KNOWLEDGE OF RADIATION SAFETY AMONGST RADIATION WORKERS IN THE DEPARTMENT OF RADIATION ONCOLOGY AT THE CHARLOTTE MAXEKE JOHANNESBURG ACADEMIC HOSPITAL

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A research report submitted to the Faculty of Health Sciences, University of Witwatersrand, in partial fulfilment for the degree of Master of Medicine (M.Med) in the branch of Radiation Oncology.

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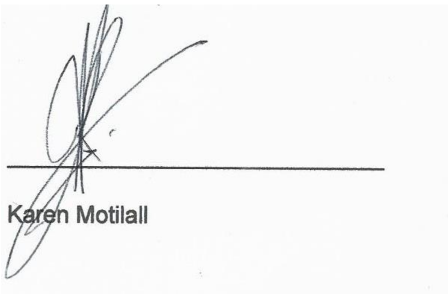
DECLARATION

I, Karen Motilall, declare that this research report is my own work. It is being submitted for the degree of Master of Medicine in Radiation Oncology in the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

This study has received ethical approval from the University of Witwatersrand Human Research Ethics committee (Medical) with clearance certificate number M151118



Signed at Johannesburg (University of Witwatersrand), South Africa on the

29 October 2017

DEDICATION

This dissertation is dedicated to:

- My amazing husband, Sooraj, whose guidance, love and unwavering support has encouraged me to persevere through every storm. You are my rock, my inspiration and my best friend.
- My wonderful children who have always been supportive and are the greatest joys in my life.
- My dear parents who have always encouraged me to reach for the stars.

ABSTRACT

TITLE

KNOWLEDGE OF RADIATION SAFETY AMONGST RADIATION WORKERS IN THE DEPARTMENT OF RADIATION ONCOLOGY AT THE CHARLOTTE MAXEKE JOHANNESBURG ACADEMIC HOSPITAL

BACKGROUND

Numerous studies have shown an increased incidence of adverse health effects in atomic bomb survivors, patients post medical exposure to ionizing radiation and in staff who are occupationally exposed to ionizing radiation. Radiation protection is therefore important to protect both people and the environment from the harmful effects of ionizing radiation. With the increasing use of ionizing radiation in diagnostic and therapeutic medicine it is important to limit the dose received by radiation workers. Several international studies have been conducted to assess the knowledge of radiation safety amongst radiation workers. The results thereof have shown that knowledge varies considerably between the different studies. This research study was done to assess the knowledge of radiation safety amongst radiation staff at the department of Radiation Oncology at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH).

OBJECTIVES

The objectives were to assess the knowledge of radiation safety amongst radiation workers and identify ways in which participants would prefer to improve their knowledge of radiation safety.

MATERIALS AND METHODS

A prospective cross sectional study was undertaken of all radiation workers in the Department of Radiation Oncology at CMJAH from the 14th to 28th of March 2016. A standardized questionnaire was used to assess the general knowledge

of radiation protection, dose limits, personal monitoring devices and the health effects of radiation amongst staff members. Respondents were asked to comment on their own knowledge of both radiation safety and the department's radiation safety procedures; as well as to suggest how to improve the overall radiation safety in the department.

RESULTS

85 staff members participated in the study with an overall response rate of 90%. The mean Knowledge score was 73%. 58% (n=49) of respondent's had a "Good" score, 35% (n=30) had a "Fair" score and 7% (n=6) a "Poor" score. 93% (n=79) of respondents had an adequate knowledge to work in a radiation environment. The mean Knowledge score was higher for those who had over 10 years of registration compared to those that had 0-5 years registration (p=0.032). The Nurses and Radiotherapy students were the poorest respondent's in certain categories. 49% (n=42) of respondents indicated that they felt that they knew enough about radiation safety in their own working environment and 49% (n=42) also indicated that they were aware of the department's radiation safety procedures. The preferred method to improve overall radiation safety was departmental lectures (67%, n=57). 32% (n=27) of respondents suggested formal refresher courses with a further 11% (n=9) suggesting other options that included the provision of educational material (in the form of booklets and pamphlets); better orientation of new staff; and for clearer safety protocols to be displayed in the department.

CONCLUSION

Our study showed that 93% of respondents had an adequate knowledge to work in a radiation environment. However the Nurses and Radiotherapy students were the poorest respondent's in certain categories and would therefore need more targeted support to improve their knowledge of radiation safety. To increase awareness levels among staff, the author suggests that greater emphasis needs to be on implementing orientation programs for all new staff joining, regular and ongoing seminars and training programs in radiation safety.

ACKNOWLEDGEMENTS

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6) My dear husband, Dr Sooraj Ramith Motilall, for his many hours of help in brainstorming with me, trying to understand Radiation Oncology with a surgeon's mind set and never giving up on me. Without you this dissertation would have never materialised. You are my hero!

7) CMJAH Department of Radiation Oncology staff for your co-operation in being part of the study and your invaluable feedback during the study.

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Nomenclature

ALARA	As Low As Reasonably Achievable
ANOVA	Analysis of Variance
CT scan	Computerized Axial Tomography scan
CMJAH	Charlotte Maxeke Johannesburg Academic Hospital
DNA	Deoxyribonucleic acid
EBRT	External Beam Radiation Treatment
ICRP	International Commission on Radiation Protection
PET	Positron Emission Tomography
RPO	Radiation Protection Officer

APPENDICES

A. Study questionnaire

B. Ethics clearance certificate from Medical Human Research Ethics Council

C. Turn it in plagiarism report

1. INTRODUCTION

1.1 BASICS OF RADIATION

Radiation is the transmission of energy in either particles or waves through space or a medium.

Depending on the energy of the particles, it may be divided into ionizing or non-ionizing radiation (Figure 1.1.1):

- Ionizing radiation – It has sufficiently high energy to eject one or more orbital electrons from the atom or molecule (i.e. ionize the atom or molecule) and therefore has a potential to cause biological damage in body cells by damaging tissues and DNA. Examples of ionizing radiation include x-rays and gamma rays.
- Non-ionizing radiation – The electromagnetic radiation that does not carry enough energy to ionize atoms. Examples include light (ultraviolet, visible and infrared), radio waves and microwaves. (1)

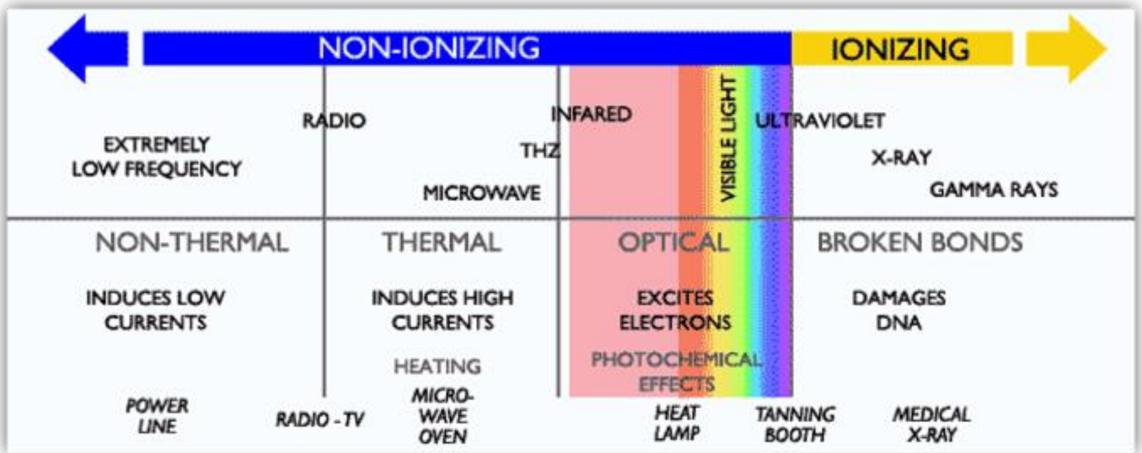

Figure 1.1.1 Spectrum of non-ionizing and ionizing radiation (1)

Ionizing radiation is further classified as directly or indirectly ionizing (Figure 1.1.2):

- Directly Ionizing radiation – These are charged particles (e.g. electrons or alpha particles) with sufficient kinetic energy that interacts with the atom/molecule of the medium through which it passes, thus ejecting the orbital electron(s) and creating a free radical that produces the chemical and biological changes.
- Indirectly Ionizing radiation – These are non-charged particles (e.g. neutron and photons) moving through a medium and first give up their energy to produce a charged particle and the charged particle interacts with atom/molecule of the medium through which it passes, thus ejecting the orbital electron(s) and creating a free radical that produces the chemical and biological changes.

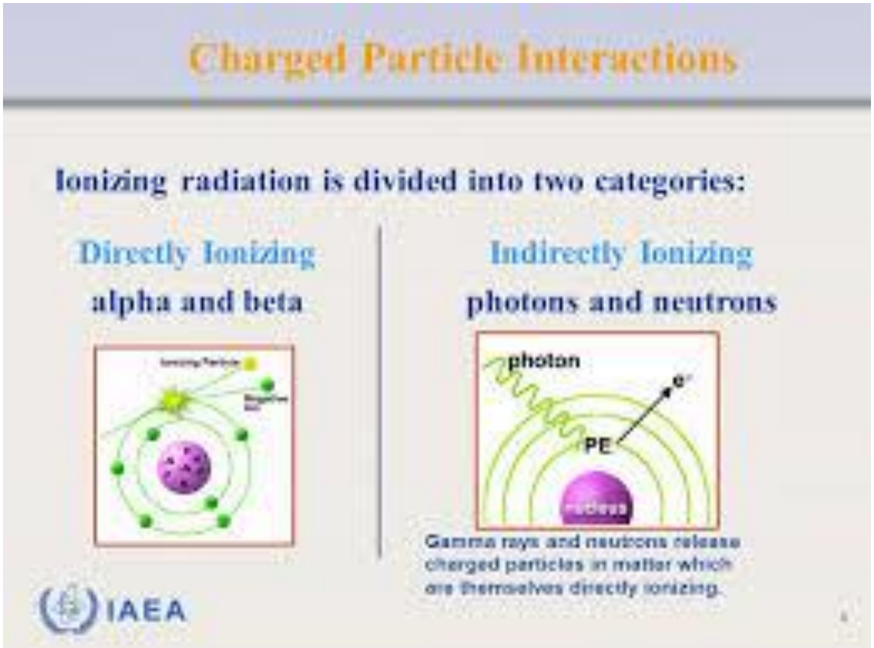

Figure 1.1.2 Interaction of radiation with matter. (2)

Background radiation occurs naturally on Earth from minerals (e.g. uranium), man-made sources (e.g. nuclear reactors) and from cosmic radiation from outer space. (2)

1.2 BIOLOGICAL EFFECTS OF IONIZING RADIATION

The critical target of radiation is the cell's DNA in its nucleus.

Biological effects occur when the cell's DNA damage is either repaired incorrectly or not repaired at all. Improperly repaired or damaged DNA lead to chromatid and chromosome aberrations, decreased cellular proliferation and sensitivity to ionizing radiation. These may result in mutations, cancers or cell death. With sufficient cells dying, organ failure or even death can occur.

The biological effects on the target DNA may be caused by direct or indirect action (figure 1.2.1):

- Direct action – the ionizing particle interacts directly with the DNA thus producing its effect and thereby leading to biological changes.
- Indirect action – the ionizing radiation interacts with e.g. a water molecule in the medium to produce a free radical. The free radicals that are produced then interact with the DNA leading to biological changes. (3)

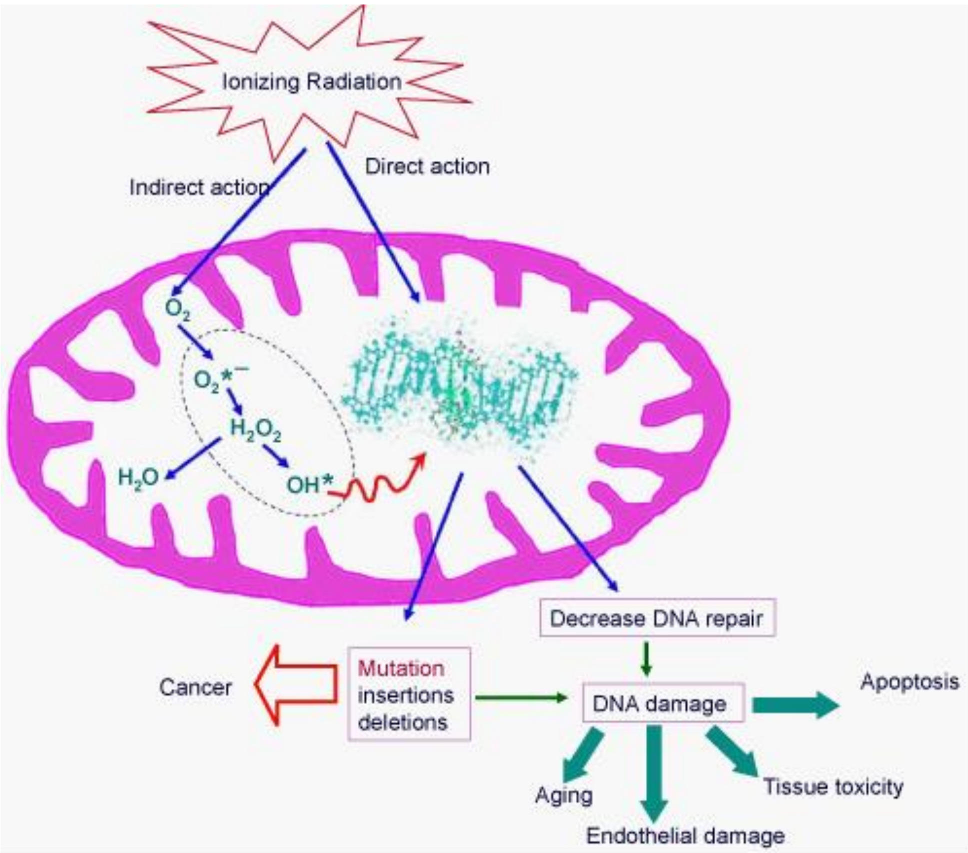

Figure 1.2.1 Direct and indirect action of ionizing radiation on the target cell (3)

1.3 DETRIMENTAL HEALTH EFFECTS OF IONIZING RADIATION

Multiple studies have looked at the complications of ionizing radiation exposure. These studies include:

- The Japanese survivors of the atomic bomb attacks on Hiroshima and Nagasaki;
- Patients who developed complications after exposure to medical radiation – e.g. patients who developed leukaemia after receiving radiation treatment for ankylosing spondylitis; children who developed thyroid cancer after receiving radiation treatment for tinea capitis or diseases of the tonsils; and women who developed breast cancer after receiving radiation treatment for postpartum mastitis;
- Workers who developed cancer after occupational exposure to radiation – e.g. increased incidence of lung cancers in uranium miners; bone cancers in dial painters who ingested radium when they licked their brushes into sharp points to apply the paint to watches (4)

(i) Deterministic (non-random) or Stochastic (random) effects

From these studies it became apparent that the effects of ionizing radiation on an individual may be broadly categorised as deterministic (non-random) or stochastic (random):

- The *severity* of deterministic effects varies with the dose of radiation and usually occurs above a certain threshold. Cataracts, sterility and tissue fibrosis are examples of deterministic effects of radiation.
- The *probability* of stochastic effects varies with the radiation dose and the effects are not dependent on a threshold. These include carcinogenesis and genetic effects. (4)

(ii) Cell and tissue sensitivity to radiation

Cells are most sensitive to the effects of ionizing radiation during cellular division. Therefore cells with a higher cell division rate (e.g. bone marrow, stem cell populations, mucosa lining of the small intestine, immune response cells) are more sensitive than slower dividing cells (e.g. muscle cells, neurons, mature blood cells) (4)

(iii) Effect on the embryo / foetus

Ionizing radiation may also seriously affect a developing embryo/foetus and may cause congenital malformations, growth restriction, mental retardation and even death. These effects depend on the stage of the pregnancy as well as the dose and the dose rate of the ionizing radiation received. (4)

(iv) Early radiation lethality

This is the death of an individual that occurs within a few weeks of exposure to a specific high intensity of radiation.

Acute Radiation syndrome follows total body irradiation and a series of stages occur, the duration and intensity of which depends on the dose of initial radiation.

During the initial prodromal phase the affected individual may experience anorexia, nausea, vomiting, diarrhoea, easy fatigability, or hypotension.

Thereafter a latent period follows and symptoms disappear. The subsequent development of manifest symptoms (cerebrovascular, hematopoietic or gastrointestinal) depends on the initial dose of radiation (figure 1.3.1). Recovery or death may follow depending on the severity of symptoms and the availability of appropriate medical care. (4)

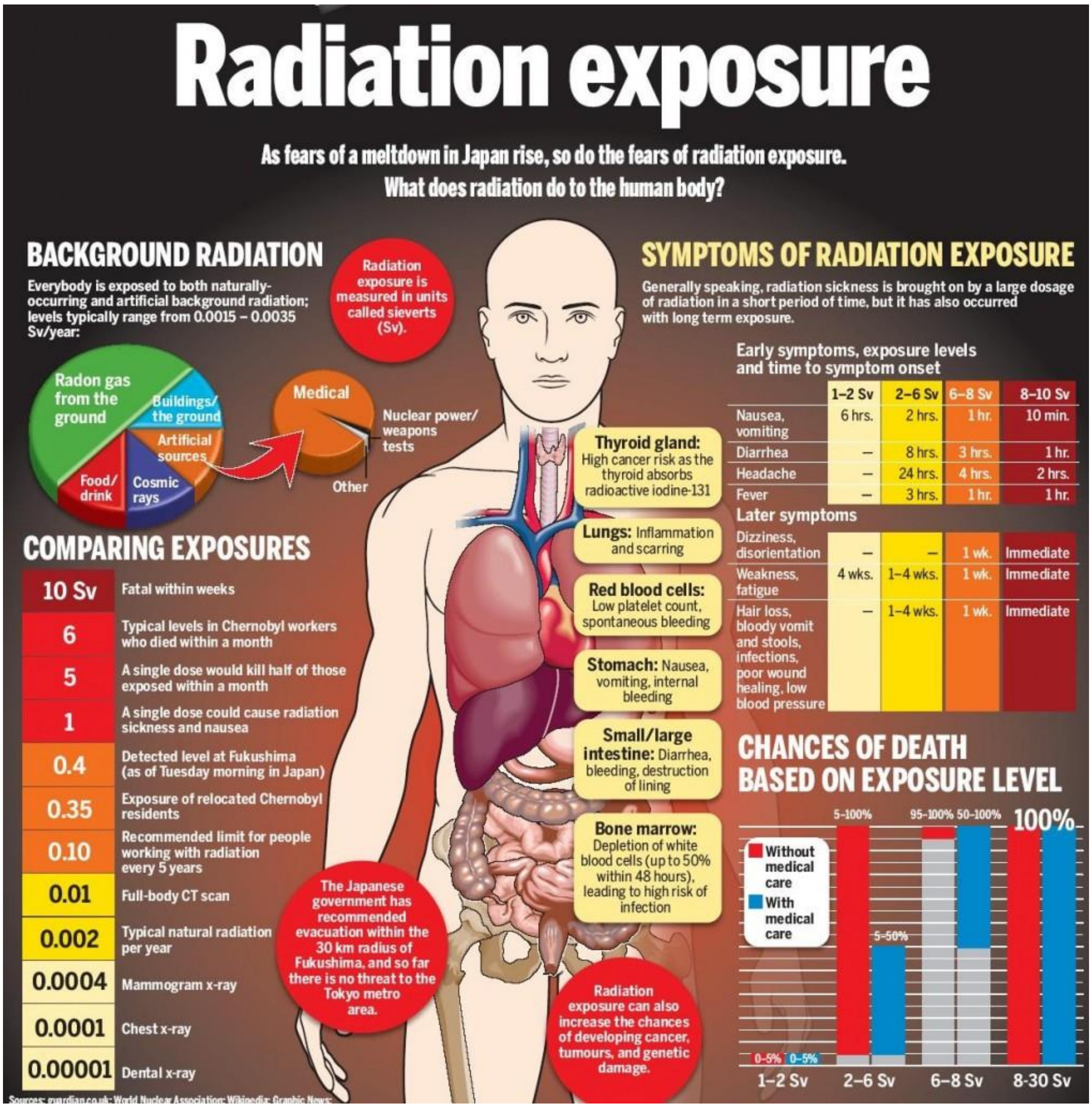

Figure 1.3.1 Adverse effects of ionizing radiation on the human body (5)

1.4 MEDICAL USE OF IONIZING RADIATION

Some forms of ionizing radiation (e.g. X-rays and gamma rays) are used medically in the diagnosis and treatment of certain medical conditions.

Imaging tests (e.g. X-rays, CT scans, PET scans and Bone scans) expose patients to low levels of radiation.

During radiation therapy, much higher doses of ionizing radiation are directed at the target volume to cause cellular death. However radiation of the surrounding normal body cells may lead to detrimental health effects.

1.5 PRINCIPLES OF RADIATION PROTECTION

Radiation protection is important to protect both people and the environment from the harmful effects of ionizing radiation. It serves to prevent the deterministic effects by keeping exposure doses to below threshold doses and to limit the risk of stochastic effects as much as reasonably possible.

The guiding principle is to keep each person's exposure to ionizing radiation to as low as reasonably achievable (ALARA) without compromising imaging quality or therapy. This is achieved by decreasing the time of radiation exposure, increasing the distance between the radiation source and the person being exposed, and placing adequate shields and protective devices between the source of radiation and the person being radiated. (6)

With the increasing use of ionizing radiation in both diagnostic and therapeutic medicine it became essential to limit the dose received by radiation-exposed workers.

To achieve this, the International Commission on Radiological Protection (ICRP) recommended dose limits for radiation-exposed workers. The annual maximum permissible dose for designated radiation workers by the ICRP is 20 mSV/yr averaged over 5 years but not more than 50 mSV in any 1 year, while that of the public is 1mSv/year. Pregnant women may work in certain radiation areas but the dose to the foetus must be less than 1mSv during the course of the pregnancy.

All radiation workers require monitoring of their radiation exposures, protection against unnecessary radiation exposure in their work environment and appropriate education to ensure their safety at work. An individual's exposure to ionizing radiation is measured with a personal dosimeter (e.g. film badge, pocket ionizing chamber or thermo luminescence badge). After a definite period (e.g. a month) the personal dosimeters are sent for reading and a lifetime record is kept of radiation exposures. (7, 8)

Additionally work places containing sources of radiation should be designed as controlled or supervised to facilitate monitoring occupational exposures.

- In a controlled area - access, occupancy and working conditions are strictly controlled for radiation protection purposes.
- In a supervised area - occupational exposure is kept under review although specific protective and safety provisions are not strictly required.

A RPO is appointed by a facility to identify safety issues, recommend corrective actions and ensure compliance with regulations to protect both the public and employees from the detrimental effects of ionizing radiation. (9)

2. LITERATURE REVIEW:

2.1 Health risks associated with Ionizing radiation

When Wihelm Conrad Roentgen discovered X-rays in 1895, he unleashed one of the most powerful discoveries that would change the future of medicine. Scientists soon discovered that there were health risks associated with this discovery.

Clarence Dally, one of Thomas Edison's assistants died an agonising death in 1904 after suffering radiation burns that necessitated amputations of his left arm above his elbow and his right arm at the shoulder. (10)

Since then multiple studies have looked at the complications of ionizing radiation exposure:

- Japanese survivors of the atomic bomb attacks on Hiroshima and Nagasaki,
- Patients who developed complications after exposure to medical radiation.
- Workers who are occupationally exposed to ionizing radiation

(a) Japanese survivors of the atomic bomb attacks on Hiroshima and Nagasaki

The Life Span Study (LSS) followed a cohort of approximately 120,000 survivors of the 1945 atomic bombings in Hiroshima and Nagasaki. This data has been used in several studies which have focused on an increased incidence in cancers of the thyroid, salivary glands, liver, lung, skin and female breast in these survivors. There have also been reports of an increased association with non-cancer diseases – viz. heart disease, strokes and diseases of the respiratory and haematopoietic

TABLE 6-1 Number of Subjects, Solid Cancer Deaths, and Noncancer Disease Deaths by Radiation Dose

	DS86 Weighted Colon Dose (Sv)[a]							
	Total	0 (<0.005)	0.005– 0.1	0.1–0.2	0.2–0.5	0.5–1.0	1.0–2.0	2.0
Number of subjects	86,572	37,458	31,650	5,732	6,332	3,299	1,613	488
Solid cancer deaths (1950–1997)	9,335	3,833	3,277	668	763	438	274	82
Noncancer disease deaths (1950–1997)	31,881	13,832	11,633	2163	2,423	1,161	506	163

[a]These categories are defined using the estimated dose to the colon, obtained as the sum of the γ-ray dose to the colon plus 10 times the neutron dose to the colon.

SOURCE: Based on data from Preston and others (2003).

Table 2.1.1 Health risks from exposure to low levels of ionizing radiation (11)

(b) Patients who developed complications after exposure to medical radiation

According to the United States Food and Drug Administration (FDA) the greatest unnatural source of radiation exposure is the medical use of radiation. (12)

Several studies have been done on patients who have received diagnostic or therapeutic radiation (for benign and malignant diseases) to assess their risk of later developing malignancies.

In the United States, radiation exposure from medical sources was 5.9 times higher in 2006 than 1980. This increase was attributed to the increased use of CT scans and nuclear medicine studies. Brenner et al. also raised awareness about the increased use of CT scans and the risks thereof (10, 13)

The Biologic Effects of Ionizing Radiation (BEIR) VII report assessed the health risks associated with exposure to low levels of ionizing radiation. Their lifetime risk model predicted a 1% increase in risk of developing a solid tumor or leukemia after a radiation exposure of 10,000 mrem. This is the equivalent dose that would be received by a large patient undergoing 2-3 CT scans of the abdomen. (11)

Previously x-rays were used to epilate children who had tinea capitis. Modan et al found an increased risk of brain tumours, salivary gland tumours, skin cancers and leukaemias in the cohort of 20,000 North African immigrant children who were treated with x-rays for tinea capitis in Israel. (14)

Radiation therapy has been linked to occurrences of secondary malignancies, including leukemia, sarcomas, thyroid carcinoma, lung carcinoma, and bladder carcinoma. (15,16)

Suit et al. reported an increased incidence of secondary malignancies in patients who were treated for cervical cancer with External Beam Radiation Therapy (EBRT). (17)

(c) Workers who are occupationally exposed to ionizing radiation

Numerous studies have addressed the incidence of cancer in various occupationally exposed groups (e.g. radiologists, radiographers, nuclear medicine specialists, dentists, miners, aircrew and nuclear power plant workers)

With nuclear industry workers, as indicated in Table 2.1.2, there was an increased risk of all cancers seen in the Rocketdyne and BNFL studies with an increase in the incidence of leukaemias in the Mound and Rocketdyne studies. (11)

TABLE of Studies of Nuclear Industry Workers with Individual External Dosimetry that Did Not Provide ERRs or EARs

			All Cancers		Leukemia	
Country	Facility	No. of Subjects	No. of Deaths	Results (90% CI)	No. of Deaths	Results (90% CI)
United States	Mound (Wiggs and others 1991a, 1991b)	3,229	66	No association with radiation dose	4	Significant ($p < .01$) positive trend with radiation dose
	Los Alamos (Wiggs and others 1994)	15,727	732	No association with radiation dose	44	No association with radiation dose
	Portsmouth Naval Shipyard (Rinsky and others 1981)	7,615	201	No association with radiation dose	7	No association with radiation dose
	Rocky Flats (Wilkinson and others 1987)	5,413	50	Slope = –3.65/10 mSv (–12.02, 4.71)	4	RR = 1.0 (0.8, 9.1) for 10mSv vs. <10 mSv
	Rocketdyne (Ritz and others 1999a)	4,563	258	Significant ($p = .036$) trend	28[a]	Significant ($p = .003$) trend
United Kingdom	BNFL (McGeoghegan and Binks 1999)	2,467	—[b]	Significant ($p < .01$) positive trend when doses are lagged by 15 years	—[b]	No association with radiation dose

Table 2.1.2 Studies of nuclear industry workers who developed cancer post occupational radiation exposure (11)

A study of 146022 United States Certified Radiologic Technologists that worked for 2 years or longer from 1926 to 1982 showed that these technologists had a higher risk for breast cancer and leukaemia (18).

In a separate cohort study of 67562 medical workers from the Canadian National Dose registry over the period 1951 to 1987, there was an increased risk of thyroid cancer observed amongst medical workers occupationally exposed to ionizing radiation (19).

2.2 Continuing education to improve awareness of safe radiation practices among ionizing radiation workers

Education is an important tool in managing radiation safety. Radiation workers need to know how important their role is in ensuring compliance to radiation safety practices in their work environment. Their safety practices have the potential to detrimentally affect not only their own health but also the health and welfare of their patients. Several studies have been undertaken to assess the knowledge and radiation protection practices amongst health care workers.

In his study among radiographers in Lagos, Nigeria, Eze CU et al. suggested that the radiographers increase their efforts to apply their knowledge in radiation protection (7).

A study by Adejumo et al. showed that knowledge and compliance did not depend on years of practice and continuing education may improve compliance to radiation safety practices (20). In his study Adejumo found that whilst 97% of his study population had a good knowledge of radiation safety standards, 80% of them had less than 10 years in practice and most of them were involved in continuing education.

Olesula et al showed a low level of awareness of radiation protection amongst doctors in a Nigerian Teaching Hospital and suggested continuous educational programs for qualified doctors. (21)

Kiguli-Malwadde et al. found that the radiation safety practices at their hospital was inadequate and stressed the importance of introductory seminars on radiation safety for workers prior to starting to work with radiation and the need for continuous education on radiation safety. (22)

From the above studies we can deduce that although it is important for workers to receive initial training in radiation protection, post qualification work experience alone is insufficient to ensure knowledge of and compliance with radiation safety guidelines. Continuing educational programs are therefore necessary to ensure safe radiation practices amongst health care workers.

Rationale of the study

A literature search using PubMed and Google Scholar amongst other search engines (conducted up to 12 October 2015) show that there are currently no published studies advising of awareness of radiation safety amongst radiation oncology workers in South Africa.

In view of the concerns regarding the adverse health effects of ionizing radiation on the human body and the varying levels of awareness of radiation protection amongst radiation workers, this study was conceived to determine the levels of awareness of radiation protection amongst radiation oncology staff in a quaternary hospital in South Africa.

3. CURRENT STUDY

3.1 STUDY OBJECTIVES

This study was undertaken to:

1. Assess the knowledge of radiation safety amongst participants;
2. Identify ways in which participants would prefer to improve their knowledge in radiation safety

3.2 MATERIALS AND METHODS

A prospective cross sectional study was undertaken in the Department of Radiation Oncology at the CMJAH. All radiation workers in the Department of Radiation Oncology at CMJAH were invited to participate in the study. These comprised the Radiation Oncology doctors (Consultants and Registrars), Radiotherapists (qualified and students), Medical Physicists and Nurses.

The sample size was fixed by the number of staff members working in the department. Sample size calculations were carried out in G*Power (23).

A standardized, semi-structured questionnaire (Appendix A) was used to collect the data. The questionnaire resulted from a literature search and on-site observation with the validity of the questions being confirmed by a senior radiation oncologist and a senior medical physicist. The questions chosen were deemed to be core knowledge for all medical radiation workers exposed to radiation on a regular basis. It would be expected that all the respondents (irrespective of their job description) should have this basic knowledge in order to work safely in a radiation exposed environment. Prior to commencing this study we had consulted with a statistician. We had looked at the potential study population and noted that the sample size within each group would be very small to make statistically significant associations within each group. It was with this reason that the groups were analyzed together and the questions which were selected were chosen so that they would not bias any particular group – i.e. first year Radiotherapy student versus a Consultant Radiation oncologist.

Data were collected from the 14th to 28th of March 2016. Those staff members who agreed to partake in the study were given 15 minutes after their morning meeting to complete the questionnaires anonymously. They were not allowed to refer to any educational material or to confer with each other.

The questionnaire had 3 parts – the first 2 of which followed a multiple choice format. The first part contained demographic questions including age, sex, job designation and years of experience as a radiation worker. Students and Registrars who had no previous exposure in a radiation environment and were in their first year of study were considered to have zero years of experience.

The second part consisted of 16 questions to assess the general knowledge of radiation protection, dose limits, personal monitoring devices and the health effects of radiation. There was no negative marking and each correct answer in section 2 earned the responder a score of +1. The "Knowledge score" was assessed as the respondent's gross score out of 16, converted to a percentage. Based on this score, the "Categorized knowledge score" was then assumed to be:- "Poor" if the score out of 16 was less than 8 (<50%), "Fair" if the score was from 8 to 11 and "Good" if the score was 12 or more (>=75%) out of 16. Additionally those that scored "Fair" and "Good" were considered to have an adequate knowledge of radiation safety. From the list of these 16 knowledge questions certain questions were identified as being core knowledge. These included identifying the department's RPO, knowledge of the ALARA principle and ICRP dose limits.

The third part of the questionnaire allowed the respondent to comment on his/her own knowledge of both radiation safety and the department's radiation safety procedures. It also requested suggestions to improve the overall radiation safety in the department. The respondents were not penalised if they chose not to make any suggestions on how to improve the overall radiation safety in the department.

3.3 DATA ANALYSIS

A descriptive analysis of the data was undertaken. Categorical variables were summarised by frequency and percentage tabulation and were illustrated with bar charts. Continuous variables were summarised by the mean, standard deviation, median and interquartile range, and their distribution was illustrated with histograms.

The Chi square ($X^{2)}$ test was used to assess the relationship between:

- Responses to each knowledge question and job designation,
- Categorised knowledge score and job designation, age, sex, years of registration,
- Selected questions and age, years of registration and job designation.

When the requirements for the X^2 test could not be met, Fisher's exact test was used. The strength of these associations was measured by Cramer's V and the phi coefficient respectively. The following scale of interpretation was used:

0.50 and above high/strong association

0.30 to 0.49 moderate association

0.10 to 0.29 weak associations

below 0.10 little if any association

The relationship between the knowledge score and job designation, age, sex, years of registration was assessed by the independent samples t-test for two groups and one-way Analysis of Variance (ANOVA) with post-hoc tests using the Tukey-Kramer adjustment for unequal group sizes) for more than two groups. Where the data did not meet the assumptions of these tests, non-parametric alternatives, the Wilcoxon rank sum test (for two groups) and the Kruskal-Wallis test (for more than two groups) were used. The strength of the associations was measured by the Cohen's d for parametric tests and the r-value for the non-parametric tests. The following scale of interpretation was used:

0.80 and above	large effect
0.50 to 0.79	moderate effect
0.20 to 0.49	small effect
below 0.20	near zero effect

The 5% significance level was used. Data analysis was carried out using SAS (version 9.4 for Windows).

4. STUDY RESULTS

The response rates, overall and by job designation, are tabulated below in Table 4.1

Job designation	**Number of staff members**		**Response Rate (%)**
	Employed	**Responded**	
Overall	95	85	**89.5**
Nurse	14	13	**92.9**
Radiotherapy student	21	21	**100.0**
Radiotherapist	32	28	**87.5**
Medical Physicist	11	9	**81.8**
Registrar	11	11	**100.0**
Consultant	6	3	**50.0**

Table 4.1 Response rates of subjects in study with respect to job designation

The overall response rate was 90% (85/95) and the response rates for the individual job designations were in the range 82-100% with the exception of the Consultants who only had a response rate of 50%.

As illustrated in Figure 4.1 below, majority of the respondents were Radiotherapists (n=28; 33%), followed by Radiotherapy students (n=21; 25%).

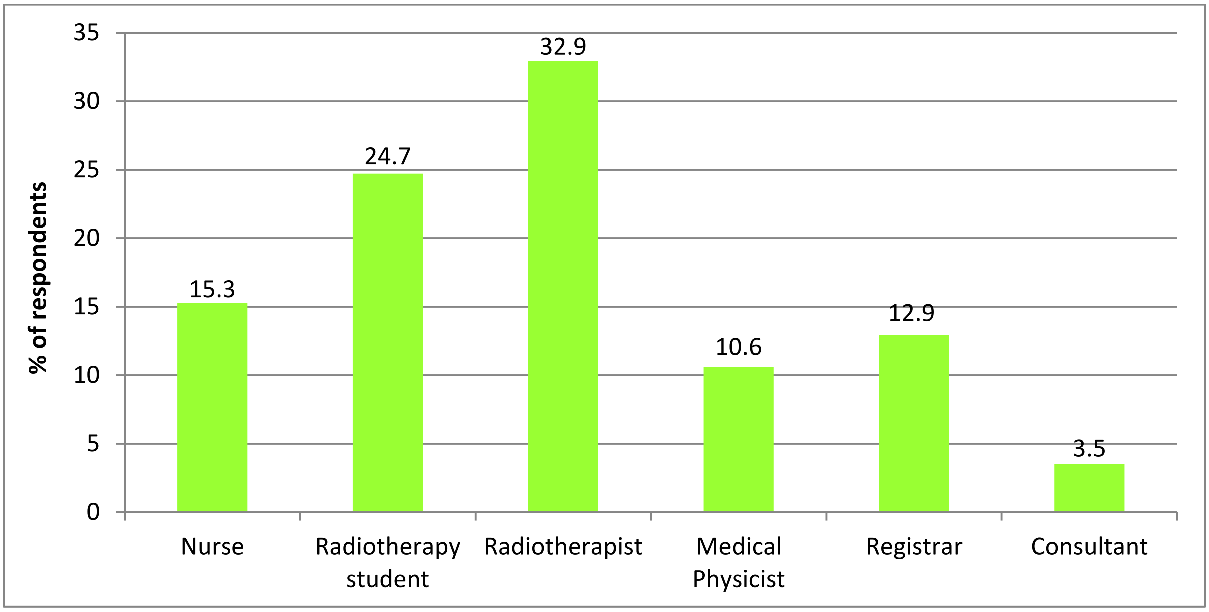

Figure 4.1 Distribution of subjects in the study with respect to job designation

Most of the participating Registrars were in their first year (n=9; 82%) of study except for 2 who were in their 4th year. Amongst the radiotherapy students 14% (n=3) were in their 1st year, 29% (n=6) in their 2nd year and 57% (n=12) in their 3rd year of study.

The majority of respondents (51%) were young (18-30y). In the graph below, it can be seen that the percentage of respondents decreased with increasing age category.

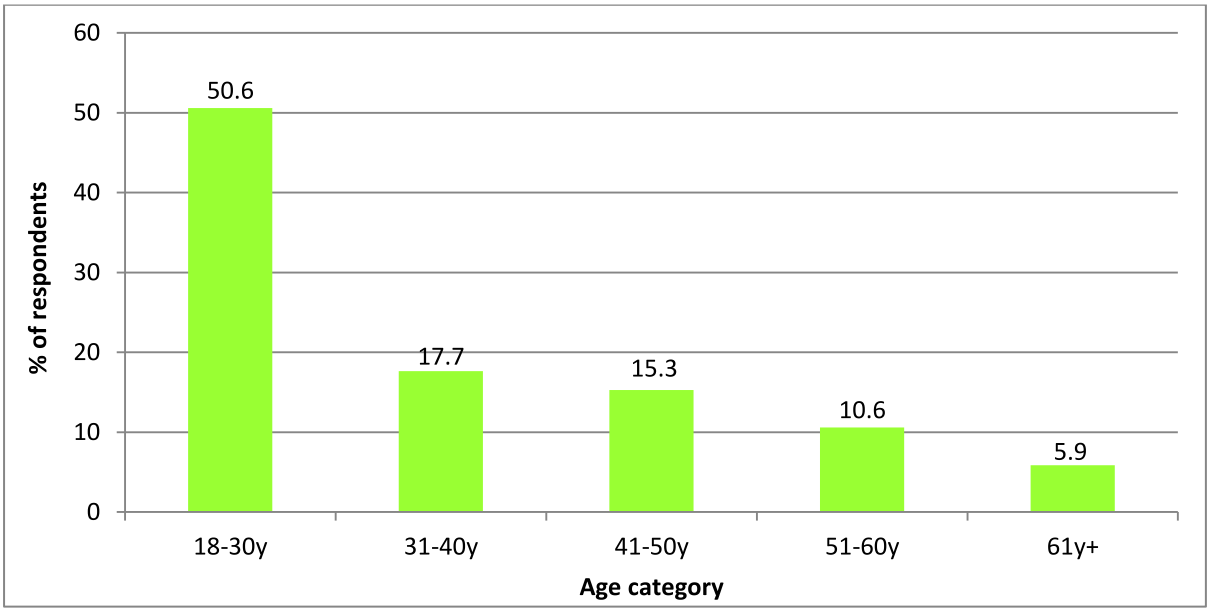

Figure 4.2 Distribution of subjects in the study with respect to age

68% (n=58) of the respondents were female. There was a significant, moderate, association between sex and job designation (Fisher's exact test: p=0.0015; phi coefficient=0.48). The proportion of males was higher in the Consultants and Medical Physicists, and lower in Nurses, compared to the other groups.

In the cross-tabulation of years of registration vs. job designation shown below, only the Nurses, Radiotherapists and Medical Physicists span most of the full range.

Years of registration	Job designation						
	Nurse	Radiotherapy student	Radiotherapist	Medical Physicist	Registrar	Consultant	Total
0-5y	4	21	14	7	10		56
5-10y	6		5	1	1		13
10-15y	1		3				4
15-20y	1		2				3
20-25y	1						1
25-30y			1				1
>30y			3	1		3	7
Total	13	21	28	9	11	3	85

Table 4.2 Response rates of subjects with respect to years of registration vs. job designation

For further analyses w.r.t. years of registration, the top five categories were combined due to small group sizes.

The median **Knowledge score** was 75% (interquartile range (IQR) 63-88%; range 19-100%; mean 73%). Most participants scored reasonably well, with a few scoring poorly (i.e. less than 50%)   (Figure 4.3)

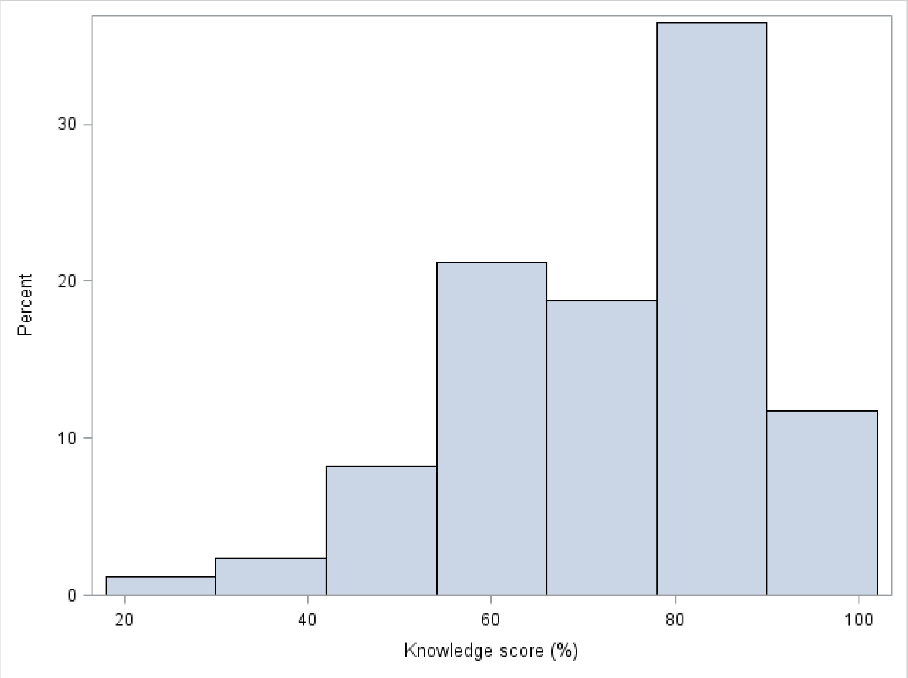

Figure 4.3 The distribution of Knowledge score of study particpants

Considering the **Categorised knowledge score**, in Figure 4.4, we find that 58% (n=49) of respondents had a “Good” score, while 35% (n=30) had a “Fair” score and 7% (n=6) had a Poor score. Therefore 93% (n=79) of respondents had an acceptable knowledge score.

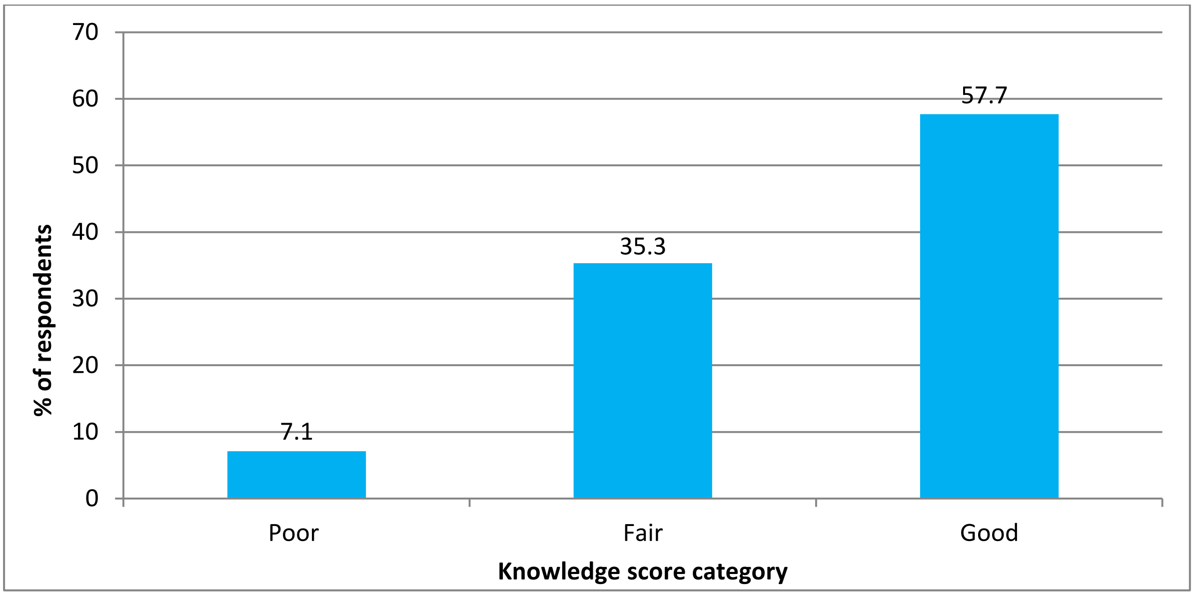

Figure 4.4 Categorized knowledge score of study particpants

Figure 4.5 shows the percentage of correct responses for each of the knowledge assessment questions, arranged in order of decreasing percentage of correct responses. With the exception of the question requesting staff to identify the department's RPO (11% correct response rate), all other questions had at least 60% correct response rates.

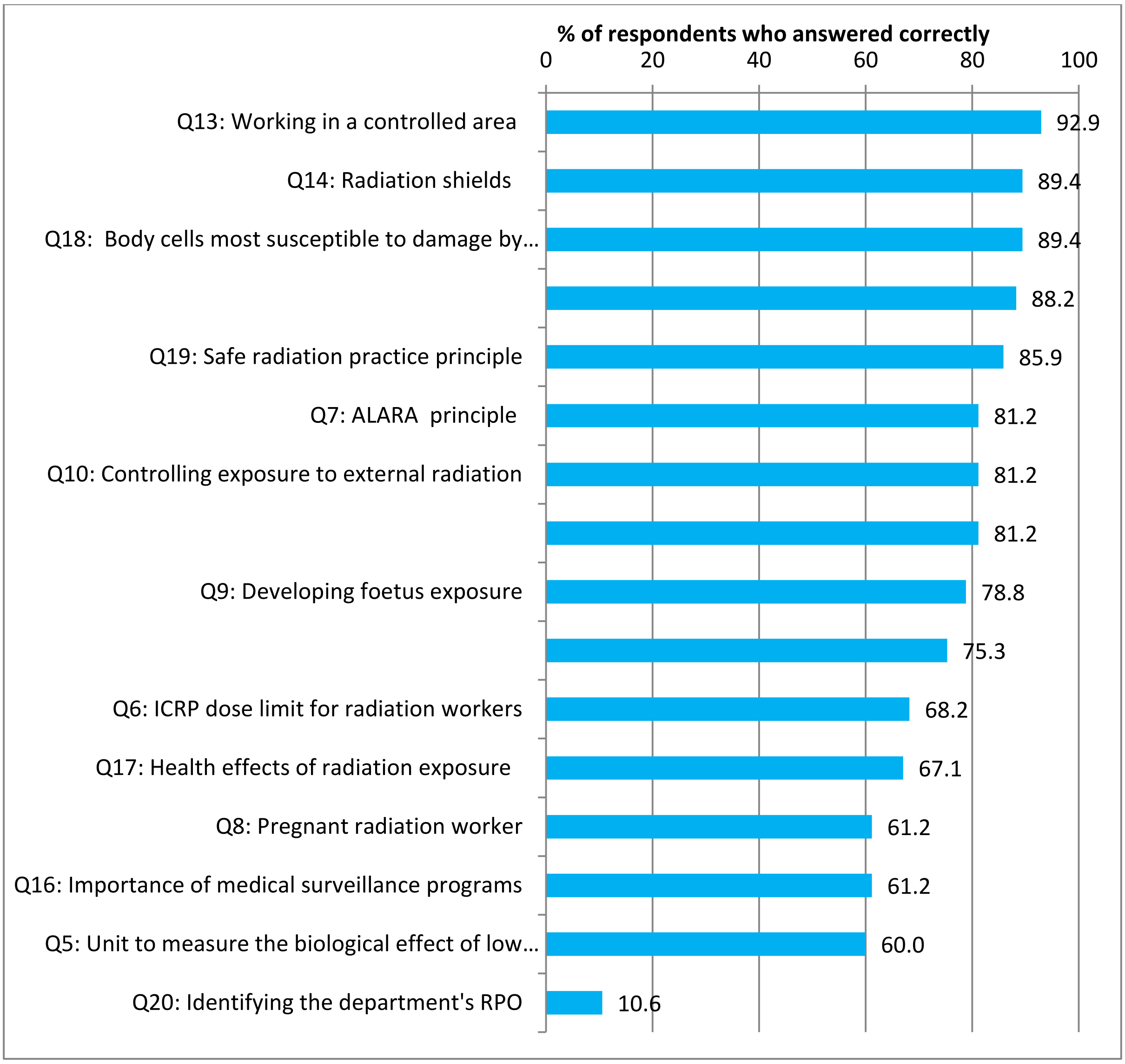

Figure 4.5 Percentage of correct responses for each of the assessment questions

There were significant differences between job designations for 9 of the 16 knowledge assessment questions.

Nurses scored lower and Radiotherapists and Consultants higher in identifying the unit which measures the biological effect of low levels of ionizing radiation on the human body ($p=0.0009$; phi coefficient=0.48).

Nurses scored lower and Radiotherapists higher in identifying the ALARA principle ($p=0.0006$; phi coefficient=0.46). Overall 81% (n=69) respondents were able to identify the correct ALARA principle.

Radiotherapy students scored lower and Radiotherapists and Medical Physicists higher in identifying the ICRP dose limit for radiation workers ($p=0.011$; phi coefficient=0.41). 68% (n=58) respondents were able to identify the correct ICRP dose limit.

In those questions which dealt with the technical aspects of radiation safety awareness, the Radiotherapy students scored lower and Radiotherapists higher: safe areas that a pregnant staff member may work in ($p=0.032$; phi coefficient=0.36); transporting of brachytherapy sources ($p=0.028$; phi coefficient=0.35) and the use of the radiation badges ($p=0.013$; phi coefficient=0.36).

Radiotherapy students scored lower and Radiotherapists higher in knowing the importance of medical surveillance programmes ($p=0.044$; phi coefficient=0.34).

Registrars scored lower and Radiotherapists higher in knowledge about a patient's radioactivity after external beam radiation treatment ($p=0.0023$; phi coefficient=0.46).

In identifying the department's RPO - Nurses, Radiotherapy students and Registrars scored lower and Consultants and Medical Physicists higher ($p<0.0001$; phi coefficient=0.65). Respondents with a 0-5 years of registration also scored lower in answering the same question ($p=0.0096$; phi coefficient=0.32). Only 11% (n=9) of respondents could identify the RPO.

There was a significant relationship between the Knowledge score and job designation (one-way ANOVA; $p<0.0001$). Post-hoc tests showed that the mean Knowledge score was higher for Consultants, Medical Physicists and Radiotherapists, compared to Nurses and Radiotherapy students. The effect sizes were all large (Cohen's d 1.5-2.5). The graph below (Figure 4.6) shows the mean Knowledge score for each group with the error bars denoting the 95% confidence interval for the mean.

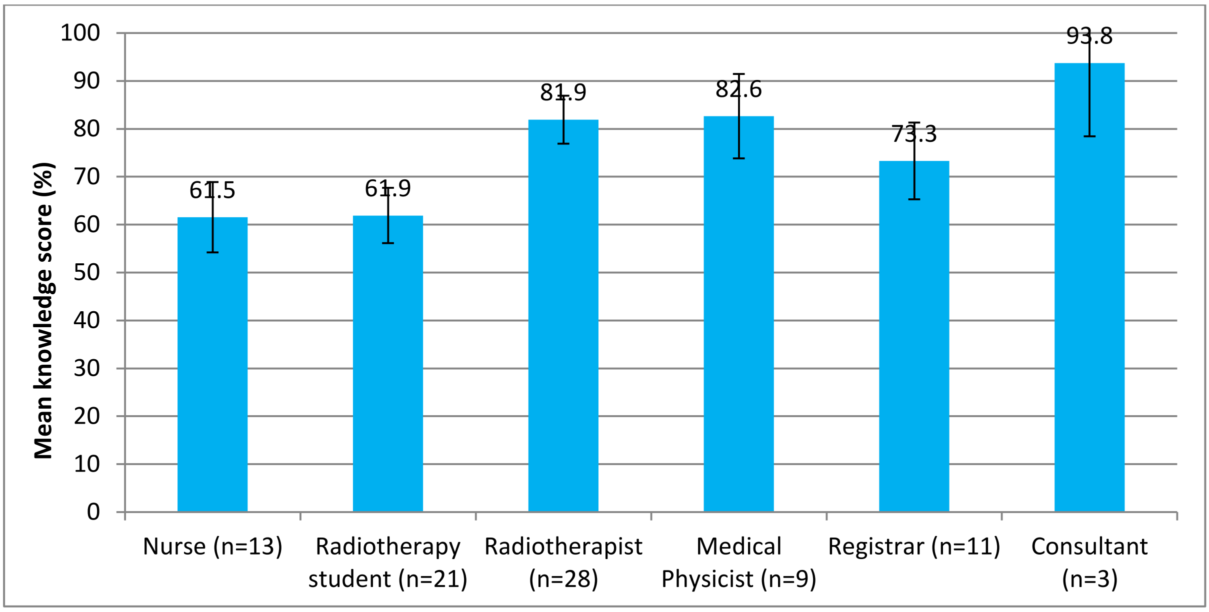

Figure 4.6 Mean Knowledge score with respect to job designation

There was a significant, strong, relationship between Categorised knowledge score and job designation (Fisher's exact test; p<0.0001; phi coefficient=0.61). Nurses and Radiotherapy students scored more poorly than Radiotherapists. (Figure 4.7)

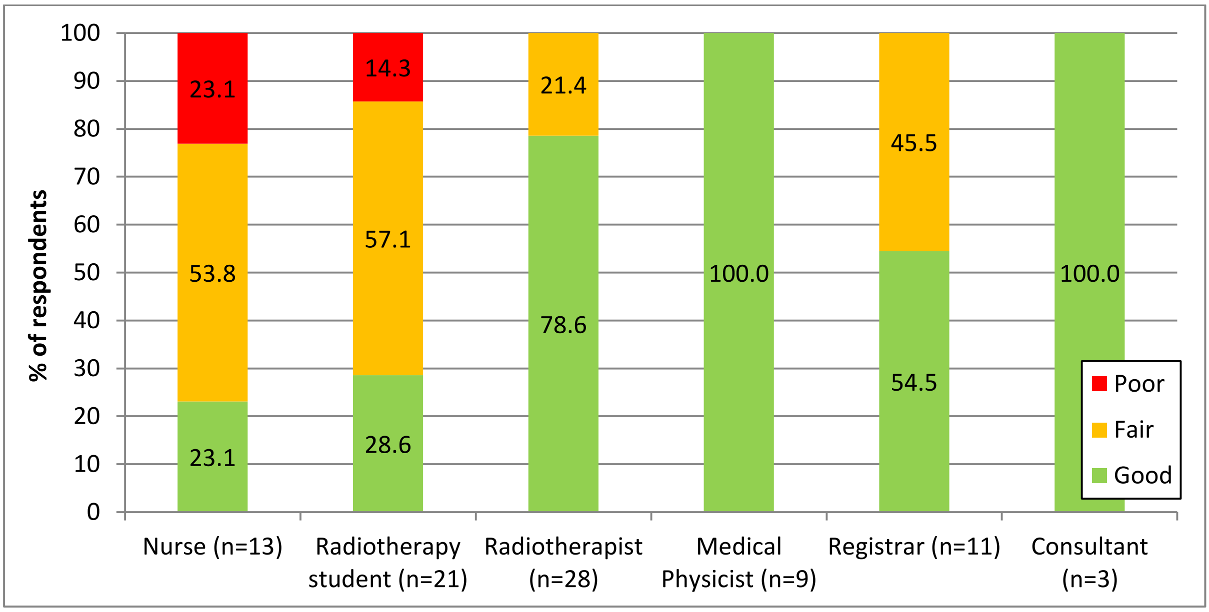

Figure 4.7 Distribution of the Categorized knowledge score with respect to job designation

There was no significant association between Knowledge score and age category (one-way ANOVA; p=0.33). However there was a significant, moderate relationship between Categorised knowledge score and age category (Fisher's exact test; p=0.031; phi coefficient=0.38). The observed differences can be explained in terms of the job designation composition of each age group as only the Nurses, Radiotherapists and Medical Physicists span most of the full age range.

There was no significant association between Knowledge score and sex (one-way ANOVA; p=0.82) or between Categorised knowledge score and sex (Fisher's exact test; p=0.66).

There was also no significant association between Categorised knowledge score and years of registration (Fisher's exact test; p=0.063). There was, however, a significant relationship between Knowledge score and years of registration (one-way

ANOVA; p=0.032). Post-hoc tests showed that the mean Knowledge score was higher for those with 10y+ registration, compared to those with 0-5yregistration. The effect size was moderate (Cohen’s d = 0.74). The mean Knowledge score for 5-10y registration did not differ significantly to that of the other two groups.

49% (n=42) of respondents indicated that they felt that they knew enough about radiation safety in their own working environment with Nurses rating themselves lower and Radiotherapists and Medical Physicists rating themselves higher compared to other groups ($p<0.0001$; phi coefficient=0.54). Additionally those with over 10 years of registration rated themselves higher compared to the other groups ($p=0.042$; phi coefficient=0.27).

49% (n=42) of respondents also indicated that they were aware of the department’s radiation safety procedures with Nurses and Registrars rating themselves lower and Medical Physicists rating themselves higher compared to the other groups ($p<0.0004$; phi coefficient=0.49).

There was no significant association between the respondent’s self assessment of knowledge of department’s radiation safety procedures and protocols and years of registration (Fisher’s exact test; $p=0.19$) or Categorised knowledge score (Fisher’s exact test; $p=0.10$).

Those with a "Good" Categorized knowledge score rated their knowledge about radiation safety in their own working environment higher compared to other groups (p=0.0016; phi coefficient=0.37). (Figure 4.8)

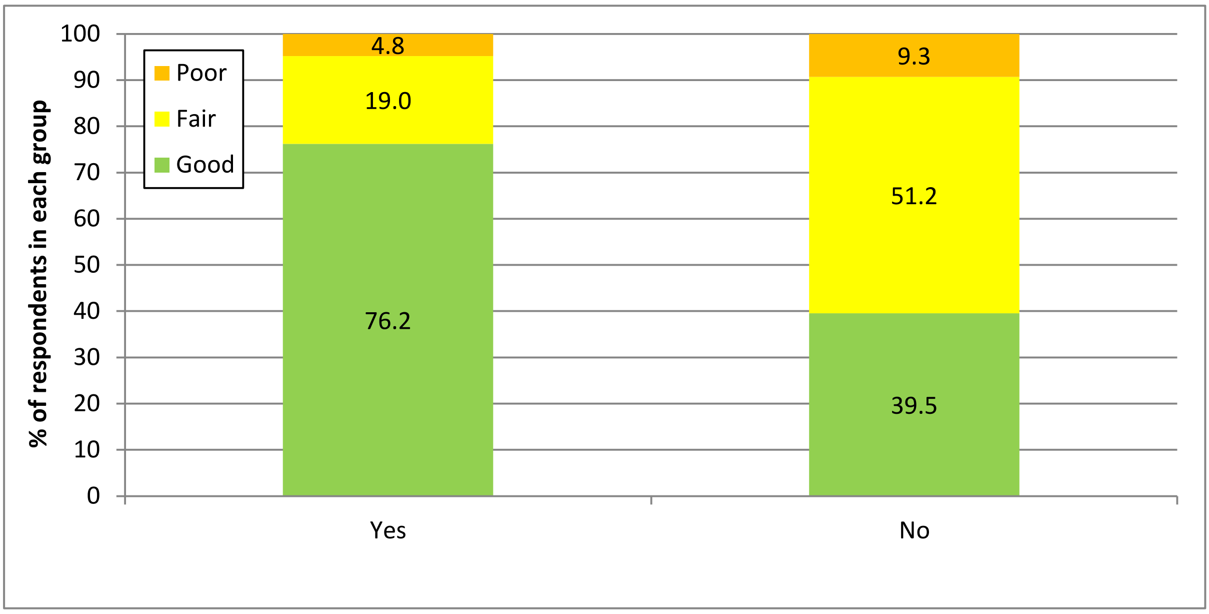

Figure 4.8 : Self assessment of knowledge of hazards at work and precautions to be taken with respect to Categorised knowledge score

The preferred method to improve overall radiation safety in the department was departmental lectures (67%, n=57). 32% (n=27) suggested formal refresher courses with a further 11% (n=9) suggesting other options that included the provision of educational material (in the form of booklets and pamphlets); better orientation of new staff; and for clearer safety protocols to be displayed in the department.

There was no significant association between the respondent's preference for departmental lectures or formal refresher courses to improve the overall radiation safety in the department with respect to: job designation (Fisher's exact test; p=0.27; 0.51 respectively), years of registration (Fisher's exact test; p=0.099 and 0.080 respectively) or Categorised knowledge score (Fisher's exact test; p=0.40 and 0.32 respectively).

5. DISCUSSION

The overall response rate was 93% and the survey responses were representative of the staff members of our department.

The study group purposefully included non-physicians (i.e. Nurses, Radiotherapists, Radiotherapy students and Medical Physicists). This was due to the frequent contact of these medical professionals with patients before and during procedures involving ionizing radiation. Dauer et al. reported that misconceptions in radiation knowledge may result in undue fears in staff which may in turn impact poorly on patient care. (24)

The mean Knowledge score was 73% (median 75%, interquartile range 63-88%; range 19-100%) with only 7% of respondents scoring poorly. This was in accordance with Eze et al. who reported that radiographers in Lagos, Nigeria had an average score of 73% in their radiation protection knowledge. However, Olesula reported scores ranging from 10-70% with a mean score of 33.8% in radiation protection awareness amongst doctors in a Nigerian Teaching hospital. (7, 21)

Due to their small group sizes, the Medical Physicists and Consultants did not contribute much to many parts of the data analysis. Further due to the small sample size of Medical Physicists, no sub analysis was undertaken of the medical physics interns.

There were significant differences between job designations for 9 of the 16 knowledge questions,

Identifying the department's RPO reflected poor knowledge with all other questions having at least 60% correct responses. Only 11% (n=9) of the respondent's correctly answered this question. Nurses, Radiotherapy students and Registrars scored lowest in this question compared to the other job designations. Respondents with a 0-5 years of registration also scored lower in answering the same question. This is extremely worrying as the RPO is very important as mentioned previously. Our RPO has been appointed by our facility to identify safety issues, recommend corrective actions and ensure compliance with regulations to protect both the public and employees from the detrimental effects of ionizing radiation.

In the general questions relating to radiation safety and awareness, the nurses scored lower in the questions relating to the unit of measurement of the biologic effect of radiation on the human body and identifying the ALARA principle. It was, however, encouraging that 81% (n=69) of our respondents were able to correctly identify the ALARA principle which is core knowledge in radiation protection. In other studies this ranged from 15-48%. (25, 26)

The radiotherapy students scored poorly in identifying the ICRP dose and knowing the role of the medical surveillance program. In our study there was no significant association between knowledge of the ICRP dose limits for radiation workers and age category or years of registration. 68% (n=58) of respondents knew the correct answer. This was between the values reported in 2 other studies which also assessed staff's knowledge on the ICRP dose limit. Mojiri et al. reported in their survey of radiographers in Hamadan City, Iran that 81.7% of radiographers knew the ICRP dose limit for workers. Amirzadeh et al. reported that 51.2% of radiation workers in hospitals in Shiraz were able to identify the correct ICRP dose limit for radiation workers. (27, 28)

In those questions which dealt with the technical aspects of radiation safety awareness -viz. safe areas that a pregnant staff member may work in; transporting of brachytherapy sources and the use of the radiation badges the Radiotherapy students scored lower.

Registrars scored lowest in identifying a patient's radioactivity after receiving radiation treatment. The may be explained by the fact that 82% of registrars were in their first year of study and there is currently no introductory seminars on radiation safety practices before staff start working in our department. Olesula et al. reported that doctor's scores were significantly affected by previous exposure to training in radiation protection. (21)

The mean Knowledge score (i.e. out of 16) and Categorized knowledge score (i.e. "Good"/ "Fair"/ "Poor") were lowest in Nurses and Radiotherapy students. This was especially disappointing as majority (57%) of the Radiotherapy students were in their 3rd and final year of study. In Nurses, the lack of knowledge on radiation safety issues is in agreement with many other studies observed. Alotaibi et al. found that in nurses working in a radiology department in Kuwait, the majority of participants were not knowledgeable about radiation protection concepts. Alotaibi and co-workers further reported a lack of awareness of radiation risks in nurses working in a nuclear medicine department in Kuwait. They advised that it was imperative to implement nursing education programs on basic knowledge of radiation, radioactive materials and radiation effects. Rassin reported that nurses' limited radiation protection knowledge could be due to their limited college-based and in-service education. (29, 30, 31)

The sample size of the Radiation oncology registrars and consultants were too low to make statistical significant inferences about their radiation awareness levels. Several other studies have shown a lack of knowledge on safety issues associated with ionizing radiation in many medical professionals such as general practitioners, radiologists, paediatricians. (26, 31, 32, 33)

In my literature review none of the other studies compared radiation protection knowledge amongst the different sexes. In view of this, the "sex" variable was chosen to determine if there was a potential difference in the knowledge of radiation protection amongst the different sexes. However no significant association was found. As this was the first study analyzing this variable it was felt that this was an important negative finding.

Categorized knowledge was better in the 31-40 year old and those >50 years old. However this observation may be explained in terms of the job designation composition of each age group as only the radiotherapists and medical physicists span the full age range.

The mean Knowledge score was higher for those who had over 10 years of registration compared to those that had 0-5 year's registration. Mojiri reported that there was a significant relation between awareness of radiation effects and work experience (years). This was in contrast to Adejumo and Olesula who reported that knowledge did not depend on years of practice or years post qualification respectively. (27, 20, 21)

49% (n=42) of respondents indicated that they felt that they knew enough about radiation safety in their own working environment with Nurses rating themselves lower and Radiotherapists and Medical Physicists rating themselves higher compared to other groups. Additionally those with over 10 years of registration rated them higher compared to the other groups.

49% (n=42) of respondents also indicated that they were aware of the department's radiation safety procedures with Nurses and Registrars rating themselves lower and Medical Physicists rating themselves higher compared to the other groups.

Those with a "Good" knowledge score rated their knowledge about radiation safety in their own working environment higher compared to other groups. This showed that staff that scored well had an ability to estimate their own knowledge. This is in disagreement with Paolicchi et al. who showed a lack of ability of Italian radiographers to estimate properly their own skills and knowledge of radiation protection and radiological dose assessment. Rassin reported that although more than 70% of physicians and nurses believed that they had great radiation protection knowledge, their knowledge was poor to moderate. (34, 31)

Education is an important tool in managing radiation safety. Radiation workers need to know how important their role is in ensuring compliance to radiation safety practices in their work environment A study by Adejumo et al showed that continuing education may improve compliance to radiation safety practices (7,20)

All respondents in the survey made suggestions on how to improve the overall radiation safety in our department. The preferred method to improve overall radiation safety was departmental lectures (67%, n=57). 32% (n=27) of respondents suggested formal refresher courses with a further 11% (n=9) suggesting other options that included the provision of educational material (in the form of booklets and pamphlets); better orientation of new staff; and for clearer safety protocols to be displayed in the department. A general positive attitude among respondents to further training was also noted in several other studies. Kiguli-Malwadde et al. stressed the need for radiation workers to have introductory seminars on radiation safety. Sadowski suggested that education in radiation protection helps to reduce unnecessary exposure to radiation. Jankowski reported that nurses' fears about their exposure to radiation can be greatly reduced through education. Continuing education programs were encouraged by Paolicchi, Dianati, (6, 22, 34, 35, 36, and 37)

6. Study Limitations

The overall population size was small and the resultant small sample size is only sufficient for the detection of large effect sizes. Due to the small individual sub groups of Medical Physicists and Consultants there were limited instances in which their results were statistically significant. Further due to the small sample size of Medical Physicists, no sub analysis was undertaken of the medical physics interns. Being a highly specialised sub group of professionals it is expected that the proportionate numbers of Medical Physicists and Consultants would be limited in a specialised department such as radiation oncology.

7. Conclusion

Our study showed that 93% of respondents had an adequate knowledge to work in a radiation environment. However the Nurses and Radiotherapy students were the poorest respondent's in certain categories and would therefore need more targeted support to improve on their knowledge of radiation safety.

The need for radiation staff to receive further training is in general agreement with the results of several similar studies. The preferred method to improve overall radiation safety in the department was departmental lectures. To increase awareness levels among staff, the author suggests that greater emphasis needs to be on implementing orientation programs for all new staff joining, regular and ongoing seminars and training programs.

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8. APPENDIX A: Study Questionnaire

SECTION 1: Please tick the correct box

<1> Age

1	18-30 years	
2	31-40 years	
3	41-50 years	
4	51-60 years	
5	>61 years	

<2> Sex

1	Male	
2	Female	

<3> Job Designation

1	Nurse	
2	Radiation therapist student (please circle year of study)	1
3		2
4		3
5	Radiation therapist	
6	Medical Physicist	
7	Registrar Radiation oncologist (please circle year of study)	1
8		2
9		3
10		4
11		5
12	Consultant Radiation oncologist	

<4> Years of registration as a radiation worker

1	0-5 years	
2	5-10 years	
3	10-15 years	
4	15-20 years	
5	20-25 years	
6	25-30 years	
7	>30 years	

<u>SECTION 2</u>:
(PLEASE NOTE THERE IS ONLY 1 CORRECT ANSWER IN EACH QUESTION. PLEASE TICK THE CORRECT ANSWER)

<5> Which unit measures the biological effect of low levels of ionizing radiation on the human body?

a) Gray (Gy)
b) Sievert (Sv)
c) Joule (J)

<6> Which of the following is true of the ICRP dose limit for radiation workers?

a) Dose of 20 mSV/yr averaged over 5 years but not more than 50 mSV in any 1 year
b) Dose of 1 mSV/yr averaged over 5 years
c) There is no accepted safe dose limit

<7> Which statement best describes the ALARA principle regarding ionisation radiation dose to patients?

a) Radiation exposure must be as low as reasonably achievable, economic and social factors considered
b) All Radiation exposure must be documented by the radiographer in the treatment chart
c) The allowable administered radiation should be dictated by patient choice

<8> Which of the following is NOT true for a pregnant radiation worker?

a) She may work in supervised and some controlled areas
b) She should wear a monitor which sounds when radiation is present
c) She is allowed in areas where therapeutic amounts of radioactive materials are prepared/administered as long as the sources are closed or sealed

<9> Which of the following statements is correct regarding a developing foetus?

a) The detrimental effects of radiation exposure to the foetus is greatest in the third trimester.
b) A foetus exposed to acceptable low levels of radiation will be more likely to have delayed milestones after birth.
c) A developing foetus is more sensitive to radiation than an adult because its cells are rapidly dividing.

<10> Which of the following is NOT an important principle in controlling exposure to external radiation?

a) There is no need to restrict the time of exposure to the source of external radiation if gloves are used
b) It is important to keep the maximum possible distance from the source of radiation
c) It is important to use adequate shielding wherever possible

<11> Which of the following statements is correct with regard to external beam Radiation treatment?

a) When the patient leaves the radiation treatment room, the site being treated is still radioactive for at least 10 minutes
b) No radiation precautions are needed after the patient has been treated and has left the treatment room because the patient is not radioactive.
c) With progressive treatments the patient may become permanently radioactive.

<12> If a closed/sealed brachytherapy source has to be transported outside The laboratory, it:

a) must always be placed in a securely closed shielded container
b) may be transported in a cooler bag on ice
c) must always be transported by a qualified physicist

<13> Which of the following regarding a controlled area is TRUE?

a) Authorized personnel only!
b) Radiation warning signs do not have to be displayed
c) Eating and drinking is permitted as long as no food is spilled on work surfaces

<14> Radiation shields can be

a) movable (stands, door), personal (gloves, aprons) and structural (door, walls and floors)
b) only structural (door, walls and floors)
c) ignored as long as treatment is carried out as quickly as possible

<15> Which of the following is TRUE regarding personal monitoring devices (i.e. radiation badge)?

a) When a person is exposed to radiation the badge will visibly change colour alerting the person immediately
b) The badge provides protection when working with radiation
c) A lifetime record should be kept of doses measured

<16> Which of the following is FALSE regarding medical surveillance programs?

a) They are important to assess the health of the workers
b) They provide baseline information which may be useful in case of accidental exposures
c) They are used only to identify wrongdoers and start disciplinary processes

<17> Health effects of radiation exposure include all of the following EXCEPT:

a) cataracts
b) mutations in DNA
c) abrasions

<18> In general, the body cells most susceptible to damage by radiation are those found in:

a) muscle tissues
b) rapidly dividing tissues
c). highly specialized tissues

<19> Safe radiation practice is the duty of:

a) the physicist
b) all radiation workers
c) the radiation oncologist

SECTION 3:

<20> Please name our department's Radiation Protection Officer?

____

<21> Do you feel that you know enough about the hazards of your work and the precautions you need to take to protect yourself in the performance of your duties?

a) Yes
b) No

<22> Are you aware of this department's radiation safety procedures and protocols?

a) Yes
b) No

<23> How do you suggest that we improve the overall radiation safety in our department?

a) Formal refresher courses
b) Departmental lectures
c) Other – please specify

APPENDIX B: Ethics clearance certificate from Medical Human Research Ethics Council

R14/49 Dr Karen Motilall

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M151118

NAME: (Principal Investigator)	Dr Karen Motilall
DEPARTMENT:	Radiation Oncology Charlotte Maxeke Johannesburg Academic Hospital
PROJECT TITLE:	A Study to Evaluate the Knowledge of Radiation Safety Amongst Radiation Workers in the Department of Radiation Oncology at the Charlotte Maxeke Johannesburg Academic Hospital
DATE CONSIDERED:	27/11/2015
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof Vinay Sharma and Mr Sikhumbuzo Mhlanga
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	22/02/2016

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004, 10th floor, Senate House/2nd Floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report.**

Principal Investigator Signature Date 1/3/16

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX C: TURN IT IN PLAGIARISM REPORT

MMEDKARENMOTILALL23May2017forTurnitinassessment....

ORIGINALITY REPORT

%13	%8	%8	%7
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to University of Witwatersrand Student Paper	%2
2	Carina Marsay, Lenore Manderson, Ugasvaree Subramaney. "Validation of the Whooley questions for antenatal depression and anxiety among low-income women in urban South Africa", South African Journal of Psychiatry, 2017 Publication	%1
3	"Toxicological Profile for Ionizing Radiation", ATSDR s Toxicological Profiles Web Version, 2002. Publication	%1
4	www.nap.edu Internet Source	%1
5	Submitted to University of Limpopo Student Paper	<%1
6	Submitted to University of Sunderland Student Paper	<%1
7	irpa12.org.ar Internet Source	<%1
8	www.ncbi.nlm.nih.gov Internet Source	<%1
9	Submitted to 87988 Student Paper	<%1
10	wiredspace.wits.ac.za Internet Source	<%1
11	Submitted to University of Warwick Student Paper	<%1
12	www.biomedcentral.com Internet Source	<%1
13	Cole, H.S.. "Carbohydrate metabolism in children: (1) Blood sugar, serum insulin, and growth hormone during oral glucose tolerance tests; (2) Blood sugar during the cortisone glucose tolerance test", Metabolism, 197302 Publication	<%1
14	Submitted to Grand Canyon University Student Paper	<%1
15	uir.unisa.ac.za Internet Source	<%1
16	media.proquest.com Internet Source	<%1
17	Paolicchi, F., F. Miniati, L. Bastiani, L. Faggioni, A. Ciaramella, I. Creonti, C. Sottocornola, C. Dionisi, and D. Caramella. "Assessment of radiation protection awareness and knowledge about radiological examination doses among Italian radiographers", Insights into Imaging, 2015. Publication	<%1
18	www.hse.gov.uk Internet Source	<%1
19	O'Neill-Mehlenbacher, Alicia, Michael Kilemade, Amy Elliott, Carmel Mothersill, and Colin Seymour. "Comparison of direct and bystander effects induced by ionizing radiation in eight fish cell lines", International Journal of Radiation Biology, 2007. Publication	<%1
20	Subcellular Biochemistry, 2002. Publication	<%1
21	scholarworks.umb.edu Internet Source	<%1
22	atvb.ahajournals.org Internet Source	<%1
23	Submitted to Curtin University of Technology Student Paper	<%1
24	Submitted to Columbia Union College Student Paper	<%1
25	Jan M. Zielinski. "Health outcomes of low-dose ionizing radiation exposure among medical workers: a cohort study of the Canadian national dose registry of radiation workers", International Journal of Occupational Medicine and Environmental Health, 01/01/2009 Publication	<%1
26	IFMBE Proceedings, 2009. Publication	<%1
27	Submitted to Midwestern State University Student Paper	<%1
28	worldwidescience.org Internet Source	<%1
29	www.nj2x.com Internet Source	<%1
30	lowdose.tricity.wsu.edu Internet Source	<%1
31	Submitted to Republic Polytechnic Student Paper	<%1
32	Radiological Safety and Quality, 2014. Publication	<%1
33	www.shef.ac.uk Internet Source	<%1
34	www.ajol.info Internet Source	<%1
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36	Internet Source	<%1
37	psych-assist.com.au Internet Source	<%1
38	www.sasae.co.za Internet Source	<%1
39	www.nrc.gov Internet Source	<%1
40	www.niport.gov.bd Internet Source	<%1
41	Antony M. Hooker. "Radiation and risk: Is it time for a regulatory threshold dose?", Australasian Physical & Engineering Sciences in Medicine, 09/2011 Publication	<%1
42	repository.smuc.edu.et Internet Source	<%1
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