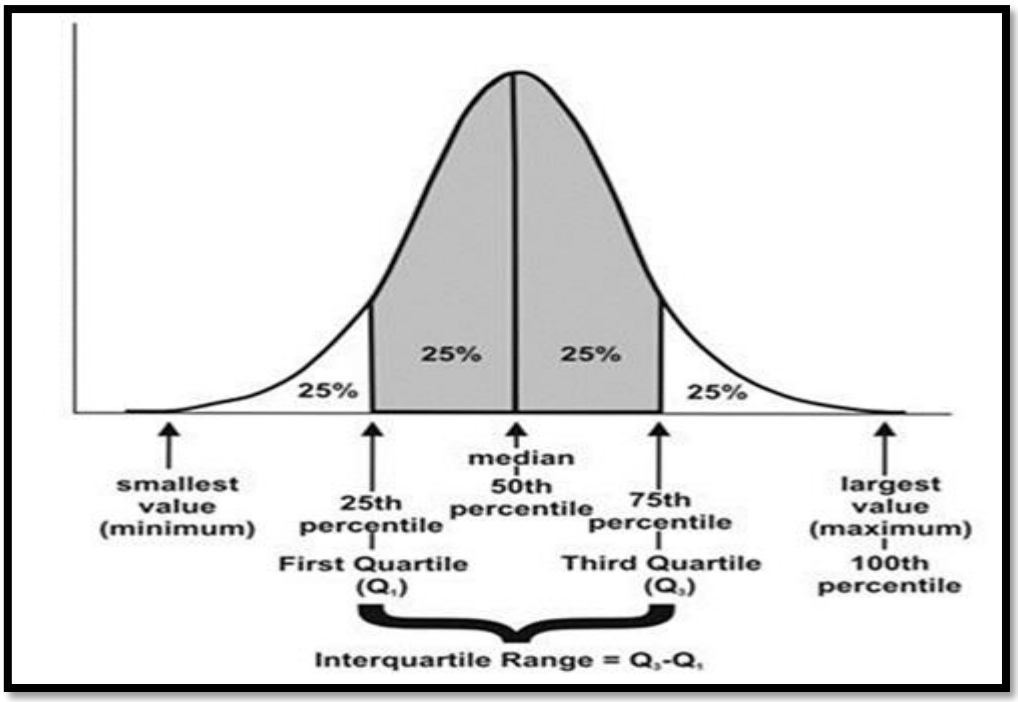


Figure 8: A graph representing the percentile distribution

(Image courtesy: Centers for Disease Control and Prevention 2019:Online)

At x-axis of the graph, the percentiles are found namely the 25th (Q_1), 50th (median) and 75th (Q_3) percentile. The y-axis represents the dose. In diagnostic radiography the curve of the graph is stipulated with a long tail. The 75th percentile is preferably used with the calculation of DRLs. The 75th percentile is the value found above the median (Q_3) (Vano *et al*. 2017:42) and was also used for this study (see page 89).

NDRLs are usually set at the third quartile value, thus meaning the 75th percentile is chosen, as it lies below the high dose tail allocation on the graph, but also serves as an identification of image quality when considering the 95th percentile value. The more practice dose distributions that would fall within the DRL with the 95th percentile means that there would be no need to investigate dose optimisation by reducing the radiation dose (Vano *et al*. 2017:42). Literature suggests that a qualified physicist should

perform the DRL calculation (NRPB 1992:13). The researcher did calculate the DRL with confirmation of a medical physicist.

The National Radiological Protection Board (NRPB 1992:18) states that, to ensure that the image quality is of acceptable value, the mean weight of the patient selected should fall within ±5 kg of 70 kg. Furthermore, NRPB states that the weight of the patient should be adequate for the average value of the dose to be a good indication of a typical dose to an average patient. The mean weight of the patient should thus be between 65-75 kg. The mean weight for this study was 84.09 kg (see section 4.5, page 117). The weight of each patient is found in the file where an occupational employee recorded the physical measurements (weight and height) of the patient prior to the medical tests.

As mentioned above, DRLs are not dose values for an individual, but only serve as values for a representative of a sample size. This is to compare radiation dose distribution of a radiographic examination for a specific diagnostic x-ray room found in a Radiology practice (European Commission Radiation Protection 102:79). The sample size selected should be sized to ensure that the mean values represent the x-ray room in Radiologic facility (Vassileva and Rehani 2014:2). Therefore, a sample size of 100 chest examinations was utilised for each radiology department in this study.

2.10 RELATED STUDIES

Research on related studies form an important part of the research, as the researcher gains insight into what is already being done on the topic, or identifies a research gap. There are several studies done by researchers on the proposed topic.

2.10.1 Chest imaging studies in occupational health

A study done by the Medical Council of Great Britain in South Wales investigated mine workers that were employed in 1945, who were exposed to coal and developed pneumoconiosis at a later age. It was found that the workers did not have medical testing done during their occupation. The British research team proposed that mine workers should undergo periodical medical testing, including a chest image, to monitor any changes and be removed from a dangerous environment with dust exposure, so that they do not develop progressive massive fibrosis, which can cause disability at a later stage (Martin 1953:590).

Another study was conducted of medical examinations of surface coal mine workers in Pennsylvania in 1984 and 1985. The study revealed that radiographic evidence of pneumoconiosis was present in 4.5% of men with no history of dust work other than surface coal mining (Laney and Weissman 2014:7). More contemporary national surveillance of surface coal miners conducted a study across the United States in 2010 and 2011. The study documented 2% radiographic appearance of pneumoconiosis. The decrease in percentage was due to the National Institute for Occupational Safety and Health (NIOSH)'s recommendation that a medical surveillance programme be

introduced for coal mine workers (Laney and Weissman 2014:7). The programme was to:

- Perform a spirometry examination and chest image as soon as possible after employment (pre-placement within three months for a spirometry examination, and within three to six months for a chest image).
- Perform a spirometry examination each year for the first three years of coal mining, and every two to three years afterwards, if the individual is still engaged in coal mining.
- A chest image and spirometry at the end of employment, if more than six months have passed since the last examination.
- Before each examination, a person should be asked about tobacco use; whether current or in the past.
- Chest images should be classified according to the ILO classification, and a small opacity profusion of 1/0 ≥ or presence of large opacities should be classified as suggestive of pneumoconiosis (Laney and Weissman 2014:7).

2.10.2 DRL studies

DRL studies have proven to be of assistance when it comes to radiation protection. It has proven to be a useful implementation as support to dose audit and practice review for promoting improvements in patient protection (IAEA 2018:Online).

A study was done by Nyathi, T., Nethwadzi, L. C., Mabhengu, T., Pule, M. L. and Van der Merwe, D. G. in 2009 titled: Potential dose reference levels. to determine the radiation doses of patients undergoing six general radiographic examinations in the main x-ray department of the Charlotte Maxeke Johannesburg Academic Hospital

(CMJAH) in the Gauteng Province, South Africa. The study involved examinations, namely PA and lateral chest images, AP pelvis, AP abdomen, AP lumbar and AP thoracic spine. Patient data and technical parameters were collected. The entrance surface of the air kerma was calculated based on the x-ray tube output of the specific unit installed in each room and the exposure parameters (kVp and mAs) used for the actual examination (Nyathi *et a*l. 2009:74).

Based on the Entrance Surface Air Kerma (ESAK) values that were calculated, the DRLs were established as follows: 0.1 mGy for chest PA, 0.22 mGy for chest LAT; 2.98 mGy for pelvis AP; 4.19 mGy for abdomen AP; 5.30 mGy for lumbar spine AP; and 3.28 mGy for thoracic spine AP. The values were compared to previously published DRLs from other countries. These values were an initial attempt locally, thus, they provided a benchmark for the statutory authorities to determine DRL values for diagnostic radiology in South Africa (Nyathi *et a*l. 2009:9). The authors suggest that lower reference levels may be due to the small scale of their research compared to the international multicenter surveys, as their research consisted of two x-ray rooms, 117 patients and a total of 166 DRL calculations. Multicenter surveys will have more variables on the equipment type, operator and radiographic techniques used (Nyathi *et a*l. 2009:74).

Another study was conducted by Abdelhalim (2010:115) in Saudi Arabia to establish a national diagnostic reference level (NDRL). The study consisted of 200 patients who were referred for x-ray examinations (skull, ankle, foot, hand and hip) at the King Khalid University Hospital. The selected examinations were performed by utilising

Harshaw Thermoluminescent dosimeters (TLD). The TLDs were assigned and attached to each patient selected to participate in the study.

2.11 CONCLUSION

Chapter 2 provided an insight to all the factors contributing to a chest x-ray image; the policies and legislation of chest x-ray images in occupational health; and the relevance, practical standards and significance thereof in medical testing. The chapter provided a review to all the factors contributing to the acquisition of a chest x-ray image and dose implications of radiation. This provides insight to the first part of objective one, which was to establish through a literature study how to calculate the diagnostic reference level (DRL) and entrance surface dose (ESD) that an adult acquires for a chest x-ray, which was an essential part of the study.

Clinics checklists, technical parameters and formulae and calculations will provide an insight on the research instruments developed and used. The technical parameters checklist and formulae sheet were compiled utilising the literature in Chapter 2, and in turn provide the possibility to see if employees had x-rays at other clinics utilising the clinic checklist.

CHAPTER 3

TECHNICAL PARAMETERS, CHECKLIST, FORMULAE AND CALCULATIONS FOR DETERMINATION OF DRL FOR CHEST RADIOGRAPHTY

3.1 INTRODUCTION

Chapter 2 outlined occupational medical surveillance, the time intervals and the standards to which these tests are to be performed according to the Mine Health and Safety Act (MHS Act 2011). The chapter focused mainly on the routine chest x-ray image.

Chapter 3 will describe the research instruments that were used to address the following objectives of the study:

1. Establish through a literature study how to calculate the entrance surface dose (ESD) (see **section 2.9.2** and **Appendix A1-A4: sheet 3**) and diagnostic reference level (DRL) that an adult acquires for a chest x-ray (see **section 2.9.3** and **Appendix A1-A4: sheet 3**).
2. Calculate the ESD for each employee with the technique parameter information recorded by the radiographer on duty (see section **2.9.2.1** and **Appendix A1-A4: sheet 1 and 3**).
3. Determine an estimated baseline DRL for the selected population group at four radiology practices (**Appendix A1-A4: sheet 3**).

4. Establish the number of chest images received per annum for individuals who are employed by four contracting and private companies (see **Table 14**: page 100).

3.2 METHODOLOGY

Methodology is an important aspect in research (Kallet 2015:Online). It includes the methods a researcher will follow in order to plan and perform a research study (Lumen 2020:Online). The Industrial Research Institute (2010: Online) defines research methodology as a method to observe something, by investigating certain criteria on a matter called the research problem. The following sections will define the research plan that was followed in this study.

3.2.1 Research design

The research design used for this study was a quantitative descriptive study. A literature study was done on the mining industry's policy and legislation regarding chest examinations. A population of 400 participants was selected to participate in order to calculate an ESD, a DRL and the number of previous x-ray examinations each employee had. A descriptive study is defined as the accurate and systematic description of a population, situation or phenomenon. It answers what, where and when questions (McCombes 2019:Online). Strasser *et al*. (2004:481) defined a descriptive study as an observational study where the researcher conducts the study at a specific time without making changes to the environment.

The study consisted of prospective as well as retrospective data collection. The prospective data collection entailed the recording of ID numbers and technical parameters information by each clinic's radiographer prior to the chest examination, which was the measurement or patient thickness. The other parameters formed part of the retrospective data collection that are recorded generally as part of each clinic's protocol. These included the employee ID number, height (cm), weight (kg), kVp and mAs. In this study there was no Body Mass Index (BMI) linked to the DRL.

The prospective data collection could not be done by the researcher, as the radiographer of each clinic interacts with the employees during the chest examination, and it was requested by the mines that the researcher should not interact with the employees. The retrospective data collection entailed the search done by the researcher for the number of previous images archived of each employee after the radiographer of each clinic recorded 100 technical parameters/participants. The employees were informed about the study and that they can refuse to participate as the researcher will use their ID number to perform a search. This corroborates with a descriptive study, as the researcher went to the clinics after hours to complete the retrospective data collection and did not interfere with the operating hours of the clinic.

The study method used was quantitative because the research instrument ensured collection of quantitative data. Quantitative data were obtained from the different selections founded on the technical parameters sheet and the checklist. The 100 participant's' technical parameters and previous x-ray examinations of selected participants per clinic were used to calculate an individual ESD and determine a DRL (numerical data), and were repeated for the four clinics selected to participate in the

study. Wyse (2011:Online) defines a quantitative research method as the method used to quantify a problem by generating numerical data that can be used and transformed into usable statistics. Creswell (2013:Online) further elaborates that it is used to measure attitudes, opinions, behaviours and other defined variables, thus, generalising results from a larger sample population.

3.3 RESEARCH INSTRUMENTS

The research methods used by the researcher ensured adequate data collection to meet the outcomes of the study. Sutton and Austin (2015:226) states that a researcher should become familiar with research methods and its uses. Research instruments are a critical part on the pathway of a research study, as they are used to perform data collection (Poelert, 2019:Online). Data collection is defined as the process of gathering and measuring information according to chosen variables, and in a systematic order, which allows one to answer the research question(s) and evaluate the outcomes (Wilcox, Gallagher, Boden-Albala, Bakken, 2012:68).

3.3.1 Materials and methods

In this research, three research instruments were used to collect data and the analysis was done with support of the statistician. In the following section, all materials and methods, the individuals who participated in the data collection process, and the three instruments will be discussed separately, and a visual presentation of each instrument of the data collection process that the instruments made possible to achieve, will be provided.

Figure 9 is a summary of the materials and methods used by the researcher to ensure accurate and systematic data collection.

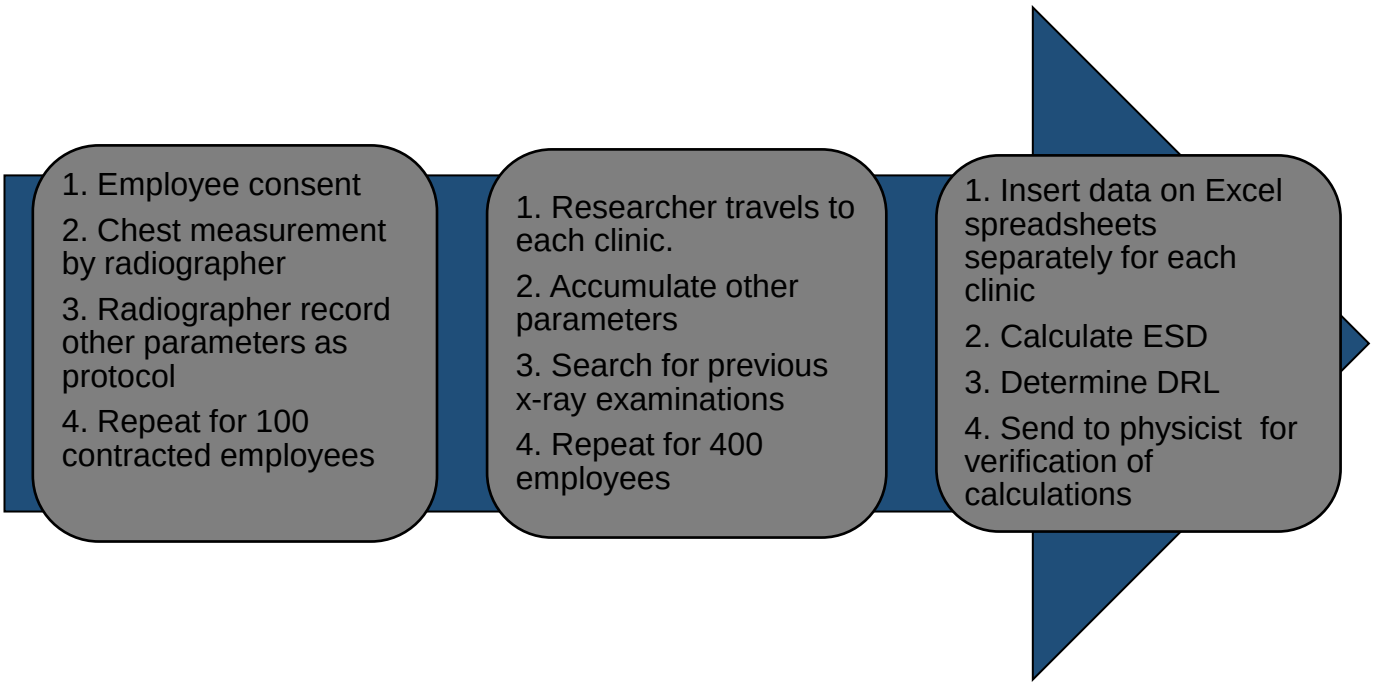


Figure 9: Materials and methods used during data collection

(Compiled by researcher, Leandré Toüa, 2020)

3.3.2 The field workers

The field workers included the researcher and four radiographers who are employed at each clinic. These four individuals assisted the researcher by explaining to the contracted employees the procedure to follow, and if the employee agreed to participate, the radiographer provided the consent form to sign. The radiographer then measured the employee's chest thickness and recorded the measurement.

3.3.3 Participant selection (sampling)

The sampling technique utilised in this research was stratified random sampling. Stratified random sampling is defined as a method where a large population group is divided into smaller subgroups known as strata. The strata are based on the population group's shared characteristics or similarities (Hayes 2020:Online). Individuals who are employed by a private company or contractor will for this study be referred to as contracted employees which is indicated on their hardcopy file at the clinic. All employees who visited participating mines were divided into permanent employees and contracted employees. The 400 participants that participated in the study were selected through stratified random sampling, and divided into four groups of 100 employees. These four groups can be classified as strata and shared the characteristic of being a contracting employee. Table 8 provides a visual presentation of the participant selection groups.

Table 8: Participation of selection groups

Clinic 1	Clinic 2	Clinic 3	Clinic 4
100 contracted employees	100 contracted employees	100 contracted employees	100 contracted employees
Total population group = 400 contracted employees			

The participants in this study were contract miners employed at any one of the participating mines. All individuals selected to participate in the study were selected randomly, as long as they were employees who are employed with private contractors and private companies that work on various industrial sites. The study was delayed

due to the pandemic so participant selection was done for the first 100 employees that were booked for medical tests regardless of their occupation.

The ID numbers of the participants were acquired from the x-ray departments, as it is protocol that all patient information must be recorded prior to the chest x-ray examination. (Hayes 2020:Online) define simple random sampling as utilising the members of the population that are numbered consecutively, so that each member is given a unique number. As seen in Appendix A1-A4: sheet 1, the radiographer recorded 100 employees' ID numbers and technical parameters prior to the chest images of only contract mine employees specific to that clinic. These ID numbers were utilised to perform the annual search, after it was established that it fits the inclusion and exclusion criteria of this study. This continued up until 400 participants' information were gathered to be used at all four clinics to perform the annual number search by the researcher. The ID numbers were then replaced by a numerical to protect the identity of the participants.

3.3.4 Technical parameters

After a literature review and guidance from a medical physicist, the researcher found that it is possible to calculate the ESD without the use of TLDs. Literature stated that if there are technical parameters that one makes use of when calculating ESD, it should include parameters which were to be found if the radiographer recorded it prospectively (Nyathi *et al*. 2009:10). The DRL calculations could not be done without the height, weight, kVp, mAs, SID and patient thickness values. Only after the parameters were collected, the dose reference level for that clinic's x-ray department

could be determined. The chest measurement was done by the radiographer, and the other parameters were also recorded by the radiographer, which is part of each clinics protocol. The researcher travelled to each clinic individually to collect and organise the data. The data were inserted in Excel (see Appendix A1-A4: sheet 3) in order to calculate the ESD and then determine the DRL for that clinic.

The technical parameters sheet for chest images was provided to each radiographer as a separate sheet to record information for each chest x-ray. Vertically labelled was the patient number from 1-100 for that specific clinic. Horizontally, space was provided to record the patient height (cm) and weight (kg), kVp, mAs, SID and chest measurement or patient thickness (cm) (see Figure 10). The ESD equation was used to calculate the entrance surface dose of 100 patients' chest images at the specific clinic. The calculations were done on a separate page/sheet for each clinic.

	A	B	C	D	E	F	G	H
1	TECHNICAL PARAMETERS FOR CHEST X-RAYS							
2	PATIENT NO	ID NUMBER	PT HEIGHT (cm)	PT WEIGHT (kg)	kVp	mAs	SID (cm)	PT THICKNESS (cm)
3	1	851201***	176	82.6	125	1.83	180	22.5
4	2	771028***	175	59.5	125	1.17	180	18
5	3	770112***	167	55.6	125	2.89	180	25
6	4	750817***	168	104.6	125	4.73	180	28
7	5	940819***	156	55.7	125	1.56	180	20.5
8	6	720828***	175	65.5	125	1.88	180	22

Figure 10: Visual presentation of the technical parameters sheet

(Compiled by researcher Leandré Toüa, 2019)

3.3.4.1 Inclusion and exclusion criteria

Only individuals who are employed at the sites and by private contractors at the four clinics were included in the study, as these individuals work on various mines and

industrial sites. Employees who are permanently employed on a mine were excluded from the study, since these individuals work on one industrial site only, thus, they are referred for one medical examination annually. The inclusion criteria for the technical parameters recorded by the radiographer and the researcher were patient height (cm), weight (kg), kVp, mAs, source image distance (SID) and patient thickness. Only the parameters stated on the Technical Parameters sheet provided to the radiographer were recorded. All the other parameters that may be used by the radiographer to produce a chest image were excluded, for example the gender, age, ethnic group and religion/culture.

3.3.4.2 Pilot study

As stated by Polit, Beck and Hungler (2001:467), the purpose of conducting a pilot study is to examine the probability of the research study on a smaller scale, and to prepare for the actual large-scale study.

All three research instruments were tested by means of a pilot study, which included five identification numbers. These selected participants for the pilot study adhered to the inclusion and exclusion criteria mentioned in section 3.3.4.1. The pilot study was performed by a radiographer field worker for the study in August 2019. The pilot study included 6 employees' technical parameters and proved that this specific research instrument was efficient to collect all technical parameters that were needed for the calculation part. The radiographer explained the process to each patient, and once they approved, they signed the consent form, and the parameters were collected (see Figure 10). The pilot study did not influence the research instruments, but proved that

it will be effective for the large-scale study. The pilot study data were not included in the main study data because the flow rate of mining employees who visit that specific clinic was high enough to collect new data for the large scale study.

3.3.4.3 Data collection and analysis

It is protocol at all clinics to routinely record the patient's weight, height (during observations), kVp and mAs (during image acquisition). Each x-ray department is equipped with an exposure chart. If a radiographer does not select exposure parameters (kVp and mAs) from the chart by considering the patient width, automatic exposure was used and recorded. The radiographers were all using manual exposure throughout as the chest measurement gave an indication on the exposure chart which exposure factors to select. With approval from the clinic's unit manager, the researcher only requested two additional records form the radiographers to prevent a decrease in workflow, namely to let the patient sign the consent form (including their ID number) and measure the patient's thickness.

The researcher went to the clinic after completion of the 100 patients' details to manually complete the technical parameters form by inserting the height (cm), weight (kg), kVp and mAs from each clinic's patient logbook by using each employee's ID number. The researcher drove to one clinic at a time, over the course of 11 months (November 2019 – October 2020) to collect and analyse the data, after the pilot study in August 2019. The researcher then transferred the technical parameters to Excel.

3.3.5 Clinic checklist

A checklist (Appendix A1-A4: sheet 2) was chosen as one of the research instruments. Wilcox and Gallagher (2012:Online) advises that a checklist is logical, collects large amounts of data consistently, accurately and safely, thus, making data collection less time consuming. The researcher consulted various resources to review the mining industry's policy and legislation regarding medical testing. It was clear that the mines strictly adhere to the MHS Act and the PoPIA. The researcher wanted to investigate the application of the ALARA principle by inspecting whether contracted employees received multiple x-rays in one year at the different clinics. Because of the PoPIA, which prevents clinics to share patient information, the researcher compiled the clinic checklist.

The checklist, patient information and consent form were designed by the researcher to capture data effectively and efficiently for each clinic. The checklist was compiled in English, as it is the language of instruction at the Central University of Technology, Free State, where the researcher is a student; it is a language used at the mines; and it is the language that the researcher is comfortable with. If an employee was uncertain or could not understand the information, the radiographer was equipped to explain the process or ask someone in the clinic to assist with the language of choice. The investigation regarding the number of x-rays had no significance without attaching a numerical dose value to each chest x-ray. The checklist ensured that data can be submitted to the statistician for further analysis and to construct a graphical descriptive representation.

The information with dates of x-rays done for each clinic was recorded on a separate sheet (Figure 11). The categories of the checklist are labelled vertically in each row one of the 400 identification numbers of the contract miners selected to participate in the study. Labelled horizontally in each column are the date of the last chest x-ray, accompanied by the subheadings PA and lateral (Table 13, p. 118). The second heading is the number of repeated chest images, accompanied by subheadings PA and lateral (Table 14, p. 120). The third heading was the date(s) of other projections, accompanied by subheadings AP/PA, lateral and oblique(s) (Table 15, p. 121). The last column to be labelled horizontally was a heading called number of repeats for other projections, accompanied by subheadings AP/PA, lateral and oblique(s) (Table 16, p. 122). This sequence was repeated to represent all four clinics. The reason for including other projections was due to the possibility that an individual may have been referred to the x-ray department for other imaging, for example an injury on duty (IOD). This information was transferred from the document that the researcher used to the clinic's checklist dates on Excel, separately for each clinic (Appendix A1-A4: sheet 2).

1	CLINIC 1										
2	ID number	Date(s) of CXR		Number of CXR repeats		Date(s) of other projections			Number of repeats for other		
3		PA	Lateral	PA	Lateral	AP/PA	Lateral	Oblique	AP/PA	Lateral	Oblique
4	1	09.01.2020									
5	2	09.01.2020									
6	3	18.06.2019,09.01.2020, 30.01.2020									
7	4	17.07.2015, 04.08.2016, 06.07.2017, 05.04.2018, 09.01.2020, 09.01.2020									
8	5	09.02.2015, 11.06.2015, 21.07.2017, 10.01.2020				05.11.2014	5.112014				
9	6	28.08.2013, 09.102013, 06.06.2015, 02.08.2016, 06.07.2017, 16.06.2018, 28.05.2019, 09.01.2020									

Figure 11: Visual presentation of the clinic checklist

(Compiled by researcher Leandré Toüa, 2019)

3.3.5.1 Inclusion and exclusion criteria

If individuals had other x-rays done, the ESD calculation was excluded for other projections other than a chest x-ray. Lateral chest images and images produced for other diagnostic purposes were excluded. Only chest images done in the year in question were calculated. Previous chest images or repeated/rejected chest images were excluded in the ESD, and therefore in the DRL calculation part of the study. The gender of the patient, age, ethnic and culture were excluded in the study. Images that were done within one year were included, and images that were older than one year were excluded from the study, due to the motivation of the annual dose restrictions.

3.3.5.2 Pilot study

Anethesiol (2017:601) states that a pilot study is not a hypothesis testing study, but rather aims to test the credibility of the research tool, and it allows the researcher to adjust the research instrument, if required. The pilot study of the checklist was done together with the pilot study of the technical parameters throughout August 2019. The pilot study was done by one of the radiographers that recorded the dates found on the checklist in the data collection (Figure 11). The pilot study proved that the checklist was efficient and did not need any changes.

3.3.5.3 Data collection and analysis

The field worker radiographer provided the researcher with access to the data at each clinic. The archives in each of the four x-ray departments store all the patient information and previous images, which are kept in folders, starting with the latest date

that the images were acquired as well as the number of rejected images. These are all available in digital format on the x-ray department's operating computer, or on the OHMP's computer. Completion of the checklist was done at all the clinics after the technical parameters were recorded and processed, to establish timelines of the previous images of the selected participants. Figure 12 is an overview of all four clinics combined, and what is found when a search is done for previous x-ray examinations.

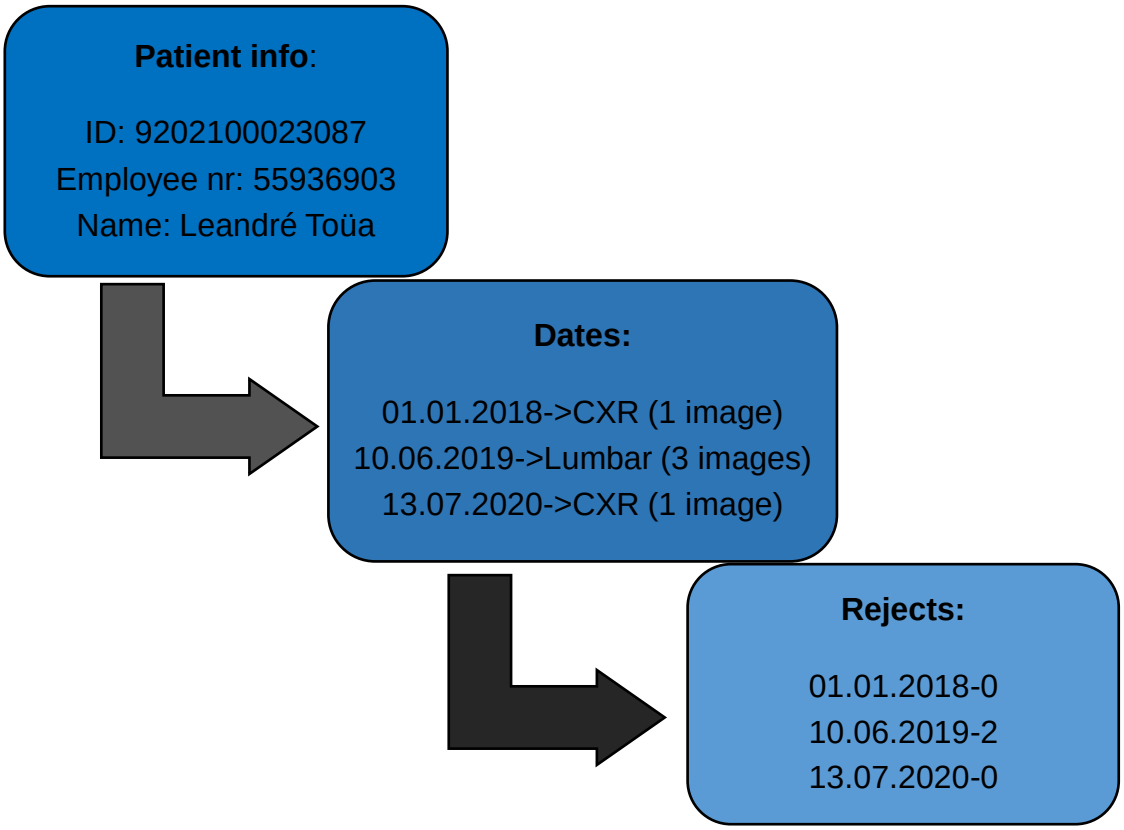


Figure 12: Visual example of search done for previous x-ray examinations

(Compiled by researcher Leandré Toüa, 2020)

Figure 12 is an example or overview of how the researcher completed the checklist. If the ID number or employee number is inserted and searched in the archive, the employee's information is retrieved. The patient information includes the name, surname and employee number. The next folder showed the dates of all the x-ray

examinations done since the employee first visited the department. The number of images available pertaining to each examination is also indicated. The last folder is the reject folder. It has the same examination dates as the previous folder and indicates the number of images that were rejected or repeated. The researcher collected all four clinic's data by utilising the patients' ID numbers and recording them on the printout made of the clinics' checklists (Appendix A1-A4: sheet 2). The researcher cross-referenced each ID number with the other clinics to establish if one employee had x-rays done at one of the other clinics.

3.3.6 Formulae and calculations

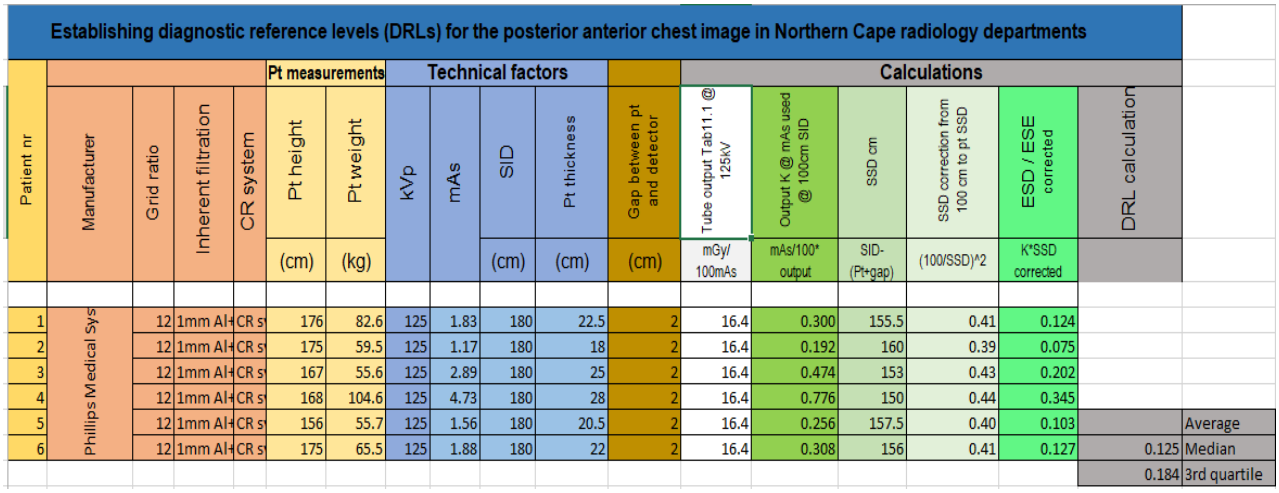
The formulae and calculations research tool contributed towards the results of the study. With the assistance of a medical physicist the researcher compiled the formulae and calculations instruments.

Each clinic was presented on a separate Excel sheet with its 100 employees, as well as on a sheet containing the technical parameters, and a third sheet with the formulae. The sheet of the formulae consisted of the title as the heading, and the columns were named as follows: patient number, ID number, manufacturer, grid ratio, inherent filtration, CR system. The patient measurements were: patient height (cm), patient weight (kg). The technical factors were: kVp, mAs, SID (cm), patient thickness (cm). This information was used to complete the columns from A-L for 100 employees. Table 9 illustrates the x-ray machine information of each clinic that the researcher had to complete before inserting the rest of the data.

Table 9: X-ray machine information of participating clinics

Item	Clinic 1	Clinic 2	Clinic 3	Clinic 4
Manufacturer	Phillips Medical Systems	DR-Gem	Toshiba	Lomaen
Grid ratio (erect Bucky)	12	10:1	10:1	10:1
Inherent filtration of x-ray tube	1 mm Al+0.1 mm CU	1.0 mm Al	0.9 mm Al	0.9 mm Al
CR/DR system	CR system	CR system	CR system	CR system

Table 9 was utilised to insert the information in Figure 13 under the labels named manufacturer (B 6-11), grid ratio (C 6-11) and inherent filtration (D 6-11), and whether it was a CR or DR system (E 6-11).



Establishing diagnostic reference levels (DRLs) for the posterior anterior chest image in Northern Cape radiology departments

					Pt measurements		Technical factors					Calculations					
Patient nr	Manufacturer	Grid ratio	Inherent filtration	CR system	Pt height	Pt weight	kVp	mAs	SID	Pt thickness	Gap between pt and detector	Tube output Tab11.1 @ 125kV	Output K @ mAs used @ 100cm SID	SSD cm	SSD correction from 100 cm to pt SSD	ESD / ESE corrected	DRL calculation	
					(cm)	(kg)			(cm)	(cm)	(cm)	mGy/ 100mAs	mAs/100* output	SID-(Pt+gap)	(100/SSD)^2	K*SSD corrected		
1	Phillips Medical Sys	12	1mm Al+	CR s	176	82.6	125	1.83	180	22.5	2	16.4	0.300	155.5	0.41	0.124		
2		12	1mm Al+	CR s	175	59.5	125	1.17	180	18	2	16.4	0.192	160	0.39	0.075		
3		12	1mm Al+	CR s	167	55.6	125	2.89	180	25	2	16.4	0.474	153	0.43	0.202		
4		12	1mm Al+	CR s	168	104.6	125	4.73	180	28	2	16.4	0.776	150	0.44	0.345		
5		12	1mm Al+	CR s	156	55.7	125	1.56	180	20.5	2	16.4	0.256	157.5	0.40	0.103		Average
6		12	1mm Al+	CR s	175	65.5	125	1.88	180	22	2	16.4	0.308	156	0.41	0.127	0.125	Median
																	0.184	3rd quartile

Figure 13: Visual presentation of formulae and calculations

(Compiled by researcher Leandré Toüa, 2019)

3.3.6.1 Inclusion and exclusion criteria

Only the ESD for chest images of selected participants was calculated, and only for 100 participants that were contracted employees. The only variables used for calculation purposes that were included are the patient number, grid ratio, inherent filtration, CR system, technical parameters and calculation variables seen in Figure 13. The DRL was determined for only that specific x-ray department. If there were other x-ray rooms/x-ray units the DRL calculation were excluded, but in this case each occupational clinic only consists of one x-ray room and machine. Only a DRL for chest x-rays will be determined, and all other body parts DRLs will be excluded. Only the four clinics that received study approval were included in the study for DRL determination. All other occupational health clinics in the province were excluded.

3.3.6.2 Pilot study

This pilot study (Figure 13) was important for the researcher to do independently and without the assistance of the medical physicist, and it proved to be a successful research tool to calculate ESD and DRL by utilising the six technical parameters' pilot study information. The results of the pilot study were sent to the medical physicist for verification.

3.3.6.3 Data collection and analysis

The researcher used the information gathered by each clinic's radiographer, i.e. the sheet with the technical parameters for chest images, to complete the calculations for

the 100 patients at each clinic, to insert each value of the calculation symbols to the equation on Microsoft Word Excel to obtain an ESD. The researcher entered all the data captured on the technical parameters sheet into the formulae sheet accordingly. The information with the equation was inserted and provided the researcher with values calculated by Excel. For example: The calculation part of the sheet included the following:

1. the gap between patient and detector (cm);
2. tube output @ 125kV (Table 5);
3. output K @ mAs used @ 100cm;
4. SID-SSD (cm), SSD correction from 100 cm to patient SSD;
5. ESD/ESE corrected; and
6. DRL calculation.

The following steps were followed in order to do the calculation part of the formulae and calculation sheet successfully.

- Column M was completed as the tube output of mGy/100 mAs, found in Table 5.
- Column N (output K @ mAs used @ 100cm) was completed by inserting +16/100*M6 in the formula bar. This provided the numerical data for the first output K and was repeated for each patient.
- Column O (SSD) (SID = Patient + gap) was completed by inserting +J6-(K6+2) in the formula bar. It provided the SSD for the first patient and was repeated for each patient.
- Column P (SSD correction from 100 cm to patient SSD) was completed by inserting =+(100/O6)*(100/O6) in the formula bar. It provided the first SSD correction and was repeated for each patient.

- Column Q (ESD/ESE corrected) was completed by inserting =+P6*N6 in the formula bar. It provided the first corrected ESD and was repeated for 100 times.
- Column R (DRL calculation) was completed by calculating the AVERAGE and typing in the formula bar = AVERAGE (Q6:Q11); followed by the MEDIAN in the formula bar = MEDIAN (Q6:Q11); and lastly the 3rd QUARTILE in the formula bar = QUARTILE (Q6:Q73,3) (see Figure 14 and Appendix A1-A4: sheet 3).

The calculated documents were sent to the medical physicist for verification.

3.4 VALIDITY, RELIABILITY AND TRUSTWORTHINESS OF THE RESEARCH INSTRUMENTS

Anney (2014:272) states that it is of great importance that researchers take into consideration the reliability, objectivity and validity of the study taking place, to ensure the trustworthiness of the research. The three research instruments ensured trustworthy data, as the researcher collected most of the data, which will in turn ensure accuracy. The researcher consulted a medical physicist with regard to the ESD calculation and the DRL estimation, in order to ensure credible and valid data output. The mining industry is of great economic importance in South Africa. This proves that the study is trustworthy, as comprehensive research can be done on the topic.

3.5 CONCLUSION

The research instruments utilised in this chapter provided valid data output. The technical parameters sheet included all the parameters that were needed for the ESD

and DRL calculations. The checklist was user friendly and exhibited which employees had multiple chest examinations in one year. The ESD and DRLs and their calculations were discussed as more factors contributing to dose implications and optimisation, and were the main goal for data collection

The output of the research instruments and the results of the analysed data will be discussed in this chapter. The chapter will provide a detailed discussion on the results of the data collection. Data were collected utilising the technical parameters sheet, the clinics checklists and the formula and calculations sheet.

CHAPTER 4

RESULTS AND DISCUSSIONS OF RESEARCH INSTRUMENTS

4.1 INTRODUCTION

This chapter will provide an overview of the results and a discussion on each research instrument, and how these were utilised to obtain the research results. A combined discussion of the research instruments is also included to demonstrate the contribution of each instrument to reach the objectives. The results of the clinic checklist assisted the researcher to confirm if contracted employees had more than one x-ray examination done in one year. The formulae and calculations assisted the researcher to calculate an individual ESD for 400 contracted employees and a PA chest DRL for each of the four clinics.

4.2 RESULTS OF THE TECHNICAL PARAMETERS SHEET

The technical parameters sheet was step one in the data collection process. This sheet was completed prior to the calculation of the ESD and DRL. The technical parameters and patient consent were the only part that was done by the radiographer on duty, as they interact with the patients. This technical parameter sheet was designed to collect the data that radiographers used to utilise a chest x-ray image and also data that the researcher needed to be able to insert on the formulae and calculations sheet in order to get an ESD and DRL value.

A quantitative technical parameters sheet was created in Microsoft Word (Excel) (see Appendix A1-A4: sheet 1) to collect technical parameters namely the ID number, patient height (cm), patient weight (kg), kVp, mAs, SID (cm) and patient thickness (cm) for 100 contracted employees. This was done for clinics one to four, which added up to a total of 400 contracting employees' technical parameters from the four separate sheets.

The ID numbers were inserted on all the technical parameters sheets (Appendix A1-A4: sheet 1) using changed numerical data to protect the identity of each participant. The ID numbers were kept on the document for the researcher to cross-reference them with the other three clinics for multiple x-rays, which in turn corroborated with objective four (see section 1.4.2, p. 6).

Each variable of the technical parameters sheet was analysed as a univariate procedure and reported as such. The Shapiro-Wilk test is defined as a test that is used to determine if a random sample comes from a normal distribution. It then calculates which percentage of the sample overlaps with a similarity percentage; thus calculating the probability of finding this observed (or smaller) similarity percentage (Bockarova 2016:Online). To test the normality, a null hypothesis has to be assumed. Null hypothesis assumes a normal distribution sample. The test was used to test the median and inter-quartile range (IQR) as well as the mean and standard deviation of each variable. The p-value refers to the probability of obtaining test results at least as near as the results of a statistical hypothesis test, assuming the null hypothesis is correct (Beers and Westfall 2020:Online).

Table 10 describes the univariate procedure used to test for normality of the variables patient height (cm), patient weight (kg), kVp, mAs and patient thickness. Interpretation of the p-value is as follows: if value $p < 0.05$, then the variable does not follow a normal distribution and the data are skewed. If $p \geq 0.05$, the variable follows a normal distribution, and the data are not skewed. The variable patient height (cm) displayed a p-value of 0.1458, which is ≥ than 0.05, meaning the patient height variable follows a normal distribution and the data are not skewed. The remaining p-values in Table 10 display a value of 0.0001, which is smaller than 0.05, therefore meaning that the variables patient weight (kg), kVp, mAs and patient thickness do not follow a normal distribution and the data are skewed.

Table 10: Univariate procedure to test for normality of the variables on the technical parameters sheet

Test for normality: Shapiro-Wilk (W)				
Variable	**Statistic**		**p-value**	
Patient height (cm)	W	0.994341	Pr<W	<0.1458
Patient weight (kg)	W	0.275826	Pr<W	<0.0001
KVp	W	0.763803	Pr<W	<0.0001
mAs	W	0.902666	Pr<W	<0.0001
Patient thickness (cm)	W	0.976733	Pr<W	<0.0005

(Compiled by statistician M. Viljoen, 2020)

Figure 14 displays the results of the normality test of the technical parameters sheet variables. As seen on the graph, the variable p-value is greater than the Shapiro-Wilk value on each technical parameter variable, but much greater on the technical parameter variable patient height (cm). If the Shapiro-Wilk value is greater than 0.05, the data displayed are normal. If the value is less than 0.05, the data deviate from a normal distribution (Laerd Statistics 2018:Online). The variables patient height (cm), patient weight (kg), kVp, mAs and patient thickness consist of values greater than 0.05, meaning these variables display data of a normal distribution.

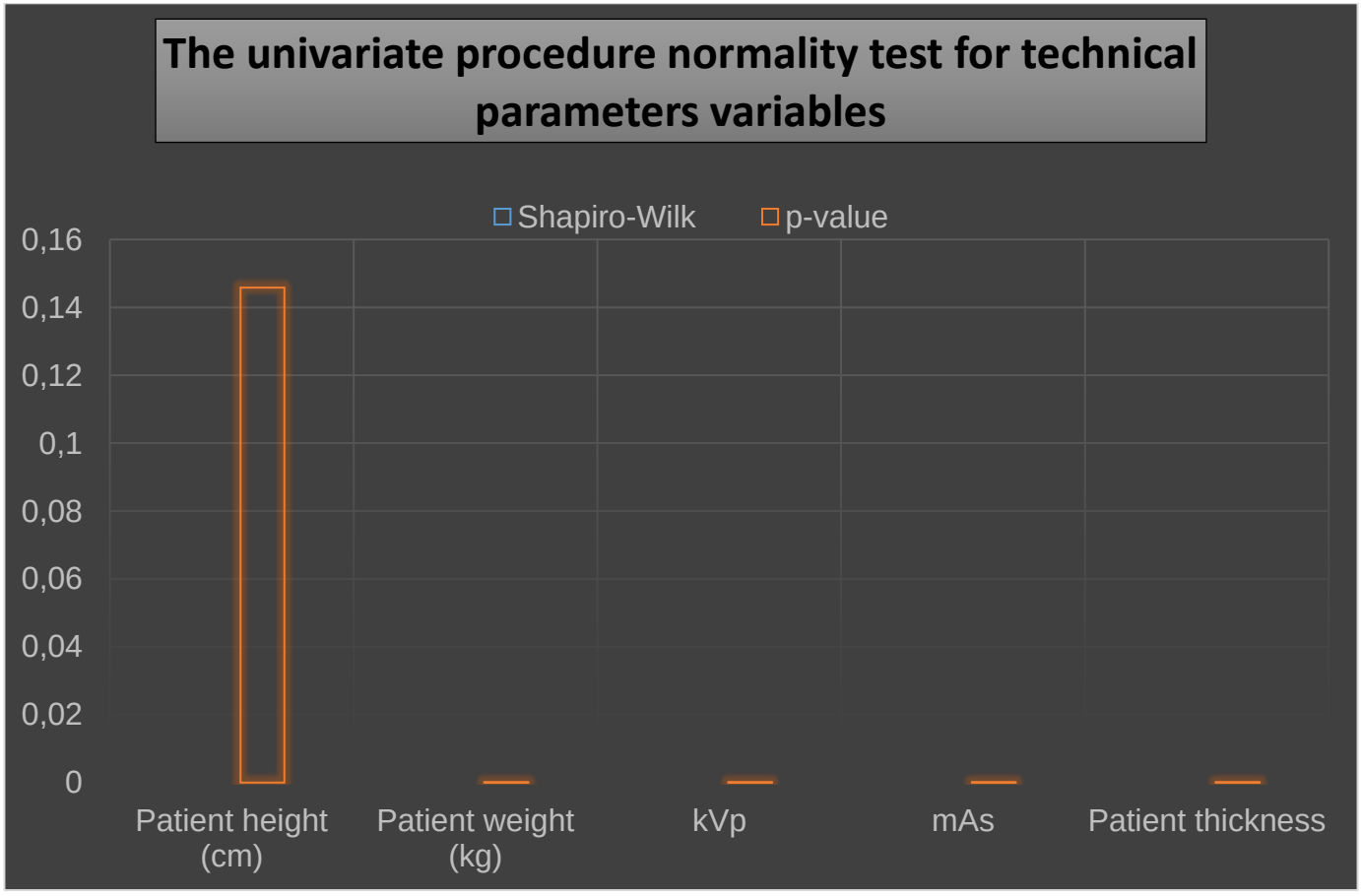


Figure 14: The univariate procedure normality test for technical parameters variables

(Compiled by researcher Leandré Toüa, 2020)

The patient thickness variable was analysed with the MEANS procedure. The MEANS procedure provides a technique for data summarised instruments to calculate or determine descriptive statistics for variables across all observations and within group observations (SAS 2020:Online). The MEANS procedure was used to analyse the variable patient thickness and compared to the median to get an idea of the distribution of the data (Figure 15). If the mean and median are similar, the data are more likely to be evenly distributed. It is evident from Figure 15 that there was no significant difference median and the mean of patient thickness. Referring to Figure 7 (page 53), it was stated that body habitus is an important aspect, as each person has a unique build or body habitus and has an influence on the ESD. Thus, the greater the patient thickness, the more mAs and kVp should be adjusted, resulting in a change of the dose entering the body (ESD).

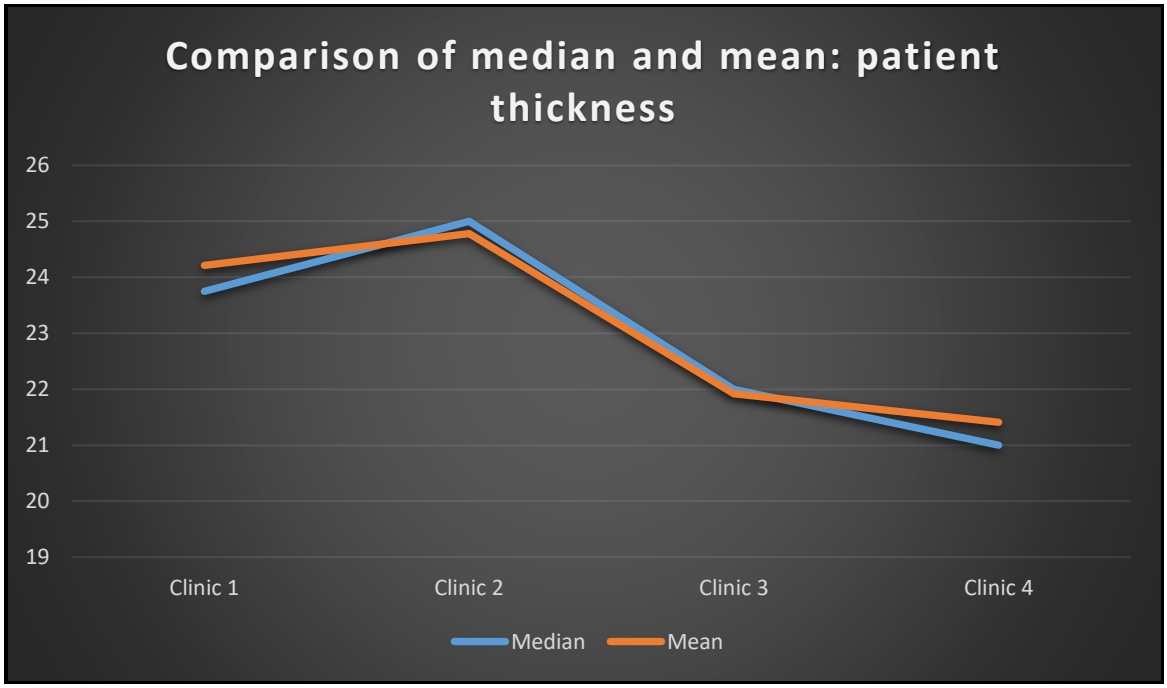


Figure 15: Comparison of median and mean: patient thickness

(Compiled by researcher Leandré Toüa, 2020)

The MEAN is defined in statistics as the middle or average of a certain numerical data set, or the measurement of a central tendency (Laerd Statistics 2018:Online). As seen in Table 11, the standard deviation values of clinics one to four are strikingly similar. Standard deviation is defined as a statistic that measures the distribution of data relative to the mean. If the data points are stipulated further from the mean, it displays a higher deviation. Thus, the more the data are spread out, the higher the standard deviation (Hargrave 2020:Online). In this patient thickness variable, the standard deviation ranged from 2.63 – 4.25. This means that the standard deviation is much lower than the mean and displays a higher deviation.

Table 11: MEANS procedure to analyse variable: patient thickness

MEANS procedure: patient thickness variable								
Clinic	**N**	**Median**	**Lower quartile**	**Upper quartile**	**Mean**	**Std dev.**	**Min.**	**Max.**
Clinic 1	100	23.75	22.00	26.10	24.21	3.02	17.50	35.00
Clinic 2	100	25.00	21.50	27.75	24.78	4.25	17.00	36.50
Clinic 3	100	22.00	20.00	24.00	21.92	2.63	16.00	27.00
Clinic 4	100	21.00	19.00	23.00	21.41	2.98	12.00	29.00

(Compiled by statistician M. Viljoen, 2020)

Subsequently, there is a difference between the median values of patient thickness of the four clinics (Table 11). The next step is to establish which clinics were different from one another. Clinic 1 and 2 had greater median patient thickness values than

Clinic 3 and 4. The Mann-Whitney U-test were utilised. This test is used to compare differences between two independent groups where the dependant variable is either ordinary or continuous (Laerd Statistics 2018:Online). To clarify, it is a non-parametric test of the null hypothesis of X and Y values from two populations that were randomly selected. The probability of X being greater than Y is equal to the probability of Y being greater than X (Laerd Statistics 2018:Online). The Mann-Whitney U-test was utilised to establish which clinics were different from each other:

Patient thickness

I Clinic 1 vs. clinic 2: p = 0.521

II Clinic 1 vs. clinic 3: p <0.0001

III Clinic 1 vs. clinic 4: p <0.0001

IV Clinic 2 vs. clinic 3: p <0.0001

V Clinic 2 vs. clinic 4: p <0.0001

VI Clinic 3 vs. clinic 4: p = 0.1845

If the p-value is < 0.5, the null hypothesis can be rejected. Thus, if patient thickness II, III, IV, V and VI has a p-value < 0.5, the null hypothesis can be rejected.

The data in Appendix G1 and G2 were utilised to compile a graphical presentation of the MEANS procedure for the IQR for the technical parameters variables of all four clinics separately.

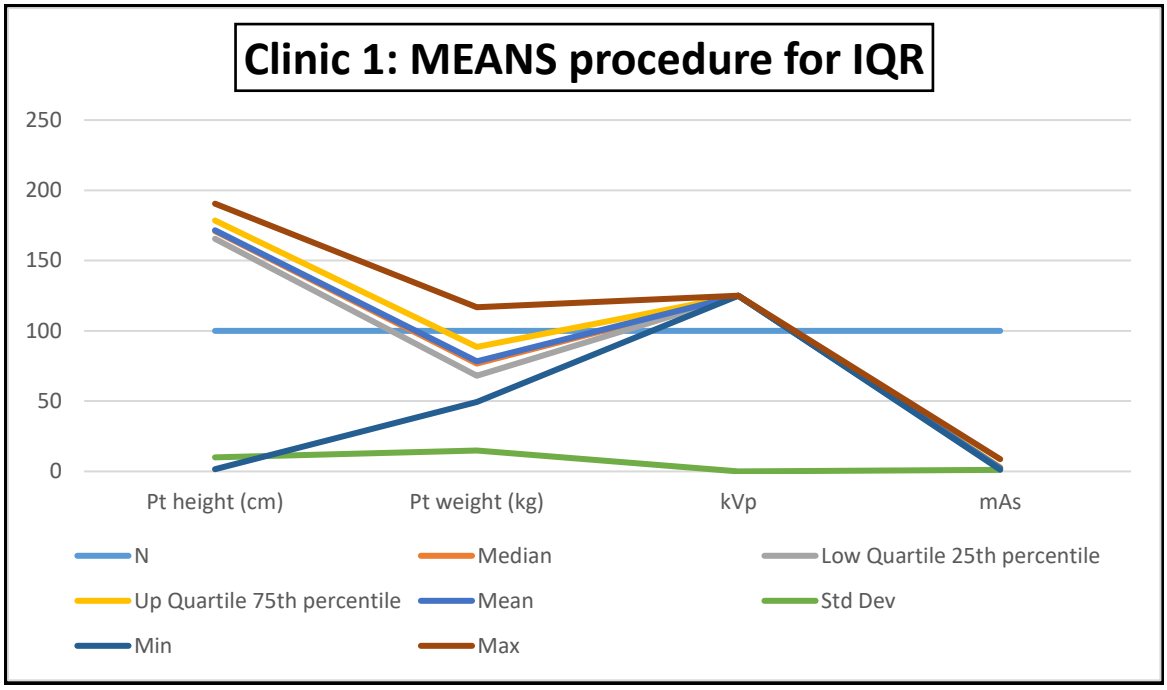


Figure 16: Graphical presentation for clinic 1: MEANS procedure for IQR

Figure 16 displays the graphical presentation for clinic one where the MEANS procedure was used to determine the IQR. The total number of observations (N Obs) were identical for all four clinics, which was 100 per clinic, and is classified as homogeneous data. The lower quartile, mean, upper quartile and the maximum point were all more or less in range with one another, where the minimum point and standard deviation were much lower.

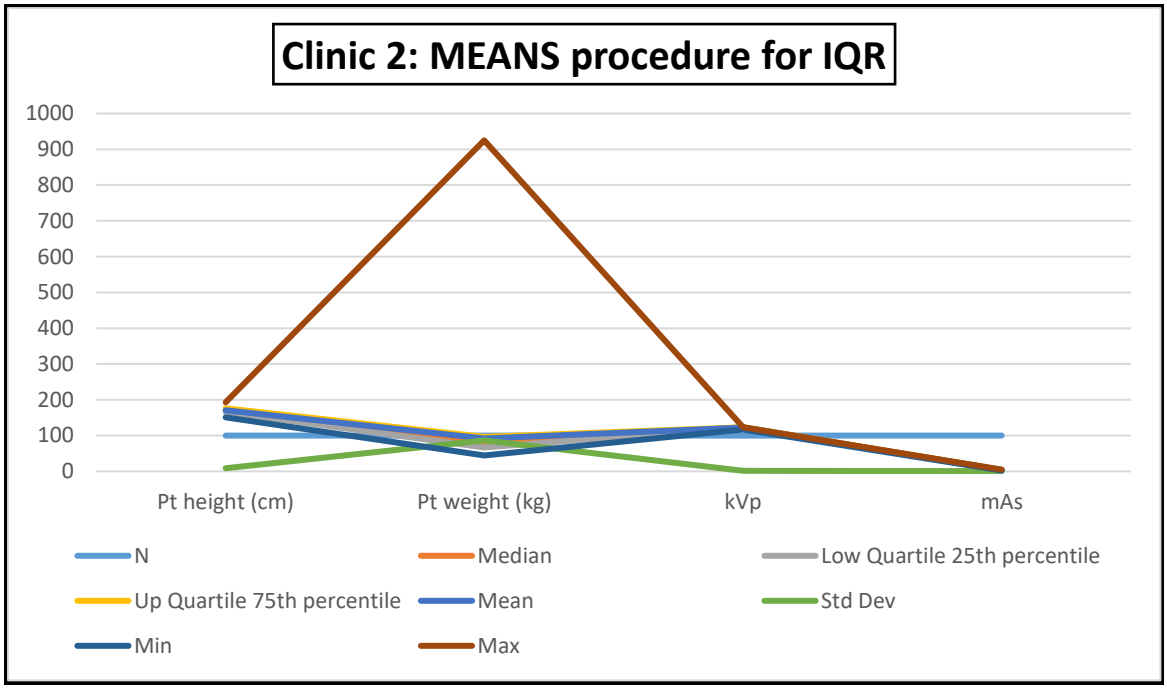


Figure 17: Graphical presentation for clinic 2: MEANS procedure for IQR

Figure 17 displays the graphical presentation for clinic two where the MEANS procedure was used to determine the IQR. The N Obs were the same for all four clinics, namely 100 per clinic. The lower quartile, mean, upper quartile, median, standard deviation and the minimum point were all in range with one another, where the maximum point was evidently higher.

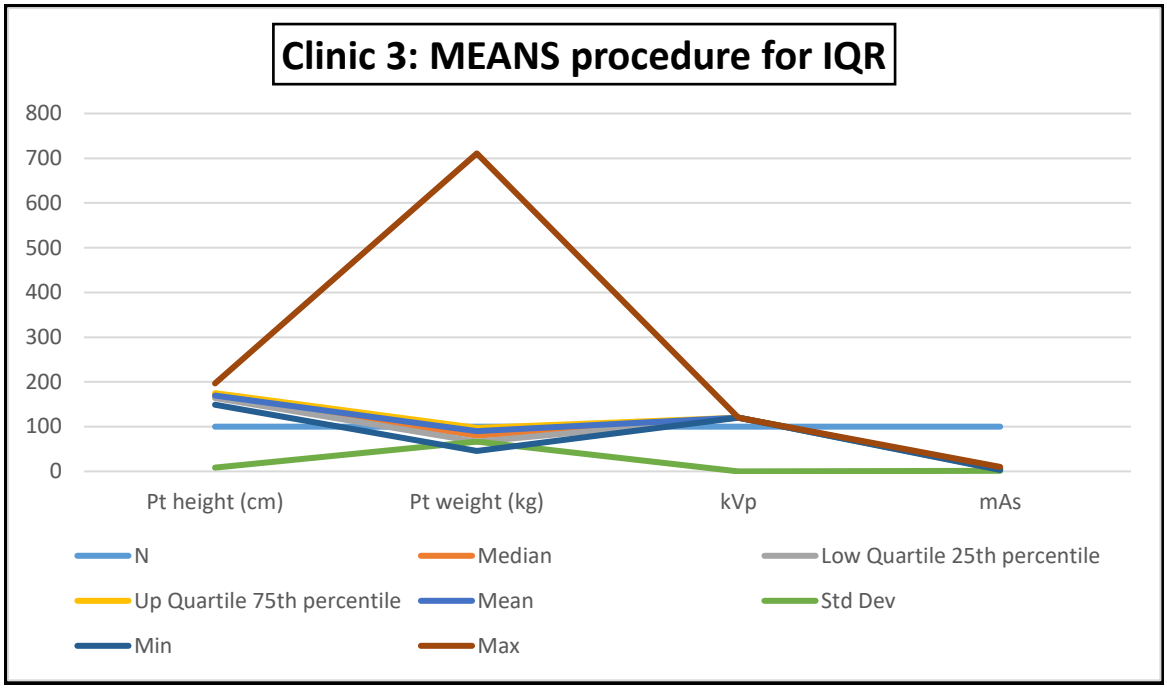


Figure 18: Graphical presentation for clinic 3: MEANS procedure for IQR

Figure 18 displays the graphical presentation for clinic three where the MEANS procedure was used to determine the IQR. The N Obs were the same for all four clinics, which was 100 per clinic. The lower quartile, mean, upper quartile, median, standard deviation and the minimum point were all in range with one another, where the maximum point was evidently higher. This presentation is similar to the MEANS procedure for IQR for clinic two (Figure 17).

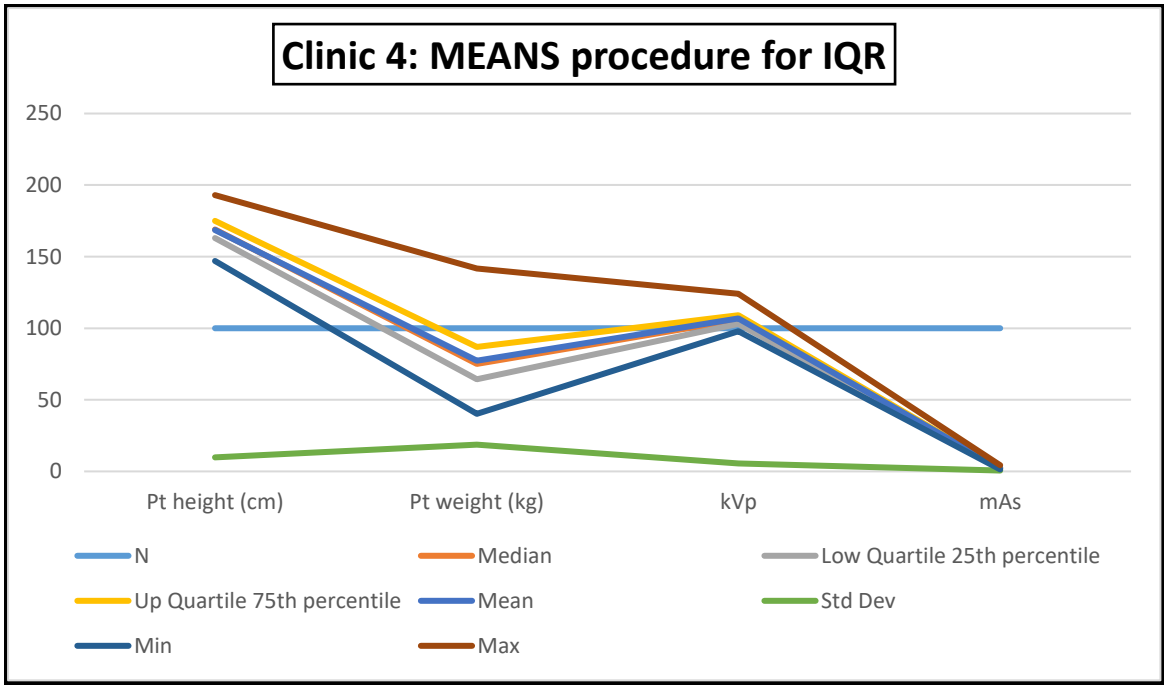


Figure 19: Graphical presentation for clinic 4: MEANS procedure for IQR

Figure 19 displays the graphical presentation for clinic four where the MEANS procedure was used to determine the IQR. The N Obs were the same for all four clinics, which was 100 per clinic. The upper quartile, median, mean, lower quartile and minimum point were similar in range, where the maximum point was higher and the standard deviation was much lower. The patient height (cm) and weight (kg) did not display a significant difference in Figure 16-19. The variables patient height (cm) and weight (kg) can be classified as homogeneous data due to their similarity.

The median values were compared in four groups utilising the Kruskal-Wallis test. This test is also called the one-way ANOVA on ranks. It is a rank-based non-parametric test that is used to determine if there are any differences between two or more groups of independent variables (Laerd Statistics 2018:Online) Utilising Table 12, the interpretation of the p-value is as follows: if $p < 0.05$, there is a significant difference

between the median values in the four groups. If p ≥0.05, there is no significant difference between the median values in the four groups. Patient height (cm) and patient weight (kg) p-value ≥ 0.05, meaning there is no significant difference between these median values.

Table 12: Comparison of median values

Comparison of median values	
Variable	**p-value**
Patient height (cm)	0.0977
Patient weight (kg)	0.0676
KVp	< 0.0001
mAs	< 0.0001
Patient thickness	< 0.0001

(Compiled by statistician M. Viljoen, 2020)

To report on the variables named patient number (number of employees/participants) and CR system, the frequency procedure (FREQ) was used. This procedure prints all values of a given categorical variable in the output window along with the counts and proportions (SAS Institute 2019:Online). The participants were 100 at each clinic, which added up to a total of 400 participants, and by utilising the FREQ, the percentage of each clinic's participants made up 25%.

4.3 RESULTS OF THE CLINIC CHECKLIST

The clinic checklist was step two of the data collection process and required the researcher to travel to each clinic to complete it. This quantitative data collection sheet was created in Microsoft Excel (Appendix A1-4: sheet 2) to provide a timeline for previous x-rays done, and it addressed research objective four (see section 1.4.2, p. 6). It included parameters such as the dates of chest x-rays (PA and lateral), number of repeat chest x-rays (PA and lateral), dates of other projections (AP/PA, lateral and oblique) and the number of repeats for other projections done. This sheet was completed by the researcher while visiting the clinic and searching on the archive for dates of previous examinations, as well as the number of repeats for 100 contracted employees per clinic, which added up to 400 contracted employees. The employees' ID numbers were replaced with a numerical data of 1,2,3 etc. The technical parameters sheets contained the actual ID numbers. The ID numbers were only needed on this one document to do the cross-referencing of the multiple examinations.

Tables 13 to 17 were generated by utilising the FREQ procedure in order to establish the number of projections/x-ray images done for this study and prior to the study. In each table the first column is the number which gives an indication in that specific row of how many times the variable appeared on the four checklists; in other words, the frequency that it was found in the second column. The third column is the percentage that the frequency of the variable appeared in the four checklists. The subheading refers to the views that were done, namely AP/PA, lateral and oblique.

Table 13: Total CXR (PA and lateral) of all four clinics combined

Total PA and lateral CXR				
	Frequency		Percentage (%)	
	PA	Lateral	PA	Lateral
0	_	399	_	99.75
1	224	1	56	0.25
2	90	_	22.50	_
3	31	_	7.75	_
4	9	_	2.25	_
5	14	_	3.50	_
6	14	_	3.50	_
7	13	_	3.25	_
8	5	_	1.25	_

(Compiled by statistician M. Viljoen, 2020)

Table 13 provides a summary of the total chest x-rays that were done between the four clinics throughout the duration of the study for all four clinics combined. The frequency of 0 PA chest x-rays that was done was 0. The frequency of 0 lateral chest x-rays done was 399 (99.75 %). The frequency of 1 PA chest x-ray done was 224 (56 %). The frequency of 1 lateral chest x-ray done was 1 (0.25 %). The frequency of 2 PA chest x-rays done was 90 (22.50 %). The frequency of 3 PA chest x-rays done was 31 (56 %). The frequency of 4 PA chest x-rays done was 9 (2.25 %). The frequency of 5 PA chest x-rays done was 14 (3.50 %). The frequency of 6 PA chest x-

rays done was 14 (3.50 %). The frequency of 7 PA chest x-rays done was 13 (3.25 %). The frequency of 8 PA chest x-rays done was 5 (1.25 %).

The results therefore indicate that 176 contracted employees are referred for more than one CXR per year.

Table 14: CXR (PA and lateral) repeats of all four clinics combined

Total chest repeats				
Number	**Frequency**		**Percentage (%)**	
	PA	**Lateral**	**PA**	**Lateral**
0	380	400	95	100
1	17	_	4.25	_
2	1	_	0.25	_
3	2	_	0.50	_

(Compiled by statistician M. Viljoen, 2020)

Table 14 provides a summary of the PA and lateral chest x-ray repeats. The frequency of 0 PA chest x-ray repeats was 380 (95 %). The frequency of 0 lateral chest x-rays repeats was 400 (100 %). The frequency of 1 PA chest x-ray repeats was 17 (4.25 %). The frequency of 2 PA chest x-ray repeats was 1 (0.25 %). The frequency of 3 PA chest x-ray repeats was 2 (0.50 %). The results therefore indicate that only 4.75 % of PA chest x-rays is repeated. The normal acceptable reject rate is below 10%, so this

indicates compliance across all four clinics (Owusu-Banahene and Okyere Asirifi 2014:589).

Table 15: Other projections AP/PA, lateral and oblique

Other projections						
Number	**Frequency**			**Percentage (%)**		
	AP/PA	**Lateral**	**Oblique**	**AP/PA**	**Lateral**	**Oblique**
0	386	389	397	96.50	97.25	99.25
1	11	8	2	2.75	2	0.50
2	2	2	1	0.50	0.50	0.25
3	1	1	_	0.25	0.25	_

(Compiled by statistician M. Viljoen, 2020)

Table 15 provides a summary of other projections done including AP/PA, lateral and oblique views done at all four clinics combined. The frequency of 0 AP/PA views done was 386 (96.50 %). The frequency of 0 lateral views done was 389 (97.25 %), and the frequency of 0 oblique views done was 397 (99.25 %). The frequency of 1 AP/PA views done was 11 (2.75 %). The frequency of 1 lateral views done was 8 (2 %), and the frequency of 1 oblique views done was 2 (0.50 %). The frequency of 2 AP/PA views done was 2 (0.50 %). The frequency of 2 lateral views done was 2 (0.50 %), whilst the frequency of 2 oblique views done was 1 (0.25 %). The frequency of 3 AP/PA views done was 1 (0.25 %). The frequency of 3 lateral views done was 1 (0.25 %), whilst the frequency of 3 oblique views done was 0.

The results indicated therefore that most patients were only referred for the routine CXR, and only 14 patients received other projections.

Table 16: Other projections AP/PA, lateral and oblique repeats

Other projections repeats						
Number	**Frequency**			**Percentage (%)**		
	AP/PA	**Lateral**	**Oblique**	**AP/PA**	**Lateral**	**Oblique**
0	398	397	400	99.50	99.25	100
1	2	2	_	0.50	0.50	_
2	_	1	_	_	0.25	_

(Compiled by statistician M. Viljoen, 2020)

Table 16 provides a summary of other projections repeats/rejects done, including AP/PA, lateral and oblique views done at all four clinics combined. The frequency of 0 AP/PA views that were rejected was 398 (99.50 %). The frequency of 0 lateral views that were rejected was 397 (99.25 %), whilst the frequency of 0 oblique views that were rejected was 400 (100 %). The frequency of 1 AP/PA views that were rejected was 2 (0.50 %). The frequency of 1 lateral views that were rejected was 2 (0.50 %), and the frequency of 1 oblique views that were rejected was 0. The frequency of 2 AP/PA views that were rejected was 0. The frequency of 2 lateral views that were rejected was 1 (0.25 %), and the frequency of 2 oblique views that were rejected was 0.

The results therefore indicate that only 1.25 % of the additional projections were repeated.

Table 17: Total of all projections of all four clinics combined

Total of all projections		
Number	**Frequency**	**Percentage (%)**
1	21	52.75
2	89	22.25
3	34	8.50
4	15	3.75
5	14	3.50
6	13	3.25
7	14	3.50
8	5	1.25
9	2	0.50
10	2	0.50
12	1	0.25

(Compiled by statistician M. Viljoen, 2020)

Table 17 provides a summary of the total projections done, including all views and clinics. The frequency of 1 projection done per examination was 21 (52.75 %). The frequency of 2 projections done per examination was 89 (22.25%). The frequency of 3 projections done per examination was 34 (8.50%). The frequency of 4 projections

done per examination was 15 (3.75%). The frequency of 5 projections done per examination was 14 (3.50%). The frequency of 6 projections done per examination was 13 (3.25%), whilst the frequency of 7 projections done per examination was 14 (3.50%). The frequency of 8 projections done per examination was 5 (1.25%), and for 9 projections done the frequency was 2 (0.50%). The frequency of 10 projections done per examination was 2 (0.50%), whilst the frequency of 12 projections done per examination was 1 (0.25%), meaning that the frequency refers to the employee being exposed over a certain time due to multiple examinations requested and not just chest.

4.4 RESULTS OF THE FORMULAE AND CALCULATIONS

This was the final step in the data collection process. This sheet was associated with the technical parameters, as the values could not be inserted and the calculations could not have been done if the technical parameters were not available. See section 3.3.6.3 for a detailed discussion on how the values were inserted in Microsoft Office (Excel), and how the calculations were done. The formulae and calculations were divided into two sections. The first section of the calculation sheet was dependant on the technical parameters sheet as seen in Figure 20, as this was the values that were needed to complete patient measurements and the technical factors. The patients' ID numbers were replaced with a numerical number of 1-100. Manufacturer, grid ratio and whether it was a CR system were found in the Quality Control (QC) Manual in the department. Grid ratio is considered an influencing factor in relation to image quality as it improves the contrast by absorbing scatter radiation before it reaches the image receptor and not all manufacturers are manufactured with the same grid ratio. Image

quality speaks to repetition of images and this, ultimately, undertakes the ALARA principle (Carlton and Adler, 2006: 431).

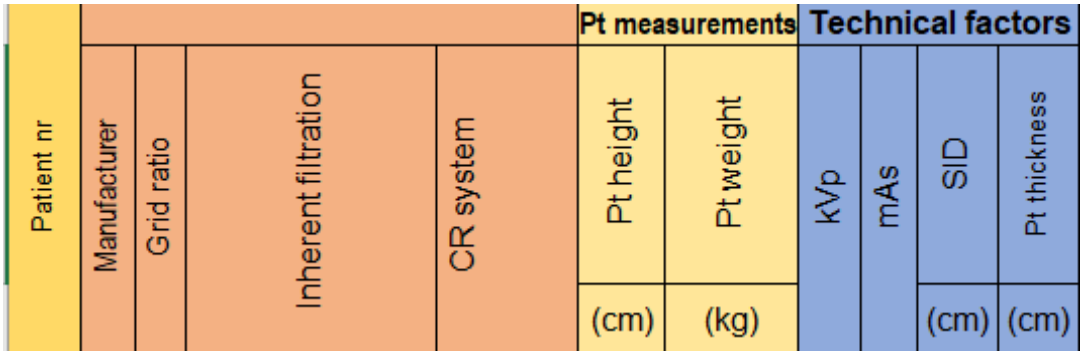


Figure 20: Section 1 of formulae and calculations sheet

This quantitative data collection sheet was specifically designed with the assistance of a medical physicist in order to calculate the ESD per employee and ultimately the DRL for that clinic. The calculation section needed to be completed and calculated (see section 3.3.6.3) in order to calculate the average, median and 3rd quartile (DRL) by utilising formulae and values from section 1. Patient measurements and technical factors were discussed in section 4.2.

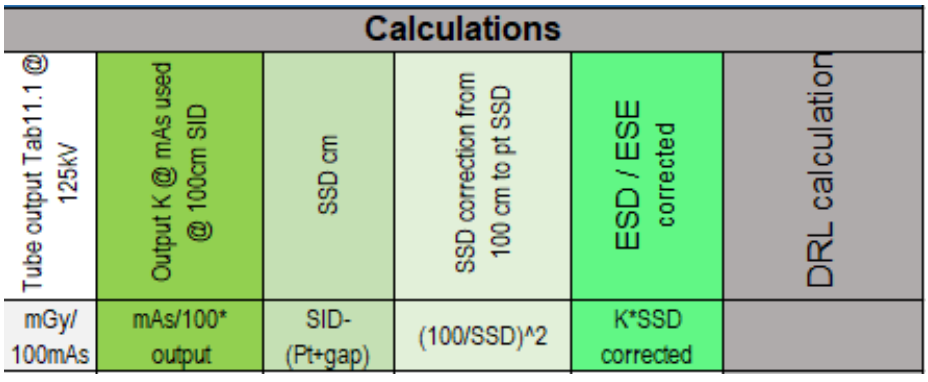


Figure 21: Section 2 of formulae and calculation sheet

Figure 21 displays section 2 of the formulae and calculation sheet that was used to achieve the ultimate goal of the study; the DRL calculation. Figure 8 (page 60) describes the percentile distribution, namely the percentiles 25th (Q_1), 50th (median) and 75th (Q_3). It was stated that the curve of the graph is stipulated with a long tail. The 75th percentile is preferably used with the calculation of DRLs. The 75th percentile is the value found above the median (Q_3) (Vano *et al*. 2017:42). The min (minimum) refers to the smallest value and the "max" refers to the largest value (maximum/100th percentile).

DRLs are usually set at the third quartile value, thus meaning the 75th percentile is chosen as it lies below the high dose tail allocation on the graph, but also serves as an identification of image quality when considering the 95th percentile value. Utilising Table 18, the statistician made use of the Shapiro-Wilk test to test for normality of the variables used in section 2 of the formulae and calculation sheet.

The gap between the patient and the image receptor (IR) was analysed using the FREQ procedure. The gap between the patient and detector was the same for all 100 participants at all four clinics which was 2 cm. See Table 5 (page 50). This table found in the textbook of Bushberg, Seibert, Leidholdt and Boone (2012:378) as Table 11.1, where the half-value layer and output levels as a function of kV for a typical general diagnostic x-ray system were measured at 100 cm. Bushberg *et al*. (2012) also stated that the air gap is approximately 2 cm, thus it was assumed the same for all participants. The tube output of 16.4 mGy/mAs at 125 kV was taken from the table for all 100 participants at all four clinics, as this was the kV used.

Table 18: Univariate procedure to test for normality of variables from section 2 of the formulae and calculation sheet

Test for normality Shapiro-Wilk (W)				
Variable	**Statistic**		**p-value**	
Output K	W	0.902666	Pr<W	<0.0001
SSD (cm)	W	0.976733	Pr<W	<0.0001
SSD correction	W	0.961016	Pr<W	<0.0001
ESD/ESE corrected	W	0.907037	Pr<W	<0.0001

(Compiled by statistician M. Viljoen, 2020)

Table 18 provides results on the univariate procedure that was used to test for normality of the variables named Output K, SSD (cm), SSD correction, ESD/ESE corrected for section 2 of the formulae and calculation part. After the Shapiro-Wilk (W) test each variable displayed a statistic and a p-value. From Table 18 (p. 126) it is evident that P < W for all four variables and P< 0.05, thus meaning the variables do not follow a normal distribution and the data are skewed. If the data do not follow a normal distribution, the test hypothesis is false and can be rejected (Grabowski 2016:194). In this study the hypothesis is to test if contracting employees undergo multiple annual x-ray imaging.

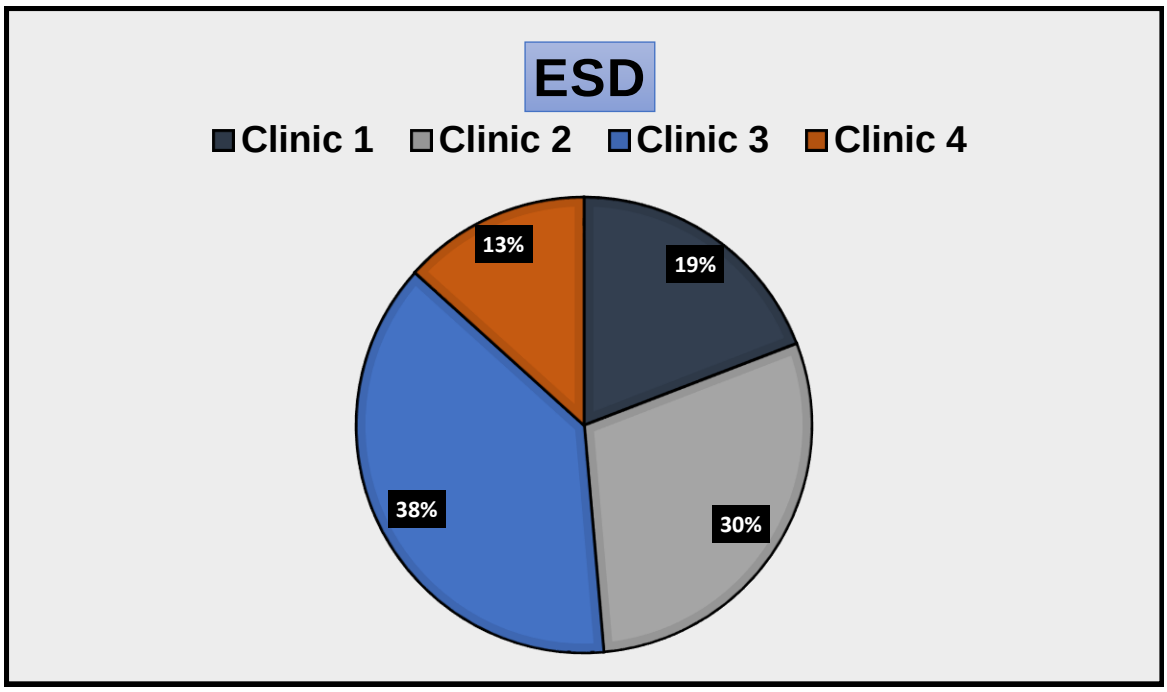


Figure 22: ESD calculated for each clinic

The ESD/ESE were calculated and displayed in the graphical presentation. Figure 22 displays the average of each clinic's ESD variable column. It is evident that Clinic 3 (38 %) employees had a greater ESD than employees from Clinic 1 (19 %), 2 (30 %) and 4 (13 %).

The IQR are described as how the data are spread, thus the middle or the half (50 %) of data, or a set of scores when displayed from lowest to highest. The average, median and 3rd quartile were the last sections to be completed for calculation. For each clinic this was the average, the median and the 3rd quartile (75th percentile) which is the DRL that was calculated. This was only done after utilising section 3.3.6.3 to complete the sheet from employee number 1-100. Appendix G2 provides results of the MEANS procedure used to determine the median, lower quartile (25th percentile), upper quartile (75th percentile), mean, standard deviation, minimum and maximum point.

Each clinic is displayed separately containing the variables output K, SSD (cm), SSD correction, ESD/ESE correction. Utilising the data from Appendix G2, graphical presentations were compiled for section 2 of the formulae and calculations sheet.

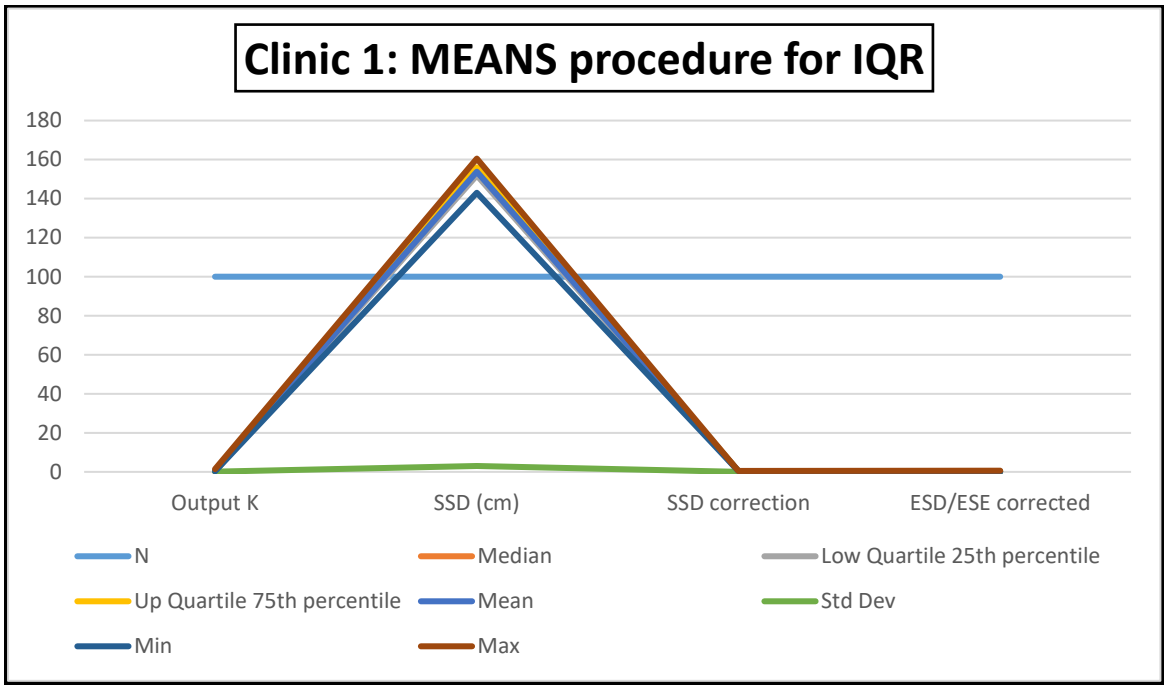


Figure 23: Graphical presentation for clinic 1: MEANS procedure for IQR

Figure 23 displays the MEANS procedure utilised to determine the IQR for clinic 1. It is evident that N had the same values throughout, because only 100 participants per clinic (contracted employees) were selected to participate in the study. Except for the significant difference between lowest and highest graphics, it is evident that the median, lower quartile 25th percentile, upper quartile 75th percentile, mean, median, minimum and maximum are perfectly aligned and close to one another for variables output K, SSD (cm), SSD correction and ESD/ESE corrected. Standard deviation is defined as a statistic that measures the distribution of the data relative to the mean,

and is calculated as the square root of the variance (Hargrave 2020:Online). The standard deviation in Figure 24 is low, thus meaning the values are close to the mean.

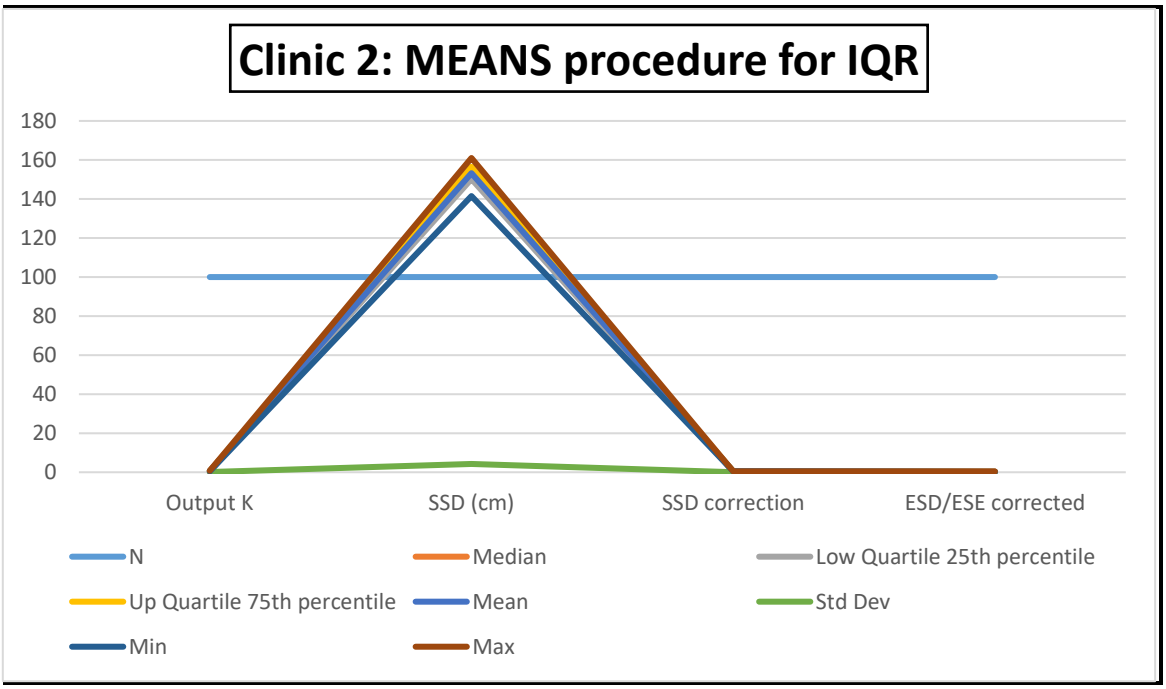


Figure 24: Graphical presentation for clinic 2: MEANS procedure for IQR

Figure 24 displays the MEANS procedure utilised to determine the IQR for clinic 2. It is evident that N had the same values throughout, because only 100 participants per clinic (contracted employees) were selected to participate in the study. Except for the significant difference between lowest and highest graphics, it is evident that the median, lower quartile 25th percentile, upper quartile 75th percentile, mean, median, minimum and maximum are perfectly aligned and close to one another for variables output K, SSD (cm), SSD correction and ESD/ESE corrected. Standard deviation is the expression of how much the members of the group differ from the mean value of the group. Thus, in this figure the low standard deviation indicated that the values are close to the mean.

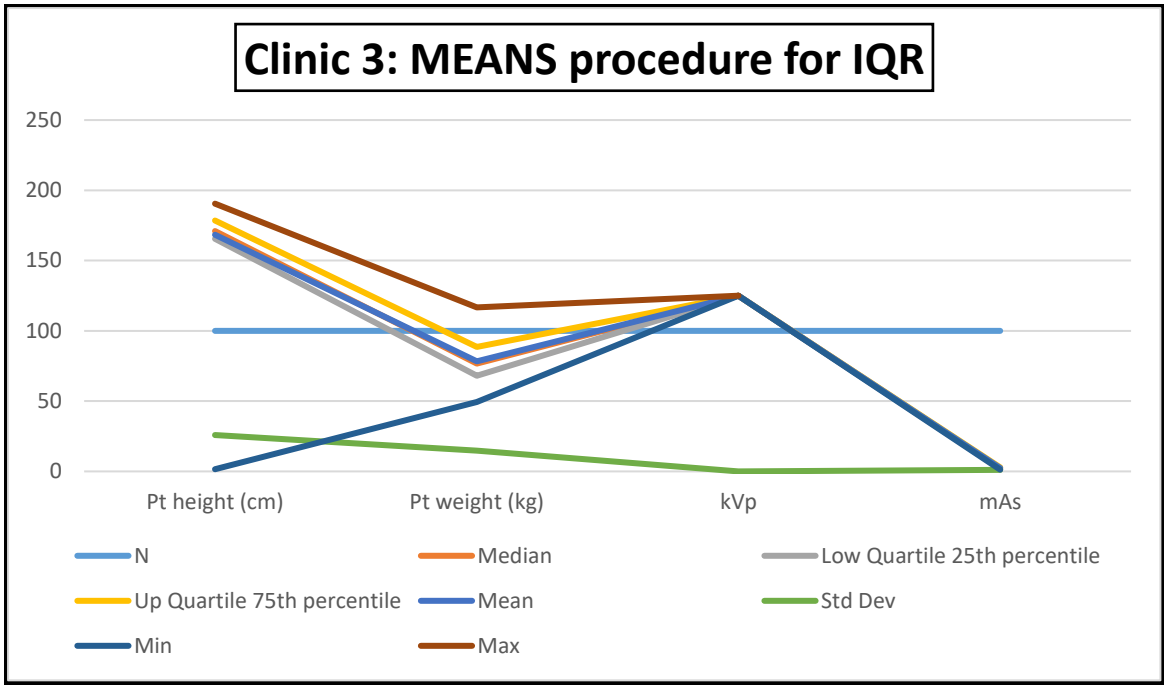


Figure 25: Graphical presentation for clinic 3: MEANS procedure for IQR

Figure 25 displays the MEANS procedure utilised to determine the IQR for clinic 3. It is evident that N had the same values throughout, because only 100 participants per clinic (contracted employees) were selected to participate in the study. Except for the significant difference between lowest and highest graphics, it is evident that the median, lower quartile 25th percentile, upper quartile 75th percentile, mean, median, and maximum are close to one another, whilst minimum and standard deviation are lower. The low standard deviation indicated the values are close to the mean.

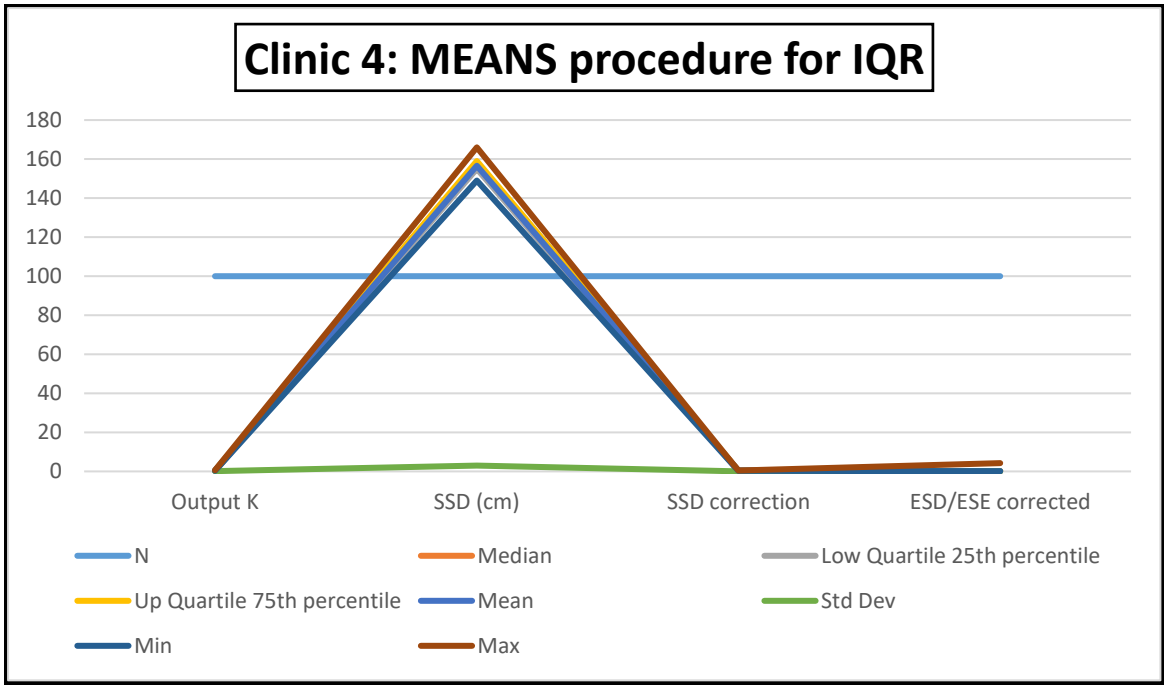


Figure 26: Graphical presentation for clinic 4: MEANS procedure for IQR

Figure 26 displays the MEANS procedure utilised to determine the IQR for clinic four. It is evident that N had the same values throughout, because only 100 participants per clinic (contracted employees) were selected to participate in the study. Except for the significant difference between lowest and highest graphics, it is evident that the median, lower quartile 25th percentile, upper quartile 75th percentile, mean, median, minimum and maximum are perfectly aligned and close to one another for variables output K, SSD (cm), SSD correction and ESD/ESE corrected. The low standard deviation indicated that the values are close to the mean. Figures 24, 25 and 26 displayed multiple similarities and were almost identical. These variables (N, Upper Quartile, Lower Quartile, Median, Mean, Standard Deviation, Minimum and Maximum) from clinic 1, 2 and 4 can be classified as homogeneous data due to their similarity and almost being identical.

The mean is also referred to as the average that is used to measure the centre of numerical data, thus the mean is the sum of all the values in the data divided by the amount of values in the data. The mean may not be a realistic or accurate demonstration of data, because the average is easily influenced by small or large values of data (Rumsey 2020:Online). The median is the other way to measure the centre of numerical data accurately. As seen in Appendix I2, there was a significant difference between the median values of the clinics. The Mann-Whitney U-test was utilised to establish which clinics were significantly different from each other for each separate variable of the second calculation part:

Output K

I Clinic 1 vs. clinic 2: $p < 0.0001$
II Clinic 1 vs. clinic 3: $p < 0.0001$
III Clinic 1 vs. clinic 4: $p = 0.9483$
IV Clinic 2 vs. clinic 3: $p < 0.0001$
V Clinic 2 vs. clinic 4: $p < 0.0001$
VI Clinic 3 vs. clinic 4: $p < 0.0001$

Mathematical probabilities like p-values ranges from 0 (no chance) to 1 (absolute certainty). Thus 0.5 means 50 % chance that the variable output K is considered as statistically significant. Interpretation of the p-value is if the p-value is < 0.5, the null hypothesis can be rejected. Thus, from the variable output K, the p-value of I, II, IV, V and VI is < 0.5, and therefore the null hypothesis can be rejected.

SSD

I Clinic 1 vs. clinic 2: $p = 0.5217$
II Clinic 1 vs. clinic 3: $p < 0.0001$
III Clinic 1 vs. clinic 4: $p < 0.0001$
IV Clinic 2 vs. clinic 3: $p < 0.0001$

V Clinic 2 vs. clinic 4: p < 0.0001

VI Clinic 3 vs. clinic 4: p = 0. 1845

The p-value of 0.5 means that there is a 50 % chance that the variable SSD is considered as statistically significant. Interpretation of the p-value is if the p-value is < 0.5, the null hypothesis can be rejected. Thus from the variable SSD II, III, IV, V and VI has a p-value < 0.5, and therefore the null hypothesis can be rejected.

SSD correction

I Clinic 1 vs. clinic 2: p = 0.5217

II Clinic 1 vs. clinic 3: p < 0.0001

III Clinic 1 vs. clinic 4: p < 0.0001

IV Clinic 2 vs. clinic 3: p < 0.0001

V Clinic 2 vs. clinic 4: p < 0.0001

VI Clinic 3 vs. clinic 4: p = 0. 1845

The p-value of 0.5 means that there is a 50 % chance that the variable SSD correction is considered as statistically significant. Interpretation of the p-value is if the p-value is < 0.5, the null hypothesis can be rejected. Thus, from the variable SSD correction II, III, IV, V and VI has a p-value < 0.5, and thus the null hypothesis can be rejected.

ESD/ESE correction

I Clinic 1 vs. clinic 2: p < 0.0001

II Clinic 1 vs. clinic 3: p < 0.0001

III Clinic 1 vs. clinic 4: p = 0.4422

IV Clinic 2 vs. clinic 3: p < 0.0001

V Clinic 2 vs. clinic 4: p < 0.0001

VI Clinic 3 vs. clinic 4: p < 0.0001

The p-value of 0.5 means that there is a 50 % chance that the variable ESD/ESE correction is considered as statistically significant. Interpretation of the p-value is if the

p-value is < 0.5, the null hypothesis can be rejected. Thus from the variable ESD/ESE correction I, II, III, IV, V and VI has a p-value < 0.5, and therefore the null hypothesis can be rejected.

Table 19: Comparison of median values of section 2 of the formulae and calculations sheet

Comparison of median values	
Variable	**p-value**
Output K	< 0.0001
SSD (cm)	< 0.0001
SSD correction	< 0.0001
ESD/ESE corrected	< 0.0001

All the p-values <0.05 in Table 19, meaning the variables do not follow a normal distribution and the data are skewed. The median is generally considered to be the best representative of the central location of the data. The more skewed the distribution, the greater the difference between the median and mean, and the greater emphasis should be placed on using the median as opposed to the mean. The IQR represents how far apart the lowest and the highest measurements were at that clinic. The IQR approximates the amount of spread in the middle half of the data for that clinic. The median divides data into half. Now 50% lies below and 50% above the median. The purpose of the quartile is to divide the data into smaller pieces, namely into 25% portions.

This data ultimately answers the research questions asked in section 1.3: Are contracted employees referred for more chest imaging than permanent employees? Yes, 174 of the contracted employees had more than one CXR per year (see section 3.4). Are contracted employees receiving a higher than necessary radiation dose compared to permanent employees due to unnecessary repetition of chest imaging at the different clinics contracted by mining companies? Yes, 47.25 % of all the selected participants had more than one projection done per year that included chest x-rays as well as other projections.

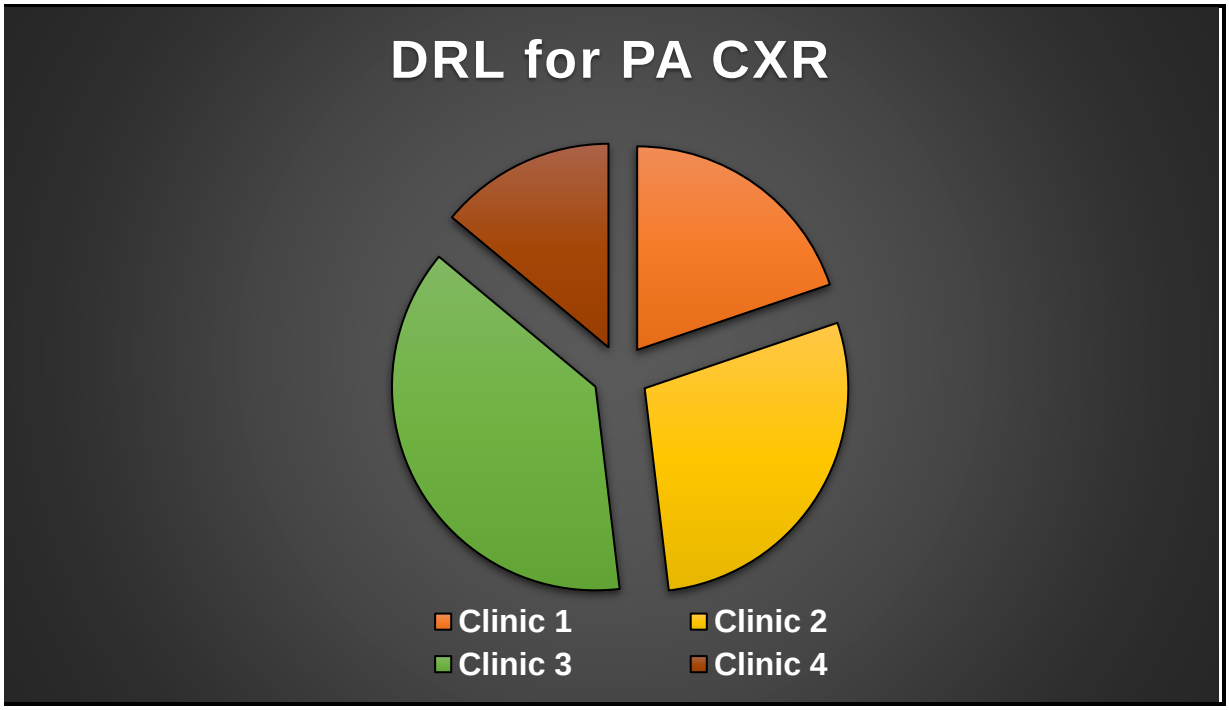


Figure 27: DRL of PA CXR calculated for each clinic

(Compiled by researcher Leandré Toüa, 2020)

Figure 27 displays the DRL values that were calculated for each clinic. The DRLs are a combination of all four body habitus mentioned in section 2.9.2 (page 46), and are as follows: clinic 1: 0.204, clinic 2: 0.292, clinic 3: 0.391 and clinic 4: 0.144. It is evident

that clinic 3 displayed the highest DRL. As mentioned in section 2.9.3 (page 54), DRLs are a selected level of a radiation dose quantity, thus meaning mAs have a great influence on the DRL. The term mAs is defined as the measurement of radiation produced; millamperage (mA) over a certain amount of time (seconds) (Bell, Murphy *et al*. 2017:Online). The mAs values used in clinic 3 (Appendix A3: sheet 1) were relatively higher compared to the other 3 clinics (Appendix A1, A2 and A4: sheet 1). The higher mAs values are the reason that clinic 3 has a greater DRL value to provide a baseline value for that specific clinic. DRLs can be compared to local, regional or national values, and was initially a concept that proved to be an effective diagnostic tool for dose optimisation and radiation protection of patients (Vano, Miller, Martin, Rehani, Kang, Rosenstein *et al*. 2017:78). The mean patient thickness for the clinics was as follows: clinic 1: 24.21 kg, clinic 2: 24.78 kg, clinic 3: 21.92 kg and clinic 4: 21.41 kg. The mean mAs value for the clinics was: clinic 1: 2.39, clinic 2: 3.64, clinic 3: 5.32 and clinic 4: 2.31. The mean ESD for the clinics was: clinic 1: 0.167, clinic 2: 0.57, clinic 3: 0.332 and clinic 4: 0.116. Clinic 3 had the lowest patient thickness but the highest mAs, and this is the result of the highest ESD of the four clinics as well as the higher DRL value. Therefore, the results indicate that the patients at clinic 3 received higher radiation doses than at the other 3 clinics. The reader is reminded that the goal is not to compare the DRLs of different sites with each other, but to provide a baseline value for that specific clinic.

4.5 DISCUSSION OF RESEARCH INSTRUMENTS

In order to get an answer to a research question, a researcher has to establish objectives that will be the route to an answer. Research instruments are part of the

route in order to answer a research question. The first was to *establish through a literature study how to calculate the entrance surface dose (ESD) that an adult acquired for a chest x-ray and diagnostic reference level (DRL) for each included clinic located on the four mines in the Northern Cape; and to then calculate a DRL* (section 1.4.2, p. 28). This objective was met in Chapter 2, where a literature study was conducted on how to calculate the entrance surface dose (ESD) and diagnostic reference level (DRL) that an adult acquires for a chest x-ray.

The technical parameters sheet proved to be beneficial, user-friendly and little time consuming in the data collection process, as most of the information that was required was recorded by the radiographer as part of the mine's protocol, namely as the ID number, height, weight, kVp and mAs. Most of the clinics require the radiographer to record the number of exposures per patient. The chest measurement or patient thickness and the patient consent form were the only parameters that were done extra by the radiographer prior to the examination. The parameters patient height and weight are classified as homogenous data, as they were almost identical parameters that were drawn from the same population. This research instrument proved to be useful as it addressed objective 2, *was to calculate the ESD for each employee with the technique parameter information recorded by the radiographer on duty* (section 1.4.2, p. 28). The only variable of the technical parameters sheet that displayed a normal distribution was patient height (cm), which was a p-value of 0.1458. If $p \geq$ than 0.05, it means the patient height variable follows a normal distribution and the data are not skewed. Patient weight (kg), kVp, mAs and patient thickness do not follow a normal distribution, and the data are skewed since the p-values were 0.0001. The patient thickness variable was also analysed with the MEANS procedure (see Table 11, p.

92). The MEANS procedure (Appendix G1 and G2) provided a technique to summarise data collection instruments to determine descriptive statistics for the variables of the technical parameters sheet. Subsequently, there was a difference between the median values of Table 11. The next step was to establish which clinics had different values from one another. A non-parametric test, the Mann-Whitney U-test, was utilised to compare the differences between the variable patient thickness amongst the four clinics.

This checklist proved to be user friendly, and all the data that needed to be collected were collected sufficiently, and addressed objective four, which was to *establish the number of chest images received per annum for individuals who are employed by four contracting and private companies* (section 1.4.2, p. 28). Nothing was changed on the sheet after the pilot study, as the checklist proved to entail everything that was needed. The checklists result in Tables 13 to 17 showed the frequency and percentage of each variable, including all four clinics. The total PA CXR, total lateral CXR, PA CXR repeats, lateral CXR repeats, other projections AP/PA, other projections lateral, other projections oblique, other repeats AP/PA, other repeats lateral, other repeats oblique, Total CXR, total other projections done and total projections done.

The formulae and calculation sheet were compiled in such a way that the researcher was able to complete the pilot study and large scale study independently. This research tool proved to be effective because it addressed objective 2, which was to *calculate the ESD for each employee with the technique parameter information recorded by the radiographer on duty*; whilst objective 3 was to *determine an estimated baseline DRL for the selected population group at four radiology practices* (section

1.4.2, p. 28). The formulae and calculations part of the research instruments were analysed by utilising the Kruskal-Wallis Test. All the variables median values (output K, SSD, SSD correction and ESD/ESE correction) had a p-value of 0.0001. With reference to Appendix G2, there was a significant difference between the median values of each clinic, so the Mann-Whitney U-test was utilised to establish which clinics were significantly different from one another. Variable output K: p-values < 0.0001 when comparing clinics to each other, meaning the variable does not follow a normal distribution and data are skewed; but clinic 1 versus clinic 4 had a p-value of 0.9483, meaning the variable follows a normal distribution and data are not skewed. Variable SSD and SSD correction p-values < 0.0001 when comparing clinics to each other, meaning the variable does not follow a normal distribution and data are skewed. For clinic 1 vs. clinic 2 p-value = 0.5217, and clinic 3 versus clinic 4 had a p-value of 0.1845, meaning the variable follows a normal distribution and data are not skewed. Variable ESD/ESE corrected p-values < 0.0001 when comparing clinics to each other, meaning the variable does not follow a normal distribution and data are skewed; but clinic 1 versus clinic 4 had p-value of 0.4422, meaning the variable follows a normal distribution and data are not skewed.

4.6 CONCLUSION

Chapter 4 demonstrated that a statistical approach of research objectives 1 and 2, which stipulated that a literature study was done on how to calculate the ESD that an adult acquires for a chest x-ray, as well as a DRL for each clinic (see sections 2.9.2 and 2.9.3); and to calculate the ESD for each employee with technique parameter information recorded by the radiographer on duty (see Appendix A1-A4: sheet 1 and

3). Each instrument was discussed separately, and contained information on how the data were accumulated and analysed, which statistical tests were used to analyse data as well as graphical presentations thereof. This chapter is important to the results of the study that was conducted.

The study demonstrated that contracted employees were referred for more chest imaging than permanent employees. 176 (44 %) contracted employees had more than one chest x-ray per annum, whilst permanent employees are referred for one chest x-ray per year. The ESD was calculated successfully for all 400 participants, and the mean ESD of each clinic was as follows: clinic 1: 0.167 mGy (19 %), clinic 2: 0.257 mGy (30 %), clinic 3: 0.332 mGy (38 %) and clinic 4: 0.116 mGy (13 %). With these ESD values the DRL of each clinic was determined. The DRL for clinic 1 was 0.204, for clinic 2 it was 0.292, for clinic 3 it was 0.391, and four clinic 4 it was 0.144 (see Appendix A1-A4: sheet 3).

The aim of the study was to calculate DRL levels at the four mining clinics, and it was determined as DRL for clinic 1 = 0.204 mGy, DRL for clinic 2 = 0.292 mGy, DRL for clinic 3 = 0.391 mGy, and DRL for clinic 4 = 0.144 mGy. These DRL values were compared to Table 6 (page 57) and section 2.10.2 (page 63), where a similar study established a DRL for a few examinations including PA chest which was 0.1 mGy. The DRL values established for this study are not much different, except for clinic 3.

The next chapter will focus on a discussion on the limitations the researcher experienced throughout the study, recommendations of the study and a final conclusion.

CHAPTER 5

LIMITATIONS, RECOMMENDATIONS AND CONCLUSION

5.1 INTRODUCTION

A research study was conducted with the aim to optimise the radiation dose for chest radiography by determining the DRL levels at four mining radiology departments and the annual number of chest x-rays that were requested.

Radiographers practice the ALARA principle throughout their practical career where they strive to keep the dose as low as reasonably achievable and limit unnecessary exposure of ionizing radiation to patients. Contracting mining employees travel from one mining site to another in certain time periods. Each time they leave one mining site they have to undergo medical screening (exit medical), and when they start on another site, another medical screening is required (initial medical) to ensure the employee meets the policy and legislation of occupational health, is healthy and fit for work and is drug, alcohol and substance free. The goal of this study was to investigate if contracted employees undergo more x-ray examinations, and to provide the mines with a dose reference level for chest radiography to use as a baseline for that specific radiology department.

This chapter provides a discussion on the overview of the study, a conclusion and a short discussion on limitations and recommendations for further research purposes.

5.2 LIMITATIONS

These were limitations that the researcher experienced throughout the study.

- The researcher found a small number of related studies done or studies that rendered similar results. The only study that could be located was an undergraduate (BTech) study that only included the DRL calculation part for a small sample size. The researcher relied on the medical physicist, as all related studies that were conducted for DRL purposes were done by using TLDs.
- The researcher envisioned to include five clinics in the data accumulation, but one clinic did not grant permission. This clinic is situated close to clinic 3, and thus a number of contracted employees are employed between these 2 clinics, meaning they conduct medical testing frequently between these 2 clinics.
- Clinic 3 granted permission at a late stage, which caused a delay in data collection, whilst the other 3 clinics, at the time, were done with data collection.
- The COVID-19 pandemic caused a delay in data collection, as 2 of the 4 clinics did not start with data collection when the National lockdown was announced in March 2020. This made the researcher change the timeline of research events and priorities were shifted. Clinic 3 only started with medical testing in October 2020. This was the reason for longer timelines found on the checklist of previous x-rays (Appendix A1-A4: sheet 2).
- The distance that the researcher had to travel between the research sites was a challenge, since the clinics are at a distance of 106 km, 70 km, 147 km and 80 km from where the researcher is based.

5.3 RECOMMENDATIONS

Recommendations of the study are as follows:

I. To publish the results in accredited journals.

II. To present the findings of the study in the faculty, and at conferences and seminars.

III. To highlight to the mining industry, the possible duplication of the routine CXR for contracting workers and possible implications of over-exposure of ionizing radiation.

IV. To extend the calculating of DRLs by including lateral CXR and the other body parts.

V. This study has potential for much broader research of all mining occupational health clinics in the Northern Cape. A study is proposed to investigate the viability of a central database to access x-ray images for all occupational health clinics.

5.4 CONTRIBUTION OF THE RESEARCH

The aim of the study was to determine DRLs for the PA chest at each clinic, and to make a positive contribution to the mines in this regard. The contribution to the mining industry to limit unnecessary x-ray examinations to contracted employees responded to objective 3 and 4, where the additional number of chest images that contracted employees received unnecessarily was established. The gap is identified in the referral procedure. A possible solution that is advocated by the researcher is to update the employee's medical file, and to add more information (obtained from the employee) to

the medical chart in the file, namely date of previous CXR as well as the site where it was done. Although not a watertight solution, it is an interim change until a long-term solution can address the communication gap. Objectives 1 and 2 were met by the researcher who conducted the literature study on how to calculate the ESD and DRL without the use of a TLD, but instead using technique parameter information. The study proved that it is possible.

A baseline DRL was determined for each clinic for the radiographers to use as a reference to ensure that employees are not over exposed. The document will be shared with each clinic as an information document on the results of the study (see Appendix H).

5.5 CONCLUSION

The research questions were answered, and the results revealed that certain contracted employees receive multiple x-rays at a clinic. The PA CXR DRL that was calculated can be used as a baseline and serve as a great contribution to the radiographers to honour the ALARA principle. Ultimately the study served as an attempt to optimise radiation protection of the contracted employees. The problem statement was addressed. It was identified that contracted employees are referred for more chest imaging procedures than permanent employees. A possible short-term solution is provided to the mines as well as the information document on the results of the study.

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APPENDICES

APPENDIX A1: Research instruments: clinic 1 (Microsoft Excel)

Appendices\Appendix A1 Clinic 1.ods

APPENDIX A2: Research instruments: clinic 2 (Microsoft Excel)

Appendices\Appendix A2 Clinic 2.ods

APPENDIX A3: Research instruments: clinic 3 (Microsoft Excel)

Appendices\Appendix A3 Clinic 3.ods

APPENDIX A4: Research instruments: clinic 4 (Microsoft Excel)

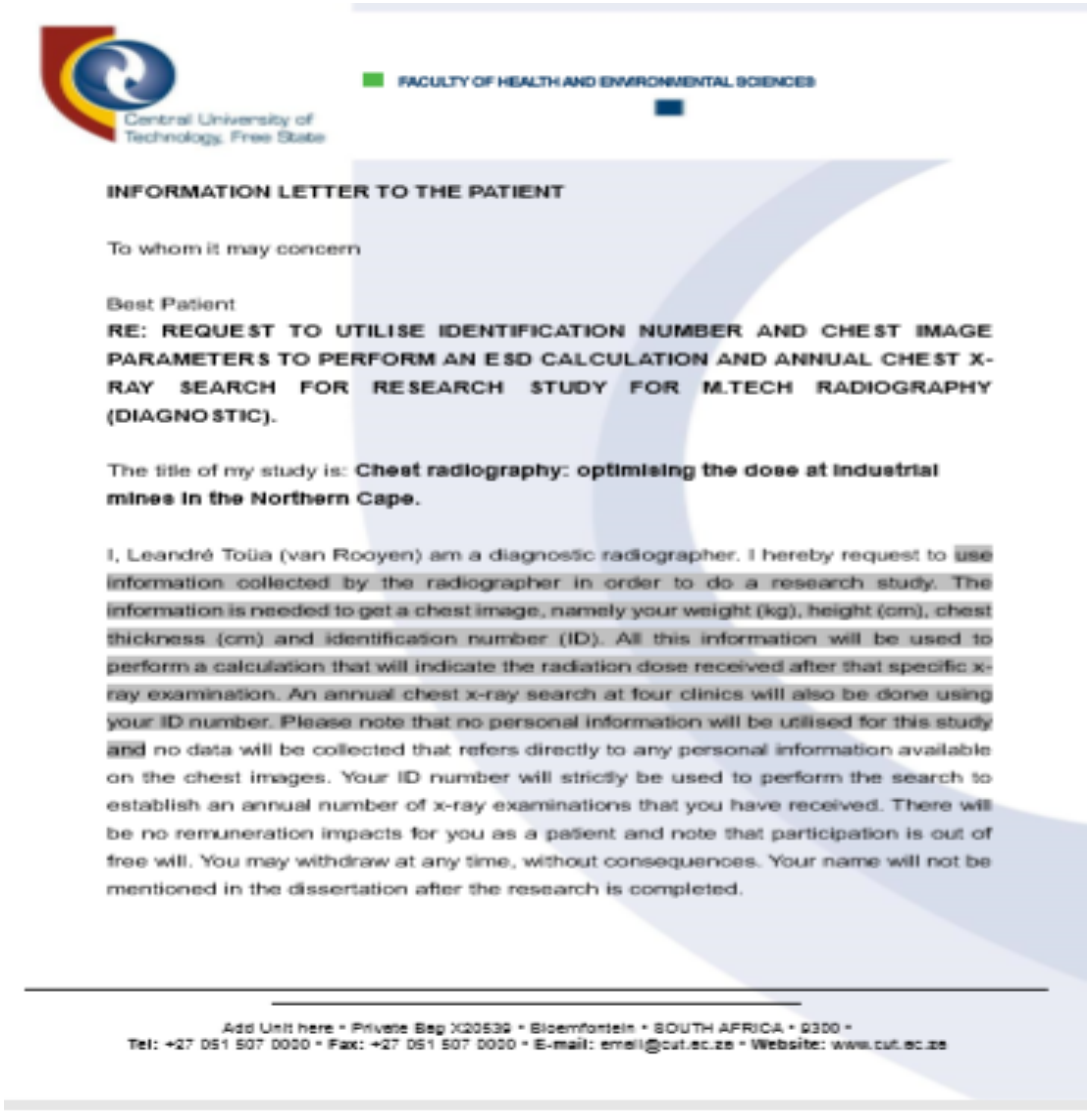
Appendices\Appendix A4 Clinic 4.ods

Example of research instrument from Clinic 1:

TECHNICAL PARAMETERS FOR CHEST X-RAYS							
PATIENT NO.	**ID NUMBER**	**PT HEIGHT (cm)**	**PT WEIGHT (kg)**	**kVp**	**mAs**	**SID (cm)**	**PT THICKNESS (cm)**
1	[redacted]	172	105,4	125	3,06	180	28
2		180,5	109,8	125	3,91	180	30
3		186	70,1	125	1,49	180	21
4		174	81,7	125	2,79	180	25
5		164	104	125	5,17	180	30
6		176	60,7	125	1,44	180	22
7		168	104,4	125	4,23	180	28,5
8		170	59,6	125	1,4	180	20,5
9		180	54,8	125	1,3	180	20,5
10		172	85,3	125	2,37	180	26,5
11		1,6	63,4	125	1,58	180	23,5
12		164	93	125	8,71	180	25,5
13		176	73,3	125	1,54	180	21,5
14		184	83,2	125	2,2	180	26,5
15		168	66,7	125	1,63	180	22,5
16		168	87,4	125	3,24	180	25
17		169	71,5	125	1,54	180	24,5
18		189	70,9	125	1,61	180	23,5
19		182	86,5	125	1,87	180	27,8
20		179	103,2	125	3,58	180	28,2
21		190,5	85,8	125	1,76	180	23
22		182	89,2	125	2,09	180	26,2
23		186	82,2	125	1,85	180	26
24		156	58,9	125	2,35	180	22
25		182	98,2	125	1,79	180	24,5
26		173	90,6	125	2,23	180	23,5
27		163	70,5	125	1,65	180	26,5

APPENDIX B: Information document for employees

[Appendices\Appendix B.pdf]



Central University of Technology, Free State

FACULTY OF HEALTH AND ENVIRONMENTAL SCIENCES

INFORMATION LETTER TO THE PATIENT

To whom it may concern

Best Patient

RE: REQUEST TO UTILISE IDENTIFICATION NUMBER AND CHEST IMAGE PARAMETERS TO PERFORM AN ESD CALCULATION AND ANNUAL CHEST X-RAY SEARCH FOR RESEARCH STUDY FOR M.TECH RADIOGRAPHY (DIAGNOSTIC).

The title of my study is: **Chest radiography: optimising the dose at industrial mines in the Northern Cape.**

I, Leandré Toûa (van Rooyen) am a diagnostic radiographer. I hereby request to use information collected by the radiographer in order to do a research study. The information is needed to get a chest image, namely your weight (kg), height (cm), chest thickness (cm) and identification number (ID). All this information will be used to perform a calculation that will indicate the radiation dose received after that specific x-ray examination. An annual chest x-ray search at four clinics will also be done using your ID number. Please note that no personal information will be utilised for this study and no data will be collected that refers directly to any personal information available on the chest images. Your ID number will strictly be used to perform the search to establish an annual number of x-ray examinations that you have received. There will be no remuneration impacts for you as a patient and note that participation is out of free will. You may withdraw at any time, without consequences. Your name will not be mentioned in the dissertation after the research is completed.

Add Unit here • Private Bag X20539 • Bloemfontein • SOUTH AFRICA • 9300 •
Tel: +27 051 507 0000 • Fax: +27 051 507 0000 • E-mail: email@cut.ac.za • Website: www.cut.ac.za

If anything is unclear to you, you may contact the researcher at any time on 072 107 0369 or vanrooyen.leandre@gmail.com. Any queries can be directed to the Health Sciences Research Ethics Committee (HSREC), E-mail: EthicsFHS@ufs.ac.za Contact number: 051 401 7794.

I trust that you will consider the above request favourably.

Yours sincerely
LM Toûa (van Rooyen)

Signature of the researcher

19 May 2019
Date

APPENDIX C: Consent document for employees

[Appendices\Appendix C.pdf]

INFORMED CONSENT

Patient

RE: REQUEST TO USE IDENTIFICATION NUMBERFOR ANNUAL NUMBER OF CHEST X-RAYS FOR RESEARCH STUDY FOR M. TECH RADIOGRAPHY (DIAGNOSTIC)

I, _____ (Name and surname) read and understand the information letter with regards to the data collection of 100 chest images. I give consent that the radiographer may record the technical parameters regarding the chest examination as stated and explained in the information letter. I hereby give consent to the researcher to use my ID number to collect the data truthfully.

Yours sincerely

LM Toüa (van Rooyen)

_____ _____

Signature of the researcher Signature of patient

_____

Date

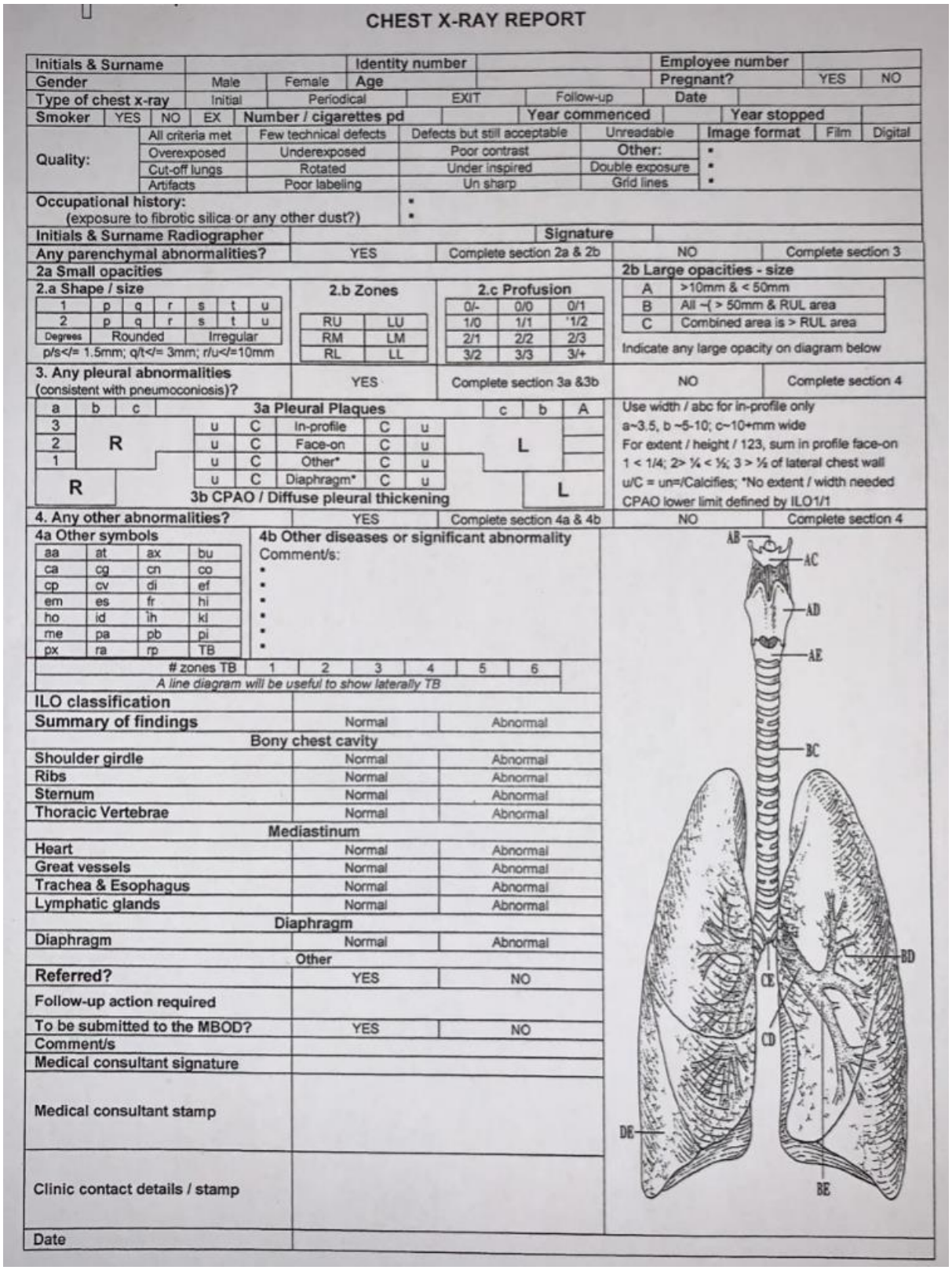
Approved by Health Sciences Research Ethics Committee (HSREC)

E-mail: EthicsFHS@ufs.ac.za

Contact number: 051 401 7794

APPENDIX D: Template of the chest x-ray report

[Appendices\Appendix D.JPG]



CHEST X-RAY REPORT

Initials & Surname			Identity number			Employee number	
Gender	Male	Female	Age			Pregnant?	YES / NO
Type of chest x-ray	Initial	Periodical	EXIT	Follow-up		Date	
Smoker	YES / NO / EX	Number / cigarettes pd		Year commenced		Year stopped	
Quality:	All criteria met	Few technical defects	Defects but still acceptable	Unreadable	Image format	Film / Digital	
	Overexposed	Underexposed	Poor contrast	Other:			
	Cut-off lungs	Rotated	Under inspired	Double exposure			
	Artifacts	Poor labeling	Un sharp	Grid lines			

Occupational history: (exposure to fibrotic silica or any other dust?)

Initials & Surname Radiographer | Signature

Any parenchymal abnormalities? YES → Complete section 2a & 2b | NO → Complete section 3

2a Small opacities

2.a Shape / size

1	p	q	r	s	t	u	
2	p	q	r	s	t	u	
Degrees	Rounded			Irregular			

p/s</= 1.5mm; q/t</= 3mm; r/u</=10mm

2.b Zones

RU	LU
RM	LM
RL	LL

2.c Profusion

0/-	0/0	0/1
1/0	1/1	1/2
2/1	2/2	2/3
3/2	3/3	3/+

2b Large opacities - size

A	>10mm & < 50mm
B	All ~(> 50mm & RUL area
C	Combined area is > RUL area

Indicate any large opacity on diagram below

3. Any pleural abnormalities (consistent with pneumoconiosis)? YES → Complete section 3a &3b | NO → Complete section 4

3a Pleural Plaques

a	b	c						c	b	A
3	R		u	C	In-profile	C	u	L		
2			u	C	Face-on	C	u			
1			u	C	Other*	C	u			
R			u	C	Diaphragm*	C	u		L	

3b CPAO / Diffuse pleural thickening

Use width / abc for in-profile only
a~3.5, b ~5-10; c~10+mm wide
For extent / height / 123, sum in profile face-on
1 < 1/4; 2> ¼ < ½; 3 > ½ of lateral chest wall
u/C = un=/Calcifies; *No extent / width needed
CPAO lower limit defined by ILO1/1

4. Any other abnormalities? YES → Complete section 4a & 4b | NO → Complete section 4

4a Other symbols

aa	at	ax	bu
ca	cg	cn	co
cp	cv	di	ef
em	es	fr	hi
ho	id	ih	kl
me	pa	pb	pi
px	ra	rp	TB

4b Other diseases or significant abnormality

Comment/s:

# zones TB	1	2	3	4	5	6

A line diagram will be useful to show laterally TB

	Normal	Abnormal
ILO classification		
Summary of findings		
Bony chest cavity		
Shoulder girdle	Normal	Abnormal
Ribs	Normal	Abnormal
Sternum	Normal	Abnormal
Thoracic Vertebrae	Normal	Abnormal
Mediastinum		
Heart	Normal	Abnormal
Great vessels	Normal	Abnormal
Trachea & Esophagus	Normal	Abnormal
Lymphatic glands	Normal	Abnormal
Diaphragm		
Diaphragm	Normal	Abnormal
Other		
Referred?	YES	NO
Follow-up action required		
To be submitted to the MBOD?	YES	NO
Comment/s		
Medical consultant signature		
Medical consultant stamp		
Clinic contact details / stamp		
Date		

APPENDIX E: Approval from Health Sciences Research Ethics Committee

Appendices\Appendix E.pdf

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

13-Aug-2019

Dear **Ms Leandré Madelené Toüa**

Ethics Clearance: **Chest radiography: optimising the dose at industrial mines in the Northern Cape**
Principal Investigator: **Ms Leandré Madelené Toüa**
Department: **Radiography - CUT**
APPLICATION APPROVED

Please ensure that you read the whole document

With reference to your application for ethical clearance with the Faculty of Health Sciences, I am pleased to inform you on behalf of the Health Sciences Research Ethics Committee that you have been granted ethical clearance for your project.

Your ethical clearance number, to be used in all correspondence is:**UFS-HSD2019/0520/2708**

The ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the HSREC for approval to ensure we are kept up to date with your progress and any ethical implications that may arise. This includes any serious adverse events and/or termination of the study.

A progress report should be submitted within one year of approval, and annually for long term studies. A final report should be submitted at the completion of the study.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | E: ethicsfhs@ufs.ac.za
IRB 00006240; REC 230408-011; IORG0005187; FWA00012784
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

APPENDIX F1: Approval from mine 1

[Appendices\Appendix F1.pdf]

FACULTY OF HEALTH AND ENVIRONMENTAL SCIENCES

Central University of
Technology, Free State

REQUEST TO CONDUCT A RESEARCH STUDY

15 A Cowburn Street
Kuruman
8460

[redacted]

To whom it may concern: Mr [redacted]

Best Mr.

RE: REQUEST TO CONDUCT RESEARCH STUDY FOR DEGREE MASTERS RADIOGRAPHY (DIAGNOSTIC)

I,Leandré Toüa am a diagnostic radiographer currently employed at [redacted] hospital. I hereby request permission to conduct research in the radiology department of [redacted] Mine's occupational health clinic in the Radiology department, Northern Cape, South Africa.

The title of my study is: Chest radiography: optimising the dose at industrial mines in the Northern Cape

- Add Unit here Private Bag X20539 Bloemfontein SOUTH AFRICA 9300
+27-051 507 0000 Fax: +27 507 0000 E-mail: email@cut.ac.za Website: www.cut.ac.za

APPENDIX F2: Approval from mine 2

Appendices\Appendix F2.pdf

CONFIDENTIAL*

15 A Cowburn Street
Kuruman
8460

Ms LM Toüa (van Rooyen)

07/08/2019

APPROVAL TO CONDUCT RESEARCH STUDY FOR M. TECH
RADIOGRAPHY (DIAGNOSTIC) AT [redacted]

I am pleased to inform you that you request to conduct research study for M. Tech diagnostic radiography has been approved. Approval is granted under the following conditions:

- Ensure complete anonymity of the employees selected for the study
- There will be no mention of [redacted] mine in your study i.e. Reseach site remains anonymous
- Ensure protection of [redacted] mine's intellectual property.

- You sign a Non — disclosure agreement prior to commencing your study
- The employees selected give written informed consent
- There will be no remuneration impacts for [redacted] mine operations as you, the researcher will be responsible for travel and financial needs for the study.
- [redacted] mine holds the right to withdraw from the study at any time without consequences to the company after withdrawal.

Yours sincerely

Dr. [redacted]

AKNOWLEDGED NOT AKNOWLEDGED

SIGNATURE: DATE:

Ltoüa 08.08.2019

APPENDIX F3: Approval from mine 3

[Appendices\Appendix F3.pdf]

FACULTY OF HEALTH AND ENVIRONMENTAL SCIENCES

Central University of
Technology, Free State

REQUEST TO CONDUCT A RESEARCH STUDY

15 A Cowburn Street
Kuruman
8460

[redacted]

To whom it may concern: Mr [redacted]

Best Mr

RE: REQUEST TO CONDUCT RESEARCH STUDY FOR DEGREE MASTERS RADIOGRAPHY (DIAGNOSTIC)

I, Leandré Toüa (van Rooyen) am a diagnostic radiographer currently employed at [redacted] hospital I hereby request permission to conduct research in the radiology department of [redacted] occupational health clinic at [redacted], Northern Cape, South Africa.

The title of my study is: Chest radiography: optimising the dose at industrial mines in the Northern Cape

Add Unit here Private Bag Bloemfontein • SOUTH AFRICA • 9300 ,
Tel: +27 051 507 0000 Fax: +27 051 507 0000 E-mail: email@cut.ac.za Website: www.cut.ac.za

APPENDIX F4: Approval from mine 4

[Appendices\Appendix F4.pdf]

FACULTY OF HEALTH AND ENVIROMENTAL SCIENCES

Central University of
Technology, Free State

REQUEST TO CONDUCT A RESEARCH STUDY

15 A Cowburn Street
Kuruman
8460

[redacted]

To whom it may concern: Mr. [redacted]

Best Mr.

RE: REQUEST TO CONDUCT RESEARCH STUDY FOR DEGREE MASTERS RADIOGRAPHY (DIAGNOSTIC)

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APPENDIX G1: MEANS Procedure for Inter-quartile range (IQR) for the technical parameters

[Appendices\Appendix G1.pdf]

MEANS Procedure: Inter-quartile range (IQR)										
Clinic	N Obs	Variables	N	Median	Lower Quartile 25th percentile	Upper Quartile 75th percentile	Mean	Std Dev	Min	Max
1	100	Pt height(cm)	100	171.00	165.50	178.50	171.58	9.88	148.00	190.50
	100	Pt weight(kg)	100	76.80	68.00	88.50	78.31	14.85	49.30	116.70
	100	kVp	100	125.00	125.00	125.00	125.00	0.00	125.00	125.00
	100	mAs	100	2.22	1.76	2.86	2.39	0.99	1.24	8.71
2	100	Pt height(cm)	100	171.00	166.00	176.25	170.75	8.39	151.00	193.00
	100	Pt weigh(kg)	100	80.45	67.35	96.80	91.59	86.59	44.40	925.00
	100	kVp	100	123.00	123.00	123.00	122.76	1.18	117.00	123.00
	100	mAs	100	4.00	3.00	4.00	3.64	0.74	2.50	5.00
3	100	Pt height(cm)	100	169.00	164.00	175.00	169.51	8.64	149.00	197.00
	100	Pt weight(kg)	100	79.80	66.65	98.45	90.09	66.53	46.00	710.85
	100	kVp	100	120.00	120.00	120.00	120.00	0.00	120.00	120.00
	100	mAs	100	5.00	4.00	6.30	5.32	1.48	3.20	10.00
4	100	Pt height(cm)	100	169.00	163.00	175.00	168.62	9.80	147.00	193.00
	100	Pt weight(kg)	100	75.00	64.40	87.00	77.44	18.68	40.30	141.70
	100	kVp	100	106.00	103.00	109.00	106.84	5.46	98.00	124.00
	100	mAs	100	2.10	1.90	2.40	2.31	0.59	1.40	4.30

APPENDIX G2: MEANS Procedure: Inter-quartile range (IQR) for section 2 of the formulae and calculations sheet

[Appendices\Appendix G2.pdf]

MEANS Procedure: Inter-quartile range (IQR)

Clinic	Variables	N	Median	Lower Quartile 25th percentile	Upper Quartile 75th percentile	Mean	Std Dev	Min	Max
1	Output K	100	0.3633	0.2878	0.4682	0.3920	0.1628	0.2034	1.4284
	SSD (cm)	100	154.2500	151.9000	156.0000	153.7910	3.1025	143.0000	160.5000
	SSD correction	100	0.4203	0.4109	0.4334	0.4233	0.0169	0.3882	0.4890
	ESD/ESE correction	100	0.1548	0.1179	0.2023	0.1675	0.0742	0.0799	0.6142
2	Output K	100	0.6560	0.4920	0.6560	0.5970	0.1212	0.4100	0.8200
	SSD (cm)	100	153.0000	150.2500	156.5000	153.2230	4.2473	141.50000	161.0000
	SSD correction	100	0.4272	0.4083	0.4430	0.4269	0.0241	0.3858	0.4994
	ESD/ESE correction	100	0.2730	0.2035	0.2916	0.2568	0.0624	0.1582	0.4095
3	Output K	100	0.8200	0.6560	1.0332	0.8725	0.2426	0.5248	1.6400
	SSD (cm)	100	156.0000	154.0000	158.0000	156.0800	2.6273	151.0000	162.0000
	SSD correction	100	0.4109	0.4006	0.4217	0.4108	0.0139	0.3810	0.4386
	ESD/ESE correction	100	0.3370	0.2661	0.4301	0.3611	0.1109	0.2050	0.7098
4	Output K	100	0.3444	0.3116	0.3936	0.3782	0.0967	0.2296	0.7052
	SSD (cm)	100	157.0000	155.0000	159.0000	156.5950	2.9786	149.0000	166.0000
	SSD correction	100	0.4057	0.3956	0.4162	0.4082	0.0156	0.3629	0.4504
	ESD/ESE correction	100	0.1415	0.1186	0.1628	0.1555	0.0454	0.0886	0.3061

APPENDIX H: Information document

[Appendices\Appendix H.pdf]

Information document for study titled; chest radiography: Optimising the dose at industrial mines in the Northern Cape

Leandré Toûa (Researcher)
Contact Information:
0721070369
vanrooyen.leandre@gmail.com

The aim of this study was to optimise the radiation dose for chest radiography by determining the DRL levels at 4 mining radiology departments and the annual number of chest x-rays requested.

Before a DRL value can be determined, an entrance surface dose (ESD) must be calculated. ESD is defined as the measurement of an ionizing radiation dose that is absorbed by the skin once it reaches the patient. The ESD is measured by the unit Milligray (mGy). The ESD was calculated with technical parameter information obtained prior to the chest x-ray and was done individually. Once the ESD was calculated, the 3rd quartile (DRL) was determined. DRL is defined as dose levels in medical radio-diagnostic practice and was introduced by the International Commission of Radiological Protection (ICRP) in 1990. DRLs are only applicable to medical radiation exposure, not to public and occupational exposure.

In this study the DRL was determined for posterior-anterior (PA) chest x-ray to serve as a baseline for the radiographer as the ultimate goal is to practice the ALARA (As Low As Reasonably Achievable) principle. Table 1 below is a summary of the mean of the technical parameters that were used for the calculation.

MEAN	CLINIC 1	CLINIC 2	CLINIC 3	CLINIC 4
HEIGHT (CM)	168.39	170.75	169.51	168.62
WEIGHT (KG)	78.31	91.60	89.03	77.44
PATIENT THICKNESS (CM)	24.21	24.78	21.92	21.41
ESD	0.167	0.257	0.361	0.156
DRL	0.204	0.252	0.425	0.201

This document serves just an indication of part of the research that was done. The results of the study can be utilised to minimize unnecessary radiation dose to patients as the radiographers can use the DRL value as a baseline when performing chest radiography.

The researcher will be available for questions at all times.

APPENDIX I: Language edit proof of dissertation title and dissertation

LINGPRO LINGUISTIC REVISION SERVICES

(Trading as Laurika's Photography)

24 years' experience

8 March 2021

Attention: Dr B van der Merwe

Senior Lecturer: Radiography

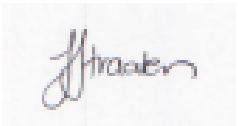
Faculty of Health and Environmental Sciences

CUT

DECLARATION: LINGUISTIC REVISION OF DISSERTATION

I, Dr Laurika van Straaten, hereby declare that I am a qualified and professional language practitioner, and that I have linguistically revised the dissertation of student Ms L Toûa, student number 211059072, titled "Chest radiography: optimising the dose at industrial mines in the Northern Cape", towards fulfilling the requirements for the Master of Radiography (Diagnostic) at the Central University of Technology, Free State.

Yours sincerely



DR L VAN STRAATEN

LINGUIST

BA (Languages)(UNISA)(1995); BA Hons (Translation Studies)(UNISA)(1999); MA (HES) (UFS)(2014); PhD (HES)(UFS)(2019)

APPENDIX J: Letter from the statistician

Maryn Viljoen
Statistics Consulting Services

082 823 5731
maryn.viljoen1@gmail.com

Protocol & research methodology consultation | Ethical consultation | Database construction & capturing of data
Analysing data using statistical software packages (SAS Version 9.2) | Statistics consultation services to analyse and interpret data
Conveys results with statistical tables & figures where needed

4 December 2020

To whom it may concern

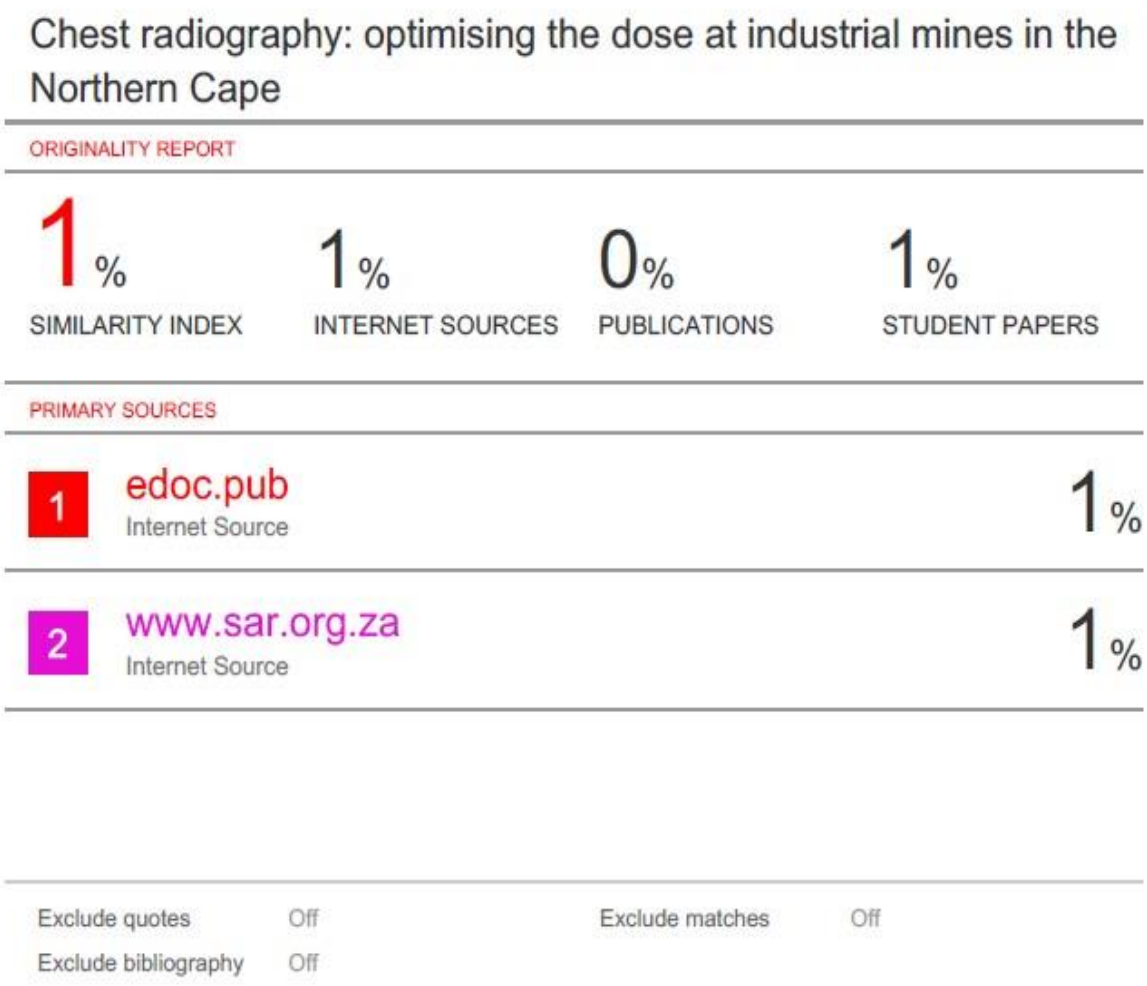
Title: "Chest radiography: The annual number and the individual diagnostic reference level at industrial mines in the Northern Cape."

Researcher: L. van Rooyen
M. Tech Radiography (Diagnostic)
Department of Clinical Sciences: Programme Radiography
Faculty of Health and Environmental Sciences
Central University of Technology, Free State

I was the biostatistician responsible for the analysis of the data.

Maryn Viljoen
M.Sc. Risk Analysis (UFS)
maryn.viljoen1@gmail.com
082 82 35 731

APPENDIX K: Plagiarism report



Chest radiography: optimising the dose at industrial mines in the Northern Cape

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