MEASUREMENT OF RADIATION DOSES TO PATIENTS UNDERGOING ROUTINE X-RAY EXAMINATIONS IN WINDHOEK, NAMIBIA TO DEVELOP DIAGNOSTIC REFERENCE LEVELS.

by

EDWIN RALPH DANIELS

Thesis submitted in fulfilment of the requirements for the degree

Master of Science: Radiography

in the Faculty of Health and Wellness Sciences

at the Cape Peninsula University of Technology

Supervisor: Ms. F Davidson
Co-supervisor: Mr. A Speelman

Bellville campus
November 2019

CPUT copyright information
The thesis may not be published either in part (in scholarly, scientific or technical journals), or as a whole (as a monograph), unless permission has been obtained from the University.

DECLARATION

I, Edwin Ralph Daniels declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

11 November 2019

Signed **Date**

ABSTRACT

Background

The National Radiation Protection Authority (NRPA) of Namibia was tasked in 2005 by the IAEA under the project RAF9/033 to develop diagnostic reference levels for conventional radiographic examinations. To date, no study that examines the radiation dose in diagnostic radiology has been undertaken in Namibia and radiation protection of patients may not be optimised. Diagnostic reference levels acts as a quality assurance tool that identifies procedures or activities where patient doses are high.

Objectives

The purpose of the study was to develop local Diagnostic Reference Levels (LDRL's) for commonly performed conventional radiography projections in Windhoek, Namibia.
The objectives of the study were to:

- Measure KAP (Kerma Area Product) for postero-anterior (PA) and lateral (LAT) chest, antero-posterior (AP) and LAT lumbar spine, AP pelvis, and PA and LAT skull projections.
- Calculate entrance skin and effective doses from the recorded KAP values.
- To compare the KAP, entrance skin doses and effective doses with internationally established reference levels for the same procedure as well as similar studies in Africa.
- Develop conversion coefficients from KAP values for estimation of effective and skin doses in clinical practice.

Method

In this study, three (3) hospitals located in Windhoek, Khomas region were selected and KAP measurements were recorded on 218 patients with a mean weight of 70±5kg.The entrance skin, and effective doses were calculated through Monto Carlo simulations by entering the geometric data, exposure parameters and equipment specifications and KAP values into PCXMC 2.0 software (Finland). Diagnostic Reference levels (75^{th} percentile), entrance skin doses (ESDs) and effective doses were calculated for anterior (PA) and lateral (LAT) chest, antero-posterior (AP) and LAT lumbar spine, AP pelvis, and PA and LAT skull projections.

Results

The 75th percentiles of the entrance skin doses combined for PA and LAT chest, AP and LAT Lumbar spine, AP Pelvis and PA and LAT skull were, 0.0333 mSv, 0.0663 mSv, 0.1970 mSv, 0.2740 mSv, 0.2497 mSv, 0.0922 mSv, and 0.0584 mSv respectively. The effective doses for the same procedures were 0.0545 mSv, 0.0942, 0.3792, 0.2970 mSv, 0.3061 mSv, 0.0267 and 0.0283 respectively. The highest skin dose was recorded for the lateral lumbar spine projection while the highest effective dose was measured for AP lumbar spine projection.

Conclusion

The ESD's in this study were much lower than previously reported values. However the effective doses were generally similar and compare well with previous studies. On the basis of the results it can be concluded that the effective dose is a better dosimetry quantity than ESD to determine deterministic effects of radiation.

ACKNOWLEDGEMENTS

I wish to thank:

- First and foremost, my Creator and Sustainer for His protection, wisdom and sustainability. For his will shall be done.
- Mrs.F. Davidson (Supervisor) for her professional guidance, direction and, pastoral nature during this research project. Thank you for taking up the challenge and accepting the supervisory role. Your dedication and supervisory skills made this project a success.
- Mr. A. Speelman (Co-supervisor) for his engagement and scientific advice.
- Dr. T. Kotze (Medical Physicist), who took up the challenge to provide statistical advice and partner with us at no extra cost. Your guidance and advice were an inspiration to finish this project.
- Ms. V. Uushona-Mikka for availing the dose area product meter and provision of technical advice regarding the research project. Ms. Uuhona-Mikka is a member of the scientific committee at the National Radiation Protection Authority Namibia.
- The management and entire radiology staff of Katutura Intermediate Hospital, Medical Imaging and Windhoek Central Hospital as well as students who permitted me to conduct this study in their radiology department. A special thanks to Mr. A Maretha and Ms. V Naimas, for assistance with data collection.
- Ms. A. Claasen (Senior Library assistant) for her moral and emotional support as well as providing assistance with locating the necessary literature.
- To my parents, siblings and friends. Your prayers were stronger than mine. Thank you for keeping me grounded, all prayers have been answered according to His Will.
- Last but not least, the financial assistance of the University of Namibia towards this research project is acknowledged. Opinions expressed in this thesis and the conclusions arrived at, are those of the author and, and not necessarily to be attributed to the University of Namibia.

DEDICATION

This thesis is dedicated to my family, through your support and prayers the road travelled was less challenging.

TABLE OF CONTENTS

Declaration ii
Abstract iii
Acknowledgements v
Dedication vi
List of figures ix
List of tables ix
List of appendices x

CHAPTER 1: INTRODUCTION

1.1 Background and rationale 1
1.2 Statement of the problem 3
1.2.1 Null hypothesis: 4
1.3 Significance of the study 4
1.4 Overview of the methodology 4
1.5 Delimitations 5
1.6 Introduction to the structure of the Thesis 5
Chapter 2 Literature review
Chapter 3 Research Methodology
Chapter 4 Research findings
Chapter 5 Discussion and conclusion

CHAPTER 2: LITERATURE REVIEW

2.1 Principles of radiation protection 7
2.1.1 Justification 7
2.1.2 Optimisation 7
2.1.3 Dose limitation 8
2.2 Biological effects of radiation 8
2.2.1 Stochastic effects 8
2.2.2 Non stochastic effects 9
2.3 Quantities for patient dosimetry 9
2.3.1 Absorbed dose (D) 9
2.3.2 Entrance skin dose (ESD) 9
2.3.3 Effective dose (E) 10
2.4 Legislation on diagnostic reference levels (DRL's) 10
2.5 Tools used to measure radiation dose 11
2.5.1 Kerma Area Product (KAP) meter 12
2.5.2 Thermoluminescent dosimeters 13
2.5.3 Mathematical method using an ionisation chamber 14
2.5.4 Monto Carlo Simulations 14
2.6 Diagnostic reference levels comparison 15
2.7 Dose optimising strategies 16
2.7.1 Tube potential energy (kVp) 16
2.7.2 Tube current (mA) 17
2.7.3 Exposure time 17
2.7.4 Radiation quantity (mAs) 17
2.7.5 Collimation 17
2.7.6 Source to skin distance (SID) 18
2.7.7 Automatic Exposure Control (AEC) 18
2.7.8 Equipment type 18

2.8 Conversion coefficients 18

CHAPTER 3: METHODOLOGY

3. Introduction 20
3.1 Research design 20
3.1.1 Site Selection 20
3.1.2 Equipment selection 22
3.1.3 Study population 25
3.1.4 Sampling of conventional radiography procedures 25
3.1.5 Inclusion criteria 25
3.1.6 Exclusion criteria 26
3.1.7 Data collection procedure 26
3.2 Research assumptions 29
3.3 Dose calculations 29
3.4 Delimitation of the research 30
3.5 Reliability and validity of the research instrument 31
3.6 Sources of uncertainty 31
3.7 Pilot study 31
3.8 Research Ethics 32
3.9 Data analysis 33
3.9.1 Linear regression 33
3.9.2 Correlation 33
3.9.3 Co-efficient of determination, R^2 33
3.9.4 Chauvenet's criterion test 34
3.9.5 Pearson's Co-efficient of skewness 34
3.10 Summary of Chapter 35

CHAPTER 4: RESULTS

4.1 Chest projections 36
4.2 Lumbar spine projections 38
4.3 Pelvis projections 40
4.4 Skull projections 42

CHAPTER 5: DISCUSSION

5.1 Diagnostic reference levels (DRLs) 46
5.1.1 Chest radiography 46
5.1.2 Lumbar spine radiography 47
5.1.3 Pelvis 48
5.1.4 Skull 49
5.1.5 Comparison of local DRLs with international values 50
5.2 Effective doses 50
5.3 Conversion Factors 50
5.4 Limitations 51
5.5 Conclusion and recommendations 51

REFERENCES 52

LIST OF FIGURES

Figure 2.1	KAP meter mounted on the x-ray collimator at one of the research sites	13
Figure 3.1	Map of Namibia illustrating, the research site	21
Figure 3.2	Philips Duradiagnost at research site 1	23
Figure 3.3	Philips Duradiagnost controls and display monitor at research site 1	23
Figure 3.4	Siemens Multix Fution Max RF 80 at research site 2	23
Figure 3.5	Siemens Multix Fution Max RF 80 controls and display at research site 2	24
Figure 3.6	Philips Duradiagnost 4 at research site 3	24
Figure 3.7	Philips Duradiagnost 4 controls and display at research site 3	24
Figure 4.1	Linear fit for PA chest projections comparing skin dose and KAP values at the three research sites	38
Figure 4.2	Linear fit for LAT chest projections comparing skin dose and KAP values at the three research sites	38
Figure 4.3	Linear fit for AP Lumbar spine projections comparing skin dose and KAP values at the three research sites	40
Figure 4.4	Linear fit for LAT Lumbar spine projections comparing skin dose and KAP values at the three research sites	40
Figure 4.5	Linear fit for AP Pelvis projections comparing skin dose and KAP values at the three research sites	42
Figure 4.6	Linear fit for PA skull projections comparing skin dose and KAP values at the three research sites	43
Figure 4.7	Linear fit for LAT Skull projections comparing skin dose and KAP values at the three research sites	44

LIST of TABLES

Table 2.1	Comparison of Entrance Skin Doses (ESDs) for the seven projections	15
Table 3.1	Specifications regarding x-ray equipment at different study sites	22
Table 3.2	Summary of patient attributes and exposure parameters used at the different study sites	26
Table 3.3	Estimated field size of image receptors for the different x-ray examinations	30
Table 3.4	Parameters selected for the Monto Carlo programme for the different radiographic projections	30
Table 4.1	KAP, skin and effective doses for Chest projections	37
Table 4.2	KAP, skin and effective doses for Lumbar spine projections	39
Table 4.3	KAP, skin and effective doses for Pelvis projections	41
Table 4.4	KAP, skin and effective doses for Skull projections	43
Table 4.5	Conversion coefficients for PA and lateral LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull projections	44
Table 5.1	Local DRLs for chest projections	46
Table 5.2	Local DRLs for lumbar spine projections	47
Table 5.3	Local DRLs for pelvis projections	48
Table 5.4	Local DRLs for skull projections	49

APPENDICES

Appendix 1: RAF9/033 Project Request 57
Appendix 2: Letter of Permission: Permanent Secretary 58
Appendix 3: Letter of Permission: Medical Imaging 61
Appendix 4: Letter of Permission: National Radiation Protection Authority 64
Appendix 5: Equipment related data for each x-ray room 67
Appendix 6: Patient related data to be completed for each patient 69
Appendix 7: Calibration certificate VACUDAP 71
Appendix 8: Input data PA chest hospital 1 72
Appendix 9: Input data LAT chest hospital 1 73
Appendix 10: Input data PA chest hospital 2 74
Appendix 11: Input data LAT chest hospital 2 75
Appendix 12: Input data PA chest hospital 3 76
Appendix 13: Input data LAT chest hospital 3 77
Appendix 14: Input data AP lumbar spine hospital 1 78
Appendix 15: Input data LAT lumbar spine hospital 1 79
Appendix 16: Input data AP lumber spine hospital 2 80
Appendix 17: Input data LAT lumbar spine hospital 2 81
Appendix 18: Input data AP lumbar spine hospital 3 82
Appendix 19: Input data LAT lumbar spine hospital 3 83
Appendix 20: Input data AP pelvis hospital 1 84
Appendix 21: Input data AP pelvis hospital 2 85
Appendix 22: Input data AP pelvis hospital 3 86
Appendix 23: Input data PA skull hospital 1 87
Appendix 24: Input data LAT skull hospital 1 88
Appendix 25: Input data PA skull hospital 2 89
Appendix 26: Input data LAT skull hospital 2 90
Appendix 27: Input data PA skull hospital 3 91
Appendix 28: Input data LAT skull hospital 3 92
Appendix 29: Uncertainty of KAP meter 93
Appendix 30: Correction Curve KAP meter 94
Appendix 31: Correction factors across different kVp's 95
Appendix 32: Ethics certificate CPUT 96
Appendix 33: Ethics certificate CPUT 97
Appendix 34: Ethics certificate CPUT 98
Appendix 35: Approval Letter Permanent Secretary MOHSS 99
Appendix 36: Support Letter NRPA 100
Appendix 37: Approval Letter Medical Imaging 101
Appendix 38: Patient information leaflet and consent form 102
Appendix 39: Linear & Exponential Fit PA chest hospital 1 107
Appendix 40: Linear & Exponential Fit LAT chest hospital 1 108
Appendix 41: Linear & Exponential Fit PA chest hospital 2 109
Appendix 42: Linear & Exponential Fit LAT chest hospital 2 110
Appendix 43: Linear & Exponential Fit PA chest hospital 3 111
Appendix 44: Linear & Exponential Fit LAT chest hospital 3 112
Appendix 45: Linear & Exponential Fit AP lumbar spine hospital 1 113
Appendix 46: Linear & Exponential Fit LAT lumbar spine hospital 1 114
Appendix 47: Linear & Exponential Fit AP lumbar spine hospital 2 115
Appendix 48: Linear & Exponential Fit LAT lumbar spine hospital 2 116
Appendix 49: Linear & Exponential Fit AP lumbar spine hospital 3 117
Appendix 50: Linear & Exponential Fit LAT lumbar spine hospital 3 118
Appendix 51: Linear & Exponential Fit AP pelvis hospital 1 119

Appendix 52: Linear & Exponential Fit AP pelvis hospital 2 120
Appendix 53: Linear & Exponential Fit AP pelvis hospital 3 121
Appendix 54: Linear & Exponential Fit PA skull hospital 1 122
Appendix 55: Linear & Exponential Fit LAT skull hospital 1 123
Appendix 56: Linear & Exponential Fit PA skull hospital 2 124
Appendix 57: Linear & Exponential Fit LAT skull hospital 2 125
Appendix 58: Linear & Exponential Fit PA skull hospital 3 126
Appendix 59: Linear & Exponential Fit LAT skull hospital 3 127
Appendix 60: Input data PA chest all three hospitals combined 128
Appendix 61: Input data LAT chest all three hospitals combined 129
Appendix 62: Input data AP lumbar spine all three hospitals combined 130
Appendix 63: Input data LAT lumbar spine all three hospitals combined 131
Appendix 64: Input data AP pelvis all three hospitals combined 132
Appendix 65: Input data PA skull all three hospitals combined 133
Appendix 66: Input data LAT skull all three hospitals combined 134
Appendix 67: CPUT plagiarism review 135
Appendix 68: Permission to use map in dissertation 145

CHAPTER 1

1.1 Background and rationale

Over the past century, ionising radiation has been readily applied in medicine and has now become an indispensable diagnostic tool to evaluate patient's health (UNSCEAR, 2000). Since the discovery of x-rays in 1895, x-ray equipment has undergone various changes with computed and digital imaging systems been introduced and having replaced traditional film-screen systems. It is therefore not surprising that radiation exposure from x-ray examinations has become the largest artificial source of radiation exposure (Sonowane et al., 2010). In the year 2000 it was reported that, medical radiation exposure in developed countries constituted about 50% of global exposure (UNSCEAR, 2000).

The benefits resulting from medical imaging cannot be overstated. However, exposure to ionising radiation has the potential to cause detrimental health effects. These effects are classified as either stochastic or non-stochastic (Kamiya et al., 2015). Stochastic effects are also known as probabilistic, where the incidence, but not severity of appearance, is proportional to the radiation dose received. These effects occur at low doses and are related to the damage to the genetic material at cellular level. Stochastic effects have no threshold dose; examples include heredity diseases (Kamiya et al., 2015). Non stochastic effects are also referred to as deterministic effects and occur once a threshold radiation dose is received. The degree of injury depends on three factors; absorbed dose, dose rate and the quality of radiation. These effects can have either a linear or exponential response to the radiation dose received. Non stochastic effects are further divided into early and late effects. Examples of early effects include haemorrhagic diarrhoea, anaemia, leucopoenia, erythema, and epilation. Late effects comprises cataracts, cardiovascular disorders and necrosis (Kamiya et al., 2015).

In a universal effort to protect patients as well as health professionals against the harmful effects of ionizing radiation, the International Atomic Energy Agency (IAEA) published its Basic Safety Standards (BSS) in 1996 (IAEA, 1996). The BSS is based on three cardinal principles, namely, justification, optimisation and dose limitation (IAEA, 1996).

In radiography, justification is the process where radiological requests are evaluated to ascertain the diagnostic efficacy of the procedure based on the clinical history of the patient. (Vom & Williams, 2017). Optimisation of radiation protection comprises the application of different radiographic techniques and imaging parameters in an effort to minimize radiation dose to

patients without compromising image quality. Clinically this implies that radiographers adjust and select imaging parameters with reference to the patient's body habitus while maintaining diagnostic quality (Freitas & Yoshimura, 2009). A quality diagnostic radiograph therefore represents a visual appreciation of the patient's anatomy under examination sufficient to make a clinical diagnosis (Vom & Williams, 2017).

In radiography dose limitation is guided by the As Low As Reasonably Achievable (ALARA) principle. According to the Dosimetry Working Party (DWP) of the Institute of Physical Sciences in Medicine of the College of Radiographers in the United Kingdom (UK), radiographers are responsible for the comfort of patients during radiological procedures (DWP, 1992). As a result, radiographers should be concerned about radiation protection and radiation dose when selecting exposure parameters during radiological procedures. Therefore, radiographers should keep radiation doses as low as reasonably achievable (ALARA) during radiological procedures. It is against this background that diagnostic reference levels were introduced as an indicator for medical exposure (IAEA, 2006), encouraging radiographers to minimise radiation dose and optimise the effects of ionising radiation.

Diagnostic reference levels (DRLs) are defined as "dose levels in medical radiodiagnostic practices for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment" (European Commission, 1999:6). DRLs measure radiation doses to patients for a defined set of procedures and act as a quality assurance tool that determines whether or not radiation exposure to patients are optimized. DRLs therefore serve as an indicator of good radiographic practice. If radiation doses delivered to patients are consistently unsually high then there is a need to investigate radiation practices in order to apply corrective measures (Edmonds, 2009; Seeram & Brennan, 2017).

In order to comply with the BSS for medical exposure, authorities that regulate x-ray equipment should determine radiation doses for typical sized adult patients (IAEA, 2006). It is for this reason that the IAEA requested the National Radiation Protection Authority (NRPA) of Namibia in, 2005, to develop diagnostic reference levels for conventional radiographic examinations (Appendix 1). The concept of diagnostic reference levels has now been formally adopted by the Ministry of Health and Social Services (MOHSS) of Namibia and is gazetted in the Atomic Energy and Radiation Protection Act of 2005 (Republic of Namibia, 2005). With the implementation of the Atomic Energy and Radiation Protection Act of 2005, there is a statutory requirement for all radiology departments to establish diagnostic reference levels. It is against this background that the researcher measured the Kerma Area Product (KAP) for conventional

postero-anterior (PA) and lateral (LAT) chest, antero-posterior (AP) and LAT lumbar spine, AP pelvis, and PA and LAT skull x-ray examinations as recommended by the Atomic Energy and Radiation Protection Act, IAEA and ICRP.

1.2 Statement of the problem

The NRPA of Namibia was tasked in 2005 by the IAEA under the project RAF9/033 to develop diagnostic reference levels for conventional radiographic examinations (Appendix 1). To date, no study that examines the radiation dose in diagnostic radiology has been undertaken in Namibia and radiation protection of patients may not be optimised. According to the International Commission on Radiological Protection (ICRP), diagnostic reference levels acts as a quality assurance tool that identifies procedures or activities where patient doses are high (ICRP, 1996). With the implementation of the Atomic Energy and Radiation Protection Act of 2005 (Republic of Namibia, 2005), there is a legal requirement for all radiology departments to establish diagnostic reference levels. Although various international diagnostic reference levels (DRLs) exist, these levels cannot be directly applied to Namibia, as DRLs are context dependent and vary according to the radiographic equipment, technique and exposure factors. Hence, there is a need for country or region specific diagnostic reference levels (ICRP, 1996; Johnston & Brennan, 2000; Seeram & Brennan, 2006). As such, the study measured radiation doses at three (3) different radiology practices in Windhoek for four commonly performed conventional radiographic examinations and established diagnostic reference levels for these procedures. The research was guided by the following research question.

- What are the radiation doses received by patients undergoing conventional x-ray examinations in Windhoek, Namibia?

The purpose of the study was to develop (Local Diagnostic Reference Levels (LDRL's) for commonly performed conventional radiography projections in Windhoek, Namibia.
The objectives of the study were to:

- Measure KAP for postero-anterior (PA) and lateral (LAT) chest, antero-posterior (AP) and LAT lumbar spine, AP pelvis, and PA and LAT skull projections.
- Calculate entrance skin and effective doses from the recorded KAP values.
- To compare the KAP, entrance skin doses and effective doses with internationally established reference levels for the same procedure as well as similar studies in Africa.

- Develop conversion coefficients from KAP values for estimation of effective and skin doses in clinical practice.

1.2.1 Null hypothesis:

DRL's determined for conventional radiography projections used in Windhoek, Namibia are in agreement with international levels.

1.3 Significance of the study

To the best of the researcher's knowledge, no local diagnostic reference dose levels existed in Namibia, and as a result, radiography procedures may not be optimised with regard to radiation dose. Therefore, the local diagnostic reference levels which have been established in this study can be used as baseline data for future studies, until such a time that national diagnostic reference levels are determined.

1.4 Overview of the methodology

The study was conducted in three (3) hospitals located in Windhoek, Namibia. Hospital one (1) was a national referral hospital with a total capacity of 964 beds. Hospital two (2) was a private radiology practice attached to a private hospital with a total capacity of 1024 beds. Hospital three (3) was an intermediate hospital with a capacity of 955 beds. All three hospitals utilise computed or digital radiography x-ray imaging systems and are affiliated to the University of Namibia. Ethical approval was gained from the research ethics committee (REC) of the Cape Peninsula University of Technology as well as the Permanent Secretary of the Ministry of Health and Social Services (Namibia), Director of the National Radiation Protection Authority (NRPA) and permission to conduct the study received from the principal radiographers of the hospitals in the study.

Geometric data, exposure parameters as well as KAP measurements were obtained from 218 patients referred for seven projections that is; PA and LAT chest, AP and LAT lumbar spine, AP Pelvis, PA and LAT skull. Specifications concerning the x-ray equipment for each hospital were obtained from the manufacturer's manual available at each hospital. The information recorded included generator type, name of the manufacturer, type of x-ray tube, anode angle, and total tube filtration.

Entrance skin, and effective doses were calculated through Monto Carlo simulations by entering the geometric data, exposure parameters and equipment specifications and KAP values into PCXMC (2008) 2.0 software (Finland).

Microsoft excel 2016 was used to analyse data. Third (3^{rd}) quartile values for KAP, ESD and ED were calculated. The research question was answered by means of inferential statistical analysis. The correlation between the ESD, ED and KAP were determined using Pearson's tests. The third quartile values of the ESD and KAP obtained were also compared with that published in the literature.

1.5 Delimitations

- Only hospitals affiliated to the University of Namibia, located in Windhoek using computed or digital radiography were included.
- In addition KAP measurements were obtained only on adult patients referred for conventional radiographic projections; PA and LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull that had a mean weight of 70kg ± 5kg.

1.6 Introduction to the structure of the Thesis

In order to understand the radiation doses delivered to patients referred for conventional radiographic projections that is; PA and lateral LAT chest, AP and LAT lumbar spine, AP pelvis; and PA and LAT skull in Windhoek, Namibia, the thesis is structured as follows:

Chapter 2 Literature review

This chapter provides a synopsis for radiation protection as well as the concepts related to radiation dosimetry. This chapter discusses the concept of diagnostic reference levels and dose measurements in radiography. The chapter similarly highlights the factors that affect radiation dose in radiography as well as legislation governing radiation dose measurements.

Chapter 3 Research Methodology

This chapter describes the methodology used in the study. It includes the design, population, sampling as well as ethical principles and procedures for data collection. The measures used to ensure validity and reliability of the research process are also described.

Chapter 4 Research findings

This chapter outlines the research findings from data analysis based on the research question.

Chapter 5 Discussion and conclusion

In this chapter, the results of study are discussed and compared to existing literature. The chapter is concluded with recommendations for future research. It further identifies the limitations experienced during the study.

CHAPTER 2: LITERATURE REVIEW

Ionising radiation plays a vital role in the imaging of the human body. However, it is evident from the literature that radiation has the potential to ionise matter, causing potential harmful effects. In order to protect patients from harmful effects of ionising radiation, radiation dose as a result of medical exposure should be minimised. In order to protect patients against the harmful effects of ionising radiation, the IAEA introduced the three principles of radiation protection, namely justification, optimisation and dose limitation (IAEA, 2006). Diagnostic reference levels (DRLs) are an important quality assurance tool that can be used to minimise radiation doses delivered to patients. Over the past decades, various researchers have investigated radiation doses to patients and have identified the factors that cause dose variation. Factors that affect radiation dose are type of filtration, generator type and the application of manual exposure techniques amongst others (Ng et al., 1998; Johnston & Brennan, 2000; Nyathi et al., 2009; Sonowane, et al., 2010; Abdelhalim, 2011). In this chapter the principles of radiation protection and dosimetry will be discussed. In addition the chapter describes; the legislation regarding DRLs, different methods used to obtain DRLs, comparisons of DRLs in different countries and explains the factors that cause dose variation.

2.1 Principles of radiation protection

2.1.1 Justification

Justification in radiography is the process where radiographers and radiologist evaluate the x-ray request for x-ray examinations by comparing it with the patient's clinical history to determine its validity. In practice justification involves the usage of correct exposure techniques while maintaining diagnostic image quality. Therefore, the principle of justification in radiology means that the risk of exposure to ionizing radiation should be balanced, against the benefits derived from the procedure. A procedure is justified when the benefits of undergoing a procedure outweigh the risk (Von & Williams, 2017).

2.1.2 Optimisation

In radiography optimisation is the process where radiographers minimize the amount of radiation delivered to patients through selection of correct exposure factors (kVp and mAs) (Martin, 2007).

The quality of radiation is dependent on the applied tube potential and the amount of filtration of the x-ray beam. Therefore optimisation of radiation protection comprises the application of different radiographic techniques and imaging parameters in an effort to minimize radiation dose to patients without compromising image quality. Clinically this implies that radiographers adjust and select exposure factors with reference to the patient's body habitus while maintaining diagnostic quality (Freitas & Yoshimura, 2009). A quality diagnostic radiograph therefore represents a visual appreciation of the patient's anatomy under examination sufficient to make a clinical diagnosis (Vom & Williams, 2017).

2.1.3 Dose limitation

Dose limitation applies to occupational exposure of radiation workers and therefore is not applicable to medical radiography procedures (ICRP, 2007). However, the principle of radiation protection in radiography is guided by the As Low As Reasonably Achievable (ALARA) principle. According to the Dosimetry Working Party (DWP) of the Institute of Physical Sciences in Medicine of the College of Radiographers in the United Kingdom (UK), radiographers are responsible for the comfort of patients during radiological procedures (DWP, 1992). As a result, radiographers should be concerned about radiation protection and radiation dose when selecting exposure parameters during radiological procedures. Therefore, radiographers should keep radiation doses as low as reasonably achievable (ALARA) during radiological procedures. Diagnostic reference levels were introduced as quality assurance tool for medical exposure (IAEA, 2006), encouraging radiographers to minimise radiation dose and optimise the effects of ionising radiation.

2.2 Biological effects of radiation

2.2.1 Stochastic effects

Stochastic effects are also known as probabilistic effects, where the incidence, but not severity of appearance, is proportional to the radiation dose received. These effects occur at low doses and are related to the damage to the genetic material at cellular level. Stochastic effects have no threshold dose; examples include heredity diseases (Kamiya et al., 2015).

2.2.2 Non stochastic effects

Non stochastic effects are also referred to as deterministic effects and occur once a threshold radiation dose is received. The degree of injury depends on three factors; absorbed dose, dose rate and the quality of radiation. These effects can have either a linear or exponential response to the radiation dose received. Non stochastic effects are further divided into early and late effects. Examples of early effects include haemorrhagic diarrhoea, anaemia, leucopoenia, erythema, epilation. Late effects comprises of cataracts, cardiovascular disorders and necrosis (Kamiya et al., 2015).

2.3 Quantities for patient dosimetry

Various quantities have been documented in the literature that can be used during patient dosimetry studies, namely absorbed dose, entrance skin dose, and entrance surface dose (Heggie, 2008; Kron, 2008; Lee et al., 2013). These quantities play a pivotal role in the assessment of radiation exposure to humans and are of great importance for radiation protection due to the potential harmful effects of ionising radiation (ICRP, 2005).

2.3.1 Absorbed dose (D)

The energy absorbed per unit mass of the patient is known as the absorbed dose and is measured in joule per kilogram (J/kg). This quantity is specific for all types of ionising radiation. The international system (SI) unit for absorbed dose is Gray (Gy). Absorbed dose was previously measured in “rad”, where 100 rad is equal to 1 Gy (Kron, 2008). Mathematically the absorbed dose can be expressed as:

$$D = \frac{d\bar{\varepsilon}}{dm}$$

Where, dm is mass of the subject and $d\bar{\varepsilon}$ is the average energy absorbed (IAEA, 2007).

2.3.2 Entrance skin dose (ESD)

The entrance skin dose (ESD) also known as entrance surface dose ,is defined by (Heggie, 2008) as the absorbed dose in air in the centre of the x-ray beam and the entrance surface of the patient’s skin including backscatter radiation. The ESD is expressed in milligray (mGy). The

ESD is measured by means of thermoluminescent dosimeters placed on the patient skin. Additionally it can be calculated by multiplying the entrance surface air kerma (ESAK) with a backscatter factor (BSF) (Sonowane et al., 2010; European Commission, 1996). Mathematically the entrance skin dose can be expressed as:

ESD (mGy) = ESAK (mGy) x BSF

The magnitude of ESD is dependent on the focal skin distance, for example it decreases as the distance from the x-ray source to the skin is increased (Sonowane et al., 2010).

2.3.3 Effective dose (E)

The effective dose is an indicator of harmful effects of exposure to ionising radiation. The effective dose is measured in Sieverts (Sv). It is the product of the tissue weight (W_T) factors of the IRCP, the applicable radiation weighting factor and organ doses (Lee et al., 2013).

2.4 Legislation on diagnostic reference levels (DRL's)

The International Commission on Radiological Protection (ICRP) defines diagnostic reference levels (DRL's) as "a form of investigation level, applied to an easily measured quantity, usually the absorbed dose in air, or tissue-equivalent material at the surface of a simple phantom or a representative patient". Furthermore, the ICRP recommends the establishment of diagnostic reference levels to optimise the radiation dose delivered to patients during radiological procedures (ICRP, 1996).

As previously mentioned, the concept of diagnostic reference levels has now been formally adopted by the Ministry of Health and Social Services (MOHSS) and is gazetted in the Atomic Energy and Radiation Protection Act of 2005 (Republic of Namibia, 2005). With the implementation of the Atomic Energy and Radiation Protection Act of 2005 (Republic of Namibia, 2005), there is now a legal requirement for every radiology department to establish diagnostic reference levels.

The Atomic Energy and Radiation Protection Act of Namibia, sub regulation 38 states that
(1) The director general may determine diagnostic reference levels as a condition of registration and ensure that:

(2) Diagnostic reference levels are used during radiological procedures using radiation as well as during optimisation of radiation protection of patients.
(3) X-ray equipment is evaluated in order to compare with diagnostic reference levels.
(4) Radiation doses or activities do not fall significantly below the diagnostic reference levels and if the need arise start an investigation to avoid loss of image quality.
(5) Corrective actions are initiated when diagnostic reference levels are exceeded to ensure optimisation of radiographic practice.
(6) Diagnostic reference levels are applied with flexibility and adjusted to allow for higher exposures if necessary, and should be revised as technological and scientific advancements take place (Republic of Namibia, 2005).

A diagnostic reference level can be described as a reference level of dose. The dose descriptor used to establish DRL's is dependent on the radiographic examination and is usually expressed in either entrance skin doses (ESD) or kerma area product (KAP) for conventional radiographic examinations, KAP for fluoroscopic examinations and the dose length product (DLP) for computed radiography (CT) examinations. Dose descriptors selected for DRL's should be an easily measurable quantity of radiation exposure (DWP, 1992; Heggie, 2008; Verdun et al., 2008).

Diagnostic reference values are usually determined by the regulatory authorities in consultation with the various professional bodies and should be established for frequently performed examinations or those that have a high radiation dose (ICRP, 1996). Regardless of the fact that technology has advanced, diagnostic imaging by means of conventional radiography remains the most common method of imaging in Namibia due to its availability and affordability.

Diagnostic reference levels are usually selected by means of the 75^{th} percentile of dose distributions and assist radiographers with the optimisation of radiation protection to patients. This means that 25% of the facilities will surpass the diagnostic reference levels and therefore, the reasons for variation should be investigated (Johnston & Brennan, 2000; Gray et al., 2005).

2.5 Tools used to measure radiation dose

The Dosimetry Working Party (DWP) of the National Radiation Protection Board (NRPB) of the Institute of Physical Sciences in Medicine (IPSM) in the United Kingdom (UK) proposes three methods to measure radiation doses, namely thermoluminescent dosimeters (TLDs) for

measurement of entrance skin doses (ESDs), Kerma area product (KAP) meters for measurement of absorbed dose and the mathematical method using an ionisation chamber and computing absorbed dose from known exposure factors (DWP, 1992). These methods have been well accepted by the International Atomic Energy Agency (IAEA) as well as the European commission and have been applied in various dosimetry studies worldwide. According to Roberts (1995), dosimetry techniques are dependent on the type of examination, whether digital or analogue.

2.5.1 Kerma Area Product (KAP) meter

The KAP is the product of the area of the x-ray beam and the absorbed dose in air at a point in a plane perpendicular to the central axis of the beam also known as the Dose Area Product (DAP) (IAEA, 2007). According to the Dosimetry Working Party (DWP) of the National Radiation Protection Board (NRPB) in the United Kingdom (UK), the KAP is a useful dosimetric quantity that can be used for both conventional and fluoroscopic x-ray examinations (DWP, 1992). KAP can be measured by means of a KAP meter or calculated by means of tube output (Akinlade et al., 2012).

$$KAP\ (mGycm^2) = L(mAs)D_O(mGy/mAs)A(cm^2)_{(FSD)}$$

Where L is the tube current, D_O is the beam output at 1 meter (m), FSD is the focus to skin distance and $A_{(FSD)}$ is the cross-sectional area of the beam on the patient's skin.

The KAP is a dose descriptor that describes the total amount of radiation used in an examination. It is measured by means of a KAP meter. The KAP meter consist of a radiolucent, flat ionisation chamber with square plates and is used to monitor radiation exposure to patients (Dowsett et al., 2006; Allisay-Roberts & Williams, 2008; Ball et al., 2008). KAP values are usually expressed in $Gycm^2$ or $mGycm^2$ and are a good indicator of stochastic effects of radiation. Due to its small size, usually 15 cm^2, it can be easily be retrofitted on the x-ray tube collimator without any interference with the x-ray procedure (DWP, 1992). According to Ball et al., (2008); and Dowsett et al., (2008) kerma area product measurements are dependent on the radiographic technique employed by the radiographer. Factors that affect the KAP reading are; applied tube potential (KVp), tube current (mA), amount of filtration (mm Al), exposure time (in milliseconds) as well as the area exposed to radiation (cm^2). Hence, the KAP is a good indicator for monitoring the effect of radiographic technique on radiation dose (Ball et al*.,* 2008; & Dowsett

et al., 2008). KAP meters do not measure backscatter radiation due to their attachment on the tube housing; however, they offer instant display of radiation used in an examination and eliminate the need for patient specific dosimeters (Seeram & Brennan, 2006). South African legislation requiring all fluoroscopy x-ray units to be fitted with KAP meters have not been implemented in Namibia (Department of Health South Africa, 2006). For this study, the researcher used a portable KAP meter.

Figure 2.1 KAP meter mounted on the x-ray collimator at one of the research sites.

2.5.2 Themoluminescent dosimeters

Thermoluminescent dosimeters (TLD's) are widely accepted tools used to measure entrance surface or entrance skin doses during conventional radiography. They are made from dielectric material doped with lithium fluoride (LiF) or lithium borate ($Li_2B_4O_7$) phosphors (Seeram & Brennan, 2006; Hobbie & Roth, 2007). The dosimeters are small in size, approximately 3 mm^2 with a thickness of 0.9 mm, and have an atomic number close to normal body tissue, and therefore, do not appear on radiographs (Abdelhalim, 2011). Usually the dosimeters are attached on the patient's skin in such a manner that it coincides with the centre of the x-ray beam (IAEA, 2006). When the TLD's are exposed to ionising radiation, electrons are trapped and stored in the conduction band of the phosphors (Hobbie & Roth, 2007). Thereafter, the TLD's are placed in a TLD reader and are heated to a temperature of approximately 250ºC (Seeram & Brennan, 2006). The trapped electrons of the conduction band overcome the binding energy and fall back to their normal state and gives off light (Hobbie & Roth, 2007). The light is read by means of a photocathode and photomultiplier tube and the signal emitted by the TLD is recorded. The advantage of this method is that it includes backscatter radiation (Seeram & Brennan, 2006). However, the dosimeters require precision and accuracy during handling and needs to be calibrated against predetermined energy levels before dosimetry studies (Abdelhalim, 2011). This makes the process expensive and cumbersome. Another disadvantage

is that the dosimeters have to be read in a laboratory, which may cause variations in the recorded signal due to variation in TLD reader performance (Seeram & Brennan, 2006). In addition, there is no immediate record of the dose received. Furthermore, TLD's are also known for signal fade (Seeram & Brennan, 2006). The dose values obtained with TLD's are expressed in milligray (mGy). Radiation dose measurements by means of TLD's for patient dosimetry during conventional radiography have been a well-established method to measure entrance skin doses during radiological procedures, however, the use of TLD's was not suitable for this research project, as it may cause patient discomfort and irritation, since the dosimeter is placed in direct contact with the patient's skin (Johnston & Brennan, 2000).

2.5.3 Mathematical method using an ionisation chamber

The ionisation chamber was introduced by Behnken in 1924 and is used to measure radiation (Ghom, 2008). It is cylindrical in form and consists of collecting electrodes, negative electrodes, an insulator, an air volume and an outer wall. According to Aird (1988), the chambers contain air at atmospheric pressure. When the ionisation chamber is exposed to ionising radiation, the x-ray photons interact with the air and the walls of the chamber and release secondary electrons. The secondary electrons ionise the air in the chamber. The total charge produced is proportional to the radiation dose imparted on the chamber (Aird, 1988). According to Roberts (1995), this method is used to measure the absorbed dose in air or air kerma at a specific distance from the x-ray source. The Entrance skin dose (ESD) is then computed with reference to the relevant exposure factors.

2.5.4 Monto Carlo Simulations

The Monto Carlo Simulations is a PCXMC (2008) version 2.0 computer programme, developed by the Finish Radiation and Nuclear Safety Authority. A hermaphrodite MIRD5 phantom is used and scaling factors are applied to modify the size of the phantom. Monto Carlo simulations are performed based on the technique factors applied in the clinical setting. The programme calculates effective and organ doses for 29 organs based on ICRP 60 and 103 tissue weighing factors (Sermovaa & Tapiovaara, 1998; Kramer et al., 2008).

The PCXMC (2008) version 2.0 programme simulates how x-ray photons are spread through tissue during exposure. These simulations are based on the interaction of x-ray photons as they pass through tissue. The simulations are completed when all particles are annihilated and drop below a specific threshold level. The organ and effective doses are calculated from the sampling

histories generated and the mean values of the energy deposits. The programme considers the following organs, adrenal glands, brain, breast, colon, gall bladder, heart, kidneys, liver, lungs, lymph nodes, muscle, oesophagus, oral mucosa, ovaries, prostate, pancreas, salivary glands, skeleton, skin , small intestine, spleen, stomach, testicles, thymus, thyroid, urinary bladder , uterus and active bone marrow (Sermovaa & Tapiovaara, 1998; Trap & Johnston, 2008).

2.6 Diagnostic reference levels comparison

As previously mentioned, diagnostic reference levels can be described as a reference level of dose. The dose descriptor used to establish DRL's is dependent on the radiographic examination and is usually expressed in either entrance skin doses (ESDs) or Kerma area product (KAP) for conventional radiographic examinations (DWP, 1992; Heggie, 2008; Verdun et al., 2008).

Table 2.1 shows the entrance skin doses for conventional x-ray examinations. Some report the mean (Aliasgharzadeh et al., 2015)**,** median (Ng et al., 1998; Ofori et al., 2014) and 75th percentile (Osibote & de Azevedo, 2008; Nyati et al., 2009; Sonowane et al., 2010). The table demonstrates ESD's for six countries and shows that values ranged from 0.10 mGy to 0.68 mGy for PA chest. In addition the table also shows that the 75th percentile radiation doses for AP pelvis range from 2.98 mGy to 10mGy. It can be noted from the table that there's a variation in radiation doses, thereby justifying the need of country specific DRLs (ICRP, 1996).

Table 2.1 Comparison of Entrance Skin Doses (ESDs) for the seven projections

Exam	**IAEA (1996)**	**Ng et al., (1998)**	**Osibote & de Azevedo (2008)**	**Sonowane et al., (2010)**	**Nyati et al., (2009)**	**Ofori et al, (2014)**	**Aliasgharzadeh et al., (2015)**
PA chest (mGy)	0.4	0.3	0.24	0.68	0.10	0.27	0.37
LAT chest (mGy)	1.5	1.2	0.62	1.74	0.22	0.43	0.99
AP lumbar spine (mGy)	10	9.1	2.60	8.39	5.30	3.25	2.18
LAT lumbar spine	30	14.0	4.75	15.66	NR	NR	5.36

(mGy)							
AP Pelvis (mGy)	10	5.3	NR	8.03	2.98	1.31	1.76
PA Skull (mGy)	5	4.7	1.55	6.89	NR	NR	1.39
LAT Skull (mGy)	3	3.0	NR	5.16	NR	NR	1.01
NR- not reported							

Some factors that cause dose variations are applied kilovoltage (kV), type of screens used, type of imaging whether digital or analogue and focus-to-skin distance (Ng et al., 1998; Compagnone et al., 2006; Nyati et al., 2009). For example the setting of manual exposures instead of automatic exposures resulted in dose variations in the study by Nyati et al., (2009), whereas poor collimation practices and short focus film distance resulted in dose variations in the study by Ng et al., (1998). Similar to Ng et al., (1998), a study conducted by Olowookere et al., (2011), found that radiographers fail to adjust the radiographic technique and exposure factors based on the patient's body habitus. Olowookere et al., (2011) found that radiographers used a constant tube potential of 80kVp for patients of different mass and body habitus. In addition, the radiographers used a short focus-to-skin-distance (FSD) for imaging of chest projections. The use of low kVp and constant tube current without adjustment to patient body habitus indicates that patients are exposed to high radiation doses in order to obtain good quality image. This is contrary to the ALARA principle that states that radiographers should obtain radiographs at the lowest possible dose without compromising image quality. Olowookere et al., (2011) concluded that radiographers are unaware of the radiation doses during radiography procedures.

2.7 Dose optimising strategies

The exposure factors selected is directly controlled by the radiographer. These are tube potential energy, tube current, exposure time and quantity of radiation produced.

2.7.1 Tube potential energy (kVp)

The tube potential, also known as the kVp, controls the penetrating ability of the x-ray beam, where high kVp x-ray beams are more penetrating then low kVp beams. When radiographers use low kVp techniques, it results in higher patient doses as some x-ray photons may not have enough energy to penetrate the patient (Seeram & Brennan, 2017). A study on ESD's conducted

by Nyathi, et al., (2009) for chest, pelvis, abdomen, lumbar spine in two x-ray rooms found ESD's to be well within internationally established reference levels. It was also noted that radiographers used a high kV technique for chest radiography (109kV to 125kV for PA chest examinations). This is consistent with international standards.

2.7.2 Tube current (mA)

The tube current controls the quantity of radiation released from the x-ray tube and is directly proportional to the mA. The patient dose is increased by high tube current (mA) (Seeram & Brennan, 2017).

2.7.3 Exposure time.

When exposure times are long the radiation dose to the patient is increased (Seeram & Brennan, 2017)

2.7.4 Radiation quantity (mAs)

The quantity of radiation is equal to the product of exposure time and tube current. When the mAs increases, the radiation dose to the patient increases (Seeram & Brennan, 2017). In a study conducted my Sonowane et al., (2010), dose variations were due to high mA set by radiographers, ranging from 17 to 32 for PA and lateral chest. The mA values were approximately 50% more than the study by Ng et al., (1998). Similar to Ng et al., (1998), a study conducted by Olowookere et al., (2011) indicate that radiographers used a constant tube current of 15 mA and 9 mA for PA chest dependent on patient body habitus. A high mA technique necessitates a lower kVp resulting in higher radiation doses in order to obtain a good quality image.

2.7.5 Collimation

Collimation is the process where radiographers select and restrict the x-ray beam to the area of interest. Collimation therefore determines the field size that will be exposed to radiation. When radiographers apply correct collimation, patient radiation doses may be reduced between 27% to 60% (Fauber & Dempsey, 2013).

2.7.6 Source to image distance (SID)

The minimum recommended SID is usually 100 cm, and is changed based on the anatomical area that need to be imaged (Seeram & Brennan, 2017). The shorter the SID, the higher the dose to the patient and vice versa. When the SID is increased it may significantly reduce the effective doses of up to factor of 23 (Joyce et al., 2013). This finding is consistent with Olowookere et al., (2011), who found that the ESD's may be dependent on the focus-to-skin-distance (FSD). In their study Olowookere et al., (2011) noticed that dose variations was a result of the short FSD (105cm) that was used for PA chest projections instead of the 150-180cm recommended (European Commission, 1996).

2.7.7 Automatic Exposure Control (AEC)

AEC are electronic devices that terminate the radiation exposure once the programmed radiation reaches the image receptor. AEC devices eliminate problems where patients may be overexposed due to different patient body habitus; patient pathology and the wear and tear of the x-ray tube. In order to effectively operate AEC devices, there is a need to train radiographers on how to operate these devices in clinical practice (Seeram & Brennan, 2017).

2.7.8 Equipment type

The type of radiographic equipment whether conventional film-screen, computed radiography or digital radiography will also have an effect on the dose delivered to patients. In a study conducted by Compagnone et al., (2006), computed radiography contributed to higher entrance skin doses when compared to conventional film screen radiography and direct digital radiography. The authors noted that direct digital radiography techniques resulted in lower effective doses up to 43% lower than when film screen radiography were used. Overall, the effective dose calculated for AP and LAT lumbar spine projections was 54% higher when computed radiography systems was used compared to film screen radiography.

2.8 Conversion coefficients

Conversion coefficients are constants that explain the relationship between two dosimetric quantities. Estimation of effective dose by means of the PCXMC programme could be laborious.

Therefore conversion coefficients may be used to estimate entrance skin dose (ESD) or effective dose (E) from KAP values in the radiology department. The conversion coefficients for radiographic procedures can be obtained by dividing the entrance skin dose (ESD) or effective dose (E) by the KAP value and is given E/KAP and skin dose (ESD/KAP) (Hansson & Karambatsakidou, 2000; Compagnone et al., 2005).

The literature review above highlights the importance of diagnostic reference levels in the optimisation of radiation protection to patients. Factors that may cause dose variation and more importantly the need for country specific and region specific diagnostic reference levels were found to be: exposure parameters used such as the tube potential and or mA selected, the radiographic technique selected and source to image distance. In order to minimise the harmful effects of ionising radiation and to keep radiation doses aligned with the ALARA principle it is evident that diagnostic reference levels are an inexpensive tool that can be used to monitor radiation doses to patients. The next chapter will describe the methodology used in the research process.

CHAPTER 3: METHODOLOGY

3. Introduction

The purpose of the study was to develop LDRL's for commonly performed conventional radiography projections in Windhoek, Namibia.
The objectives of the study were to:

- Measure KAP for PA and lateral LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull projections.
- Calculate entrance skin and effective doses from the recorded KAP values.
- To compare the KAP, entrance skin doses and effective doses with internationally established reference levels for the same procedure as well as similar studies in Africa.
- Develop conversion coefficients from KAP values for estimation of effective and skin doses in clinical practice.

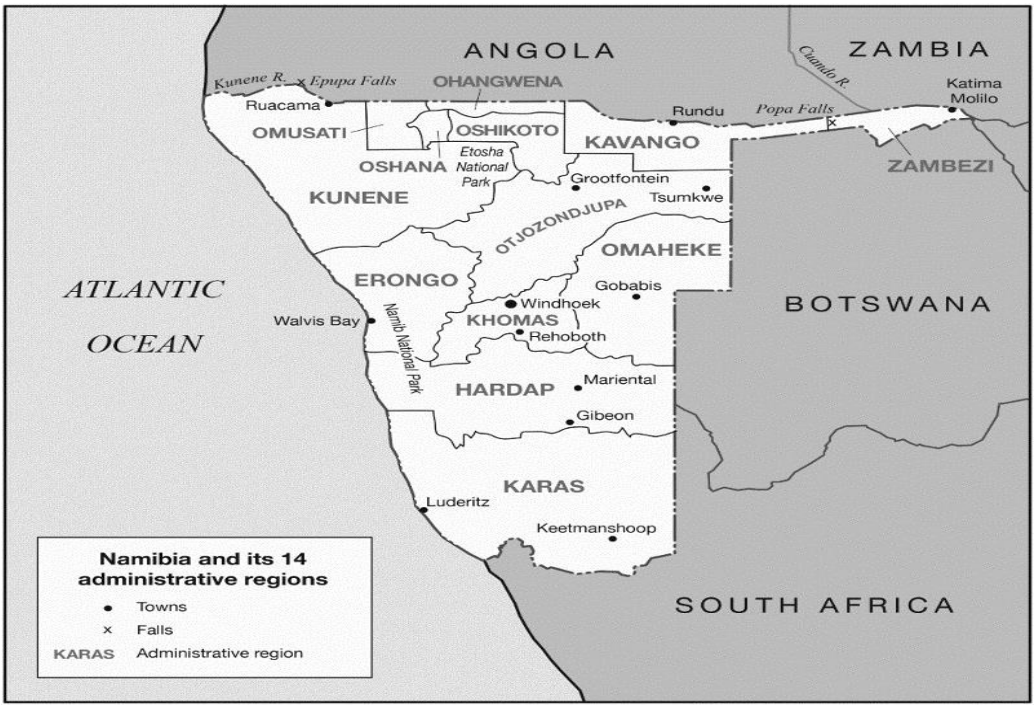
This chapter describes the research design, sampling strategies, scope, research instrument and procedures that were followed to collect data as well as ethical considerations applied during the study.

3.1 Research design

A prospective, quantitative research design was adopted to measure the KAP values, and calculate ESD, ED and develop conversion factors for four conventional radiographic examinations. The study was divided into two phases. Phase one involved a quantitative approach where KAP measurements were obtained and phase two was a correlational approach to calculate ESD and ED using the PCXMC (2008) 2.0 Monto Carlo Software.

3.1.1 Site Selection:

The sampling frame for selecting the research sites was the geographical location of Windhoek Namibia (Figure 3.1).



Source: (Hitchcock, 2015)

Figure 3.1 Map of Namibia illustrating, the research site

Two public and one private hospital located in Windhoek registered with the National Radiation Protection Authority were approached to participate in the study through a letter of invitation (refer to appendix 2 to 4). The letter of invitation explained the purpose and motivation of the study. Windhoek is located in the Khomas region of Namibia and consists of one (1) national referral hospital, one (1) Intermediate hospital, and one (1) health centre that provide radiological services to patients. In addition, there are approximately seven private radiology facilities that also provide x-ray services to patients. The three hospitals in Windhoek were selected because they employ computed radiography and digital radiography in their radiology departments whereas the other regions still employ analogue systems. In addition, they are the three training hospitals affiliated to the University of Namibia, and are the largest hospitals in Namibia. The researcher is employed as an assistant lecturer at the University of Namibia and could therefore gain access to the selected research sites.

These hospitals were purposefully selected in the geographical area of Windhoek as they are representative of radiography practices in the area thus increasing the reliability and validity of the results for radiation dosimetry studies (Hart et al., 2000).

3.1.2 Equipment selection

From each hospital, the x-ray room dedicated for conventional radiographic examinations was identified using a purposeful sampling method. Information regarding the x-ray equipment was recorded. This included; type of generator, type of x-ray tube, filtration, waveform, presence of a anti scatter grid and the ratio, focal spot size, automatic exposure control (AEC), and presence of quality assurance programmes. Refer to (appendix 5) for a copy of the data collection sheet (DWP, 1992; Council of European Commission, 1996; Johnston & Brennan, 2000; Abdelhalim, 2009). Specifications regarding the x-ray equipment are given in table 3.1 below.

Table 3.1 Specifications regarding x-ray equipment at different study sites

Hospital	1	2	3
Type of x-ray unit	Computed (CR)	Direct Digital (DR)	Direct Digital (DR)
Manufacturer	Philips	Siemens	Philips
X-ray tube	Ceiling-suspended	Ceiling-suspended	Floor mounted
Generator	Optimus 50kW	HV 50kW generator	M cabinet CXA Pro 50kW
Total filtration	≥2.5mm Al at 100 kV	≥2.5mm Al at 80 kV	≥2.5mm Al at 100 kV
Inherent filtration	≤0.30mm Al	≤0.60 mm Al	≤0.30mm Al
Motorized filters	2mm Al 1mm Al + 0.1 Cu 1mm Al + 0.2 Cu	2mm Al 1mm Al + 0.1 Cu 1mm Al + 0.2 Cu	2mm Al 1mm Al + 0.1 Cu 1mm Al + 0.2 Cu
Anode angle	13º	12º	13º

Information regarding the anode angle was collected retrospectively as this was not included during the initial phase of the data collection process. This information was used as input data for Monto Carlo Simulations in phase two of the research project.

- The x-ray unit at hospital 1 was a Philips Duradiagnost. It consisted of a 50kW Optimus generator, with a ceiling suspension (Figures 3.2 and 3.3).
- The x-ray unit at hospital 2 was a Siemens Multix Fution Max RF 80. It consisted of 50kW generator with ceiling suspension (Figures 3.4 and 3.5).

- The x-ray unit at hospital 3 was a Philips Duradiagnost 4. It was a floor mounted x-ray tube with a CXA Pro 50kW generator (Figures 3.6 and 3.7).

Figure 3.2 Philips Duradiagnost at research site 1

Figure 3.3 Philips Duradiagnost controls and display monitor at research site 1

Figure 3.4 Siemens Multix Fution Max RF 80 at research site 2

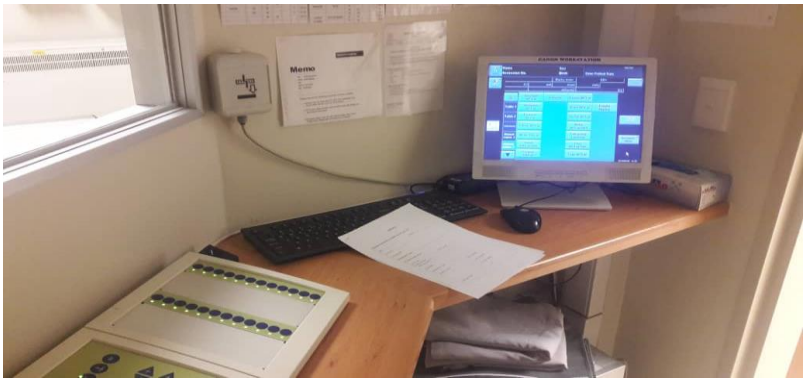


Figure 3.5 Siemens Multix Fution Max RF 80 controls and display at research site 2

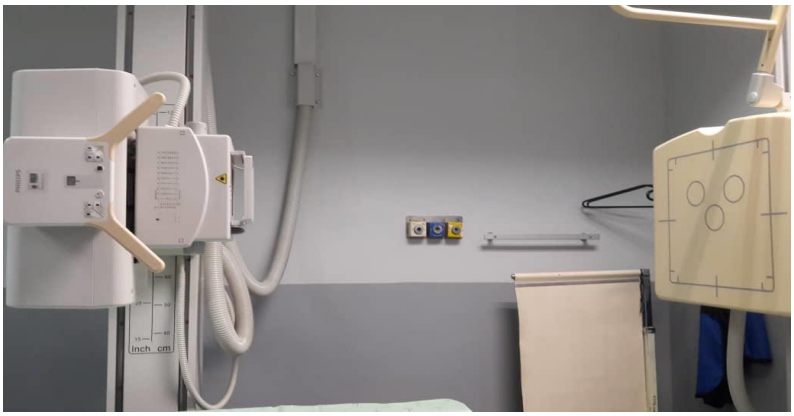


Figure 3.6 Philips Duradiagnost 4 at research site 3

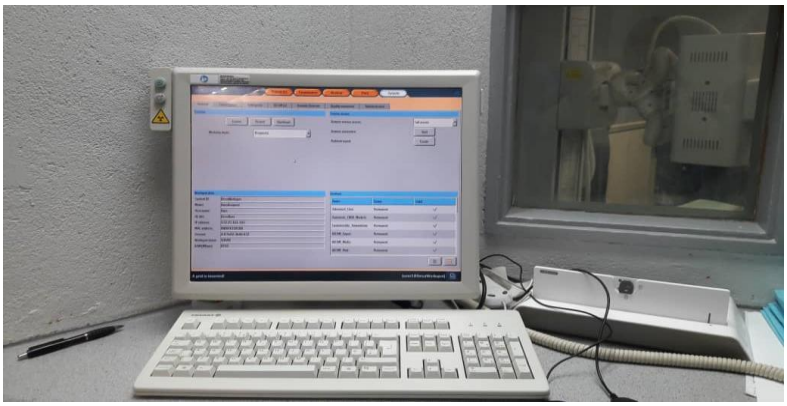


Figure 3.7 Philips Duradiagnost 4 controls and display at research site 3

KAP values were obtained from a portable KAP meter (VACUDAP, Germany) (Figure 2.1) that was retrofitted onto the collimator of each of the x-ray machines. The KAP values was obtained by the research assistant and recorded on the research instrument (refer to appendix 6). The KAP meter was reset after each exposure. The KAP meter was calibrated prior to commencement of the study (see appendix 7). There was only one KAP meter available to the

researcher, therefore data could not be collected concurrently. It was initially anticipated that KAP values be obtained on a sample of 20 patients for each examination at each hospital. However, for some examinations a minimum of 10 patients were recruited. This was consistent with international guidelines which recommend that 10 patients be included for each examination (DWP, 1992; European Commission, 1996; IAEA, 2007).

3.1.3 Study population

The population was all adult patients that underwent chest PA and LAT, lumbar spine AP and LAT, pelvis AP, and skull PA and LAT at the different study sites from June 2014 to July 2017.

3.1.4 Sampling of conventional radiography procedures

A purposive sampling method was used to select research participants. Chest examinations were included because they are most commonly performed procedure, whilst lumbar spine examinations have a high radiation dose and low diagnostic yield (Khoo et al., 2003; IAEA, 2009). The ICRP recommends that diagnostic reference levels be established on the most frequently performed examinations or examinations with high radiation doses (ICRP, 1996). However, the IAEA request in 2005 suggested the establishment of diagnostic reference levels for common radiographic examinations. Extremity radiographs have not been considered, as the exposure factors employed during these procedures are usually relatively low. According to (Ofori et al., 2012), it is important to include pelvic radiographs in patient dosimetry studies. The pelvis contains both male and female sex organs, which are highly sensitive to ionising radiation and should always be protected during radiography examinations hence it was included as part of establishing DRLs for this study.

3.1.5 Inclusion criteria

It is known that the patient's weight may affect radiation dose results. Therefore only adults that underwent chest, lumbar spine, skull and pelvis x-ray examinations aged ≥18 years and that weighed ≥ 65 kg and ≤ 75 kg were included in this study. Guidelines provided by the dosimetry working party, European commission, and IAEA states that patients must weigh more than 60 kg but less than 80 kg (DWP, 1992; European Commission, 1996; IAEA, 2007). The weight restriction in this study ensured that the mean weight of patients were in the range of 65-75kg which is indicative of an average patient of 70kg (Hart et al., 2000). The study followed

guidelines on direct dose measurements as established by the dosimetry working party (1992) of the National Radiological Protection Board (NRPB) of the College of Radiographers in the United Kingdom, European commission (1996) and International Atomic Energy Agency (IAEA, 2007).The NRPB recommends that dose measurement studies be performed on a minimum of 10 patients, rather than phantoms or free air in order to provide a true measurement of clinical practice. In order to meet the objectives, KAP measurements were obtained from 218 participants undergoing conventional radiography examinations.

3.1.6 Exclusion criteria

All patients that were younger than 18 years and whose weight was outside the recommended range of 65kg to 75 kg were excluded. Similarly all vulnerable population such as mentally, physically challenged, imprisoned patients or critically ill patients were excluded from the study.

3.1.7 Data collection procedure

Data was collected by the researcher and a trained research assistant at each research site. The research assistants were all qualified diagnostic radiographers. Data was collected on 218 patients and 7 projections (379 examinations). A total of 61 participants were recruited for chest examinations (mean weight =69.86 kg), 48 for lumbar spine examinations (mean weight = 69.51kg), 57 for pelvis examinations (mean weight =70.59 kg) and 52 for skull examinations (mean weight =69.77 kg) refer to Table 3.2 below.

Table 3.2 Summary of the sample size and exposure parameters used at the different study sites

Examination	**PA Chest**	**LAT Chest**	**AP Lumbar Spine**	**LAT Lumbar Spine**	**AP Pelvis**	**PA Skull**	**LAT Skull**
Hospital 1	CR unit						
No of patients	20	20	20	20	26	21	21
Mean age	33 (20-73)	33 (20-73)	42(23-81)	42(23-81)	44(18-73)	30(20-44)	30(20-44)
Mean mass (kg)	69.51(65.3-74.6)	69.51(65.3-74.6)	69.45(65.1-75)	69.45 (65.1-75)	69.74(65.1-75)	69.03(65.1-74.8)	69.03(65.1-74.8)
Mean kVp	109 (102-117)	113 (109-117)	77.8 (70-85)	83.5 (73-96)	76.2 (73-81)	72.8 (63-77)	71 (66-73)
Mean mAs	4.6 (4-6.3)	5.4(4-6.3)	34.5 (25-50)	42.95(32-63)	26.06 (10.7-40.0)	27.03 (16-40)	24.3 (10.1-32)

Image receptor size	35X43	35X43	35X43	35X43	35X43	24X30	24X30
Mean SID (cm)	150	150	100	100	102	103	103
AEC used	No	No	No	No	No	No	No
Hospital 2	DR Unit						
No of patients	21	21	17	17	13	12	12
Mean age	42 (19-75)	42 (19-75)	46 (31-75)	46 (31-75)	46 (27-74)	33 (18-51)	33 (18-51)
Mean mass (kg)	71.4 (65.5-75.0)	71.4 (65.5-75.0)	70.57 (65.1-75)	70.57 (65.1-75)	71.80 (65.6-75)	70.43 (65.3-75)	70.43 (65.3-75)
Mean kVp	118 (105-125)	118 (117-125)	73.7 (69-87)	86.6 (81-90)	77.7 (70-81)	68.4 (66-73)	70.5 (66-73)
Mean mAs	1.9 (0.7-4.7)	8.01 (1.3-16.6)	50.57 (17.9-87.25)	58.6 (21.6-100.8)	76.3 (17.9-183)	34.6 (10.9-59.8)	19.3 (7.5-64.8)
Image receptor size	35X43	35X43	35X43	35X43	35X43	24X30	24X30
Mean SID (cm)	176	176	119	119	117	1150	129
AEC used	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospital 3	DR unit						
No of patients	20	20	11	11	18	19	19
Mean age	36(18-54)	36(18-54)	47 (22-79)	47 (22-79)	44(25-60)	34(21-53)	34(21-53)
Mean mass (kg)	68.67 (65.1-74.8)	68.67 (65.1-74.8)	68.50 (65.9-75)	68.50(65.9-75)	70.82(65.1-75)	69.85 (65.1-74.4)	69.85 (65.1-74.4)
Mean kVp	125	125	77	88.8 (77-90)	79.5 (77-80)	77.5 (77-80)	73.8 (73-80)
Mean mAs	1.5 (0.8-6.3)	3.8 (1.4-9.6)	18.66 (7.4-33.7)	13.7 (8.2-23.4)	13.72 (7.2-27.1)	17.9 (7-20.1)	10.4 (7-10.1)
Image receptor size	35X43	35X43	35X43	35X43	35X43	24X30	24X30
Mean SID (cm)	150	152	104	104	108	103	103
AEC used	Yes	Yes	Yes	Yes	Yes	Yes	Yes
*ranges are shown in parenthesis ()							

The researcher and trained research assistant recorded the participants weight, height, x-ray number, anatomical thickness of part under investigation, age, gender, hospital, applied kilovoltage (kV), exposure time, source to image distance (SID), tube current (mA or mAs), automatic exposure control (AEC) settings if applied as well as KAP meter values for each

radiographic examination. [Refer to appendix 6. (European Commission, 1996; Johnston and Brennan, 2000; IAEA, 2004)].

The participants' weights were measured inside the x-ray room, with a digital bathroom scale. Height measurements were obtained by means of a measuring tape that was attached on the wall. The patient thickness (PT) in the centre of the x-ray beam was measured by means of a measuring tape running from the x-ray tube to the table top. Once the distance from the x-ray source to the table top has been measured, the thickness of the anatomical part was measured by measuring the distance from the x-ray source to the patient (STP) where the beam is centred. Therefore, patient thickness was calculated for each projection by subtracting the source to patient distance from the source to table top distance.

In order to determine patient thickness: the source to patient thickness was measured as follows:

PA Chest projection: distance from the x-ray source to the surface of the patient in the midline at the level of the 7th thoracic vertebra where the radiographer centres the x-ray beam (Bontrager & Lampignano, 2013).
LAT Chest projection: distance from the x-ray source to the surface of the patient in the midaxillary region at the level of the 7th thoracic vertebra where the radiographer centres the beam (Bontrager & Lampignano, 2013).
AP Pelvis: distance from the x-ray source to the surface of the patient in the midline 5 cm below the level of the Anterior Superior Iliac Spine (ASIS) where the radiographer centres the beam (Bontrager & Lampignano, 2013).
AP Lumbar spine: distance from the x-ray source to the surface of the patient in the midline at the level of the iliac crest where the radiographer centres the beam (Bontrager & Lampignano, 2013).
LAT Lumbar spine: distance from the x-ray source to surface of the patient at the level of the iliac crest where the radiographer centres the beam (Bontrager & Lampignano, 2013).
PA skull: distance from the x-ray source to the surface of the patient, in the midline midway between the External Auditory Meatuses to exit at the Glabella (Bontrager & Lampignano, 2013).
LAT skull: distance from the x-ray source to the surface of the patients' skin at a point midway between the Glabella and inion where the radiographer centres the beam (Bontrager & Lampignano, 2013).

3.2 Research assumptions

The research was based on the following assumptions:

- KAP values were consistently and accurately recorded.
- The research assistant and researcher adhered to the data collection procedure when recruiting research participants.
- All equipment was properly calibrated and working properly.
- The x-ray equipment underwent the mandatory periodic quality assurance checks.

3.3 Dose calculations

During the second phase a correlational approach was adopted to calculate the effective and entrance skin doses from the KAP measurements using PCXMC 2.0 software programme. The Monto Carlo programme was developed in 1997. It calculates organ and effective doses based on the ICRP (60) and ICRP (103) using the different tissue weighting factors of patients. The physical parameters for patients (height, weight, as well as the exposure data (focal to skin distance (FSD), x-ray field size, filtration material and anode angle, projection (AP, PA or LAT), KAP value, kilovoltage (kVp), source to detector distance (SID) was entered into the Monto Carlo PCXMC 2.0 (Finland, 2008) software programme (Bor, et al, 2004). Refer to appendix (8-28)

The PCXMC (2008) 2.0 programme simulates how x-ray photons are spread through tissue. The simulation is based on different attenuations and interactions that the photons experience as they pass through the different body tissues (Sermomaa & Topiovaara, 1998). In this study simulations were performed with 20000 histories for each radiographic projection using the exposure factors for each patient. A study conducted by (Behardien Peters, 2017) shows that using more interactions only slows the computer while the effective and skin doses may not differ significantly (1%). The energy deposited was used to calculate effective and entrance skin doses for each projection. The x-ray field size for some projections was not recorded. It was assumed that the collimated field size was spread over the maximum area of the image receptor (refer to table 3.3).

Table 3.3 Estimated field size of image receptors for the different x-ray examinations

Examination	Field size (cm x cm)
Chest (PA)	35 x 43
Chest (LAT)	35 x 43
Lumbar Spine (AP)	35 x 43
Lumbar Spine (LAT)	35 x 43
Pelvis (AP)	35 x 43
Skull (PA)	24 x 30
Skull (LAT)	24 x 30

Additional parameters entered into the Monto Carlo programme is shown in the table 3.4 below.

Table 3.4 Parameters selected for the Monto Carlo programme for the different radiographic projections.

Parameters	Chest (PA)	Chest (LAT)	Lumbar Spine (AP)	Lumbar Spine (LAT)	Pelvis (AP)	Skull (PA)	Skull (LAT)
X ref and Y ref	0	0	0	0	0	0	0
Z ref	50	50	20	20	10	83	83
Projection angle	90^o	0^o	270^o	0^o	270^o	90^o	0^o
Cranio-caudal angle	0^o	0^o	0^o	0^o	0^o	0^o	0^o
Maximum energy	150 kV	150 kV	150 kV	150 kV	150 kV	150 kV	150 kV
Number of photons	20000	20000	20000	20000	20000	20000	20000
Anode angle Hospital 1	13^o	13^o	13^o	13^o	13^o	13^o	13^o
Anode angle Hospital 2	12^o	12^o	12^o	12^o	12^o	12^o	12^o
Anode angle Hospital 3	13^o	13^o	13^o	13^o	13^o	13^o	13^o
Filtration	2.5mm Al	2.5mm Al	2.5mm Al	2.5mm Al	2.5mm Al	2.5mm Al	2.5mm Al

3.4 Delimitation of the research

- Only hospitals affiliated to the University of Namibia, located in Windhoek using computed or digital radiography were included.

- In addition KAP measurements were obtained only on adult patients referred for conventional radiographic projections; PA and LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull that had a mean weight of 70kg ± 5kg.

3.5 Reliability and validity of the research instrument

Reliability of a research instrument can be described as the extent to which the research instruments yields the same results over time. In other words, the ability to consistently and accurately reproduce the data needed for analysis (Schneider et al., 2003). For the purpose of this research, digital bathroom scales were used to obtain patients' weights. This eliminated inter-reader variability when obtaining patients' weights. Similarly measuring tapes attached to the x-ray tube marked in millimetres (mm) were used to measure participants' thickness, as well as the participants' height. These measurements were verified by the radiographer positioning the patient. The KAP meter (VACUDAP, Germany) was calibrated at the manufacturer (refer to appendix 7). It is recommended that KAP meters be calibrated annually. A medical physicist employed at the National Radiation Protection services of Namibia was consulted to calibrate the KAP meter upon installation at each research site. In order to ensure that data were collected in a consistent manner, the researcher provided training to the research assistants regarding the research protocol.

3.6 Sources of uncertainty

The KAP meter was calibrated against a reference instrument IEC 60580 and has a combined uncertainty of ±25%. Therefore the KAP meter might overestimate the KAP values (refer to appendix 29). The KAP meter values were corrected using the correction factor for kilovoltage ≥ 70 kVp (refer to appendices 30 and 31).The digital scale was calibrated by placing it on a flat surface; it was reset to zero before weight measurement were obtained, only patients whose weight has been obtained by the researcher or research assistant was included in the study.

3.7 Pilot study

Uys and Basson (1985) describe piloting as a small study that helps the researcher to refine the data collection plans with reference to the data collection procedure and equipment. In addition, it helps with conceptual clarification of the research design as well. A pilot study was conducted on five patients at one of the selected hospitals using the methodology described in the research

proposal. This allowed for adjustments in the data collection sheet and allowed the researcher to accustom himself with the research instruments and research participants (Uys & Basson, 1985). The data obtained during the piloting of the instrument was not included in the final data analysis.

3.8 Research Ethics

Ethical approval was sought from the Health and Wellness Research Ethics committee of the Cape Peninsula University of Technology (appendices 32-34). Permission to conduct the study was granted by the; Permanent Secretary of the Ministry of Health and Social Services (MOHSS) in Namibia (appendix 35), the Director of the Radiation Protection Services (appendix 36), as well as the principal radiographers and practice managers at the research sites (refer to appendix 37).

The ethical principles of non-maleficence, beneficence, justice and respects for autonomy were followed throughout the research process (Pera & van Tonder, 2011).The objectives of the research were explained to participants upon arrival at the x-ray department. The risk of the study was negligible, as it only recorded the patient's weight, height and anatomical thickness as well as the kerma area product values of patients referred for the selected examinations without changing the protocol or positioning technique and did not interfere with the management or diagnosis of the patient. Patients were also not exposed to any additional radiation during the research process. In order to respect the patient's right to privacy, all measurements were obtained inside the x-ray room. Patients were included in the study on a voluntary basis after careful explanation of the research objectives and after informed consent had been obtained. Consent letters was in English and a translator was used in cases were the participant could not converse in English. The patient information leaflet and consent form is found in appendix 38. The translator was a qualified radiographer or student as not to breach patient confidentiality. The data obtained was stored and locked in the researcher's office, where only the researcher had access. The data collection form was also coded in order to protect the identity of research participants and to maintain anonymity. The data recorded from the patient was limited to the patients' weight, height, and anatomical thickness, age, gender and exposure factors and x-ray number (refer to appendix 6). No names or hospital number was required for this study. The hospitals were each assigned a study code so that the identity of participants were not be revealed during publication of the results.

3.9 Data analysis

The raw data obtained in this study was entered into a computer using Microsoft Excel 2016, and was analysed by using descriptive and inferential statistics (Marshall & Jonker, 2010). The data analysed included the patient's height, weight, equipment was well as exposure parameters. The researcher used the 3rd quartile of KAP meter values to set DRL's for the four conventional x-ray examinations (7 projections) (DWP, 1992). Six statistical tests were used during data analysis, correlation, regression analysis, linear correlation co-efficient, Co-efficient of determination (R^2), Chauvenet's criterion test as well as Pearson's co-efficient of skewness. In this study a regression line was drawn to correlate entrance skin doses with KAP values for each radiographic examination.

3.9.1 Linear regression

In this study linear regression was used to assess the relationship between the KAP values and the calculated skin dose for the four conventional (7 projections) examinations. A straight (regression) line was drawn to join all data points on the scatter plots. The regression line was used to quantify the relationship been the KAP and ESD's. When there is a linear relationship between two variables, the linear regression model is applied to predict the effect on the independent variable on dependant variable (De Muth, 2006).

3.9.2 Correlation

This is a statistical technique that determines the relationship between two variables (Machin et al., 2007). The strength and direction of the relationship is denoted by the correlation coefficient abbreviated r. The correlation coefficient ranges from -1 to +1, and demonstrate the relationship between variables. A positive relationship is demonstrated by a linear correlation where negative relationship is depicted by an inverse proportional correlation. Therefore when one value increases the other value decreases (Machin et al., 2007). A linear relationship is therefore between (-1≤ or +1).

3.9.3 Co-efficient of determination, R^2

The co-efficient of determination, R^2, is a statistical measure that is used to evaluate the relationship between the independent and dependant variable. R^2 is applied to explain how one

variable influences the other and ranges from ($0 \geq R^2 \leq 1$). In addition R^2 illustrates the strength of the relationship between the independent and dependant variable. On a scatter plot diagram, R^2 is used to determine how data is scattered around the mean of y values. R^2, is therefore described as the ratio of explained variation to the total variation expressed as percentage. R^2 describes data adjacent to the regression line. For example if r=0.91, then R^2=0.8281.This suggests that 82.81% of the difference in y values can be explained by the linear relationship between x and y whereas the residual 17.79% remains unexplained (De Muth, 2006; Mckillup, 2006; Mathbits, 2019).

3.9.4 Chauvenet's criterion test

The Chauvenet's criterion test is a test used in the rejection of outliers (Harris & Taylor, 2006; Lin & Sherman, 2007; Reddy, 2011). Knowledge of the standard deviation and mean of the sample under investigation is required. It is used to a reject a data point for small data sets up to a 1000, and is applied to samples that are either normally distributed, skew or multi-modal (Harris & Taylor, 2006; Lin & Sherman, 2007; Reddy, 2011).

The formula for data rejection were

$$\frac{dmax}{Sx} = 0.819 + 0.544.In(n) - 0.02346.In(n2)$$

Where, S_x, is the standard deviation of the data set and n is the number of data points. Data can be rejected by comparing a specific data point to the mean of the data by using a normal probability table (Harris & Taylor, 2006; Lin & Sherman, 2007; Reddy, 2011).

The KAP values for each of the projections that were very different from the means were investigated to see if they influenced the results. The data points were retained as they did not have a significant effect on the results.

3.9.5 Pearson's Co-efficient of skewness

The Pearson's co-efficient of skewness was used to determine how data was distributed around the mean.

Co-efficient of skewness = $\frac{3(Mean-Median)}{\sigma}$

The coefficient of skewness ranges from -3 to 3 and indicates whether data is positively or negatively skewed. When data is positively skewed the mean is greater than the median, whereas negatively skewed data is presented when the mean is smaller than the median. If the data is greatly skewed, one has to be cautious when removing outliers (Arulmozhi & Muthulakshmi, 2009; Statistics How To, 2019).

3.10 Summary of Chapter

This chapter described the methodology used to measure KAP for PA and lateral LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull projections. The chapter also highlights the statistical measures employed to execute the research study. In the following chapter the results of the study will be presented.

CHAPTER 4: RESULTS

The research study measured KAP for PA and lateral LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull projections. The 75th percentile of KAP values were used to establish local DRLs for the seven projections using a protocol established by the dosimetry working party (1992), which recommends that radiation dose measurements be obtained on a minimum of 10 patient whose weight lies between 65 and 75 kg. This method ensured that the mean weight of the study sample was between (65kg-75kg) which is considered the average weight of an adult (70 kg).

The relationship between the recorded KAP values and the patient's estimated skin dose was assessed using regression analysis, correlation coefficient, R as well as coefficient of determination, R^2.

This chapter presents the mean, median and 75th percentile KAP values of entrance skin doses and effective doses recorded for PA and, AP and LAT lumbar spine, AP pelvis AP, PA and LAT skull at the three study sites.

4.1 Chest projections

Table 4.1 shows the mean, median and 75th percentile KAP values, skin and effective doses for the PA and lateral chest projections at each hospital separately and then the combined values for PA and lateral chest projections (refer to appendices 8-13). The 75th KAP value for PA chest projections was 38.2 cGy.cm^2, 10.4 cGy.cm^2, and 7.6 cGy.cm^2 at hospitals 1, 2 and 3 respectively (appendices 8-13). The combined 75th percentile of KAP was 26.3 cGy.cm^2. The median effective dose calculated by the PCXMC 2.0 programme was 0.0687 mSv, 0.0208 mSv, and 0.0169 mSv respectively, with a combined effective dose of 0.0220 mSv. The 75th percentile KAP value for hospital 1 was considerably higher than the combined KAP value, while the KAP values for hospital 2 and 3 were considerably lower.

For the LAT chest projections, the 75th KAP value was 51.6 cGy.cm2, 52.9 cGy.cm2, and 26.7 cGy.cm2 at hospitals 1, 2 and 3 respectively. The combined 75th percentile of KAP was 47.0 cGy.cm2. The median effective dose calculated by the PCXMC 2.0 programme was 0.0793 mSv, 0.0855 mSv, and 0.0474 mSv respectively, with a combined effective dose of 0.0687 mSv. The 75th percentile KAP value for hospital 1 and 2 was considerably higher than the combined KAP value, while the KAP values for hospital 2 and 3 were considerably lower.

A regression line was drawn to correlate skin dose with KAP. There was a linear correlation for both PA (R=0.9936) and LAT (R=0.9295) chest projections combined (refer to table 4.1 and figure 4.1 and 4.2). Similarly a linear correlation was observed for both PA and LAT chest at hospitals 1, 2 and 3 respectively (refer to appendices 8-13, and 39-44).

Table 4.1: KAP, skin and effective doses for Chest projections

	Hospital 1		**Hospital 2**		**Hospital 3**		**Combined**	
Radiographic projection	**PA**	**LAT**	**PA**	**LAT**	**PA**	**LAT**	**PA**	**LAT**
Mean KAP ($cGy.cm^2$)	34.3	44.9	9.4	44.3	7.2	22.5	17.0	37.4
Median KAP ($cGy.cm^2$)	31.9	38.7	9.0	41.5	7.1	20.8	9.5	33.8
DRL (75^{th} percentile KAP) ($cGy.cm^2$)	38.2	51.6	10.4	52.9	7.6	26.7	26.3	47.0
Skin dose (mSv) (75^{th} percentile)	0.0496	0.0702	0.0140	0.0799	0.0104	0.0386	0.0333	0.0663
Accuracy of fit (R^2)[#]	0.9715	0.9451	0.9717	0.9415	0.9423	0.8686	0.9936	0.9295
Effective dose (mSv)*	0.0687	0.0793	0.0208	0.0855	0.0169	0.0474	0.0220	0.0687
Effective dose (mSv) 75th percentile	0.0759	0.1056	0.0229	0.1086	0.0202	0.0616	0.0545	0.0942

*Median values

[#] Values are for linear fit unless otherwise stated.

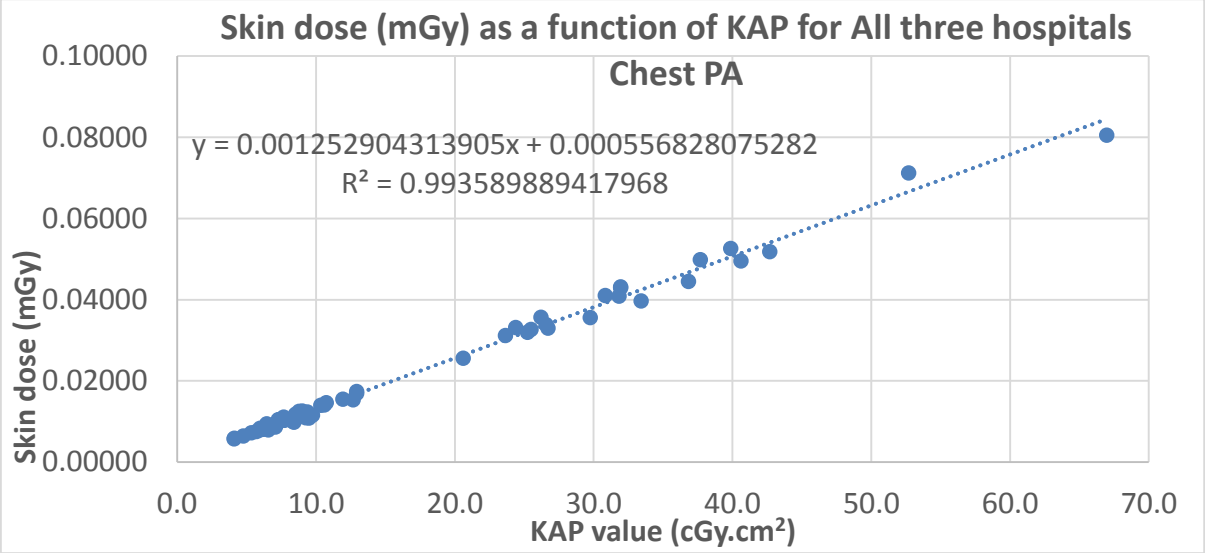


Figure 4.1 Linear fit for PA chest projections comparing skin dose and KAP values at the three research sites.

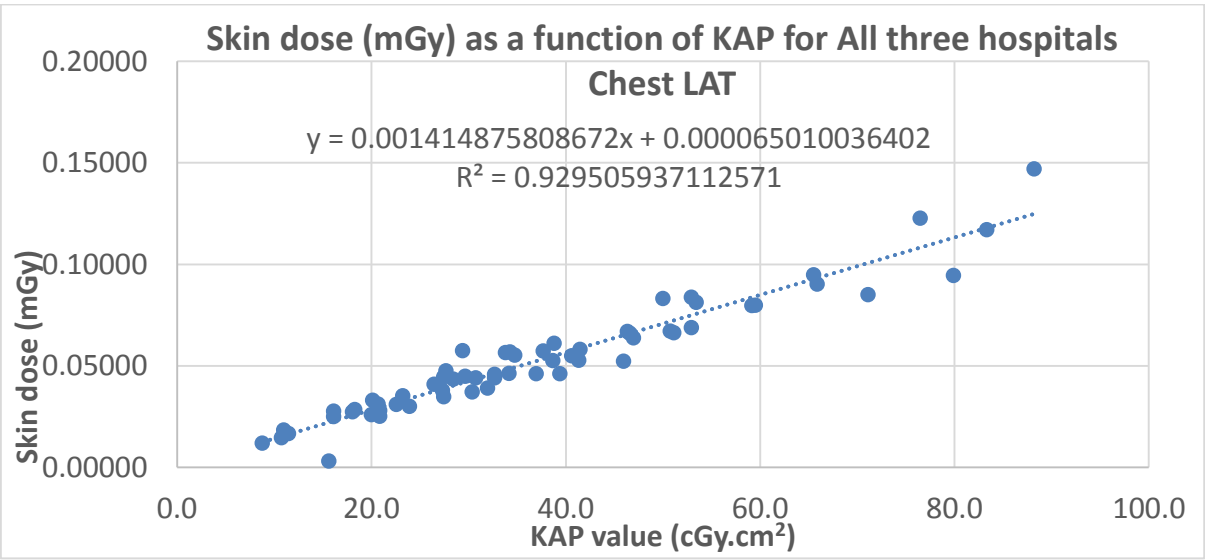


Figure 4.2 Linear fit for LAT chest projections comparing skin dose and KAP values at the three research sites.

4.2 Lumbar spine projections

Table 4.2 shows the mean, median and 75th percentile KAP values, skin and effective doses for the AP and lateral lumbar spine projections at each hospital separately and then the combined values for AP and lateral lumbar spine projections (refer to appendices 14 -19).

The 75th KAP value for AP lumbar spine projections was 129.7 cGy.cm^2, 307.1 cGy.cm^2, and 124.6 cGy.cm^2 at hospitals 1, 2 and 3 respectively (refer to appendices 14 – 19). The combined 75th percentile of KAP was 175.2 cGy.cm^2. The median effective dose calculated by the PCXMC 2.0 programme was 0.2017 mSv, 0.3771 mSv, and 0.1176 mSv respectively, with a combined

effective dose of 0.2248 mSv. The 75th percentile KAP value for hospital 2 was considerably higher than the combined KAP value, while the KAP values for hospital 1 and 3 were considerably lower.

For the LAT lumbar projections, the 75th KAP value was 231.7 cGy.cm2, 279.7 cGy.cm2, and 130.0 cGy.cm2 at hospitals 1, 2 and 3 respectively. The combined 75th percentile of KAP was 235.5 cGy.cm2. The median effective dose calculated by the PCXMC 2.0 programme was 0.1593 mSv, 0.3273 mSv, and 0.1245 mSv respectively, with a combined effective dose of 0.1864 mSv. The 75th percentile KAP value for hospital 2 was considerably higher than the combined KAP value, while the KAP values for hospital 1 and 3 were considerably lower.

A regression line was drawn to correlate skin dose with KAP. There was a linear correlation for both AP (R=0.9938) and LAT (R=0.7085) lumbar spine projections combined (refer to table 4.2 and figure 4.3 and 4.4). Similarly, a linear correlation was observed for both AP and LAT Lumbar spine projections at hospitals 1, 2 and 3 respectively (refer to appendices 14-19, and 45-50).

Table 4.2: KAP, skin and effective doses for Lumbar spine projections

	Hospital 1		**Hospital 2**		**Hospital 3**		**Combined**	
Radiographic projection	**AP**	**LAT**	**AP**	**LAT**	**AP**	**LAT**	**AP**	**LAT**
Mean KAP (cGy.cm^2)	117.3	192.0	240.4	250.1	90.5	94.6	154.7	190.2
Median KAP (cGy.cm^2)	93.1	181.6	175.6	234.1	68.8	80.1	124.9	182.6
DRL (75th percentile)	129.7	231.7	307.1	279.7	124.6	130.0	175.2	235.5
Skin dose (mSv) (75th percentile)	0.1439	0.2749	0.3198	0.3007	0.1415	0.1310	0.1970	0.2740
Accuracy of fit (R^2)$^{\#}$	0.9952	0.8888	0.9941	0.5575	0.9753	0.6127	0.9938	0.7085
Effective dose (mSv)*	0.2017	0.1593	0.3771	0.3273	0.1176	0.1245	0.2488	0.1864
Effective dose (mSv) 75th percentile	0.2617	0.2161	0.5783	0.4285	0.2704	0.1792	0.3792	0.2970

*Median values
$^{\#}$ Values are for linear fit unless otherwise stated.

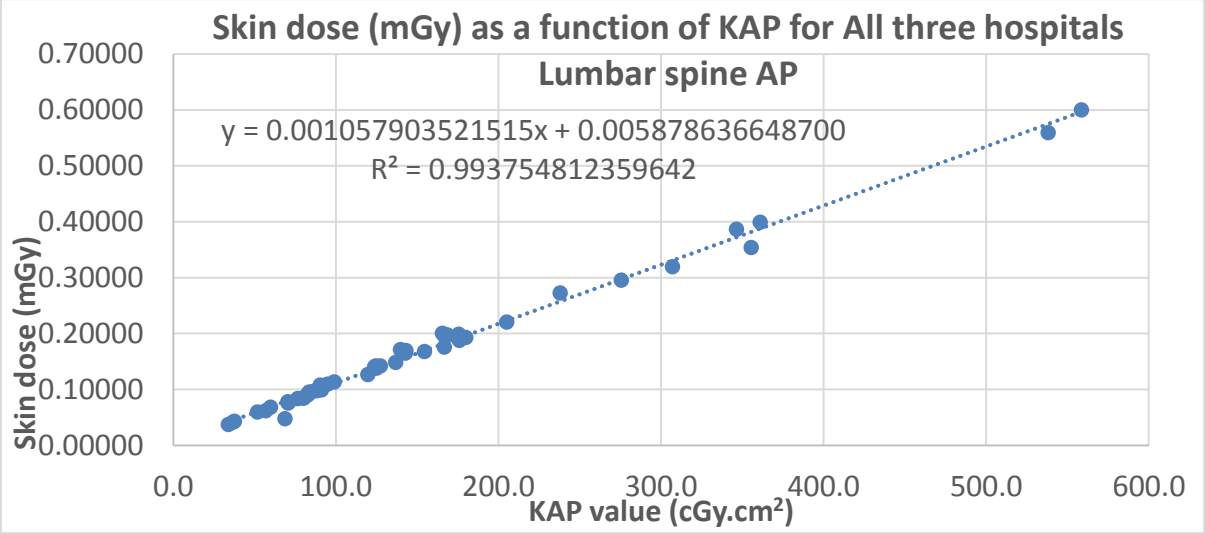


Figure 4.3 Linear fit for AP Lumbar spine projections comparing skin dose and KAP values at the three research sites.

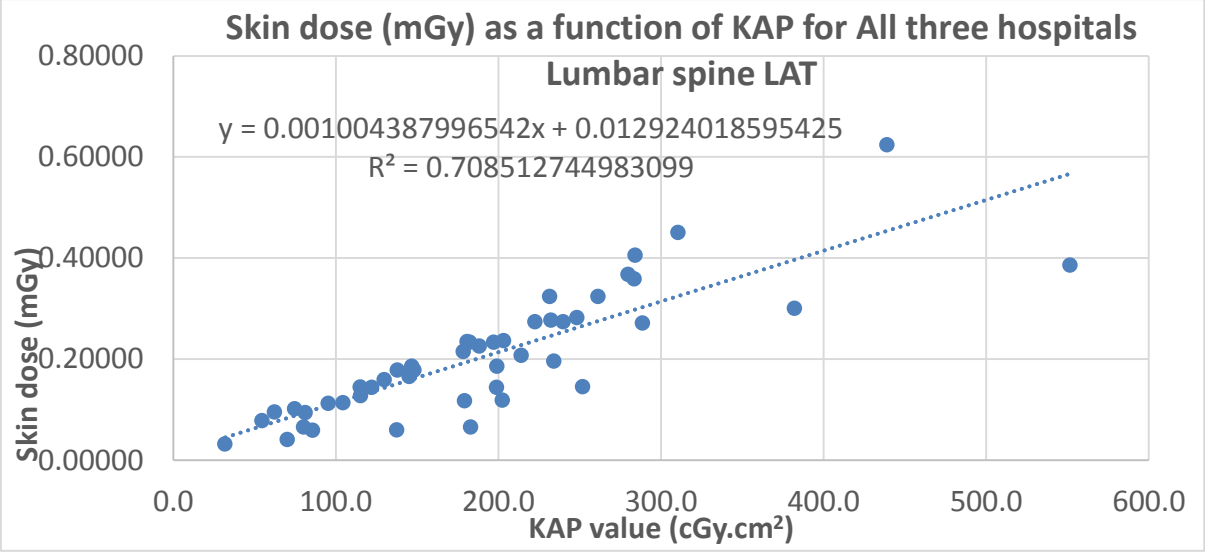


Figure 4.4 Linear fit for LAT Lumbar spine projections comparing skin dose and KAP values at the three research sites.

4.3 Pelvis projections

Table 4.3 shows the mean, median and 75th percentile KAP values, skin and effective doses for the AP pelvis projections at each hospital separately and then the combined values for AP pelvis projections (refer to appendices 20-22).

The 75th KAP value for AP pelvis projections was 194.9 cGy.cm^2, 328.8 cGy.cm^2, and 137.7 cGy.cm^2 at hospitals 1, 2 and 3 respectively (refer to appendices 20-22). The combined 75th percentile of KAP was 209.5 cGy.cm^2. The median effective dose calculated by the PCXMC 2.0

programme was 0.2220 mSv, 0.3386 mSv, and 0.1562 mSv respectively, with a combined effective dose of 0.2186 mSv. The 75th percentile KAP value for hospital 2 was considerably higher than the combined KAP value, while the KAP values for hospital 1 and 3 were considerably lower.

A regression line was drawn to correlate skin dose with KAP. There was linear correlation for AP Pelvis (R=0.9913) projections combined (refer to table 4.3 and figure 4.5). Similarly a linear correlation was observed for AP pelvis projections at hospitals 1, 2 and 3 respectively (refer to appendices 20-22, and 51-53).

Table 4.3: KAP, skin and effective doses for Pelvis projections

	Hospital 1	**Hospital 2**	**Hospital 3**	**Combined**
Radiographic projection	**AP**	**AP**	**AP**	**AP**
Mean KAP (cGy.cm^2)	155.7	260.2	122.1	168.9
Median KAP (cGy.cm^2)	155.1	223.4	96.9	147.9
DRL (75th percentile)	194.9	328.8	134.7	209.5
Skin dose (mSv) (75th percentile)	0.2246	0.3510	0.1500	0.2497
Accuracy of fit (R^2)$^{\#}$	0.9911	0.9875	0.9930	0.9913
Effective dose (mSv)*	0.2220	0.3386	0.1562	0.2186
Effective dose (mSv) 75th percentile	0.2605	0.4832	0.2149	0.3061

*Median values
$^{\#}$ Values are for linear fit unless otherwise stated.

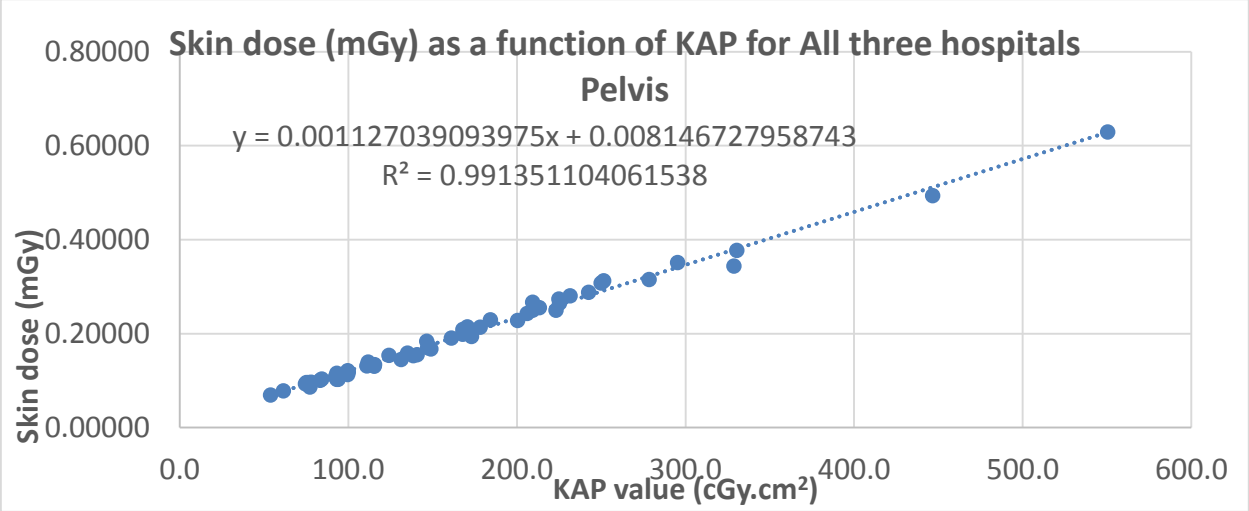


Figure 4.5 Linear fit for AP Pelvis projections comparing skin dose and KAP values at the three research sites.

4.4 Skull projections

Table 4.4 shows the mean, median and 75th percentile KAP values, skin and effective doses for the PA and lateral skull projections at each hospital separately and then the combined values for PA and skull projections (refer to appendices 23-28).

The 75th KAP value for PA skull projections was 70.9 cGy.cm^2, 103.7 cGy.cm^2, and 77.1 cGy.cm^2 at hospitals 1, 2 and 3 respectively (refer to appendices 23-28). The combined 75th percentile of KAP was 86.7 cGy.cm^2. The median effective dose calculated by the PCXMC 2.0 programme was 0.0156 mSv, 0.0271 mSv, and 0.0223 mSv respectively, with a combined effective dose of 0.0197 mSv. The 75th percentile KAP value for hospital 2 was considerably higher than the combined KAP value, while the KAP values for hospital 1 and 3 were considerably lower.

For the LAT skull projections, the 75th KAP value was 62.8 cGy.cm^2, 80.4 cGy.cm^2, and 47.6 cGy.cm^2 at hospitals 1, 2 and 3 respectively. The combined 75th percentile of KAP was 62.3 cGy.cm^2. The median effective dose calculated by the PCXMC 2.0 programme was 0.0204 mSv, 0.0220 mSv, and 0.0155 mSv respectively, with a combined effective dose of 0.0178 mSv. The 75th percentile KAP value for hospital 2 was considerably higher than the combined KAP value, while the KAP values for hospital 1 and 3 were considerably lower.

A regression line was drawn to correlate skin dose with KAP. There was a linear correlation for both PA (R=0.8454) and LAT (R=0.7949) skull projections combined. Refer to (table 4.4 and figure 4.7 and 4.8). Similarly a strong linear correlation was observed for both PA and LAT Lumbar skull projections at hospitals 1, 2 and 3 respectively (refer to appendces 23-28 and 54-59).

Table 4.4: KAP, skin and effective doses for Skull projections

	Hospital 1		**Hospital 2**		**Hospital 3**		**Combined**	
Radiographic projection	**PA**	**LAT**	**PA**	**LAT**	**PA**	**LAT**	**PA**	**LAT**
Mean KAP ($cGy.cm^2$)	55.9	56.5	82.0	54.8	63.0	40.6	64.5	50.3
Median KAP ($cGy.cm^2$)	50.1	49.4	92.5	52.8	60.7	36.2	61.4	46.4
DRL (75^{th} percentile)	70.9	62.8	103.7	80.4	77.1	47.6	86.7	62.3
Skin dose (mSv) (75^{th} percentile)	0.0736	0.0639	0.1233	0.0673	0.0894	0.0446	0.0922	0.0584
Accuracy of fit (R^2)$^{\#}$	0.8007	0.7578	0.8890	0.8453	0.7065	0.7508	0.8454	0.7949
Effective dose (mSv)*	0.0156	0.0204	0.0271	0.0220	0.0223	0.0155	0.0197	0.0178
Effective dose (mSv) 75^{th} percentile	0.0195	0.0283	0.0328	0.0338	0.0271	0.0224	0.0267	0.0283

*Median values
$^{\#}$ Values are for linear fit unless otherwise stated.

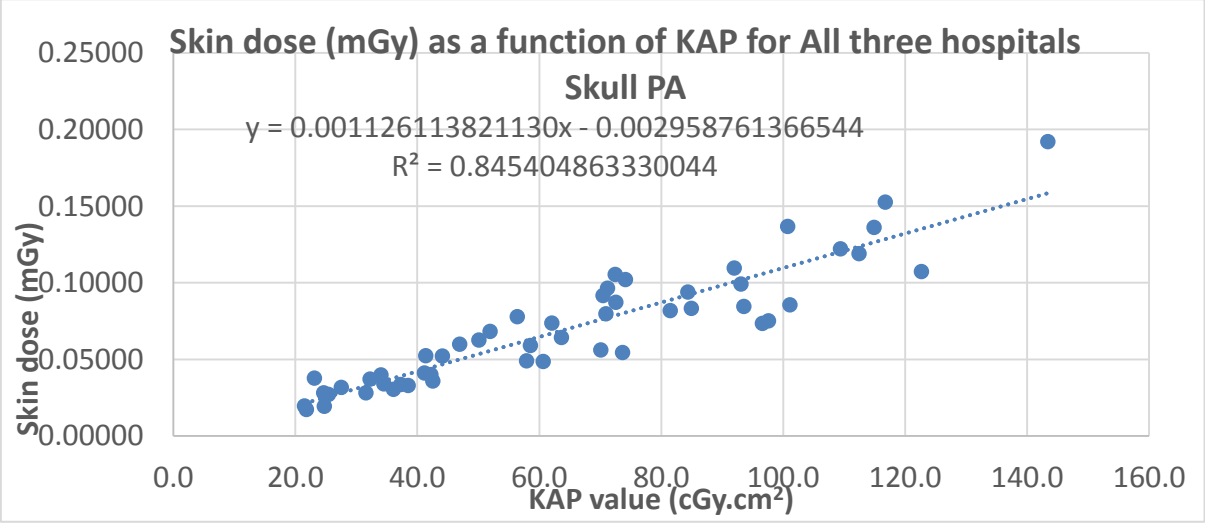


Figure 4.6 Linear fit for PA skull projections comparing skin dose and KAP values at the three research sites.

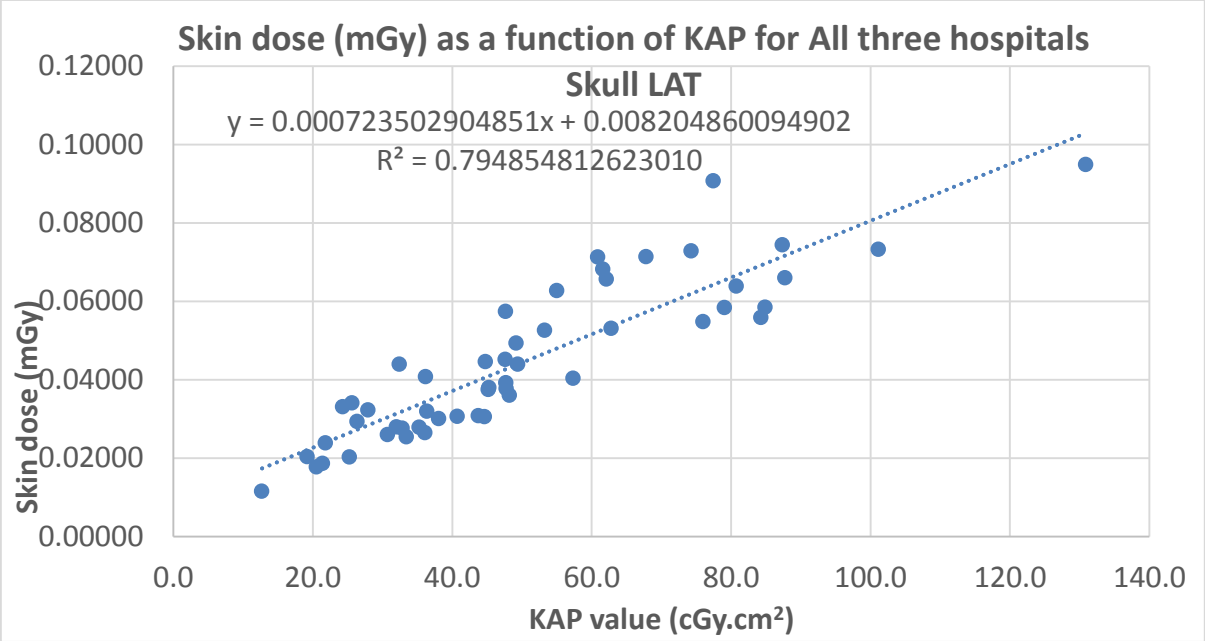


Figure 4.7 Linear fit for LAT Skull projections comparing skin dose and KAP values at the three research sites.

In this study the exposure factors and equipment parameters were entered into the PCXMC 2.0 software programme and entrance and effective doses were calculated. The 75th percentile KAP values were used to calculate conversion coefficients for the different radiographic examinations. The conversion coefficients for effective dose (E) were calculated with the following formulae (E/KAP) and skin dose (ESD/KAP) (Hansson & Karambatsakidou, 2000; Compagnone et al, 2005).

(Refer to table 4.5 below)

Table 4.5 Conversion coefficients for PA and lateral LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull projections

Research site	75th percentile (DRL) KAP cGy.cm^2	Skin dose (mSv) 75th percentile (ESD)	Effective dose (mSv) 75th percentile (E)	Conversion coefficient (ESD/KAP)	Conversion coefficient (E/KAP)
PA Chest					
Hospital 1	38.2	0.0496	0.0759	0.0013	0.0020
Hospital 2	10.4	0.0140	0.0229	0.0013	0.0022
Hospital 3	7.6	0.0104	0.0202	0.0014	0.0027
LAT Chest					
Hospital 1	51.6	0.0702	0.1056	0.0014	0.0020
Hospital 2	52.9	0.0799	0.1086	0.0015	0.0021

Hospital 3	26.7	0.0386	0.0616	0.0014	0.0023
AP Lumbar Spine					
Hospital 1	129.7	0.1439	0.2617	0.0011	0.0020
Hospital 2	307.1	0.3198	0.5783	0.0010	0.0019
Hospital 3	124.6	0.1415	0.2704	0.0011	0.0022
LAT Lumbar Spine					
Hospital 1	231.7	0.2749	0.2161	0.0012	0.0009
Hospital 2	279.7	0.3007	0.4285	0.0011	0.0015
Hospital 3	130.0	0.1310	0.1792	0.0010	0.0014
AP Pelvis					
Hospital 1	194.9	0.2246	0.2605	0.0012	0.0013
Hospital 2	328.8	0.3510	0.4832	0.0011	0.0014
Hospital 3	134.7	0.1500	0.2149	0.0011	0.0016
PA Skull					
Hospital 1	70.9	0.0736	0.0195	0.0010	0.0003
Hospital 2	103.7	0.1233	0.0328	0.0012	0.0003
Hospital 3	77.1	0.0894	0.0271	0.0012	0.0004
LAT Skull					
Hospital 1	62.8	0.0639	0.0283	0.0010	0.0005
Hospital 2	80.4	0.0673	0.0338	0.0008	0.0004
Hospital 3	47.6	0.0446	0.0224	0.0009	0.0005

The results of the study were presented in this Chapter. The 75th percentile of KAP values were used to establish local DRLs and develop conversion coefficients for the conventional radiography examinations. The next chapter will discuss the results and make recommendations surrounding the research study.

CHAPTER 5: DISCUSSION

This study developed LDRL's for ESD and E from measured KAP values for four conventional x-ray examinations (AP and LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull) in three hospitals in Windhoek Namibia. Additionally conversion factors were derived from 3rd quartile values in order to have a simple indicator of patient dose in clinical practice. This chapter discusses our findings in relationship to similar studies in literature, and makes recommendations for future research.

5.1 Diagnostic reference levels (DRLs)

It is recommended that 3rd quartile of KAP measurements be used to establish DRLs (Edmonds, 2009; Seeram & Brennan, 2017).

5.1.1 LDRL's for Chest radiography

The LDRL's for Chest examinations in this study are presented in table 5.1. (combined values).

Table 5.1 Local DRLs for chest projections

	75th percentile KAP (cGy.cm^2)	75th percentile ESD (mGy)	75th percentile E (mSv)
This study: PA chest	**26.3**	**0.0333**	**0.0545**
IAEA (1996)	NR	0.4	NR
Ng et al., (1998)	NR	0.3 (median)	NR
Osibote & de Azevedo (2008)	NR	0.24	NR
Sonowane et al., (2010)	NR	0.68	NR
Nyati et al., (2009)	NR	0.10	NR
Ofori et al, (2014)	NR	0.27 (median)	0.02
Aliasgharzadeh et al., (2015)	NR	0.37(mean)	0.04
This study Lat chest	**47.0**	**0.0663**	**0.0942**
IAEA (1996)	NR	1.5	NR
Ng et al., (1998)	NR	1.2 (median)	NR
Osibote & de Azevedo (2008)	NR	0.62	NR
Sonowane et al., (2010)	NR	1.74	NR
Nyati et al.,	NR	0.22	NR

(2009)			
Ofori et al, (2014)	NR	0.43 (median)	0.01
Aliasgharzadeh et al., (2015)	NR	0.99 (mean)	0.10
NR-not reported			

In this study, the local DRLs value for PA and LAT chest was 0.0333 mSv and 0.0663 mSv respectively by combining the skin dose measurements from the three research sites (refer to table 5.1). The ESDs for PA chest in hospital 2 and 3 were below the third quartile value but in hospital 1 was found to be higher (refer to table 4.1). The reason for the high ESD in hospital 1 could be attributed to the high mAs used at hospital 1 when compared to hospital 2 and 3. It is known that higher mAs with lower kVp will result in higher radiation dose to patients (Seeram & Brennan, 2017).

5.1.2 Lumbar spine radiography

The LDRL's for lumbar spine examinations in this study are presented in table 5.2. (combined values).

Table 5.2 Local DRLs for lumbar spine projections

	75^{th} percentile KAP ($cGy.cm^2$)	75th percentile ESD (mGy)	75^{th} percentile E (mSv)
This study: AP lumbar spine	**175.2**	**0.1970**	**0.3792**
IAEA (1996)	NR	10	NR
Ng et al., (1998)	NR	9.1 (median)	NR
Osibote & de Azevedo (2008)	NR	2.60	NR
Sonowane et al., (2010)	NR	8.39	NR
Nyati et al., (2009)	NR	5.30	NR
Ofori et al, (2014)	NR	3.25 (median)	0.02
Aliasgharzadeh et al., (2015)	NR	2.18 (mean)	0.04
This study Lat lumbar spine	**235.5**	**0.2740**	**0.2970**
IAEA (1996)	NR	30	NR
Ng et al., (1998)	NR	14 (median)	NR
Osibote & de Azevedo (2008)	NR	4.75	NR

Sonowane et al., (2010)	NR	15.66	NR
Nyati et al., (2009)	NR	NR	NR
Ofori et al, (2014)	NR	NR (median)	0.01
Aliasgharzadeh et al., (2015)	NR	5.36 (mean)	0.10
NR-not reported			

In this study, the local DRLs value for AP and LAT lumbar spine was 0.1970 mSv and 0.2740 mSv respectively by combining the skin dose measurements from the three research sites (refer to table 5.2). The ESDs for AP lumbar spine in hospital 1 and 3 were below the third quartile value but in hospital 2 was found to be higher (refer table 4.2). The reason for the high ESD in hospital 2 could be attributed to the high mAs used at hospital 2 when compared to hospital 1 and 3 (Seeram & Brennan, 2017).

.

5.1.3 Pelvis

The LDRL's for pelvis examinations in this study are presented in table 5.3. (combined values).

Table 5.3 Local DRLs for pelvis projections

	75th percentile KAP (cGy.cm^2)	75th percentile ESD (mGy)	75th percentile E (mSv)
This study: AP pelvis	**209.5**	**0.2497**	**0.3061**
IAEA (1996)	NR	10	NR
Ng et al., (1998)	NR	5.3 (median)	NR
Osibote & de Azevedo (2008)	NR	NR	NR
Sonowane et al., (2010)	NR	8.03	NR
Nyati et al., (2009)	NR	2.98	NR
Ofori et al, (2014)	NR	1.31 (median)	NR
Aliasgharzadeh et al., (2015)	NR	1.76 (mean)	0.13
NR-not reported			

In this study, the local DRLs value for AP Pelvis was 0.2497 mSv by combining the skin dose measurements from the three research sites (refer to table 5.3). The ESDs for AP Pelvis in hospital 1 and 3 were below the third quartile value but in hospital 2 was found to be higher (refer to table 4.3). The reason for the high ESD in hospital 2 could be attributed to the high mAs used at hospital 2 when compared to hospital 1 and 3 (Seeram & Brennan, 2017). .

5.1.4 Skull

The LDRL's for skull examinations in this study are presented in table 5.4. (combined values).

Table 5.4 Local DRLs for skull projections

	75th percentile KAP (cGy.cm^2)	75th percentile ESD (mGy)	75th percentile E (mSv)
This study: PA skull	**86.7**	**0.922**	**0.0267**
IAEA (1996)	NR	5	NR
Ng et al., (1998)	NR	4.7 (median)	NR
Osibote & de Azevedo (2008)	NR	1.55	NR
Sonowane et al., (2010)	NR	6.89	NR
Nyati et al., (2009)	NR	NR	NR
Ofori et al, (2014)	NR	NR (median)	NR
Aliasgharzadeh et al., (2015)	NR	1.39 (mean)	0.01
This study Lat skull	**62.3**	**0.584**	**0.0283**
IAEA (1996)	NR	3	NR
Ng et al., (1998)	NR	3 (median)	NR
Osibote & de Azevedo (2008)	NR	NR	NR
Sonowane et al., (2010)	NR	5.86	NR
Nyati et al., (2009)	NR	NR	NR
Ofori et al, (2014)	NR	NR (median)	NR
Aliasgharzadeh et al., (2015)	NR	1.01 (mean)	0.01
NR-not reported			

In this study, the local DRLs value for AP and LAT skull was 0.0922mSv and 0.0584 respectively by combining the skin dose measurements from the three research sites (refer to table 5.4). The ESDs for PA and LAT lumbar spine in hospital 1 and 3 were below the third quartile value but in hospital 2 was found to be higher (refer to table 4.2). The reason for the high ESD in hospital 2 could be attributed to the high mAs used at hospital 2 when compared to hospital 1 and 3.

A comparison was done between hospital 1 and 3 because they both had equipment from the same manufacturer. Entrance skin doses were higher in hospital 1 than in hospital 3. This could be attributed to the fact that hospital 3 employed direct digital radiographic systems with automatic exposure control devices while hospital 1 employed computed radiography systems with manual exposures (Nyati et al, 2009; Seeram & Brennan, 2017).

5.1.5 Comparison of local DRLs with international values

The ESD's in this study was lower than those reported in the literature (IAEA, 1996; Ng et al., 1998; Osibote & Azevedo, 2008; Nyathi et al., 2009; Sonowane et al., 2009; Ofori et al., 2014; Aliasgharzadeh et al., 2015) refer to tables (5.1 to 5.4). In this study the lateral chest, lateral lumbar spine and lateral skull had higher skin doses when compared to the AP or PA projections of the same examination. This could be attributed to the shorter focus to skin distance for lateral examinations when compared to PA or AP examinations (Olowookere et al., 2011; Joyce et al, 2013).

5.2 Effective doses

In radiation protection effective dose is used to calculate annual dose limits to members of the public as well as radiation workers. It is used to maintain standards (Fisher & Fahey, 2017). In this study the highest effective dose recorded was for AP lumbar spine (0.3792 mSv) and the lowest (0.0267 mSv) for PA skull (refer to tables 5.2 and 5.4) respectively. The high dose reported for lumbar spine examinations is consistent with the literature (Khoo et al., 2003; IAEA, 2009). It can be noted from this study that the effective doses for (PA and LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull) are similar than those reported in the literature (refer to tables 5.1 to 5.4). The high effective doses in this study could be as a result of the adjustment of some of the tissue weighing factors (Obed et al., 2015).

5.3 Conversion Factors

The conversion factors established in this study can be used as a simple means to calculate entrance skin and effective doses from KAP values, thereby creating awareness amongst

radiology staff in the department. This can be achieved by multiplying the conversion factor with the displayed KAP value as indicated on table 4.5 in chapter 4.

5.4 Limitations of the study

- Possible limitations of the study was that the total field size (collimation) may not have been a true indication of the area exposed to radiation as some field sizes was not recorded. This may have affected the KAP values.

5.5 Conclusion and recommendations

The 75th percentile ESD's for (PA and LAT chest, AP and LAT lumbar spine, AP pelvis, and PA and LAT skull) in this study were lower than those reported in the literature, while the effective doses generally compared well with those reported in the literature.

The following are recommendations from the study:

It was noticed in this study that radiographers use manual exposures even though AEC devices were available.Therefore it is recommended that radiographers should undergo training on how to effectively use AEC devices during radiological examinations so that lower exposure factors can be achieved.

A national dose management programme should be established to create awareness of radiation doses amongst radiographers.

Radiographers in the clinical area should use the conversion coefficients (ESD/KAP) to convert KAP to ESD to get an immediate indication of patient doses. Similarly departmental managers and radiation safety officers (RSOs) should use the conversion coefficients (E/KAP) to calculate effective doses for the different radiographic projections.

The results of the study will be forwarded to the NRPA to be endorsed as initial local DRLs for Windhoek, Namibia.

It is further recommended that the study be repeated at five (5) year intervals in order to comply with Namibian legislation and as a means towards implementation of national diagnostic reference levels.

REFERENCES

Abdelhalim, M.K. 2011. Patient dose levels for seven different radiographic examination types. *Saudi Journal of Biological Sciences*, 17: 115-118.

Aird, E.G.A. 1988. *Basic physics for Medical imaging*. Oxford: Heinemann.

Akinlade, B.I., Farai, I.P. & Okunade, A.A. 2012. Survey of dose area product received by patients undergoing common radiological examinations in four centers in Nigeria. *Journal of Applied Clinical Medical Physics,* 13(4): 3712

Aliasgharzadeh, A., Mihandoost, E., Masoumbeigi, M., Salimian, M. & Mohseni, M. 2015. Measurement of entrance skin doses and calculation of effective dose for common diagnostic x-ray examinations in Kashan, Iran. *Global Journal of Health Science*, 7(5): 202-207.

Allisay-Roberts, P. & Williams, J. 2008. *Farr's physics for medical imaging*. 2nd ed. Philadelphia: Elsevier.

Arulmozhi, G. & Muthulakshimi, S. 2009. Statistics for management. 2nd ed. India: Tata McGraw-Hill Education.

Ball, J., Moore, A.D., & Turner. 2008. *Ball and Moore's essential physics for radiographers.* 4th ed. Chichester: Blackwell.

Behardien Peters, N.B. 2017. Determination of effective dose and entrance skin dose from dose area product values for barium studies in adult patients at a large tertiary hospital in the Western Cape. [Unpublished Master of Science thesis] CPUT, Cape Town

Bontrager, K.L. & Lampignano, J.P. 2013. *Textbook of radiographic positioning and related anatomy*. 8th ed. St. Louis: Elsevier.

Bor, D., Sancak, T., Olgar, T., Elcim, Y., Adanali, A., Sanlidilek, U. & Akyar, S. 2004. Comparison of effective doses obtained from dose-area product and air kerma measurements in interventional radiology. *The British Journal of Radiology*, 77: 1-8.

Compagnone, G., Baleni, M.C., Pagan, L., Calzolaio, F.L., Barozzi, L. & Bergamini, C. 2006. Comparison of radiation doses to patients undergoing standard radiographic examinations with conventional screen-film radiography, computed radiography and direct digital radiography. *The British Journal of Radiology*, 79: 899-904.

Compagnone, G., Pagan, L. & Bergamini, C. 2005. Comparison of six phantoms for entrance skin dose evaluation in 11 standard x-ray examinations. *Journal of Applied Clinical Medical Physics*, 6(1): 101-113. Winter.

De Muth, J.E. 2006. Basic statistics and pharmaceutical statistical applications. 2nd ed. United States of America: Taylor & Francis Group.

Department of Health South Africa. 2006. *Radiography conditions (excluding radiotherapy simulators) - Annexure to licence*.

http://www.doh.gov.za/department/radiation/licencing/electronicproducts/conditions/radiography.pdf [accessed 06 June 2013].

Dosimetry Working Party (DWP) of the Institute of Physical Sciences in Medicine. 1992. *National protocol for patient dose measurement in diagnostic radiology*. Chilton: NRPB (National Radiation Protection Board).

Dowsett, D.J., Kenny, P.A., & Johnston, R.E. 2006. *The physics of diagnostic imaging*. 2nd ed. London: Hodder Arnold.

Edmonds, K.D. 2009. "Diagnostic reference levels as a quality assurance tool." The *Radiographer* 56(3): 32-37.

European Commission, 1999. Radiation Protection 109: Guidance on diagnostic reference levels (DRLs) for medical exposures.

European Commission. 1996. European guidelines on quality criteria for diagnostic radiographic images.

Fauber, T.L. & Dempsey, M.C. 2013. X-ray field size and patient dosimetry. *Radiologic Technology*, 85(2): 155-161.

Fisher, D.R. & Fahey, F.H. 2017. Appropriate use of effective dose in radiation protection and risk assessment. *Health Physics*, 113(2):102-109.

Freitas, M.B., & Yoshimura, E.M. 2009. Diagnostic reference levels for the most frequent radiological exams carried out in Brazil. *American Journal Public Health*, 25(2): 95-104.

Gray, J.E., Archer, B.R., Butler, P.F., Hobbs, B.B., Mettler, F.A., Pizzutiello, R.J., Schueler, B.A., Strauss, K.J., Suleiman, O.H. & Yaffe, M.J. 2005. Reference values for diagnostic radiology: application and impact. *Radiology*, 235: 354-358.

Ghom, A.G. 2008. Units of measurement and dosimetry. In Ghom, A.G. (eds). *Textbook of oral radiology*. Logix Park: Elsevier. 64.

Hansson, B. & Karambatsakidou, A. 2000. Relationship between entrance skin dose, effective dose and dose area product for patients in diagnostic and interventional cardiac procedures. *Radiation Protection Dosimetry*, 90(1-2): 141-144.

Harris, M. & Taylor G. 2003. Medical statistics made easy. New York: Springer. 48-54

Hart, D., Hillier, M.C. & Wall, B.F. 2000. *Doses to patients from medical x-ray examinations radiographic x-ray imaging procedures in the UK-2000 review*. Chilton: NRPB-RW14.

Heggie, J. 2008. Radiation protection in diagnostic and interventional radiology. In Trapp, T.V. & Kron T. (eds). *An introduction to radiation protection in medicine*. New York: Taylor & Francis.109, 124-125.

Hobbie, R.K., & Roth, B.J. 2007. *Intermediate physics for medicine & biology*. 4th ed. New York: Springer.

Hitchcock, R. 2015. Authenticity, Identity, and Humanity: The Haillom San and the State of Namibia. *Antropological forum*, 25(3): 262-284. https://doi.org/10.1080/00664677.2015.1027658 [accessed 20/01/2020]

International Atomic Energy Agency. 2009. International Workshop on Justification of Medical Exposures in Diagnostic Imaging, Brussels, Belgium. Http://rpop.iaea.org/RPOP/RPoP/content/pastEvents/justification-medical-exposure [05/08/2013]

International Atomic Energy Agency. 2007. Technical report series No. 457: Dosimetry in diagnostic radiology: An international code of practice.

International Atomic Energy Agency. 2006. Safety support series No. 39: Applying radiation safety standards in diagnostic radiology and interventional procedures using x-rays

International Atomic Energy Agency. 1996. Safety support series No .115: International Basic Safety Standards for protection against ionizing radiation and for the safety of radiation sources.

International Commission on Radiological Protection. 2005. Basis for dosimetric quantities used in radiation protection, ICRP draft for discussion. Task group of ICRP committee 2.

International Commission on Radiological Protection. 1996. Radiological protection and safety in medicine, ICRP publication 73. *Annals of the ICRP,* 26 No. 2.

ICRP-103. International Commission on Radiological Protection. 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Annals of the ICRP, 1-322.

Johnston, D.A., & Brennan. 2000. Reference levels for patients undergoing common diagnostic x-ray examinations in Irish hospitals. The *British Journal of Radiology*, 73: 396-402.

Joyce, M., McEntee, M., Brennan, P.C. & O'Leary, D. 2013. Reducing dose for digital cranial radiography: the increased source to image-receptor distance approach. *Journal of Medical Imaging and Radiation Sciences*, 1-8

Kamiya, K., Ozaza, K., Akiba, S., Niwa, O., Kodama, K., Takumara, N., Zaharieva, E.K., Kimura, Y., & Wakeford, R. 2015. From Hirosjima and Nagasaki to Fukushima 1. Long-term effects of radiation exposure on health. The *Lancet*, 386: 469-78.

Khoo, L.A. L., Heron, C., Patel, U., Given-Wilson, R., Grundy, A., Khaw, K. T. & Dundas, D. 2003. The diagnostic contribution of the frontal Lumbar spine radiograph in community referred low back pain- a prospective study of 1030 patients. Clinical *Radiology*, 58 (6): 606-609.

Kramer, R., Khoury, H.J. & Vieira, J.W. 2008. CALDose_X-a software tool for the assessment of organ and tissue absorbed doses, effective dose and cancer risk in diagnostic radiology. *Physics in Medicine and Biology*, 53: 6437-6459.

Kron, T. 2008. Introduction. In Trapp, T.V. & Kron T. (eds). *An introduction to radiation protection in medicine*. New York: Taylor & Francis. 7.

Lee, G-S., Kim, J-S., Seo, Y-S. & Kim, J-D. 2013. Effective dose from direct and indirect digital panoramic units. *Imaging Science in Dentistry*, 43: 77-84

Lin, L. & Sherman, P.D. 2007. *Cleaning data the chauvenet way*. The proceedings of the SouthEAST SAS User Group. SESUG proceedings. Paper SA11.

Machin, D., Campbell, M.J. & Walters, S.J. 2007. *Medical statistics a textbook for the health sciences*. 4th ed. West Sussex: John Wiley & Sons Ltd.

Marshall, G. & Jonker, L. 2010. An introduction to descriptive statistics: A review and practical guide. *Radiography* : e1-e7.

Martin, C.J. 2007. Optimisation in general radiography. *Biomedical Imaging and Intervention Journal*, 3(2): 1-14.

Mathbits.2019.Correlationcoefficient. http://mathbitsnotebook.com/Algebra1/StatisticsReg/ST2CorrelationCoefficients.html [accessed 06/09/2019]

Mckillup, S. 2005. Statistics explained: an introductory guide for life scientist. Cambridge: Cambridge University Press.

Ng, K-H., Rassiah, P., Wang, H-B., Hambali, A.S., Muthuvellu, P. & Lee, H-P. 1998. Doses to patients in routine x-ray examinations in Malaysia. *The British Journal of Radiology*, 71: 654-660, June.

Nyathi, T., Nethwadzi, L.C., Mabhengu, T., Pule, M.L. & Van der Merwe, D.G. 2009. Patient dose audit for patients undergoing six common radiography examinations: potential dose reference levels. *The South African Radiographer*, 47(2): 9-14

Obed, R., Ogbole, G. & Majoglabe, S. 2015. Comparison of the ICRP 60 and ICRP 103 recommendations on determination of the effective dose from abdominopelvic computed tomography. International Journal of Medical Physics, Clinical Engineering and Radiation Oncology, 4: 172-176 http://dx.doi.org/10.4236/ijmpcero.2015.42021 [accessed 09/09/2019]

Ofori, E.K., Antwi, W.K., Scutt, D.N. & Ward, M. 2012. Optimization of patient radiation protection in pelvic x-ray examination in Ghana. *Journal of Applied Clinical Medical Physics*, 13(4): 3719

Ofori, K., Gorden, S.W., Akrobortu, E., Ampene, A.A. & Darko, E.O. 2014. Estimation of adult patient doses for selected x-ray examinations. Journal of Radiation Research and Applied Sciences, 1-4.

Olowookere, C.J., Obed, R.I., Babolola, I.A. & Bello,T. O. 2011. Patient dosimetry during chest, abdomen, skull and neck radiography in SW Nigeria. *Radiography*, 17: 245-249.

Osibote, O.A. & de Azevedo, A.C.P. 2008. Estimation of adult patient doses for common x-ray examinations in Rio de Janeiro, Brazil. *Physica Medica*, 24: 21-28

Pera S. & van Tonder, S. 2011. Ethics in healthcare. 3rd ed. Lansdowne: Juta & Co.Ltd.

Reddy, T.A. 2011. *Applied data analysis and modelling for energy engineers and scientist*. New York: Springer Science & Business Media.

Republic of Namibia, 2005. *Atomic Energy and Radiation Protection Act 5 of 2005*. Radiation Protection and Waste Disposal Regulations, government notice 221 of 2011. Government printer.

Roberts, P.J. 1995. National patient dose measurement protocols: an investigation on behalf of the ICRU. *Radiation Protection Dosimetry*, 57(1-4):355-358.

Schneider, Z., Elliot, D., LoBiondo-Wood, G. & Haber, J. 2003. *Nursing research methods, critical appraisal and utilisation*. 2nd ed. Marrickville: Elsevier.

Seeram, E. & Brennan, P.C. 2006. Diagnostic reference levels in radiology. *Radiologic Technology*, 77(5):373-384, May/June.

Seeram, E. & Brennan, P.C. 2017. *Radiation Protection in Diagnostic Imaging*. Burlington: Jones & Barlett Learning.

Servomaa, A. & Taapiovaara, M. 1998. Organ dose calculation in medical x ray examinations by the program PCXMC. *Radiation Protection Dosimetry*, 80(1-3): 213-219.

Sonowane, A.U., Shirva, V.K. & Pradhan, A.S. 2010. Estimation of skin entrance doses (ESDs) for common medical x-ray diagnostic examinations in India and proposed diagnostic reference levels (DRLs). *Radiation Protection Dosimetry*, 138(2): 129-136.

Pearsons coefficient of skewness. http://statisticshowto.com/pearson-coefficient-of-skewness/ [accessed 05/09/2019]

Trap, J.V. & Johnston, P. Radiation detection and simulation methods. In Trapp, T.V. & Kron T. (eds). *An introduction to radiation protection in medicine*. New York: Taylor & Francis. 81.

United Nations Scientific Committee on the Effects of Radiation. 2000. Sources, effects and risk of ionizing radiation. Volume 2. Report to General Assembly http://www.unscear.org/docs/reports/gareport.pdf. (Accessed 14 May 2013).

Uys, H.H.M. & Basson, A.A. 1985. *Research methodology in nursing*. Durban: Colographic.

Verdun, F.R., Bochud, F., Gudinchet, F., Aroua, A., Schnyder, P. & Mueli. 2008. Quality Initiatives Radiation Risk: What you should know to tell your patient. *Radiographics*, 28(7): 1807-1816.

Vom, J., & Williams, I.J. 2017. Justification of radiographic examinations: what are the key issues? *Journal Medical Radiation Sciences*, 64: 212-219.

APPENDIX 1 (RAF9/033 PROJECT REQUEST)

Ministry of **H**ealth and **S**ocial **S**ervices
Primary **H**ealth **C**are **S**ervices
Office of the **D**irector
Interoffice **M**emorandum

To: Ms. P. Nghipandulwa
Acting Director: THC & CSS

Dr Ithindi – Shipanga
Director: Khomas Region

Dr. H. Nkandi – Shiimi
Senior Medical Superintendent: WCH

Dr. R. C. Gariseb
Acting: Medical Superintendent: KSH

From: Ms. M. Nghatanga
Director: PHC

Date: 18 August 2005

Re: Strengthening Radiological Protection of Patients and Protection in Medical Exposure RAF/9/033

As you are aware, Namibia is one of the Member states in the African region which participates in projects under the International Atomic Energy Agency (IAEA). The above-mentioned project is one such project.

During a meeting held earlier this year in Libya, each member state was requested to participate in a pilot study under IAEA on the above – mentioned topic.

The purpose of the study is to strengthen radiological protection of patients and control medical exposure. On the other hand, we hope to improve diagnostic information content on images produced, reduce unnecessary radiation exposure, reduce medical costs and improve departmental management.

In order to achieve this, surveys of image quality and patient doses in simple radiographic examinations will be done, guidance levels established and compared with international standards.

There is a need for this study to be done in a practical set-up. Therefore Windhoek Central Hospital and Katutura State Hospital were identified for this project.

The project is divided into two phases. The first phase of the project is expected to be finalised towards the end of October 2005 and the second phase will start in 2006.

The following staff members from your departments will be key role players in the study.

1. Ms L. Beukes (Control Radiographer): National Coordinator
2. Ms N. Bloodstaan (Radiographer): Project Coordinator
3. Ms. N. Cupido (Chief Radiog.: Training): Assist Project Coordinator
4. Dr. J. A. Gabone (Radiologist): Consultant
5. Ms. Sikai Shambira (Medical Physicist): Consultant

I therefore request you kindly to support this project and assist the staff members to carry out these activities successfully.

Thanking you in anticipation.

APPENDIX 2:

Letter of permission: Permanent Secretary

P O Box 20323
Windhoek
Namibia
29 May 2013

To: The Permanent Secretary
Ministry of Health and Social Services
Private Bag 13301
Windhoek

Dear Sir/Madam

RE: Request for permission to carry out a research study at Windhoek Central and Katutura Intermediate hospitals.

I am registered for a Masters Degree in Technology - Radiography (Diagnostic), at the Cape Peninsula University of Technology, (student number 213009641).

As a course requirement I am expected to complete a research project. The title of the study is **"Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek Namibia to develop diagnostic reference levels".**

As part of a global effort to minimise radiation doses delivered to patients radiographers are obliged to keep radiation doses as low as reasonably achievable. The study intends to measure radiation doses delivered to patients during routine x-ray examinations. A portable Dose Area Product (DAP) meter will be attached to the x-ray tube housing of the collimator and will be used to measure the radiation doses delivered to some patients. The study will involve patients referred for the Chest, Lumbar Spine, Pelvis and Skull radiographs. Participants will be asked to participate voluntarily after the research objectives have been explained to them thoroughly. After consenting to the study, the patients' weight, height, age,

gender and thickness of anatomical part under investigation will be recorded along with the exposure factors used during the examination. Besides these measurements there will be no difference to what is routinely done in the department and there will be no interference with the management of patients as well as the daily duties of radiographers employed at these hospitals.

I have selected the departments at Windhoek Central Hospital (WCH) and Katutura Intermediate Hospital (KIH) to conduct my research as it is the largest public hospitals and utilise computed radiography techniques which may be associated with higher radiation doses. It is anticipated that the research may contribute towards the optimisation of radiation doses delivered to patients.

In addition I am also an employee at the University of Namibia (Assistant Lecturer) responsible for Clinical Practice at Windhoek Central Hospital and Katutura Intermediate Hospital respectively; on staff development leave to pursue this qualification. I am therefore familiar with the radiography department and management of radiographic matters.

The data obtained in this study will be strictly confidential. In order to respect the patient's right to privacy, all measurements will be taken inside the x-ray room. Patients will be included in the study on a voluntary basis after careful explanation of the research and after informed consent has been obtained. Consent letters will be in English and will be translated into indigenous languages by means of a translator. The data obtained will be stored and locked in the researcher's office, where only the researcher has access. The data collection form will be coded in order to protect the identity of the research participants and maintain anonymity. The data recorded from the patient will be limited to the patients' weight, height, and anatomical thickness, age, gender and exposure factors (Appendix 13). Please see the attached patient information leaflet and consent form (Appendix 12).

It is anticipated that the proposed study will have the following advancement in knowledge and benefits:

- Development of preliminary diagnostic reference levels values for chest posterior-anterior (PA) and lateral (LAT) lumbar spine anterior-posterior (AP) and LAT pelvis AP and skull PA and LAT which may aid in the optimisation of radiographic technique.
- The insight from this study may create awareness of radiation doses and provide knowledge about diagnostic reference levels amongst radiographers in Windhoek, Namibia.
- The results will contribute to research knowledge about radiation doses in Windhoek.
- The diagnostic reference levels can be used as a benchmark to support the need for legislative measures to implement diagnostic reference levels at national level.

- The data obtained may inform whether radiographic practices in Windhoek conform or differ to that of international norms.

The proposed study will have no financial implication for your Ministry and no consumables of the hospital will be used.

I hereby request your support in granting me permission to carry out this proposed study at the above mentioned hospitals. Please find attached a copy of my full proposal and data collection instruments for further reference. Should you have any enquiries regarding this research do not hesitate to contact me or my supervisors.

I trust that my request will receive your approval.

Yours faithfully

Edwin Ralph Daniels
edwindaniels2003@yahoo.com / edaniels@unam.na
Cell: 0027 721374566
Supervisor: Mrs F Davidson, Lecturer: Radiography, Groote Schuur Hospital
Tel: 0027 21 442 6174
Co-supervisor: Mr A Speelman, Lecturer: Radiography, Groote Schuur Hospital
Tel: 0027 21 442 6170

APPENDIX 3:

Letter of permission: Medical Imaging Windhoek

P O Box 20323
Windhoek
Namibia
29 May 2013

To: Dr. JA van Rooyen and partners
Medical Imaging Windhoek
P. O. Box 9471
Eros
Windhoek

Dear Dr. JA van Rooyen and partners

RE: Request for permission to carry out a research study at Medical Imaging Windhoek Branches (Roman Catholic, Eros and Rhino Park).

I am registered for a Masters Degree in Technology - Radiography (Diagnostic), at the Cape Peninsula University of Technology, (student number 213009641).

As a course requirement I am expected to complete a research project. The title of the study is **"Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek Namibia to develop diagnostic reference levels".**

As part of a global effort to minimise radiation doses delivered to patients radiographers are obliged to keep radiation doses as low as reasonably achievable. The study intends to measure radiation doses delivered to patients during routine x-ray examinations. A portable Dose Area Product (DAP) meter will be attached to the x-ray tube housing of the collimator and will be used to measure the radiation doses delivered to some patients. The study will involve patients referred for the Chest, Lumbar Spine, Pelvis and Skull radiographs. Participants will be asked to participate voluntarily after the research objectives have been explained to them thoroughly. After consenting to the study, the patients' weight, height, age,

gender and thickness of anatomical part under investigation will be recorded along with the exposure factors used during the examination. Besides these measurements there will be no difference to what is routinely done in the department and there will be no interference with the management of patients as well as the daily duties of radiographers employed at these hospitals.

I have selected the departments at Medical Imaging (**Roman Catholic, Eros and Rhino Park)** to conduct my research as it is located in Windhoek and utilise computed radiography techniques which may be associated with higher radiation doses. It is anticipated that the research may contribute towards the optimisation of radiation doses delivered to patients.

In addition I am also an employee at the University of Namibia (Assistant Lecturer) responsible for Clinical Practice at Windhoek Central Hospital and Katutura Intermediate Hospital respectively; on staff development leave to pursue this qualification. I am therefore familiar with the radiography department and management of radiographic matters.

The data obtained in this study will be strictly confidential. In order to respect the patient's right to privacy, all measurements will be taken inside the x-ray room. Patients will be included in the study on a voluntary basis after careful explanation of the research and after informed consent has been obtained. Consent letters will be in English and will be translated into indigenous languages by means of a translator. The data obtained will be stored and locked in the researcher's office, where only the researcher has access. The data collection form will be coded in order to protect the identity of the research participants and maintain anonymity. The data recorded from the patient will be limited to the patients' weight, height, and anatomical thickness, age, gender and exposure factors (Appendix 13). Please see the attached patient information leaflet and consent form (Appendix 12).

It is anticipated that the proposed study will have the following advancement in knowledge and benefits:

- Development of preliminary diagnostic reference levels values for chest posterior-anterior (PA) and lateral (LAT) lumbar spine anterior-posterior (AP) and LAT pelvis AP and skull PA and LAT which may aid in the optimisation of radiographic technique.
- The insight from this study may create awareness of radiation doses and provide knowledge about diagnostic reference levels amongst radiographers in Windhoek, Namibia.
- The results will contribute to research knowledge about radiation doses in Windhoek.
- The diagnostic reference levels can be used as a benchmark to support the need for legislative measures to implement diagnostic reference levels at national level.

- The data obtained may inform whether radiographic practices in Windhoek conform or differ to that of international norms.

The proposed study will have no financial implication for your departments and no consumables of the department will be used.

I hereby request your support in granting me permission to carry out this proposed study at the above mentioned hospitals. Please find attached a copy of my full proposal and data collection instruments for further reference. Should you have any enquiries regarding this research do not hesitate to contact me or my supervisors.

I trust that my request will receive your approval.

Yours faithfully

Edwin Ralph Daniels
edwindaniels2003@yahoo.com / edaniels@unam.na
Cell: 0027 721374566
Supervisor: Mrs F Davidson, Lecturer: Radiography, Groote Schuur Hospital
Tel: 0027 21 442 6174
Co-supervisor: Mr A Speelman, Lecturer: Radiography, Groote Schuur Hospital
Tel: 0027 21 442 6170

APPENDIX 4:

Letter of permission: National Radiation Protection Authority

P.O. Box 20323
Windhoek
Namibia
29 May 2013

To: The Director
National Radiation Protection Authority (NRPA)
Ministry of Health and Social Services
P/Bag 13198
Windhoek

Dear Mr. A Tibinyane.

RE: Request for permission to carry out a research study.

I am registered for a Masters Degree in Technology - Radiography (Diagnostic), at the Cape Peninsula University of Technology, (student number 213009641).

As a course requirement I am expected to complete a research project. The title of the study is **"Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek Namibia to develop diagnostic reference levels".**

As part of a global effort to minimise radiation doses delivered to patients radiographers are obliged to keep radiation doses as low as reasonably achievable. The study intends to measure radiation doses delivered to patients during routine x-ray examinations. A portable Dose Area Product (DAP) meter will be attached to the x-ray tube housing of the collimator and will be used to measure the radiation doses delivered to some patients. The study will involve patients referred for the Chest, Lumbar Spine, Pelvis and Skull radiographs. Participants will be asked to participate voluntarily after the research objectives have been explained to them thoroughly. After consenting to the study, the patients' weight, height, age, gender and thickness of anatomical part under investigation will be recorded along with the exposure

factors used during the examination. Besides these measurements there will be no difference to what is routinely done in the department and there will be no interference with the management of patients as well as the daily duties of radiographers employed at these hospitals.

I have selected the departments at Windhoek Central Hospital (WCH) and Katutura Intermediate Hospital (KIH) to conduct my research as it is the largest public hospitals and utilise computed radiography techniques which may be associated with higher radiation doses. It is anticipated that the research may contribute towards the optimisation of radiation doses delivered to patients.

In addition I am also an employee at the University of Namibia (Assistant Lecturer) responsible for Clinical Practice at Windhoek Central Hospital and Katutura Intermediate Hospital respectively; on staff development leave to pursue this qualification. I am therefore familiar with the radiography department and management of radiographic matters.

The data obtained in this study will be strictly confidential. In order to respect the patient's right to privacy, all measurements will be taken inside the x-ray room. Patients will be included in the study on a voluntary basis after careful explanation of the research and after informed consent has been obtained. Consent letters will be in English and will be translated into indigenous languages by means of a translator. The data obtained will be stored and locked in the researcher's office, where only the researcher has access. The data collection form will be coded in order to protect the identity of the research participants and maintain anonymity. The data recorded from the patient will be limited to the patients' weight, height, and anatomical thickness, age, gender and exposure factors (Appendix 13). Please see the attached patient information leaflet and consent form (Appendix 12).

It is anticipated that the proposed study will have the following advancement in knowledge and benefits:

- Development of preliminary diagnostic reference levels values for chest posterior-anterior (PA) and lateral (LAT) lumbar spine anterior-posterior (AP) and LAT pelvis AP and skull PA and LAT which may aid in the optimisation of radiographic technique.
- The insight from this study may create awareness of radiation doses and provide knowledge about diagnostic reference levels amongst radiographers in Windhoek, Namibia.
- The results will contribute to research knowledge about radiation doses in Windhoek.
- The diagnostic reference levels can be used as a benchmark to support the need for legislative measures to implement diagnostic reference levels at national level.
- The data obtained may inform whether radiographic practices in Windhoek conform or differ to that of international norms.

The proposed study will have no financial implication for your Ministry and no consumables of the hospital will be used.

I hereby request your support in granting me permission to carry out this proposed study at the above mentioned hospitals. Please find attached a copy of my full proposal and data collection instruments for further reference. Should you have any enquiries regarding this research do not hesitate to contact me or my supervisors.

I trust that my request will receive your approval.

Yours faithfully

Edwin Ralph Daniels
edwindaniels2003@yahoo.com / edaniels@unam.na
Cell: 0027 721374566
Supervisor: Mrs F Davidson, Lecturer: Radiography, Groote Schuur Hospital
Tel: 0027 21 442 6174
Co-supervisor: Mr A Speelman, Lecturer: Radiography, Groote Schuur Hospital
Tel: 0027 21 442 6170

APPENDIX 5:

Equipment related data to for each x-ray room.

Date: _____ Hospital: _____

X-ray room: _____

X-ray generator:

Manufacturer / Type: _____ / _____

Waveform: Please tick one

Six (6) pulse: _____ Twelve (12) pulse: _____

Constant potential: _____

Other: Please specify _____

X-ray tube:

Manufacturer / Type: _____ / _____

Inherent Filtration: _____ mm Al equivalent

_____ mm Cu equivalent

_____ mm other equivalent

Focal spot values: _____ to _____

Is the x-ray unit equipped with Automatic Exposure Control (AEC)

Yes _____ or No _____

Is the x-ray unit equipped with an anti scatter grid: Yes _____ or No _____

If an antiscatter grid is present, please state the Grid Ratio; "r" _____

Number of Lead (Pb) strips per cm: _____

Image plate sensitivity:

Screen Manufacturer: _____

Type of screen (CR or DR): _____

Adapted and from (European Commission 1996, Johnston & Brennan 2000, Abdelhalim 2009)

APPENDIX 6:

Patient related data to be completed by the researcher / research assistant for each patient

Demographic data of patient

A1 Hospital: _____

A2. Age: _____in years

A3. Gender: _____

A4. Weight: _____ in (kilograms)

A5. X-ray number: _____

A6. Height: _____ in centimetres (cm)

B. Dose related data AP/PA projection

B1. Name of projection: _____ (i.e PA chest)

B2. Patient thickness in the centre of the beam: _____ in centimetres

B3. Additional filtration used: _____

B4. Applied Voltage: _____ kV

B5. Applied focal spot size: _____

B6. SID: _____cm

B7. Film size: _____ cm x _____ cm

B8. Automatic Exposure Control (AEC) used. Please state yes or no _____

B9. If (AEC) was used please state the selected chamber: (i.e left, right, central) _____

B10. Exposure time: _____ milliseconds (ms)

B11. Tube current used: _____ mA or _____ mAs

B12. Type -of screen (DR or CR) _____

B13. Total dose area product _____$Gycm^2$

C. Dose related data Lateral (LAT) projection

C1. Name of projection: _____ (i.e LAT chest)

C2. Patient thickness in the centre of the beam: _____ in centimetres

C3. Additional filtration used: _____

C4. Applied Voltage: _____ kV

C5. Applied focal spot size: _____

C6. FFD: _____cm

C7. Film size: _____ cm x _____ cm

C8. Automatic Exposure Control (AEC) used. Please state yes or no _____

C9. If (AEC) was used please state the selected chamber: (i.e left, right, central) _____

C10. Exposure time: _____ milliseconds (ms)

C11. Tube current used: _____ mA or _____ mAs

C12. Type of screen (CR or DR): _____

C13. Total dose area product: _____$Gycm^2$

Adapted and from (European Commission 1996, Johnston & Brennan 2000, Abdelhalim 2009)

APPENDIX 7: CALIBRATION CERTIFICATE VACUDAP

VACUTEC

Prüfschein
Calibration Certificate

VacuDAP *compact*	S/N	090 1482

Das Dosisflächenprodukt-Messgerät VacuDAP *compact* wurde entsprechend EN 60580:2000 mit einem kalibrierten Referenzgerät (IEC 61674) abgeglichen und hält alle Daten gemäß Datenblatt ein.

In accordance to the European standard IEC 60580:2000 the above Dose Area Product meter VacuDAP compact has been adjusted with a calibrated reference instrument (IEC 61674) and corresponds to all data of the data sheet.

Dresden, 08. Nov. 2013

VACUTEC Messtechnik GmbH Dornblüthstraße 14 01277 Dresden

VacuTec Messtechnik GmbH
Dornblüthstraße 14
D-01277 Dresden
Germany

DIN EN ISO 9001
DNV
Certified Company

Tel.: +49 - (0) 351 - 3 17 24-0
Fax: +49 - (0) 351 - 3 10 50 85
Email: info@vacutec-gmbh.de
www.vacutec-gmbh.de

APPENDIX 8: INPUT DATA PA CHEST HOSPITAL 1

Hospital 1 Chest PA									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
31A	23.7	0.03117	0.04473	0.23546	0.03096	0.03077	-0.66	-1.27	2.99
29A	24.4	0.03314	0.05119	0.22936	0.03184	0.03168	-3.89	-4.40	3.59
39A	25.3	0.03194	0.05007	0.21960	0.03287	0.03273	2.92	2.48	4.40
41A	25.5	0.03267	0.05222	0.23668	0.03317	0.03303	1.51	1.10	4.66
46A	26.2	0.03567	0.05718	0.24766	0.03405	0.03393	-4.56	-4.87	5.48
45A	26.6	0.03384	0.05358	0.24278	0.03449	0.03438	1.91	1.60	5.93
27A	26.7	0.03299	0.06270	0.24766	0.03463	0.03453	4.99	4.68	6.09
28A	29.8	0.03555	0.06772	0.27084	0.03831	0.03827	7.75	7.66	10.80
42A	30.9	0.04107	0.07370	0.29524	0.03963	0.03961	-3.50	-3.53	12.85
44A	31.8	0.04086	0.06539	0.30012	0.04080	0.04080	-0.14	-0.13	14.81
33A	32.0	0.04319	0.06911	0.29646	0.04095	0.04095	-5.19	-5.17	15.06
34A	32.0	0.04293	0.06832	0.29646	0.04095	0.04095	-4.62	-4.61	15.06
38A	33.4	0.03967	0.07009	0.28670	0.04271	0.04274	7.65	7.72	18.15
30A	36.8	0.04452	0.08255	0.34160	0.04682	0.04688	5.17	5.30	14.56
35A	37.7	0.04982	0.06981	0.35502	0.04785	0.04791	-3.97	-3.84	12.85
43A	39.9	0.05263	0.07322	0.36966	0.05049	0.05056	-4.06	-3.93	8.92
36A	40.6	0.04951	0.09032	0.42822	0.05137	0.05144	3.77	3.91	7.78
37A	42.7	0.05186	0.08619	0.36722	0.05387	0.05394	3.87	4.00	5.06
32A	52.7	0.07120	0.11396	0.48922	0.06591	0.06589	-7.43	-7.45	0.25
40A	67.0	0.08052	0.14551	0.63074	0.08309	0.08276	3.19	2.79	0.00

Mean:	34.3	0.0437	0.0724
DRL:	38.2	0.0496	0.0759
Median:	31.9	0.0410	0.0687

n:	20
Population standard deviation:	10.4
Chauvenet criterion value:	0.5

APPENDIX 9: INPUT DATA LAT CHEST HOSPITAL 1

Hospital 1 Chest LAT									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
39B	22.6	0.03101	0.04845	0.27938	0.03075	0.03293	-0.83	6.17	1.09
29B	27.7	0.04757	0.04946	0.27816	0.03900	0.04053	-18.01	-14.80	2.76
31B	30.7	0.04403	0.06059	0.31964	0.04391	0.04506	-0.27	2.34	4.45
41B	32.7	0.04403	0.06872	0.34526	0.04705	0.04797	6.86	8.94	5.86
42B	33.8	0.05656	0.06528	0.36356	0.04882	0.04960	-13.69	-12.30	6.77
46B	34.2	0.04623	0.07065	0.33672	0.04941	0.05015	6.88	8.48	7.10
34B	34.3	0.05690	0.06123	0.37454	0.04960	0.05033	-12.82	-11.55	7.21
30B	34.8	0.05522	0.06389	0.37454	0.05039	0.05106	-8.74	-7.54	7.66
28B	37.7	0.05738	0.07052	0.39162	0.05510	0.05542	-3.96	-3.41	10.70
45B	38.7	0.05263	0.08074	0.41602	0.05667	0.05688	7.68	8.07	11.84
27B	38.8	0.06111	0.07778	0.40870	0.05687	0.05706	-6.94	-6.63	11.99
33B	41.4	0.05274	0.08592	0.42822	0.06099	0.06089	15.65	15.45	15.21
35B	46.4	0.06692	0.09299	0.48922	0.06904	0.06837	3.18	2.17	17.98
38B	50.8	0.06708	0.11089	0.58316	0.07611	0.07495	13.47	11.74	12.26
36B	51.1	0.06631	0.10380	0.53924	0.07670	0.07550	15.67	13.86	11.83
37B	52.9	0.08373	0.09416	0.57950	0.07965	0.07824	-4.88	-6.55	9.74
44B	59.2	0.07968	0.12351	0.62464	0.08966	0.08758	12.53	9.92	4.36
32B	65.5	0.09484	0.13568	0.73078	0.09987	0.09712	5.30	2.40	1.51
40B	76.5	0.12266	0.14287	0.82350	0.11754	0.11366	-4.17	-7.33	0.13
43B	88.2	0.14692	0.14518	0.86010	0.13639	0.13135	-7.17	-10.60	0.00

Mean:	44.9	0.0667	0.0876
DRL:	51.6	0.0702	0.1056
Median:	38.7	0.0571	0.0793

n:	20
Population standard deviation:	16.4
Chauvenet criterion value:	0.5

APPENDIX 10: INPUT DATA PA CHEST HOSPITAL 2

Hospital 2 Chest PA									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
100A	4.1	0.00590	0.01019	0.06466	0.00554	0.00551	-6.18	-6.62	0.55
98A	4.8	0.00642	0.01127	0.06710	0.00633	0.00632	-1.37	-1.52	1.05
95A	5.7	0.00750	0.01342	0.04758	0.00753	0.00754	0.34	0.43	2.53
105A	7.0	0.00893	0.01692	0.06222	0.00914	0.00915	2.32	2.48	6.57
93A	7.1	0.00861	0.01649	0.06466	0.00920	0.00921	6.79	6.96	6.78
97A	8.3	0.01015	0.01925	0.07564	0.01072	0.01073	5.58	5.67	13.32
88A	8.4	0.00985	0.01987	0.07930	0.01087	0.01088	10.39	10.48	14.10
86A	8.5	0.01176	0.01956	0.07564	0.01102	0.01103	-6.30	-6.23	14.89
87A	8.8	0.01133	0.01863	0.07564	0.01132	0.01133	-0.09	-0.05	16.53
102A	8.8	0.01252	0.02083	0.07808	0.01132	0.01133	-9.53	-9.50	16.53
84A	9.0	0.01261	0.02045	0.07808	0.01163	0.01163	-7.83	-7.81	18.20
89A	9.3	0.01092	0.02264	0.10126	0.01193	0.01193	9.27	9.25	19.91
106A	9.4	0.01232	0.02100	0.08906	0.01208	0.01208	-1.94	-1.97	20.77
103A	9.5	0.01087	0.02222	0.08418	0.01223	0.01223	12.55	12.50	20.37
101A	9.8	0.01153	0.02206	0.08296	0.01254	0.01253	8.75	8.67	18.66
91A	10.4	0.01399	0.02303	0.09028	0.01330	0.01328	-4.97	-5.12	14.52
85A	10.6	0.01408	0.02288	0.09394	0.01360	0.01358	-3.39	-3.58	12.97
104A	12.0	0.01547	0.02517	0.10736	0.01527	0.01521	-1.28	-1.67	6.03
90A	12.9	0.01688	0.02933	0.12932	0.01649	0.01640	-2.37	-2.89	2.95
99A	12.9	0.01736	0.02688	0.11346	0.01649	0.01640	-5.04	-5.55	2.95
94A	20.6	0.02557	0.03859	0.18544	0.02605	0.02561	1.87	0.15	0.00

Mean:	9.4	0.0121	0.0210
DRL:	10.4	0.0140	0.0229
Median:	9.0	0.0115	0.0208

n:	21
Population standard deviation	3.4
Chauvenet criterion value:	0.5

APPENDIX 11: INPUT DATA LAT CHEST HOSPITAL 2

Hospital 2 Chest LAT									
Patient	**DAP value (cGy.cm^2) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
100B	8.8	0.01190	0.02148	0.15006	0.01358	0.01287	14.19	8.24	0.20
98B	11.0	0.01840	0.02441	0.17080	0.01640	0.01590	-10.85	-13.59	0.31
86B	27.5	0.04447	0.04792	0.26596	0.03742	0.03758	-15.85	-15.48	4.57
97B	27.5	0.03470	0.05995	0.27694	0.03742	0.03758	7.85	8.32	4.57
95B	30.4	0.03721	0.06454	0.27816	0.04116	0.04134	10.61	11.09	6.47
88B	32.0	0.03897	0.06909	0.32696	0.04318	0.04336	10.82	11.28	7.70
85B	32.7	0.04587	0.06562	0.32086	0.04412	0.04429	-3.83	-3.44	8.31
93B	37.0	0.04616	0.07941	0.36234	0.04957	0.04970	7.37	7.67	12.42
103B	39.4	0.04608	0.08553	0.38186	0.05268	0.05278	14.33	14.54	15.12
87B	40.6	0.05499	0.08030	0.38918	0.05424	0.05431	-1.36	-1.23	16.54
104B	41.5	0.05805	0.08330	0.40138	0.05533	0.05538	-4.69	-4.59	17.56
105B	46.0	0.05234	0.09934	0.44896	0.06106	0.06099	16.66	16.54	18.97
99B	46.6	0.06593	0.09761	0.43432	0.06187	0.06178	-6.16	-6.29	18.20
92B	47.0	0.06378	0.09381	0.44896	0.06233	0.06224	-2.27	-2.42	17.76
84B	50.0	0.08320	0.08795	0.49044	0.06623	0.06603	-20.40	-20.64	14.20
102B	52.9	0.06889	0.10862	0.49898	0.06996	0.06965	1.55	1.10	11.08
94B	59.5	0.07986	0.11198	0.57706	0.07837	0.07776	-1.87	-2.63	5.57
106B	65.9	0.09027	0.13669	0.67466	0.08647	0.08552	-4.21	-5.26	2.41
89B	71.1	0.08506	0.14429	0.66856	0.09316	0.09189	9.53	8.04	1.05
101B	79.9	0.09456	0.17106	0.77348	0.10437	0.10251	10.38	8.41	0.19
90B	83.3	0.11697	0.17733	0.86864	0.10873	0.10662	-7.04	-8.85	0.09

Mean:	44.3	0.0589	0.0910
DRL:	52.9	0.0799	0.1086
Median:	41.5	0.0550	0.0855

n:	21
Population standard deviation:	19.3
Chauvenet criterion value:	0.5

APPENDIX 12: INPUT DATA PA CHEST HOSPITAL 3

Hospital 3 Chest PA									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
180A	4.1	0.00575	0.00921	0.04636	0.00590	0.00571	2.60	-0.66	0.33
171A	5.4	0.00721	0.01488	0.06100	0.00740	0.00732	2.70	1.46	3.06
166A	6.0	0.00789	0.01495	0.05490	0.00814	0.00809	3.09	2.44	6.74
168A	6.0	0.00836	0.01424	0.05368	0.00814	0.00809	-2.63	-3.24	6.74
172A	6.2	0.00808	0.01577	0.07198	0.00843	0.00839	4.38	3.92	8.78
169A	6.3	0.00882	0.01368	0.05856	0.00858	0.00855	-2.76	-3.12	9.92
174A	6.5	0.00946	0.01403	0.07442	0.00872	0.00870	-7.74	-8.00	11.13
173A	6.6	0.00792	0.01693	0.05978	0.00887	0.00885	12.02	11.79	12.41
175A	6.6	0.00850	0.01665	0.07564	0.00887	0.00885	4.31	4.09	12.41
178A	7.1	0.00895	0.02070	0.07930	0.00946	0.00946	5.60	5.64	17.96
179A	7.1	0.00910	0.01886	0.08052	0.00946	0.00946	3.90	3.94	17.96
181A	7.1	0.00905	0.01718	0.08174	0.00946	0.00946	4.46	4.50	17.96
176A	7.3	0.01048	0.01565	0.06832	0.00971	0.00972	-7.39	-7.28	17.59
167A	7.4	0.01050	0.01726	0.06954	0.00990	0.00991	-5.79	-5.62	15.74
170A	7.7	0.01028	0.02013	0.08784	0.01019	0.01022	-0.93	-0.67	12.99
180AB	7.7	0.01108	0.02023	0.08906	0.01019	0.01022	-8.03	-7.78	12.99
165A	7.7	0.01031	0.02036	0.08906	0.01022	0.01025	-0.88	-0.61	12.73
215A	10.7	0.01459	0.02195	0.08174	0.01387	0.01396	-4.97	-4.35	0.10
177A	12.7	0.01534	0.03227	0.14762	0.01620	0.01629	5.61	6.20	0.00

Mean:	7.2	0.0096	0.0176
DRL:	7.6	0.0104	0.0202
Median:	7.1	0.0091	0.0169

n:	19
Population standard deviation:	1.8
Chauvenet criterion value:	0.5

APPENDIX 13: INPUT DATA LAT CHEST HOSPITAL 3

Hospital 3 Chest LAT									
Patient	**DAP value (cGy.cm^2) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
215A	10.7	0.01459	0.02195	0.08174	0.01318	0.01179	-9.67	-19.21	1.21
178B	11.5	0.01663	0.03303	0.14518	0.01438	0.01282	-13.51	-22.88	1.56
167B	15.6	0.00314	0.00316	0.16836	0.02131	0.01915	579.57	510.77	5.41
165B	16.1	0.02496	0.03974	0.20008	0.02212	0.01993	-11.37	-20.15	6.11
174B	16.1	0.02769	0.03678	0.20618	0.02212	0.01993	-20.12	-28.03	6.11
175B	18.1	0.02733	0.04319	0.22326	0.02538	0.02312	-7.12	-15.38	9.51
171B	18.3	0.02847	0.04780	0.24278	0.02579	0.02353	-9.43	-17.36	9.99
215B	20.0	0.02600	0.04013	0.19154	0.02866	0.02644	10.24	1.71	13.76
180B	20.1	0.03305	0.04457	0.24888	0.02884	0.02663	-12.73	-19.42	14.02
182B	20.7	0.03122	0.04712	0.25254	0.02980	0.02762	-4.54	-11.52	15.40
166B	20.9	0.02799	0.04762	0.21716	0.03007	0.02790	7.43	-0.32	15.79
172B	20.9	0.02510	0.04139	0.20374	0.03007	0.02790	19.81	11.16	15.79
176B	23.2	0.03518	0.04868	0.23668	0.03402	0.03208	-3.32	-8.83	18.26
173B	23.9	0.03010	0.06055	0.25742	0.03516	0.03331	16.82	10.66	16.55
170B	26.5	0.04091	0.06499	0.33916	0.03944	0.03801	-3.60	-7.07	10.63
168B	27.3	0.03787	0.06127	0.27938	0.04086	0.03962	7.90	4.61	8.92
179B	28.4	0.04347	0.07337	0.36966	0.04269	0.04170	-1.78	-4.08	6.98
180BC	29.4	0.05752	0.06277	0.39528	0.04432	0.04356	-22.94	-24.27	5.50
169B	29.6	0.04488	0.06301	0.31232	0.04473	0.04403	-0.34	-1.89	5.16
177B	53.4	0.08130	0.13142	0.71858	0.08445	0.09466	3.88	16.43	0.00

Mean:	22.5	0.0329	0.0506
DRL:	26.7	0.0386	0.0616
Median:	20.8	0.0293	0.0474

n:	20
Population standard deviation:	8.9
Chauvenet criterion value:	0.5

APPENDIX 14: INPUT DATA AP LUMBAR SPINE HOSPITAL 1

Hospital 1 Lumbar spine AP									
Patient	**DAP value (cGy.cm^2) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
75A	70.5	0.07799	0.13041	0.78934	0.07898	0.07777	1.27	-0.29	5.73
72A	70.8	0.07546	0.13287	0.88084	0.07926	0.07804	5.04	3.43	5.78
67A	80.3	0.08438	0.15950	0.87718	0.08992	0.08885	6.57	5.30	7.98
80A	80.9	0.08685	0.13963	0.83936	0.09060	0.08954	4.32	3.10	8.13
65A	82.8	0.08983	0.15244	0.86010	0.09279	0.09176	3.29	2.16	8.64
71A	85.4	0.09578	0.17651	0.90646	0.09566	0.09468	-0.13	-1.15	9.35
66A	88.1	0.09864	0.18204	0.98576	0.09866	0.09774	0.03	-0.91	10.11
73A	88.6	0.09816	0.16952	0.94062	0.09921	0.09830	1.07	0.14	10.25
64A	90.4	0.10797	0.21793	1.09800	0.10126	0.10039	-6.22	-7.02	10.80
69A	91.3	0.09895	0.18446	1.07482	0.10221	0.10136	3.29	2.43	11.06
78A	95.0	0.10932	0.19688	1.03944	0.10645	0.10568	-2.63	-3.33	12.24
68A	99.1	0.11370	0.20652	1.10898	0.11096	0.11029	-2.41	-3.01	13.56
74A	119.7	0.12649	0.23411	1.45302	0.13405	0.13394	5.98	5.89	19.13
81A	124.7	0.14240	0.24528	1.43350	0.13966	0.13970	-1.93	-1.90	17.32
70A	127.4	0.14220	0.28948	1.46400	0.14266	0.14279	0.32	0.41	16.36
76A	136.9	0.14834	0.25239	1.66164	0.15332	0.15377	3.36	3.66	13.10
63A	142.9	0.16519	0.31270	1.64212	0.16002	0.16067	-3.13	-2.73	11.19
83A	143.1	0.16942	0.35135	1.68482	0.16029	0.16096	-5.39	-5.00	11.12
82A	166.8	0.19677	0.41357	2.02520	0.18680	0.18838	-5.07	-4.27	5.18
79A	361.1	0.39937	0.82058	4.89708	0.40447	0.41675	1.28	4.35	0.00

Mean:	117.3	0.1314	0.2484
DRL:	129.7	0.1439	0.2617
Median:	93.1	0.1086	0.2017

n:	20
Population standard deviation:	62.0
Chauvenet criterion value:	0.5

APPENDIX 15: INPUT DATA LAT LUMBAR SPINE HOSPITAL 1

Hospital 1 Lumbar spine LAT									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
75B	95.4	0.11264	0.08594	1.18706	0.08064	0.09218	-28.41	-18.17	1.79
80B	104.3	0.11383	0.07588	1.16754	0.09463	0.10284	-16.87	-9.66	2.46
67B	115.0	0.14502	0.12420	1.51524	0.11149	0.11596	-23.12	-20.04	3.52
73B	115.2	0.12753	0.09566	1.35542	0.11168	0.11611	-12.43	-8.95	3.53
69B	129.8	0.15939	0.12312	1.76046	0.13467	0.13445	-15.51	-15.65	5.48
68B	137.5	0.06000	0.15970	1.86416	0.14674	0.14427	144.57	140.46	6.76
72B	146.6	0.18583	0.13078	2.11060	0.16111	0.15613	-13.30	-15.98	8.51
78B	148.1	0.17835	0.14264	1.83976	0.16341	0.15804	-8.38	-11.39	8.81
66B	178.5	0.21528	0.18478	2.34972	0.21112	0.19865	-1.93	-7.72	16.25
70B	180.8	0.23439	0.19270	11.27158	0.21476	0.20182	-8.37	-13.89	16.89
74B	182.4	0.23315	0.17372	2.85724	0.21725	0.20399	-6.82	-12.51	17.33
64B	182.9	0.06559	0.03592	0.50386	0.21801	0.20466	232.40	212.05	17.46
81B	188.2	0.22561	0.15767	2.53638	0.22645	0.21205	0.37	-6.01	18.96
63B	197.2	0.23339	0.15884	2.74256	0.24043	0.22441	3.02	-3.84	18.54
77B	231.6	0.32390	0.25940	3.33182	0.29446	0.27332	-9.09	-15.61	9.72
71B	232.3	0.27718	0.22087	2.97314	0.29561	0.27438	6.65	-1.01	9.56
65B	239.7	0.27409	0.21445	2.98290	0.30730	0.28520	12.12	4.05	8.01
82B	284.1	0.40541	0.37779	4.08822	0.37704	0.35125	-7.00	-13.36	2.10
83B	310.5	0.45083	0.44395	4.46764	0.41843	0.39159	-7.19	-13.14	0.74
79B	439.0	0.62399	0.54716	7.12602	0.62018	0.59864	-0.61	-4.06	0.00

Mean:	192.0	0.2323	0.1953
DRL:	231.7	0.2749	0.2161
Median:	181.6	0.2204	0.1593

n:	20
Population standard deviation:	80.4
Chauvenet criterion value:	0.5

APPENDIX 16: INPUT DATA AP LUMBAR SPINE HOSPITAL 2

Hospital 2 Lumbar spine AP									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
122A	57.0	0.06206	0.11984	1.04920	0.07127	0.06557	14.84	5.66	1.00
114A	124.0	0.14065	0.30480	1.86050	0.14033	0.13849	-0.23	-1.54	3.92
121A	125.1	0.13808	0.21315	4.65430	0.14148	0.13970	2.47	1.17	4.00
111A	139.8	0.17161	0.38938	2.25822	0.15669	0.15552	-8.69	-9.37	5.11
119A	154.6	0.16774	0.28871	1.60796	0.17192	0.17130	2.49	2.12	6.41
117A	166.8	0.17613	0.29594	3.70514	0.18451	0.18430	4.76	4.64	7.63
120A	168.6	0.19779	0.36803	3.49530	0.18641	0.18626	-5.75	-5.83	7.82
116A	175.1	0.19296	0.34729	2.12280	0.19307	0.19312	0.06	0.08	8.52
123A	175.6	0.19879	0.35307	3.95524	0.19366	0.19373	-2.58	-2.54	8.59
113A	180.0	0.19313	0.37710	3.44284	0.19810	0.19830	2.58	2.68	9.08
109A	238.1	0.27280	0.57832	3.54532	0.25814	0.25972	-5.37	-4.80	16.69
118A	275.7	0.29573	0.49503	3.00364	0.29694	0.29909	0.41	1.14	12.17
115A	307.1	0.31980	0.54984	5.22038	0.32926	0.33175	2.96	3.74	8.37
107A	346.5	0.38674	0.65477	6.94668	0.36992	0.37265	-4.35	-3.64	4.67
112A	355.6	0.35387	0.61140	6.67462	0.37936	0.38212	7.20	7.98	4.00
108A	538.1	0.55964	1.00163	9.74292	0.56767	0.56941	1.44	1.75	0.04
110A	558.8	0.60017	1.07621	9.32202	0.58894	0.59040	-1.87	-1.63	0.02

Mean:	240.4	0.2605	0.4720
DRL:	307.1	0.3198	0.5783
Median:	175.6	0.1978	0.3771

n:	17
Population standard deviation:	137.4
Chauvenet criterion value:	0.5

APPENDIX 17: INPUT DATA LAT LUMBAR SPINE HOSPITAL 2

Hospital 2 Lumbar spine LAT									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
122B	85.7	0.05952	0.13058	1.87636	0.12126	0.07721	103.72	29.71	0.29
119B	145.1	0.16557	0.13503	1.78608	0.16299	0.13243	-1.56	-20.01	2.18
121B	198.9	0.14394	0.26658	8.28624	0.20072	0.18286	39.45	27.04	7.78
117B	199.1	0.18583	0.23717	4.72750	0.20092	0.18312	8.12	-1.46	7.82
113B	202.5	0.11851	0.32733	4.53840	0.20329	0.18630	71.54	57.20	8.34
120B	203.2	0.23658	0.28692	4.73116	0.20376	0.18692	-13.88	-20.99	8.44
112B	214.1	0.20736	0.28669	3.77102	0.21143	0.19723	1.96	-4.89	10.23
109B	222.4	0.27400	0.36648	3.60998	0.21725	0.20505	-20.71	-25.16	11.70
115B	234.1	0.19616	0.33139	4.66040	0.22548	0.21612	14.94	10.17	13.88
118B	248.3	0.28237	0.22643	3.12198	0.23544	0.22955	-16.62	-18.71	16.65
107B	251.8	0.14555	0.47214	6.07560	0.23789	0.23285	63.45	59.98	16.67
116B	261.2	0.32412	0.28017	3.16712	0.24449	0.24175	-24.57	-25.41	14.83
114B	279.7	0.36751	0.32845	3.45504	0.25751	0.25933	-29.93	-29.44	11.35
111B	283.5	0.35905	0.49614	4.59574	0.26016	0.26292	-27.54	-26.77	10.68
123B	288.6	0.27133	0.42848	7.33464	0.26370	0.26771	-2.81	-1.33	9.82
108B	382.1	0.30068	0.58107	8.11544	0.32936	0.35686	9.54	18.68	0.95
110B	551.6	0.38591	0.82866	10.14308	0.44832	0.51965	16.17	34.66	0.00

Mean:	250.1	0.2367	0.3535
DRL:	279.7	0.3007	0.4285
Median:	234.1	0.2366	0.3273

n:	17
Population standard deviation:	97.6
Chauvenet criterion value:	0.5

APPENDIX 18: INPUT DATA AP LUMBAR SPINE HOSPITAL 3

Hospital 3 Lumbar spine AP									
Patient	DAP value ($cGy.cm^2$) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
211A	33.9	0.03720	0.07586	0.56974	0.03557	0.03655	-4.38	-1.74	1.91
187A	36.6	0.04159	0.08058	0.47702	0.03856	0.03944	-7.29	-5.18	2.15
192A	37.6	0.04324	0.08910	0.52948	0.03971	0.04055	-8.15	-6.21	2.24
185A	51.9	0.05987	0.11758	0.74786	0.05555	0.05583	-7.20	-6.74	3.88
186A	59.8	0.06814	0.11322	1.99104	0.06446	0.06442	-5.40	-5.46	5.07
189A	68.8	0.04748	0.09960	0.61976	0.07441	0.07401	56.71	55.87	6.62
183A	76.7	0.08366	0.15999	1.07848	0.08325	0.08253	-0.49	-1.35	8.14
184A	83.6	0.09509	0.18466	1.20536	0.09094	0.08994	-4.36	-5.41	9.55
190A	165.6	0.20041	0.38552	2.77184	0.18228	0.17788	-9.04	-11.24	0.79
188A	176.0	0.18786	0.35614	2.13744	0.19391	0.18906	3.22	0.64	0.44
191A	205.1	0.22048	0.40669	2.97436	0.22635	0.22027	2.66	-0.10	0.06

Mean:	90.5	0.0986	0.1881
DRL:	124.6	0.1415	0.2704
Median:	68.8	0.0681	0.1176

n:	11
Population standard deviation:	58.9
Chauvenet criterion value:	0.5

APPENDIX 19: INPUT DATA LAT LUMBAR SPINE HOSPITAL 3

Hospital 3 Lumbar spine LAT									
Patient	DAP value ($cGy.cm^2$) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
211B	31.8	0.03185	0.04699	0.59414	0.04921	0.03746	54.47	17.61	0.43
187B	54.7	0.07848	0.06891	0.85522	0.06842	0.06086	-12.82	-22.46	2.09
192B	62.3	0.09509	0.08527	0.97356	0.07482	0.06841	-21.31	-28.06	3.18
186B	70.2	0.04121	0.12455	2.05936	0.08149	0.07617	97.74	84.83	4.65
185B	74.7	0.10153	0.08650	1.27002	0.08527	0.08053	-16.01	-20.68	5.64
190B	80.1	0.06588	0.14573	1.69824	0.08985	0.08578	36.39	30.21	6.98
184B	81.3	0.09410	0.11808	1.50792	0.09082	0.08689	-3.48	-7.67	7.28
189B	122.0	0.14442	0.17986	2.10450	0.12517	0.12519	-13.33	-13.32	4.05
188B	137.9	0.17845	0.17845	1.91784	0.13854	0.13972	-22.37	-21.70	1.71
183B	146.5	0.17414	0.18793	2.64008	0.14575	0.14749	-16.30	-15.31	0.98
191B	179.3	0.11755	0.27441	3.25496	0.17336	0.17682	47.48	50.42	0.06

Mean:	94.6	0.1021	0.1361
DRL:	130.0	0.1310	0.1792
Median:	80.1	0.0951	0.1245

n:	11
Population standard deviation:	43.1
Chauvenet criterion value:	0.5

APPENDIX 20: INPUT DATA AP PELVIS HOSPITAL 1

Hospital 1 Pelvis

Patient	DAP value ($cGy.cm^2$) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
16	53.9	0.06911	0.07093	0.47702	0.06438	0.06458	-6.85	-6.55	0.18
20	74.7	0.09324	0.11966	0.85888	0.08849	0.08886	-5.10	-4.70	0.82
15	77.3	0.08597	0.10893	0.82106	0.09156	0.09194	6.50	6.94	0.97
11	93.3	0.10258	0.13314	1.09922	0.11020	0.11060	7.43	7.83	2.54
19	99.8	0.11256	0.14936	1.43594	0.11772	0.11812	4.58	4.94	3.58
13	111.1	0.13154	0.16267	1.17974	0.13091	0.13127	-0.48	-0.20	6.16
18	111.8	0.13965	0.18160	1.51646	0.13169	0.13205	-5.70	-5.45	6.35
17	124.3	0.15346	0.19748	1.32004	0.14623	0.14652	-4.71	-4.53	10.53
14	135.2	0.15866	0.19599	1.43472	0.15886	0.15906	0.12	0.25	15.25
10	138.6	0.15326	0.18544	1.55062	0.16283	0.16300	6.25	6.36	16.91
25	147.3	0.17012	0.20017	1.48962	0.17290	0.17299	1.64	1.69	21.41
7	147.9	0.17254	0.21452	1.69946	0.17361	0.17369	0.62	0.66	21.74
6	149.1	0.16705	0.19932	1.71410	0.17503	0.17509	4.77	4.81	22.40
12	161.2	0.19073	0.25120	2.18502	0.18907	0.18900	-0.87	-0.91	22.98
9	167.9	0.19884	0.24373	1.87880	0.19688	0.19671	-0.99	-1.07	19.39
2	168.4	0.20009	0.23727	1.78730	0.19744	0.19727	-1.32	-1.41	19.13
23	169.0	0.20524	0.24511	1.79462	0.19815	0.19797	-3.45	-3.54	18.81
22	173.1	0.19408	0.22940	1.93736	0.20298	0.20274	4.59	4.46	16.71
21	178.2	0.21367	0.25611	1.94956	0.20894	0.20862	-2.22	-2.36	14.26
5	200.4	0.22820	0.26190	2.56566	0.23475	0.23408	2.87	2.58	6.09
8	206.2	0.24296	0.28284	2.42658	0.24142	0.24064	-0.63	-0.95	4.67
24	209.5	0.24973	0.28283	2.34362	0.24525	0.24441	-1.79	-2.13	3.97
26	213.5	0.25544	0.30615	2.51320	0.24993	0.24902	-2.16	-2.51	3.23
3	225.3	0.26469	0.32389	2.46440	0.26369	0.26255	-0.38	-0.81	1.67
4	231.7	0.28058	0.34530	2.66326	0.27107	0.26980	-3.39	-3.84	1.13
102163	278.5	0.31553	0.40829	3.56484	0.32555	0.32321	3.17	2.43	0.03

Mean:	155.7	0.1827	0.2228
DRL:	194.9	0.2246	0.2605
Median:	155.1	0.1816	0.2220

n:	26
Population standard deviation:	53.2
Chauvenet criterion value:	0.5

APPENDIX 21: INPUT DATA AP PELVIS HOSPITAL 2

Hospital 2 Pelvis									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
137	112.4	0.13413	0.19038	1.14680	0.14205	0.13774	5.90	2.69	1.19
138	131.4	0.14516	0.16408	1.76412	0.16267	0.15962	12.07	9.96	1.84
140	146.6	0.18402	0.26291	1.77998	0.17921	0.17702	-2.62	-3.80	2.53
144	170.7	0.21415	0.25380	1.48352	0.20527	0.20425	-4.14	-4.62	3.99
145	184.5	0.22946	0.29878	1.91540	0.22022	0.21977	-4.02	-4.22	5.03
143	209.5	0.26678	0.33551	2.12646	0.24735	0.24776	-7.28	-7.13	7.31
141	223.4	0.24945	0.33857	3.15492	0.26243	0.26324	5.20	5.53	8.77
146	251.6	0.31258	0.43367	2.78770	0.29299	0.29444	-6.27	-5.80	11.98
148	295.4	0.35103	0.47448	3.35012	0.34049	0.34254	-3.00	-2.42	8.94
139	328.8	0.34355	0.48319	3.56118	0.37674	0.37897	9.66	10.31	5.63
136	330.6	0.37741	0.54856	3.60144	0.37867	0.38091	0.33	0.93	5.47
142	446.8	0.49337	0.57325	4.63844	0.50468	0.50599	2.29	2.56	0.43
147	550.6	0.62896	0.74469	5.71570	0.61727	0.61616	-1.86	-2.03	0.01
Mean:	260.2	0.3023	0.3925						
DRL:	328.8	0.3510	0.4832						
Median:	223.4	0.2668	0.3386						
n:	13								
Population standard deviation:	123.8								
Chauvenet criterion value:	0.5								

APPENDIX 22: INPUT DATA AP PELVIS HOSPITAL 3

Hospital 3 Pelvis									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
205	61.7	0.07830	0.10647	0.60146	0.07333	0.07487	-6.34	-4.38	2.52
204	75.3	0.09575	0.12556	0.78202	0.08977	0.09102	-6.24	-4.94	4.55
207	76.5	0.09570	0.12991	1.11996	0.09128	0.09249	-4.62	-3.35	4.79
208	78.0	0.09656	0.12801	0.69174	0.09312	0.09430	-3.57	-2.35	5.08
202	83.5	0.10053	0.12453	1.08702	0.09968	0.10072	-0.84	0.19	6.22
196	84.3	0.10337	0.13158	0.94306	0.10067	0.10169	-2.61	-1.63	6.41
210	92.5	0.10795	0.15471	0.88694	0.11061	0.11140	2.46	3.20	8.47
201	93.3	0.11561	0.15711	1.36884	0.11152	0.11229	-3.53	-2.87	8.67
199	94.1	0.10230	0.15185	1.71044	0.11254	0.11328	10.01	10.74	8.90
200	99.8	0.12110	0.20397	2.68034	0.11941	0.11999	-1.39	-0.92	10.55
193	100.1	0.11852	0.21856	1.40666	0.11978	0.12034	1.06	1.54	10.65
195	115.5	0.13034	0.17140	1.29320	0.13838	0.13846	6.17	6.22	15.70
198	115.8	0.13393	0.17308	1.36274	0.13871	0.13877	3.57	3.61	15.80
209	141.0	0.15537	0.15537	1.60918	0.16917	0.16832	8.88	8.34	11.60
206	168.1	0.20886	0.23745	1.27246	0.20199	0.20003	-3.29	-4.23	4.69
197	225.1	0.27391	0.36865	2.64984	0.27084	0.26625	-1.12	-2.80	0.21
203	242.7	0.28825	0.42990	3.61730	0.29208	0.28659	1.33	-0.58	0.06
194	250.1	0.30759	0.44038	2.45830	0.30105	0.29518	-2.12	-4.03	0.03

Mean:	122.1	0.1463	0.2005
DRL:	134.7	0.1500	0.2149
Median:	96.9	0.1171	0.1562

n:	18
Population standard deviation:	57.9
Chauvenet criterion value:	0.5

APPENDIX 23: INPUT DATA PA SKULL HOSPITAL 1

Hospital 1 Skull PA									
Patient	**DAP value (cGy.cm^2) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
51A	21.8	0.01731	0.00460	0.26718	0.02146	0.01967	23.94	13.59	1.08
62A	24.8	0.01920	0.00506	0.32330	0.02431	0.02249	26.61	17.11	1.57
53A	27.6	0.03159	0.00903	0.50996	0.02705	0.02522	-14.36	-20.17	2.20
65A	31.6	0.02808	0.00811	0.42456	0.03098	0.02916	10.30	3.83	3.45
61A	36.1	0.03029	0.00800	0.47092	0.03538	0.03362	16.79	10.99	5.40
50A	37.3	0.03346	0.00808	0.47580	0.03657	0.03483	9.28	4.09	6.04
64A	38.6	0.03283	0.00894	0.50264	0.03776	0.03605	15.01	9.81	6.73
55A	41.2	0.04099	0.01030	0.91622	0.04038	0.03873	-1.50	-5.51	8.42
48A	42.6	0.03586	0.00904	0.58438	0.04169	0.04008	16.26	11.77	9.35
57A	47.0	0.05984	0.01610	1.04310	0.04597	0.04450	-23.18	-25.64	12.78
59A	50.1	0.06260	0.01803	1.08824	0.04906	0.04771	-21.62	-23.78	15.56
47A	58.0	0.04891	0.01556	0.73932	0.05668	0.05567	15.88	13.83	19.06
54A	58.6	0.05908	0.01734	1.14436	0.05727	0.05630	-3.06	-4.72	18.49
60A	62.1	0.07364	0.02212	0.79178	0.06072	0.05993	-17.54	-18.61	15.21
58A	70.2	0.05603	0.01637	0.91378	0.06858	0.06825	22.39	21.80	8.74
56A	70.9	0.07973	0.02261	0.75396	0.06935	0.06907	-13.01	-13.36	8.20
63A	73.7	0.05441	0.01458	0.93940	0.07203	0.07193	32.38	32.19	6.51
59AB	74.2	0.10210	0.03138	1.64700	0.07251	0.07244	-28.99	-29.05	6.23
52A	97.6	0.07508	0.01946	1.29076	0.09535	0.09706	27.00	29.28	0.36
49A	101.1	0.08558	0.02403	1.31760	0.09880	0.10082	15.45	17.80	0.20
62AB	109.4	0.12216	0.03462	1.42618	0.10690	0.10966	-12.49	-10.23	0.05

Mean:	55.9	0.0547	0.0154
DRL:	70.9	0.0736	0.0195
Median:	50.1	0.0544	0.0156

n:	21
Population standard deviation:	24.7
Chauvenet criterion value:	0.5

APPENDIX 24: INPUT DATA LAT SKULL HOSPITAL 1

Hospital 1 Skull LAT									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
51B	25.3	0.02025	0.00952	0.29036	0.02711	0.02324	33.85	14.75	1.17
62B	27.9	0.03231	0.03231	0.41968	0.02912	0.02559	-9.87	-20.79	1.68
61B	33.4	0.02545	0.01169	0.37698	0.03323	0.03037	30.56	19.33	3.31
50B	36.4	0.03198	0.01646	0.42090	0.03542	0.03290	10.76	2.90	4.56
55B	38.1	0.03010	0.00761	0.74786	0.03670	0.03438	21.93	14.22	5.43
53B	44.8	0.04459	0.01585	0.78812	0.04172	0.04014	-6.44	-9.99	9.93
65B	45.3	0.03799	0.01835	0.52338	0.04208	0.04056	10.78	6.75	10.32
64B	47.7	0.03920	0.01759	0.56364	0.04391	0.04264	12.02	8.78	12.39
48B	48.2	0.03599	0.01508	0.55754	0.04428	0.04306	23.02	19.63	12.83
58B	49.2	0.04931	0.01708	0.96624	0.04501	0.04389	-8.73	-11.00	13.72
54B	49.4	0.04391	0.01330	0.99186	0.04519	0.04410	2.92	0.43	13.95
59BA	55.0	0.06268	0.02274	1.08092	0.04939	0.04886	-21.21	-22.05	19.49
58B	57.3	0.04035	0.02070	0.54046	0.05113	0.05083	26.72	25.98	20.13
56B	61.6	0.06821	0.03207	0.60512	0.05434	0.05445	-20.33	-20.17	15.81
62BA	62.1	0.06561	0.03326	0.73322	0.05469	0.05484	-16.65	-16.41	15.36
47B	62.8	0.05309	0.02685	0.72712	0.05524	0.05546	4.03	4.46	14.65
57B	67.8	0.07139	0.02505	1.33224	0.05898	0.05967	-17.39	-16.43	10.23
60B	77.5	0.09074	0.04525	0.91500	0.06619	0.06773	-27.05	-25.36	4.17
49B	80.8	0.06385	0.02832	0.93452	0.06866	0.07048	7.53	10.37	2.88
63B	84.9	0.05849	0.02044	0.95038	0.07176	0.07393	22.70	26.40	1.71
52B	130.9	0.09483	0.03439	1.58966	0.10619	0.11175	11.98	17.84	0.00

Mean:	56.5	0.0505	0.0221
DRL:	62.8	0.0639	0.0283
Median:	49.4	0.0446	0.0204

n:	21
Population standard deviation:	23.1
Chauvenet criterion value:	0.5

APPENDIX 25: INPUT DATA PA SKULL HOSPITAL 2

Hospital 2 Skull PA

Patient	DAP value ($cGy.cm^2$) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
130A	24.7	0.02807	0.00803	0.48556	0.02714	0.02705	-3.31	-3.65	0.09
135A	34.6	0.03398	0.00914	0.64050	0.03902	0.03848	14.85	13.25	0.32
133A	44.2	0.05218	0.01610	0.75030	0.05053	0.04970	-3.15	-4.75	0.93
128A	72.5	0.10530	0.03087	1.49694	0.08447	0.08334	-19.78	-20.86	7.88
127A	84.4	0.09389	0.02623	1.47620	0.09881	0.09774	5.24	4.10	10.91
129A	92.0	0.10950	0.02795	1.82756	0.10788	0.10690	-1.48	-2.37	7.68
131A	93.1	0.09905	0.02551	1.79096	0.10919	0.10823	10.24	9.26	7.25
125A	93.6	0.08440	0.02102	1.44692	0.10978	0.10882	30.07	28.93	7.06
124A	100.8	0.13660	0.03893	1.98738	0.11841	0.11757	-13.32	-13.93	4.56
126A	112.5	0.11904	0.02866	1.58356	0.13245	0.13187	11.27	10.78	1.85
132A	114.9	0.13603	0.03876	2.45708	0.13538	0.13486	-0.48	-0.86	1.49
134A	116.8	0.15261	0.04324	2.00812	0.13757	0.13710	-9.85	-10.16	1.25

Mean:	82.0	0.0959	0.0262
DRL:	103.7	0.1233	0.0328
Median:	92.5	0.1022	0.0271

n:	12
Population standard deviation:	30.3
Chauvenet criterion value:	0.5

APPENDIX 26: INPUT DATA LAT SKULL HOSPITAL 2

Hospital 2 Skull LAT									
Patient	DAP value ($cGy.cm^2$) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
135B	12.7	0.01152	0.00387	0.21838	0.01495	0.01267	29.79	10.02	0.48
130B	19.2	0.02037	0.00691	0.33550	0.01957	0.01814	-3.94	-10.97	0.99
133B	21.8	0.02383	0.01330	0.33428	0.02143	0.02026	-10.07	-14.96	1.29
134B	35.3	0.02786	0.01669	0.59780	0.03099	0.03074	11.23	10.32	4.09
129B	36.1	0.02650	0.00946	0.43676	0.03160	0.03138	19.25	18.44	4.35
132B	44.7	0.03056	0.01484	0.45628	0.03767	0.03773	23.27	23.45	7.46
124B	60.9	0.07132	0.03819	0.81252	0.04921	0.04936	-31.01	-30.79	9.18
126B	74.3	0.07282	0.03784	0.83692	0.05875	0.05867	-19.33	-19.44	4.08
131B	79.1	0.05840	0.03061	0.64904	0.06213	0.06191	6.39	6.01	2.83
125B	84.3	0.05586	0.02735	0.79178	0.06586	0.06546	17.89	17.18	1.79
128B	87.7	0.06600	0.03706	0.79178	0.06829	0.06775	3.47	2.65	1.29
127B	101.1	0.07322	0.03270	1.10532	0.07783	0.07665	6.29	4.68	0.28

Mean:	54.8	0.0449	0.0224
DRL:	80.4	0.0673	0.0338
Median:	52.8	0.0432	0.0220

n:	12
Population standard deviation:	29.0
Chauvenet criterion value:	0.5

APPENDIX 27: INPUT DATA PA SKULL HOSPITAL 3

Hospital 3 Skull PA									
Patient	**DAP value ($cGy.cm^2$) - X-axis**	**PCXMC Skin dose (mGy) - Y-axis**	**PCXMC Effective dose (mSv) - ICRP103**	**PCXMC Incident air kerma (mGy)**	**Skin dose (mGy) - calculated linear fit**	**Skin dose (mGy) - calculated power fit**	**% Diff linear fit**	**% Diff power fit**	**Chauvenet criterion**
155A	21.5	0.01941	0.00570	0.30134	0.02938	0.02602	51.35	34.07	1.31
160A	23.2	0.03765	0.01298	0.88572	0.03116	0.02792	-17.25	-25.83	1.54
214A	25.4	0.02695	0.00777	0.55388	0.03359	0.03051	24.62	13.21	1.90
151A	32.3	0.03709	0.01146	0.43188	0.04090	0.03823	10.29	3.07	3.39
212A	34.1	0.03967	0.01230	0.63318	0.04280	0.04021	7.87	1.35	3.89
213A	41.4	0.05231	0.02057	0.89426	0.05069	0.04842	-3.10	-7.45	6.55
157A	42.3	0.03993	0.01133	0.43920	0.05161	0.04936	29.24	23.62	6.92
163A	52.0	0.06811	0.02262	0.67710	0.06199	0.06004	-8.98	-11.85	11.96
162A	56.4	0.07780	0.02796	1.25416	0.06679	0.06494	-14.15	-16.53	14.72
158A	60.7	0.04863	0.01391	0.81130	0.07134	0.06956	46.70	43.05	17.49
161A	63.6	0.14140	0.02230	0.14140	0.07450	0.07277	-47.31	-48.54	18.55
150A	70.5	0.09159	0.03009	1.27124	0.08183	0.08017	-10.65	-12.47	14.09
156A	71.2	0.09637	0.02855	1.58234	0.08261	0.08096	-14.27	-15.99	13.64
164A	72.6	0.08716	0.02483	0.94550	0.08410	0.08245	-3.50	-5.40	12.78
153A	81.5	0.08185	0.02612	1.08824	0.09363	0.09200	14.39	12.40	7.91
152A	85.0	0.08312	0.02614	1.19316	0.09733	0.09569	17.10	15.13	6.37
159A	96.6	0.07336	0.01985	1.35786	0.10985	0.10813	49.74	47.40	2.66
154A	122.7	0.10734	0.03227	1.72508	0.13776	0.13560	28.34	26.34	0.17
149A	143.4	0.19209	0.05441	3.45748	0.15996	0.15723	-16.73	-18.14	0.01

Mean:	63.0	0.0738	0.0216
DRL:	77.1	0.0894	0.0271
Median:	60.7	0.0734	0.0223

n:	19
Population standard deviation:	32.3
Chauvenet criterion value:	0.5

APPENDIX 28: INPUT DATA LAT SKULL HOSPITAL 3

Hospital 3 Skull LAT

Patient	DAP value (cGy.cm^2) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
157B	20.5	0.01775	0.00974	0.19276	0.02380	0.02205	34.09	24.20	1.84
214B	21.4	0.01868	0.00669	0.33550	0.02441	0.02278	30.68	21.95	2.13
163B	24.3	0.03306	0.01549	0.28670	0.02646	0.02521	-19.96	-23.76	3.38
160B	25.6	0.03407	0.01337	0.73322	0.02738	0.02627	-19.65	-22.91	4.09
151B	26.4	0.02934	0.01534	0.31110	0.02789	0.02686	-4.93	-8.46	4.53
212B	30.7	0.02597	0.01059	0.40138	0.03095	0.03030	19.15	16.67	7.84
213B	32.0	0.02795	0.01810	0.45506	0.03187	0.03133	14.04	12.08	9.08
162B	32.4	0.04397	0.01909	0.39284	0.03216	0.03164	-26.87	-28.05	9.47
155B	32.9	0.02758	0.01286	0.40626	0.03246	0.03196	17.66	15.88	9.90
164B	36.2	0.04072	0.02046	0.41602	0.03478	0.03448	-14.61	-15.34	13.54
158B	40.7	0.03063	0.01107	0.49288	0.03799	0.03788	24.02	23.67	18.83
159B	43.8	0.03081	0.00986	0.51728	0.04012	0.04009	30.23	30.13	15.09
156B	45.2	0.03749	0.01732	0.53314	0.04110	0.04110	9.63	9.62	13.42
152B	47.6	0.04518	0.02438	0.57584	0.04281	0.04284	-5.23	-5.17	10.69
150B	47.6	0.05744	0.03057	0.62098	0.04283	0.04286	-25.43	-25.39	10.67
154B	47.8	0.03771	0.01487	0.57828	0.04292	0.04294	13.80	13.88	10.54
153B	53.3	0.05261	0.02834	0.62952	0.04677	0.04679	-11.10	-11.05	5.63
149B	76.0	0.05479	0.02828	0.74664	0.06271	0.06195	14.46	13.06	0.07
161B	87.4	0.07435	0.03390	1.05652	0.07070	0.06916	-4.91	-6.98	0.00

Mean:	40.6	0.0379	0.0179
DRL:	47.6	0.0446	0.0224
Median:	36.2	0.0341	0.0155

n:	19
Population standard deviation:	17.1
Chauvenet criterion value:	0.5

VacuTec Meßtechnik GmbH
Dornblüthstr. 14a
01277 Dresden
Germany
Phone: +49 351 317 24 - 0
Fax: +49 351 310 50 85
E-Mail: info@vacutec-gmbh.de
Web: www.vacutec-gmbh.de

VacuDAP *compact*

REF 158 00 05

Technical data

All technical data are valid for the specified ambient conditions according to IEC 60580.

Ionization chamber

Response	
without absorber	800 pC / µGy·m²
with absorber (0.5 mm Al)	920 pC / µGy·m²
Leakage current	≤ 0.1 pA
Response versus radiation quality	- 6% / + 0% (50 kV …150 kV, acc. to IEC 60580)
Quality equivalent filtration (70 kV)	0.2 mm Al
Transparency	> 70%
Useful field	(1 ... 200) cm²
Chamber voltage	300 V
Distance of the electrodes	6 mm
Stabilization time	5 min

Measuring device

Combined standard uncertainty (acc. to IEC 60580) ±25 %

Measured quantity	Dose area product		Dose area product rate	
Mode	High Resolution	High Rate	High Resolution	High Rate
Unit of measure	[µGy·m²]	[µGy·m²]	[µGy·m²/min]	[µGy·m²/min]
Digital resolution	0.01	0.1	0.6	6
Measuring range	0.1 ... 99 999 999	1 ... 99 999 999	6.0 ... 280 000	60 ... 2 200 000

Rated range of use	
Radiation quality	(40 ... 150) kV
Dose area product rate (High Res. Mode)	(0.6 ... $2.8 \cdot 10^5$) µGy·m²/min
Dose area product rate (High Rate Mode)	(6.0 ... $2.2 \cdot 10^6$) µGy·m²/min
Air kerma rate	(6.0 ... $1.1 \cdot 10^5$) mGy/min (at the position of the chamber)
Air pressure	(80.0 ... 106.0) kPa
Temperature	(+10 ... +40) °C
Air humidity	(10 ... 80) % rel. humidity (max. 20 g/m³)

The maximum dose area product rate must not be exceeded.
The ionization chamber must frame the radiation field at all times!

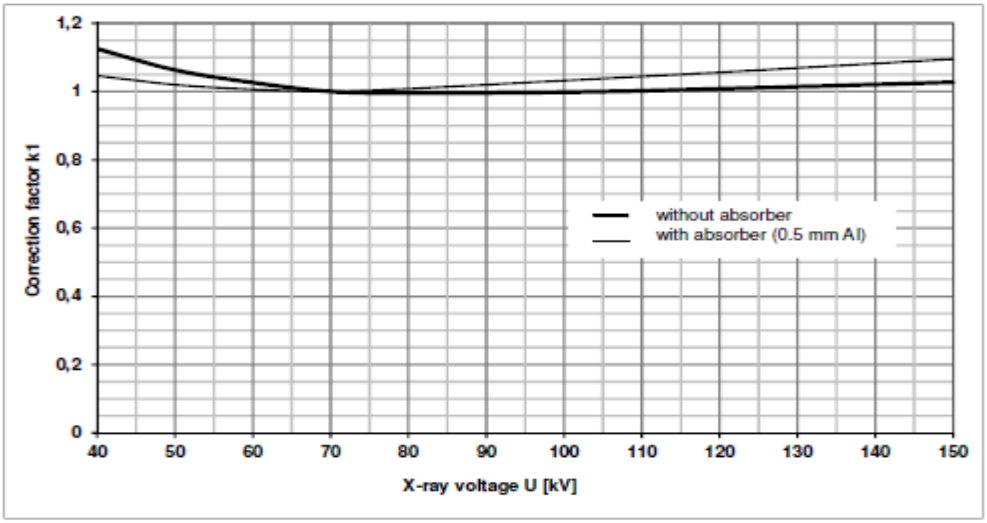
Serial interface	RS-485; half-duplex
Supply voltage (+U_S)	(+ 10 ... + 30) V DC
with *Battery for VacuDAP* (REF 950 00 64)	(+ 6.5 ... + 8.4) V DC
Power consumption	max. 3 W
Weight without guide rails	260 g

Only values given with tolerance ranges, or limits are guaranteed. All other values are for information only. Subject to change.

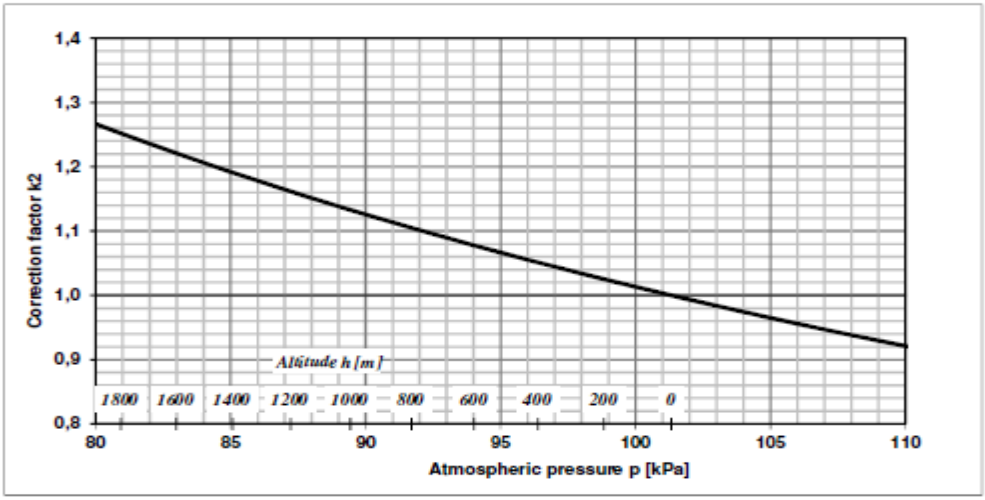
VacuTec Meßtechnik Gm
Dornblüthstr.
01277 Dres
Germa
Phone: +49 351 317 24
Fax: +49 351 310 50
E-Mail: info@vacutec-gmbh
Web: www.vacutec-gmbh

VacuDAP *compac*

REF 158 00 0



Graph 1: Response correction versus radiation quality



Graph 2: Response correction versus air density

Only values given with tolerance ranges, or limits are guaranteed. All other values are for information only. Subject to change.

APPENDIX 31: CORRECTION FACTORS ACROSS DIFFERENT kVp's

kV	k_P without absorber	$k_{P\text{-}0,5Al}$ with absorber (0,5 mm Al)
40	1,125	1,046
50	1,063	1,02
60	1,026	1,006
70	1	1
80	0,996	1,008
100	0,998	1,032
120	1,008	1,056
150	1,027	1,095

APPENDIX 32: ETHICS CERTIFICATE CPUT

Cape Peninsula
University of Technology

HEALTH AND WELLNESS SCIENCES RESEARCH ETHICS COMMITTEE (HW-REC)

Registration Number NHREC: REC- 230408-014

P.O. Box 1906 • Bellville 7535 South Africa
Symphony Road Bellville 7535
•Tel: +27 21 959 6352 • Fax +27 21 953 8490
Email: danielso@cput.ac.za

3 October 2013
CPUT/HW-REC 2013/H32

Faculty of Health and Wellness Sciences – Nursing and Radiography Department

Dear Mr Edwin Ralph Daniels

APPLICATION TO THE HW-REC FOR ETHICAL CLEARANCE

Approval was granted on 20 September 2013 by the Health and Wellness Sciences-REC to Edwin Ralph Daniels for your Ethical Clearance application. This approval is for research activities related to an MTech: Radiography at this Institution.

Title: Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek, Namibia to develop diagnostic reference levels.

INTERNAL SUPERVISOR: Mrs F Davidson

INTERNAL CO-SUPERVISOR: Mr A Speelman

Comment:
Approval will not extend beyond 3 October 2014. An extension should be applied for 6 weeks before this expiry date should data collection and use/analysis of data, information and/or samples for this study continue beyond this date.

Note:
The investigator(s) should understand the conditions under which they are authorized to carry out this study and they should be compliant to these conditions. **It is required that the investigator(s) complete an annual progress report that should be submitted to the HW-REC in December of that particular year, for the HW-REC to be kept informed of the progress and of any problems you may encounter.**

Kind Regards

Zulcika Nortjé
CHAIRPERSON – ETHICS RESEARCH COMMITTEE
FACULTY OF HEALTH AND WELLNESS SCIENCES

APPENDIX 33: ETHICS CERTIFICATE CPUT

Cape Peninsula
University of Technology

HEALTH AND WELLNESS SCIENCES RESEARCH ETHICS COMMITTEE (HW-REC)
Registration Number NHREC: REC- 230408-014

P.O. Box 1906 • Bellville 7535 South Africa
Symphony Road Bellville 7535
Tel: +27 21 959 6917
Email: sethn@cput.ac.za

25 April 2016
REC Approval Reference No:
CPUT/HWS-REC 2015/H02 (renewal)

Faculty of Health and Wellness Sciences

Dear Mr Edwin Ralph Daniels

Re: APPLICATION TO THE HWS-REC FOR ETHICS CLEARANCE

Your application for ethics approval has reference. This serves to inform you that approval was granted by the Health and Wellness Sciences-REC on 14 April 2016 to Mr Daniels for ethical clearance. This approval is for research activities related to the MTech: Radiography at this Institution.

TITLE: Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek, Namibia to develop diagnostic reference levels.

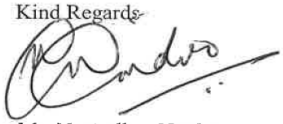
Internal Supervisor:
1. Mrs F Davidson

Internal Co-Supervisor:
1. Mr A Speelman

Comment:
Approval will not extend beyond 26 April 2017. An extension should be applied for 6 weeks before this expiry date should data collection and use/analysis of data, information and/or samples for this study continue beyond this date.

The investigator(s) should understand the ethical conditions under which they are authorized to carry out this study and they should be compliant to these conditions. It is required that the investigator(s) complete an **annual progress report** that should be submitted to the HWS-REC in December of that particular year, for the HWS-REC to be kept informed of the progress and of any problems you may have encountered.

Kind Regards



Mr. Navindhra Naidoo
Chairperson – Research Ethics Committee
Faculty of Health and Wellness Sciences

APPENDIX 34: ETHICS CERTIFICATE CPUT

Cape Peninsula University of Technology

HEALTH AND WELLNESS SCIENCES RESEARCH ETHICS COMMITTEE (HW-REC)
Registration Number NHREC: REC- 230408-014

P.O. Box 1906 • Bellville 7535 South Africa
Symphony Road Bellville 7535
Tel: +27 21 959 6917
Email: sethn@cput.ac.za

14 August 2019
REC Approval Reference No:
CPUT/HWS-REC 2015/H02 (renewal)

Faculty of Health and Wellness Sciences - Medical Imaging and Therapeutic Sciences

Dear Mr Edwin Ralph Daniels

Re: YOUR APPLICATION TO THE HWS-REC FOR EXTENSION OF ETHICS APPROVAL

Approval was granted by the Health and Wellness Sciences-REC on 30 March 2017 5 to Mr Daniels for ethical clearance. This approval is for research activities related to Medical Imaging and Therapeutic Sciences at this Institution.

TITLE: Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek, Namibia to develop diagnostic reference levels.

Supervisors
Mrs F Davidson and Mr A Speelman

Comment:
Approval will not extend beyond 15 August 2020. An extension should be applied for 6 weeks before this expiry date should data collection and use/analysis of data, information and/or samples for this study continue beyond this date.

The investigator(s) should understand the conditions under which they are authorized to carry out this study and they should be compliant to these conditions. **It is required that the investigator(s) complete an annual progress report that should be submitted to the HWS-REC in December of that particular year, for the HW-REC to be kept informed of the progress and of any problems you may encounter.**

Kind Regards

Dr. Navindhra Naidoo
Chairperson – Research Ethics Committee
Faculty of Health and Wellness Sciences

APPENDIX 35: APPROVAL LETTER PERMANENT SECRETARY MOHSS

Re: PERMISSION TO CONDUCT RESEARCH

Ester Shaama [eshaama80@gmail.com]
Sent: Friday, May 31, 2013 1:10 PM
To: Daniels, Edwin
Attachments: Research application form[1].doc (43 KB)

Dear Mr. Daniels

Please submit your request letter with all the relevant documents attached to the Permanent Secretary's office. The following documents should be attached;

- request/cover letter addressed to the PS,
- full research proposal with all the data collection tools attached,
- IRB approval from your university
- completed research application form with you cv attached

You are advised to submit the hard copies. For further communication, please make use my work email: eshaama@mhss.gov.na. Attached is the research application form that you have to complete.
Regards,
Ester

On Fri, May 31, 2013 at 1:30 PM, Daniels, Edwin <edaniels@unam.na> wrote:

TO EHO IT MAU CONCERN

RE: Request for permission to carry out a research study at Windhoek Central and Katutura Intermediate hospitals.

I am a postgraduate student (Masters in Technology- Radiography (diagnostic), registered at the Cape Peninsula University of Technology, registration number 213009641),
In addition I am also an employee at the University of Namibia (Assistant Lecturer) responsible for Clinical Practice at Windhoek Central Hospital and Katutura Intermediate Hospital respectively; on staff development leave to peruse this qualification.

It is a requirement at this level for a student to conduct research for fulfilment of the award of a Masters degree.

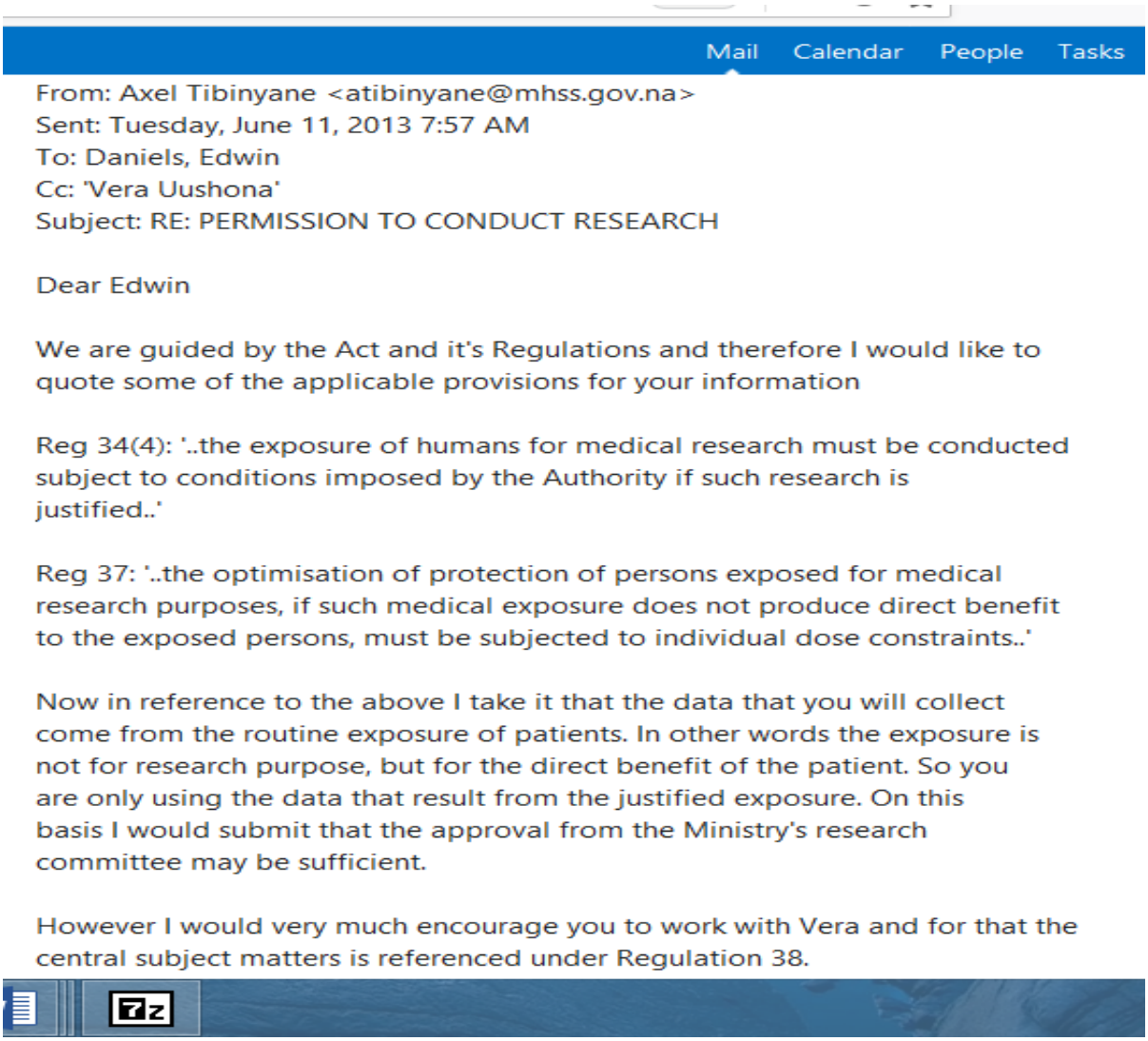
The title of the study is "Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek Namibia to develop diagnostic reference levels".

I have selected the departments at Windhoek Central Hospital (WCH) and Katutura Intermediate Hospital (KIH) to conduct my research as it is the largest public hospitals and utilise computed radiography techniques which may be associated with higher radiation doses. It is anticipated that the research may contribute towards the optimisation of radiation doses delivered to patients.

I hereby request the support in my studies and permission to carry out this proposed study and the above mentioned hospitals.

A copy of the summarised proposal is attached and full proposal availed on request.

APPENDIX 36: SUPPORT LETTER NRPA



Mail Calendar People Tasks

From: Axel Tibinyane <atibinyane@mhss.gov.na>
Sent: Tuesday, June 11, 2013 7:57 AM
To: Daniels, Edwin
Cc: 'Vera Uushona'
Subject: RE: PERMISSION TO CONDUCT RESEARCH

Dear Edwin

We are guided by the Act and it's Regulations and therefore I would like to quote some of the applicable provisions for your information

Reg 34(4): '..the exposure of humans for medical research must be conducted subject to conditions imposed by the Authority if such research is justified..'

Reg 37: '..the optimisation of protection of persons exposed for medical research purposes, if such medical exposure does not produce direct benefit to the exposed persons, must be subjected to individual dose constraints..'

Now in reference to the above I take it that the data that you will collect come from the routine exposure of patients. In other words the exposure is not for research purpose, but for the direct benefit of the patient. So you are only using the data that result from the justified exposure. On this basis I would submit that the approval from the Ministry's research committee may be sufficient.

However I would very much encourage you to work with Vera and for that the central subject matters is referenced under Regulation 38.

APPENDIX 37: APPROVAL LETTER MEDICAL IMAGING

MEDICAL IMAGING

DIAGNOSTIC RADIOLOGISTS
PR NO 038 000 0008400
VAT REG NO: 5151 659-015

P.O. Box 9471, Eros, Namibia

E-mail: xray1@medicalimaging.com.na

20 June 2013
Ref: MI 8.5

Dear Mr Daniels

RE: ACCESS TO MEDICAL IMAGING FOR RESEARCH PAPER

The Partners recognize receipt of your emailed request to use Medical Imaging for your research in fulfillment of the requirements for your M Tech (Radiology) as received on 31 May 2013.

It is noted that the research is an endeavor to develop diagnostic reference levels for patients undergoing routine x-ray examinations that may contribute to optimization of radiation doses delivered to patients and that you wish to gain access to the clinics located at Mediclinic, Roman Catholic Hospital and Rhino Park for the purpose of data gathering.

It is further noted that data gathered from the three sites will be kept strictly confidential.

Referring to the above, the partners are pleased to inform you that your request has been approved and wish you success with the dissertation.

From an operational perspective, you are requested to provide details of when you will be at the various clinics, what information you will be seeking/ the Practice will need to make available and the methodology you will use to collect data. You are also politely requested to report to both the Radiologist/s on duty and the Clinic Manager when entering and leaving the clinic.

Partners look forward to an ongoing academic partnership with you and your department.

Yours sincerely

Dr JA van Rooyen
Partner: Medical Imaging

Partners: Jean van Rooyen, Pierre le Roux, Paddy Murphy, Johan Venter, Ryan Volker & Marco van der Merwe
Associate Partner: Willie Davel Assistants: Hedi Boonzaier-Botha, and Faiz Petker

Medi-Clinic Windhoek	Roman Catholic Hospital	Windhoek Central Hospital	Rhino Park Hospital	Maerua Park	Cottage Medi-Clinic:Swkp
Tel: +61-379600	Tel: +61-256452/3	Tel: +61-248492	Tel: +61-400631	Tel: +61-301184	Tel: +64-403878
Fax: +61-379621	Fax: +61-256837	Fax: +61-248492	Fax: +61-301135	Fax: +61-301187	Fax: +64-407029

APPENDIX 38: PATIENT INFORMATION LEAFLET AND CONSENT FORM

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT: Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek Namibia to develop diagnostic reference levels.

PRINCIPAL INVESTIGATOR: Edwin Ralph Daniels.
Registered for: M Tech Radiography at the Cape Peninsula University of Technology.

ADDRESS: P.O.Box 20323, Windhoek, Namibia.

Contact number: +27 0721374566 or + 00264 812575787

Dear Participant,

As a radiographer it is part of our goal to continuously improve the quality of our services as well as striving into research ventures that will bring new knowledge, enabling us to improve our patient management service.

On this note we request your participation in a project titled: **"Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek Namibia to develop diagnostic reference levels.**

Please take some time to read the information presented here which will explain the details of this project. Please ask the principal investigator about any part of the project that you do not fully understand. It is very important that you are fully satisfied as to what the research entails. Your participation is **entirely voluntary** and you are free to withdraw at any stage if you say no, this will not affect you negatively in any way whatsoever.

The research study has been approved by the Permanent Secretary (Ministry of Health and Social Services as well as the Cape Peninsula University of Technology research Ethics committee of the Faculty of Health and Wellness Sciences. The study has also been approved by the heads of the various radiology departments and is supported by the National Radiation Protection Authority of Namibia.

Purpose of research study:

The study aims to measure radiation to patients undergoing routine x-ray examinations in Windhoek Namibia and develop diagnostic reference levels.

What is the study about?

The study will explore whether radiographers optimise the radiation delivered to patients during four selected radiography procedures, namely chest, skull, lumbar spine and pelvis. These examinations have been selected because they are frequently performed in these hospitals.

In a global effort to minimise the harmful effects of ionising radiation and an effort to keep radiation doses as low as reasonably achievable (ALARA) the researcher decided to measure radiation doses that patients receive during the above mentioned procedures and establish diagnostic reference levels for these procedures. The diagnostic reference levels will be compared with international reference levels and determine whether our radiation protection measures conform to international levels or not.

The results will also be forwarded to the National Radiation Protection Authority of Namibia and propose that these values be used as provisional diagnostic reference levels until such a time when National reference values are established. Once these reference values have been established x-ray departments can compare their radiation practices against these values and investigate the cause of the dose variation if the values are exceeded.

Why have you been invited to participate?

You have been chosen to participate because the Doctor have referred you for one of the x-ray procedures we are interested in monitoring.

What will your responsibilities be?

To allow us to measure your weight, height, and anatomical thickness for the body part under examination. You will be asked to stand on a digital scale and your weight bill be recorded. You will also stand against the wall of the x-ray room and your height will be measured. The radiographer will then position you as per departmental protocol and measure the distance from the x-ray source to your skin. This measurement will be used to determine the thickness of your body part in the centre of the x-ray source. The radiographer will then record the dose area

product displayed on the DAP meter after exposure. This is normally not part of an x-ray procedure.

Will you benefit from this research?

There are no direct benefits to you as a volunteer. There will be no results that can tell us anything about your health or possible diseases. Your radiographs will be reported by radiologist as per normal routine. This study will not interfere with your results or management of your health. However the study will help us determine whether we are conforming to international norm and whether or nor not our radiation protection practices are optimised.

Are there any risks from taking part in this research?

X-rays usually involve radiation which poses a small risk. The risk of this study is however negligible. We will only perform the normal radiographic views that the Doctor requested without any alteration in the positioning technique procedure, or reading of the image.

If you do not agree what alternatives do you have?

Whether or not you participate in this study will not affect your clinical care in any way.

Who will have access to the data?

All information collected will be treated as confidential. In order to assure anonymity and protect your identity you will be assigned a study code. Access to the information will only be limited to the principal investigator and immediate supervisors. There will be no means to trace the data to the participant as the study will only record data related to radiation exposure received during the x-ray examination procedure.

Data to be collected

The following data will be collected from each participant:

- Age
- Gender (male/female)
- Weight

- Height
- Thickness of anatomical part under examination

No other data will be collected.

Will you be paid to take part in this study?

You will not be paid to take part in this study, and you will not incur any cost either.

(Declaration by participant, Principal investigator and Translator.)

NB...!

(Consent form must be signed by Participant, Principal Researcher & Language Translator)

Declaration by participant:

By signing below, I…….agree to take part in a research study titled: Measurement of radiation doses to patients undergoing routine x-ray examinations in Windhoek Namibia to develop diagnostic reference levels.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable. I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is voluntary and I have not been pressurized to take part.
- I understand that all data collected in this research will be handled confidentially.

Signed at (place)……on (date)……

…… ……

Signature of participant Signature of witness

Declaration by principal investigator:

I (name) ……declare that:

- I explained the information in this document to …….
- I encouraged him/her to ask questions and took adequate time to answer them.

- I am satisfied that he/she adequately understands all aspects of the research as discussed above.
- I did/did not use a translator.

Signed at (place)……on (date)……

…… ……
Signature of investigator Signature of witness

Declaration by language translator

I (name) ……declare that:

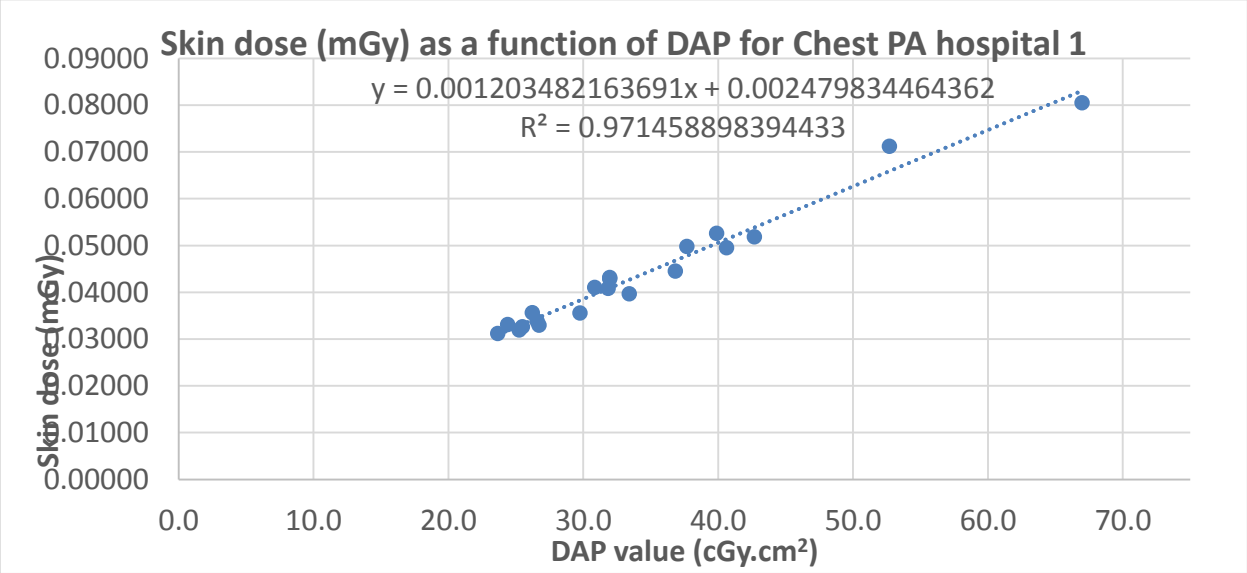
- I assisted the investigator (name) ……..to explain the Information in this document to (name of participant) ……..using the medium of ……...

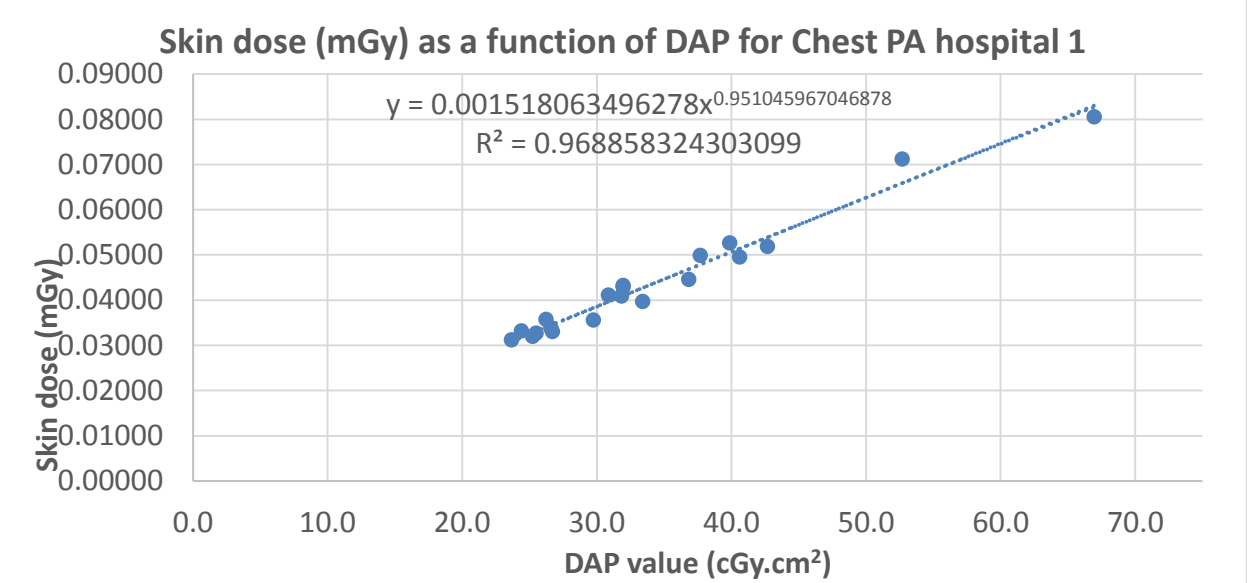
- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (place)……on (date)……

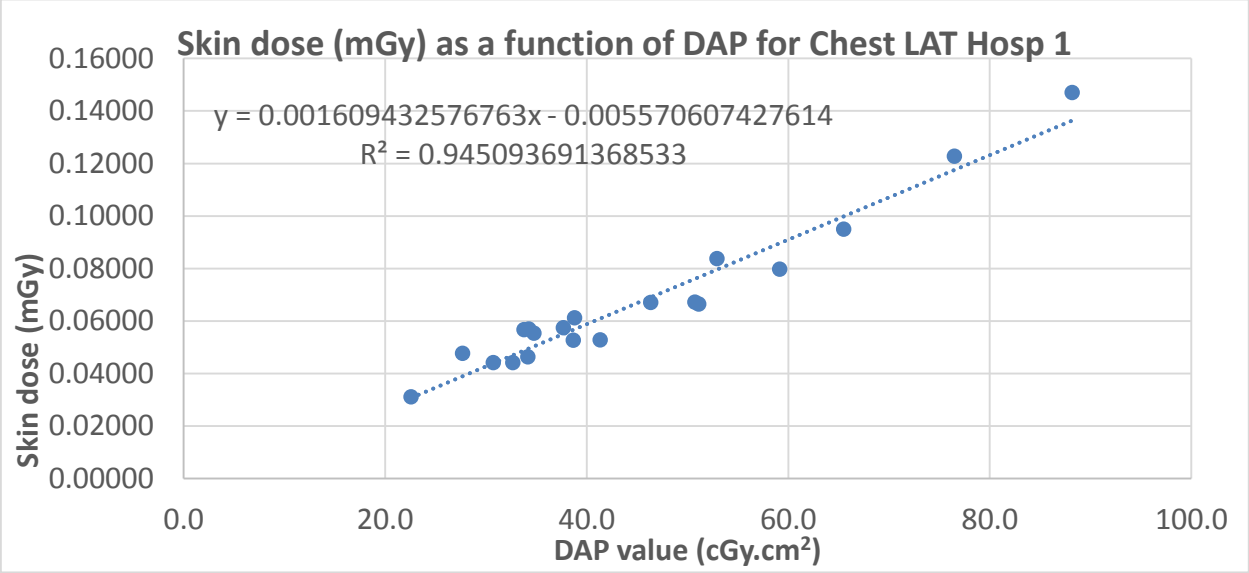
…… ……
Signature of translator Signature of witness

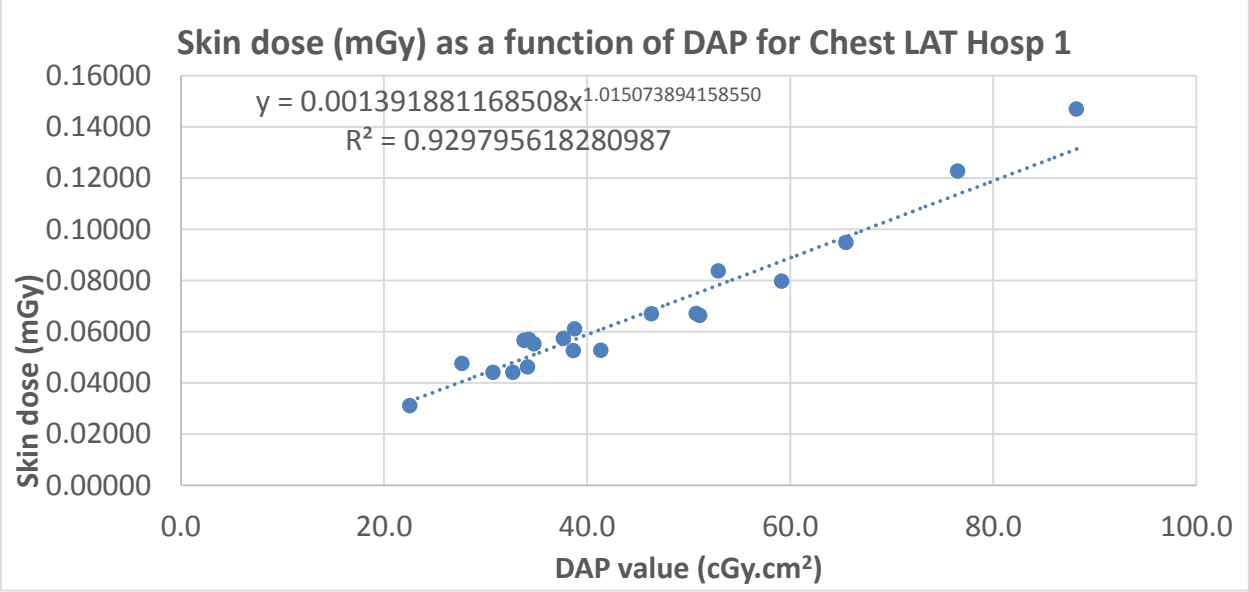
APPENDIX 39: LINEAR & EXPONENTIAL FIT PA CHEST HOSPITAL 1



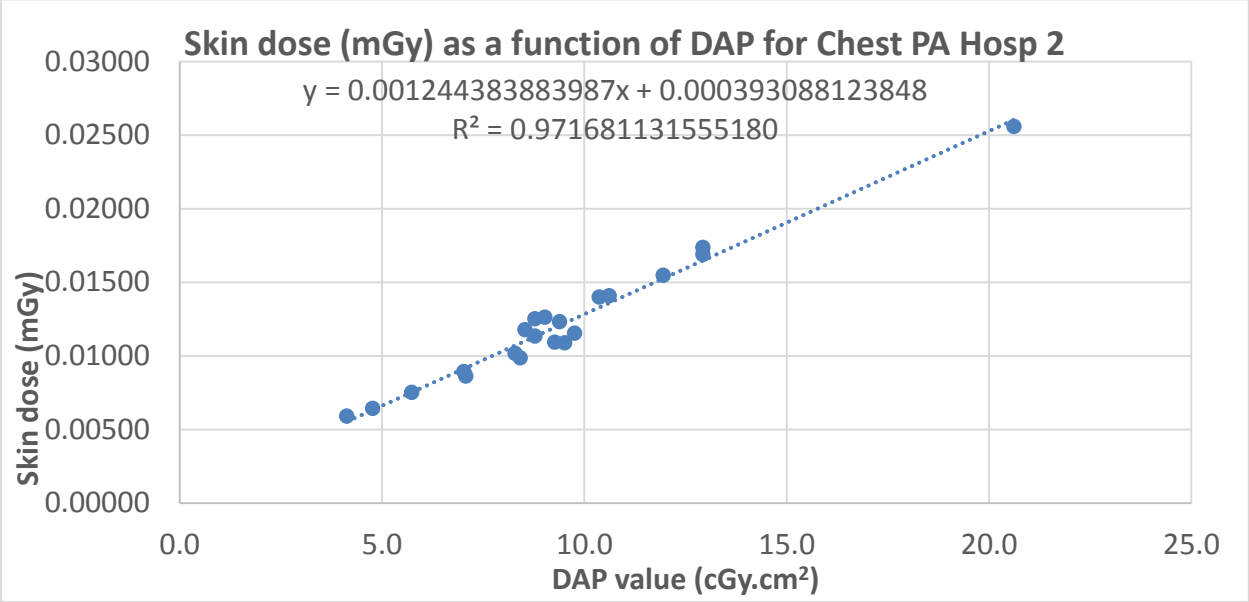


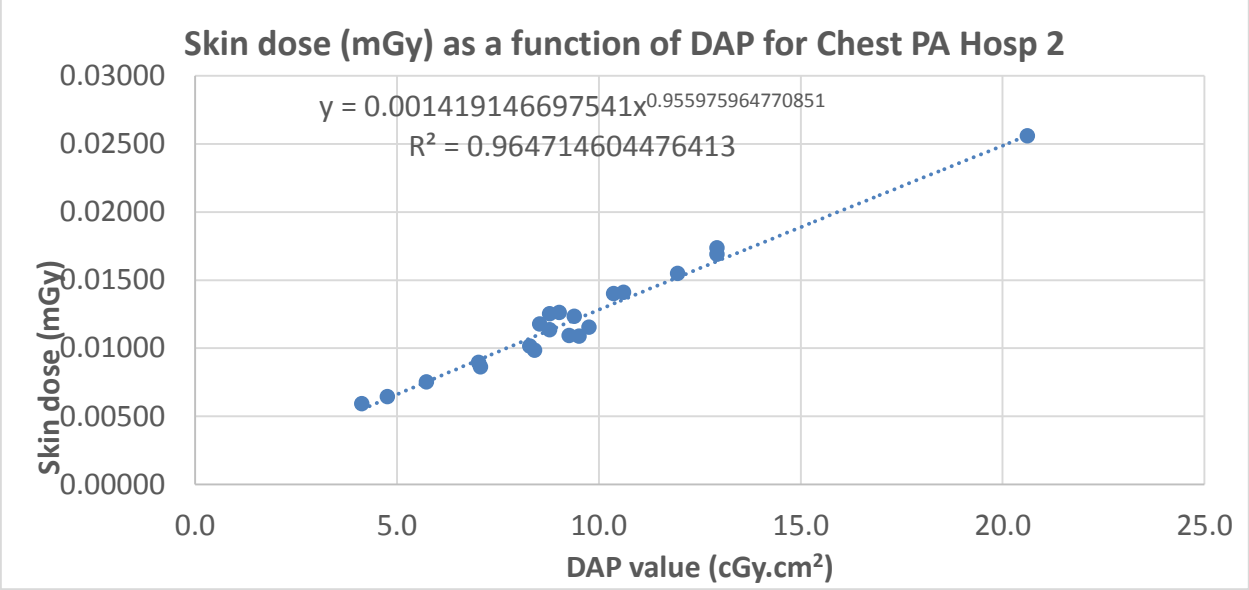
APPENDIX 40: LINEAR & EXPONENTIAL FIT LAT CHEST HOSPITAL 1



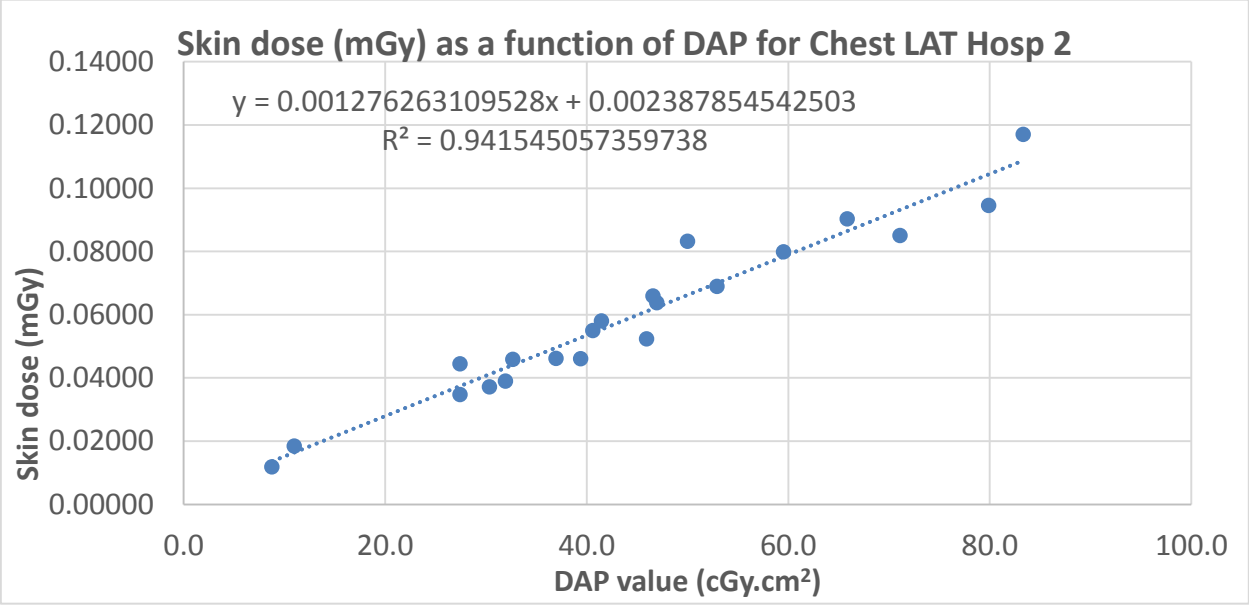


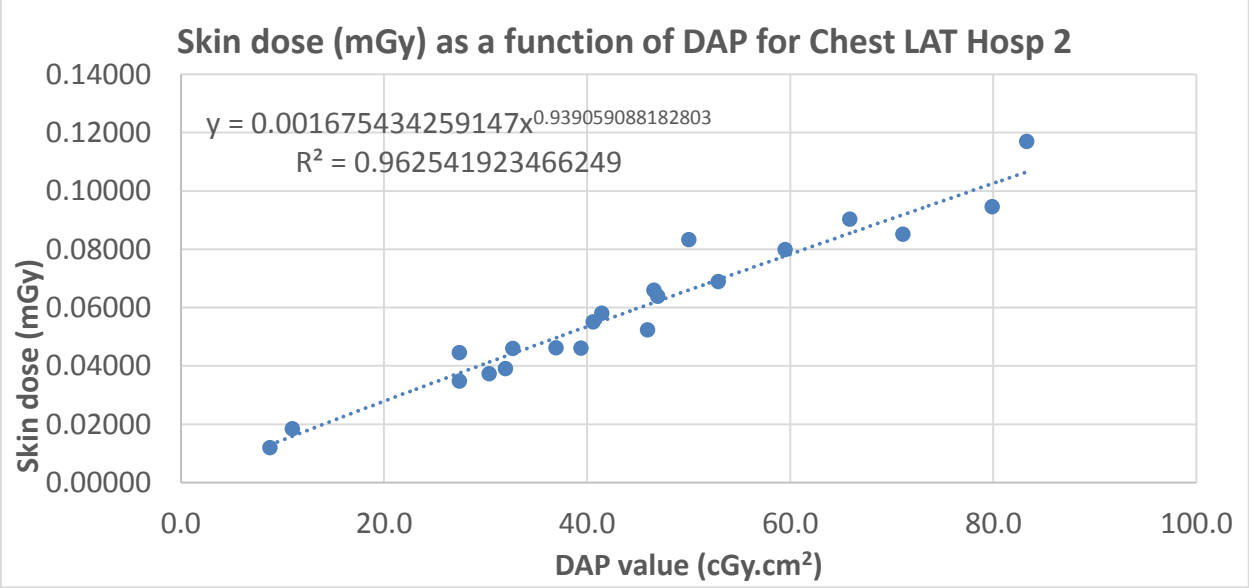
APPENDIX 41: LINEAR & EXPONENTIAL FIT PA CHEST HOSPITAL 2



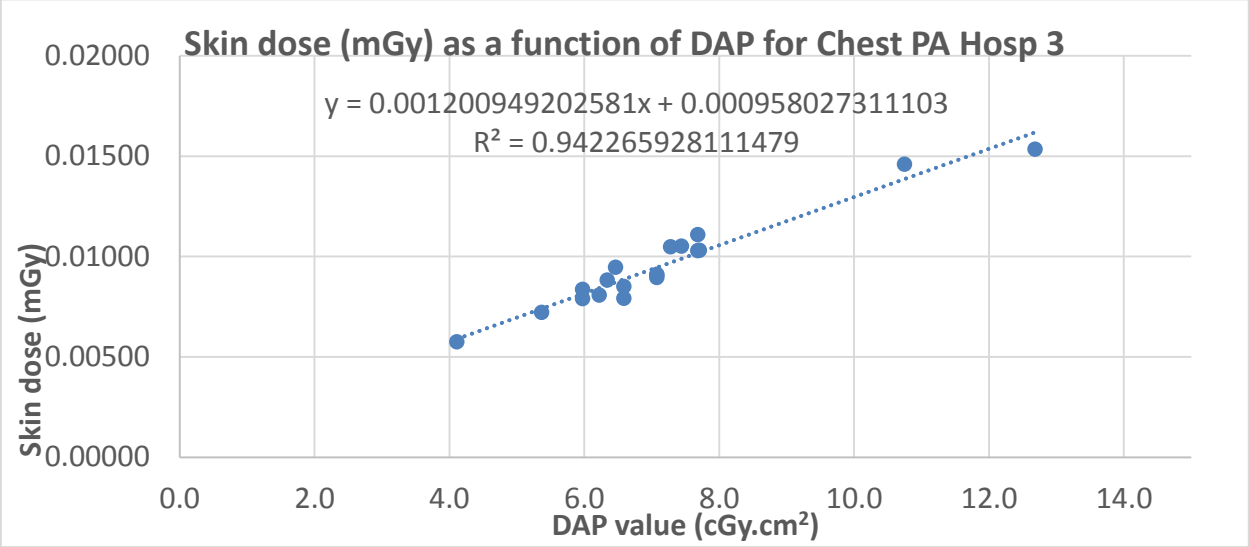


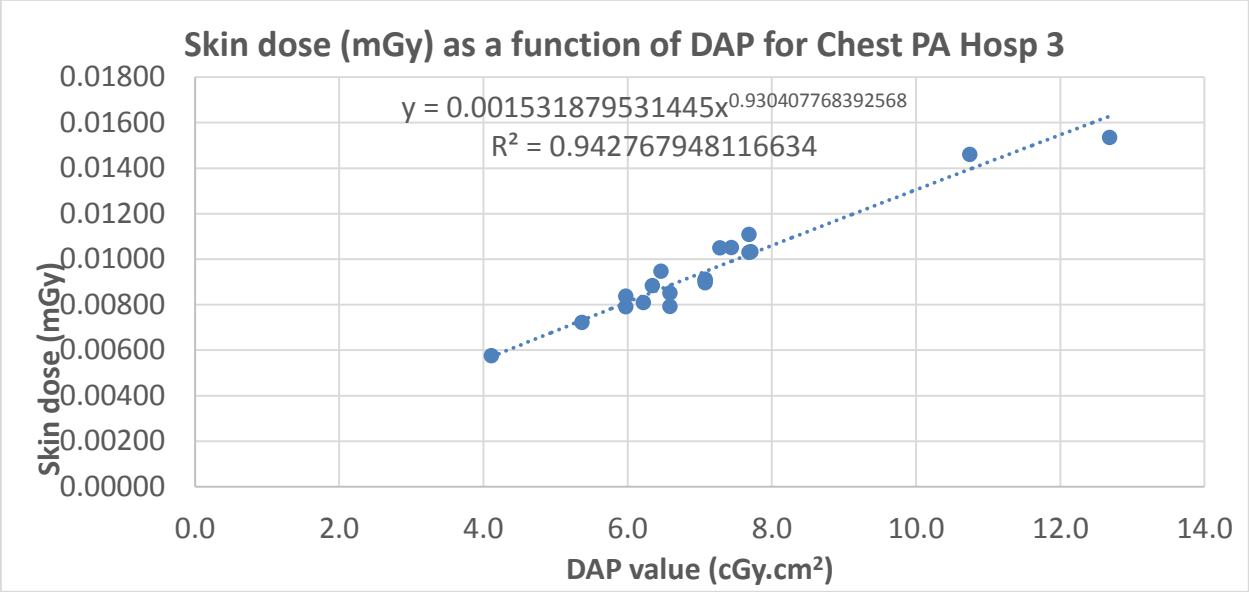
APPENDIX 42: LINEAR & EXPONENTIAL FIT LAT CHEST HOSPITAL 2



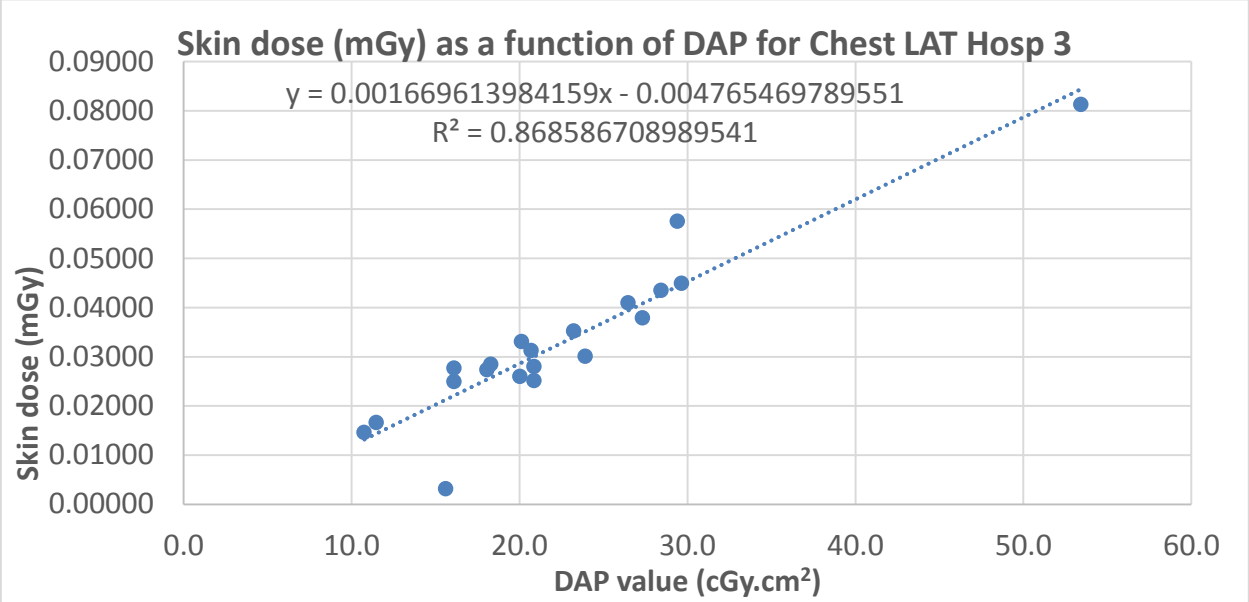


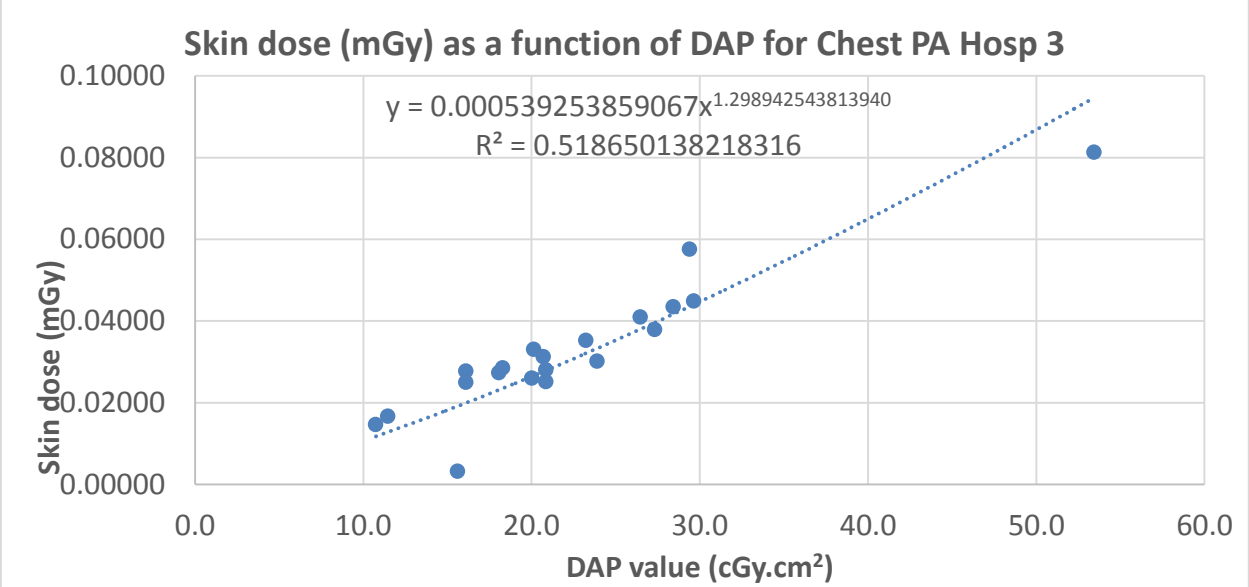
APPENDIX 43: LINEAR & EXPONENTIAL FIT PA CHEST HOSPITAL 3



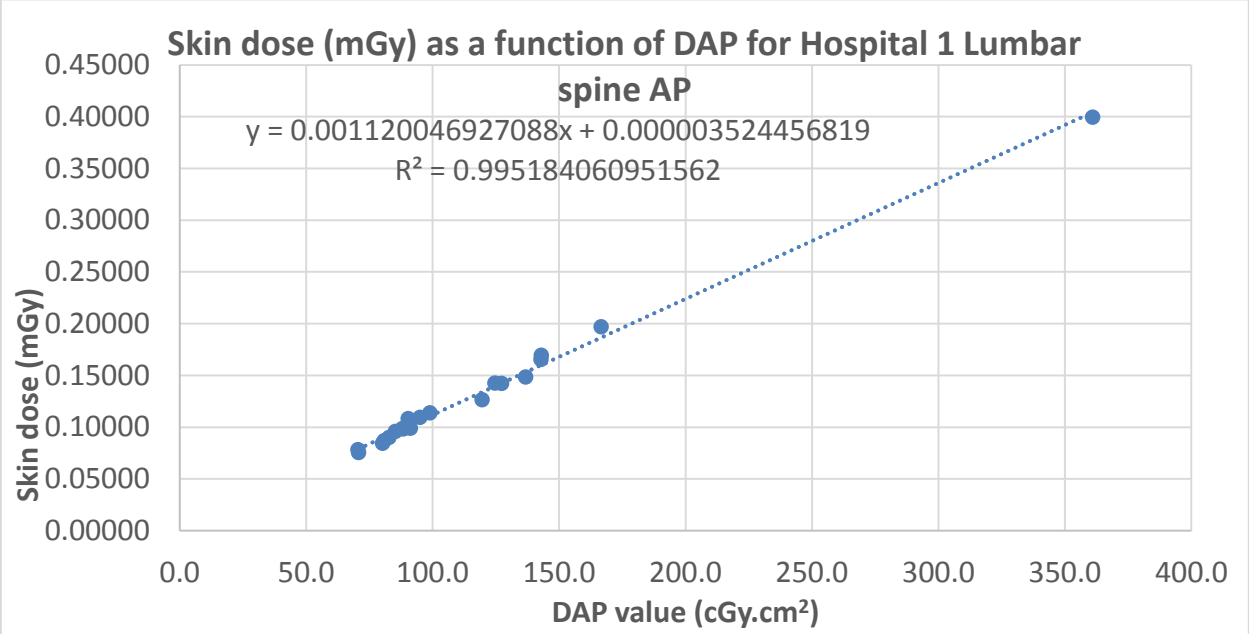


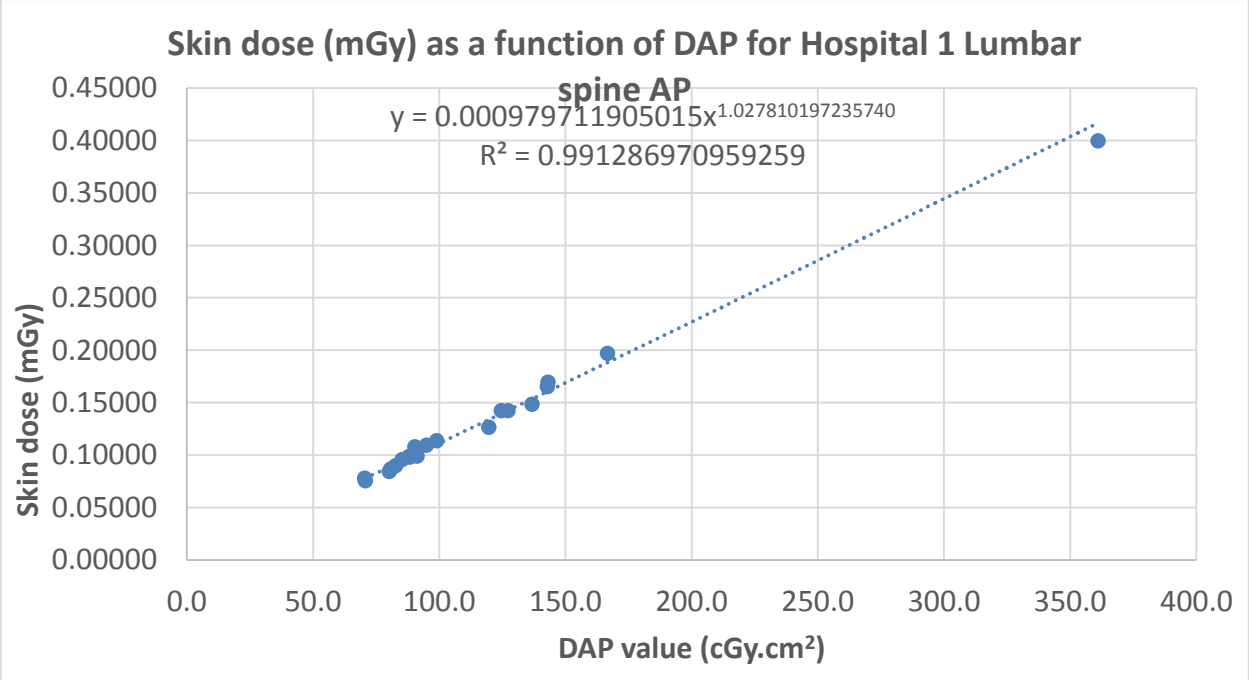
APPENDIX 44: LINEAR & EXPONENTIAL FIT LAT CHEST HOSPITAL 3



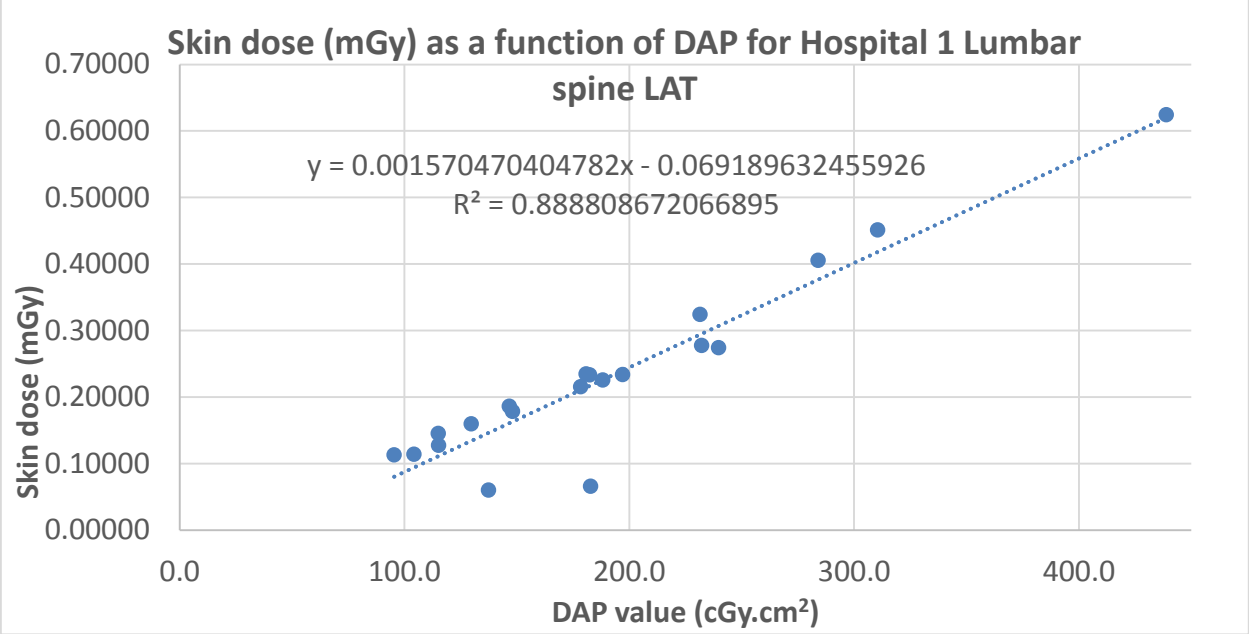


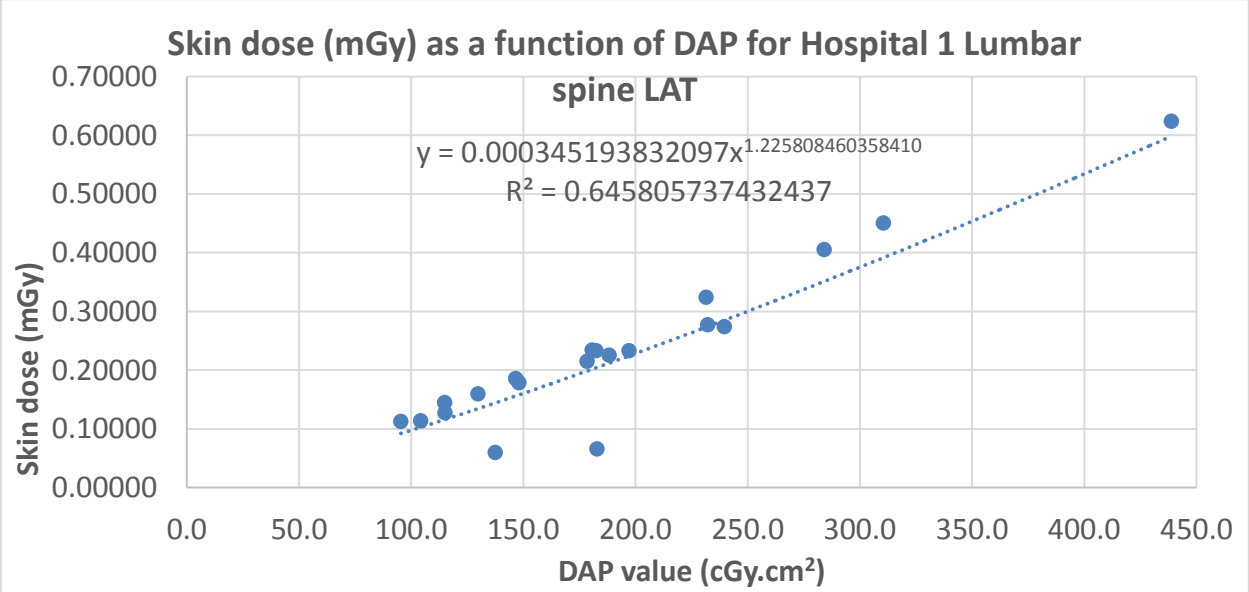
APPENDIX 45: LINEAR & EXPONENTIAL FIT AP LUMBAR SPINE HOSPITAL 1



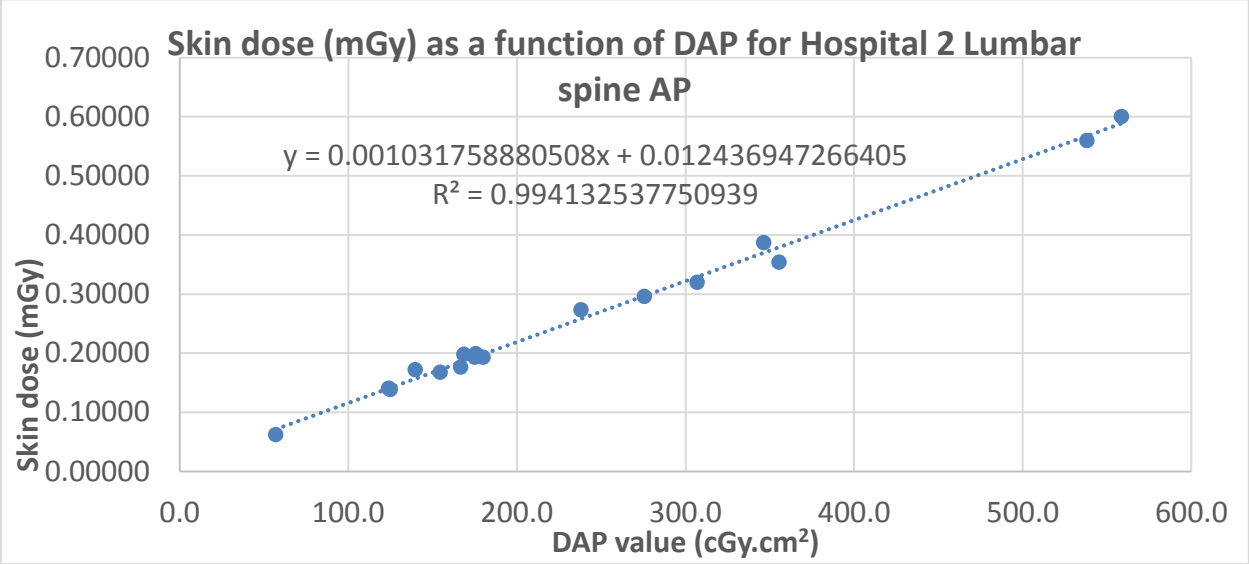


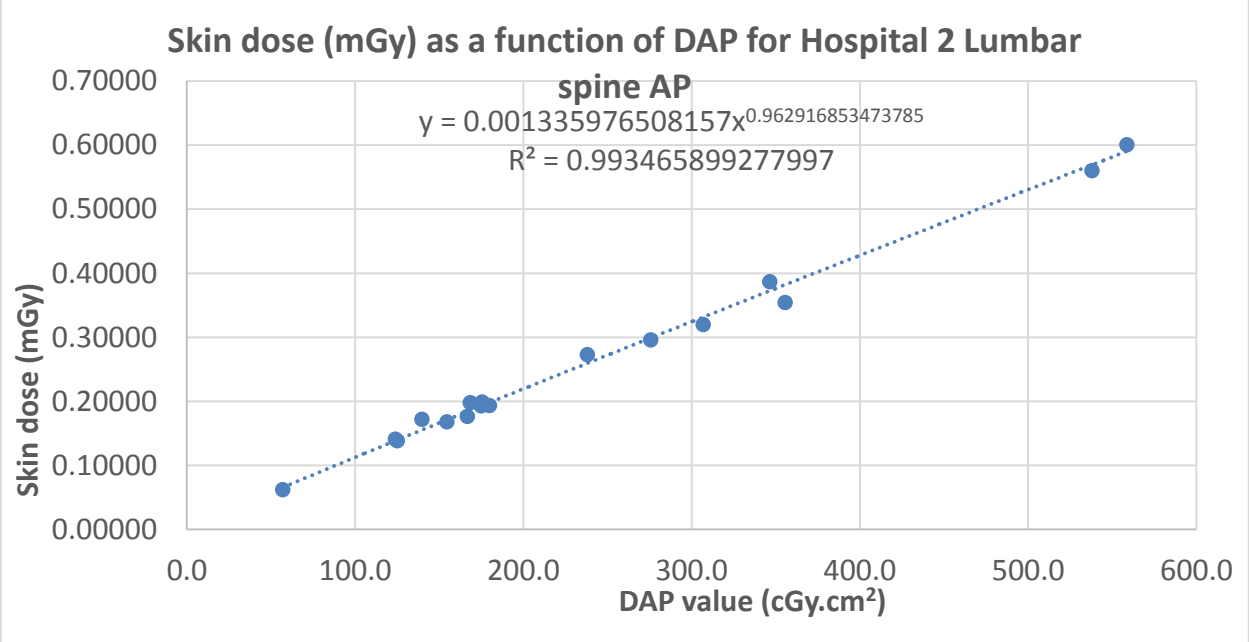
APPENDIX 46: LINEAR & EXPONENTIAL FIT LAT LUMBAR SPINE HOSPITAL 1



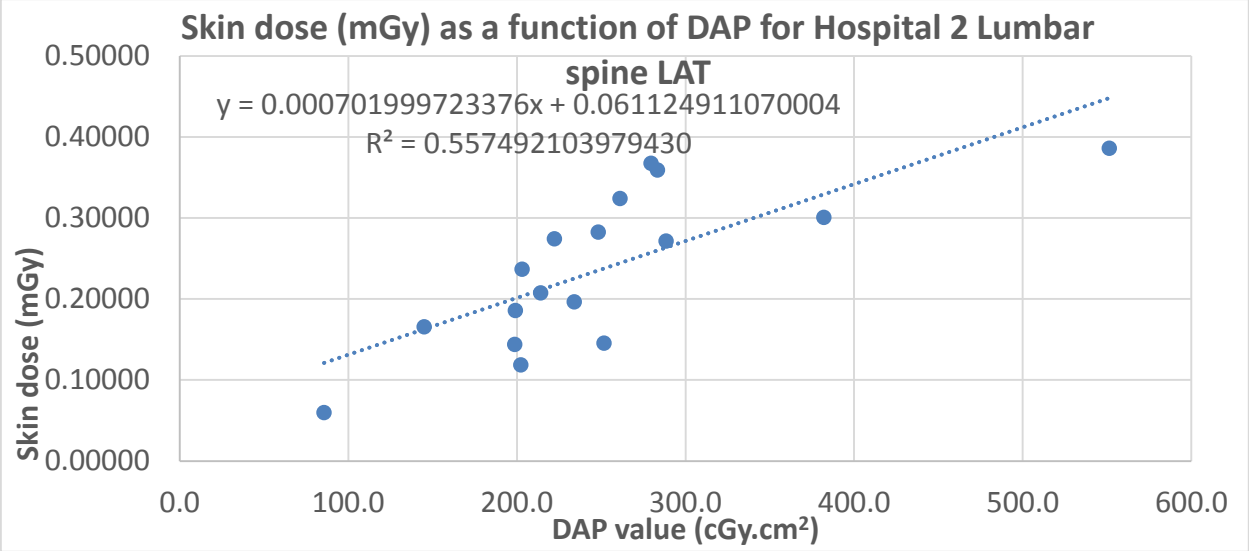


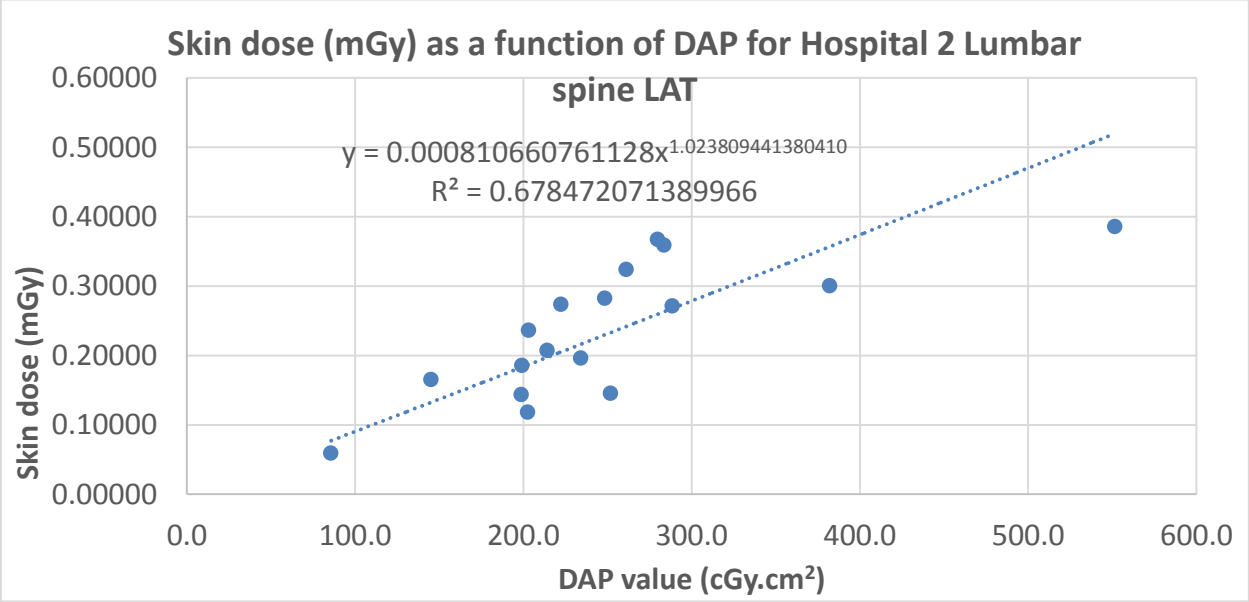
APPENDIX 47: LINEAR & EXPONENTIAL FIT AP LUMBAR SPINE HOSPITAL 2



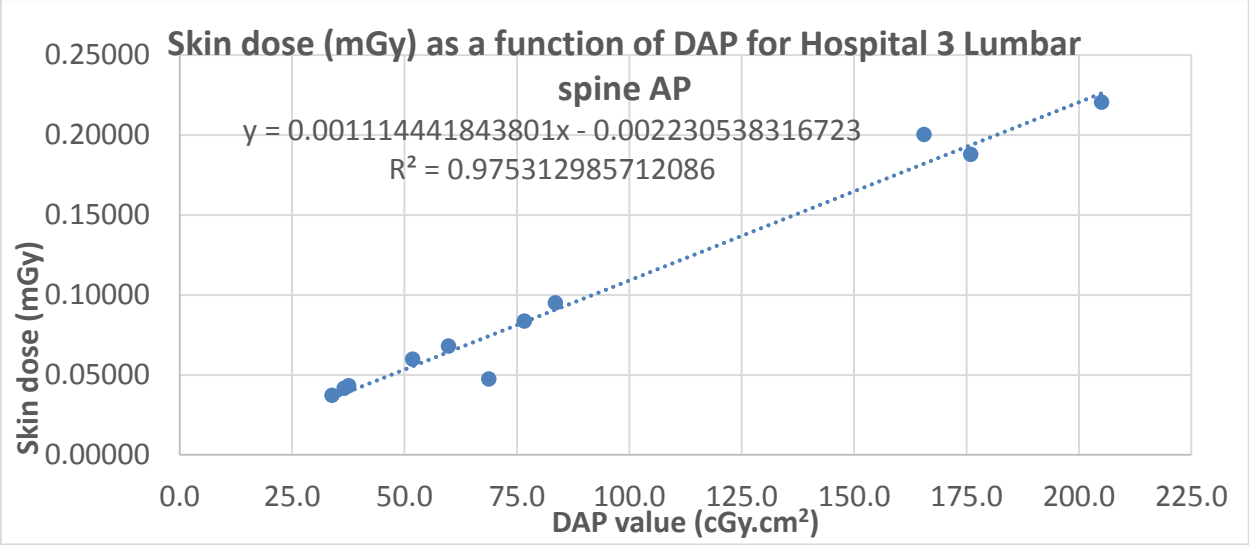


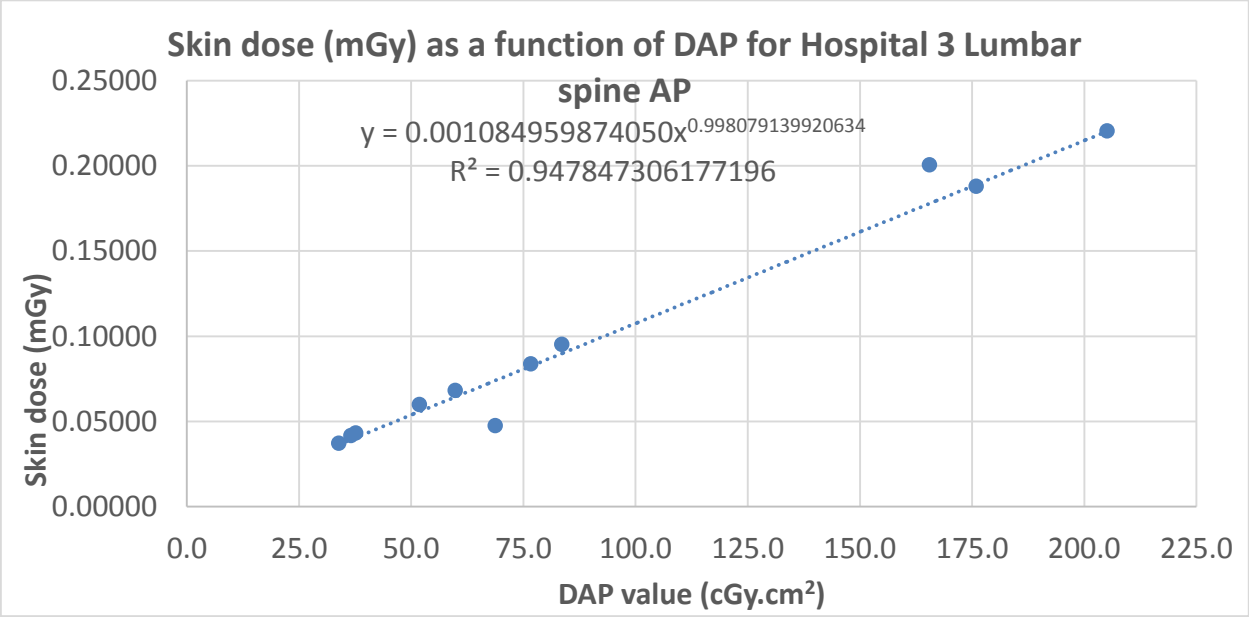
APPENDIX 48: LINEAR & EXPONENTIAL FIT LAT LUMBAR SPINE HOSPITAL 2



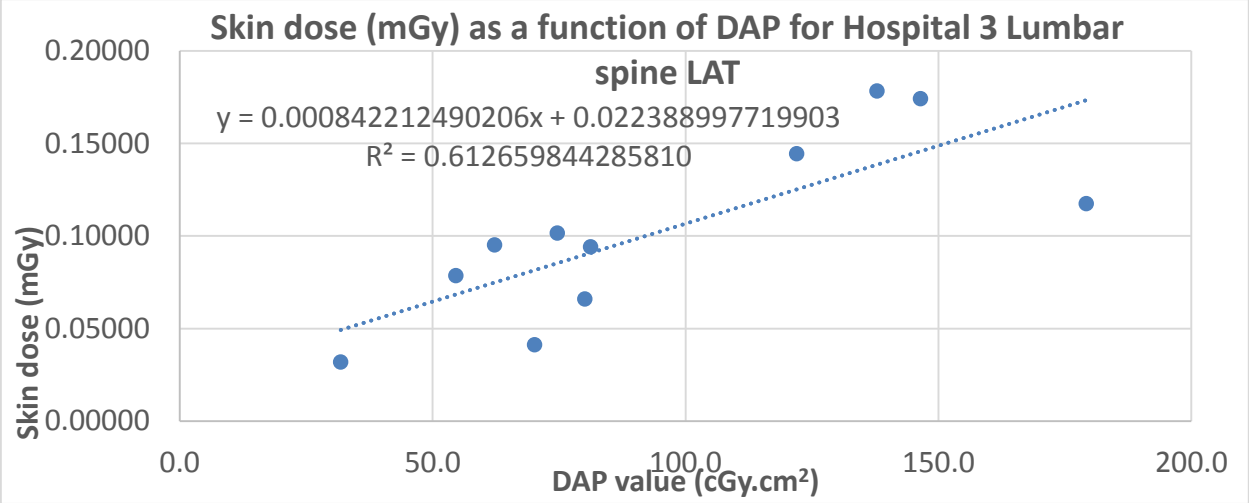


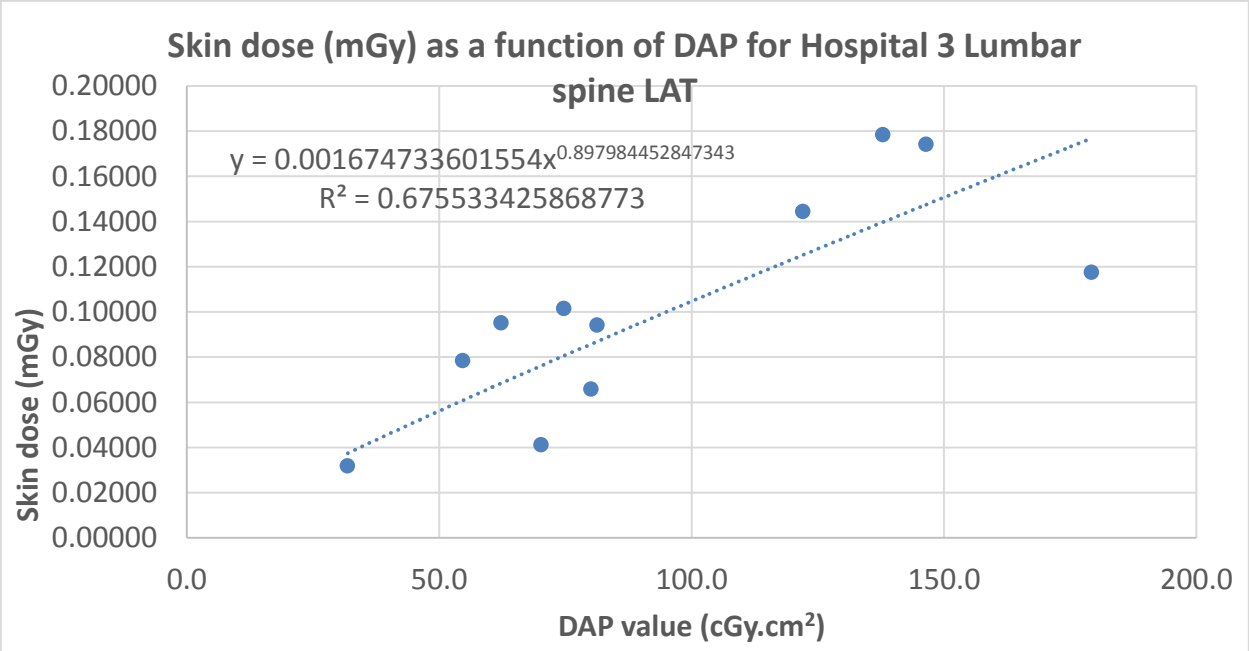
APPENDIX 49: LINEAR & EXPONENTIAL FIT AP LUMBAR SPINE HOSPITAL 3



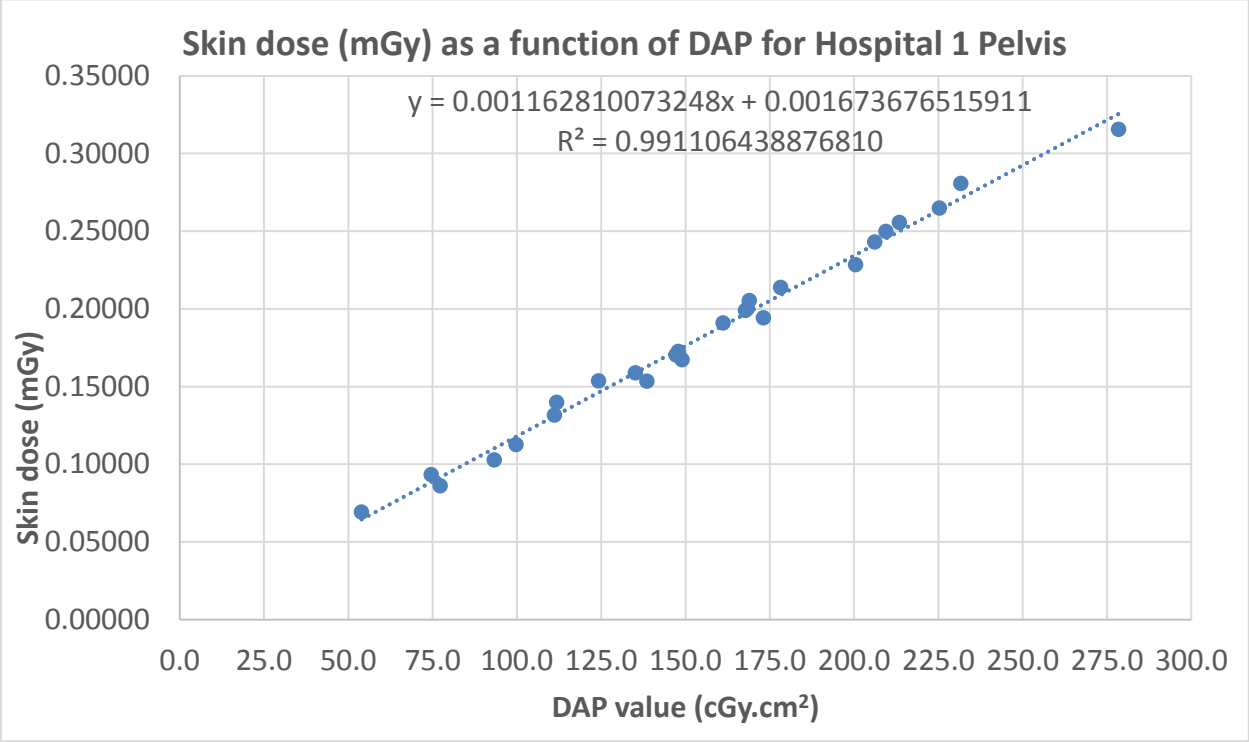


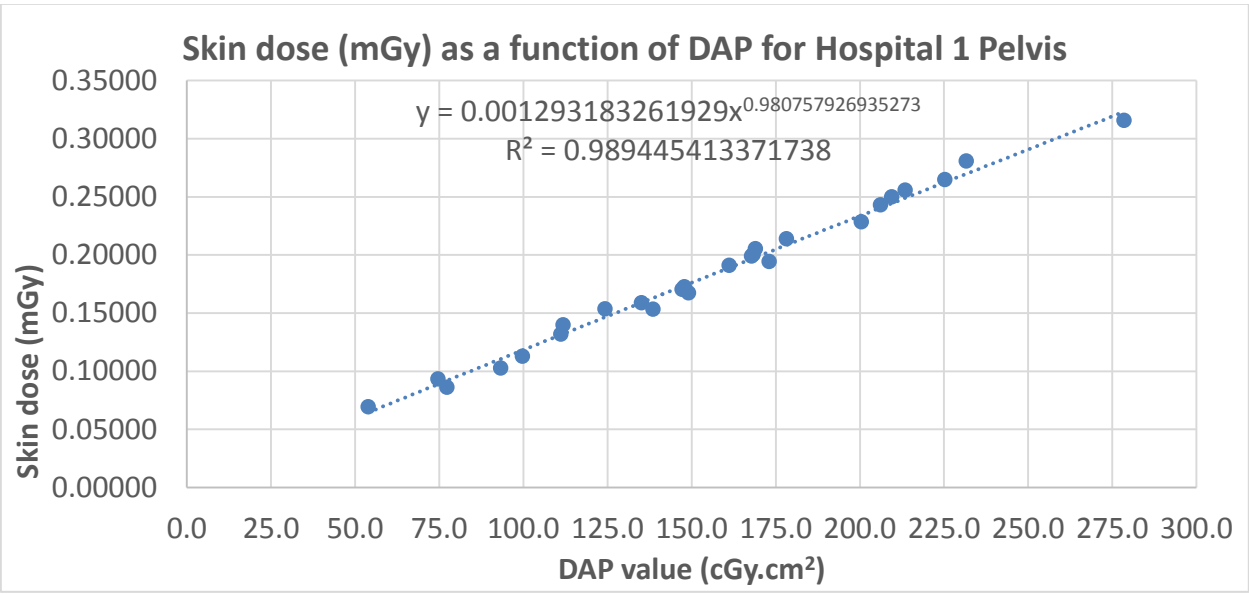
APPENDIX 50: LINEAR & EXPONENTIAL FIT LAT LUMBAR SPINE HOSPITAL 3



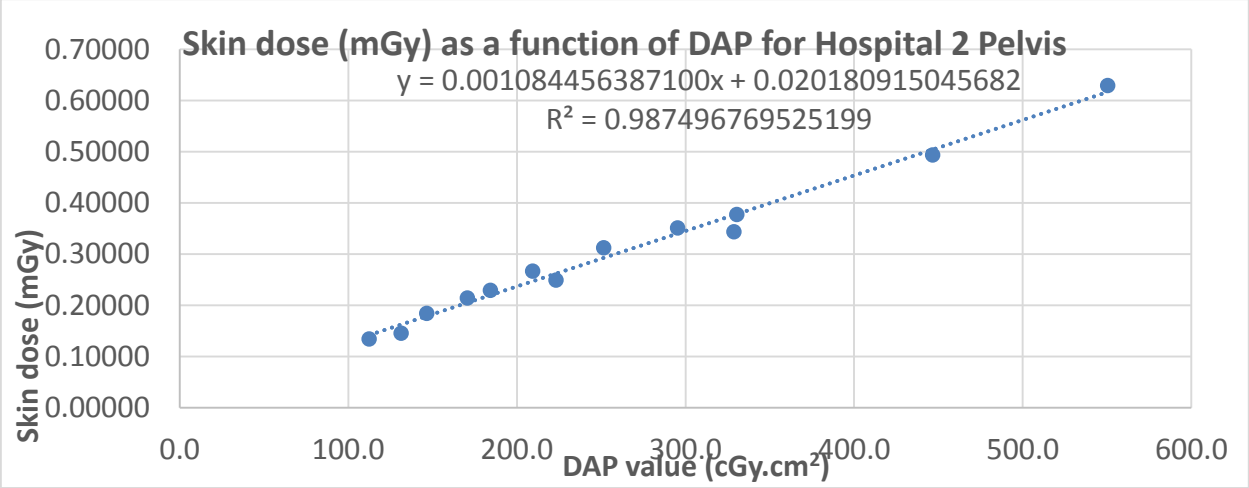


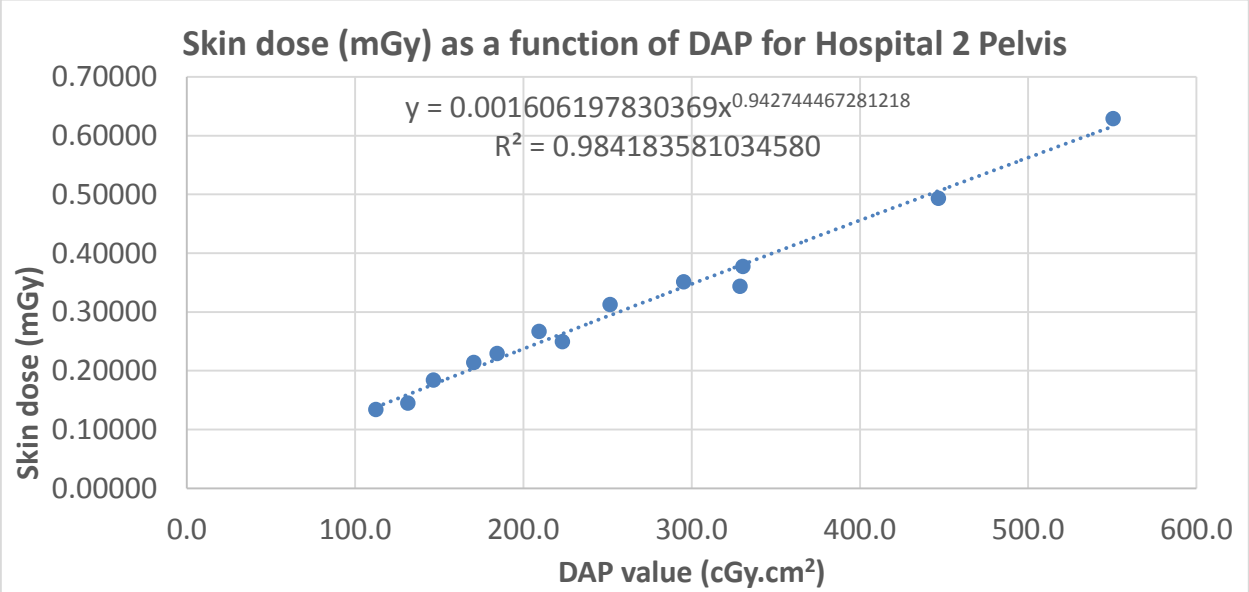
APPENDIX 51: LINEAR & EXPONENTIAL FIT AP PELVIS HOSPITAL 1



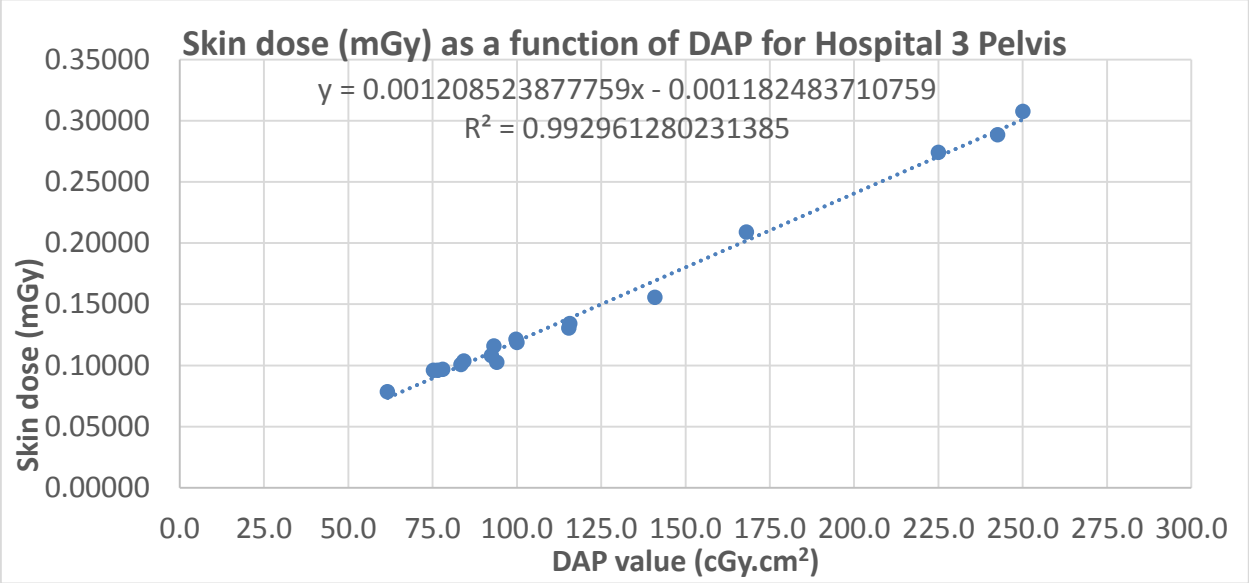


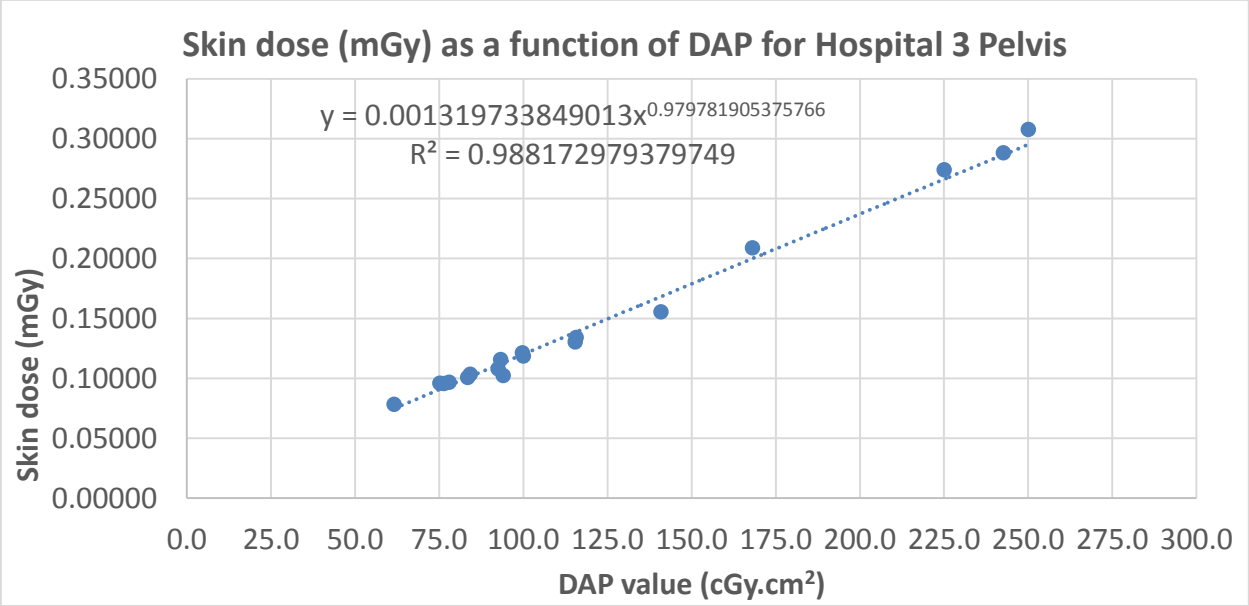
APPENDIX 52: LINEAR & EXPONENTIAL FIT AP PELVIS HOSPITAL 2



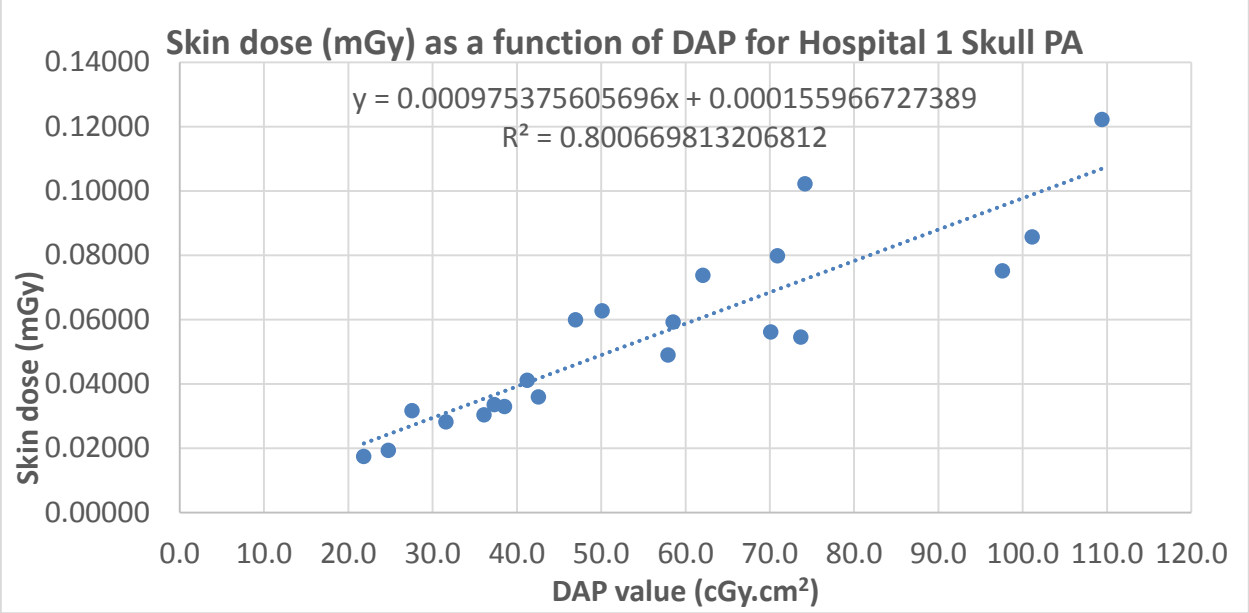


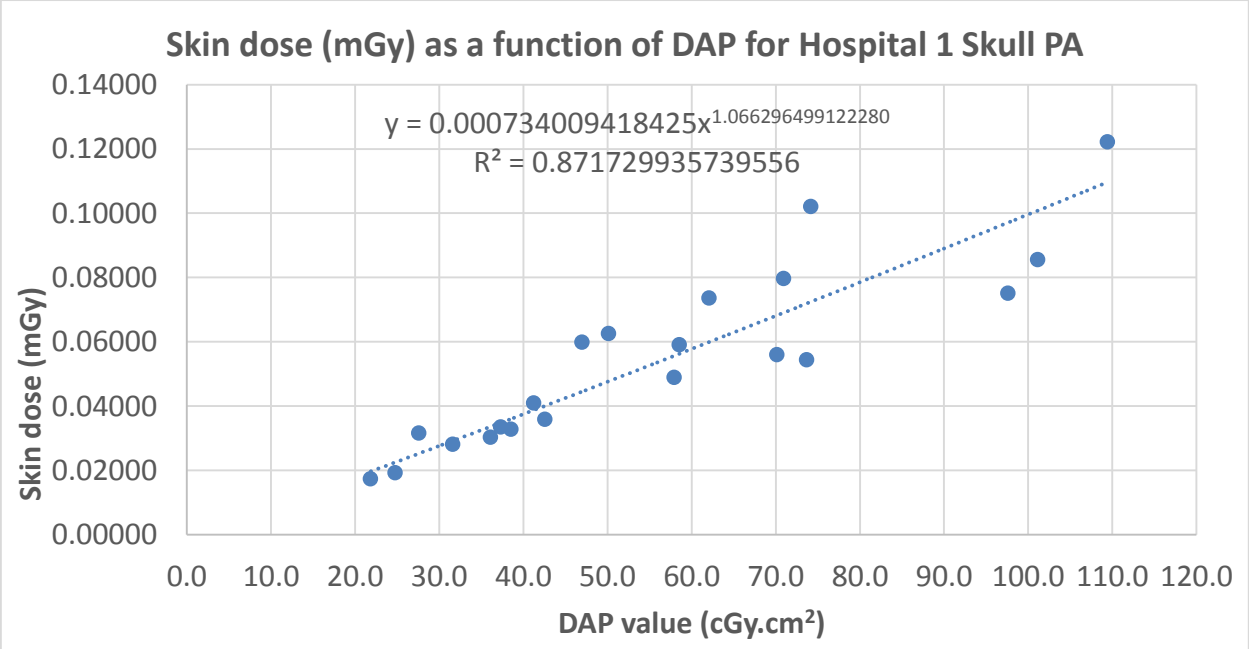
APPENDIX 53: LINEAR & EXPONENTIAL FIT AP PELVIS HOSPITAL 3



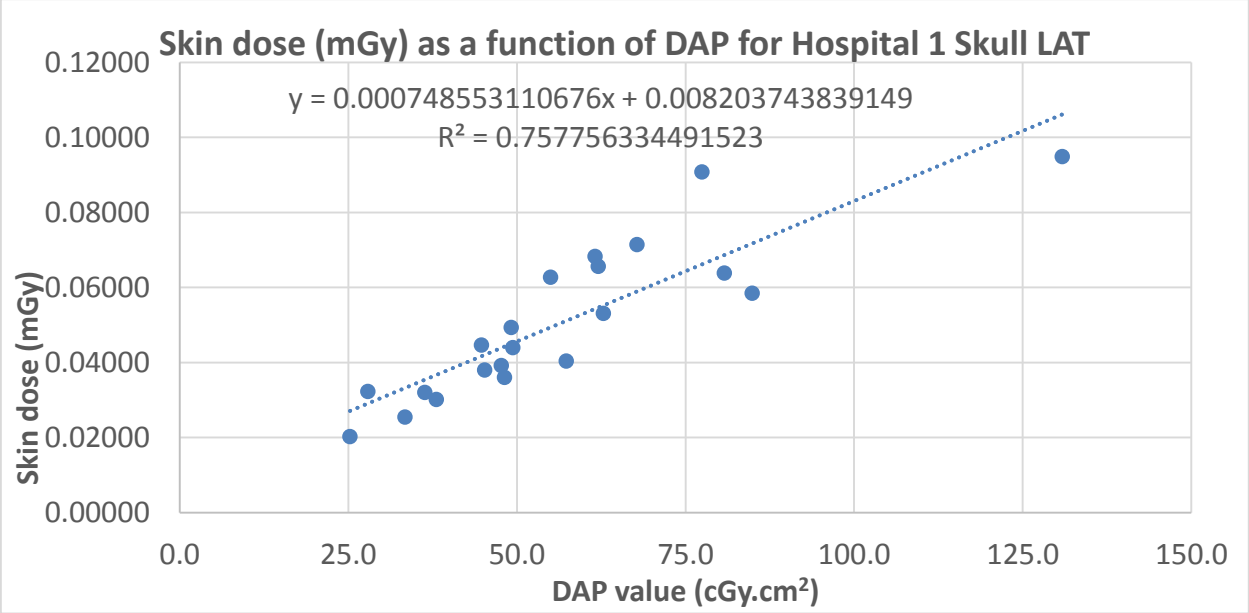


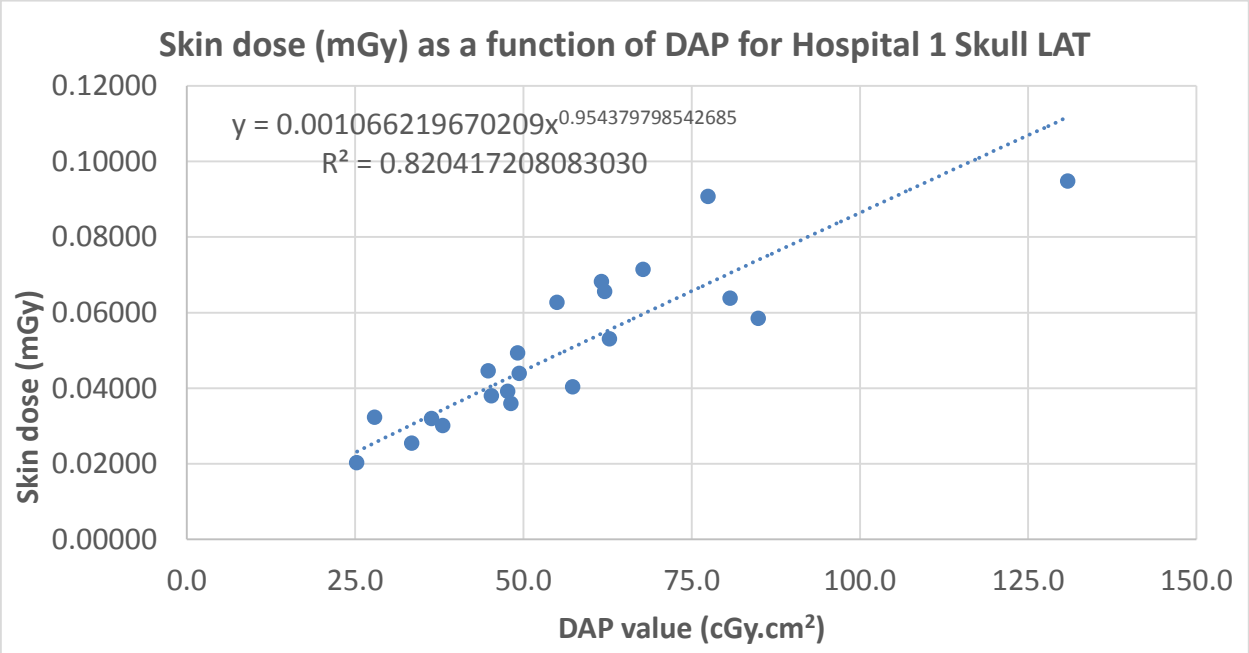
APPENDIX 54: LINEAR & EXPONENTIAL FIT PA SKULL HOSPITAL 1



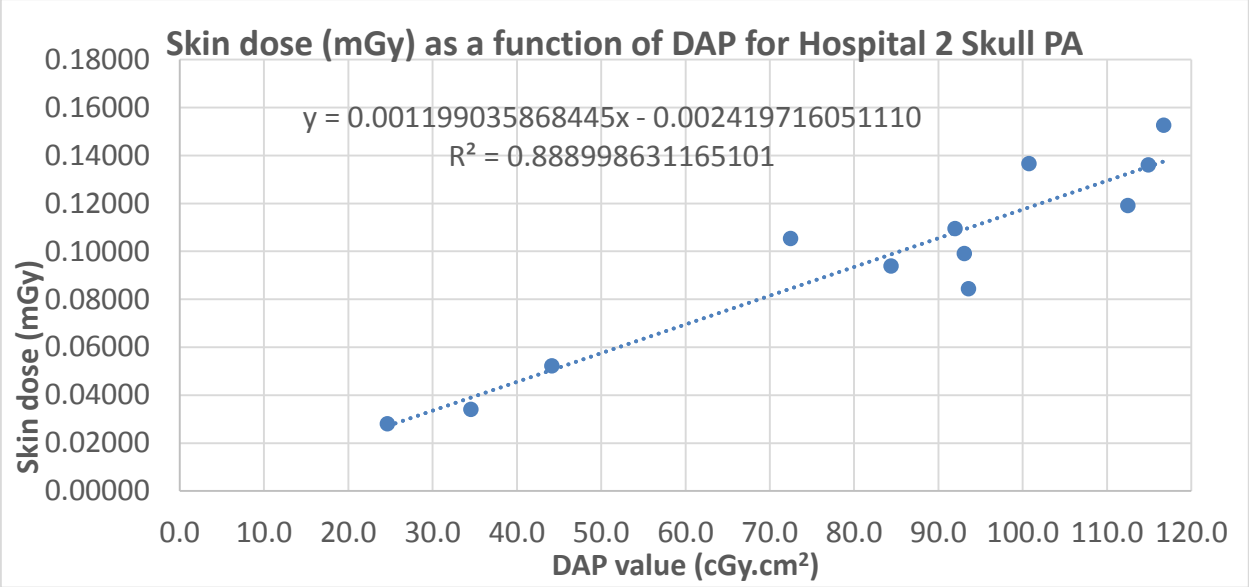


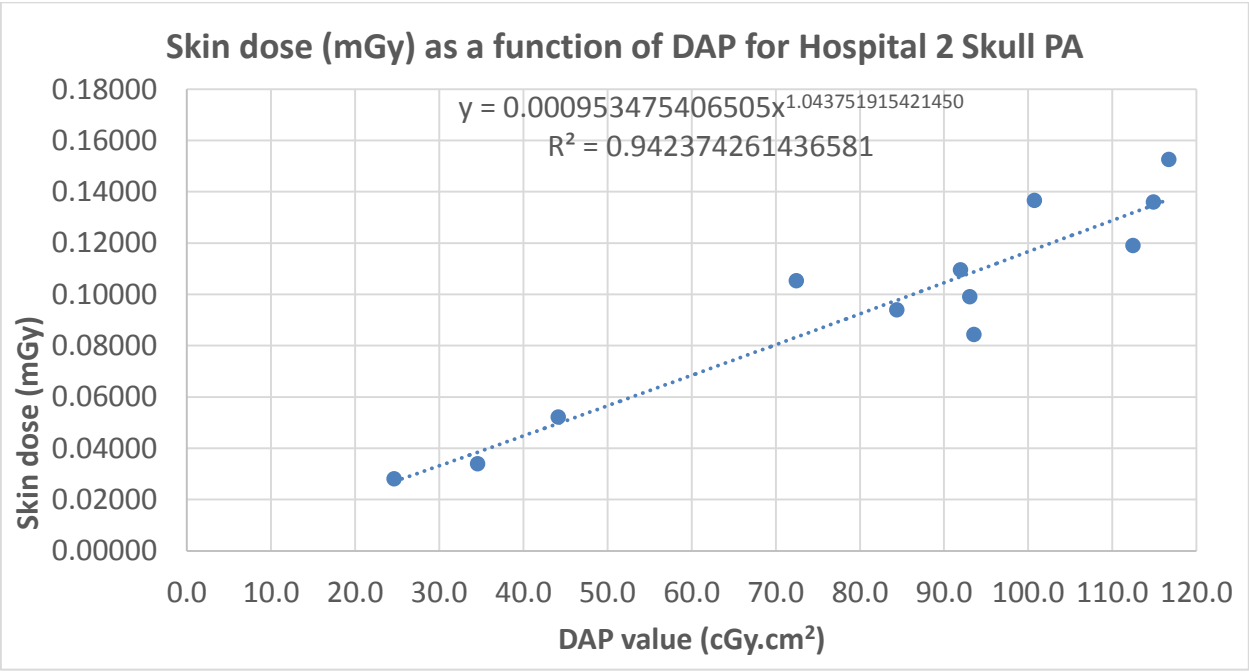
APPENDIX 55: LINEAR & EXPONENTIAL FIT LAT SKULL HOSPITAL 1



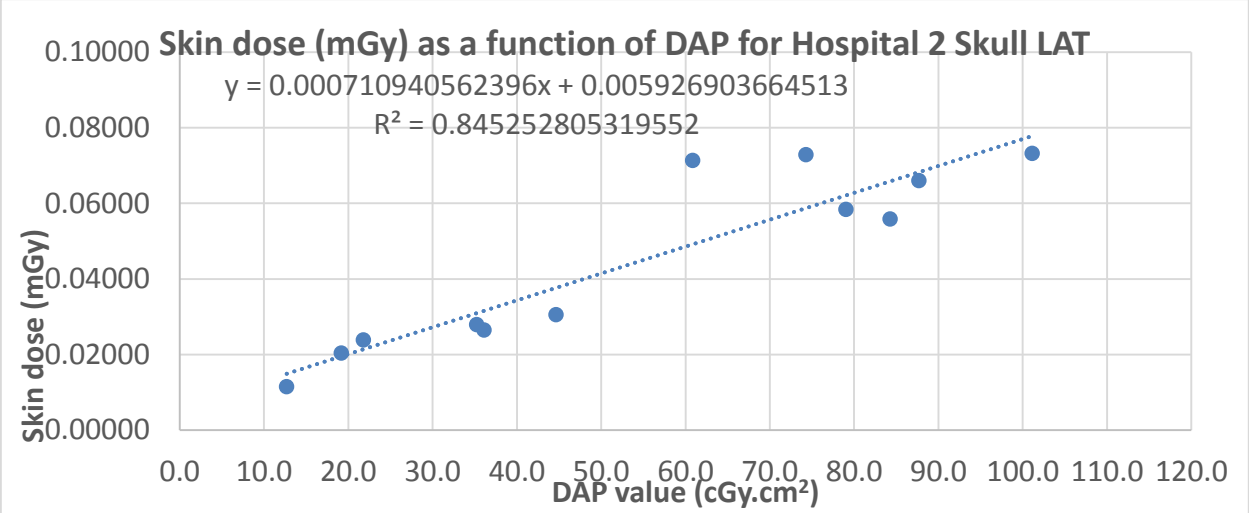


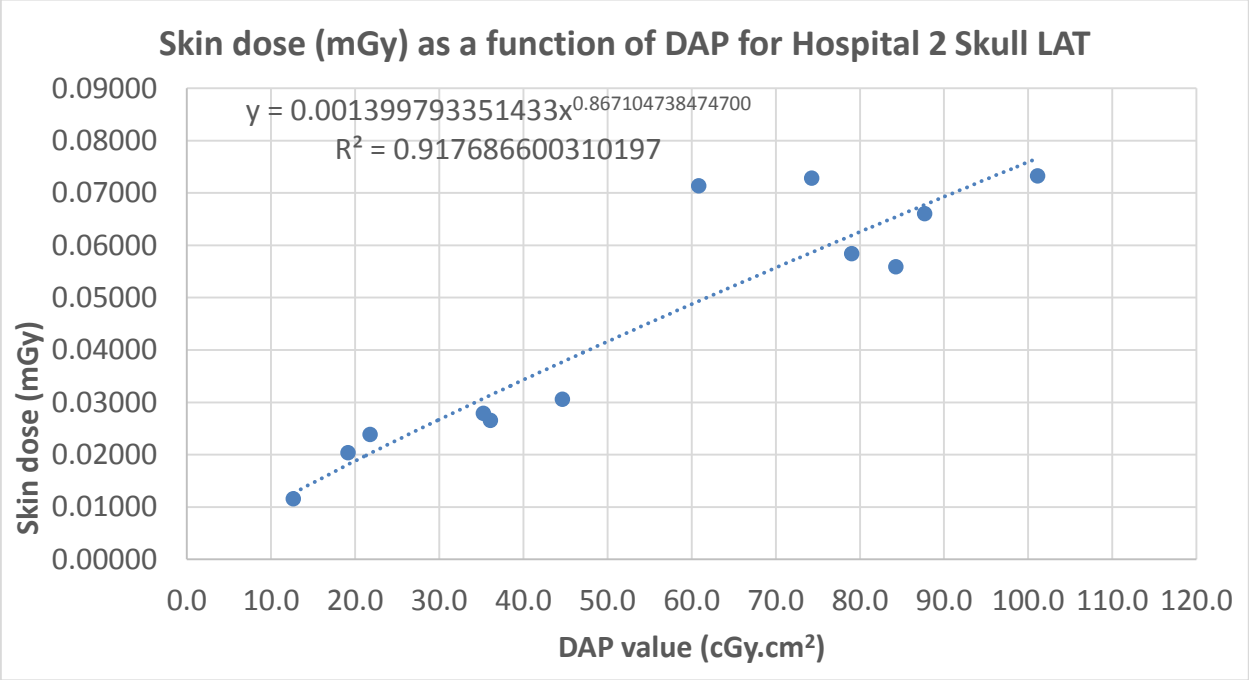
APPENDIX 56: LINEAR & EXPONENTIAL FIT PA SKULL HOSPITAL 2



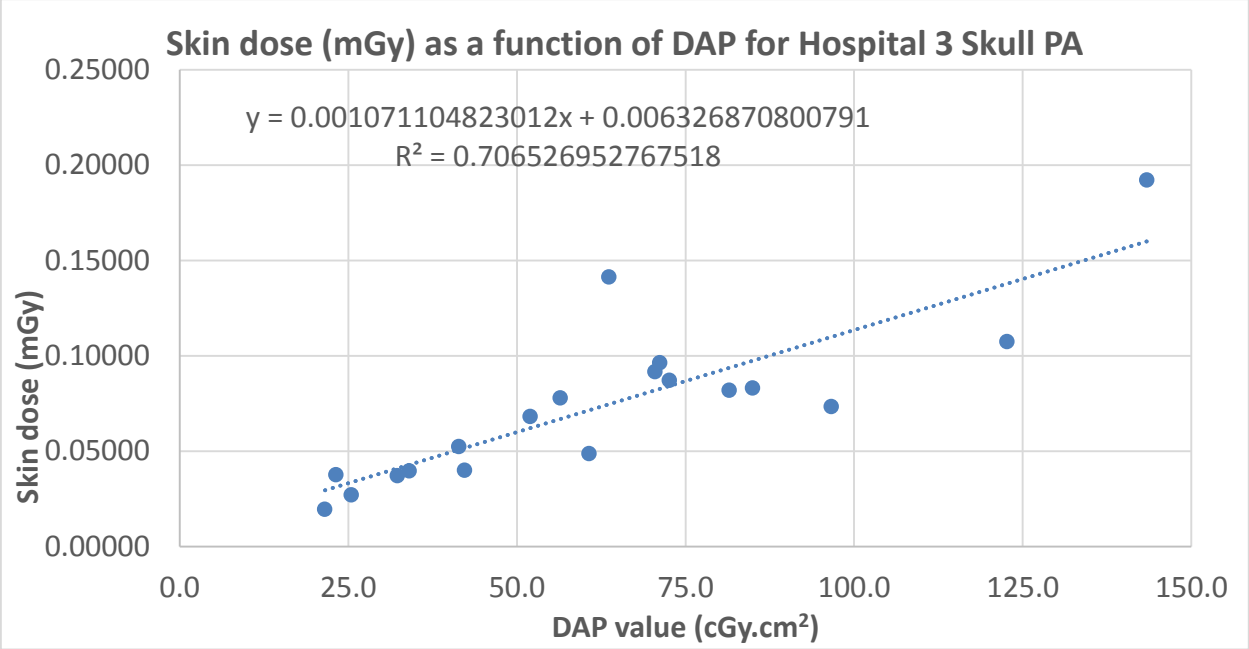


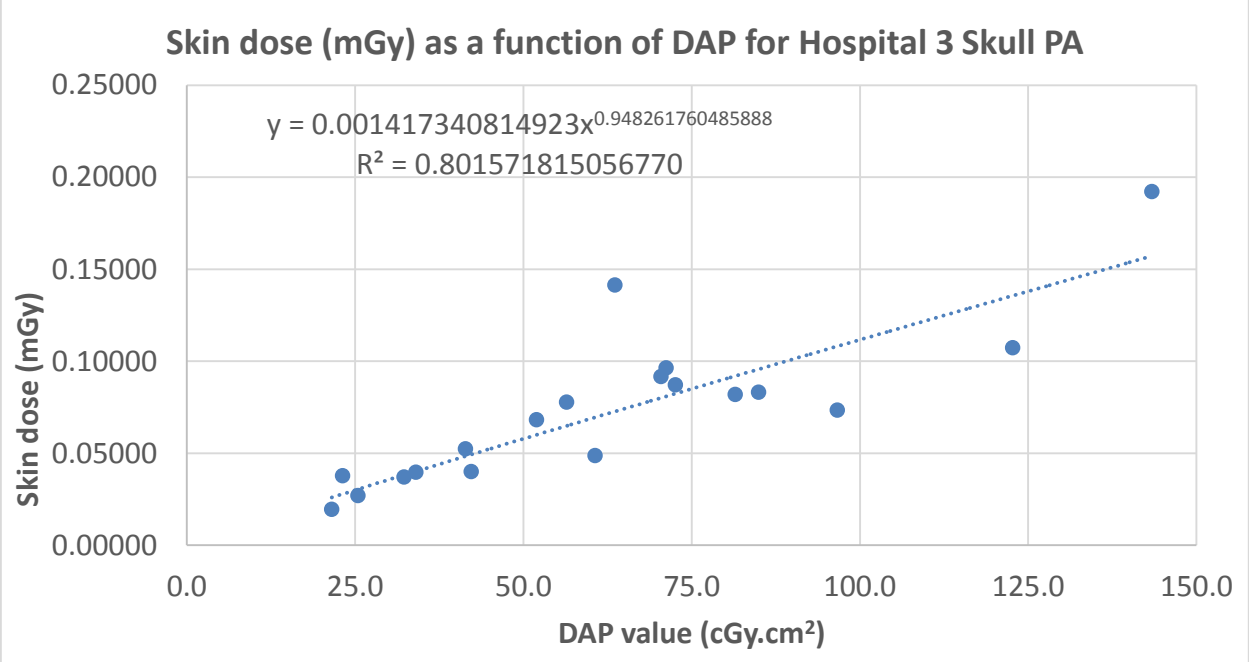
APPENDIX 57: LINEAR & EXPONENTIAL FIT LAT SKULL HOSPITAL 2



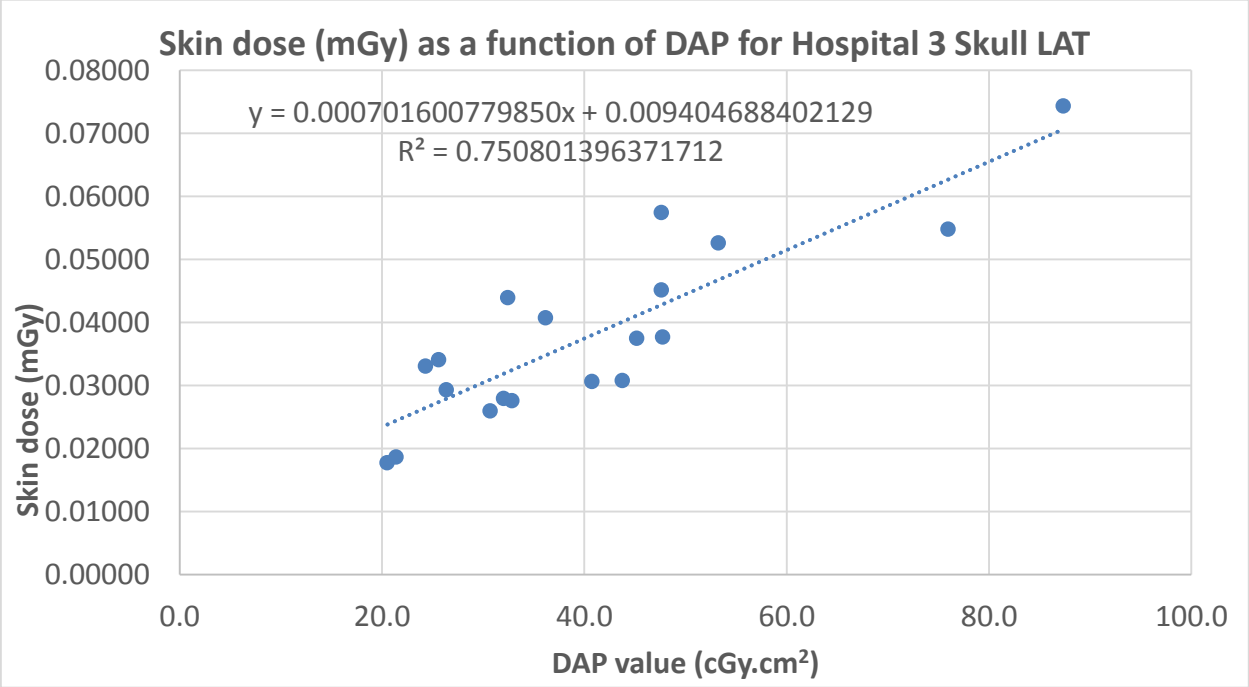


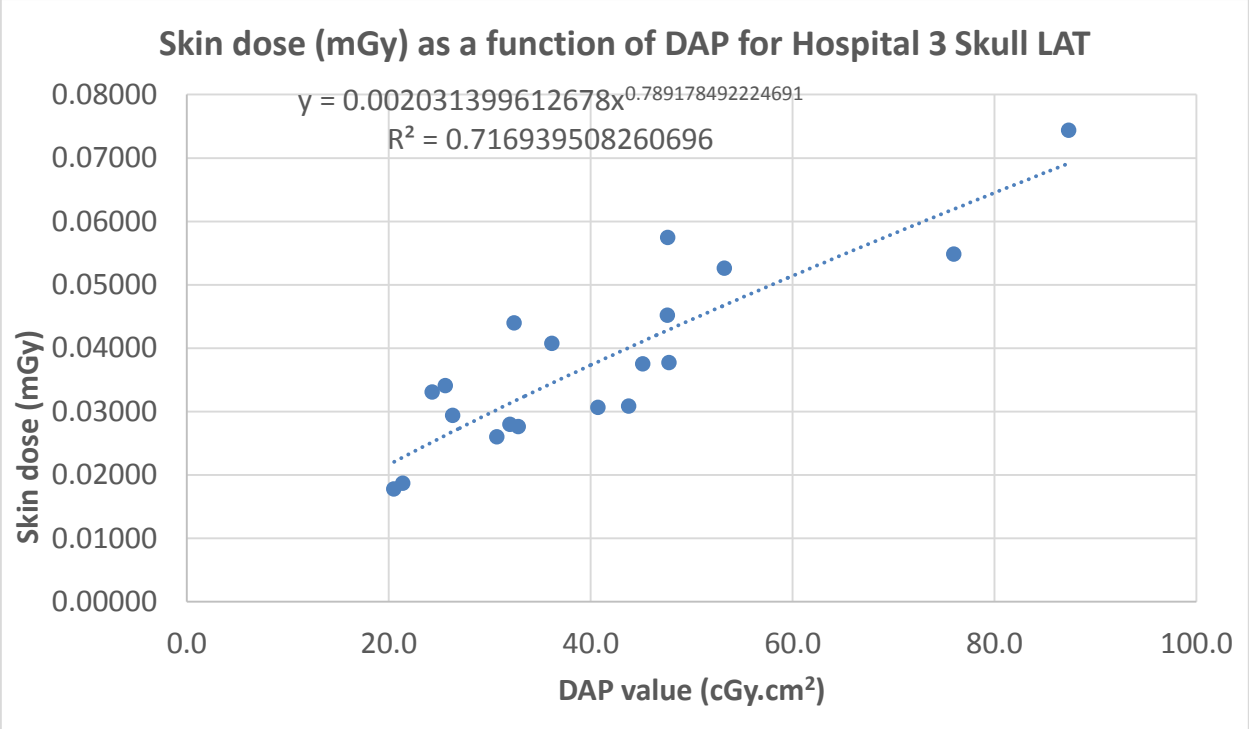
APPENDIX 58: LINEAR & EXPONENTIAL FIT PA SKULL HOSPITAL 3





APPENDIX 59: LINEAR & EXPONENTIAL FIT LAT SKULL HOSPITAL 3





APPENDIX 60: INPUT DATA PA CHEST ALL THREE HOSPITALS COMBINED

All three hospitals Chest PA

Patient	DAP value (cGy.cm^2) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
180A	4.1	0.00575	0.00921	0.04636	0.00571	0.00550	-0.66	-4.21	11.27
100A	4.1	0.00590	0.01019	0.06466	0.00574	0.00554	-2.81	-6.25	11.32
98A	4.8	0.00642	0.01127	0.06710	0.00653	0.00636	1.81	-0.86	12.69
171A	5.4	0.00721	0.01488	0.06100	0.00728	0.00714	1.00	-1.00	14.08
95A	5.7	0.00750	0.01342	0.04758	0.00774	0.00761	3.17	1.45	14.98
166A	6.0	0.00789	0.01495	0.05490	0.00805	0.00793	1.94	0.44	15.61
168A	6.0	0.00836	0.01424	0.05368	0.00805	0.00793	-3.71	-5.14	15.61
172A	6.2	0.00808	0.01577	0.07198	0.00835	0.00824	3.42	2.06	16.25
169A	6.3	0.00882	0.01368	0.05856	0.00851	0.00840	-3.58	-4.76	16.58
174A	6.5	0.00946	0.01403	0.07442	0.00866	0.00856	-8.43	-9.49	16.91
173A	6.6	0.00792	0.01693	0.05978	0.00881	0.00872	11.28	10.07	17.24
175A	6.6	0.00850	0.01665	0.07564	0.00881	0.00872	3.62	2.49	17.24
105A	7.0	0.00893	0.01692	0.06222	0.00936	0.00928	4.82	3.93	18.49
93A	7.1	0.00861	0.01649	0.06466	0.00942	0.00934	9.39	8.49	18.64
178A	7.1	0.00895	0.02070	0.07930	0.00942	0.00934	5.22	4.35	18.64
179A	7.1	0.00910	0.01886	0.08052	0.00942	0.00934	3.53	2.67	18.64
181A	7.1	0.00905	0.01718	0.08174	0.00942	0.00934	4.09	3.22	18.64
176A	7.3	0.01048	0.01565	0.06832	0.00968	0.00961	-7.61	-8.29	19.25
167A	7.4	0.01050	0.01726	0.06954	0.00988	0.00981	-5.93	-6.56	19.73
170A	7.7	0.01028	0.02013	0.08784	0.01019	0.01013	-0.95	-1.52	20.48
180AB	7.7	0.01108	0.02023	0.08906	0.01019	0.01013	-8.04	-8.57	20.48
165A	7.7	0.01031	0.02036	0.08906	0.01022	0.01016	-0.89	-1.45	20.55
97A	8.3	0.01015	0.01925	0.07564	0.01095	0.01091	7.89	7.50	22.43
88A	8.4	0.00985	0.01987	0.07930	0.01110	0.01107	12.78	12.41	22.84
86A	8.5	0.01176	0.01956	0.07564	0.01126	0.01122	-4.29	-4.56	23.25
87A	8.8	0.01133	0.01863	0.07564	0.01156	0.01154	2.02	1.79	24.08
102A	8.8	0.01252	0.02083	0.07808	0.01156	0.01154	-7.63	-7.83	24.08
84A	9.0	0.01261	0.02045	0.07808	0.01187	0.01185	-5.92	-6.07	24.92
89A	9.3	0.01092	0.02264	0.10126	0.01217	0.01216	11.49	11.37	25.79
106A	9.4	0.01232	0.02100	0.08906	0.01233	0.01232	0.04	-0.04	26.23
103A	9.5	0.01087	0.02222	0.08418	0.01248	0.01247	14.80	14.74	26.67
101A	9.8	0.01153	0.02206	0.08296	0.01279	0.01278	10.90	10.89	27.57
91A	10.4	0.01399	0.02303	0.09028	0.01355	0.01356	-3.17	-3.08	29.90
85A	10.6	0.01408	0.02288	0.09394	0.01386	0.01387	-1.59	-1.46	30.85
215A	10.7	0.01459	0.02195	0.08174	0.01402	0.01404	-3.89	-3.75	31.39
104A	12.0	0.01547	0.02517	0.10736	0.01554	0.01558	0.43	0.72	36.39
177A	12.7	0.01534	0.03227	0.14762	0.01645	0.01651	7.29	7.66	39.58
90A	12.9	0.01688	0.02933	0.12932	0.01676	0.01682	-0.74	-0.39	40.67
99A	12.9	0.01736	0.02688	0.11346	0.01676	0.01682	-3.46	-3.12	40.67
94A	20.6	0.02557	0.03859	0.18544	0.02639	0.02650	3.20	3.64	42.67
31A	23.7	0.03117	0.04473	0.23546	0.03021	0.03032	-3.08	-2.74	29.71
29A	24.4	0.03314	0.05119	0.22936	0.03113	0.03123	-6.06	-5.74	26.95
39A	25.3	0.03194	0.05007	0.21960	0.03220	0.03230	0.81	1.12	23.91
41A	25.5	0.03267	0.05222	0.23668	0.03250	0.03260	-0.51	-0.22	23.09
46A	26.2	0.03567	0.05718	0.24766	0.03342	0.03351	-6.31	-6.05	20.71
45A	26.6	0.03384	0.05358	0.24278	0.03388	0.03397	0.11	0.37	19.58
27A	26.7	0.03299	0.06270	0.24766	0.03403	0.03412	3.16	3.43	19.22
28A	29.8	0.03555	0.06772	0.27084	0.03785	0.03791	6.48	6.64	11.50
42A	30.9	0.04107	0.07370	0.29524	0.03923	0.03927	-4.47	-4.36	9.37
44A	31.8	0.04086	0.06539	0.30012	0.04045	0.04048	-0.99	-0.91	7.75
33A	32.0	0.04319	0.06911	0.29646	0.04060	0.04064	-5.98	-5.91	7.56
34A	32.0	0.04293	0.06832	0.29646	0.04060	0.04064	-5.42	-5.35	7.56
38A	33.4	0.03967	0.07009	0.28670	0.04244	0.04245	6.97	6.99	5.58
30A	36.8	0.04452	0.08255	0.34160	0.04672	0.04667	4.94	4.84	2.55
35A	37.7	0.04982	0.06981	0.35502	0.04779	0.04773	-4.09	-4.21	2.06
43A	39.9	0.05263	0.07322	0.36966	0.05054	0.05044	-3.97	-4.17	1.15
36A	40.6	0.04951	0.09032	0.42822	0.05146	0.05134	3.94	3.70	0.94
37A	42.7	0.05186	0.08619	0.36722	0.05406	0.05389	4.23	3.91	0.52
32A	52.7	0.07120	0.11396	0.48922	0.06659	0.06616	-6.47	-7.07	0.02
40A	67.0	0.08052	0.14551	0.63074	0.08447	0.08358	4.91	3.80	0.00

Mean:	17.0	0.0219	0.0371
DRL:	26.3	0.0333	0.0545
Median:	9.5	0.0124	0.0220

n:	60
Population standard deviation	13.8
Chauvenet criterion value:	0.5

APPENDIX 61: INPUT DATA LAT CHEST ALL THREE HOSPITALS COMBINED

All three hospitals Chest LAT									
Patient	DAP value ($cGy.cm^2$) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
100B	8.8	0.01190	0.02148	0.15006	0.01248	0.01096	4.88	-7.90	1.87
215A	10.7	0.01459	0.02195	0.08174	0.01527	0.01370	4.67	-6.14	2.70
98B	11.0	0.01840	0.02441	0.17080	0.01560	0.01402	-15.20	-23.79	2.81
178B	11.5	0.01663	0.03303	0.14518	0.01629	0.01471	-2.03	-11.56	3.07
167B	15.6	0.00314	0.00316	0.16836	0.02216	0.02064	606.76	558.42	6.11
165B	16.1	0.02496	0.03974	0.20008	0.02285	0.02135	-8.46	-14.45	6.59
174B	16.1	0.02769	0.03678	0.20618	0.02285	0.02135	-17.49	-22.89	6.59
175B	18.1	0.02733	0.04319	0.22326	0.02561	0.02421	-6.28	-11.40	8.81
171B	18.3	0.02847	0.04780	0.24278	0.02596	0.02457	-8.84	-13.70	9.13
215B	20.0	0.02600	0.04013	0.19154	0.02839	0.02712	9.20	4.32	11.58
180B	20.1	0.03305	0.04457	0.24888	0.02855	0.02729	-13.63	-17.44	11.76
182B	20.7	0.03122	0.04712	0.25254	0.02936	0.02814	-5.96	-9.86	12.68
166B	20.9	0.02799	0.04762	0.21716	0.02958	0.02838	5.70	1.40	12.95
172B	20.9	0.02510	0.04139	0.20374	0.02958	0.02838	17.88	13.08	12.95
39B	22.6	0.03101	0.04845	0.27938	0.03200	0.03064	3.18	-1.20	16.07
176B	23.2	0.03518	0.04868	0.23668	0.03293	0.03193	-6.41	-9.24	17.41
173B	23.9	0.03010	0.06055	0.25742	0.03390	0.03297	12.63	9.53	18.87
170B	26.5	0.04091	0.06499	0.33916	0.03752	0.03687	-8.27	-9.88	25.04
168B	27.3	0.03787	0.06127	0.27938	0.03873	0.03817	2.28	0.81	27.34
86B	27.5	0.04447	0.04792	0.26596	0.03890	0.03836	-12.52	-13.73	27.68
97B	27.5	0.03470	0.05995	0.27694	0.03890	0.03836	12.12	10.56	27.68
29B	27.7	0.04757	0.04946	0.27816	0.03925	0.03874	-17.49	-18.57	28.36
179B	28.4	0.04347	0.07337	0.36966	0.04028	0.03986	-7.33	-8.29	30.46
180BC	29.4	0.05752	0.06277	0.39528	0.04167	0.04137	-27.57	-28.08	33.39
169B	29.6	0.04488	0.06301	0.31232	0.04201	0.04175	-6.40	-6.99	34.14
95B	30.4	0.03721	0.06454	0.27816	0.04305	0.04288	15.68	15.24	36.45
31B	30.7	0.04403	0.06059	0.31964	0.04356	0.04345	-1.06	-1.32	37.63
88B	32.0	0.03897	0.06909	0.32696	0.04529	0.04535	16.23	16.37	41.68
41B	32.7	0.04403	0.06872	0.34526	0.04633	0.04649	5.21	5.58	44.18
85B	32.7	0.04587	0.06562	0.32086	0.04633	0.04649	0.99	1.34	44.18
42B	33.8	0.05656	0.06528	0.36356	0.04788	0.04821	-15.35	-14.77	48.03
46B	34.2	0.04623	0.07065	0.33672	0.04840	0.04878	4.70	5.52	49.33
34B	34.3	0.05690	0.06123	0.37454	0.04857	0.04897	-14.64	-13.94	49.77
30B	34.8	0.05522	0.06389	0.37454	0.04926	0.04974	-10.79	-9.93	51.52
93B	37.0	0.04616	0.07941	0.36234	0.05237	0.05320	13.44	15.24	59.54
28B	37.7	0.05738	0.07052	0.39162	0.05340	0.05436	-6.93	-5.26	59.76
45B	38.7	0.05263	0.08074	0.41602	0.05478	0.05590	4.09	6.22	56.18
27B	38.8	0.06111	0.07778	0.40870	0.05496	0.05610	-10.07	-8.20	55.73
103B	39.4	0.04608	0.08553	0.38186	0.05582	0.05707	21.14	23.85	53.51
87B	40.6	0.05499	0.08030	0.38918	0.05755	0.05901	4.66	7.32	49.11
33B	41.4	0.05274	0.08592	0.42822	0.05858	0.06018	11.07	14.11	46.52
104B	41.5	0.05805	0.08330	0.40138	0.05875	0.06038	1.22	4.01	46.09
105B	46.0	0.05234	0.09934	0.44896	0.06511	0.06759	24.40	29.14	31.43
35B	46.4	0.06692	0.09299	0.48922	0.06566	0.06822	-1.88	1.95	30.28
99B	46.6	0.06593	0.09761	0.43432	0.06600	0.06862	0.11	4.08	29.57
92B	47.0	0.06378	0.09381	0.44896	0.06652	0.06921	4.30	8.51	28.53
84B	50.0	0.08320	0.08795	0.49044	0.07084	0.07416	-14.86	-10.87	20.66
38B	50.8	0.06708	0.11089	0.58316	0.07187	0.07535	7.15	12.34	19.00
36B	51.1	0.06631	0.10380	0.53924	0.07239	0.07595	9.17	14.54	18.20
37B	52.9	0.08373	0.09416	0.57950	0.07498	0.07894	-10.45	-5.72	14.56
102B	52.9	0.06889	0.10862	0.49898	0.07498	0.07894	8.83	14.59	14.56
177B	53.4	0.08130	0.13142	0.71858	0.07567	0.07974	-6.93	-1.92	13.68
44B	59.2	0.07968	0.12351	0.62464	0.08378	0.08919	5.15	11.94	6.05
94B	59.5	0.07986	0.11198	0.57706	0.08430	0.08980	5.56	12.44	5.72
32B	65.5	0.09484	0.13568	0.73078	0.09276	0.09975	-2.20	5.17	2.03
106B	65.9	0.09027	0.13669	0.67466	0.09328	0.10036	3.33	11.18	1.90
89B	71.1	0.08506	0.14429	0.66856	0.10070	0.10917	18.39	28.35	0.65
40B	76.5	0.12266	0.14287	0.82350	0.10829	0.11826	-11.71	-3.59	0.19
101B	79.9	0.09456	0.17106	0.77348	0.11313	0.12407	19.63	31.21	0.08
90B	83.3	0.11697	0.17733	0.86864	0.11796	0.12991	0.84	11.06	0.03
43B	88.2	0.14692	0.14518	0.86010	0.12487	0.13829	-15.01	-5.88	0.01

Mean:	37.4	0.0529	0.0766
DRL:	47.0	0.0663	0.0942
Median:	33.8	0.0462	0.0687

n:	61
Population standard deviation	18.7
Chauvenet criterion value:	0.5

APPENDIX 62: INPUT DATA AP LUMBAR SPINE ALL THREE HOSPITALS COMBINED

All three hospitals Lumbar spine AP

Patient	DAP value (cGy.cm^2) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
211A	33.9	0.03720	0.07586	0.56974	0.04176	0.03748	12.26	0.75	6.58
187A	36.6	0.04159	0.08058	0.47702	0.04460	0.04043	7.23	-2.79	7.01
192A	37.6	0.04324	0.08910	0.52948	0.04569	0.04157	5.69	-3.85	7.18
185A	51.9	0.05987	0.11758	0.74786	0.06073	0.05720	1.45	-4.45	9.86
122A	57.0	0.06206	0.11984	1.04920	0.06620	0.06289	6.67	1.33	11.00
186A	59.8	0.06814	0.11322	1.99104	0.06918	0.06599	1.54	-3.16	11.66
189A	68.8	0.04748	0.09960	0.61976	0.07863	0.07579	65.60	59.63	13.93
75A	70.5	0.07799	0.13041	0.78934	0.08048	0.07771	3.18	-0.36	14.40
72A	70.8	0.07546	0.13287	0.88084	0.08074	0.07798	7.00	3.34	14.47
183A	76.7	0.08366	0.15999	1.07848	0.08702	0.08450	4.02	1.01	16.17
67A	80.3	0.08438	0.15950	0.87718	0.09080	0.08842	7.62	4.80	17.26
80A	80.9	0.08685	0.13963	0.83936	0.09145	0.08909	5.29	2.58	17.45
65A	82.8	0.08983	0.15244	0.86010	0.09351	0.09124	4.10	1.57	18.06
184A	83.6	0.09509	0.18466	1.20536	0.09433	0.09208	-0.80	-3.16	18.31
71A	85.4	0.09578	0.17651	0.90646	0.09622	0.09405	0.46	-1.81	18.89
66A	88.1	0.09864	0.18204	0.98576	0.09906	0.09699	0.43	-1.67	19.78
73A	88.6	0.09816	0.16952	0.94062	0.09958	0.09753	1.44	-0.65	19.95
64A	90.4	0.10797	0.21793	1.09800	0.10152	0.09954	-5.98	-7.81	20.57
69A	91.3	0.09895	0.18446	1.07482	0.10242	0.10047	3.50	1.53	20.87
78A	95.0	0.10932	0.19688	1.03944	0.10642	0.10462	-2.66	-4.30	22.20
68A	99.1	0.11370	0.20652	1.10898	0.11068	0.10904	-2.66	-4.11	23.68
74A	119.7	0.12649	0.23411	1.45302	0.13249	0.13164	4.74	4.07	31.98
114A	124.0	0.14065	0.30480	1.86050	0.13701	0.13632	-2.59	-3.08	33.83
81A	124.7	0.14240	0.24528	1.43350	0.13778	0.13712	-3.24	-3.71	34.15
121A	125.1	0.13808	0.21315	4.65430	0.13820	0.13755	0.08	-0.39	34.32
70A	127.4	0.14220	0.28948	1.46400	0.14062	0.14006	-1.11	-1.51	35.34
76A	136.9	0.14834	0.25239	1.66164	0.15069	0.15048	1.58	1.45	39.65
111A	139.8	0.17161	0.38938	2.25822	0.15379	0.15369	-10.38	-10.44	41.00
63A	142.9	0.16519	0.31270	1.64212	0.15701	0.15703	-4.95	-4.94	42.42
83A	143.1	0.16942	0.35135	1.68482	0.15727	0.15730	-7.17	-7.15	42.54
119A	154.6	0.16774	0.28871	1.60796	0.16940	0.16986	0.99	1.26	47.92
190A	165.6	0.20041	0.38552	2.77184	0.18103	0.18189	-9.67	-9.24	42.91
82A	166.8	0.19677	0.41357	2.02520	0.18231	0.18321	-7.35	-6.89	42.35
117A	166.8	0.17613	0.29594	3.70514	0.18231	0.18321	3.51	4.02	42.35
120A	168.6	0.19779	0.36803	3.49530	0.18426	0.18523	-6.84	-6.35	41.49
116A	175.1	0.19296	0.34729	2.12280	0.19109	0.19229	-0.97	-0.34	38.52
123A	175.6	0.19879	0.35307	3.95524	0.19169	0.19292	-3.57	-2.95	38.26
188A	176.0	0.18786	0.35614	2.13744	0.19207	0.19331	2.24	2.90	38.10
113A	180.0	0.19313	0.37710	3.44284	0.19625	0.19763	1.62	2.33	36.31
191A	205.1	0.22048	0.40669	2.97436	0.22286	0.22515	1.08	2.12	25.70
109A	238.1	0.27280	0.57832	3.54532	0.25781	0.26128	-5.50	-4.23	14.63
118A	275.7	0.29573	0.49503	3.00364	0.29759	0.30237	0.63	2.25	6.55
115A	307.1	0.31980	0.54984	5.22038	0.33073	0.33659	3.42	5.25	2.92
107A	346.5	0.38674	0.65477	6.94668	0.37242	0.37962	-3.70	-1.84	0.88
112A	355.6	0.35387	0.61140	6.67462	0.38210	0.38960	7.98	10.10	0.65
79A	361.1	0.39937	0.82058	4.89708	0.38791	0.39560	-2.87	-0.94	0.53
108A	538.1	0.55964	1.00163	9.74292	0.57518	0.58866	2.78	5.19	0.00
110A	558.8	0.60017	1.07621	9.32202	0.59699	0.61113	-0.53	1.83	0.00

Mean:	154.7	0.1696	0.3138
DRL:	175.2	0.1970	0.3792
Median:	124.9	0.1414	0.2488

n:	48
Population standard deviation	114.9
Chauvenet criterion value:	0.5

APPENDIX 63: INPUT DATA LAT LUMBAR SPINE ALL THREE HOSPITALS COMBINED

All three hospitals Lumbar spine LAT									
Patient	DAP value (cGy.cm^2) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
211B	31.8	0.03185	0.04699	0.59414	0.04491	0.03401	40.97	6.76	1.15
187B	54.7	0.07848	0.06891	0.85522	0.06782	0.05770	-13.59	-26.48	2.57
192B	62.3	0.09509	0.08527	0.97356	0.07545	0.06554	-20.65	-31.08	3.28
186B	70.2	0.04121	0.12455	2.05936	0.08341	0.07368	102.39	78.79	4.19
185B	74.7	0.10153	0.08650	1.27002	0.08792	0.07829	-13.41	-22.89	4.79
190B	80.1	0.06588	0.14573	1.69824	0.09338	0.08387	41.74	27.31	5.60
184B	81.3	0.09410	0.11808	1.50792	0.09453	0.08504	0.46	-9.62	5.79
122B	85.7	0.05952	0.13058	1.87636	0.09897	0.08957	66.27	50.47	6.55
75B	95.4	0.11264	0.08594	1.18706	0.10875	0.09951	-3.46	-11.66	8.48
80B	104.3	0.11383	0.07588	1.16754	0.11769	0.10859	3.40	-4.60	10.61
67B	115.0	0.14502	0.12420	1.51524	0.12847	0.11952	-11.41	-17.59	13.64
73B	115.2	0.12753	0.09566	1.35542	0.12860	0.11964	0.84	-6.18	13.68
189B	122.0	0.14442	0.17986	2.10450	0.13550	0.12662	-6.18	-12.33	15.90
69B	129.8	0.15939	0.12312	1.76046	0.14330	0.13450	-10.10	-15.61	18.69
68B	137.5	0.06000	0.15970	1.86416	0.15102	0.14229	151.70	137.15	21.72
188B	137.9	0.17845	0.17845	1.91784	0.15144	0.14271	-15.14	-20.03	21.89
119B	145.1	0.16557	0.13503	1.78608	0.15867	0.15000	-4.17	-9.40	24.97
183B	146.5	0.17414	0.18793	2.64008	0.16004	0.15138	-8.10	-13.07	25.58
72B	146.6	0.18583	0.13078	2.11060	0.16021	0.15155	-13.79	-18.45	25.66
78B	148.1	0.17835	0.14264	1.83976	0.16168	0.15303	-9.35	-14.20	26.32
66B	178.5	0.21528	0.18478	2.34972	0.19219	0.18368	-10.72	-14.68	41.62
191B	179.3	0.11755	0.27441	3.25496	0.19297	0.18445	64.16	56.92	42.03
70B	180.8	0.23439	0.19270	11.27158	0.19452	0.18601	-17.01	-20.64	42.87
74B	182.4	0.23315	0.17372	2.85724	0.19611	0.18761	-15.89	-19.53	43.73
64B	182.9	0.06559	0.03592	0.50386	0.19660	0.18810	199.76	186.80	43.99
81B	188.2	0.22561	0.15767	2.53638	0.20200	0.19350	-10.47	-14.23	46.91
63B	197.2	0.23339	0.15884	2.74256	0.21094	0.20246	-9.62	-13.25	44.24
121B	198.9	0.14394	0.26658	8.28624	0.21266	0.20417	47.74	41.85	43.31
117B	199.1	0.18583	0.23717	4.72750	0.21294	0.20445	14.59	10.02	43.16
113B	202.5	0.11851	0.32733	4.53840	0.21633	0.20785	82.54	75.38	41.34
120B	203.2	0.23658	0.28692	4.73116	0.21699	0.20851	-8.28	-11.87	40.98
112B	214.1	0.20736	0.28669	3.77102	0.22797	0.21948	9.94	5.84	35.23
109B	222.4	0.27400	0.36648	3.60998	0.23631	0.22780	-13.76	-16.86	31.05
77B	231.6	0.32390	0.25940	3.33182	0.24550	0.23696	-24.21	-26.84	26.70
71B	232.3	0.27718	0.22087	2.97314	0.24623	0.23770	-11.17	-14.25	26.36
115B	234.1	0.19616	0.33139	4.66040	0.24807	0.23953	26.46	22.11	25.54
65B	239.7	0.27409	0.21445	2.98290	0.25371	0.24514	-7.44	-10.56	23.08
118B	248.3	0.28237	0.22643	3.12198	0.26233	0.25373	-7.10	-10.14	19.59
107B	251.8	0.14555	0.47214	6.07560	0.26584	0.25722	82.65	76.73	18.27
116B	261.2	0.32412	0.28017	3.16712	0.27527	0.26661	-15.07	-17.74	14.98
114B	279.7	0.36751	0.32845	3.45504	0.29390	0.28512	-20.03	-22.42	9.71
111B	283.5	0.35905	0.49614	4.59574	0.29770	0.28889	-17.09	-19.54	8.83
82B	284.1	0.40541	0.37779	4.08822	0.29831	0.28949	-26.42	-28.59	8.69
123B	288.6	0.27133	0.42848	7.33464	0.30276	0.29391	11.58	8.32	7.75
83B	310.5	0.45083	0.44395	4.46764	0.32478	0.31574	-27.96	-29.96	4.16
108B	382.1	0.30068	0.58107	8.11544	0.39670	0.38683	31.94	28.65	0.30
79B	439.0	0.62399	0.54716	7.12602	0.45381	0.44306	-27.27	-29.00	0.02
110B	551.6	0.38591	0.82866	10.14308	0.56691	0.55399	46.90	43.56	0.00
Mean:	190.2	0.2040	0.2377						
DRL:	235.5	0.2740	0.2970						
Median:	182.6	0.1821	0.1864						
n:	48								
Population standard deviation	99.3								
Chauvenet criterion value:	0.5								

APPENDIX 64: INPUT DATA AP PELVIS ALL THREE HOSPITALS COMBINED

All three hospitals Pelvis

Patient	DAP value (cGy.cm^2) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
16	53.9	0.06911	0.07093	0.47702	0.06892	0.06569	-0.28	-4.96	4.45
205	61.7	0.07830	0.10647	0.60146	0.07764	0.07482	-0.84	-4.44	5.72
20	74.7	0.09324	0.11966	0.85888	0.09230	0.09010	-1.02	-3.37	8.48
204	75.3	0.09575	0.12556	0.78202	0.09297	0.09080	-2.90	-5.17	8.63
207	76.5	0.09570	0.12991	1.11996	0.09437	0.09226	-1.38	-3.59	8.94
15	77.3	0.08597	0.10893	0.82106	0.09527	0.09319	10.81	8.39	9.15
208	78.0	0.09656	0.12801	0.69174	0.09609	0.09404	-0.49	-2.61	9.34
202	83.5	0.10053	0.12453	1.08702	0.10221	0.10039	1.67	-0.14	10.86
196	84.3	0.10337	0.13158	0.94306	0.10313	0.10135	-0.23	-1.96	11.10
210	92.5	0.10795	0.15471	0.88694	0.11240	0.11093	4.12	2.77	13.78
201	93.3	0.11561	0.15711	1.36884	0.11325	0.11181	-2.04	-3.28	14.05
11	93.3	0.10258	0.13314	1.09922	0.11333	0.11190	10.49	9.09	14.08
199	94.1	0.10230	0.15185	1.71044	0.11420	0.11279	11.64	10.26	14.35
200	99.8	0.12110	0.20397	2.68034	0.12061	0.11941	-0.40	-1.40	16.51
19	99.8	0.11256	0.14936	1.43594	0.12062	0.11942	7.16	6.10	16.52
193	100.1	0.11852	0.21856	1.40666	0.12095	0.11976	2.05	1.04	16.63
13	111.1	0.13154	0.16267	1.17974	0.13341	0.13258	1.42	0.79	21.45
18	111.8	0.13965	0.18160	1.51646	0.13416	0.13336	-3.93	-4.51	21.76
137	112.4	0.13413	0.19038	1.14680	0.13480	0.13401	0.50	-0.09	22.03
195	115.5	0.13034	0.17140	1.29320	0.13830	0.13761	6.11	5.58	23.55
198	115.8	0.13393	0.17308	1.36274	0.13861	0.13792	3.49	2.98	23.69
17	124.3	0.15346	0.19748	1.32004	0.14826	0.14782	-3.39	-3.68	28.20
138	131.4	0.14516	0.16408	1.76412	0.15623	0.15599	7.63	7.46	32.24
14	135.2	0.15866	0.19599	1.43472	0.16050	0.16034	1.16	1.06	34.51
10	138.6	0.15326	0.18544	1.55062	0.16435	0.16428	7.24	7.19	36.62
209	141.0	0.15537	0.15537	1.60918	0.16701	0.16700	7.50	7.49	38.12
140	146.6	0.18402	0.26291	1.77998	0.17342	0.17354	-5.76	-5.70	41.80
25	147.3	0.17012	0.20017	1.48962	0.17411	0.17424	2.35	2.42	42.20
7	147.9	0.17254	0.21452	1.69946	0.17480	0.17494	1.30	1.39	42.60
6	149.1	0.16705	0.19932	1.71410	0.17617	0.17634	5.46	5.56	43.41
12	161.2	0.19073	0.25120	2.18502	0.18978	0.19020	-0.50	-0.28	51.63
9	167.9	0.19884	0.24373	1.87880	0.19735	0.19788	-0.75	-0.48	56.30
206	168.1	0.20886	0.23745	1.27246	0.19762	0.19816	-5.38	-5.12	56.47
2	168.4	0.20009	0.23727	1.78730	0.19790	0.19844	-1.10	-0.82	56.64
23	169.0	0.20524	0.24511	1.79462	0.19858	0.19914	-3.24	-2.97	56.94
144	170.7	0.21415	0.25380	1.48352	0.20051	0.20109	-6.37	-6.10	55.75
22	173.1	0.19408	0.22940	1.93736	0.20326	0.20389	4.73	5.05	54.05
21	178.2	0.21367	0.25611	1.94956	0.20903	0.20974	-2.17	-1.84	50.50
145	184.5	0.22946	0.29878	1.91540	0.21604	0.21685	-5.85	-5.49	46.24
5	200.4	0.22820	0.26190	2.56566	0.23406	0.23507	2.57	3.01	35.83
8	206.2	0.24296	0.28284	2.42658	0.24052	0.24160	-1.01	-0.56	32.35
24	209.5	0.24973	0.28283	2.34362	0.24423	0.24535	-2.20	-1.76	30.43
143	209.5	0.26678	0.33551	2.12646	0.24423	0.24535	-8.45	-8.03	30.43
26	213.5	0.25544	0.30615	2.51320	0.24877	0.24992	-2.61	-2.16	28.17
141	223.4	0.24945	0.33857	3.15492	0.25991	0.26115	4.19	4.69	23.01
197	225.1	0.27391	0.36865	2.64984	0.26183	0.26309	-4.41	-3.95	22.18
3	225.3	0.26469	0.32389	2.46440	0.26211	0.26336	-0.98	-0.50	22.06
4	231.7	0.28058	0.34530	2.66326	0.26926	0.27056	-4.03	-3.57	19.15
203	242.7	0.28825	0.42990	3.61730	0.28163	0.28301	-2.30	-1.82	14.72
194	250.1	0.30759	0.44038	2.45830	0.29001	0.29142	-5.72	-5.26	12.16
146	251.6	0.31258	0.43367	2.78770	0.29167	0.29309	-6.69	-6.24	11.69
102163	278.5	0.31553	0.40829	3.56484	0.32206	0.32354	2.07	2.54	5.30
148	295.4	0.35103	0.47448	3.35012	0.34103	0.34252	-2.85	-2.42	3.00
139	328.8	0.34355	0.48319	3.56118	0.37871	0.38010	10.23	10.64	0.81
136	330.6	0.37741	0.54856	3.60144	0.38071	0.38210	0.88	1.24	0.75
142	446.8	0.49337	0.57325	4.63844	0.51167	0.51193	3.71	3.76	0.00
147	550.6	0.62896	0.74469	5.71570	0.62868	0.62709	-0.04	-0.30	0.00

Mean:	168.9	0.1985	0.2544
DRL:	209.5	0.2497	0.3061
Median:	147.9	0.1725	0.2186

n:	57
Population standard deviation	92.3
Chauvenet criterion value:	0.5

APPENDIX 65: INPUT DATA PA SKULL ALL THREE HOSPITALS COMBINED

All three hospitals Skull PA

Patient	DAP value (cGy.cm^2) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
155A	21.5	0.01941	0.00570	0.30134	0.02128	0.02178	9.61	12.23	2.46
51A	21.8	0.01731	0.00460	0.26718	0.02163	0.02212	24.96	27.76	2.55
160A	23.2	0.03765	0.01298	0.88572	0.02314	0.02353	-38.53	-37.50	2.94
130A	24.7	0.02807	0.00803	0.48556	0.02481	0.02509	-11.63	-10.63	3.43
62A	24.8	0.01920	0.00506	0.32330	0.02493	0.02520	29.83	31.25	3.47
214A	25.4	0.02695	0.00777	0.55388	0.02570	0.02593	-4.64	-3.80	3.72
53A	27.6	0.03159	0.00903	0.50996	0.02809	0.02817	-11.07	-10.80	4.59
65A	31.6	0.02808	0.00811	0.42456	0.03262	0.03246	16.16	15.56	6.70
151A	32.3	0.03709	0.01146	0.43188	0.03339	0.03318	-9.96	-10.53	7.13
212A	34.1	0.03967	0.01230	0.63318	0.03539	0.03507	-10.81	-11.60	8.32
135A	34.6	0.03398	0.00914	0.64050	0.03596	0.03562	5.84	4.84	8.69
61A	36.1	0.03029	0.00800	0.47092	0.03771	0.03728	24.48	23.07	9.89
50A	37.3	0.03346	0.00808	0.47580	0.03908	0.03859	16.78	15.31	10.91
64A	38.6	0.03283	0.00894	0.50264	0.04046	0.03990	23.23	21.53	12.01
55A	41.2	0.04099	0.01030	0.91622	0.04348	0.04278	6.06	4.37	14.71
213A	41.4	0.05231	0.02057	0.89426	0.04368	0.04298	-16.50	-17.84	14.91
157A	42.3	0.03993	0.01133	0.43920	0.04465	0.04390	11.81	9.95	15.85
48A	42.6	0.03586	0.00904	0.58438	0.04499	0.04423	25.47	23.36	16.20
133A	44.2	0.05218	0.01610	0.75030	0.04677	0.04594	-10.36	-11.95	18.09
57A	47.0	0.05984	0.01610	1.04310	0.04993	0.04898	-16.55	-18.16	21.75
59A	50.1	0.06260	0.01803	1.08824	0.05351	0.05241	-14.52	-16.27	26.38
163A	52.0	0.06811	0.02262	0.67710	0.05557	0.05440	-18.42	-20.13	29.27
162A	56.4	0.07780	0.02796	1.25416	0.06061	0.05927	-22.09	-23.81	36.91
47A	58.0	0.04891	0.01556	0.73932	0.06230	0.06091	27.38	24.53	39.62
54A	58.6	0.05908	0.01734	1.14436	0.06299	0.06157	6.60	4.21	40.74
158A	60.7	0.04863	0.01391	0.81130	0.06539	0.06391	34.47	31.41	44.73
60A	62.1	0.07364	0.02212	0.79178	0.06697	0.06544	-9.06	-11.14	47.38
161A	63.6	0.06420	0.02230	0.14140	0.06872	0.06713	7.03	4.57	50.34
58A	70.2	0.05603	0.01637	0.91378	0.07604	0.07427	35.70	32.54	41.34
150A	70.5	0.09159	0.03009	1.27124	0.07642	0.07464	-16.56	-18.50	40.71
56A	70.9	0.07973	0.02261	0.75396	0.07693	0.07514	-3.51	-5.75	39.88
156A	71.2	0.09637	0.02855	1.58234	0.07725	0.07545	-19.84	-21.71	39.36
128A	72.5	0.10530	0.03087	1.49694	0.07865	0.07682	-25.31	-27.05	37.11
164A	72.6	0.08716	0.02483	0.94550	0.07881	0.07698	-9.57	-11.68	36.85
63A	73.7	0.05441	0.01458	0.93940	0.08002	0.07816	47.07	43.64	34.95
59AB	74.2	0.10210	0.03138	1.64700	0.08057	0.07870	-21.09	-22.92	34.11
153A	81.5	0.08185	0.02612	1.08824	0.08883	0.08679	8.53	6.03	22.52
127A	84.4	0.09389	0.02623	1.47620	0.09211	0.09001	-1.89	-4.13	18.64
152A	85.0	0.08312	0.02614	1.19316	0.09272	0.09060	11.55	9.01	17.97
129A	92.0	0.10950	0.02795	1.82756	0.10063	0.09839	-8.10	-10.14	10.66
131A	93.1	0.09905	0.02551	1.79096	0.10187	0.09961	2.84	0.57	9.75
125A	93.6	0.08440	0.02102	1.44692	0.10242	0.10016	21.35	18.67	9.37
159A	96.6	0.07336	0.01985	1.35786	0.10588	0.10357	44.33	41.19	7.19
52A	97.6	0.07508	0.01946	1.29076	0.10695	0.10463	42.45	39.36	6.60
124A	100.8	0.13660	0.03893	1.98738	0.11052	0.10816	-19.09	-20.82	4.91
49A	101.1	0.08558	0.02403	1.31760	0.11093	0.10857	29.62	26.86	4.74
62AB	109.4	0.12216	0.03462	1.42618	0.12028	0.11783	-1.54	-3.54	1.99
126A	112.5	0.11904	0.02866	1.58356	0.12371	0.12124	3.93	1.85	1.40
132A	114.9	0.13603	0.03876	2.45708	0.12646	0.12397	-7.04	-8.87	1.04
134A	116.8	0.15261	0.04324	2.00812	0.12852	0.12602	-15.79	-17.42	0.83
154A	122.7	0.10734	0.03227	1.72508	0.13522	0.13270	25.98	23.63	0.38
149A	143.4	0.19209	0.05441	3.45748	0.15857	0.15603	-17.45	-18.77	0.01

Mean:	64.5	0.0697	0.0202
DRL:	86.7	0.0922	0.0267
Median:	61.4	0.0634	0.0197

n:	52
Population standard deviation	30.7
Chauvenet criterion value:	0.5

APPENDIX 66: INPUT DATA LAT SKULL ALL THREE HOSPITALS COMBINED

All three hospitals Skull LAT									
Patient	DAP value (cGy.cm^2) - X-axis	PCXMC Skin dose (mGy) - Y-axis	PCXMC Effective dose (mSv) - ICRP103	PCXMC Incident air kerma (mGy)	Skin dose (mGy) - calculated linear fit	Skin dose (mGy) - calculated power fit	% Diff linear fit	% Diff power fit	Chauvenet criterion
135B	12.7	0.01152	0.00387	0.21838	0.01738	0.01352	50.95	17.42	1.35
130B	19.2	0.02037	0.00691	0.33550	0.02209	0.01934	8.42	-5.06	3.40
157B	20.5	0.01775	0.00974	0.19276	0.02305	0.02050	29.86	15.47	4.05
214B	21.4	0.01868	0.00669	0.33550	0.02368	0.02124	26.77	13.73	4.52
133B	21.8	0.02383	0.01330	0.33428	0.02398	0.02160	0.64	-9.35	4.76
163B	24.3	0.03306	0.01549	0.28670	0.02580	0.02374	-21.98	-28.20	6.44
51B	25.3	0.02025	0.00952	0.29036	0.02648	0.02453	30.73	21.12	7.18
160B	25.6	0.03407	0.01337	0.73322	0.02674	0.02484	-21.52	-27.11	7.49
151B	26.4	0.02934	0.01534	0.31110	0.02727	0.02545	-7.06	-13.27	8.12
62B	27.9	0.03231	0.03231	0.41968	0.02842	0.02677	-12.03	-17.14	9.65
212B	30.7	0.02597	0.01059	0.40138	0.03042	0.02905	17.12	11.84	12.80
213B	32.0	0.02795	0.01810	0.45506	0.03138	0.03012	12.25	7.78	14.52
162B	32.4	0.04397	0.01909	0.39284	0.03167	0.03045	-27.98	-30.74	15.08
155B	32.9	0.02758	0.01286	0.40626	0.03198	0.03080	15.92	11.65	15.69
61B	33.4	0.02545	0.01169	0.37698	0.03239	0.03126	27.27	22.84	16.53
134B	35.3	0.02786	0.01669	0.59780	0.03371	0.03274	20.99	17.49	19.41
129B	36.1	0.02650	0.00946	0.43676	0.03433	0.03342	29.56	26.13	20.85
164B	36.2	0.04072	0.02046	0.41602	0.03437	0.03346	-15.61	-17.83	20.94
50B	36.4	0.03198	0.01646	0.42090	0.03451	0.03362	7.92	5.13	21.28
55B	38.1	0.03010	0.00761	0.74786	0.03574	0.03498	18.76	16.22	24.39
158B	40.7	0.03063	0.01107	0.49288	0.03769	0.03710	23.02	21.12	29.74
159B	43.8	0.03081	0.00986	0.51728	0.03988	0.03947	29.44	28.14	36.37
132B	44.7	0.03056	0.01484	0.45628	0.04051	0.04016	32.56	31.41	38.40
53B	44.8	0.04459	0.01585	0.78812	0.04060	0.04025	-8.95	-9.73	38.68
156B	45.2	0.03749	0.01732	0.53314	0.04089	0.04057	9.07	8.21	39.62
65B	45.3	0.03799	0.01835	0.52338	0.04095	0.04063	7.79	6.96	39.82
152B	47.6	0.04518	0.02438	0.57584	0.04266	0.04246	-5.58	-6.02	45.46
150B	47.6	0.05744	0.03057	0.62098	0.04267	0.04247	-25.71	-26.05	45.51
64B	47.7	0.03920	0.01759	0.56364	0.04272	0.04252	8.98	8.48	45.66
154B	47.8	0.03771	0.01487	0.57828	0.04276	0.04257	13.40	12.88	45.81
48B	48.2	0.03599	0.01508	0.55754	0.04307	0.04290	19.67	19.19	46.85
58B	49.2	0.04931	0.01708	0.96624	0.04378	0.04365	-11.23	-11.49	49.24
54B	49.4	0.04391	0.01330	0.99186	0.04395	0.04384	0.10	-0.16	49.84
153B	53.3	0.05261	0.02834	0.62952	0.04673	0.04677	-11.16	-11.09	44.76
59BA	55.0	0.06268	0.02274	1.08092	0.04801	0.04811	-23.40	-23.25	40.52
58B	57.3	0.04035	0.02070	0.54046	0.04969	0.04986	23.16	23.58	35.17
124B	60.9	0.07132	0.03819	0.81252	0.05225	0.05251	-26.74	-26.37	27.59
56B	61.6	0.06821	0.03207	0.60512	0.05280	0.05307	-22.60	-22.19	26.09
62BA	62.1	0.06561	0.03326	0.73322	0.05313	0.05342	-19.02	-18.58	25.19
47B	62.8	0.05309	0.02685	0.72712	0.05366	0.05396	1.07	1.64	23.80
57B	67.8	0.07139	0.02505	1.33224	0.05728	0.05766	-19.77	-19.24	15.54
126B	74.3	0.07282	0.03784	0.83692	0.06196	0.06239	-14.92	-14.33	8.06
149B	76.0	0.05479	0.02828	0.74664	0.06318	0.06361	15.31	16.09	6.66
60B	77.5	0.09074	0.04525	0.91500	0.06425	0.06468	-29.19	-28.72	5.59
131B	79.1	0.05840	0.03061	0.64904	0.06540	0.06583	11.99	12.72	4.60
49B	80.8	0.06385	0.02832	0.93452	0.06664	0.06706	4.36	5.01	3.70
125B	84.3	0.05586	0.02735	0.79178	0.06920	0.06959	23.87	24.57	2.29
63B	84.9	0.05849	0.02044	0.95038	0.06964	0.07003	19.07	19.73	2.10
161B	87.4	0.07435	0.03390	1.05652	0.07141	0.07177	-3.95	-3.46	1.46
128B	87.7	0.06600	0.03706	0.79178	0.07167	0.07202	8.59	9.12	1.39
127B	101.1	0.07322	0.03270	1.10532	0.08138	0.08146	11.14	11.25	0.14
52B	130.9	0.09483	0.03439	1.58966	0.10292	0.10183	8.53	7.38	0.00

Mean:	50.3	0.0446	0.0206
DRL:	62.3	0.0584	0.0283
Median:	46.4	0.0398	0.0178

n:	52
Population standard deviation	23.9
Chauvenet criterion value:	0.5

APPENDIX 67: CPUT PLAGIARISM REVIEW

DLR's WINDHOEK

ORIGINALITY REPORT

15%	5%	8%	12%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Cape Peninsula University of Technology Student Paper	1%
2	IFMBE Proceedings, 2009. Publication	1%
3	www.julkari.fi Internet Source	1%
4	Ursprung, W.M.. "Plain Film Radiography, Pregnancy, and Therapeutic Abortion Revisited", Journal of Manipulative and Physiological Therapeutics, 200601 Publication	1%
5	Submitted to University of Ulster Student Paper	<1%
6	etd.uwc.ac.za Internet Source	<1%
7	Submitted to Kingston University Student Paper	<1%
	Submitted to University of Salford	

8	Student Paper	<1%
9	Fatuma Osman, Imelda Williams. "Should the lateral chest radiograph be routinely performed?", Radiography, 2014 Publication	<1%
10	Submitted to Nottingham Trent University Student Paper	<1%
11	"ECR 2005 – Scientific Programme – Abstracts", European Radiology Supplements, 2005 Publication	<1%
12	Submitted to St George's Hospital Medical School Student Paper	<1%
13	Submitted to University of Portsmouth Student Paper	<1%
14	Submitted to University of Glasgow Student Paper	<1%
15	Medical Radiology, 2012. Publication	<1%
16	link.springer.com Internet Source	<1%
17	academic.oup.com Internet Source	<1%

18	Submitted to University of Southampton Student Paper	<1%
19	Submitted to Queen Margaret University College, Edinburgh Student Paper	<1%
20	www-pub.iaea.org Internet Source	<1%
21	Submitted to Cardiff University Student Paper	<1%
22	Osibote, O.A.. "Estimation of adult patient doses for common diagnostic X-ray examinations in Rio de Janeiro, Brazil", Physica Medica, 200803 Publication	<1%
23	Submitted to Manipal University Student Paper	<1%
24	Submitted to Central Queensland University Student Paper	<1%
25	Submitted to UNITEC (Te Whare Wananga o Wairaka) Student Paper	<1%
26	Submitted to International Islamic University Malaysia Student Paper	<1%
27	Valentin, J.. "Radiation and your patient: A guide for medical practitioners", Annals of the ICRP,	<1%

	2001 Publication	
28	Submitted to University of Sydney Student Paper	<1%
29	Per Hetland. "Calibration of reference KAP-meters at SSDL and cross calibration of clinical KAP-meters", Acta Oncologica, 2008 Publication	<1%
30	Submitted to RMIT University Student Paper	<1%
31	www.fmoh.gov.sd Internet Source	<1%
32	Vasileios I Metaxas, Gerasimos A Messaris, Aristea N Lekatou, Theodore G Petsas, George S Panayiotakis. "PATIENT DOSES IN COMMON DIAGNOSTIC X-RAY EXAMINATIONS", Radiation Protection Dosimetry, 2019 Publication	<1%
33	"ECR 2019: Book of Abstracts", Insights into Imaging, 2019 Publication	<1%
34	Submitted to The Hong Kong Polytechnic University Student Paper	<1%
	Luis Lanca, Augusto Silva. "Digital Imaging	

35	Systems for Plain Radiography", Springer Nature, 2013 Publication	<1%
36	Submitted to South Bank University Student Paper	<1%
37	kb.psu.ac.th Internet Source	<1%
38	Bidemi I. Akinlade, Idowu P. Farai, Akintunde A. Okunade. "Survey of dose area product received by patients undergoing common radiological examinations in four centers in Nigeria", Journal of Applied Clinical Medical Physics, 2012 Publication	<1%
39	Submitted to Midlands State University Student Paper	<1%
40	Submitted to Durban University of Technology Student Paper	<1%
41	Submitted to University of New South Wales Student Paper	<1%
42	Submitted to Glasgow Caledonian University Student Paper	<1%
43	"Quality in Nuclear Medicine", Springer Nature, 2017 Publication	<1%

44	Submitted to Universiti Tenaga Nasional Student Paper	<1%
45	Submitted to UNITEC Institute of Technology Student Paper	<1%
46	nrl.northumbria.ac.uk Internet Source	<1%
47	www.entrepreneur.com Internet Source	<1%
48	www.leanmath.com Internet Source	<1%
49	Submitted to University of Minnesota System Student Paper	<1%
50	Submitted to Higher Education Commission Pakistan Student Paper	<1%
51	pt.scribd.com Internet Source	<1%
52	Menglong Zhang, Cunkun Chu. "Optimization of the Radiological Protection of Patients Undergoing Digital Radiography", Journal of Digital Imaging, 2011 Publication	<1%
53	Sierra Rayne, Kaya Forest. "Perfluoroalkyl sulfonic and carboxylic acids: A critical review of	<1%

	physicochemical properties, levels and patterns in waters and wastewaters, and treatment methods", Journal of Environmental Science and Health, Part A, 2009 Publication	
54	Submitted to Coastal Carolina University Student Paper	<1%
55	docslide.us Internet Source	<1%
56	www.ncbi.nlm.nih.gov Internet Source	<1%
57	mytutorial.srtcube.com Internet Source	<1%
58	"ECR 2017 – BOOK OF ABSTRACTS", Insights into Imaging, 2017 Publication	<1%
59	Submitted to University of Cape Town Student Paper	<1%
60	Submitted to University at Buffalo, SUNY Student Paper	<1%
61	www.aph.gov.au Internet Source	<1%
62	"Posters", European Journal of Nuclear Medicine and Molecular Imaging, 2008 Publication	<1%

63	Aliasgharzadeh, Akbar, Ehsan Mihandoost, Mahboubeh Masoumbeigi, Morteza Salimian, and Mehran Mohseni. "Measurement of Entrance Skin Dose and Calculation of Effective Dose for Common Diagnostic X-Ray Examinations in Kashan, Iran", Global Journal of Health Science, 2015. Publication	<1%
64	Submitted to Queensland University of Technology Student Paper	<1%
65	www.ttmhn.org.au Internet Source	<1%
66	Submitted to Mahidol University Student Paper	<1%
67	www.state.vt.us Internet Source	<1%
68	E. K. Ofori. "COMPARISON OF PATIENT RADIATION DOSE FROM CHEST AND LUMBAR SPINE X-RAY EXAMINATIONS IN 10 HOSPITALS IN GHANA", Radiation Protection Dosimetry, 07/20/2011 Publication	<1%
69	Submitted to HELP UNIVERSITY Student Paper	<1%
	Submitted to Indian Institute of Technology,	

70	Bombay Student Paper	<1%
71	"Poster Presentations", European Journal of Nuclear Medicine and Molecular Imaging, 2011 Publication	<1%
72	www.afs-journal.org Internet Source	<1%
73	Submitted to Harper Adams University College Student Paper	<1%
74	knowledgecommons.lakeheadu.ca Internet Source	<1%
75	Submitted to Sheffield Hallam University Student Paper	<1%
76	Horst Aichinger, Joachim Dierker, Sigrid Joite-Barfuß, Manfred Säbel. "Radiation Exposure and Image Quality in X-Ray Diagnostic Radiology", Springer Nature, 2012 Publication	<1%
77	Submitted to National University of Singapore Student Paper	<1%
78	Submitted to University of Hull Student Paper	<1%
79	Submitted to The Robert Gordon University Student Paper	<1%

80	Submitted to National College of Ireland Student Paper	<1%
81	Submitted to St. Martin's College, Lancaster Student Paper	<1%

Exclude quotes	On	Exclude matches	< 9 words
Exclude bibliography	On		

APPENDIX 68: PERMISSION TO USE MAP IN DISSERTATION

RE: canf20:Authenticity, Identity, and Humanity: The Haillom San and the State of Namibia
DELETEREPLYREPLY ALLFORWARD
Mark as unread

Academic UK Non Rightslink <permissionrequest@tandf.co.uk>

Tue 1/21/2020 11:08 AM
To:
Daniels, Edwin;

To help protect your privacy, some content in this message has been blocked. To re-enable the blocked features, click here.
To always show content from this sender, click here.
21 January 2020

Dear Edwin Ralph Daniels ,

Figure 2 from Robert K. Hitchcock (2015) Authenticity, Identity, and Humanity: The Haillom San and the State of Namibia, Anthropological Forum, 25:3, 262-284, DOI: 10.1080/00664677.2015.1027658

Thank you for your correspondence requesting permission to reproduce the above material from our Journal in your **printed** and to be posted in your university's repository - Cape peninsula University of Technology.

We will be pleased to grant entirely free permission on the condition that a full acknowledgement must be included showing article title, author, full Journal title, copyright © 2015 Discipline of Anthropology and Sociology, The University of Western Australia, reprinted by permission of Taylor & Francis Ltd, http://www.tandfonline.com on behalf of Discipline of Anthropology and Sociology, The University of Western Australia.

Please note that this licence **does not allow you to post our content on any third party websites or repositories**.

Thank you for your interest in our Journal.

With best wishes

Lee-Ann

Lee-Ann Anderson – Senior Permissions & Licensing Executive, Journals
Routledge, Taylor & Francis Group
3 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN, UK.
Permissions Tel: +44 (0)20 7017 7617
Permissions e-mail: permissionrequest@tandf.co.uk
Direct Tel: +44 (0)20 7017 7932
Web: www.tandfonline.com
e-mail: lee-ann.anderson@tandf.co.uk

Taylor & Francis is a trading name of Informa UK Limited, registered in England under no. 1072954