OCCUPATIONAL EXPOSURE OF HEALTH WORKERS TO ELECTROMAGNETIC FIELDS IN THE MAGNETIC RESONANCE IMAGING ENVIRONMENT

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DEDICATION

TO MY HUSBAND AND SON

My inspiration, my positive energy, my everything. I love you two more than anything else on earth.

CERTIFICATION

TO WHOM IT MAY CONCERN

This serves to certify that the thesis of Ms A. D. Grobler [OCCUPATIONAL EXPOSURE OF HEALTH WORKERS TO ELECTROMAGNETIC FIELDS IN THE MAGNETIC RESONANCE IMAGING ENVIRONMENT] has been edited in terms of language usage, spelling and syntax.

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MS L VAN DER WESTHUIZEN   DATE

DECLARATION OF INDEPENDENT WORK

I, ANNA DORATHEA GROBLER, do hereby declare that this research project submitted for the degree MAGISTER TECHNOLOGIAE: RADIOGRAPHY (DIAGNOSTIC) at the Central University of Technology is my own independent work that has not been submitted before to any institution by me or anyone else as part of any qualification.

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SUMMARY

Electromagnetic fields created in the Magnetic Resonance Imaging (MRI) environment is of the non-ionising type. These electromagnetic fields can be divided into three groups: static magnetic fields (0.2 – 3.0 Tesla), rapidly changing fields (imaging gradients), and radio-frequency (RF) fields (63,86 MHz) for 1,5 Tesla units).

Health workers working in this environment are usually exposed to the predominantly static magnetic fields, but can also be exposed to the radio-frequency and gradient fields during an examination, when they have to attend to a very sick patient, a sedated child or interventional procedures in the imaging room.

Internationally accepted guidelines for exposure to electromagnetic fields in the MRI environment, are set by the International Commission on Non-Ionising Radiation Protection (ICNIRP). In South Africa these guidelines are endorsed by the Department of Health, Directorate: Radiation Control and it is expected (not regulated) that exposure to MRI units in South Africa must comply with these limits.

This study was done to establish whether the limits (1 mW/cm^2 at 64 MHz) for exposure of health workers to radio-frequency fields in the MRI environment in the vicinity of 1.5 Tesla units, comply with the ICNIRP guidelines. Measurements were done at three 1.5 Tesla MRI units in Bloemfontein. Three sets of measurements per unit were done. The first set was done to test the efficiency of the Narda Safety Test Solutions measuring instruments in the strong magnetic field. The second set was done at one meter increment from the bore opening, on the right hand side of the bed, during different examinations and pulse sequences. The third set was done exactly like the second set, but close against the bore.

Measurements were done at an extremely low frequency (5 Hz - 32 Hz) range (gradient fields), as well as at a higher frequency (300 kHz – 40 GHz) range (radio-frequency fields). The Narda Safety Test Solution's EFA-300 with a magnetic field probe was used to measure the frequency

range from 5 Hz to 32 Hz. The higher frequency range, 300 kHz to 40 GHz was measured with an EMR and Type 26 probe.

The first measurement set was done at peak levels only. All the measurements in the high frequency range were well within the safety exposure limits. However, some of the measurements in the low frequency range exceeded the safety limits at all three units. The second and third set of measurements was taken as the average over a six minute window period. These measurements in the low as well as the high frequency range were well within the safety limits. Noticeable was the fact that some of the measurement in the low frequency range during the third round of measurements exceeded the public safety exposure limits. It should be noted that for purposes of medical examination, exposure levels higher than that allowed for in the case of general public exposure is sometimes noted. The exposure of health workers to gradient and radio-frequency fields in a 1.5 Tesla MRI environment is well within the safe exposure limits when measured as an average over a six minute window period. If peak values were considered the limits would have been exceeded in the gradient (low frequency) fields.

Considering that the influence of the electromagnetic fields on health workers in the MRI is not physically measurable, a questionnaire was used to measure the stressors and stress levels of all health workers working in a 1.5 T MRI environment in South Africa.

The stress level of the health workers with a mean of 67.8 indicates a relatively low personal stress level. The mean of 24.2 is an indication of a low stress level due to circumstances outside the work environment.

Stressors within the work place causing medium to high stress levels were: organisation functioning (ORG), task characteristics (TA), physical working conditions (PHY), career matters (CAR), social activities at work (SO), remuneration, fringe benefits and staff policy (REM). ORG, TA and REM had a significant correlation with stressors outside the workplace. However, REM also had a highly significant correlation with personal stress levels. The highest percentage of very high stress levels were recorded in REM.

OPSOMMING

Elektromagnetiese velde wat in die Magnetiese Resonans Beeldingsproses ontstaan is nie-ioniserende straling. Die frekwensies van die velde kan in drie groepe verdeel word nl: statiese velde, hoofsaaklik magneetvelde (0.2 – 3.0 Tesla), vinnige varierende magneetvelde (beeldings-gradiënte) en radiofrekwensie (RF) velde (63.86 MHz vir die 1,5 T eenhede).

Gesondheidswerkers wat in hierdie omgewing werk word hoofsaaklik blootgestel aan die statiese magneetvelde, maar kan ook tydens ondersoeke blootgestel word aan die radiofrekwensie velde en gradiënt velde, indien hulle `n baie siek pasient of `n kind onder verdowing moet bystaan, of interventionele prosedures moet doen in die beeldingskamer.

Internasionale riglyne vir blootstelling aan elektromagnetiese velde in die Magnetiese Resonans Beeldingsomgewing, word deur die International Commission on Non-Ionising Radiation Protection (ICNIRP) voorgeskryf. In Suid Afrika word hierdie limiete net so deur die Departement van Gesondheid, Direktoraat: Stralingsbeskering, ondersteun. Alle Magnetiese Resonans Beeldingseenhede in Suid-Afrika moet voldoen aan hierdie limiete.

Hierdie studie is uitgevoer om vas te stel of die limiete (1mW/cm^2 by 64 MHz) vir blootstelling van gesondheidswerkers aan radio-frekwensie velde in die Magnetiese Resonans Beeldings omgewing van 1.5 Tesla eenhede, wel aan die (Suid-Afrikaanse) riglyne voldoen. Metings is gedoen op drie 1.5 Tesla Magnetiese Resonans Beeldings eenhede in Bloemfontein. Drie stelle metings per eenheid is gedoen. Die eerste stel is gedoen op verskeie plekke in en om die magneet, om die werking van die meetinstrumente van "Narda Safety Test Solutions" in die sterk magneetveld te toets. Die tweede stel metings is gedoen een meter vanaf die magneet opening, aan die regterkant van die bed gedurende ondersoeke met spesifieke puls volgorde. Die derde stel metings is gedoen direk langs die magneet opening gedurende dieselfde ondersoeke en puls volgorde.

Metings is gedoen met `n ekstreem lae frekwensie (5 Hz – 32 Hz) veldgrens (sluit gradiënt velde in) sowel as in `n hoër frekwensie (300 kHz – 40 GHz) veldgrens (radiofrekwensie velde). Gedurende die meetings is "Narda Safety Test Solutions" se EFA-300 met `n magnetiese

sondeerder gebruik om die veldgrens vanaf 5 Hz tot 32 Hz, te meet. Die hoër frekwensies, 300 kHz tot 40 GHz is gemeet met die EMR Tipe 26 sondeerder.

Die eerste stel metings is geneem met piek waardes alleenlik. Alle metings in die hoë frekwensie reeks was binne die veilige blootstellings limiete. Die metings in die lae frekwensie reeks het egter die veilige blootstellings limiete, in enkele gevalle by al drie die eenhede oorskry. Die tweede en derde stel metings is geneem as `n gemiddelde oor `n ses minute venster periode. Gedurende hierdie stelle metings was die hoë en lae frekwensie reeks metings veilig binne die voorgeskrewe limiete. Opvallend was dat die metings in die lae frekwensie reeks die veilige blootstellings limiete vir die publiek oorskry het. Die blootstelling van gesondheidswerkers aan gradiënt en radio-frekwensie velde in `n 1.5 Tesla Magnetiese Resonans Beeldings omgewing is onder die vasgestelde aangenome veilige limiete van Suid-Afrika. Indien piek waardes in berekening gebring word sal die gradiënt velde (lae frekwensie) die limiete oorskrei.

Aangesien die invloed van die elektromagnetiese velde op die werkers nie fisies meetbaar is nie, is `n vraelys gebruik om die stressors te bepaal waaraan gesondheidswerkers in hierdie omgewing blootgestel is. Die algemene stresvlakke van die werkers is ook gemeet.

`n Gemiddelde stresvlak van 67.8 is `n aanduiding van `n relatiewe lae persoonlike stresvlak onder hierdie gesondheidswerkers. Die stresvlak a.g.v. omstandighede buite die werksplek met `n gemiddeld van 24.2 is ook `n aanduiding van `n lae stresvlak.

Stressors in die werkplek wat medium tot hoë stresvlakke veroorsaak is: organisatoriese funksies (ORG), taak georiënteerde karakteristieke (TA), fisiese werksomstadighede (PHY), loopbaan aangeleenthede (CAR), sosiale aktiwiteite (SO), vergoeding, byvoordele en personeel beleid (REM).

`n Beduidende korrelasie bestaan tussen ORG, TA en REM en stressors van buite die werkomgewing. `n Hoogs beduidende korrelasie bestaan tussen REM en die persoonlike stresvlakke van die werkers. Die hoogste persentasie van baie hoë stresvlakke was aangeteken in REM.

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AM	Amplitude Modulation
Am-1	Ampere per meter
ANSI	American National Standards Institute
CAR	Career matters
cm	centimetre
CSF	Cerebrospinal fluid
CUT	Central University of Technology
dB/dt	change in magnetic field per unit time
DWI	Diffusion Weighted Imaging
EFA	Electric Field Analyser
ELF	Extremely low frequencies
ELM	Extremely Low Magnetic fields
EMF	Electromagnetic fields
EMR	Electromagnetic Radiation
EPA	Environmental Protection Agency
EPI	Echo Planar Imaging
eV	electron volts
f	frequency
FCC	Federal Communication Commission
FDA	Food and Drug Administration
FFT	Fast Fourier Transformation
FLAIR	Fluid Attenuated Inversion Recovery
FM	Frequency Modulations
FSE	Fast Spin Echo
FT	Fourier Transformation
GHz	Gigahertz
HSREB	Health Service Research Ethic Board
Hz	Hertz
ICNIRP	International Committee of Non-Ionizing Radiation Protection
INIRC	International Non-ionizing Radiation Committee

IRB	Investigation Review Board
IRPA	International Radiation Association
ISMRM	International Society for Magnetic Resonance Medicine
M	metre
mA/m^2	milliampere per square meter (gebruik eerder mA/m^2)
MHz	Megahertz
mm	millimetre
MRA	Magnetic resonance angiography
MRCP	Magnetic Resonance Cholangiopancreatography
MRI	Magnetic Resonance Imaging (Imager)
MRS	Magnetic Resonance Spectroscopy
mT	millitesla
mW	milliwatt
mW/cm^2	milliwatt per square centimetre (gebruik eerder mW/cm^2)
NIR	Non-ionizing radiation
NMR	Nuclear Magnetic Resonance
NMV	Nuclear Magnetization Vector
NRPB	National Radiological Protection Board
NRPB	National Radiation Protection Board
OES	Occupational Environmental Scale
OHSA	Occupational Health and Safety Administration
ORG	Organizational functioning
PHY	Physical working conditions and job equipment
PRQ	Personal Resource Questionnaire
REM	Remuneration, fringe benefits and personnel policy
RF	Radio-frequency
rms	root mean square
SAFRP	South African Forum for Radiation Protection
SAR	Specific Absorption Rate
SE	Spin Echo
SO	Social matters
SPGR	Spoiled Gradient Echo

T	Tesla
TA	Task characteristics
UK	United Kingdom
UNEP	United Nations Environmental Programme
USA	United States of America
Vm-1	Volt per meter
W	Watt
WHO	World Health Organization
Wkg^{-1}	Watt per kilogram kan ook W/kg gebruik
WLQ	Work & Life Questionnaire

Chapter 1

1 Introduction

1.1 Background

1.1.1 Background on limits

The progress experienced since the first clinical image in 1984 in magnetic resonance imaging (MRI) has been extraordinary. Medical imaging specialists were quick to grasp the advantages of MRI; it produces a clear anatomical display in any of three planes (axial, coronal or sagital), with no evident nuclear radiation risk to the patient and the clinical personnel (Westbrook & Kaut, 1998: v).

Electromagnetic radiation experienced at a MRI system is non-ionising and exposure limits are based on exposure to magnetic and electromagnetic fields associated with MRI systems (Department of Health: Electromedical Devices and Radiological Health, 1994: 1); (International Commission on Non-ionizing Radiation Protection, 1998: 495). The three exposure areas of interest are static magnetic fields (0.2 – 3 Tesla), extremely low time varying magnetic fields (imaging gradients- induced current density less than 400 mA/m^2), and the radiofrequency fields (63,86 MHz for 1,5 Tesla units) (Price, 1999: 1641).

Static magnetic fields (B_o) are created by 0.2 to 3 Tesla (1 T = 10000 Gauss) magnets. Radio frequency fields (RF) are created by the RF coils, which are positioned close to the anatomy of the patient, who has to be examined. These coils can be the receiver coil only, or can be a combination of a transmitter and receiver coil. The time varying magnetic fields are created by three gradient coils positioned in the magnet bore in a three-dimensional way (x, y, z-axis). These magnetic fields are manipulated to produce different MRI pulse sequences that allow the creation of frequency encoded data to produce spatial images of the selected anatomical part (Westbrook & Kaut, 1998: 5); (MRI for Technologists, 2001:296).

The creation of an image during clinical MRI is based on the fact that the clinical MRI active nucleus (^1H) has angular moment (spin) as well as a relatively large magnetic dipole moment (equivalent to a bar magnet). The total magnetic angular moment of the hydrogen nuclei are called the nuclear magnetization vector (NMV). The interaction of the NMV with the static magnetic field (B_o) is the basis of MRI. Excitation of the NMV can only take place when the RF pulses used are of the same precession frequencies, in this case 63.86 MHz (1.5 T magnetic fields), as the hydrogen nuclei (Westbrook & Kaut, 1998: 3); (Westbrook, Kaut Roth & Talbot, 2005:5)

Humans exposed to the frequencies of MRI electromagnetic fields (EMF) can be divided into three exposure groups: Patients and volunteers, public, and clinical personnel. Patients and volunteers are usually exposed to all three EMF fields, whereas the general public is only exposed to the static magnetic fields, because they are only allowed outside the 0.5 mT (5 Gauss) line. Exposure limits for the public have much more stringent restrictions, because they cannot reasonably be expected to take precautions to minimize or avoid exposure (Department of Health, 1994:1); (ICNIRP, 1998: 495). Exposure of clinical personnel is called occupational exposure. Occupational exposure affects that part of the population who are exposed to EMF under known conditions during their normal working day at the MR imager. These people are usually trained to take appropriate precautions (Department of Health: Radiation Control, 2002: 1). Appropriate precautions may include controlled admission to the MRI room, screening of all people allowed to enter the room, and to allow as little as possible time spent in the room. Clinical personnel are exposed to all three fields, although in "Safe use Guidelines for Magnetic Resonance Imaging Systems" (Department of Health, 1994: 4) it is stated that in real life they are only exposed to the static magnetic fields. The limits for occupational exposure are more relaxed compared to public exposure limits, because "the occupationally exposed population consists of adults who are generally exposed to EMF under known conditions during the normal course of their particular employment, and who are trained to be aware of the potential risk and to take appropriate precautions (Department of Health, 2002:1)

Limits for exposure to non-ionising radiation at MRI systems, adopted by the Department of Health, Directorate: Electromedical Devices and Radiological Health, were derived from the guidelines given by the International Radiation Protection Association (IRPA) as well as those of the National Radiological Protection Board (NRPB) in the United Kingdom (UK) (Department of Health, 1994:1).

The limits for public, patients' and volunteers' exposure to static magnetic fields are restricted to 2 T for the head and trunk and 4 T for limbs (Department of Health, 1994: 2). Occupational exposure limits for clinical personnel to static fields are restricted to 0.2 T average exposures for a prolonged period. An increase in the occupational exposure limit up to 2 T are allowed for short periods totalling less than 15 minutes, on one hour interval conditions between exposures (Department of Health, 1994: 4).

The exposure of clinical personnel to RF fields in the frequency range of 10 to 400 MHz is $f/400$ mW/cm^2 where the frequency f is measured in MHz (Department of Health, 1994: 4). The patient safety criteria in RF fields are based on temperature rise, which are allowed from 0.5 °C – 1 °C. The whole body Specific Absorption Rate (SAR) of the patient should be restricted to 1 W/kg for all exposures of more than 30 minutes (Department of Health, 1994: 4).

The occupational and general public exposure limits for time-varying magnetic fields (gradient coils) can be viewed in Table 1.1.

Table1.1: Basic restrictions for time-varying electric, magnetic, and electromagnetic

fields for frequencies up to 10 GHz

Exposure characteristics	Frequency range	Current density (head & trunk) (mA/m^2) (rms)	Whole-body average SAR (W/kg)	Local SAR (head & trunk) (W/kg)	Local SAR (limbs) (W/kg)
Occupational	10 MHz –10 GHz	_	0.4	10	20
General public	10 MHz – 10 GHz	_	0.08	2	40

"Notes for Table 1.1:

1. *f is the frequency in Hz (hertz).*
2. *Because of electrical inhomogeneity of the body, current densities should be averaged over a cross section of 1 cm^2 perpendicular to the current direction.*
3. *All SAR values are to be average over any 6-minute period"* (Department of Health: Radiation Control, 2002: 2).

1.1.2 Background on biological, physical and psychological effects

In the MRI environment it is difficult to distinguish between the effects of individual types of fields. Therefore, it is important to assess bio-magnetic effects resulting from the simultaneous exposure of all three types of fields, at the same time the effects of each field must be well understood (Mathur-De Vre, 1987: 398).

In the static fields the most significant bio-electromagnetic effect is considered to be the magneto-hydrodynamic effect associated with electric fields induced by blood flowing through the static field. Various mechanisms of biological interactions of static magnetic fields (> 2 T) have been postulated, like:

- "Changes in macromolecular orientation, leading to changes in chemical kinetics and membrane permeability;
- Reduction in nerve conduction;
- Induction of a low EMF on natural bio-potential."

The interaction of extremely low magnetic fields with living objects is usually subtle and mostly difficult to detect (Mathur-De Vre, 1987: 400).

The primary effect of the exposure to electromagnetic RF field, of ample magnitude at a certain frequency, is the generation of heat in the exposed tissue resulting in biological effects associated with thermally induced changes. These changes can arise from: (Mathur-De Vre.1987: 406)

- "Changes in metabolic heat production;
- Changes in blood flow;
- Resistive loss and molecular vibration."

One of the most sensitive biological effects of RF exposure is considered to be the disruption of operant behaviour (inability to perform the task for which trained), observed in monkeys when the mean SAR in the body exceed 4W/kg. Symptoms such as lack of alertness, headache, fatigue and sleep disturbances have been described among workers exposed to RF exposure levels as low as 1mW.cm^{-2} (Mathur-De Vre.1987: 408).

The biological effects of the time-varying fields (induced by switched field gradients) are related to the change in magnetic field per unit time (dB/dt) that is responsible for induced currents (eddy currents). Visual phosphenes (non-hazardous and resulting from optic nerve stimulation response between 2 and 5 T/s) and ventricular fibrillation (current density of 3 A/m^2 rms) are biological effects commonly attributed to the impact of high field gradients. The acoustic noise created by the gradient coils in a static magnetic field under the most stringent conditions tested for MRI, was reported to be much less than the permissible level for occupational exposure (92 dBA, 2hrs /day) (Mathur-De Vre.1987: 410).

1.2 Problem statement

Many studies have been done on patient and public safety at MRI units, but little attention has been granted to the occupational safety of clinical personnel at MRI units or to the development of dosimetry monitors for MRI staff (Olsen, 1991: 237). Occupational exposure to gradient, RF and static magnetic fields at MRI units is of continuing concern to personnel who routinely work in this environment. Questions regarding occupational gradient, RF and static field exposure have increased with the commensurate demand for anaesthetics and interventional radiological procedures to be administered in this environment. Registered nurses are also often required to stay in the MRI room close to the bore to attend to ventilated patients. Patient's safety is always stressed during training, while safety regarding the clinical personnel exposure is almost never mentioned. "The site-specific RF power density measurement and the static fringe fields necessary to answer these questions are not available to clinical personnel, owing to the detrimental effects of the strong magnetic field (1.5 T) on the measurement equipment" (Felmlee & Vetter, 1995: 571). According to available literature, the threshold limits adopted by the Department of Health in South Africa have never been tested to verify that occupational exposure fall within these limits. The values for these threshold limits adopted, were determined by consensus after the 'best available information from industrial experiments, from experimental human and animal studies, and where possible, from combination of the three', is considered (Fermlee & Vetter, 1995: 571).

During a telephonic conversation (14 January 2008: 11:45) with Leon du Toit, Director for occupational exposure at the Department of Health, Directorate Radiation Control, it was established that their work only concern the static magnetic field (gradient) fall of around the magnet, controlled access within the 5 Gauss line and the influence of the static field on certain ferromagnetic objects in people. Also, that they do not really do any research.

1.3 Aims and objectives

1.3.1 Aim

The aim of this study was to evaluate occupational exposure of health workers to electromagnetic fields in the MRI environment. Also to try and establish whether the exposure at specific points close to the bore comply with the threshold limits.

1.3.2 Primary objectives

- Measure the exposure of clinical personnel, to RF electromagnetic fields, at three MRI units in Bloemfontein, and to compare the results to the reference levels adopted by the Department of Health in South Africa, to ensure that the measured exposures fall well within the occupational limits.

- Prove that the occupational exposure is not only restricted to static magnetic fields in real life by trying to evaluate the gradient and RF fields a Radiographer or Registered Nurse is subjected to during her daily duties in and around the bore at the MRI unit.

1.3.3 Secondary objectives

- Explore the possibility of the EMF as a stressor to clinical personnel, by means of a questionnaire.

1.4 Reference list

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Chapter 2

2 Literature review

2.1 Introduction

The physical environment of electromagnetic fields include: the natural magnetic field due to the sum of the internal field of the earth acting as a permanent magnet and the external field generated in the environment from such factors as solar activity or atmospherics; artificial field coming from all devices containing wires carrying direct current, including many appliances and equipment in industry and health care like magnetic resonance imaging (MRI). Magnetic resonance imaging is used to create sectional imaging of the body for diagnosis of pathology or functional disorders in the health profession. Radiology training includes the MRI spectrum (Grandolfo, 1998: 28).

The phenomena that permit MRI are based on magnetism, electricity and radiofrequencies applied according to the principle of nuclear physics and quantum mechanics. For this reason the imaging process was referred to as nuclear magnetic resonance (NMR) (Carlton & Adler, 1996: 664).

The aim of this chapter is to provide the reader with background knowledge of the origin of MRI and a basic understanding off the mechanism involved in MR image formation. Furthermore, to provide an overview of the safety aspect and exposure limits involved with the electromagnetic fields in the MRI environment. Also to familiarise the reader with the parties and procedures involved in the process of setting exposure limits to EMF in the MRI environment and the current position regarding exposure limits in the rest of the world.

2.2 History of nuclear magnetic resonance

Although the origin of atoms dates back to 400 B.C., when the atom was discovered by the Greeks, it was only 2000 years later that Hans Christian Oersted (1977-1851) discovered that electricity produced magnetism (MRI for Technologists, 1995: 1).

Michael Faraday (1831) then stated and proved that if electricity can produce magnetism, magnetism can produce electricity (Carlton & Adler, 1996: 62). Faraday's two laws of electromagnetism stated:

- that a change in the magnetic flux linked with a conductor induces an electromagnetic force (EMF) in the conductor [law of induction];
- that the magnitude of the induced EMF is proportional to the rate of change of the magnetic flux linkage. Faraday is regarded as the father of electricity (Graham, 1996: 169). The laws of Faraday form the basis of MR signal detection and modern-day magnetic resonance imaging (MRI for Technologists, 1995: 2); (MRI for Technologists, 2001: 2). The mathematical equation for the law of induction: $E = -N\Delta\Phi_B/\Delta t$, where:
    - *E = electromotive force (emf) in volts;*
    - *N = number of turns of wire;*
    - *$\Phi = BA$ = magnetic flux;*
    - *B = external magnetic field;*
    - *A = area of coil* (Hall, 2001:234).

In 1860 Sir James Maxwell of Scotland discovered that magnetic lines of force could be expressed mathematically. He proved that electrical and magnetic lines coexist at 90^0 to each other. MRI signal from the spins can only be detected when the spins are at an angle to the main magnetic field, and the best signal will be when the electric and magnetic lines are at a 90 degree angle with each other (Westbrook, Kaut Roth & Talbot, 2005:15). During the same year, Heinrich Hertz of Germany discovered that invisible electromagnetic waves do exist. He also discovered that all the electromagnetic waves have identifiable values, which led to the discovery of the electromagnetic spectrum (MRI for Technologists, 2001: 1).

Wilhelm Conrad Roentgen (1895) was the first to discover high frequency electromagnetic x-rays after which Frederic Joliot and Marie Curie discovered gamma rays. This discovery demonstrated that high frequency wave energies are identifiable, detectable, can be measured and often cause biological damage (MRI for Technologists, 1995: 3).

The 20th Century is synonymous with the atomic era. During this century many physicists, scientists and physicians collectively set the stage for NMR/MRI. During World war II physicists like Albert Einstein (1905) set the law of conservation of energy, Ernest Rutherford (1911) recognized the nucleus, J. J. Thompson showed objective proof of the existence of electrons, Niels Bohr (1913) opened the door to quantum physics, and Otto Stern developed a method to measure magnetic dipole moment; all contributed to the birth of NMR. However, Wolfgang Pauli (1931) was the first to coin the phrase "nuclear magnetic resonance" and Isidor Isaac Rabi (1913) conducted the first NMR experiment (MRI for Technologists, 1995: 5).

Although Pauli was the first to suggest that some nuclei spin, the two physicists Swiss born Felix Bloch (1905-1983) at Stanford and the American Edward Purcell (1912 -) at Harvard, continued to explore the mystery of the atom, discovered and implemented the use of atomic energy for analytical purposes in 1946. They discovered that a pure substance could be analyzed into its frequency components solely from their molecular perspective. This principle is called spectroscopy. Bloch and Purcell received the Nobel Price in 1952 for their contribution to science and technology (Carlton and Adler, 1995:664). For the next 25 years spectroscopy flourished and more than 100 NMR units where manufactured. Spectroscopy was initially used as an analytical tool in the industry. At this stage human NMR images were viewed as impossible and lunatic (MRI for Technologists, 1995: 5).

During the late 1960 to early 1970 several researchers developed the basis for diagnostic MRI. Jasper Jackson was the first to produce MR signal from live animals. In 1972 Paul Lauterbur produced the first MR image. He designed and implemented the use of Gx, Gy and Gz gradients for spatial encoding. The physicist/physician Raymond Damadian reported NMR differences between normal tissue and tumours (Carlton & Adler, 1995: 664). In 1970 Raymond Damadian started to build a whole body scanner for body imaging. He and his team spent seven years on designing and building this scanner. They performed the first diagnostic, whole body trans-axial proton density weighted slice image on 3rd of July 1977. This one slice took 4 h 45 min to complete. The patient had to be physically moved 106 times with a trambler to accomplish spatial excitation (Shellock & Kanal, 1994: 167). He named the scanner the Indomitable. The Indomitable is currently located at the Smithsonian Institute of Technology in Washington, D. C. (MRI for Technologists, 1995).

Several other scientists and physicians contributed to MRI over the past 30 years, like Prof. Dr. R. R. Ernst from Switzerland, who created the phase *vs*. frequency coordinates on the MR matrix for faster imaging. He also implemented the Fourier transformation (FT) imaging process (MRI for Technologists, 1995:8). Fourier transformation forms the heart of MRI mathematics and was first introduced by the French Mathematician Jean-Baptiste Fourier (1768-1830) over 200 years ago. Fourier transformation is a complex mathematical process currently used to translate a raw MR signal into spatial location (Dowsett, Kenny & Johnston, 1998: 18).

Damadian and Lauterbur's discovery was the beginning of MRI unit manufacturing. By 1995 there were over 2000 MR systems in the United States and approximately the same number throughout the rest of the world. The rapid growth of MRI like magnetic resonance angiography (MRA), magnetic resonance spectroscopy (MRS), higher gradients, and faster pulse sequences emphasized the essentiality of MRI safety (MRI for Technologists, 1995: 9).

The electromagnetic spectrum is the categorical arrangement of wave energy corresponding to their properties. The electromagnetic spectrum ranges in frequencies from lower than 10^{6} (0 Hz) to higher than 10^{20} waves per second. Radio waves are in the lower frequency range of less than 10^{-1} waves per second. The size of radio waves ranges from a basketball to a soccer field, and even larger. Therefore their wavelengths are from 0.1 m up to 100 m and larger. Radio waves are usually caused by microwave ovens, frequency modulation (FM) radio and amplitude modulation (AM) radio towers, television and other (Electro-optical Industries, 2000: 2). Radio frequencies (RF) are sometimes used as a generic term for frequencies up to 300 GHz but the term microwaves is more usually applied to the frequency range 300 MHz to 300 GHz (wavelength interval 1 m to 1 mm) and RF restricted to frequencies below 300 MHz (Mild,1998: 7).

Electromagnetic emission can be defined as the propagation of energy through space by electric and magnetic fields that vary in time (Newhouse & Wiener, 1991: 24). The electromagnetic waves in the MRI environment, namely static magnetic fields, radiofrequency and gradient fields are non-ionizing (Westbrook & Kaut, 1998: 234).

Non-ionizing electromagnetic waves consist of photons with energy levels less than 10 eV. These photons do not have sufficient energy to set ions free from an atom during a collision with such an atom (Mild, 1998: 7). The electromagnetic fields consist of the electric field E (V/m) and the magnetic fields (A/m). In the far-field the E-field and the H-field are strongly independent. However, in the near-field the H- and E-fields must be measured separately. In MRI imaging the health worker and the patient within the MRI room, during an examination, will be in the near-field [1 x λ(m)] at the lower frequencies (0 – 30 kHz). However, at the higher frequencies (> 30 kHz) they will be in the far-field [3 x λ(m)] (Narda Test Solutions, 2004: 2).

Microwaves, infrared light waves, visible light and ultraviolet light waves make up the central part of the spectrum. These wavelengths vary from 10^{-3} m to 10^{-8} m and have frequencies from 10^{12} to 10^{17} waves per second.

The upper end of the spectrum is made up of ionizing soft X-rays, X-rays and gamma rays in the frequency range of 10^{16} to 10^{20} and even higher. These wavelengths are very short (10^{-8} up to 10^{-12} m and even smaller). The waves have energy levels in the range 100 eV up to 1 000000 eV and higher. Therefore these waves have sufficient energy to set an ion free from an atom during a collision with such an atom. These waves are thus called ionizing radiation (HEASARC, 2006: 7).

2.3 Mechanism of magnetic resonance imagers (MRI)

The MRI unit consists of an enclosed room, lined with copper sheet on the walls (Faraday cage) and copper wire mesh in the windowpane. Although costly, it provides effective protection for the extremely sensitive receiver within the magnet from interfering environmental RF signals. The magnet, shim, gradient and RF coils are housed in the MRI room (Westbrook & Kaut, 1998: 3).

Magnetic resonance imaging uses magnetism and RF to create diagnostic sectional images of the body. The processes that permit MRI are based on the principles of nuclear physics and quantum mechanics. This is also the reason why the imaging process was originally called nuclear magnetic resonance (NMR). In order to understand how MR images are created and viewed, it is critical to understand the physical concept involved in MRI (Carlton & Adler, 1996: 664).

The creation of an image during clinical MRI is based on the fact that the MRI active nuclei have a tendency to align their axis of rotation to an applied static magnetic field. The nuclei most commonly used in MRI are those with an odd mass number (usually odd number of protons and even number of neutrons). The hydrogen (^{1}H) nuclei are the most abundant of these nuclei in the human body and are usually referred to as the MR active nucleus. Hydrogen has only one proton in its nucleus. Therefore, the hydrogen nucleus is sometimes referred to as a proton. The nucleus is a tiny but highly charged (positive charge) piece of matter, and spins about its own axis. Due to the laws of electromagnetic induction, nuclei that have a net charge and spin about their own axis acquire a magnetic moment and are able to align with an applied external static magnetic field. The process of this interaction is called angular moment (spin). In the external static magnetic field the spinning nucleus starts to wobble like a spinning top when it loses momentum. The wobbling is actually a rotation of the rotation axis and is called precession (Carlton & Adler, 1996: 665). Nuclei with an even number of protons and neutrons exhibit no spin. The laws of electromagnetism state that a magnetic field is created when a charged particle moves around. Therefore, the hydrogen nucleus induces a magnetic field around itself, and acts as a small bar magnet (dipole). The north/south axis of each nucleus is represented by a magnetic moment, and has vector properties. The spin is quantized and characterized by the spin quantum number, *I*, which may be either an integer or half-integer. The total net magnetic moment of all the hydrogen (^1H) nuclei (proton), aligned parallel and anti-parallel to the external static magnetic field are called the nuclear magnetization vector (NMV). The interaction of the NMV with the static magnetic field ($B_{0)}$ forms the basis of MRI (Westbrook, Kaut Roth & Talbot, 2005: 8).

The NMV can only be measured when it is perpendicular to the external applied static magnetic field. By applying a burst of a magnetic field (radio-frequency field switch on and then off again) that oscillates at the same frequency at which the protons are spinning, the NMV can be flipped from being aligned with the magnetic field, to a 90 degree angle with the magnetic field. Radio frequency fields (‘second magnetic field” B^1) are used to excite the NMV to rotate to the static magnetic field. The best RF signal detected is usually at a 90 degree angle to the static magnetic field. The rotating net magnetization will induce a voltage or RF pulse (at the Lamor frequency) in a receiver coil placed close to the anatomy under examination. This is then the NMR signal that is detected. Different molecules possess different relapse frequencies which play a vital role in MRI identification of different molecules or soft tissue structures (Westbrook & Kaut, 1998: 10).

Excitation of the NMV can only take place when the RF fields used are of the same precession frequencies as the hydrogen nuclei. Precession frequency refers to the speed at which the NMV wobbles around B_o after excitation by the RF pulse. Precession frequency, also called the Lamor frequency (of a specific nucleus), of the hydrogen nucleus in a 1.5 T static magnetic field is 63.86 MHz. Precession in a magnetic field requires the coupling and interaction of two different physical properties of the system, electromagnetic and mechanical (Bushong, 2003:10).

During the rotational pathway the MR signal is created and detected by RF receivers. The value of the precession frequency depends on the strength of B_o and the gyro-magnetic ratio (characteristics of the specific nucleus). Therefore, the precession frequency for a specific nucleus will be different in different magnetic field strengths. However, the chemical environment of the nucleus will also influence the resonant frequency of the nucleus. The effect of this influence is also called chemical shift of a nucleus in a molecule. Chemical shift is the basis of widespread use of NMR spectroscopy in chemical analysis (Gowland, 2005: 176). The gyro-magnetic ratio expresses the relationship between the angular moment and the magnetic moment of each MR active nucleus. The gyro-magnetic ratio is unique for each different element's nuclei (Westbrook & Kaut, 1998: 6).

The linear variation of the static field (a magnetic field gradient) through space is responsible for the creation of an image (Hashemi, Bradley & Lisanti, 2004: 162). Thus, the Lamor frequency of the NMR signal codes for spatial position. The magnetic field gradient is switched on and off very rapidly during imaging sequences (Gowland, 2005: 177). The gradient coils are conductors that produce a linear superimposed gradient magnetic field on the main magnetic field. The gradient is defined as the rate at which magnetic field strength changes with position. Typically, a perfectly homogeneous magnetic field contains no gradient. Therefore wire coils (gradient coils) are placed in a three-dimensional way, x-, y-, and z-direction, inside the cylinder of the magnet. The gradient coils are responsible for the rapidly changing electromagnetic fields in the MRI environment. They are responsible for the banging noise one hears during imaging. The flexing and force experienced by the gradient coils from the rapidly changing magnetic field when energized, causes the noise (Bushberg, Siebert & Boone, 2002: 260). When current is allowed to flow through these coils, they act as magnets within magnets, and shape the overall magnetic field to have a particular gradient (Newhouse & Wiener, 1991: 16). This means that the magnetic field within a 1.5 T unit will vary slightly higher than 1.5 T in the centre of the magnet, in one direction of the z-axis where the gradient magnetic fields strengthen the main magnetic field, and slightly lower on the opposite side where the gradient magnetic field opposes the main magnetic field (Elster & Burdette, 2001: 4). Nuclei of the atom of the same element have different precession frequencies at different magnetic field strengths. Therefore it is possible to spatially establish the position of a certain nuclei. The three gradient coils are used for the spatial slice-, frequency- and phase-encoding of the MR image (Westbrook, Kaut Roth & Talbot, 2005: 62).

Gradient switching is one of the greatest factors that will affect the timing of pulse sequences. Each time a gradient is switch on, power is applied to the gradient to eventually reach peak amplitude. Gradient amplitude refers to the strength of the gradient. Gradient strengths are typically between 10 and 60 mT/m. Image resolution is directly affected by gradient amplitudes. High gradient amplitudes are needed for small field of view (FOV) and thin slice imaging. The gradient rise time (time to reach maximum amplitude) plays an important role in MR imaging timing factors. The strength of the gradient over distance is known as the slew rate. Typical slew rates are in the order of 70 mT/m. Gradient strength over distance create different frequency content over distance in the bore. In a 1.5 T MRI unit the centre frequency will be 63.86 MHz, which is the precession frequency (Lamor frequency) of hydrogen at 1.5 T (Westbrook, Kaut Roth & Talbot, 2005: 317).

The magnet is essentially the heart of the MRI system. Field strength, temporal stability and field homogeneity are some of the elements that make up the performance criteria of a particular magnet type. The magnet design plays a major role in these parameters (Bushberg, Siebert & Boone, 2002: 458). Magnets of strength 0.2 T up to 3 T produce the main magnetic fields, also called the static magnetic fields in clinical MRI. The main magnetic field is responsible for the alignment of the nuclei, parallel and anti-parallel to the magnetic field. In solenoid electromagnets the main magnetic field is usually horizontal, but in permanent magnets the field is usually vertical. The direction of the magnetic field is also called the z-axis (Westbrook & Kaut, 1998: 233).

The magnet can either be a resistive, superconductive or a permanent magnet. The super-conductive magnets are most widely used for clinical imaging. The superconductive magnets use an air core electromagnet configuration, and consist of a large cylinder, wrapped with a long, continuous strand of superconductive wire. Certain metals (niobium-titanium alloys) exhibit no resistance to electric current when kept at extremely low temperatures. Superconductivity is a characteristic of these metals (Bushberg, *et al*., 2002: 459). The low temperatures are made possible by liquid helium (boiling point 4 K) as coolant. These magnets achieve high field strengths, from 0.3 T up to 3.0 T in clinical systems. In research, clinically large bore magnets achieving 4.0 T up to 7.0 T are used. The superconductive magnets have high field uniformity. However, several disadvantages of the superconductive magnets include high initial costs, cryogen costs, and difficulty in turning off the main magnetic field in an emergency as well as extensive fringe fields (Carlton & Adler, 1996: 677).

Enclosing walls, floors or ceilings cannot contain the static magnetic field. Stray magnetic field outside the magnet and MRI unit are called fringe fields (Westbrook & Kaut, 1998: 233). The fringe field of the magnet is the magnetic fields surrounding the central magnet. A 1.5 T magnet has a magnetic field of 1.5 T in the centre of the magnet. The magnetic field reduces with increasing distance from the centre point of the magnet. Unshielded magnets have a larger fringe field than shielded magnets. Disruption of the fringe field can reduce the homogeneity of the active imaging volume. The fringe fields are measured in milliTesla (mT) or Gauss (G) (1 T = 1000 G).

The fringe field is usually confined to an acceptable location by shielding within the scan room. The fringe field should always be taken into consideration when positioning new systems. The field strength above as well as below the magnet should also be considered. Shim coils are used for shielding the fringe fields (Westbrook & Kaut, 1998: 235).

Shim coils are active or passive magnetic field devices and are used to adjust the main magnetic field (shielding). They are also used to improve the homogeneity in the sensitive central volume of the scanner. In active shielding, the pattern or spectrum of the field inhomogeneities is mapped and then corrected by setting the shim coils currents via a precision power supply. In passive shielding carefully shaped iron plates are placed inside or outside the magnet. Passive shielding is not power supply stability dependent, but requires considerable time to fit and adjust (Dowsett, Kenny & Johnstone, 1998: 490); (Bushberg, Siebert & Boone., 2002: 464).

The static field effectively exposes staff and patients to both large static fields, a spatial gradient of field (as it falls off around the magnet) and a small time-varying field as they move around in the spatially varying, static field (Gowland, 2005: 177).

Radio frequency transmitter and receiver body coils are located within the magnetic bore. The RF coils can be transmitter and receiver, or only receiver coils. Radio frequency coils need to be tuned prior to each acquisition and also be matched to accommodate the different magnetic inductance of each patient. The RF excitation pulses can be used at different angles and in different orders or repetitions, which will create different pulse sequences (Bushberg, Siebert & Boone, 2002: 461).

The pulse sequences are used to differentiate between different tissues as well as to detect specific pathology. Examples of these pulse sequences are as follow. Fast spin echo (FSE) is a spin echo (SE) pulse sequence (uses a 90^{o} RF excitation pulse followed by one or more 180^{o} RF rephasing pulse), but the scan times are drastically shorter than the conventional spin echo. Fast spin echo uses more than one 180^{o} RF rephasing pulses.

These multiple rephasing pulses are called echo trains. The spatial encoding of the data (filling of K-space) can therefore be performed in a shorter time (Westbrook & Kaut, 1998: 106).

The fluid attenuated inversion recovery (FLAIR) pulse sequence is a variation of the inversion recovery sequence. Inversion recovery is a pulse sequence that begins with an 180° inverting pulse. It inverts the NMV through 180° into full saturation and is then followed by the conventional spin echo pulse sequence (Westbrook & Kaut, 1998: 113). In FLAIR the signal from cerebrospinal fluid (CSF) is nullified by selecting a TI (time to invert) corresponding to the time of recovery of CSF to the transverse plane and there is no longitudinal magnetization present in CSF (Westbrook & Kaut, 1998: 117).

Gradient echo pulse sequence uses a variable RF excitation pulse (not just 90°). The NMV can be flipped through any angle. A gradient pulse is then used as a rephasing pulse (Westbrook & Kaut, 1998: 37).

In the pulse sequence, echo planar imaging (EPI) or diffusion imaging, the filling of K-space is all done after only one repetition. Echo planar imaging is a MR acquisition method that collects all the data required to fill the lines of K-space from a single echo train (Westbrook & Kaut, 1998: 132).

2.4 Safety in magnetic resonance imaging

Magnetic resonance imaging safety entails consideration of two aspects, namely the patient's and operator's safety recommendations. The most important part of patient safety regulations is the screening (for metal implants and foreign metal bodies) of patients before entering the MRI room. A screening document was developed by the International Society for Magnetic Resonance in Medicine (ISMRM) and should be used as a screening guideline at all MRI sites. The patient should also be monitored verbally as well as visually in the bore during an examination (Shellock, 2004: 15). Monitoring should be done for possible claustrophobia and any adverse biological effects due to the static magnetic, radiofrequency and gradient fields (Westbrook & Kaut, 1998: 234); (Bushong, 2003: 404).

Although there is currently no convincing evidence that there is any long-term or irreversible biological effects associated with electromagnetic fields and static magnetic fields used in MRI, screening of patients and personnel remains important, because hazards in MRI do exist (Westbrook, Kaut Roth & Talbot, 2005: 350).

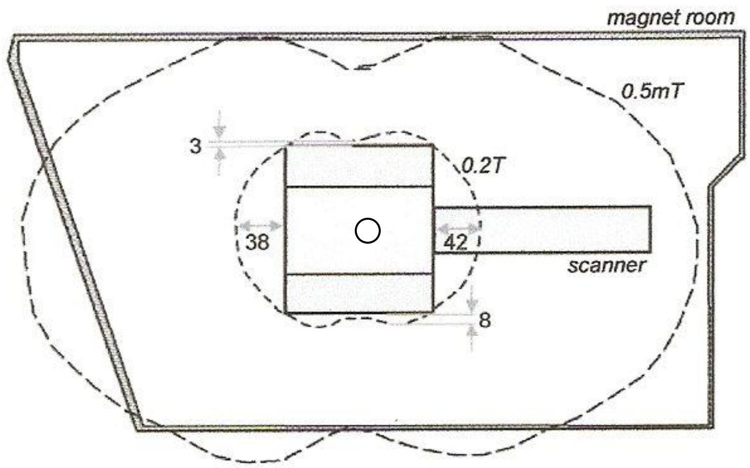
These hazards can be the result of the strong force the static magnetic fields exert on ferromagnetic objects brought into their influence. Conditions and devices which is considered as an absolute contraindication to MR imaging until the contrary is proven, is the presence of:

- An active electronic device in the body, such as cardiac pacemaker, cochlear implant, nerve or bone stimulator;
- Cerebral aneurysm clip;
- Intraocular metal fragments;
- Ferromagnetic foreign bodies;
- Magnetic eye sockets; or
- Any unfamiliar devices (Westbrook, Kaut Roth & Talbot, 2005: 350).

Other potential hazardous situations are things like:

- Jewellery and body piercing;
- Tattoos and permanent make-up;
- Loose ferromagnetic objects in pockets;
- Bras and belts; and
- Credit cards (Westbrook, Kaut Roth & Talbot, 2005: 348).

Figure 2.1: Schematic illustration of spatial regions at 1.5 T MRI units.



(EU Directive 2004/40, 2007: 485).

The area surrounding the isocentre (O in fig 2.1) of the magnetic field is called region one. This region is contained within the bore. The magnetic field strength in the very centre of the bore of a 1.5 Tesla MRI is 1.5 T provided the homogeneity of the magnet is very good. Any ferromagnetic object either inside or outside the body will experience a rotational force called a torque. This torque can cause rotational motion of the object and can cause the object to tear the surrounding tissue. The static field strength decreases with an increase in distance from the isocentre of the magnet and this area is then called region two. Region two is external to the physical magnet and is a gradient field because its strength varies with spatial position. In region two a ferromagnetic object in or outside the body may experience rotational and translational forces. The direction of the translational force will be in the direction of the isocentre of the magnet. Objects not secured will transfer into projectiles towards the bore and result in injuries to either patients or personnel (Price, 1999: 1641).

Reversible biological effects due to the high static magnetic fields do exist, like elevation of the T wave in the electrocardiography tracing. This is caused by blood flow in the vessel through the static magnetic field. In ultra-high static fields (10 T), a potential of 64 mV could be produced across an aorta about 16 mm in diameter (Price, 1999: 1642). Since 2000 the interest in static fields shifted to ultra-high-magnetic-fields systems (3 T and higher) for functional MRI. Although 3 T MRI scanners appeared in the early 1990s, their use has been restricted to research labs until recently. However, they are rapidly becoming the magnets of choice in high profile centres, and in sites dedicated to neuron-imaging (Gowland, 2005:177). The concern for adverse bio-effects due to static fields has increased once more. In the USA more than 30 ultra-high systems in excess of 3 T are in operation (Shellock & Crues, 2004: 636). Even in South Africa 3T MRI units are now operational although, "Safe use guidelines" (Department of Health, 1994: 4) state the static magnetic field exposure limit as 2 Tesla.

Although these ultra-high MRI units are a huge advantage to patient diagnosis, it involves exposing staff that do not benefit directly from the exposure (Gowland, 2005: 179). Staff moving around in the ultra-high fields (2 T and higher), can experience transient sensory effects like dizziness (caused by disturbance of the action of the balance organs), metallic taste in mouth (probably due to electrolysis of fillings), or phosphenes (flashing lights in eyes due to electrical pulses induced in the retina) (Gowland, 2005: 181).

Radio frequency fields cause tissue heating at sufficient power levels, which results in biological effects associated with thermally induced changes. Although no convincing evidence exists for non-thermal biological effects from RF radiation in diagnostic MRI, clear evidence of RF burns in patients is an essential component of MRI safety (Shellock & Crues, 2004: 637). Radio frequency burns can result from inadvertently induced currents in conductive loops placed on the patient's skin surface (Price, 1999: 1643).

Rapidly changing magnetic fields and the auditory noise levels can lead to muscle and nerve stimulation. The mean threshold levels (Ts^{-1}) for various stimulations are: 3.600 Ts^{-1} for the heart, 900 Ts^{-1} for respiratory systems, 90 Ts^{-1} for pain, and 60 Ts^{-1} for peripheral nerves. However, the stimulated threshold varies from individual to individual, some higher and some lower. Peripheral nerve and cardiac stimulation levels are respectively about three and 30 times higher than the Food and Drug Administration (FDA) guidelines. The FDA guidelines are specified as a function of the switching rate (Shellock & Crues, 2004: 636); (Price, 1999: 1647).

All these possible hazardous effects to patients and personnel make the MRI environment a very stressful working environment. An indept discussion on stress, stressors and measuring technique of stress follow in chapter four.

In summary, the most commonly recognized safety policy is the so-called 5 Gauss (5 mT) line. This line goes horizontally as well as vertically. If this safety policy is not always possible, safety rules should include the following: limited access, entrance controlled by lockable door, entrance visible to system operator, visitors screened, and appropriate warning signs posted (Price, 1999: 1648).

In May 1996, the International EMF (IEMF) project was launched by the World Health Organization (WHO) as part of its charter to protect health and in response to public concern regarding EMF exposure. The project is located at the WHO's headquarters in Geneva, Switzerland. The project is run within the Radiation and Environmental Act and has in its action plan on radiation protection, activities which deal with both ionizing and non-ionizing radiation (WHO, 2005: 2). The aim of the project is to assess health and environmental effects of exposure to static and time-varying magnetic fields in the frequency range 0 to 300 GHz. For this purpose this range is divided into the following fields: static (0 Hz), extremely low frequency (ELF, 0 – 300 Hz), intermediate frequency (IF, 300 Hz – 10 MHz) and radio-frequency (RF, 10 MHz – 300 GHz) (WHO, 2005: 4). Initially the IEMF was scheduled to complete their health risk assessment in 2006, however, the latest date will only be 2007 after completion of the WHO's health risk assessment of RF fields. The WHO anticipates that current and proposed research should provide sufficient results within this time frame to allow more definitive health risk assessments (WHO, 2005: 2).

Very little useful research has been conducted on the static magnetic field in MRI up to 2004. Many new technologies in MRI exist and much higher static fields are explored for use. Therefore, the need for further elaboration of static field research was made part of the IEMF project. Extremely low fields (ELF) in MRI are also a concern in MR imaging and benefits will be gained from the project findings on ELF (WHO, 2005: 3).

2.5 Exposure limits to electromagnetic fields (EMF)

Different bodies were responsible for setting limits for exposure to electromagnetic fields, like: the International Radiation Protection Association (IRPA); International Non-Ionizing Radiation Committee (INIRC); World Health Organization (WHO); International Commission on Non-Ionizing Radiation Protection (ICNIRP); United States Food and Drug Association (US FDA), International Electro-technical Commission (IEC) and European Committee for Electro-technical Standardization (CENELEC). These bodies responsible for setting guidelines need scientific information on which to set their limits (Renew & Glover, 2002: 395).

2.5.1 History of exposure limits to EMF

Much research has been done on MRI safety and the biological effects of electromagnetic fields over the past 25 years. Most of the research was done in the USA. In order to create a standard for exposure to electromagnetic radiation the American National Standards Institute (ANSI) developed a voluntary standard for occupational exposure in 1966. This voluntary standard was reaffirmed with minor changes in 1974 (Shellock & Kanal, 1994:183).

Other role players in the creation of the standards were bodies like the FDA of the USA. They issued guidelines to Hospital Investigation Review Boards (IRBs) in "Guidelines for Evaluating Electromagnetic Exposure Risks for Trials of Clinical MRI". The 1988 version of the data for safety was published in the Federal Register in the USA. The Environmental Protection Agency (EPA) and the Federal Communication Commission (FCC) proposed the adoption of interim standards until such federal guides were adopted. The FCC then decided to use the 1982 ANSI voluntary guidelines for public exposure. The Occupational Health and Safety Administration (OHSA) adopted the ANSI standards for occupational exposure in 1971, and retained its standards in 1984 because it provided useful advice to employers (Shellock & Kanal, 1994: 183).

In 1974, the International Radiation Protection Association (IRPA) formed a working group on non-ionising radiation (NIR), which examined the problems arising in the field of protection against the various types of NIR. In 1977, this working group became the International Non-Ionising Radiation Committee (INIRC). The IRPA/INIRC in cooperation with the WHO, developed a number of health criteria documents on NIR as part of WHO's Environmental Health Criteria Programme, sponsored by the United Nations Environment Programme (UNEP). Each document includes an overview of the physical characteristics, measurement and instrumentation, sources, and applications of NIR, a thorough review of the literature of the biological effects, and an evaluation of the health risks of exposure to NIR. These health criteria have provided the scientific database for the subsequent development of exposure limits and codes of practice relating to NIR. In 1992 the International Commission on Non-Ionising Radiation Protection (ICNIRP) was established as a successor to the IRPA/INIRC (ICNIRP, 1997: 494).

In the absence of detailed and conclusive evidence on the biological and physiological effects of electromagnetic fields, the guidelines given by the International Radiation Association (IRA) as well as those from the National Radiological Board in the UK form the basis of South Africa's Guidelines for static magnetic fields exposure (ICNIRP, 1997: 1). In 2000 guidelines, derived from the 1998 ICNIRP guidelines for time-varying electric, magnetic and electromagnetic fields up to 300 GHz were documented by South Africa's Department of Health, Directorate: Radiation Control. MRI units, currently used in South-Africa, fall into the 10 MHz to 10 GHz occupational exposure limit. In table 2.2 the basic restrictions for time-varying electric, magnetic, and electromagnetic fields for frequencies up to 10 GHz, accepted by the Department of Health (from ICNIRP), can be viewed. Basic restrictions between 1 Hz and 10 MHz are provided on current density in order to prevent nervous system function effects. In the frequency range 100 kHz and 10 GHz, the restriction in SAR are to prevent whole body heat stress and tissue heating. However, SAR as well as current density is used in the frequency range 100 kHz to 10 MHz. Power density restriction in the frequency range 10 to 300 GHz is to prevent excessive heating in tissue at or near the body surface (table 2.1) (Department of Health, Directorate: Radiation Control, 2002: 2).

Table 2.1 Exposure limits for time-varying electromagnetic fields for frequencies between 10 and 300 GHz

Exposure characteristics	Power density (W/m^2)
Occupational	50
General Public	10

Notes for table 2.1:

1. " Power densities are to be averaged over any 20 cm^2 of exposed area and any period of $68/f^{1.05}$ (where f is in GHz) to compensate for progressively Shallower penetration depth as the frequency increase.
2. Spatial maximum power density, averaged over 1 cm^2, should not exceed 20 times the values above."
(Department of Health, Directorate: Radiation Control, 2002: 3).

Table 2.2: Exposure limits to time-varying electric, magnetic and electromagnetic fields for frequencies up to 10 GHz.

Exposure characteristics	Frequency range	Current density (head & trunk) (mA/m^2) (rms)	Whole-body average SAR (W/kg)	Local SAR (head & trunk) (W/kg)	Local SAR (limbs) (W/kg)
Occupational	Up to 1 Hz	40			
	1-4 Hz	$40/f$			
	4 Hz-1 kHz	10			
	1-100 kHz	$f/100$			
	100 kHz-10 MHz	$f/100$	0.4	10	20
	10 MHz –10 GHz	_	0.4	10	20
General public	Up to 1 Hz	8			
	1-4 Hz	$8/f$			
	4 Hz-1 kHz	2			
	1-100 kHz	$f/500$			
	100 kHz-10 MHz	$f/500$	0.08	2	4
	10MHz – 10 GHz	_	0.08	2	4

Notes for Table 2.2:

1. *"f is the frequency in Hz (hertz).*
2. *Because of electrical inhomogeneity of the body, current densities should be averaged over a cross section of 1 cm^2 perpendicular to the current direction.*
3. *For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$(~1.414).*
4. *For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of flux density. The induced current density can then be compared with the appropriate basic restriction.*
5. *All SAR values are to be averaged over any 6-min period.*
6. *Localised SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.*
7. *For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/2t_p$). For pulsed exposures in the frequency range 0.3 to 10 GHz and for localised exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended i.e. the SA should*

not exceed 10 mJ/kg for occupational and 2mJ/kg for general public exposure, averages over 10 g of tissue." (Department of Health, Directorate: Radiation Control, 2002: 3).

Reference levels for occupational and general public exposure to time-varying electric, magnetic, and electromagnetic fields for frequencies up to 300 GHz expressed in E-field, H-field, B-field flux density and power density values, can be viewed in table 2.3.

Table 2.3: Occupational and general public exposure limits up to 300 GHz expressed in E-field, H-field, B-field and power density values

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field flux density (µT)	Power density S_{eq} (W/m^2)
Occupational exposure				
Up to 1 Hz		1.63×10^5	2×10^5	
1-8 Hz	20 000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	
8 -25 Hz	20 000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	
0.025-0.82 kHz	$500/f$	$20/f$	$25/f$	
0.82-65 kHz	610	24.4	30.7	
65-1 MHz	610	$1.6/f$	$2/f$	
1-10 MHz	$610/f$	$1.6/f$	$2/f$	
10 - 400MHz	61	0.16	0.2	10
400-2000 MHz	$3f^{0.5}$	$0.008f^{0.5}$	$0.02f^{0.5}$	$f/40$
2-300 GHz	137	0.36	0.45	50

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field flux density (μT)	Power density S_{eq} (W/m^2)
Public exposure				
Up to 1 Hz		3.2×10^4	4×10^4	
1-8 Hz	10 000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	
8-25 Hz	10 000	$4\,000/f$	$5\,000/f$	
0.025-0,8 kHz	$250/f$	$4/f$	$5/f$	
0.8-3 kHz	$250/f$	5	6.25	
3-150 kHz	87	5	6.25	
0.15-1 MHz	87	$0.73/f$	$0.92/f$	
1-10 MHz	$87/f^{0.5}$	$0.73/f$	$0.92/f$	
10 - 400MHz	28	0.073	0.092	2
400-2 000 MHz	$1.375\,f^{0.5}$	$0.0037f^{0.5}$	$0.0046f^{0.5}$	$f/200$
2-300 GHz	61	0.16	0.2	10

Notes for Table 2.3:

1. *" f is the frequency as indicated in the frequency range column.*
2. *For purpose of demonstration compliance with the basic restrictions, the reference levels for the electric and magnetic fields should be considered separately and not additively, because the currents induced by electric and magnetic fields are, for protection purpose, NOT additive.*
3. *For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2 and B^2 are to be averaged over any 6-minute period.*
4. *For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2 and B^2 are to be averaged over any $68/f^{.05}$-minute period (f in GHz).*
5. *For peak values at frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$(~1.414).*
6. *Peak field strength values at frequencies between 100 kHz and 10 MHz are obtained by interpolation from the 1.5-times peak at 100 kHz to the 32-times peak at 32-times peak at 10 MHz.*

For frequencies exceeding 10 MHz it is suggested that the peak power density as averaged over the pulse width not exceed 1000 times the S_{eq} restrictions, or that the field strength not exceed 32 times the field strength exposure levels given in Tables3.2 and 3.3 (for peak values see MS Excell™ document: "Exposure Reference Levels (Average & Peak) – Tables & Graphs.xls").

7. *No E-field value is provided for frequencies < 1 Hz, which are effectively static magnetic electric fields. Perception of surface electric charges will not occur at electric field strength of less than25 kV/m. Sparks discharges causing stress or annoyance should be avoided. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment"* (Department of Health: Radiation Control, 2002: 5).

Although the ICNIRP guidelines form the basis of the exposure limits in different countries, most countries compiled their own documents. The USA, Canada, Germany, UK and Italy have already investigated the safety aspects of the MRI environment, mostly patient safety aspects. (Reports from the Canadian Coordinating Office for Health Assessment, 1993: 593).

In the USA the American National Standard Institute (ANSI), the Institute of Electrical and Electronic Engineers (IEEE) and Food and Drug Association (FDA) are involved in the setting of limits for exposure to EMF. Currently the IEC 60601-3 series prescribe the standards for radiation protection. The Association for Advancement of Medical Instrumentation (AAMI) in conjunction with ANSI presented the AAMI/ANSI 60601-1 in 2006, which is essentially the same as the IEC/EN 60601-1 document. Current standard for exposure to EMF in the USA involve a 4.1 T threshold for static fields, 4 W/kg/15min SAR for body and a 3 W/kg/10min for head in RF, and state to avoid painful nerve stimulation in time-varying fields. A work group has been appointed to explore the occupational exposure to EMF. Future based standards are expected to be effective between 2009 and 2012. USA is expected to adopt whatever transition is agreed to between International Electro-technical Commission (IEC) and European Committee for Electro-technical Standardization (CENELEC) (Schmidt, 2005: 2). Canada as well as New Zeeland adopted the USA standards (Armstrong, 2005:3).

UK used to set its own standards for exposure limits to EMF via the Health Protection Agency (HPA) and the former National Radiological Protection Board (NRPB).

However, in March 2004 the NRPB recommended that the UK should adopt the ICNIRP guidelines, published in 1998. The recommendation was then accepted by the Government (Electromagnetic Field exposure limitation and the future of MRI, 2005: 973)

The exposure limits to EMF in Europe were set by countries individually. However, in 2004 the European Union (EU) adopted a Directive limiting occupational exposure to EMF. The Physical Agent Directive includes MR, but only occupational exposures and must be incorporated into domestic law by each EU member state by 30 April 2008. Due to an outcry from the MR community the implementation of the Directive has been postponed to be implemented between 2009 and 2012. It currently includes exposure to time-varying magnetic field generated by the gradients (gradient fields, 100 – 1000 Hz) and the radiofrequency fields (RF, 10 - 100 MHz), which are both generated during active pulse sequences (EU Directive 2004/40, 2004:483).

In table 2.4 the proposed occupational exposure limits to EMF (EU Directive) in the MRI environment can be viewed. Although the 2 T static field limit has been removed from the Directive, it may still be introduced at a later stage by a review currently being undertaken by ICNIRP. The estimate limits for the static field is based on someone entering the magnet bore for cleaning purposes or to position experimental apparatus. Due to no static field limit, the gradient field limit poses the biggest problem. The gradient field (time-varying field) is based on a health worker standing very close to the bore during imaging. The gradient field limits are absolute without the scope for time averaging. Therefore, it will become illegal for a Health worker to lean into the bore even for a brief moment. The RF exposure is averaged over the whole body and seems unlikely to be exceeded in the near future (Electromagnetic field exposure limitation and the future of MRI, 2005: 973)

Table 2.4: Proposed exposure limit and action values for occupational exposure to electromagnetic fields at typical MRI frequencies

Field	Exposure limit	Action value (Magnetic

		flux density)
Static Magnetic field (f= 0 Hz)	2 T[a]	0.2 T
Gradient fields (e.g. f = 500 Hz)	10 mA/m^2 (3 – 1000 Hz) f/100 mA/m^2 (1 – 100 kHz)	2.5 x 104/f uT (e.g. 50 uT for 500 Hz)
RF field (f = 10 – 400 MHz)	10 W/kg (SAR – head and trunk) 20 W/kg (SAR – limbs)	0.2 uT (== 10 W/m^2)

RF, radiofrequencies: SAR, specific absorption rate.

[a]Limit removed from current version.

(Electromagnetic field exposure limitation and the future of MRI, 2005: 974)

According to literature no evaluation was previously done on the South African standards. However, the South African forum for Radiation Protection (SAFRP) made several comments regarding the 1991 IRPA guidelines on protection against NIR (South African Forum for Radiation Protection, 1991:1-11).These comments and recommend-dations were based on the NIR spectrum, aim of IRPA guidelines, biological effects and general principles for protection against NIR.

NIR spectrum included all electromagnetic radiations with wavelength equal to or greater than 10^{-7}m. This wavelength spectrum included:

- Ultraviolet (UV) radiation (100 – 400 nm);
- Visible light (400 – 760 nm);
- Infrared radiation (760 nm – 1 mm);
- Radiofrequencies from upper limit microwaves (300 GHz), radio-waves (100 kHz or 3 km) and the ELF range (below 300 Hz)

IRPA guidelines were mainly aimed at defining standards related to exposure to NIR, either of the tissues or the whole body. The purpose of these standards, also called product performance standards, was to minimise health effects by ensuring safe operation of the products.

Biological effects or physiological importance due to the various type of NIR varies and depend on a number of factors like:

- Parameters that will determine the penetration depth of the incident radiation (e.g. resonance, power density, coherent, non-coherent, continuous, modulated or pulsed);
- Parameters that will contribute to exposure conditions (continuous or intermittent exposure) or spatial distribution (whole body or partial body);
- Parameters that will contribute to biological effects (as in ionising radiation);
    - Deterministic effects, where the severity varies as a function of the exposure (usually above limit exposure);
    - Stochastic effects, which is where the probability of occurrence increase with incident exposure (South African Forum for Radiation Protection, 1991: 2).

The protection doctrine on NIR, established by IRPA/INIRC, includes the following general principles;

- Compliance with the health protection standards in IRPA/INIRC guidelines for occupational and general public exposure;
- Performance standard to guarantee the compliance with health protection standards;
- Protection measurement to be implemented if safety of exposure can not be guaranteed (South African Forum for Radiation Protection, 1991: 3).

The recommendations were not final because the IRPA invited comments from interested organisations. In 2002 new guidelines were recommended by the SAFRP after the ICNIRP published new recommendations on NIR to time-varying electric-, magnetic and electromagnetic fields up to 300 GHz (ICNIRP, 1997: 494-522); (Department of Health: Radiation Control, 2002: 24).

In Germany the Berufsgenossenschaft (BG) Fur Feinmechanik und Elektotechnik (Ordidge, Fullerton & Norris, 2000:1) and in USA the American Conference of Governmental Industrial Hygienist were the bodies who provided these countries with their occupational limits for EMF at MRI units (Bailey, Su, Dan Bracken & Kavet, 1997: 435). A review of Canadian MRI exposure guidelines raised some uncertainties regarding the safety of control subjects' exposure to the magnetic fields. In the UK, magnetic field strength ranging from 1.5 T up to 4 T is operated. Bailey *et al*. came to the conclusion that theoretically and experimentally the static field appears to have a very high threshold of safety to human tissue at least well above 4 T. Almost all human tissue are diamagnetic, which, means that most human tissue tend to be expelled from magnetic fields (Schenck, 2005: 192). Biological processes at cellular and subcellular levels are driven by several types of forces like:

- Tissue elasticity and viscosity;
- Random thermal forces;
- Gravitational and electrostatic components.

The sum of these individual forces determines tissue morphology and motion. Magnetic force measured in piconewtons (pN) is superimposed on these pre-existing forces when the tissue (macromolecules) is places in a magnetic field. The magnetic force on a large protein in even a very high magnetic field MR unit is less than 10^{-6} pN. This means that it is consistent with the observation that magnetic fields do not produce measurable harmful effects on human tissue. However, the sum of a combination of magnetic forces on a large number of molecules can produce a detectable effect (Schenck, 2005:193).

Human studies have been done on static magnetic fields up to 10 T and from clinical evidence involving well over 100 million clinical MRI scans 4 T appears to be a substantial margin of safety for human exposure (Health Sciences Research Ethics Board guidelines, 2001: 3).

2.6 Previous Research Findings of EMF in the MRI environment

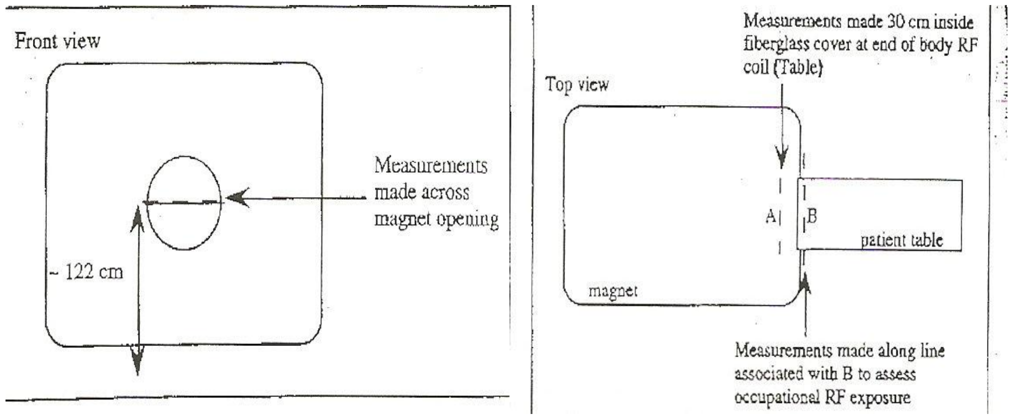
In 1995 Fermlee and Vetter conducted a RF survey at the bore of a 1.5 T MR Imager. The RF field strength was measured with an isotropic field strength meter designed to measure occupational RF exposure. Separate electric and magnetic field measurement probes were used. These probes used the peak detection mode and 8 kHz sampling rate. Phantoms were used for the imaging process and the body coil was used as a transmitter-gain setting. Radio frequency measurement was at the entry to the bore (Fermlee & Vetter, 1995: 571). Different pulse sequences were used and included:

- T1-weighted spin echo where, contrast depends predominantly on the differences in T1 times between fat and water;,
- T2-weighted spin echo where, contrast depends predominantly on the differences in T2 times between fat and water
- Fast spin echo (FSE) imaging where, multiple 180 degree rephasing pulses are used to decrease imaging time (Westbrook, Kaut Roth & Talbot, 2005: 30).

The phantoms used were: Vendor quality-control phantom, body-coil loader, and a human volunteer (Fermlee & Vetter, 1995: 571).

Threshold limit value for occupational RF exposure at 64 MHz is 1 $mWcm^{-2}$. At a point A just inside the bore ("30 cm inside the fibreglass cover at the end of the body RF coil, inside the") the power density was above 1 $mWcm^{-2}$. However, at a point B just outside the bore all the values were below the threshold limit. During the measurements the highest exposure came from the fast spin echo (FSE) sequences (Fermlee & Vetter, 1995: 572).

Figure 2.2: Front and top views of the magnet reflect power density measurement positions



(Fermlee & Vetter, 1995: 572).

At high static magnetic field MRI units, the specific absorption rate (SAR) is proportional to:

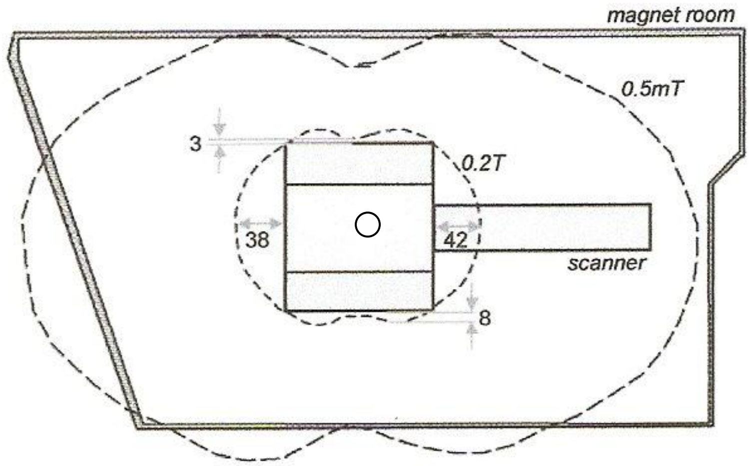
- The square of the static field strength;
- The square of the RF pulse flip angle being used (Elster & Burdette, 2001: 304)

Therefore, 180º RF pulse uses four times the power used by a 90º RF pulse, because the RF pulse is doubled. For this reason FSE sequences give the greatest concern for adverse RF effects, as they use a train of 180º RF pulses (Westbrook, Kaut Roth & Talbot, 2005:344). The RF energy deposited by a pulse producing a given flip angle, say 180º, increases with frequency with the field strength of the applied magnetic field. Therefore in the presence of the ultra-high static field strengths it is necessary to de-rate the maximum number of 180º pulses (but not the SAR) applied in a given time (Hore, 2005: 200).

Static magnetic fields effects at the MRI had been research as early as 1986 (Shellock, Schaefer & Gordon, 1986: 644). Since the early 2000's the interest in MRI research has shifted to the ultra-high static magnetic fields. Although several papers were published regarding the effect or hazards of static fields of 2 T and higher, no similar data on the RF and rapidly changing fields (gradient) were available (Ordidge, Fullerton & Norris, 2000:2); (Schenck, 2005: 199). However, in December 2005 the Health Physics published an article: "IEEE committee on man and radiation (COMAR) technical information statement exposure of medical personnel to electromagnetic fields from open magnetic resonance imaging systems". The research in this article involved the occupational exposure of health workers to static, gradient, and radiofrequency fields during interventional radiology at a 0.7 T Open MRI system. Measurements were done in all three fields and then compared to international exposure limits including those set by IEEE and ICNIRP. The static field exposure limits were well within the limits. The gradient field limits for exposure of the head or torso of a health worker close to the patient imaging centre can exceed the limit values even for times less than a second. Radiofrequency exposure limits can be exceeded if sustained exposure occurs to parts of the body ("IEEE committee on man and radiation (COMAR) technical information statement exposure of medical personnel to electromagnetic fields from open magnetic resonance imaging systems, 2005: 684).

In June 2007 the British Journal of Radiology published research compiled by the Cancer Research UK Clinical Resonance Group on static field fall of around a 1.5 T MRI unit, as well as, occupational exposure to the gradient and RF fields during clinical sequences. This research was done to assess whether the EU directive would have an impact on the clinical use of MRI. They used a THM 7025 Hall probe (Narda Safety Test Solutions) to map the 0.2 T field strength action value line around the scanner. An ELT 400 and a 100 cm^2 magnetic field probe (Narda) were used to measure gradient fields (100 Hz – 1000 Hz) and an EMR-300 Broadband RF survey meter with a Type 18.0 electric field probe (Narda) to measure the RF fields (10 MHz – 100 MHz). The gradient fields were measured during a fast spin echo (FSE) and an echo planar imaging (EPI) pulse sequence which are most frequently used and have high gradient strength. The RF fields were measured during a single-shot magnetic resonance cholangiopancreatography (MRCP) which has a high amount of RF power. The scanner was loaded with a 40 cm diameter cylindrical phantom with a bottle phantom on either side. The body coil was used as transmitter and receiver (EU Directive 2004/40, 2007: 484).

Figure 2.3: Mapping of the 0.2 T field strength action value line around a 1.5 MRI system



(EU Directive 2004/40, 2007: 485).

The results of this study compared to the UE's proposed new exposure limits in fig 2.2 showed that:

- The static field action value will be exceeded at any distance less than 42 cm from the patient landmark position (at the entrance to the bore), which, means that it will be exceeded while positioning a patient.
- The gradient field limits will be exceeded at 52 cm from the patient landmark position, which, means that it will have a severe effect on safe clinical practice.
- The RF limits were not exceeded on this 1.5 T system, but it may be different on open magnets where RF shielding is less contained (EU Directive 2004/40, 2007: 485).

In view of the latest research findings on EMF exposure in the MRI environment, the EU's proposed new exposure limits and the telephonic conversation (14 January 2008: 11:45) with Leon du Toit, Director for occupational exposure at the Department of Health, Directorate: Radiation Control, who stated that their tests in South Africa mainly concern static magnetic field (fringe field) fall of around the magnet, the situation around EMF testing in the MRI environment in South African creates great concern. In view of the temporarily removal of the proposed restriction (in the EU directive) on the static magnetic field, concern arises in South Africa especially in the occupational exposure to gradient and RF fields in the MRI environment.

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Chapter 3

3. Electromagnetic fields (EMF) associated with the magnetic resonance imaging environment

3.1 Introduction

The internal construction of the magnetic resonance imaging (MRI) unit responsible for creating the electromagnetic fields associated with the MRI environment, consists of a: stationary magnet responsible for the static magnetic field (0 Hz); with three fitted gradient coils responsible for the gradient or time-varying fields [1 - 300 kHz, extremely low frequencies (ELF) and 300 kHz - 10 MHz, intermediate frequencies (IMF)]; and radio frequency (RF) coils, either within the magnet (body coil) or surface coils for anatomically specific imaging, responsible for the RF fields production (10 MHz – 200 MHz for up to 3 T). (Carlton & Adler, 1996: 676); (Bushberg, Siebert & Boone., 2002: 458). The mechanism of the MRI units was discussed in chapter 2.

3.2 Problem Statement

The attention granted to the occupational safety of clinical personnel at the MRI up to 2004 has been of great concern (Olsen, 1991: 237). Research emphasis since 2005 has moved towards very high static magnetic field in the MRI environment (Schenck, 2005: 199). The proposed new exposure limits by the European Union Directive were announced in 2005 and the emphasis shifted once more, this time especially to the gradient fields in the MRI environment (EU Directive 2004/40: field measurement of a 1.5 T clinical MR scanner, 2007:483).The increasing demand for anaesthetics to be administered in this environment has caused continuing concern amongst health workers about the Occupational exposure to RF, gradient and static magnetic fields at MRI units. (Mc Brien, Winder, & Smyth, 2000: 740). The time spent by health workers in the room close to the bore to attend to ventilated patients has been of great concern. Although patient's safety is first priority and has always been stressed during training, safety regarding the clinical personnel exposure to RF and gradient fields has rarely been mentioned before 2004 and needs more attention (Felmlee & Vetter, 1995: 571).

As mentioned in chapter 1 page 6, the testing of MRI units in South Africa is mainly aimed at the static magnetic field and the fringe field falls off around the MRI units.

The present study was thus designed towards addressing the lack of evidential testing of the occupational exposure limits of the gradient and RF fields in the MRI environment in South Africa, by gathering information regarding exposure levels of health workers at MRI units in South Africa.

3.3 Aim and objectives

3.3.1 Aim

The aim of this chapter is to provide the reader with background information on human exposure to EMF and applicable recommended occupational exposure limits in the MRI environment, which, will be used during this study to make a comparison with the measurement values of occupational exposure to EMF of health worker at selected MRI units in South-Africa.

3.3.2 Objectives

- Measure the exposure of health workers to gradient and RF fields at three MRI units in Bloemfontein, and to compare the results to the occupational exposure limit levels (ICNIRP) adopted by the Department of Health in South Africa, to ensure that the measured exposures fall within the limits.

3.4 Human exposure at MRI

Humans exposed to the frequencies of MRI electromagnetic fields (EMF) can be divided into three exposure groups: Patients and volunteers, general public, and health workers (Department of Health: Electromedical Devices, 1994: 1).

Patients are members of the public, referred by medical practitioners for MRI examinations. Magnetic resonance imaging is a functional imaging modality, and to optimize a pulse sequence it is often necessary to use human volunteers, because phantoms cannot be created to adequately mimic living tissue. Local ethics committees approve the use of volunteers. Patients and volunteers are in most cases exposed to all three (gradient, RF and static fields) electromagnetic fields (Gowland, 2005: 181).

The general public includes individuals of all ages and of varying health status. Particularly susceptible groups of individuals may be included in this group. The general public is only exposed to the static magnetic fields, where family and friends, however, are sometimes required to accompany patients into the MRI room during examinations. Members of the general public are not always aware of their exposure to EMF (Department of Health: Electromedical Devices, 1994:1); (International Commission on Non-Ionizing Radiation Protection [ICNIRP], 1998: 495).

Exposure of health workers in the MRI environment is classified as occupational exposure. Occupational exposure affects that part of the population who are generally exposed to EMF under known conditions during the normal course of their particular employment and who are trained to take appropriate precautions (Department of Health: Radiation Control, 2002:1). Appropriate precautions may include the controlled admission to the MRI room, screening of all people allowed to enter the room and to allow as little as possible time spent in the room. From the literature review it was established that health workers are exposed to all three fields; static, gradient and RF fields, although in "Safe use Guidelines for Magnetic Resonance Imaging Systems" (Department of Health: Electromedical Devices, 1994: 4) it is stated that in real life they are only exposed to the static magnetic fields. The health workers who are occupationally exposed to static magnetic fields can be divided into different groups: radiographers, radiologists, anaesthetists, nurses and registered nurses. Health workers sometimes have to stay with a patient in the MRI room during scanning and could be exposed to these fields for a prolonged period of time (Gowland, 2005: 181).

Radiographers comprise the largest group of workers who are occupationally exposed to static magnetic fields. They are the paramedical staff responsible for the patient's comfort and safety, as well as for producing good-quality images in all circumstances, for diagnostic purposes (Gowland, 2005: 180). Radiographers have to walk through the static magnetic field around the magnet all day and they are exposed to the static magnetic field to a large extent. Careful planning of working practices and patient bed design can minimize the exposure to static magnetic fields. However it is often necessary for the radiographers to lean into the bore to comfort and reassure sick or distressed patients during an examination, resulting in additional exposure to gradient and RF fields (Gowland, 2005: 181).

Radiologists are the medical staffs who are responsible for MRI scans. They are less involved with the patient care but still have to enter the static magnetic field for the administration of contrast agents required during the examination. Radiologists and other specialists can also be subjected to the gradient (time-varying) and RF fields during the new development of interventional MRI procedures (Gowland, 2005: 181). Sometimes anaesthetists have to enter the static field to stay in the RF and gradient fields (close to the bore) for anaesthesia procedures on sick or uncooperative patients.

Physicists, engineers and development staff are further groups who are exposed to the static magnetic fields. Especially the engineers, who are involved in the construction and the maintenance of the MRI scanners, are frequently exposed to static magnetic fields. They sometimes have to climb inside the magnet to adjust new pieces of hardware. The time spent inside the magnet can vary from seconds to hours but mostly 1-3 min (calibrations service average about 15 min total per service) Engineers generally only spend long periods of time in or next to the magnet on upgrades and breakdowns. A

Coldhead change will put them next to the magnet for 4-6 hours and happens only every 4-5 years per magnet. The dc field is not turned off because the cost of Helium, down time and tools shipping cost (ramp & shim supply's shipping) is high to very high. DC power down may mean 1 day to 2 days down time to turn the magnet on and off. Helium lost in this ramp down ramp up is 15 % or higher (100 L of Helium or more is valued at ± R14000). However, some manufacturers are said to be able to ramp down and up in 2-4 hour's. The type of fields will only be dc / static but can vary from 0 to magnet field strength. (Gowland, 2005: 181).

The number of people exposed to EMF in the MRI environment accentuates the need for appropriate precautions as mentioned above. Regulatory control intends to minimize potential health hazards to general public, patients, volunteers, and health workers operating the equipment. Protection against established adverse health effects of RF exposure requires that the basic restrictions set by the Department of Health are not exceeded (Department of Health: Electromedical Devices, 1994: 1).

3.4.1 Exposure limits for non-ionizing radiation in the MRI environment

Limits for exposure to non-ionizing radiation at MRI systems, adopted by the Department of Health, Directorate: Electromedical Devices and Radiological Health, were derived from the guidelines of the International Radiation Protection Association (IRPA) as well as those of the National Radiological Protection Board (NRPB) in the United Kingdom (UK) (Department of Health: Electromedical Devices, 1994:1). “The reference levels have been obtained from the basic restrictions by mathematical modelling and by extrapolation from the results of laboratory investigations at specific frequencies” (Department of Health, 2002: 3).

The limits for public, patients and volunteers exposure to static magnetic fields are restricted to 2 T for the head and trunk, and 4 T for limbs (Department of Health: Electromedical Devices, 1994: 2). Occupational exposure limits for health workers to static fields are restricted to 0.2 T average exposures for a prolonged period. An increase to the limit up to 2 T is allowed for short periods totalling less than 15 minutes, on one-hour interval conditions between exposures (Department of Health: Electromedical Devices, 1994: 4).

The patient safety criteria in RF fields are based on temperature rise, from 0.5 °C to 1 °C. The whole body specific absorption rate (SAR) of the patient should be restricted to 1 W/kg for all exposures of more than 30 minutes (Department of Health: Electromedical Devices, 1994: 3).

The occupational and general public exposure limits for time-varying magnetic fields and RF fields can be viewed in table 3.1.

Table 3.1: Basic restrictions for time-varying electric, magnetic, and electromagnetic fields for frequencies up to 10 GHz

Exposure characteristics	**Frequency range**	**Current density (head & trunk) (mA/m^2) (rms)**	**Whole-body average SAR (W/kg)**	**Loc SAR (head & trunk) (W/kg)**	**Loc SAR (limbs) (W/kg)**
Occupational	Up to 1 Hz	40			
	1 – 4 Hz	40/*f*			
	4 Hz – 1 kHz	10			
	1 – 100 kHz	*f*/100			
	100 kHz –10MHz	*f*/100	0.4	10	20
	10 MHz –10 GHz	_	0.4	10	20

General Public	Up to 1 Hz	8			
	1 – 4 Hz	8/*f*			
	4 Hz – 1 kHz	2			
	1 – 100 kHz	*f*/500			
	100 kHz –10MHz	*f*/500			
	10MHz – 10 GHz	_	0.08	2	4

Notes for Table 3.1:

1. *"f is the frequency in Hz (hertz).*
2. *Because of electrical in homogeneity of the body, current densities should be averaged over a cross section of 1 cm² perpendicular to the current direction.*
3. *For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414).*
4. *For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restrictions.*
5. *All SAR values are to be averaged over any 6-minute period.*
6. *Localized SAR averaging mass is 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of the exposure.*
7. *For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = (1/2\ t_p)$. For pulsed exposure in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended i.e. the SA should not exceed 10 mJ/kg for occupational and 2 mJ/kg for general public exposure, averaged over 10 g of tissue."* (Department of Health: Radiation Control, 2002: 2).

The reference levels for the electric and magnetic fields should be considered separately and as a combination for the purpose of demonstrating compliance with the basic restrictions. The currents induced by electric and magnetic fields are not dependent on each other, for protective purposes. Electromagnetic fields can be split into two components: the electric field E (V/m) and the magnetic field H (A/m). The E-field and H-field are strongly interdependent for far field, which is anywhere more than a certain distance from the source. Measurement of the H-field in the far field enables calculations of the magnitudes of the E-field and the power density S from it. In the near field (close to the source), the H-field and the E-field have to be measured separately (Narda Test Solutions: Radiation meters, 2004: 2).

The boundary between the near and far field at a MRI unit are typically indicated by the following formula: $\lambda/(2.\pi)$ where λ is the wavelength (m) of the frequency concerned (Near and Far fields, 2008:1). The Lamor frequency at a 1.5 T MRI is 63.87 MHz, and by calculation ($\lambda = c/f$) the wavelength is 4.68 m (Electromagnetic Fields, 2008:2). Therefore the boundary will be 0.7455 m from the centre of the magnetic field in the bore. All exposures closer to the bore than 75 cm will be in the near field and further away than 75 cm will be in the far field

Reference levels for occupational and general public exposure to time-varying electric, magnetic, and electromagnetic fields for frequencies from 10 MHz to 400 MHz, expressed in E-field, H-field, B-field flux density and power density values, can be viewed in table 3.2 and table 3.3.

Table 3.2: Occupational exposure limits to gradient, magnetic, and electromagnetic fields (0 – 300 GHz)

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field flux density (µT)	Power density S_{eq} (W/m²)
Up to 1 Hz		1.63×10^5	2×10^5	
1-8 Hz	20 000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	
8 -25 Hz	20 000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	

0.025-0.82 kHz	$500/f$	$20/f$	$25/f$	
0.82-65 kHz	610	24.4	30.7	
65-1 MHz	610	$1.6/f$	$2/f$	
1-10 MHz	$610/f$	$1.6/f$	$2/f$	
10 - 400MHz	61	0.16	0.2	10
400-2000 MHz	$3f^{0.5}$	$0.008f^{0.5}$	$0.02f^{0.5}$	$f/40$
2-300 GHz	137	0.36	0.45	50

Table 3.3: General Public exposure limits to gradient, magnetic, and electromagnetic fields (0 – 300 GHz)

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field flux density (μT)	Power density S_{eq} (W/m²)
Up to 1 Hz		3.2×10^4	4×10^4	
1-8 Hz	10 000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	
8-25 Hz	10 000	$4\ 000/f$	$5\ 000/f$	
0.025-0,8 kHz	$250/f$	$4/f$	$5/f$	
0.8-3 kHz	$250/f$	5	6.25	
3-150 kHz	87	5	6.25	
0.15-1 MHz	87	$0.73/f$	$0.92/f$	
1-10 MHz	$87/f^{0.5}$	$0.73/f$	$0.92/f$	
10 - 400MHz	28	0.073	0.092	2
400-2 000 MHz	$1.375\,f^{0.5}$	$0.0037f^{0.5}$	$0.0046f^{0.5}$	$f/200$
2-300 GHz	61	0.16	0.2	10

Notes for Table 3.2 and 3.3:

1. *" f is the frequency as indicated in the frequency range column.*
2. *For purpose of demonstration compliance with the basic restrictions, the reference levels for the electric and magnetic fields should be considered separately and not additively, because the currents induced by electric and magnetic fields are, for protection purpose, NOT additive.*
3. *For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2 and B^2 are to be averaged over any 6-minute period.*
4. *For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2 and B^2 are to be averaged over any $68/f^{1.05}$-minute period (f in GHz).*
5. *For peak values at frequencies up to 100 kHz, peak current density values can be obtained by*

multiplying the rms value by √2(~1.414).

6. *Peak field strength values at frequencies between 100 kHz and 10 MHz are obtained by interpolation from the 1.5-times peak at 100 kHz to the 32-times peak at 32-times peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak power density as averaged over the pulse width not exceed 1000 times the S_{eq} restrictions, or that the field strength not exceed 32 times the field strength exposure levels given in Tables3.2 and 3.3 (for peak values see MS Excell™ document: "Exposure Reference Levels (Average & Peak) – Tables & Graphs.xls").*
7. *No E-field value is provided for frequencies < 1 Hz, which are effectively static magnetic electric fields. Perception of surface electric charges will not occur at electric field strength of less than 25 kV/m. Sparks discharges causing stress or annoyance should be avoided. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment"* (Department of Health: Radiation Control, 2002: 5).

3.5 Methodology

This study was centred on the gradient RF fields in the MRI environment. The study design was descriptive, and included evaluations between measurements of exposure to RF fields and time-varying (gradient) fields in the MRI environment, and exposure limits set by the Radiation Control Directorate of the Department of Health.

3.5.1 Population and sample

Three 1.5 T MRI units in Bloemfontein were identified and utilized to measure the exposure of health workers to the gradient RF fields present in the MRI environment. Three rounds of measurements of RF fields in the MRI environment were done. All three measurement rounds were focused on the low frequencies 5 Hz to 32 kHz (ELF), as well as the high frequencies 300 kHz to 40 GHz [IMF (300 kHz - 10 MHz) and RF (10 MHz – 200 MHz for up to 3T)].

First round measurements were done to establish the background of the RF fields in and around the magnet room during an MRI examination. This was done to establish which of the RF fields were measurable, and to test the ability of the measuring instrument to work properly in the high magnetic field (1.5 T) environment. Round one measurement of the three sites were all done during one working day and were taken during different pulse sequences in a brain examination. The measurements were done at different locations in and around the MRI room, namely left and right front up against the bore, left and right rear one metre away from the bore, and in front of the window at the control console inside the MRI room. The pulse sequences performed in round one at all three units were: fast spin echo (FSE), fluid attenuated inversion recovery (FLAIR), spoiled gradient (SPGR), and echo planar diffusion imaging (EPI). The sequences were chosen because they were the most frequently used sequences using high gradient strength (Bernstein, King & Zhou, 2004: 585).

Second round RF field measurements were done at a specific location, one meter away from the bore on the right hand side of the bed, in the MRI room. This position was a simulation of presumed safe distance, which a parent or health worker would be, while staying with a patient during an examination. The measurements were done on different examinations and pulse sequences during one working weekday at each site. Measurements were done on three different examinations, namely lumbar spine, cervical spine, and brain. These are the examinations mostly performed at these MRI sites. The pulse sequences in round two and three included: SE and FSE T1 and T2 weighted imaging, EPI, FLAIR, spoiled gradient imaging (SPGR), and gradient 3D volume imaging.

The third round measurements were of the same format as the second round, but the specific location was against the magnet bore.

Schematic illustrations showing the fringe field gradient fall off around the magnet, layout and measurement locations (*) at the three units can be viewed below in figures 3.1, 3.2 and 3.3. The magnetic field strength is expressed in gauss (G) on the contours in figure 3.1, in mille-Tesla and gauss in brackets in figure 3.2 and in mille-Tesla in figure

3.3. The distances of the magnetic field contours apart from the centre of the magnet are expressed in feet and in meters (in brackets) in figures 3.1 and 3.2. In fig 3.3 the distance indication is in meters.

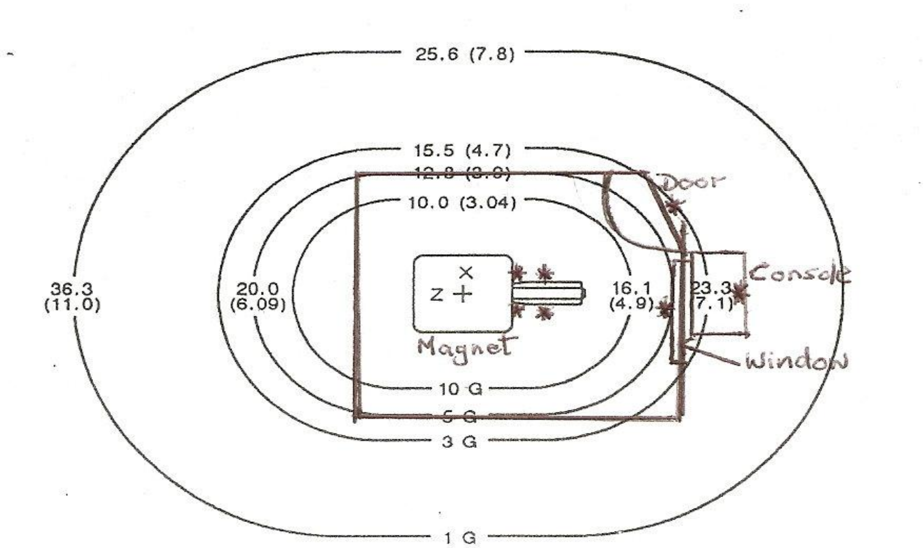

Figure 3.1: Fringe field gradient fall off around the magnet, layout and measurement locations at unit one

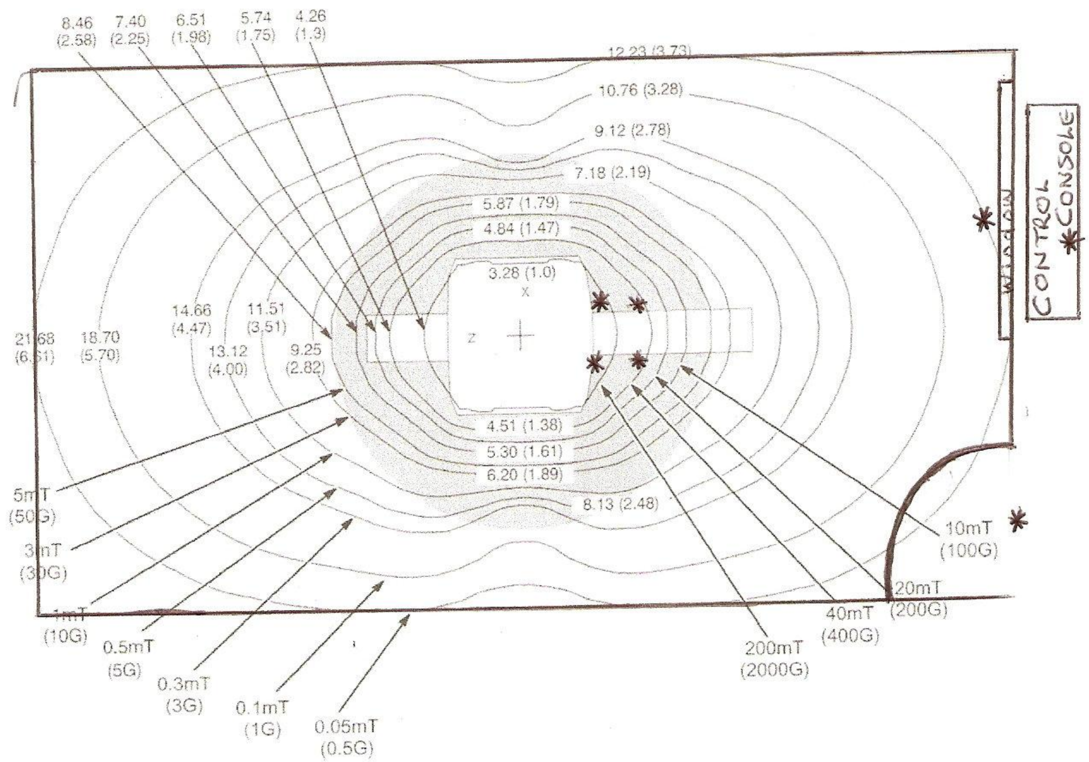

Figure 3.2: Fringe field gradient fall off around the magnet, layout and measurement locations at unit two.

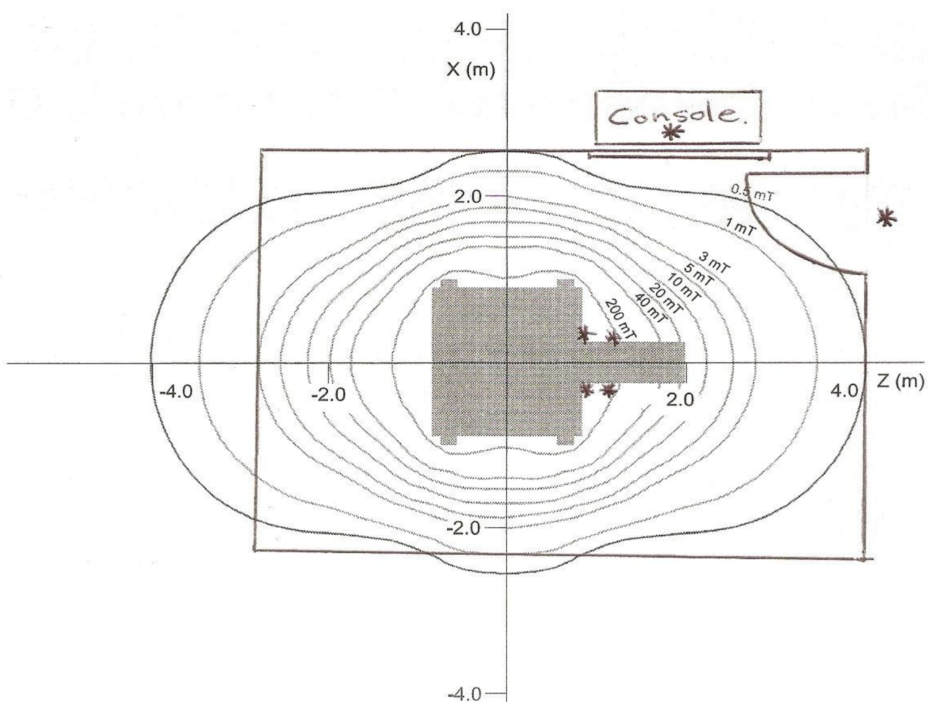

Figure 3.3: Fringe field gradient fall off around the magnet, layout and measurement locations at unit three.

3.5.2 Materials

Magnetic Resonance Imaging (MRI) units examined

The 1.5 T superconductive magnet systems were the common factor in this research. Unit one, an older magnet with a wide-open high-field system design, provides unmatched homogeneity for superb image quality across all the applications. Unit two has a bigger gradient amplifier and two sets of gradient coils (x, y and z) (GE Healthcare, 2004:2). Unit three compares technically well to unit one. The technical specifications of the three units can be viewed in table 3.4.

Table 3.4: Technical specifications of MRI units examined

		Unit 3	**Unit 2**	**Unit 1**
Requirements	**Unit**	**Features**	**Features**	**Features**
Type of magnet		lightweight, ultra short, superconducting, magnet with active shielding and External Interference Shielding (E.I.S.)	Ultra-low boil off, superconductive short bore magnet with active shielding and 99% External Magnetic Interference (EMI) shielding factor	Old fashion heavy magnet with magno-shielding
Magnet system				
Field strength	Tesla	1.5	1.5	1.5
Number of magnet coils?		12 (6 magnet + 2 AS + 4 E.I.S coils)	4	
Are magnet coils actively shielded?		Yes	yes	magno-shielding
Shim-System				
Number of independent active shim channels?		3	3	3
Number of installed shim coils used for active shimming?		20	18	18
Name of option:		*Advanced High Order Shim*	High Order Auto-shim	
Magnet Shielding				
Is the magnet equipped with magnetic shielding?		Yes	yes	yes

		Unit 3	Unit 2	Unit 1
Requirements	**Unit**	**Features**	**Features**	**Features**
Distance of the 0.5-mT line from isocenter				
x-axis:	m (feet)	2.5 (8' 3)	2.48	3.0
y-axis:	m (feet)	2.5 (8' 3)	2.48	3.0
z-axis:	m (feet)	4.0 (13' 2)	4.0	6.0
Gradient System				
Actively shielded gradient coils?		Yes	yes	yes
Duty-Cycle?	%	100	100	100
Basic Gradient System				
The specific parameters of the basic gradient system are:				
Maximum gradient field strength per axis (in x-, y-, z-direction)	mT/m	20 in each direction	33 in each direction	
Maximum effective gradient field strength (diagonal in x-, y-, z-direction)	mT/m	34		
Maximum slew rate (in x-, y-, z-direction)	T/m/s	50 in each direction		
Maximum effective slew rate (diagonal in x-, y-, z-direction)	T/m/s	86		
Name of option:		*Ultra Gradient System*		
Advanced Gradient System				
Maximum gradient field strength per axis (in x-, y-, z-direction)	mT/m	30 in each direction		
Maximum effective gradient field strength (diagonal in x-, y-, z-direction)	mT/m	52		
Maximum slew rate per axis (in x-, y-, z-direction)	T/m/s	75 in each direction		
Maximum effective slew rate (diagonal in x-, y-, z-direction)	T/m/s	129		
Name of option:		*Sprint Gradient System*	Advanced-Concept-Gradient-Driver	

		Unit 3	Unit 2	Unit 1
Requirements	**Unit**	**Features**	**Features**	**Features**
			(ACGD)	
Most Advanced Gradient System				
The specific parameters of the most advanced gradient system are:				
Maximum gradient field strength per axis (in x-, y-, z-direction)	mT/m	30 in each direction	40	40
Maximum effective gradient field strength (diagonal in x-, y-, z-direction)	mT/m	52	69	
Maximum slew rate per axis	T/m/s	125 in each direction	138	138
Maximum effective slew rate (diagonal in x-, y-, z-direction)	T/m/s	216	259	259
Name of option:		*Quantum Gradient System*	Signa Twin Speed gradient subsystem, dual, non-resonant gradients.	
Radio Frequency (RF) System				
Signal generation and –processing (analog/digital)?		digital	digital	digital
Frequency resolution of the RF-synthesizer:	kHz	0.015		
Is RF spoiling possible?		Yes	yes	yes
Is gradient spoiling possible?		Yes	yes	yes
Power of the transmitter amplifier:	kW	max 15	16	16
Bandwidth of the receiver channel:	kHz	1000	500 Hz to 2 MHz	500 Hz to 2 MHz
Bandwidth of each additional receiver channel:	kHz	1000	500 Hz to 2 MHz	500 Hz to 2 MHz

Instrumentation

Two pieces of Narda Safety Test Solution instruments, the EFA-300 and EMR-300, were used to measure the electromagnetic and magnetic exposure fields generated from the MRI scanners. The EFA-200 and EFA-300 are field analyzers used for simple and precise measurement of the low frequency range, up to 30 kHz. The EFA-300 has storage capabilities, and was therefore the measuring instrument of choice in this study (Narda Test Solutions: Field Analyzers, 2004: 1). The EFA-300 has built in isotropic (non-directional) magnetic field probes. During this study the EFA-300 with a magnetic field probe was used to measure gradient field frequencies from 5 Hz to 32 kHz.

The EMR-200 and EMR-300 are the field analyzers used for precision measurement of the high frequency (above 30 kHz) electromagnetic fields. The EMR-200 and EMR-300 are designed for frequency response measurements of electric fields. It uses three separate sensor elements, which comprise of three dipole detector diodes, for isotropic measurement of the EMF. The EMR-300 with a Type 26 probe was used to measure the frequency range 100 kHz to 40 GHz (Narda Test Solutions: Radiation Meters, 2004: 1).

The spatial distribution of a field is seldom homogeneous and homogeneity within the borders of a low-reflection chamber cannot be accomplished. Therefore, several measurements should be taken within the field. Complete body exposure can be estimated much easier by determining the root mean square (rms) of several measurements. The rms can be calculated by the statistical equation: $x_{rms} = \sqrt{\Sigma^{n}_{i=1}}(x_i)^2$ where n indicates the total amount of measurements and x_i an individual measurement. The EMR-300 can be set to spatial averaging mode, which can then make a new measurement by simply pressing a key. Automatically, the EMR-300 will sum the square of these measurements and display average field strength for the area. The time period the spatial key is held down will determine the period of time over which the averaging will be done. The EMR range of instruments are all equipped with an averaging function for the six minute averaging specified by the relevant standards. This six minute averaging time is also called a window period (Narda Test Solutions: Radiation Meters, 2004: 3).

Both the Narda Safety Test Solution instruments use fast Fourier transformation (FFT) computation to provide field analysis. The shaped frequency response probes deliver a direct display of the measurements as a percentage of the ICNIRP limit value when used with an EFA-300 or EMR-300 radiation meter (Narda Test Solution: Field Analyzers, 2004: 1).

3.5.3 Methods

The instruments mentioned previously, were used to measure the RF fields generated by the MRI scanners. The following parameters were measured at each MRI site: maximum RF field (EMR - 300), average RF field (EMR - 300), maximum average RF field (EMR - 300), maximum percentage of the ICNIRP98 – occupational ELF field strength (EFA - 300) and, maximum field strength (EFA - 300).

Measurements in round one were only done on single peak values and no window period or averaging was done. However, in round two and three the measurements were done as an averaging of the root mean square over a window period of six minutes.

3.6 Results and Discussion

The results, presented as graphs, of the three rounds of measurements follow. They all indicate a percentage graph showing the actual measurements of the low frequency range taken and compared to the ICNIRP guidelines endorsed by the Department of Health of South Africa (2001), and a second graph that shows the high frequency data comparison.

3.6.1 First case (round) measurements results and discussion

In all the graphs presented for the first round measurements (figures 3.4 – 3.9), the data readings on the horizontal axis are displayed as a percentage graph of the ICNIRP limit value on the vertical axis. The vertical axis represents a percentage of the ICNIRP limit values, up to three % in the high frequency range (300 kHz to 40 GHz), and up to 800 %

in the low frequency range (5 Hz to 32 kHz). The solid horizontal line at 100 percent on the vertical axis represents ICNIRP's exposure limit value for the general public in the low frequency range graphs. Occupational exposure limit values are five times higher than general public exposure limit values; therefore the 500 percent horizontal line represents the occupational exposure limit values in the low frequency range (Narda Test Solutions: Radiation meters, 2004:2).

UNIT ONE

Figure 3.4 represents the gradient field measurement, in the low frequency range (5 Hz to 32 kHz) at Unit one during the first round measurements. The numbers on the horizontal line from one to 27 each represent data reading in and around the MRI unit.

Table 3.5 indicates the positions where the different readings were taken (marked with a * in figure 3.1). The readings shown on the horizontal axis in figure 3.4 are peak RF measurements and represent the amount of measurements taken. Reading 1, 6, 11 and 16 were measured left front up against the bore. Readings, 3, 8, 13 and 18 were measured right front up against the bore. Readings 2, 7, 12 and 17 were measured left side one meter away from the bore and 4, 9, 14 and 19 right side one meter away from the bore. Readings 21, 22 and 23 were measured outside the MRI chamber door, whereas 24, 25, 26 and 27 were measured in the control console area (table 3.5). None of these readings exceeded the 500 % line. However, readings 8, 13, 16, 18, 23 and 25 exceeded the 100 % line.

Table 3.5: Measurement readings positions for low frequency data

READING NUMBERS	POSITION (Facing the MRI machine bore)
1, 6, 11, 16	Left front
2, 7, 12, 17	Left rear (1m away from the opening)
3, 8, 13, 18	Right front
4, 9, 14, 19	Right rear (1m away from the opening)
5, 10, 15, 20	Front of window
21, 22, 23	Outside the MRI chamber door
24, 25, 26, 27	Control console area

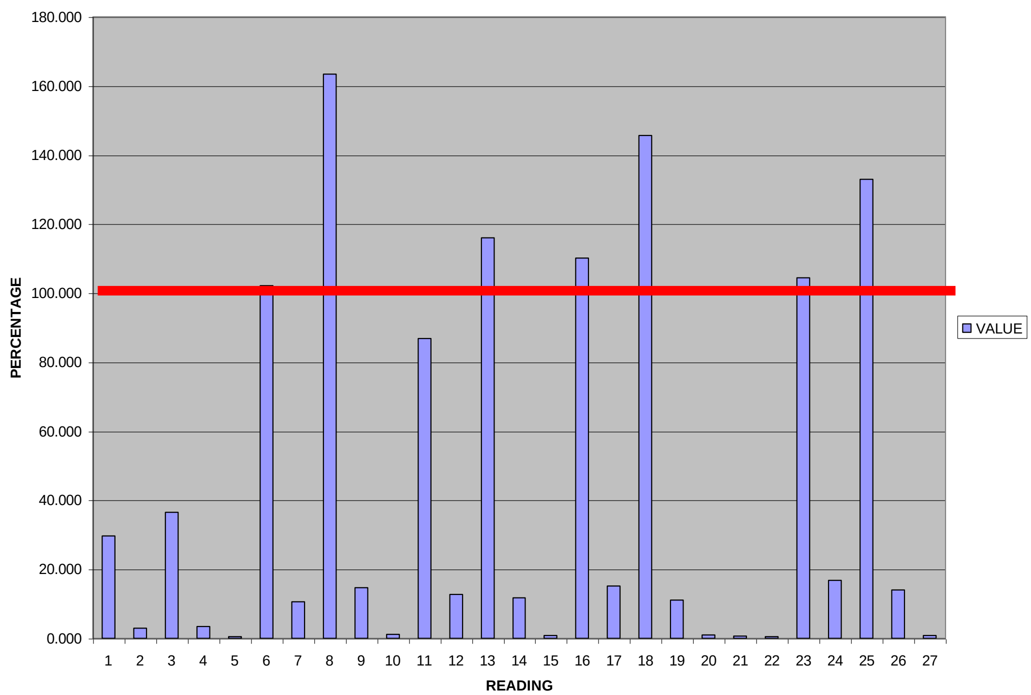

Figure 3.4: Low frequency data percentage graph versus ICNIRP guidelines for occupational exposure at Unit one

(ICNIRP – International Committee for Non-Ionic Radiation Protection)

Figure 3.5 represents the RF field measurement, in the high frequency range (300 kHz to 40 GHz) at Unit one during the first round measurements. The numbers on the horizontal line from 1 to 79 each represent a frequency reading. The positions where the readings were taken are displayed in table 3.6. None of these readings was above the 1.5 % line.

Table 3.6: Measurements readings positions for high frequency data (300 kHz to 40 GHz)

READING NUMBERS	POSITION (Facing the MRI machine hole)
1, 16, 31, 46, 61	Left front (Maximum instantaneous value)
2, 17, 32, 47, 62	Left front (Average value)
3, 18, 33, 48, 63	Left front (Maximum average value)
4, 19, 34, 49, 64	Left rear (1m away from the opening) (Maximum instantaneous value)
5, 20, 35, 50, 65	Left rear (1m away from the opening) (Average value)
6, 21, 36, 51, 66	Left rear (1m away from the opening) (Maximum average value)
7, 22, 37, 52, 67	Right front (Maximum instantaneous value)
8, 23, 38, 53, 68	Right front (Average value)
9, 24, 39, 54, 69	Right front (Maximum average value)
10, 25, 40, 55, 70	Right rear (1m away from the opening) (Maximum instantaneous value)
11, 26, 41, 56, 71	Right rear (1m away from the opening) (Average value)
12, 27, 42, 57, 72	Right rear (1m away from the opening) (Maximum average value)
13, 28, 43, 58, 73	Front of window (Maximum instantaneous value)
14, 29, 44, 59, 74	Front of window (Average value)
15, 30, 45, 60, 75	Front of window (Maximum average value)
76, 77, 78	Outside door
79, 80	Control console area

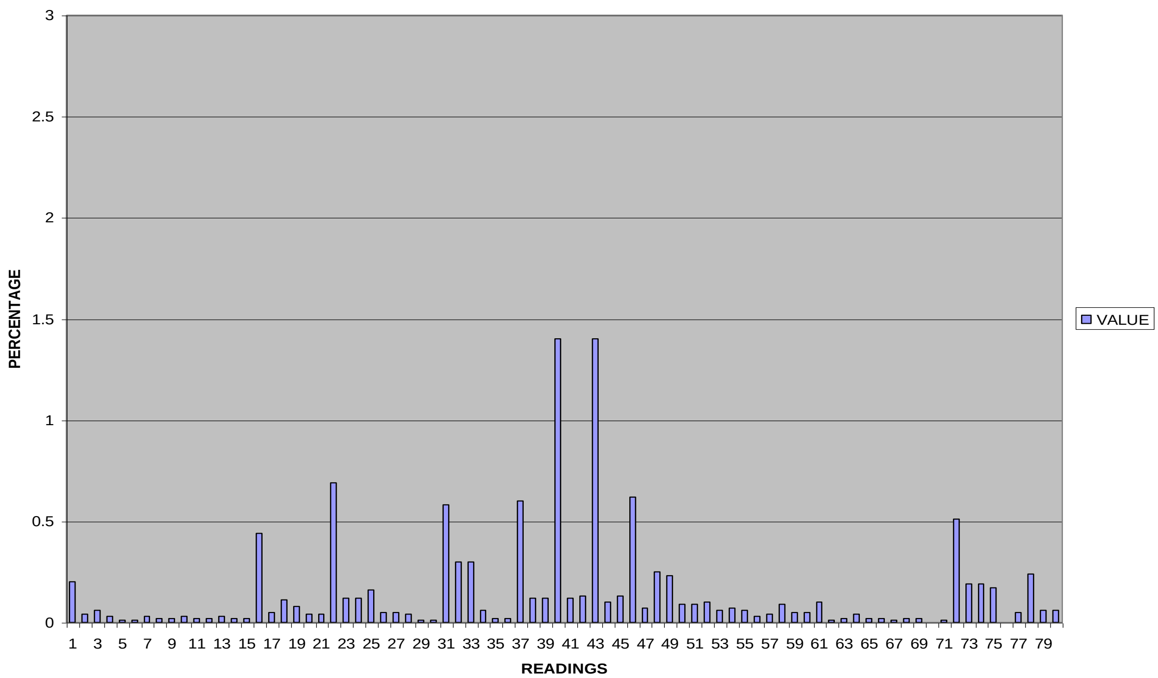

Figure 3.5: High frequency data percentage graph versus ICNIRP guidelines for occupational exposure at Unit one

(ICNIRP – International Committee for Non-Ionic Radiation Protection)

UNIT TWO

Figure 3.6 represents the RF measurement, in the low frequency range (5 Hz to 32 kHz), at Unit two during the first round measurements. The numbers on the horizontal line from 1 to 23 each represent a reading. Readings 13, 16 and 18 exceeded the 500 % line. The positions where the readings were taken are displayed in table 3.7.

Table 3.7: Measurement readings positions for low frequency data

READING NUMBERS	POSITION (Facing the MRI machine hole)
1, 6, 11, 16	Left front
2, 7, 12, 17	Left rear (1 m away from the opening)
3, 8, 13, 18	Right front
4, 9, 14, 19	Right rear (1 m away from the opening)
5, 10, 15, 20	Front of window
21, 22, 23	Outside the MRI chamber

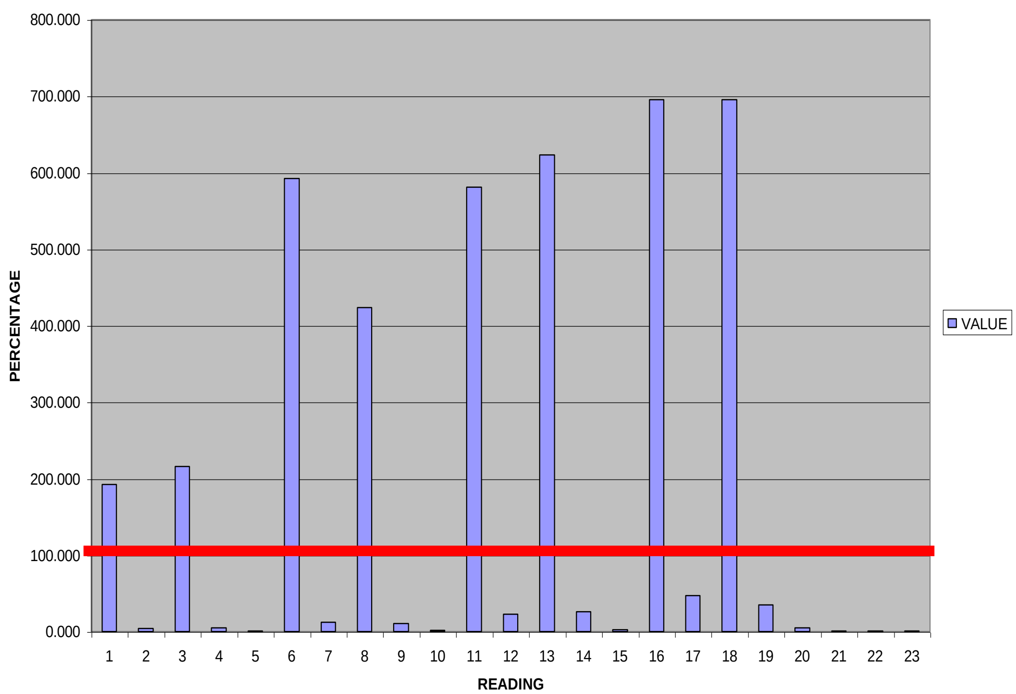

Figure 3.6: Low frequency data percentage graph versus ICNIRP guidelines for occupational exposure at Unit two

(ICNIRP – International Committee for Non-Ionic Radiation Protection)

Figure 3.7 represents the RF measurement in the high frequency range (300 kHz to 40 GHz) at Unit two during the first round measurements. The numbers on the horizontal line from 1 to 69 each represent a reading. All the readings were well within the safety limits. The positions of the readings are displayed in table 3.8

Table 3.8: Measurement readings positions for high frequency data

READING NUMBERS	POSITION (Facing the MRI machine hole)
1, 16, 31, 46	Left front (Maximum instantaneous value)
2, 17, 32, 47	Left front (Average value)
3, 18, 33, 48	Left front (Maximum average value)
4, 19, 34, 49	Left rear (1m away from the opening) (Maximum instantaneous value)
5, 20, 35, 50	Left rear (1m away from the opening) (Average value)
6, 21, 36, 51	Left rear (1m away from the opening) (Maximum average value)
7, 22, 37, 52	Right front (Maximum instantaneous value)
8, 23, 38, 53	Right front (Average value)
9, 24, 39, 54	Right front (Maximum average value)
10, 25, 40, 55	Right rear (1m away from the opening) (Maximum instantaneous value)
11, 26, 41, 56	Right rear (1m away from the opening) (Average value)
12, 27, 42, 57	Right rear (1m away from the opening) (Maximum average value)
13, 28, 43, 58	Front of window (Maximum instantaneous value)
14, 29, 44, 59	Front of window (Average value)
15, 30, 45, 60	Front of window (Maximum average value)
61, 62, 63	Outside door
64, 65, 66	At computer station
67, 68, 69	Centre of room

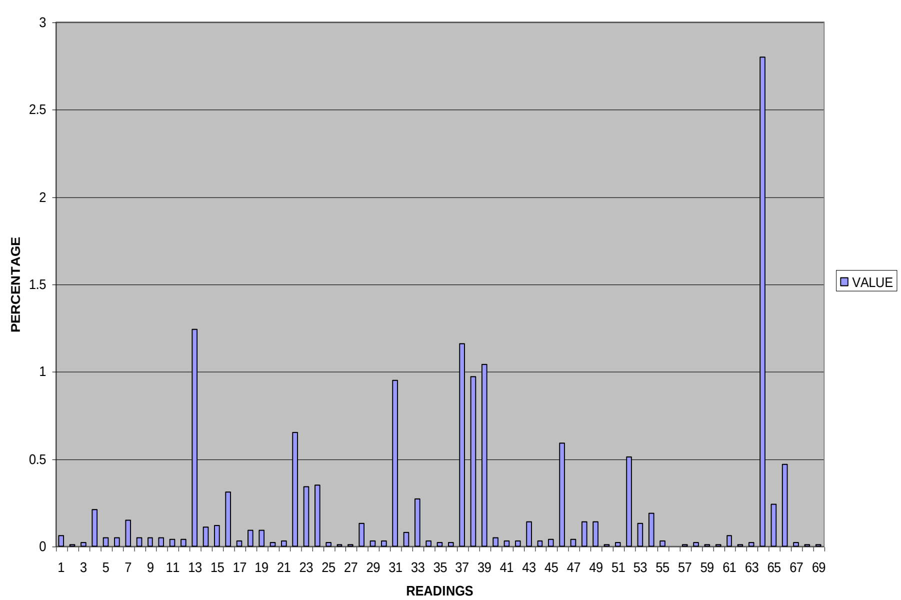

Figure 3.7: High frequency data percentage graph versus ICNIRP guidelines for occupational exposure at Unit two

(ICNIRP – International Committee for Non-Ionic Radiation Protection)

UNIT THREE

Figure 3.8 represents the RF measurement in the low frequency range (5 Hz to 32 kHz), at Unit three during the first round measurements. The numbers on the horizontal line from 1 to 17 each represent a reading. Only reading 16 exceeded the safety limits. All the positions of the readings are demonstrated in table 3.9.

Table 3.9: Measurement readings positions for low frequency data

READING NUMBERS	POSITION (Facing the MRI machine hole)
1, 6, 10, 14	Left front
2, 7, 11, 15	Left rear (1m away from the opening)
3, 8, 12, 16	Right front
4, 9, 13, 17	Right rear (1m away from the opening)
5	Front of window

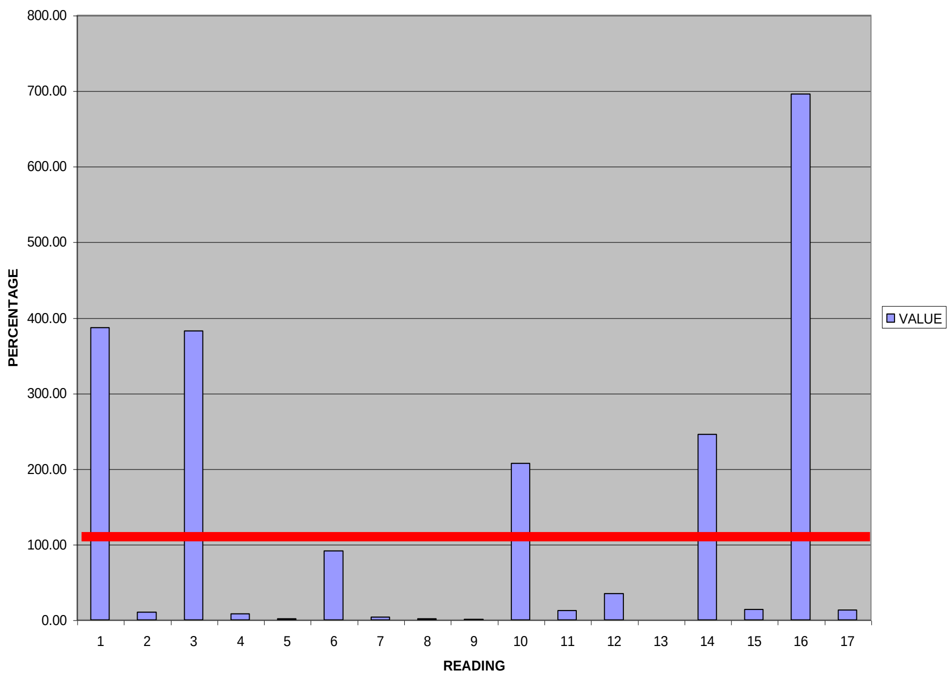

Figure 3.8: Low frequency data percentage graph versus ICNIRP guidelines for occupational exposure at Unit three

(ICNIRP – International Committee for Non-Ionic Radiation Protection)

Figure 3.9 represents the RF measurement in the high frequency range (300 kHz to 40 GHz) at Unit two during the first round measurements. The numbers on the horizontal line from 1 to 57 each represent a reading. None of the readings exceeded the safety limits. The positions of all the readings are demonstrated in table 3.10.

Table 3.10: Measurement readings positions for high frequency data

READING NUMBERS	POSITION (Facing the MRI machine hole)
1, 16, 28	Left front (Maximum instantaneous value)
2, 17, 29	Left front (Average value)
3, 18, 30	Left front (Maximum average value)
4, 19, 31	Left rear (1m away from the opening) (Maximum instantaneous value)
5, 20, 32	Left rear (1m away from the opening) (Average value)
6, 21, 33	Left rear (1m away from the opening) (Maximum average value)
7, 22, 34	Right front (Maximum instantaneous value)
8, 23, 35	Right front (Average value)
9, 24, 36	Right front (Maximum average value)
10, 25, 37	Right rear (1m away from the opening) (Maximum instantaneous value)
11, 26, 38	Right rear (1m away from the opening) (Average value)
12, 27, 39	Right rear (1m away from the opening) (Maximum average value)
13	Front of window (Maximum instantaneous value)
14	Front of window (Average value)
15	Front of window (Maximum average value)

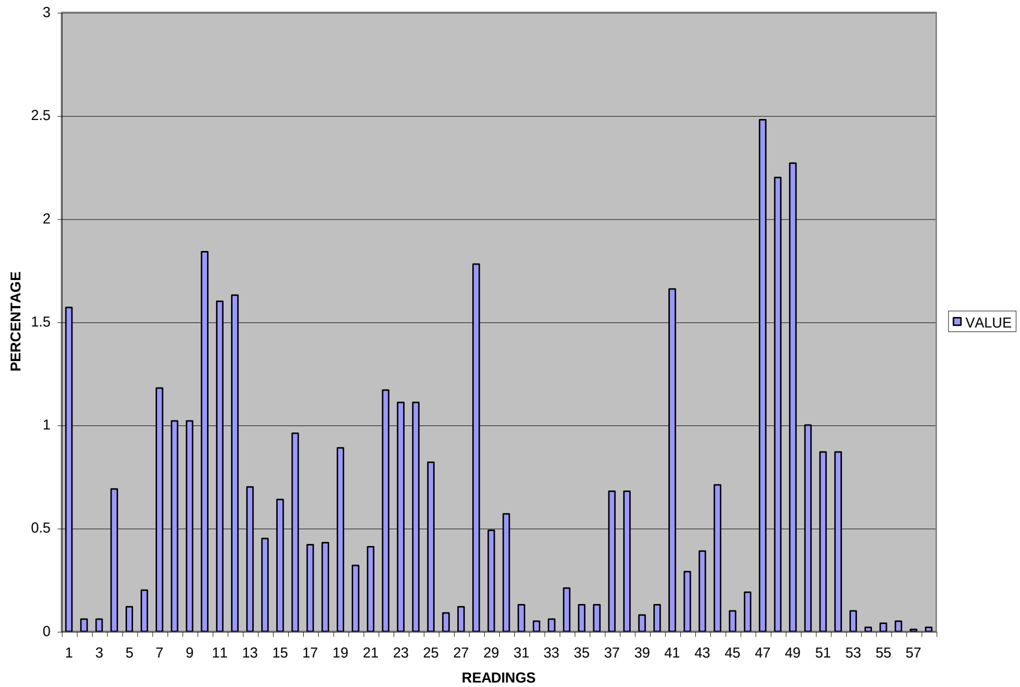

Figure 3.9: High frequency data percentage graph versus ICNIRP guidelines for occupational exposure at Unit three

(ICNIRP – International Committee for Non-Ionic Radiation Protection)

During the first round measurements maximum peak values were measured. At Unit one, one peak value in the low frequency range was above ICNIRP guidelines. However, at Unit two five and at Unit three six peak values in the low frequency range were above ICNIRP's occupational guidelines.

From six high frequency data sets, represented by Figures 3.5, 3.7 and 3.9 it was evident that the high frequency peak values were well within the ICNIRP limits, less than three % of the limits (upper border horizontal line on graph). On the other hand, from six low frequency data sets, represented by graphs 3.4, 3.6 and 3.8, it was evident that a large part of the measurements exceeded the ICNIRP guidelines for occupational exposure (500 %).

Discussion case (round) one

First round measurements were primarily done to test the measuring instruments: EFA-300 for the low frequency range (5 Hz – 32 kHz); and the EMR -300 for the high frequency range (100 kHz – 40 GHz). During this round several measurements at different positions around the magnet bore were done, in both frequency ranges and only single peak values were taken. Only the low frequency range showed measurements above the ICNIRP occupational exposure threshold limit values. The threshold limit for occupational exposure is 500 %. Unit two showed five values above the 500 % line in Figure 3.6. Unit three showed only one measurement in Figure 3.8 that exceeded the threshold limit. However, measurements at Unit one (Figure 3.4) were all well within the limits.

The low frequency range (5 Hz – 32 kHz) is part of the range where the gradient fields (100 – 1000 Hz) fit in (EU Directive2004/40, 2007: 483).

3.6.2 Second case (round) measurements results and discussion

All the results from the measurements taken in round two are subsequently presented. Each MRI unit is represented by two graphs per examination, thus six per unit. These are: a graph showing the low frequency readings as a percentage of the ICNIRP guidelines endorsed by the Department of Health of South Africa, and the second graph shows the high frequency measurements as a percentage of the ICNIRP guidelines endorsed by the Department of Health of South Africa (2002).

The data readings on the horizontal axis are displayed as a percentage graph of the ICNIRP limit value on the vertical axis. A 100 % on the vertical axis represents ICNIRP's exposure limit value for the general public, and 500 % the occupational exposure limit values.

UNIT ONE

Figure 3.10 displays the data on a brain examination in the low frequency range at Unit one during second round measurements. About 200 sample (frequency readings) readings were taken and none of them exceeded the 1.50 % of ICNIRP exposure limit value.

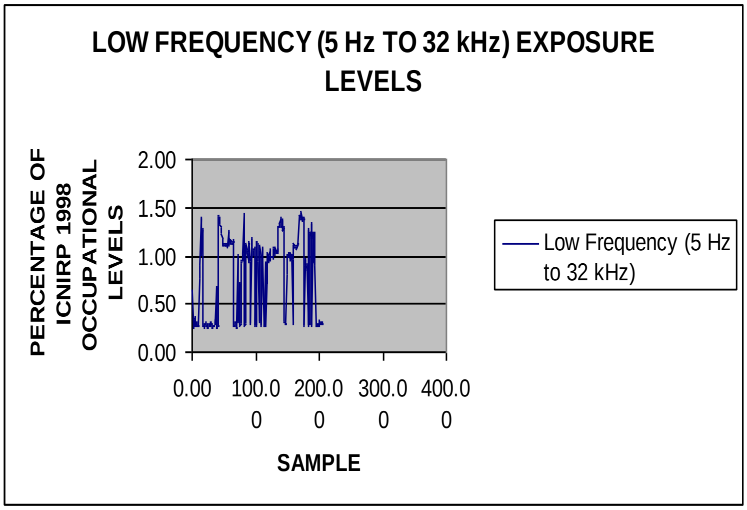

Figure 3.10: Low frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.11 represents data measured in the high frequency range at Unit one. The highest measurement was less than 0.5 % of the limit values of ICNIRP.

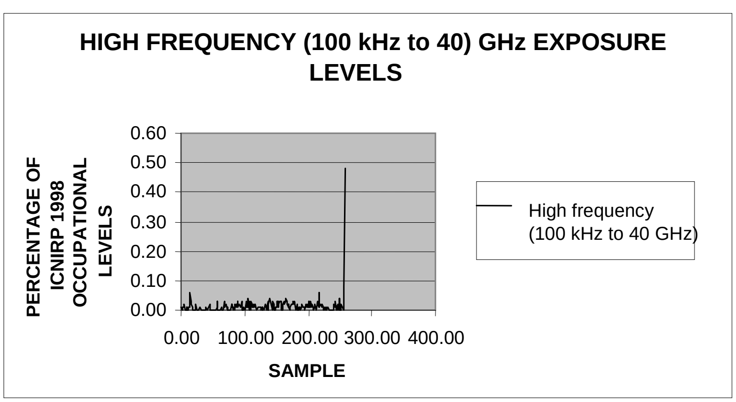

Figure 3.11: High frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

Figure 3.12 displays the data measurements in the low frequency range at Unit one during round two on a cervical spine examination. Out of 250 samples taken none were above 1.50 % of the limit values of ICNIRP.

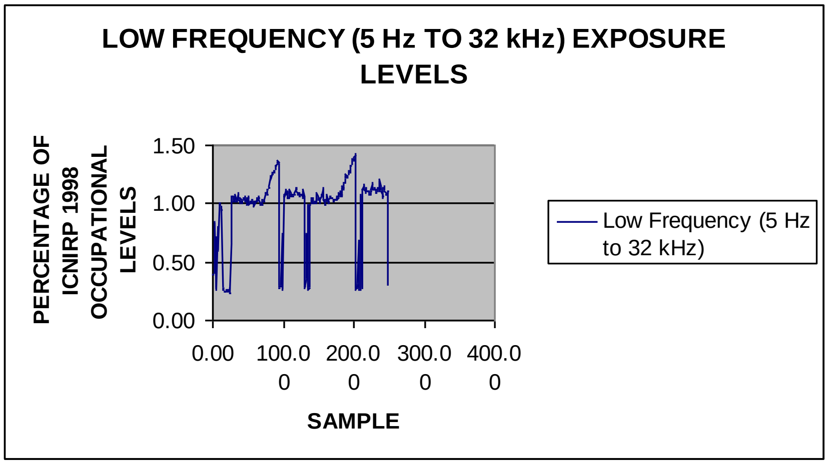

Figure 3.12: Low frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.13 displays the data measured at Unit one during the second round in the high frequency range. Three hundred samples were taken and none exceeded 1.20 % of the ICNIRP limit values.

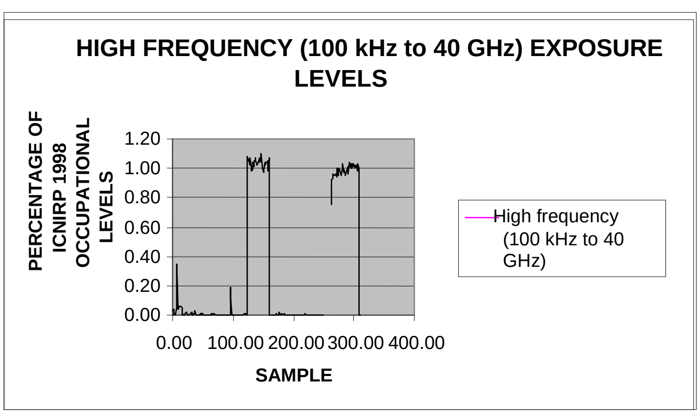

Figure 3.13: High frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

Figure 3.14 represents the RF measurement, in the low frequency range (5 Hz to 32 kHz) at Unit one during second round measurements for a lumbar spine examination. The measured data for the 400 samples (horizontal axis) did not exceeded 1.5 % of the ICNIRP exposure limits.

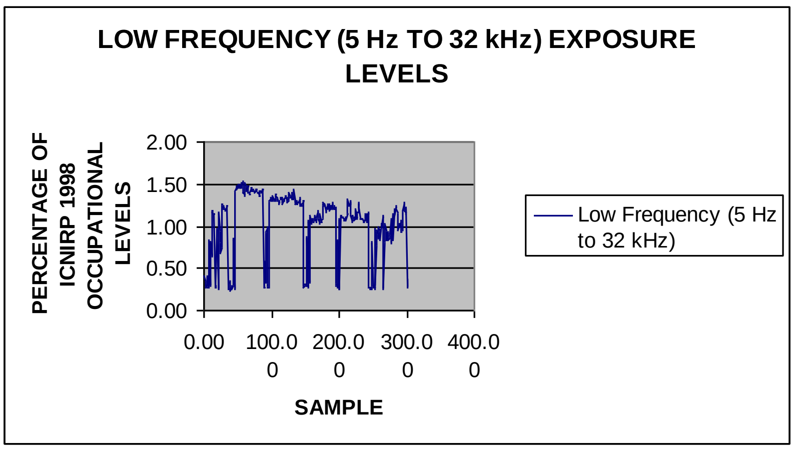

Figure 3.14: Low frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.15 represents the RF measurement in the high frequency range (100 kHz to 40 GHz), at Unit one during second round measurements. About 300 sample readings were taken and none of the readings exceeded 0.8 % of ICNIRP exposure limits.

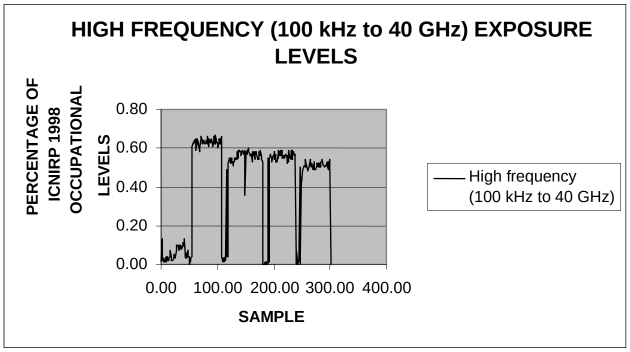

Figure 3.15: High frequency data percentage graph versus ICNIRP limit (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

UNIT TWO

Figure 3.16 displays the data on the brain examination in the low frequency range at Unit two during second round measurements. Four hundred measurements were done, but the measurements were too low to be displayed on the scale of this graph.

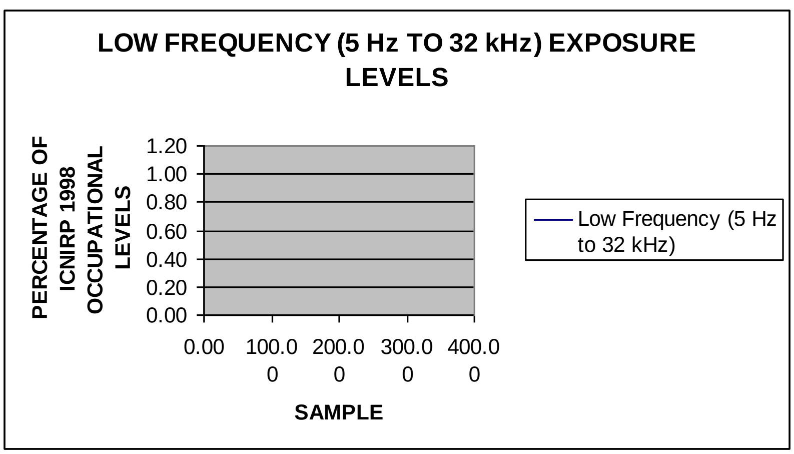

Figure 3.16: Low frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.17 represents the data measured in the high frequency range at Unit two. These measurements were taken during the second round on a brain examination. The highest measurement was less than 0.6 % of the ICNIRP limit values.

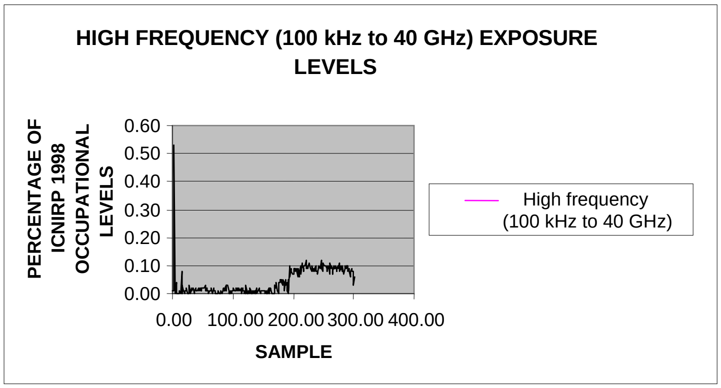

Figure 3.17: High frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

Figure 3.18 displays the data measurements in the low frequency range at Unit two during second round measurements on a cervical spine examination. Out of 250 samples taken, none were above six percent of the ICNIRP limit values.

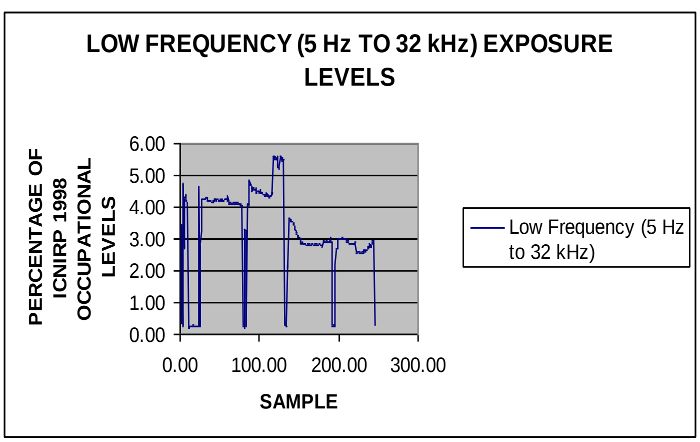

Figure 3.18: Low frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.19 displays the data measured in the high frequency range at Unit two during second round measurements. The measurements were done during a cervical spine examination, 230 samples were taken, and none exceeded one percent of the ICNIRP limit values.

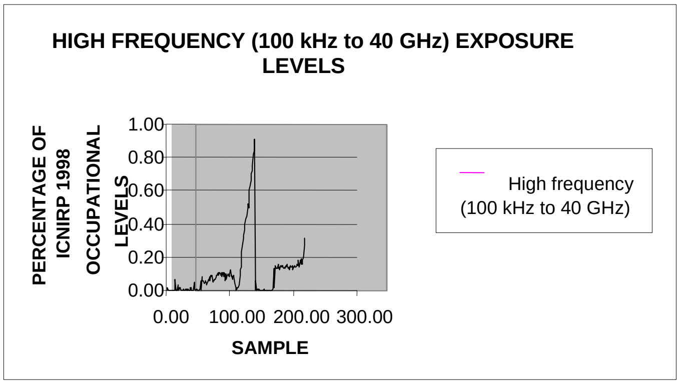

Figure 3.19: High frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

Figure 3.20 represents the RF measurement in the low frequency range (5 Hz to 32 kHz) at Unit two during second round measurements for a lumbar spine examination. None of the measurements were large enough to be displayed on the scale of this graph. Sample on the horizontal scale refer to RF reading taken.

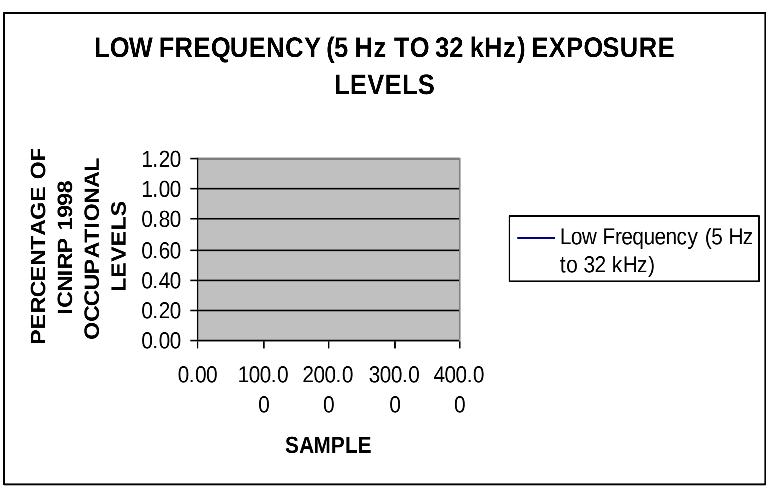

Figure 3.20: Low frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.21 represents the RF measurement in the high frequency range (100 kHz to 40 GHz) at Unit two during second round measurements. About 300 sample readings were taken and none of these readings exceeded the 0.20 % ICNIRP exposure limits.

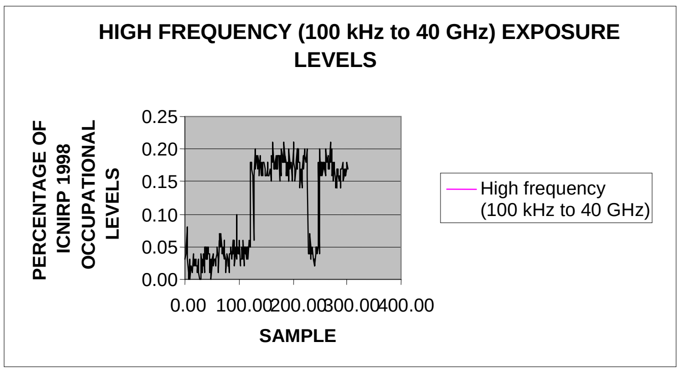

Figure 3.21: High frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

UNIT THREE

Figure 3.22 displays the data on a brain examination in the low frequency range at Unit three during second round measurements. None of the samples exceeded 1.50 % of the ICNIRP limit values.

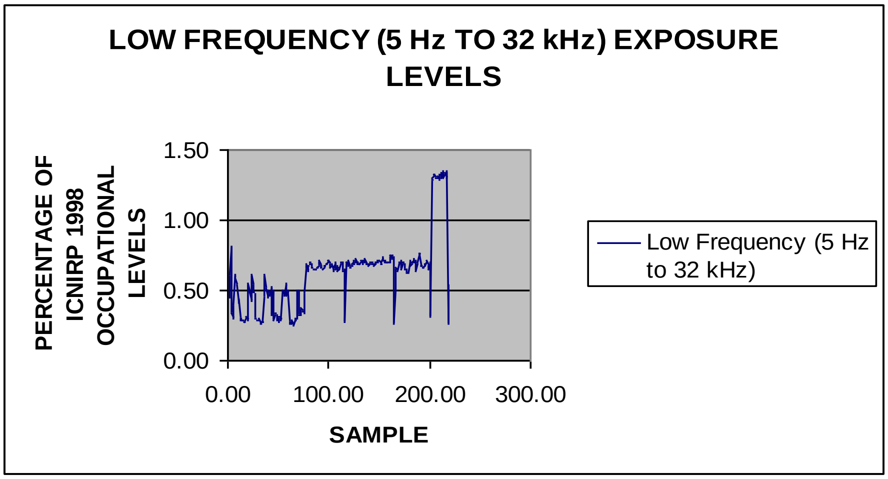

Figure 3.22: Low frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.23 represents the data measured in the high frequency range at Unit three. These measurements were taken during the second round on a brain examination. The highest measurement was less than 1.20 % of the ICNIRP limit values.

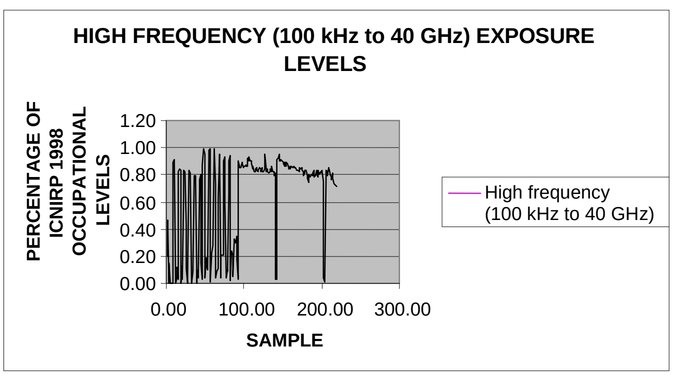

Figure 3.23: High frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

Figure 3.24 displays the data measurements in the low frequency range at Unit three during round second round measurements, on a cervical spine examination. Out of 150 samples taken none were above 3.5 % of the ICNIRP limit values.

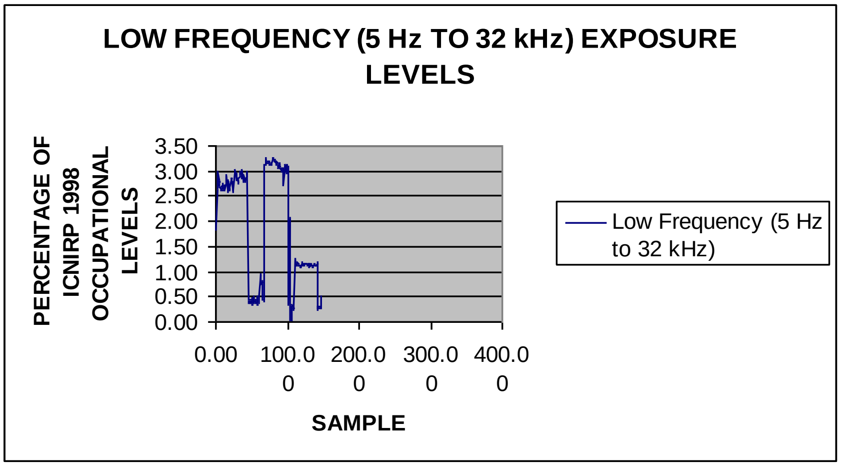

Figure 3.24: Low frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.25 displays the data measured in the high frequency range at Unit three during second round measurements. The measurements were done during a cervical spine examination, 200 samples were taken and none exceeded three percent of the ICNIRP limit values.

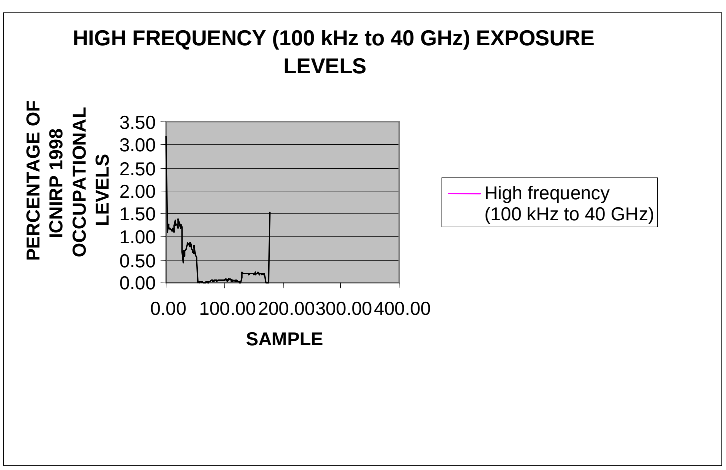

Figure 3.25: High frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

Figure 3.26 represents the RF measurement in the low frequency range (5 Hz to 32 kHz) at Unit three during second round measurements for a lumbar spine examination. From the measured data for 400 samples none exceeded the eight percent ICNIRP limit value.

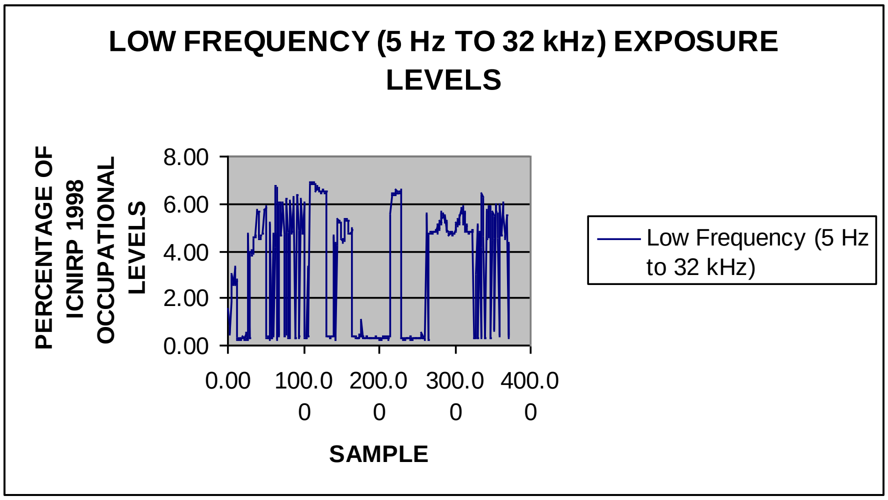

Figure 3.26: Low frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

Figure 3.27 represents the RF measurement in the high frequency range (100 kHz to 40 GHz), at Unit three during second round measurements. About 120 sample readings were taken and none of these readings exceeded one percent of ICNIRP exposure limit values.

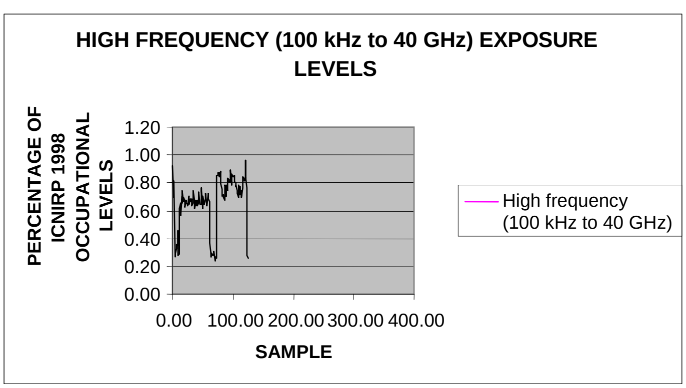

Figure 3.27: High frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

Figures 3.10 to 3.15 represent the data collected at Unit one. All three examinations: brain, cervical spine and lumbar spine were evaluated. Figures 3.10, 3.12 and 3.14 represented the low frequency (5 Hz to 32 Hz) range. In the low frequency range it was evident from the results that all the measurements fell well below the ICNIRP limits. The measurements did not exceed the two percent level of the ICNIRP limits. The high frequency (100 kHz to 40 GHz) range was represented by Figures 3.11, 3.13 and 3.15. The high frequency data showed an even lower percentage of the ICNIRP guidelines.

Figures 3.16 to 3.21 represented the data collected at Unit two. All three examinations were evaluated again. Figures 3.16, 3.18 and 3.20 represented the low frequency range and 3.17, 3.19 and 3.21 the high frequency range. The ICNIRP guidelines were not exceeded.

Unit three's data were represented by Figures 3.22, 3.24 and 3.26 for the low frequencies and 3.23, 3.25 and 3.27 for the high frequencies. From the graphs it was evident that the ICNIRP guidelines were not exceeded.

3.6.3 Third case (round) measurements results and discussion

All measurements taken in round three follow. Each MRI unit has four graphs per examination, thus twelve per unit. The first graph shows the low frequency readings as a percentage of the ICNIRP guidelines as endorsed by the Department of Health of South Africa and the second graph shows the same readings averaged over a six minute window period. The third graph shows the high frequency measurements as a percentage of the ICNIRP guidelines as endorsed by the Department of Health of South Africa, and the fourth graph shows the high frequency readings averaged over a six minute window period.

The data readings on the horizontal axis are displayed as a percentage graph of the ICNIRP limit value on the vertical axis. A 100 % on the vertical axis represents ICNIRP's exposure limit value for the general public, and 500 % represents the occupational exposure limit values.

UNIT ONE

About 200 readings were taken on the low frequency measurements of a brain examination, as represented in Figure 3.28. Averaged over a six minute window period, none of the readings exceeded the seven % limit of ICNIRP guidelines (Figure 3.29).

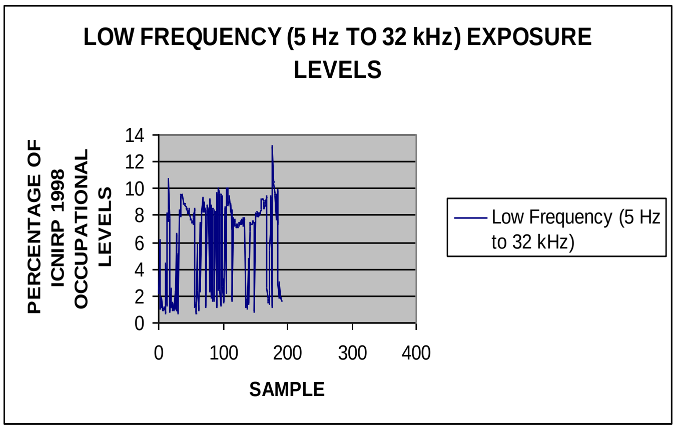

Figure 3.28: Low frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

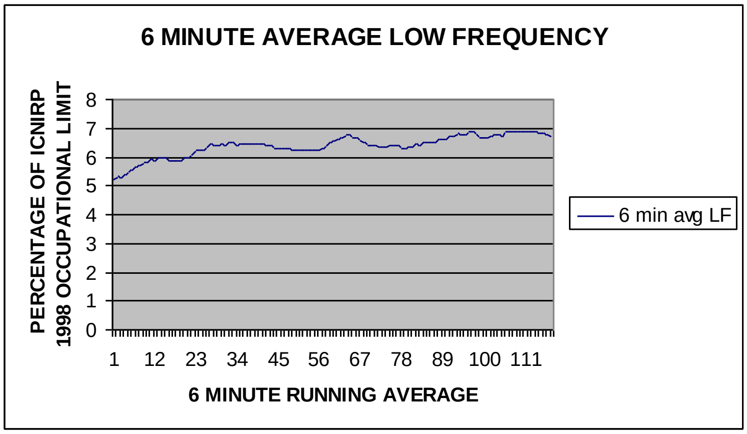

Figure 3.29: Graph for six minute averages of low frequency data (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – Low frequencies)

More than 200 readings were taken in the high frequency measurement of a brain examination, represented in Figure 3.30. None of the six minute average readings exceeded 0.1 % of ICNIRP guidelines (Figure 3.31).

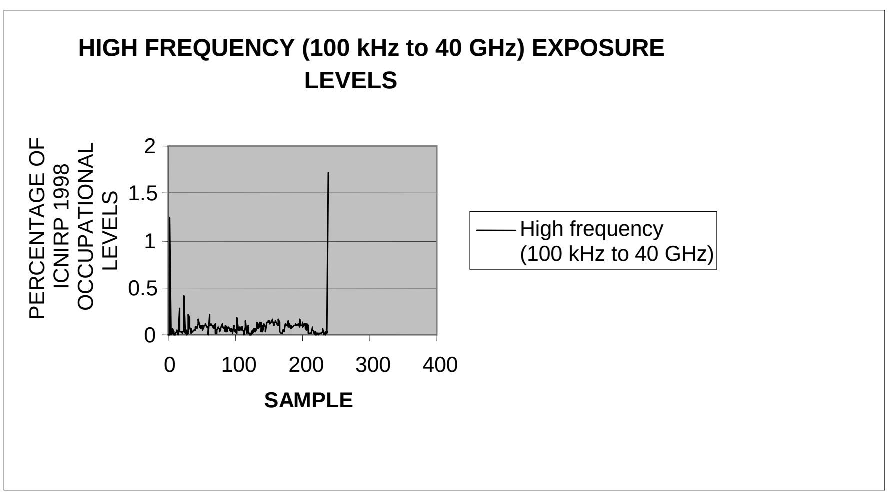

Figure 3.30: High frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, kHz – kilohertz, GHz – Gigahertz)

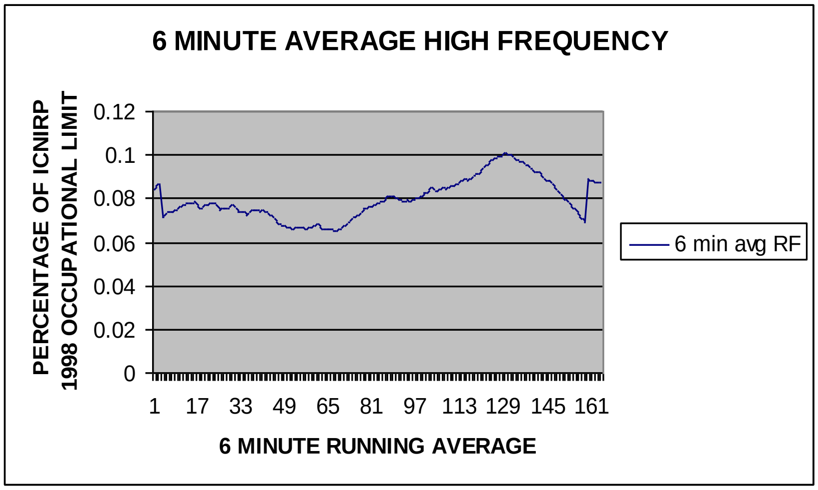

Figure 3.31: Graph for six minute averages of high frequency data (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg – averages)

In the cervical spine examination at Unit one about 250 readings in the low frequency range was taken (Figure 3.32). All the readings were below the 10 % line of ICNIRP guidelines as seen on the six-minute average graph (Figure 3.33).

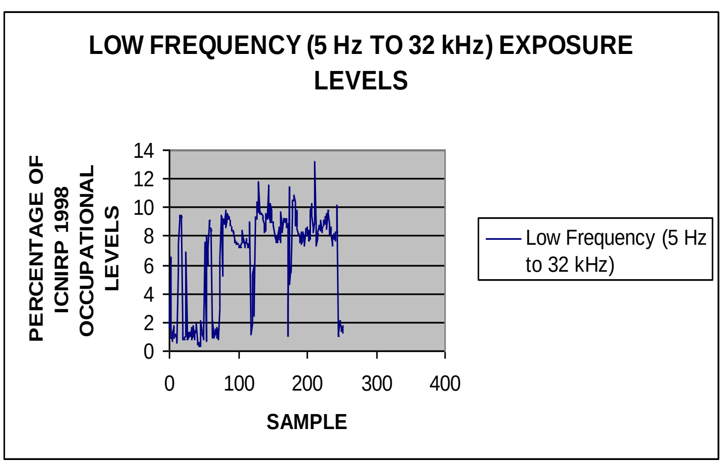

Figure 3.32: Low frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

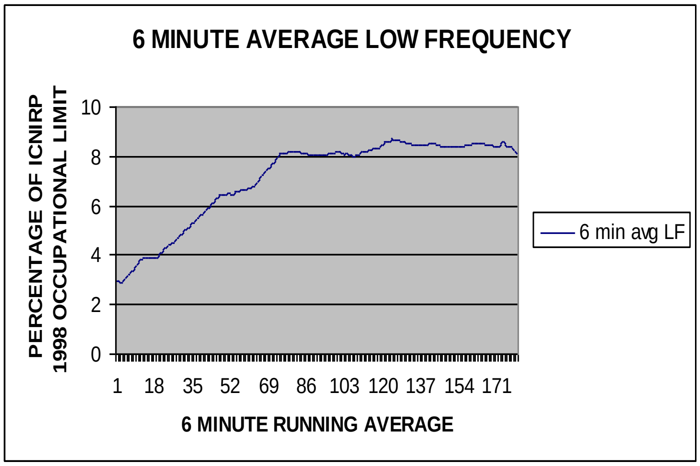

Figure 3.33: Graph for six minute averages of low frequency data (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – low frequencies, avg – averages)

Three hundred readings were taken in the high frequency range during a cervical spine examination at Unit one (Figure. 3.34). On the six-minute average graph (Figure3.35) the readings were all below 1.4 % of ICNIRP guidelines.

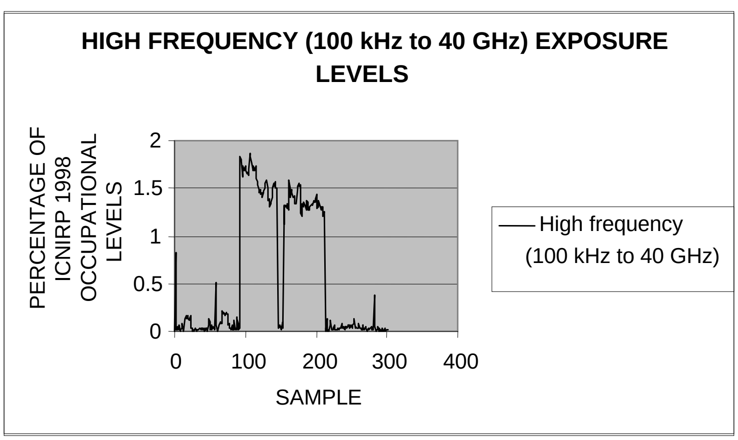

Figure 3.34: High frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, kHz – kilohertz, GHz – Gigahertz)

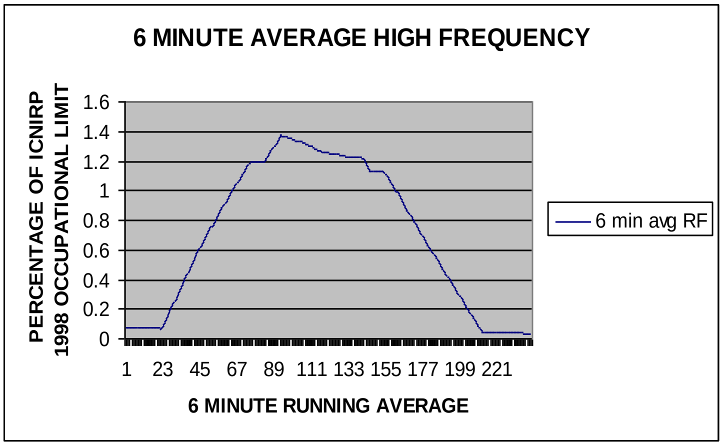

Figure 3.35: Graph for six minute averages of high frequency data (Cervical spine examination)

(ICNIRP - International Committee for Non-Ionizing Radiation Protection, RF - Radio frequencies, avg- averages)

More than 200 readings were taken during a lumbar spine examination in the low frequency range at Unit one (Figure 3.36). On the six-minute average graph the highest readings fell between eight and nine % of ICNIRP guidelines (Figure 3.37).

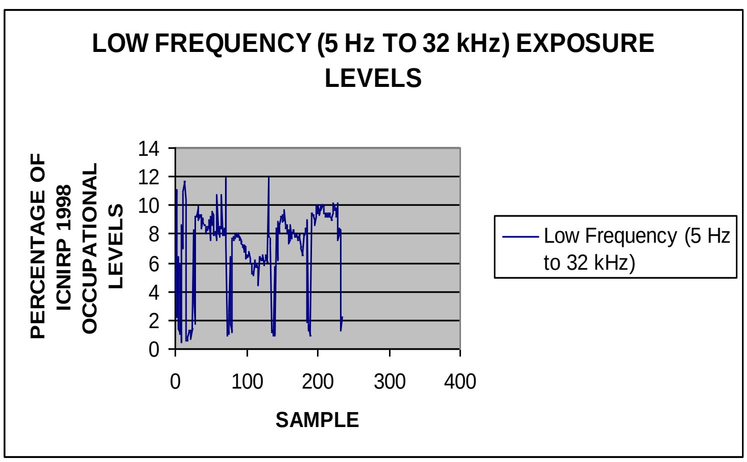

Figure 3.36: Low frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

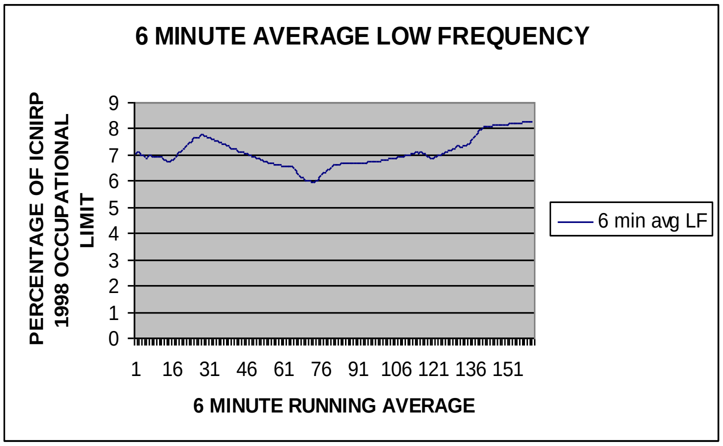

Figure 3.37: Graph for six minute averages of low frequency data (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – Low frequencies, avg – averages)

About 200 readings were taken during a lumbar spine examination in the high frequency range at Unit one (Figure 3.38). On the six-minute average graph the highest readings fell between 0.5 and 0.6 % of ICNIRP guidelines (Figure 3.39).

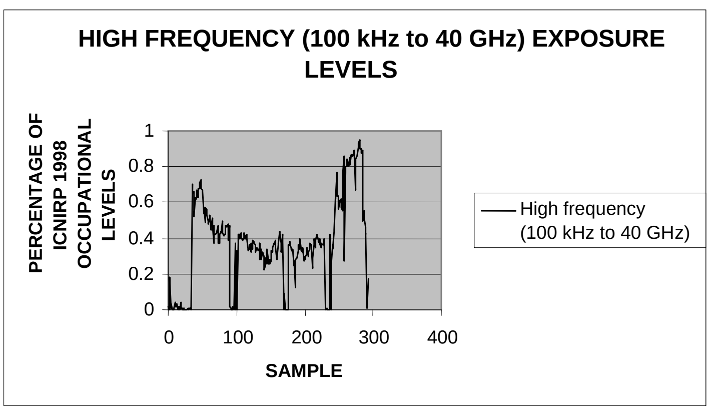

Figure 3.38: High frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, kHz – kilohertz, GHz – Gigahertz)

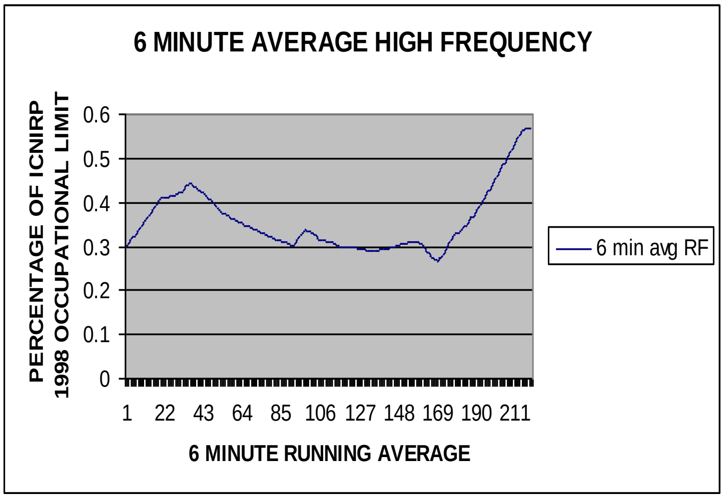

Figure 3.39: Graph for six minute averages of high frequency data (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg – averages)

UNIT TWO

In the low frequency range for a brain examination at Unit two, about 180 readings were taken. The highest readings fell between 40 and 50 % of ICNIRP guidelines (Figure 3.40). However, the highest readings on the six-minute average graph fell between 20 and 25 % of ICNIRP guidelines (Figure 3.41).

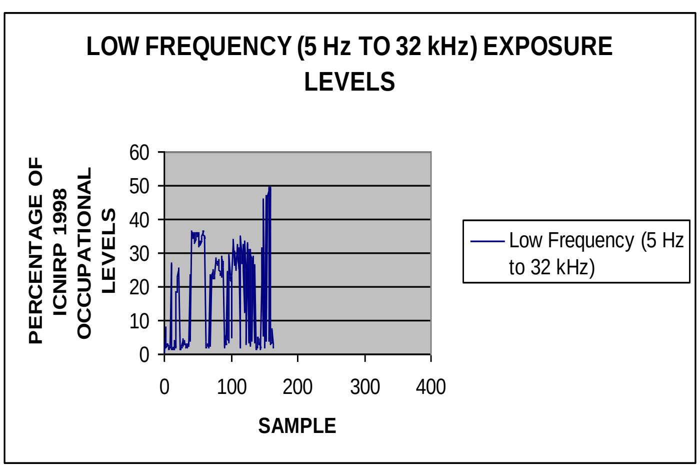

Figure 3.40: Low frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

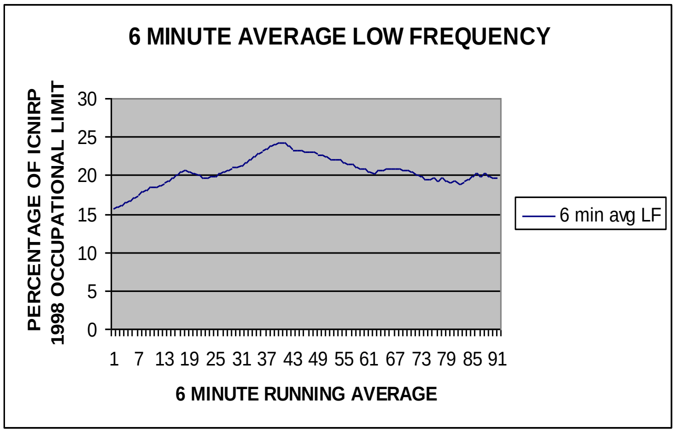

Figure 3.41: Graph for six minute averages of low frequency data (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – Low frequencies, avg – averages)

In the high frequency range for the brain examination at Unit two, 300 readings were taken (Figure 3.42). The highest six minute average readings fell between 3.5 and four % of ICNIRP guidelines (Figure 3.43).

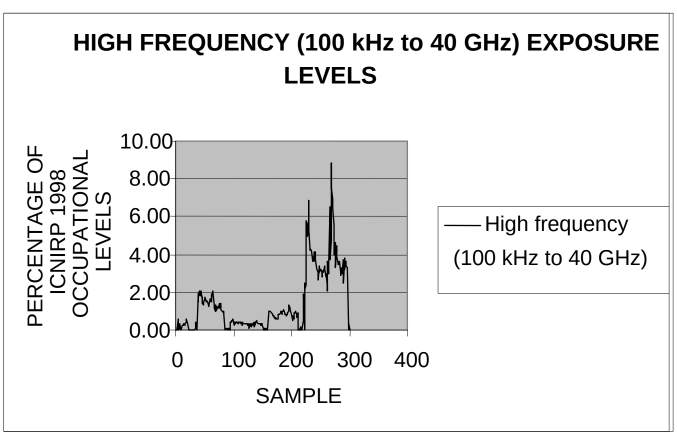

Figure 42: High frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, kHz – kilohertz, GHz – Gigahertz)

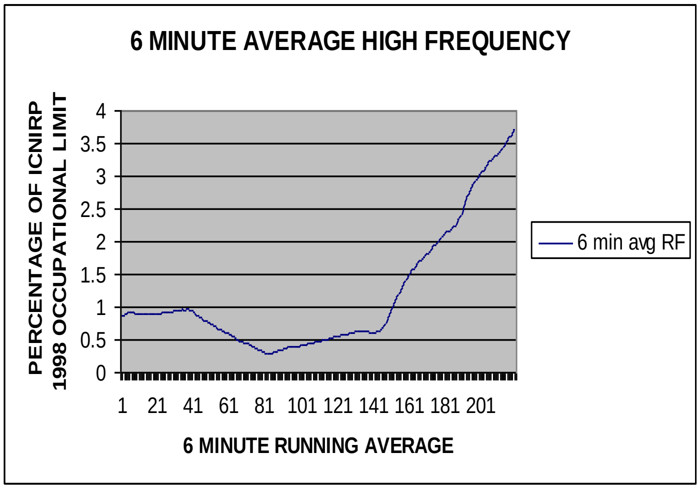

Figure 3.43: Graph for six minute averages of high frequency data (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg – averages)

More than 200 readings were taken at Unit two in the low frequency range, during a cervical spine examination (Figure 3.44). On the six minute average graph (Figure 3.45) the highest readings fell between 35 and 40 % of ICNIRP guidelines.

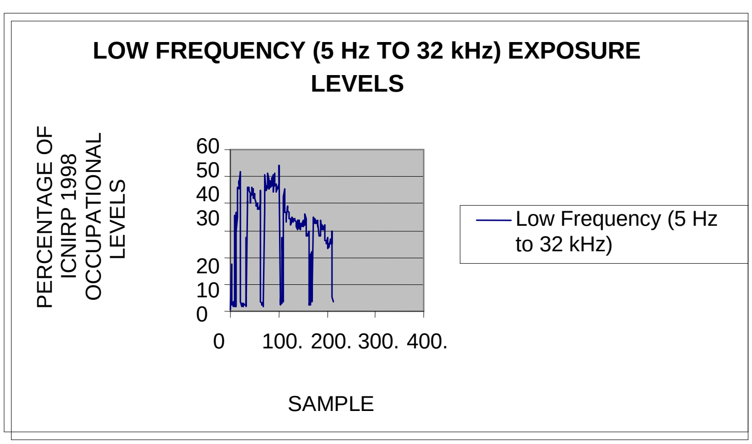

Figure 3.44: Low frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

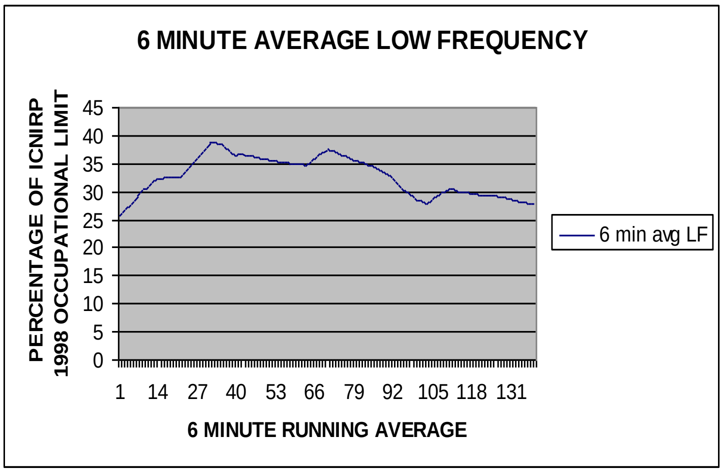

Figure 3.45: Graph for six minute averages of low frequency data (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – low frequencies, avg – averages)

In the high frequency range for a cervical spine examination at Unit two, 250 readings were taken (Figure 3.46). The highest six minute average readings fell between two and 2.5 % of ICNIRP guidelines (Figure 3.47).

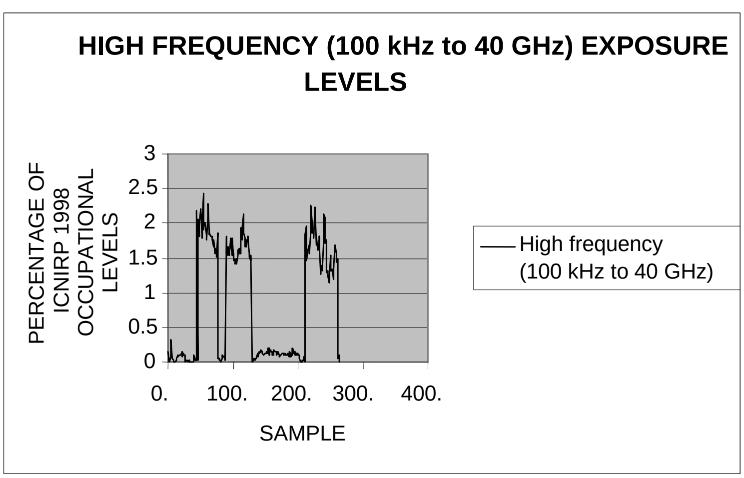

Figure 3.46: High frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, kHz – kilohertz, GHz – Gigahertz)

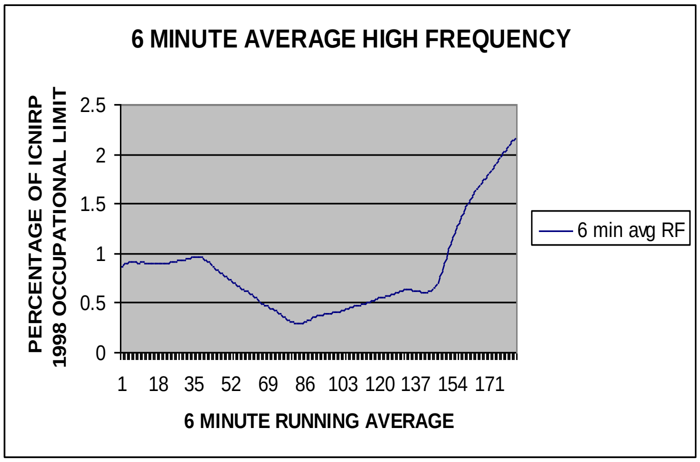

Figure 3.47: Graph for six minute averages of high frequency data (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg –averages)

Two hundred and fifty readings were taken in the low frequency range at Unit two during a lumbar spine examination (Figure 3.48). On the six-minute average graph (Figure 3.49) the highest readings were between 50 and 60 % of ICNIRP guidelines.

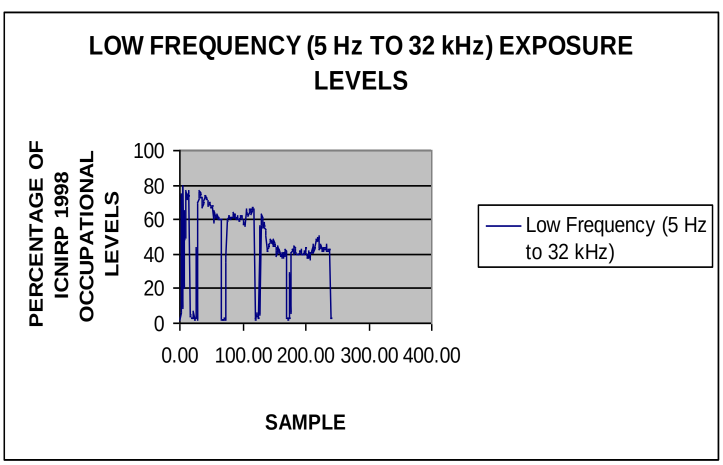

Figure 3.48: Low frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

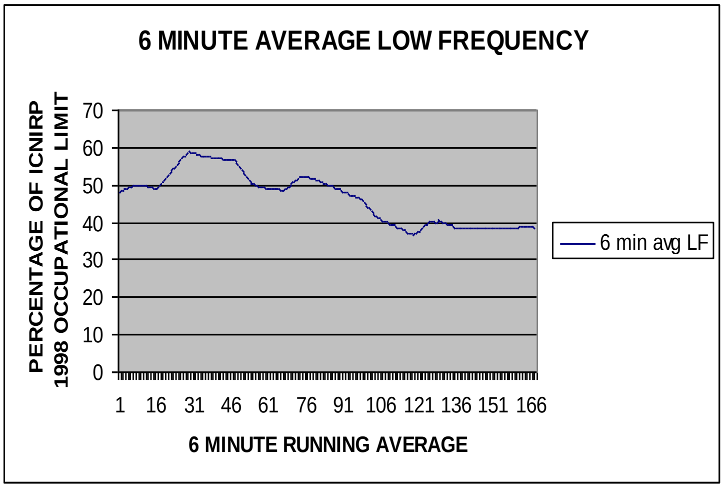

Figure 3.49: Graph for six minute averages of low frequency data (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – low frequencies, avg – averages)

About 200 readings were taken during a lumbar spine examination in the high frequency range at Unit two (Figure 3.50). On the six-minute average graph (Figure 3.51) the highest readings were between 0.3 and 0.35 % of ICNIRP guidelines.

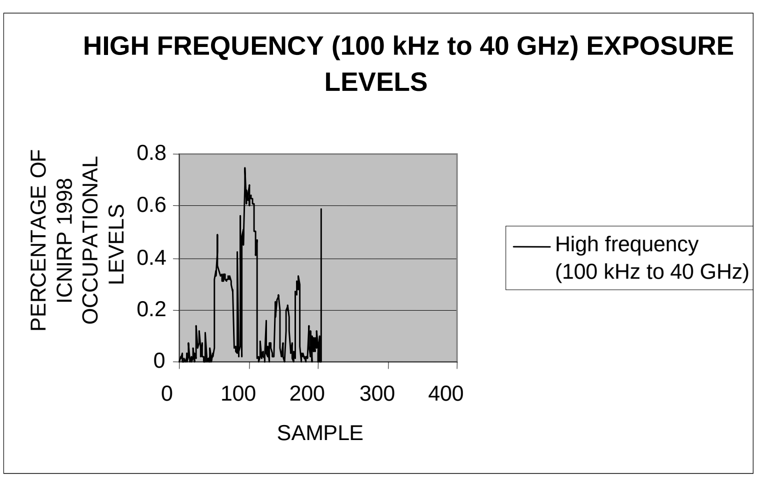

Figure 3.50: High frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, kHz – kilohertz, GHz – Gigahertz)

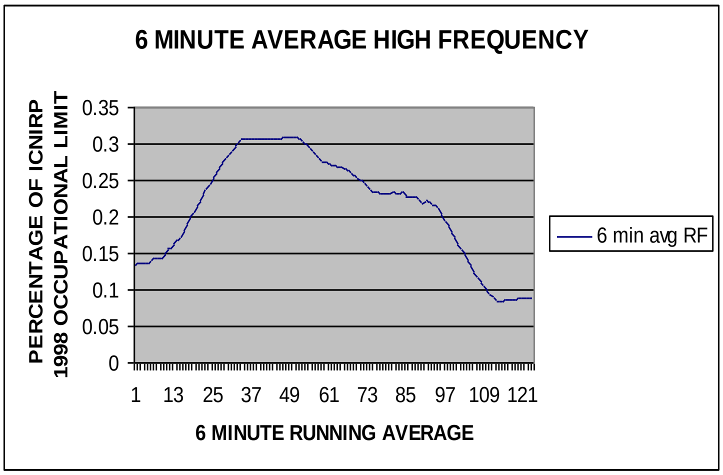

Figure 3.51: Graph for six minute averages of high frequency data (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg – averages)

UNIT THREE

Three hundred readings were taken in the low frequency range at Unit three during a brain examination (Figure 3.52). The highest readings on the six-minute average graph (Figure 3.53) were between 20 and 25 % of ICNIRP guidelines.

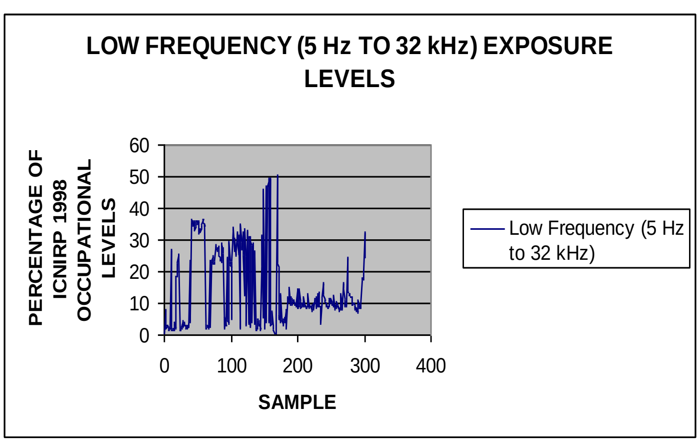

Figure 3.52: Low frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

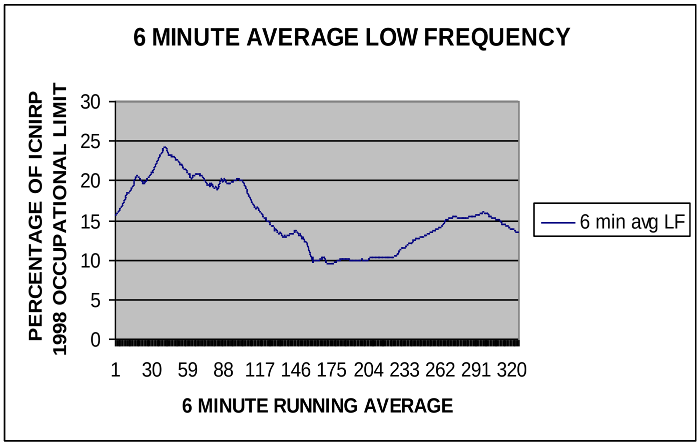

Figure 3.53: Graph for six minute averages of low frequency data (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – low frequencies, avg –averages)

In the high frequency range on the brain examination at Unit three, more than 300 readings were taken (Figure 3.54). The readings on the six minute average graph were all below 1.6 % of ICNIRP guidelines (Figure 3.55).

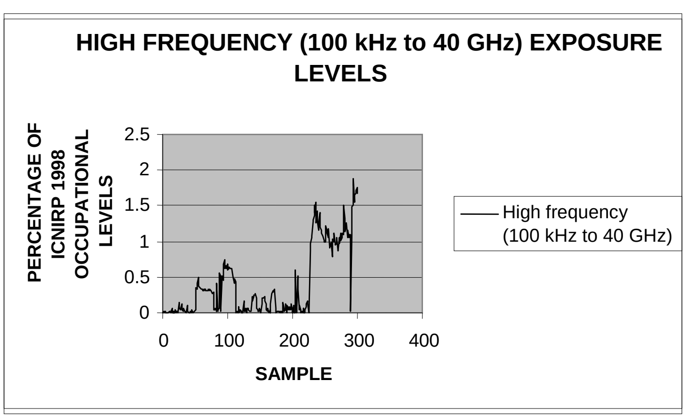

Figure 3.54: High frequency data percentage graph versus ICNIRP limits (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, kHz – kilohertz, GHz – Gigahertz)

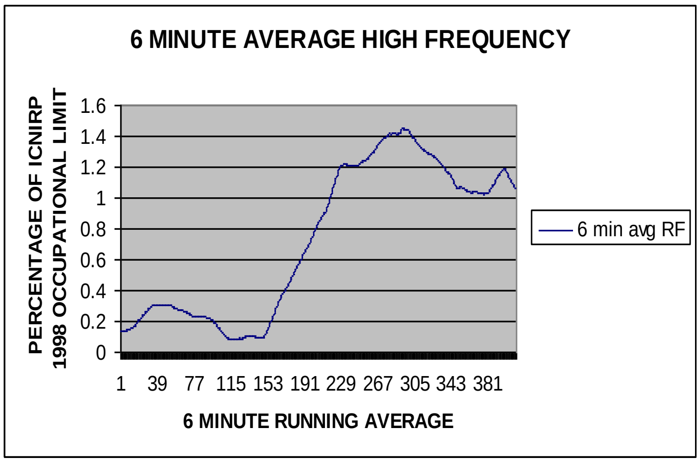

Figure 3.55: Graph for six minute averages of high frequency data (Brain examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg – averages)

More than 200 readings were taken in the low frequency range at Unit three during a cervical spine examination (Figure 3.56). On the six minute average graph (Figure 3.57) the highest reading was 16 % of ICNIRP guidelines.

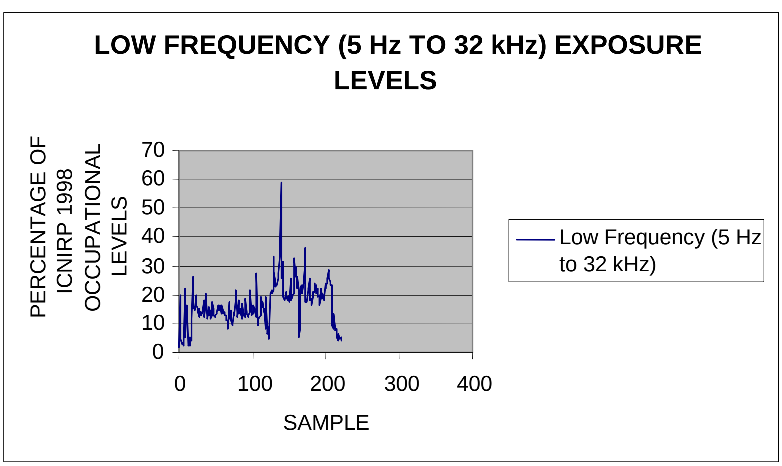

Figure 3.56: Low frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

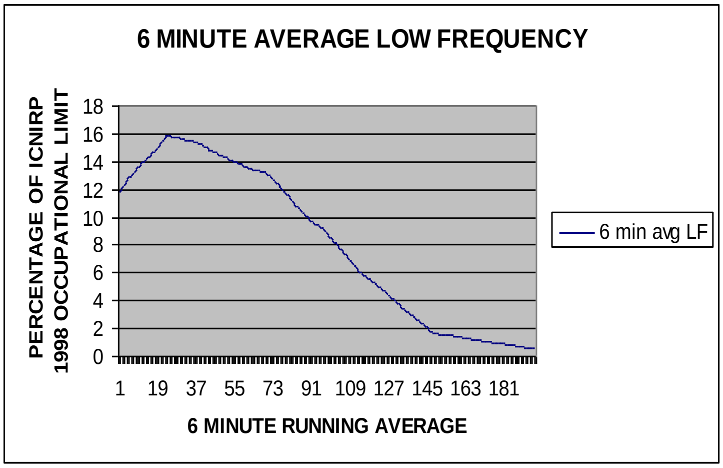

Figure 3.57: Graph for six minute averages of low frequency data (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – low frequencies, avg – averages)

Although more than 400 readings were taken at Unit three in the high frequency range during a cervical spine examination (Figure 3.58), none of these readings fell above 1.6 % of ICNIRP guidelines on the six minute average graph (Figure 3.59).

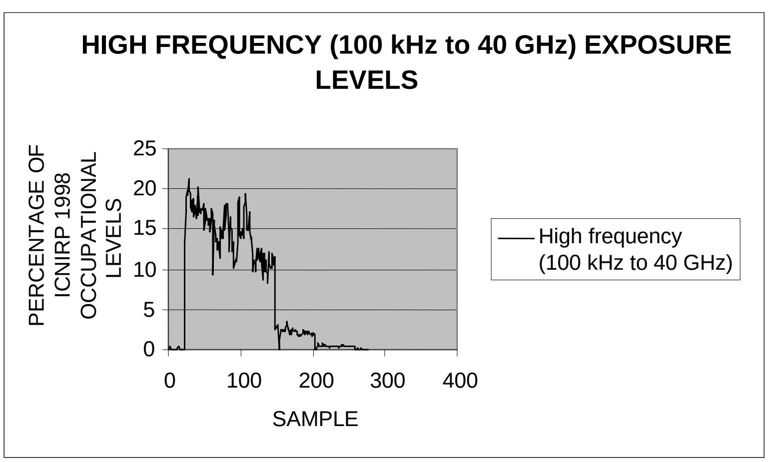

Figure 3.58: High frequency data percentage graph versus ICNIRP limits (Cervical spine examination)

(CNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

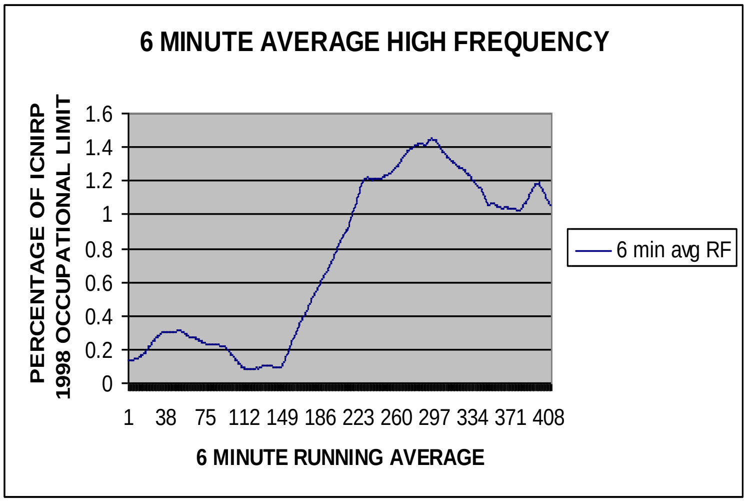

Figure 3.59: Graph for six minute averages of high frequency data (Cervical spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg – averages)

Figure 3.60 displays more than 200 sample readings taken at Unit three in the low frequency range during a lumbar spine examination. On the six-minute average graph (Figure 3.61) the highest readings were 16 % of ICNIRP guidelines.

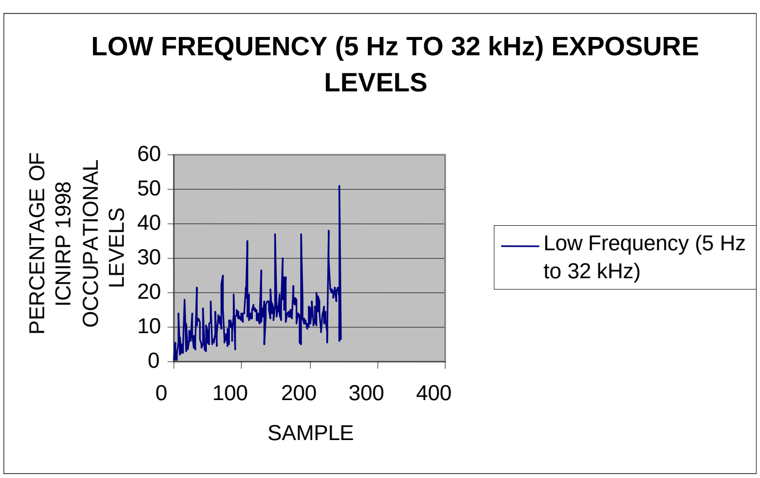

Figure 3.60: Low frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, Hz – Hertz, kHz – kilohertz)

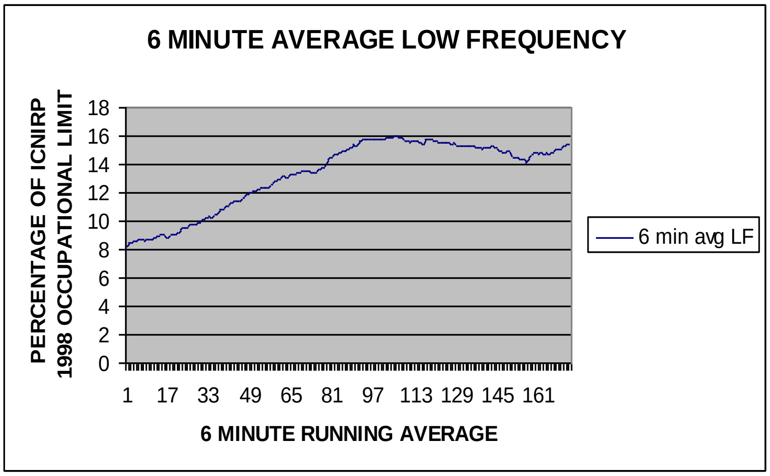

Figure 3.61: Graph for six minute averages of low frequency data (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, LF – low frequencies, avg – averages)

More than 300 readings were taken at Unit three in the high frequency range during a lumbar spine examination (Figure 3.62). On the six minute average graph, the highest readings were between five and six % of ICNIRP guidelines (Figure 3.63).

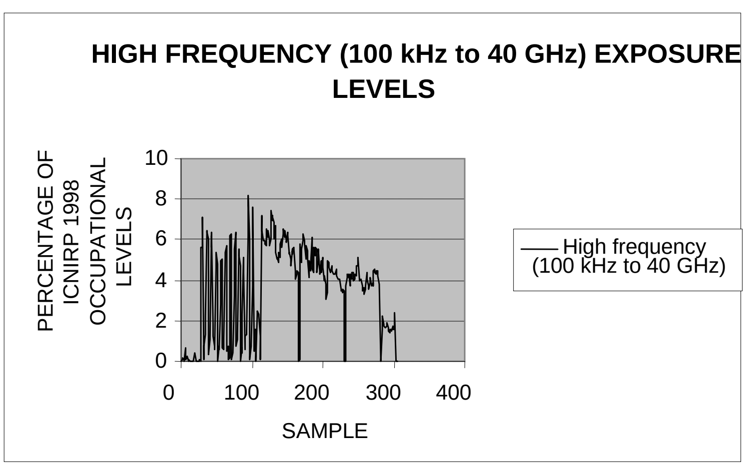

Figure 3.62: High frequency data percentage graph versus ICNIRP limits (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, GHz – Gigahertz, kHz – kilohertz)

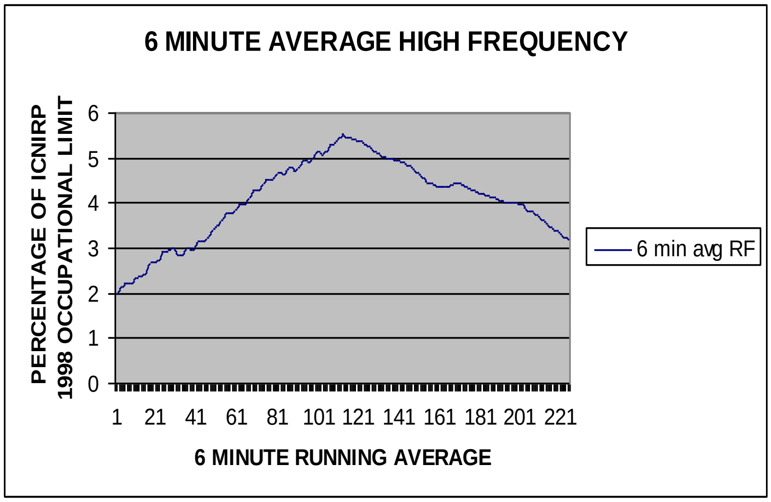

Figure 3.63: Graph for six minute averages of high frequency data (Lumbar spine examination)

(ICNIRP – International Committee for Non-Ionizing Radiation Protection, RF – Radio frequencies, avg – averages)

Discussion of case (round) two and three's measurements

At Unit two during the second round measurements, several measurements were taken for both the low and the high frequency ranges, during brain, cervical spine and lumbar spine examinations. Between 200 and 400 measurements were done for each frequency range. The position (one metre from bore) where the measurements were taken was presumed as a safe position for a health worker to be while staying with a patient during an examination. The low and the high frequency data at all three Units (Figures: 3.10 – 3.27) were well within ICNIRP's threshold limit values. However, for accuracy, measurements during round two were taken over a six minute window period and the root mean square (RMS) of the values was calculated.

Round three measurements were done in the low frequency range (5 Hz – 32 kHz) as well as the high frequency range (100 kHz – 40 GHz). Measurements during similar examinations as in round two were explored. As in round two the six minute window period was also used. However, during round three the measurements were done close-up against the bore. Between 200 and 400 readings were also taken during each frequency range and examination.

Data from Unit one are represented in Figures 3.28 to 3.39. The highest measurements were between nine and ten percent of ICNIRP's threshold values, therefore none of these readings exceeded the limits. Measurements in the low frequency range taken at Unit two during round three were much higher than in round two. Figures 3.40 to 3.51 represent the data for Unit two during round three. A 59 % recording on the lumbar spine examination, in the low frequency range (Figure 3.49), during round three showed a much higher recording than in round two on the same examination. Unit one showed the most stable measurements during round two and three.

Although some of round one's measurements exceeded the ICNIRP guidelines in the low frequency range, the contrary was proved during round two and three's measurements. The difference was because only peak value measurements were done in round one. However, for accuracy measurements should be taken over a six minute window period and the RMS of these values is required. This calculation is a build in feature of the Narda Test unit (Narda Test Solutions: radiation meters, 2004: 3).

A similar study conducted by Fermlee and Vetter (1995: 571) in Northern America showed that the occupational exposure at the entrance to the 1.5 T magnets bore was well within the threshold limits of 1 $mW.cm^{-2}$ at 64 MHz. Fermlee and Vetter used separate electric and magnetic field measurement probes (model HI-3002, Holaday Industries, Eden Prairie, Minn). This article was revised in 2001.

Fermlee and Vetter (1995: 571) used Fast Spin Echo (FSE), Spin Echo (SE) and Fast Gradient (FGRE) pulse sequences to obtain measurements. However, during this study FSE, SE, Fast FGRE and Echo Planar Imaging (EPI) pulse sequences were used. The EPI sequence is one of the newest ultra-fast pulse sequences, which make use of higher gradients.

In the "EU Directive 2004/40: field measurements of a 1.5 T clinical MR scanner" (2007: 484) the EPI (Diffusion-weighted imaging) pulse sequence (high gradients) was again used to test the gradient fields around a 1.5 T MRI unit, however, the magnetic resonance cholangiopancreatography (MRCP) pulse sequence was used to test the RF fields because it requires a high amount of RF power. Although some of the pulse sequences used in this study required high gradients (Diffusion Weighted Imaging or EPI) they were not of the highest RF power required sequences (MRCP).

3.7 Conclusion and recommendations

In this study the measurements were separated between low (5 Hz – 32 kHz) and high (100 kHz – 40 GHz) frequency levels. Therefore, the low frequency levels included the gradient fields (100 Hz – 1000 Hz) and the high frequency levels included the RF fields (10 MHz – 200 MHz). The range 32 kHz to 100 kHz was not considered because gradient field and RF fields were mainly tested. After the first round measurements, concern was raised that the low frequency levels might be above the threshold limits. However, the results from round two and three showed clearly that the RF and gradient (emission) exposure one metre, and up against the bore entrance is not a concern in the low as well as in the high frequency range (rms averaged over 6 min). Noticeable were the higher exposure levels at Units two and three in the low frequency ranges during round three measurements as displayed in Figures 3.49 and 3.60.

Imaging data performed with the described pulse sequences and specific position close to the bore during patient imaging procedures showed that the RF occupational exposure limits (ICNIRP guidelines) at the entrance to a 1.5 T MR unit were not exceeded. However, nursing staff or doctors leaning into the bore to attend to a ventilated patient or to do interventional procedure will receive exposure above the limits set by the Department of Health in South Africa according to the study done by Fermlee & Vetter (1995, 572); (EU Directive 2004/40, 2007: 485); (IEEE committee on man and radiation (COMAR) technical information statement exposure of medical personnel to electromagnetic fields from open magnetic resonance imaging systems, 2005: 687)

Further research on occupational exposure to gradient and RF fields, with ultra-high magnetic fields (≥3 T) and ultra-fast pulse sequences (like single shot fast spin echo), can be useful, because the gradient fringe field fall of around the magnet is higher and the pulse sequences produce either higher RF power (EU Directive 2004/40, 2007: 485) or higher gradient fields (EU Directive 2004/40, 2007: 484). Occupational exposure and hazardous effects due to high static fields in the MRI environment have been well observed and researched. However, occupational exposure due to the rapidly changing gradient fields and the RF fields in this environment did not get the attention that was expected (before 2005). Therefore, in the light of the new purposed EU Directive's absolute legal exposure limits, above which even brief exposure will be illegal, the low frequency or gradient field exposure (peak values) should be further investigated (EU Directive 2004/40, 2007: 483); (Electromagnetic field exposure limitation and the future of MRI, 2005: 973)

According to Karpowicz and Gryz (2007) only a few informative studies have been done to measure exposure above 2 T. Although the static field restriction in the EU Directive has been removed, exposure to the ultra-high magnetic fields should still be investigated because it may still be introduced in a future version of the EU Directive (EU Directive 2004/40, 2007: 483)

The open magnet MRI systems produce complex pulsed waveforms of the gradient fields and the occupational exposure limits can be exceeded under plausible circumstances. Therefore, gradient field exposure at open magnet MRI systems in South Africa should be investigated (IEEE committee on man and radiation (COMAR) technical information statement exposure of medical personnel to electromagnetic fields from open magnetic resonance imaging systems, 2005: 687).

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Chapter 4

Assessment of the psychological wellbeing of health workers in the magnetic resonance imaging (MRI) environment

4.1 Introduction

Living systems continuously interact with their environment and many things in the environment may or may not be hostile to the organism (human-living things). The smallest example of a human living thing is a human cell. The entire biological history is a reflection of this continuous antagonism between the organism (human) and its environment. The diversity of life forms is primarily the result of this dynamic conflict, which is perceived by the organism (human) or its cells as stress (Lakhotia, 2000:24). Whether an event in the environment is perceived as stressful depends on the nature of the event and the organism's (person's) resources, psychological defences and coping mechanism (Sadock & Sadock, 2003: 592).

Stress is a difficult concept to pin down. In human beings it involves the ego, and a collective abstraction for the process by which a person perceives, thinks, and acts on external events or internal drives (Sadock & Sadock, 2003: 593).

4.2 Problem statement

Several environmental stressors exist in the magnetic resonance imaging (MRI) workplace. In available literature, noise levels, as well as ionizing and non-ionizing radiation are mentioned as possible environmental stressors in the work environment (Lakhotia, 2000:24). The MRI (Hospital) environment is highly stressful (Quinn, 2000:

419). Stressors in this environment range from clients' demands, noise levels, subdued lighting, constant patient safety consciousness, work load, the high static magnetic field and many more (Quinn, 2000: 422).

Unlike ionising radiation, the interaction of low-level magnetic fields with living objects is generally subtle and difficult to detect (Mathur-De Vre, 1987: 400). Several *in vivo* research studies indicated that electromagnetic fields have an effect on living things. The smallest living thing is a cell. These effects are usually of a biological origin. One of the most sensitive biological effects of radio-frequency (RF) exposure is considered to be the disruption of operant behaviour (inability to perform the task for which trained). The biological effects can lead to physiological symptoms such as lack of alertness, headache, fatigue and sleep disturbances that have been described among workers exposed to RF exposure levels as low as $1mW.cm^{-2}$ (Mathur-De Vre, 1987: 408). The question arises whether the environmental stressors in the MRI environment have any effect on the psychological condition of the health workers working in this environment and ultimately on their ability to perform in the workplace.

4.3 Aims and Objectives

4.3.1 Aim

The aim of this chapter was to establish whether the work environment at three 1.5T MRI units in Bloemfontein have any influence on the psychological "stature" of health workers, working in this environment.

4.3.2 Objectives

The objectives were to:

- Supply background information on stress and stress related problems.
- To carry out a personnel survey to establish the average time a health worker spent in the MRI environment.

- To evaluate the stress levels of health workers arising from factors outside as well as inside the workplace.
- Finally, to draw a possible conclusion regarding the relationship between time spent in the MRI unit and the psychological wellbeing of the health worker.

4.4 Background

4.4.1 Electromagnetic fields in the MRI environment

The electromagnetic fields in the MRI environment might be a work related stressor that could actually affect the wellbeing of the health worker. However, according to Kanal (1996:1), there is no definite proof that low or high frequencies of electromagnetic fields influence the wellbeing of the health worker in this environment. No data is available, which indicates short-term or long-term memory reduction, and very little data is available on the consequences of exposure of health workers to low magnetic fields for a long period of time. However, in a study done by Weiss, Herrick, Taber, Constant and Plishker, (1992), it was found that rats showed a bio-detectability to high magnetic fields (4 T) and thus showed avoidance behaviour toward the field (Kanal, 1996:1).

The possible effect of ultrasound on humans and the hazardous effects on humans and especially pregnant women were extensively researched. No clear evidence was produced to prove that ultrasound might hazardously affect humans (Kanal, 1996:1). Electromagnetic fields at the MRI environment are also of a non-ionizing nature as is ultrasound. From available literature, it is also evident that adverse health effects from electromagnetic fields (EMF) at MRI units have not yet been proven (Grandolfo, 1998: 25). However, considering the high demands, workload and responsibilities it must be considered that stress is part of this environment.

4.4.2 Stress

Stress can be seen as the perception of pressure or strain arising from an event or events in the everyday environment. Stressors thus cause stress. These stressors range from toxic and harmful chemicals from within or present in this environment, to physical factors, like various kinds of ionizing radiation, and abnormal physiological temperatures due to emotional or neural stressors (Sharf, 2001: 304).

Mental depression and anxiety were recognized as illnesses in the 15^{th} Century and were seen as curable diseases (Barlow & Durand, 2005: 8). Depression and anxiety can be caused by stress. Stress in life can be either predictable life events (eustress), or unpredictable life events (distress) (Quinn, 2000: 305).

4.4.3 Stressors

A stressor is any event or stimulus that causes an individual to experience stress. We have many stressors in our lives like external stressors, internal stressors, developmental stressors and situational stressors (Kozier, Erb, Berman & Snyder, 2004: 1013). External stressors relate to events that we experience while internal stressors relate to our reaction for example, feeling tense, depressed and frustrated.

External stressors can be divided into categories: daily stressors and life events (situational stressors). Daily external stressors relate to work and relationship stressors. Some life events contribute to stress as well as enjoyment. Some events can be predicted and others cannot. Examples of predictable life events are graduation, christening and marriage. Unpredictable life events include trauma, which can be from injury or the death of a loved one, or if fired from a job. Predictable life events have less negative impact than unpredictable life events (Sharf, 2001: 305).

In the MRI environment, based on perceived harm the magnetic field (biological effect resulting from induced current and tissue heating) can act as a psychological stressor. This RF heating effect is usually applicable to the patient in the bore during imaging sequences and does not affect the health worker directly and therefore was not accounted for in this study.

Individuals can experience internal stressors in different ways. Frustration is one form of internal stress. Frustration usually occurs when you cannot get or achieve what you want to achieve (Sharf, 2001: 306).

Environmental stressors are more often unavoidable. They include air pollution, high noise levels, extreme temperatures, bad ventilation or lighting and, ionizing or non-ionizing radiation in the workplace (Sharf, 2001: 306). Stressor can have different effects on individuals. Too much noise can cause the following: fatigue or tiredness, headaches, irritability, rise in blood pressure or poor concentration levels. Excessive noise also impairs the quality of interpersonal relations at work because it can force people into isolation (Louw & Edwards, 1998: 614).

4.4.4 Effects of stress

Stress can have physical, emotional, intellectual, social and spiritual consequences. These effects are usually mixed because stress often affects the whole person. The body and the mind do not function as two separate entities. Therefore when a person reacts psychologically, there are also physiological effects (Kozier, *et al.*, 2004: 1014). Stress refers to the physiological (of the body) and psychological (of the mind) reactions people exhibit in response to stressors (Louw & Edwards, 1998: 608). A person's ability to perceive an event stressful depends on the nature of the event, the person's resources, psychological defences, and coping mechanism (Sadock & Sadock, 2003: 592). The reaction of the body and mind to stressors varies from person to person. Mood disorders are only one of the mind's reactions to stressors and virtually always result in impaired interpersonal social and occupational functioning (Sadock & Sadock, 2003: 534); (Beaton, 1998: 3).

The body's reaction to stressful events range from; heart palpitations, skin problems, infectious deceases, allergies, high blood pressure, loss of appetite, and overeating (Quinn, 2000: 306). The effects of stress can be physiological and sometimes emotional or psychological (Sharf, 2001: 304). However stress can also have intellectual, social and spiritual consequences (Kozier, *et al*., 2004: 1013).

Physically, stress threatens a person's physiological homeostasis. Negative or non-constructive feelings about oneself can be caused emotionally. A person's perceptual and problem-solving abilities can be influenced intellectually. Socially, stress can alter the relationship of a person with others. Regarding spiritually, stress can challenge one's beliefs and values (Kozier, *et al*., 2004: 1014).

Health workers in the MRI environment are totally cut off from sunlight and fresh air is restricted to air conditioning. Bad ventilation can cause symptoms like stuffy noses, dry throats, eye trouble, headaches, and rashes (Louw & Edwards, 1998: 615). Ionizing radiation can cause: fear for radiation, cancer when exposed to excessive radiation, skin disorders and cataract of the eye (Grandolfo, 1998: 29). Non- ionizing radiation from cell phones, microwave ovens, communication satellites, radar, wireless cameras, cordless phones, Bluetooth and walky-talkies and others with frequencies above 10 MHz may cause a thermal effect on the human body. Several cell phones in a small enclosed space can act like a "hot spot", and all the electromagnetic waves inside the space will be referred to as electro-smog (Walraven, 2005: 14).

4.4.5 The body's response to stress

When people face stressors, their response is referred to as coping strategies, coping responses or coping mechanisms (Kozier, *et al.,* 2004: 1013). Seyle (1956: 15) noticed that humans experienced physiological arousal followed by deterioration and exhaustion. Seyle also concluded that the body responds in a certain way to prolonged exposure to stressors. The response includes three predictable stages: the alarm stage, the resistance stage, and the stage of exhaustion or collapse. He named this sequence of three stages the General Adaptation Syndrome (GAS) (Kozier *et al*., 2004: 1015); (Barlow & Durand, 2005: 306).

The alarm stage consists of two phases, shock and counter shock. In the shock phase, there is a rapid lowering in the body's ability to cope with a stressor. In the counter-shock phase, the body's resources are mobilised to produce an emergency reaction, the so-called flight or fight response. The symptoms experienced in this stage are rapid heartbeat, sweating and shaking. The stress stage can be negative or positive (Louw & Edwards, 1998: 625).

The early part of the resistance stage can be described as a positive variety of stress (eustress). During this stage a performance plateau can be reached and can last for some time. The stage of resistance comes to an end when resources become depleted and the person is unable to cope with the stressors any longer. This is the distress stage (Louw & Edwards, 1998: 626).

Distress is an unhealthy or unpleasant form of stress (Edelman & Mandle, 1990: 225). The person will show symptoms of fatigue and exhaustion, struggles to concentrate, is irritable and can be extremely pessimistic (Louw & Edwards, 1998: 626).

Stress can lower immune system response within two hours of exposure to stress. Increased rate of infectious diseases such as colds, herpes and mononucleosis can occur (Barlow & Durand, 2005: 309).

4.4.6 Coping with stress

The body and mind can only cope with stress up to a certain point. When pushed beyond the limit of tolerance, distress is caused, which can cause temporary or permanent damage to the body or the mind (Louw & Edwards, 1998: 609).

Stress, anxiety and depression are closely related (Barlow & Durand, 2005: 307). Coping with stress can be defined as any effort to tolerate the effects of stressors in the least hurtful way. Efforts can be healthy or unhealthy, conscious or unconscious in order to prevent, eliminate or weaken the stressors. Examples of healthy coping efforts are physical efforts such as exercise, or passive efforts such as relaxation techniques and meditation. Unhealthy coping efforts are smoking, drinking and substance abuse (Louw & Edwards, 1998: 646).

4.4.7 Stress in the workplace

Most adults spend more time at their workplace than any other place. In the work situation there are many sources of stress. They are all called occupational stressors (Louw & Edwards 1998: 614). Work related stress has been extensively researched, and has become a major issue for employers and employees, especially in the Health sector (Houtman & Kompier, 1998: 13). Stressors in the workplace can be divided into three categories: physical stressors, task demands, and interpersonal and organizational factors. Examples of physical stressors, also called the sick building syndrome (SBS), are noise, vibrations, extreme temperature, ventilation, lighting and cleanliness of work area. However, the stressors can also be experienced emotionally like fear, anxiety depression, anger and certain behaviours. Stress, anxiety and depression are closely related. All these factors can cause physical and psychological distress to workers (Louw & Edwards, 1998: 615).

A health worker's profession involves many stressors related to both clients (referring doctors and patients) and the work environment. Stressors, like understaffing, adjusting to various work shifts, difficult patients, difficult referring doctors, presuming to cope with unprepared responsibilities, and inadequate support from supervisors and peers occur (Kozier, *et al.*, 2004: 1026).

Different kinds of work make different demands on people. Shift work is a major source of distress. Techno-stress is stress caused by the demands of installing new technology. Personnel have to keep their skills up to date constantly (Louw & Edwards, 1998: 617). Noise, subdued lighting, no windows and a constant fear of people taking hazardous objects into the magnet room are some of the stressors in the MRI environment (Louw & Edwards, 1998: 614).

In the workplace optimum demand can lead to best performance from the worker and is a form of positive stress, eustress. However, low demand will cause poor performance or with excessive demand, performance will deteriorate and the worker will experience it as unpleasant and distressing (negative) (Louw & Edwards, 1998: 611).

Poor relationships can be an important source of stress. The climate in the organisation refers to employment practices, organisational goals and management philosophy. Role conflict can happen when people are expected to do conflicting things. Role ambiguity happens when the goals or objectives of the job are unclear and the job cannot be carried out. Increased demands and accompanying high stress can be carried over to the non-work environment. Work stress can influence other people with whom the employee interacts. Spouses, children and family can therefore be affected by the work stress situation.

Work related stress cannot be taken lightly. The consequences of work related stress can be devastating, not only in terms of costs and labour turnover but also in terms of suffering (Grobler & Hiemstra, 1998: 26).

It is clear that employers should be concerned about both the physical and psychological health of their employees and employers are legally obliged by the OHS Act 85 (1993) to be concerned. The workplace is an ideal forum to pursue the initiative to promote and maintain the mental wellbeing of employees (Miller, 1999: 42).

4.4.8 Measuring stress in the workplace

According to Van Zyl (2002) a system of stress measurement and management in South Africa is not a luxury. It has become a matter of physical, psychological, economic and social survival. Stress management should be used as a "preventative tool and not be seen as a cure" (Van Zyl, 2002: 30).

The most common way of measuring stress is the self-report collection methods (Van Zyl, 2002: 30) provided the questions are structured in such way that it will cover the area of interest. Data can be collected orally in an interview or in a written questionnaire. The questionnaires can vary in structure, length, complexity, and in their administration. Qualitative self-report techniques are usually oral interviews, where as quantitative self report instruments almost always use a formal written instrument. A structured instrument is usually a set of questions in which the wording of both questions and in most cases response alternatives is predetermined. In structured questionnaires, subjects are asked to respond to the same questions in the same order, and with the same response options (Polit & Beck, 2004: 341).

The assessment of stress is best done as a self-report assessment. It is the most cost-effective method since it can be applied to a whole group of people at the same time (Van Zyl, 2002: 30). In the measuring process, the focus should fall on identifying levels as well as causes of stress. The degree of stress levels and the origin, outside or inside the workplace, should also be identified (Van Zyl, 2002: 28). The identification of stressors in the workplace should be a continuous process and should not be seen as a once-only occurrence (Van Zyl, 2002: 29).

There are several self-report questionnaires available to measure an individual's stress in the workplace, for example the Personal Resources Questionnaire (PRQ), the Holmes-Rake Social Adjustment Scale, the Occupational Environment Scale (OES) and the one used in this study, the Work and Life circumstances Questionnaire (WLQ), from Dr Ebben Van Zyl's (1991) Doctoral Thesis (Louw & Edwards, 1998: 621).

4.5 Work and Life circumstances Questionnaire (WLQ)

Van Zyl (1991) developed the WLQ during his Doctoral Thesis: "Die ontwikkeling van `n meetinstrument van werkstress vir Hoëvlak werknemers". The questionnaire was developed according to the framework of Smit's (1981) questionnaire and it was supplemented by the work of other authors (Van Zyl, 1991: 8). This questionnaire was aimed at the workers in the middle to higher income group for black and white South African workers.

The questionnaire was tested several times by Dr Van Zyl as well as other researchers in the Psychology and Industrial Psychology field over the last 15 years. Therefore the reliability, accuracy and validity of the questionnaire are of a high standard. The questionnaire was constructed to evaluate the stress levels of the individual and to distinguish between stress levels arising from factors outside as well as inside the workplace (Van Zyl, 1991).

4.6 Methodology

A survey to explore the stress levels of health workers working at the 1.5 T MRI units in South Africa was conducted.

4.6.1 Population and sample

All the health workers especially the radiographers, working at 1.5 T MRI units throughout South Africa were asked to complete a WLQ questionnaire. The manufacturer of the MRI unit was not brought into consideration. Time allocated for completion and returning of the questionnaire was six months. Any change in personnel during the six months was used as a substitute sample.

4.6.2 Materials

Permission was received from Dr Van Zyl (1991), from the department of Industrial Psychology at the Free State University, to use his "Work & Life Questionnaire" in this study.

The questionnaire contains relevant questions to evaluate possible psychological effects of the stressors in the MRI environment on the Radiographers with reference to disruptive operator behaviour and depression. It is divided into three parts, namely Scale A, Scale B and Scale C. Scale A (experience of work), question one to forty indicates the level of stress of the individual health worker. Scale B (circumstances) indicates the stress levels from stressors outside the workplace. Scale C (expectations) indicates stress level from stressors within the work place. The questionnaire was constructed on a scale format from one to five. Number one indicating virtually never, and number five indicating virtually always. The questionnaire can be viewed in Appendix A.

4.6.3 Methods

A pilot study was done to test the response to the questionnaire amongst health workers. The aim of the pilot study was to establish the time needed to complete the questionnaire and to test the consumer friendliness of the questionnaire to health workers. Two MRI sites were identified and questionnaires were sent to all the health workers working at the sites.

The questionnaires for the main study were sent to thirty-four (34) 1.5 Tesla MRI sites throughout South Africa. The sites were telephonically contacted before the questionnaires were despatched, to establish the number of questionnaires needed per site and to verbally ask whether they would be willing to complete the questionnaire. The radiographer in charge at the MRI site was then used as a mediator, and all the questionnaires were sent to his/her address for distribution amongst co-workers.

One hundred and twenty questionnaires were despatched to the thirty-four MRI sites early July 2004. Health workers were given a six-month responding period. Follow-up per telephone was done after three months. The questionnaire was accompanied by a covering letter to explain the purpose of the questionnaire and to assure the health workers of confidentiality. Numbers were allocated to each site to control the return of the questionnaires. The sites were situated in Johannesburg, Pretoria, Durban, Cape Town and Bloemfontein.

4.7 Results and discussion

4.7.1 Pilot study

The results from the pilot study showed that completion of the questionnaire would take approximately thirty-five minutes if completed without any interruption. The response of the radiographers was very positive. All the questionnaires were returned on time.

4.7.2 Results and discussion of personnel survey

4.7.2.1 Results of personnel survey

Table 4.1 exhibits the results from the personnel survey. In the main study 79 out of the 120 questionnaires were returned. Although follow-up was good, problems like fear of their employer's reaction, staff changes, refusal to complete and the personal nature of the questions prevented some of the health workers from returning their questionnaire.

Eighty nine percent of the health workers were from private hospitals and only eleven percent worked in the public sector. The health workers at the MRI sites were mostly female (97 %) and only three percent were male. Six percent of the health workers were registered nurses. Most health workers (69 %) were aged between 30 – 50 years, followed by twenty-eight percent in the 20 – 30 year age group, with the least (3 %) being older than 51 years.

Table 4.1: Geographical and biographical data from the personnel survey (n=79)

Institution	**Number of Workers**
Government Hospitals	9 (11%)
Private Hospitals	70 (89%)
Health worker category	
Radiographer	74 (93.6%)
Registered nurse	5 (6.3%)

Gender	
Male	2 (3%)
Female	77 (97%)
Age (years)	
20-30	22 (28%)
31-40	39 (49%)
41-50	16 (20%)
51-60	2 (3%)

Results from the personnel survey on the time spent in the MRI environment are displayed in table 4.2. The average time spent by a health worker in the MRI room during positioning of a patient was five to ten minutes per patient. Most of the health workers (n=66) had worked in the MRI environment for more than two years and they worked an average of two weeks per month at the MRI unit. A quarter (22 %) of the health workers needed not to spend time in the MRI room during an examination, whereas the majority (43 %) had to stay with a patient during an examination once every two months. Few (15 %) health workers stayed with patients one to three times a week, followed by eight % staying once a month, eight % twice a month, and only four % stayed once every two weeks.

Table 4.2: Results from the personnel survey on time spent in the MRI environment (n=79)

Average time spent in MRI room during examination	Number of Workers
Never	17 (22%)
Once every 2 months	34 (43%)
Once a month	7 (8%)
Twice a month	6 (8%)
Once every 2 weeks	3 (4%)
1 – 3 times a week	12 (15%)

Average time spent in MRI room for positioning, taking patients off bed and injection of contrast media	5-10 min/patient
Average period worked at MRI per month	2 weeks

Table 4.3 displays the stressors identified by health workers in the MRI environment. Few (15 %) of the health workers were previously treated for depression. However, most of them indicated that they had depression before they started working at the MRI. Most (77 %) of the health workers found working at the MRI unit stressful. The stressors named were, noise levels, patient demands and needs, subdued lighting, demands of referring doctors and radiologists, working on a computer, type of examination, and the workload.

Fourteen percent of the health workers found the noise levels in the MRI environment stressful. The majority (39% and 38%) found the demands and needs of the patient, and the radiologists respectively, very stressful, while 22 % found the demands of the referring doctors stressful. Subdued lighting (15 %), working on a computer (11 %), workload (2 %) and type of examination (7 %) made up the rest of the stressors in the MRI environment.

Table 4.3: Results from personnel survey on stressors in the MRI environment (n=79)

Stressors		**% of Workers**
Health workers treated previously for depression		15.2%
Health workers finding work at MRI stressful		77.2%
Perceived Reasons:	Patient demands and needs	39%
	Demands of radiologists	38%
	Demands of referring doctors	22%
	Subdued lighting	15%

	Noise levels	14%
	Working on computer	11%
	Type of examination	7%
	Workload	2%

4.7.2.2 Discussion of personnel survey

In South Africa, MRI units were first installed in private hospitals only. The first MRI site in a Government hospital was installed in 1992. Therefore, the 89 % (table 4.1) of health workers in the private hospitals was an indication of the installation statistics of MRI sites.

The results of this study may lead to the conclusion that radiography is primarily a career followed by women; males are thus shown to be a minority group in this career field. The 93 % women (table 4.1) may be an indication of radiography career statistics.

The six % (table 4.1) response by the registered nurses was due to the fact that they did not work at MRI units, full time but had to cover x-ray departments as a whole each day. Government hospitals were an exception, were the registered nurses were specifically allocated to MRI and CT.
The 69% (table 4.1) representation in the age group 30 to 50 years was most probably due to the fact that the radiographers had more experience and had probably been working in the MRI unit for many years. The 20 to 30 year age group of 28 % (table 4.1) was an indication that more junior radiographers were attracted to the MRI environment. The reason for this might be that experiential learning in MRI was introduced into the syllabus only in the last ten years (Personal experience).

Patients were mostly accompanied by parents, family, friends, or a nurse from the ward. Radiographers working at the MRI had to operate the unit at the operator's console; therefore, they were usually unable to stay with a patient in the MRI room during an examination. Most health workers spent little time with patients during an examination with 43 % spending once every two months in the MRI room and 22 % never (table 4.2).

Health workers spent an average of two weeks every month at the MRI (table 4.2) and took five to ten minutes, depending on the examination, to position or take a patient off the MRI bed. When working as a team of two and taking turns to do so, it will mean a health worker will have to enter the MRI room (the 1.5 T static field) every 15 minutes when doing four brain examinations in one hour (Personal experience).

Although not included in tables in this survey, it was found that most of the radiographers working in a MRI environment were aware of the non-ionizing EMF environment, but only a few were knowledgeable about standards and safety aspects of RF fields at MRI units (Informal personal conversations).

From table 4.3 it is evident that a high percentage (77%) of the health workers found working at the MRI stressful. According to Quinn (2000), the following additional stressors can be added: aggressive patients, unpredictable workloads, always in the public eye, new technology, lack of managerial supervision, fluctuating shift times, unpredictable workload, and lack of proper training. Hospitals and community health settings have some of the highest stress potentials (Quinn, 2000: 419). Due to the high stress potentials of hospitals it was not uncommon to find that 15.2 % (table 4.3) of the health workers were previously treated for depression.

4.7.3 Results and discussion of Work and Life Questionnaire (WLQ)

4.7.3.1 Results of Work and Life Questionnaire (WLQ)

Table 4.4 exhibits the results from Scale A or Stress A (experience of work) of the WLQ (see appendix A). Scale A consists of forty questions and each question may score a maximum count of five. Therefore, a total score of 200 is possible, and a high score will point to a very high level of stress. Stress A, personal stress level, is divided into three levels: 40 to 119 (level one) indicates a normal stress level, 120 (level two) indicates a high stress level and 121 to 200 (level three) indicates a very high stress level. Most (98.7 %) health workers indicated a normal stress level.

Stress A is a measurement of the personal stress levels of the individual health worker. The health workers' mean stress level was 68 with a standard deviation of 18. The total range for the stress levels is from 40 to 200, with 120 the centre value. A high score for Stress A indicates a high stress level. Therefore, a mean of 68 indicated a normal personal stress level for these health workers.

In the study done by Van Zyl (1991: 187), **:** " Die ontwikkeling van `n meetinstrument van werkstress vir Hoëvlak werknemers"**,** his aim in the setting of limits was to have at least 75 % of health workers to fall into the normal category, 15 % into the high category and 10 % into the very high category. The results of this study of 98.7 % in the normal category and 1.3 % in the very high category did not correspond to Van Zyl's expected guidelines.

Table 4.4: Results from Work and Life Questionnaire on experience of work (Scale A)

Stress levels	**Number of health workers**	**Mean**	**Std Deviation**
1.00	78 (98.7%)	67.8228	18.12970
3.00	1 (1.3%)		
Total	79 (100%)		

Stress A or Scale A – Experience of work

The section of the WLQ on Circumstances (also called Scale B or Stress B) indicates the stress levels from stressors outside the workplace. Stress B consists of 16 questions, with a maximum scoring value of five per question, which will give a total score of 80. Scale B is divided into three scoring levels: 16 to 47 (level one) indicates a normal stress level, 48 (level two) indicates a high stress level and 49 to 80 (level three) indicates a very high stress level. A high score indicates that a health worker experiences the factors in Scale

B as problematic. The results displayed in table 4.5 indicated a normal stress level for all the health workers.

Table 4.5: Results from Work and Life Questionnaire on circumstances outside the workplace (Scale B)

Stress levels	Number of health workers	Mean	Std Deviation
1.0	79 (100%)	24.772	5.38459

Stress B or Scale B – Circumstances outside the workplace

The section of the WLQ on Expectations (also called Scale C) indicates stress levels from stressors within the work place. Scale C is divided into six categories: organizational functioning (ORG), task characteristics (TA), physical working conditions and job equipment (PHY), career matters (CAR), remuneration, fringe benefits and personnel policy (REM), and social matters (SO). In Scale C a low score (very high stress level) implies that a health worker has a problem with the issues raised, in categories one to six.

Table 4.6 displays the results from the WLQ on organizational functions. Organizational functions are divided into three scoring levels: 25 to 40 (level one) indicating a normal stress level, 24 (level two) indicating a high stress level and 8 to 23 (level three) indicating a very high stress level. Number seven in table 4.6 indicates spoiled answers. Most (74.7%) of the health workers indicated a very high stress level due to organizational function.

A mean of 19 indicated a very high stress level from organisational functions. Compared to the guidelines of Van Zyl (1991: 187) this was an extremely high percentage for the very high stress level category.

Table 4.6: Results from Work and Life Questionnaire on organizational function (Scale C)

Stress	Number of	Mean of	Std Deviation

level	health workers	ORG	of ORG
1.00	19 (24.1%)	19.3038	6.33945
3.00	59 (74.7%)		
7.00	1 (1.3%)		
Total	79 (100%)		

ORG – Organizational functions

In table 4.7 the results of task characteristics (TA) are displayed as follows: the total 46 to 75 (level one) indicates a normal stress level, 45 (level two) indicates a high stress level and 15 to 44 (level three) indicates a very high stress level. A low score will indicate high stress levels. Most (63.3%) of the health workers indicated a normal stress level due to task characteristics. However, 29 % of the health workers indicated a very high stress level due to task characteristics. For task orientated stressors the score can be from 15 to 75 with 45 as the centre value. A mean of 49 in this study indicated a normal stress level due to task characteristics.

Table 4.7: Results from Work and Life Questionnaire on task characteristics (Scale C)

Stress level	Number of health workers	Mean of TA	Std Deviation of TA
1.00	50 (63.3%)	49.3291	8.01236
2.00	6 (7.6%)		
3.00	23(29.1%)		
Total	79 (100%)		

TA – Task characteristics

Table 4.8 displays the results of stress levels due to physical working conditions and job equipment (PHY) in the following order: 25 to 40 (level one) indicates a normal stress level, 24 (level two) indicates a high stress level, and 8 to 23 (level three) indicates a very high stress level. Approximately half (54.4 %) of health workers indicated a normal stress level, whereas 39.2 % indicated a very high stress level due to physical working conditions and job equipment. Physical working condition stressors have a score between 8 and 40, with 24 as the centre value. A 25 mean in this study indicated a high stress level.

Table 4.8: Results from Work and Life Questionnaire on physical working conditions and job equipment (Scale C)

Stress level	Number of health workers	Mean of PHY	Std Deviation of PHY
1.00	43 (54.4%)	25.1013	5.57144
2.00	5 (6.3%)		
3.00	31 (39.2%)		
Total	79 (100%)		

PHY – Physical working conditions and job equipment

Table 4.9 displays the results of career matters (CAR) in Scale C. A score of 27 to 45 (level one) indicates a normal stress level, 26 (level two) indicates a high stress level and 9 to 25 (level three) indicates a very high stress level. The numbers seven and eight in table 4.9 indicate spoiled answers. Approximately half (54.4 %) the health workers reported a very high stress level due to career matters, whereas only 38 % reported normal stress levels. The career stressor score is between 9 and 45 with 27 the centre. Therefore 25 reported in this study indicated a very high stress level.

Table 4.9: Results from Work and Life Questionnaire on career matters (Scale C)

Stress level	Number of health workers	Mean of CAR	Std Deviation of CAR
1.00	30 (38%)	24.1139	7.38152
2.00	4 (5.1%)		
3.00	43 (54.4%)		
7.00	1 (1.3%)		
8.00	1 (1.3%)		

CAR – Career matters

In table 4.10 the results on stress due to social matters (SO) in the work place are displayed. A total score of 25 to 40 (level one) indicates a normal stress level, 24 (level two) indicates a high stress level, and 8 to 23 (level three) indicates a very high stress level. Most of the health workers (53.2 %) experienced a normal stress level due to social matters in the workplace. However, 39.2 % of the health workers reported a very high stress level due to social matters in the work place. Social activities stressors score are between 8 and 40, with 24 in the centre. Therefore, a mean of 25 in this study indicated a high stress level.

Table 4.10: Result from Work and Life Questionnaire on social matters (Scale C)

Stress level	Number of health workers	Mean of SO	Std Deviation of SO
1.00	42 (53.2%)	24.6203	5.32605
2.00	6 (7.6%)		
3.00	31 (39.2%)		
Total	79 (100%)		

SO – Social matters

Table 4.11 displays the results of the stress levels due to remuneration, fringe benefits and personnel policy (REM). This category is divided into three scoring levels: 37 to 60 (level one) indicates a normal stress level, 36 (level two) indicates a high stress level and 12 to 35 (level three) indicates a very high stress level. A high score (37 to 60) indicates low stress levels due to REM. The majority of (79.7 %) of the health workers reported very high stress levels due to remunerations, fringe benefits and personnel policy. The score for remuneration is between 12 and 60, with 36 the centre. A mean of 21 in this study indicated very high stress levels due to remuneration, fringe benefits and personnel policies.

Table 4.11: Results from Work and Life Questionnaire on remuneration, fringe benefits and personnel policy (Scale C)

Stress level	Number of health workers	Mean of REM	Std Deviation of REM
1.00	8 (10.1%)	20.6709	8.94244
2.00	2 (2.5%)		
3.00	63 (79.7%)		
5.00	1 (1.3%)		
6.00	1(1.3%)		
8.00	1 (1.3%)		

9.00	1 (1.3%)		
10.00	1 (1.3%)		
11.00	1 (1.3%)		
Total	79 (100%)		

REM – Remuneration, fringe benefits and personnel policies

Tables 4.12 to 4.19 show the correlation between the different stressors in and outside the working environment. Signa (2-tail) is the correlation value (p). The correlation value p must be: $-1 < p < 1$. If p equals zero no relation between the stressors exists and this is called the H_o hypothesis. If $p < 0.05$ the hypothesis (H_o) is rejected and there is a significant correlation between the stressors. For $p < 0.01$, a highly significant correlation exists. Table 4.12 and Table 4.19 indicated that between the personal stress level (Stress A) and remuneration, fringe benefits and staff policy (REM) ($p = 0.002$), a highly significant correlation existed.

Table 4.12: Results of correlations between experience of work (Scale A) and circumstances outside the workplace (Scale B), and circumstances in the workplace (Scale C)

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
Scale A	Pearson Correlation	1	0.418	-0.452	-0.426	-0.423	-0.413	-0.450	-0.348
	Sig.(2-tailed)		0.000	0.000	0.000	0.000	0.000	0.000	0.002

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

Furthermore, organisational function (ORG), task characteristics (TA) and remuneration (REM) also had a highly significant correlation with circumstances causing stress outside the workplace (Stress B) and *vice versa*, as displayed in tables 4.13, 4.14, 4.15 and 4.19.

Table 4.13: Results of correlation between circumstances outside the workplace (Scale B), experience of work (Scale A), and circumstances in the workplace (Scale C)

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
Scale B	Pearson Correlation	0.418	1	-0.335	-0.360	-0.418	-0.423	-0.440	-0.333
	Sig.(2-tailed)	0.000		0.003	0.001	0.000	0.000	0.000	0.003

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

Table 4.14: Results of correlation between organizational function (Scale C), experience of work (Scale A), circumstances outside the workplace (Scale B), and the rest of Scale C

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
ORG	Pearson Correlation	-0.452	-0.335	1	0.672	0.554	0.812	0.627	0.709
	Sig.(2-tailed)	0.000	0.003		0.000	0.000	0.000	0.000	0.000

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

Table 4.15: Results of correlation between task characteristics (Scale C), experience of work (Scale A), circumstances outside the workplace (Scale B), and the rest of Scale C

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
TA	Pearson Correlation	-0.426	-0.360	0.672	1	0.755	0.701	0.689	0.556
	Sig.(2-tailed)	0.000	0.001	0.000		0.000	0.000	0.000	0.000

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

Physical working conditions, career matters, and social matters indicated no significant correlation with personal stress level (Scale A), the stress level related to stressors outside the workplace (Scale B) or any of the stressors in the workplace (Scale C).

Table 4.16: Results of correlation between physical working conditions (Scale C), experience of work (Scale A), circumstances outside the workplace (Scale B) and the rest of Scale C

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
PHY	Pearson Correlation	-0.423	0.418	0.554	0.755	1	0.625	0.668	0.483
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		0.000	0.000	0.000

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

Table 4.17: Results of correlation between career matters (Scale C), experience of work (Scale A), circumstances outside the workplace (Scale B) and the rest of Scale C

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
CAR	Pearson Correlation	-0.413	-0.423	0.812	0.701	0.625	1	0.731	0.709
	Sig.	0.000	0.000	0.000	0.000	0.000		0.000	0.000

	(2-tailed)								

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

Table: 4.18: Results of correlation between social matters (Scale C), experience of work (Scale A), circumstances outside the workplace and the rest of Scale C

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
SO	Pearson Correlation	-0.450	-0.440	0.627	0.689	0.668	0.731	1	0.565
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000		0.000

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

Table 4.19: Results of correlation between remuneration (Scale C), experience of work (Scale A), circumstances outside the workplace (Scale C) and the rest of Scale C

		Scale A	Scale B	ORG	TA	PHY	CAR	SO	REM
REM	Pearson Correlation	-0.348	-0.333	0.709	0.556	0.483	0.709	0.565	1
	Sig. (2-tailed)	0.002	0.003	0.000	0.000	0.000	0.000	0.000	

Scale A – Experience of work, Scale B – Circumstances outside workplace, Scale C – Circumstances in workplace: ORG – organisational function, TA –Task characteristics, PHY - Physical working conditions, CAR – Career matters, SO – Social matters, REM – Remuneration, fringe benefits and personnel policy.

4.7.3.2 Discussion of Work and Life Questionnaire

According to Van Zyl (1991:183), changes and adjustments can be brought into context with stress and the stress measurement. Therefore, the amount of time spent at the MRI by the health workers can have an influence on their stress levels and their ability to handle stress. He is also of the opinion that a person who makes proper use of a social support network will most probably have an outgoing lifestyle and will accomplish a high score in scale A (Van Zyl, 1991:184).

The personal stress level of the health workers or their experiences of work were measured by Scale A. Normal stress levels were indicated by 98.7 % (table 4.4) of the health workers. However, the ability to handle stress can not be measured primarily by the WLQ (Van Zyl, 1991:193). The very high percentage of normal stress levels seemed to be abnormal for health workers if measured by the expectations set by Van Zyl (1991:187), which may mean that the health workers were either not truthful in their answers or might have completed the questionnaires as a group.

Stress levels due to factors outside the workplace (circumstances) were measured by Scale B. All the health workers (table 4.5) indicated a normal stress level due to circumstances outside the workplace. According to the expectations set by Van Zyl for the normal stress level (75 %) these results were abnormal (Van Zyl, 1991: 187). The reason for this could have been the personal nature of the questions. Fear of exposing themselves and an uncertainty of confidentiality might also have been the reason for this outcome. It could mean that the frequency of stressors may be high, but a person possesses the ability to handle these demands, which means that the person may probably experience normal levels of stress (Van Zyl, 2002: 33).

Scale C (expectations) measured the stress levels due to circumstances in the work place. This part of the WLQ, divided into six parts, measured the expectations of the health workers. In the category, organisational functioning, 74.7 % (table 4.6) of health workers indicated very high stress levels versus the expected outcome of 10 % (Van Zyl, 1991: 187). Questions in the WLQ (Appendix A) like: "The organization as a whole does not function satisfactorily?"; "You receive recognition for what you do?"; and "You can trust your supervisors in all circumstances?", which contributed to the high stress levels, indicated that they might have experienced that the employers had little confidence in them as employees and felt that the leadership styles were incorrect. They might also have felt that they could not trust their employers and that their efforts and achievements went unnoticed.

The category, task characteristics, showed that 63.3 % (versus 75 %) of the health workers had a normal stress level (table 4.7). Questions in the WLQ (Appendix A) like: “You are dissatisfied about the nature of your work……?”; “You are able to function independently?”; “You can get the work assigned to you done in time?”, contributed to normal stress levels on task characteristics and meant that the health workers were satisfied with their nature of work and found their work interesting and stimulating. They also felt that they were able to finish the work in due time and that the nature of their work was not too physical. Independent work and responsibility were also possible. However, the 29 % (versus 10 %) in the very high stress level indicated that almost a third of the health workers were dissatisfied with the nature of their work. They found that their work and actions could endanger other people's lives and that they were seldom able to function independently or assume full responsibility for their actions.

Physical working conditions showed a response of 54.4 % in the normal stress level. However the concern was due to the 39.2 % (versus 10 %) in the very high stress level. Questions in the WLQ (Appendix A) like: “You encounter one or more of the following: considerable noise, high/low temperatures, odours, gasses poor lighting, crowding of people and/or any other problems that concern your physical working conditions?”, showed that the health workers found the noise levels, poor lighting and the gas (Helium and possibly quenching) level in the MRI environment very stressful.

In the category career matters a response of 54.4 % in the very high stress level category did not comply with the expectations of Van Zyl's WLQ. The following questions from the WLQ (Appendix A): “Situations in which you find yourself, have a negative effect on the progress and development of your career?”; “Your abilities and skills are developed and extended?”; “The requirement of your job correspond to with what you have to offer?” and “You are making progress?”, contributed to a very high response (54 %) in the very high stress level category. It indicated that health workers in the MRI environment might often experience that they are expected to do work out of their professional field, and found it very stressful. They might also have felt that their good qualities were not always used and they were not exposed to adequate training.

Furthermore, it could also be an indication that they may feel like they were not making any progress because promotion in radiography is very limited and skills development is not always important to the employees. As a group it seemed as if MRI radiographers were not very satisfied with the outcome of their career expectations and were suppressed by their employers.

Questions from the WLQ (Appendix A) like: "You find it difficult to deal with social matters?"; "You have status?"; "You have good relationship with your colleagues?"; and "The social demands made on you are of such nature that you can easily satisfy them?", contributed to the high score of 39.2 in the very high stress level of social matters category. This can be an indication that some of the health workers found it difficult to socialize in a group or to maintain good interpersonal relationships in the workplace. They could also have felt like they have no status in the workplace and could not get along with their supervisors

The stress levels amongst health workers were very high (79.7 %) in the remuneration, fringe benefits and staff policies categories (table 4.11). Only 10 % (table 4.11) of the health workers indicated a normal stress level in this category. Most of the health workers completing the WLQ (89 %) were radiographers, worked in the private sector and were female. Questions from the WLQ (Appendix A) like: "You are dissatisfied with one of the following: pension, medical and housing aid, bursaries, achievement bonuses, group and/or any other aspects of your remuneration?"; "You are dissatisfied with working hours etc."; and "Your salary is adequate to motivate you to work hard at all times", contributed to the high percentage (79.7 %) in the very high stress level category. This could be an indication that matters like pension and medical aid funds, housing aid, bursaries and achievement bonuses were experienced not to be at the same standards as in the public sector and might have contributed to the stress levels of the radiographers in the private sector. Working hours and overtime work in the private sector might also be very strenuous.

Stress from the workplace can have an affect on your personal life and *vice versa*, therefore it is important to "asses and accept your personal limitations, celebrate your strengths and the ability to cope effectively with stress, as well as maintaining satisfying relationship with other" (Van der Merwe, 2000: 18). The significantly high correlation (table 4.12 and 4.19) between the health workers' personal stress levels and remuneration, fringe benefits and staff policy (p = 0.002) was a clear indication of the *vice versa* effect of stress on the life of a health worker in the MRI environment. The results showed that organisational function, task characteristics and remuneration also had a highly significant correlation with circumstances outside the workplace (stress B). However, remarkable was the fact that the high stress levels experienced by the health workers in the MRI environment due to remuneration, fringe benefits and staff policies as well as organisational function and task characteristics, did not influence their personal stress levels or their stress levels due to factors outside the workplace.

Van Zyl (1991:179) is of the opinion that the most common reasons that causes stress for workers can be established by evaluating the circumstances where under they function and the expectations that they have. His opinion that work related stress can have an impact on the workers home environment and *vice versa* was not really proven by this research. The reason maybe that radiographers may experience high stress levels at work but still have the ability to cope or that they are just not willing to admit that their stress at work did influence their personal lives and *vice versa*.

Radiography is shown to be a dominantly female occupation (Coomb, Park, Loan-Clark, Preston, & Wilkinson, 2001: 67), and it is now widely known that females report a higher psychological distress than men. It is also known that the sex-distress relationship is more pronounced amongst married women than the previously or never married group and that this has been attributed to differences in their social roles and stresses that men and women experience (Barnett, Biener, & Baruch, 1987: 144). Although it is difficult to establish the role that these social roles play in distress, it is impossible to establish whether women's stressors or feelings of helplessness and low moral came first. Being married and submitting to men as the "head of the house" female radiographers may also experience the same helpless feelings in the working situation, where radiologists are mainly men (Coomb, *et al*., 2001: 67).

Measurement of the static magnetic fields are easy, however, it is not directly related to occupational risk. Measurements of electrical fields are impossible and are not directly related to occupational risks. (Karpowicz & Gryz, 2007: 4). The effect of EMF on the psychological wellbeing of the health worker in the MRI environment is not physically possible with measurement tools. The personnel survey and the WLQ as measuring tools were mainly used to expose the stressors in the MRI environment and the influence of these stressors on the health worker's wellbeing.

4.8 Conclusion

The environmental stressors like remuneration, organisational function and task characteristics in the MRI environment do create high stress levels amongst a large percentage of health workers in this environment and may be due to the greater vulnerability and striving towards better security that women have (Barnett, Biener, & Baruch, 1987: 146).

Radiographers in the private sector MRI environment experienced high levels of stress due to stressors in the workplace but had the ability to cope with the stress and did not allow it to interfere with their personal lives and *vice versa;* this could be due to their social support outside the workplace.

This study did not show that the time spent in the MRI environment had any effect on the wellbeing of the health worker, but it was shown that the demands and amount of work done, had an effect on their wellbeing. The amount of experience the health workers had in the MRI environment might have played a part in the coping strategy of these workers.

Radiographers were frustrated with the managerial side of their occupation. They were often disappointed in the Radiography occupation and felt that their abilities and potentials were not used to the full extent.

Whether EMF had any influence on the psychological wellbeing of the health worker in the MRI environment could not be established in this study.

4.9 Reference list

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Chapter 5

5. Conclusions, recommendations and the way forward

5.1 Introduction

Magnetic resonance imaging (MRI) as an imaging modality has changed imaging specialist and clinicians' ability to visualize anatomy, pathology and physiology. As a clinical tool it has advanced rapidly over the last 20 years, and is still evolving at a rapid pace. Magnetic resonance imaging specialists and their colleagues were quick to realize the advantages of MRI scanning (Westbrook, Kaut Roth & Talbot, 2005: xi). It produces a clear anatomical cross-sectional, multi-plane, display in axial, coronal, or sagital images. Due to the non-ionic nature of the electromagnetic radiation in the MRI environment there is no evident nuclear radiation risk to the patient as well as the clinical personnel (Westbrook & Kaut, 1998: v).

Exposure limits at a MRI system are based on three exposure areas caused by associated magnetic and electromagnetic fields (EMF) (Department of Health, 1994: 1). Static magnetic fields, rapidly changing magnetic fields or extremely low magnetic fields (ELM) and the radiofrequency fields (RF) are the three areas of interest (International Commission on Non-Ionizing Radiation Protection, 1998: 495).

Static magnetic fields (B_o) are created by magnets from 0.2 T up to 3 T and even higher, and can cause changes in macromolecular orientation, membrane permeability and reduction in nerve conduction. Radio frequency fields are created by the surface (RF) coils, and can cause changes in metabolic heat production, changes in blood flow and resistive loss, and molecular vibration. The rapidly changing magnetic fields are created by three gradient coils positioned in the magnet bore in a three-dimensional way (x, y, z-axis) and can cause visual phosphenes and ventricular fibrillation. The different EMF fields are manipulated to produce different MRI pulse sequences (Westbrook & Kaut, 1998: 5); (Mathur-De Vre. 1987: 410). Spatial images are then produced through frequency encoding of the data by the different pulse sequences (MRI for Technologist, 2001: 296).

Image formation at the MRI is based on the total magnetic angular moment (also called nuclear magnetic vector or NMV) as well as the relative large magnetic dipole moment (bar magnet) of the clinical MRI active nucleus (^{1}H). Interaction between the nuclear magnetic vector and the static magnetic field (B_{0}) is the corner stone of MRI image formation. Nuclear magnetic vector excitation is created by RF pulses of similar precession frequencies as the hydrogen nuclei (Westbrook & Kaut, 1998: 3).

Three human exposure groups, to RF fields and electromagnetic fields (EMF), exist at the MRI namely, patients and volunteers, public, and clinical personnel. The public are usually only exposed to the static magnetic field, whereas, patients and volunteers are usually exposed to all three EMF fields (Department of Health: 1994: 1); (ICNIRP, 1998: 495).

Occupational exposure (exposure of clinical personnel) affects the part of the population who are generally exposed to EMF during the normal course of their particular employment (Department of Health, 2002: 1). Clinical personnel are exposed to all three fields (proved by the literature). Exposure limits for occupational exposure are more relaxed than those for public exposure (Department of Health, 2002: 1).

The ICNIRP guidelines for public, patients' and volunteers' exposure to electromagnetic fields (EMF) in South Africa were endorsed by the Department of Health and replaced the IRPA guidelines in 1998. Limits exist for all three the exposure fields in the MRI environment (Department of Health, 1994: 4).

Ongoing new developments in MRI scanning create the need for continuously monitoring of occupational, public and patient exposure to the three existing EMF fields in the MRI environment. The International EMF project group is running a health risk assessment of EMF that has to be completed in 2007 (World Health Organization, 2005: 2).

The new proposed EU Directive regarding occupational exposure to EMF includes the MRI environment. The occupational exposure limits suggested in the Directive were to be employed in April 2008 in the EU, but an outcry from the MRI community made them postpone the implementation to between 2009 and 2012 (EU Directive 2004/40, 2007: 485).

The latest developments in MRI include spectroscopy, rapid pulse sequences and functional MRI, which, means higher static magnetic, gradient and radio-frequency fields. (EU Directive 2004/40, 2007: 485).

5.2 Objectives

The aim of this study was to enable the reader to get a clear understanding of MRI image formation, regarding the hardware and some of the pulse sequences used to produce data.. Also to provide information on exposure and exposure limits to EMF and RF exposure as well as to measure the occupational exposure of health workers at selected MRI sites. Furthermore, the aim was to establish the possible influence of the MRI environment on the “psychological stature” of the clinical personnel in this environment.

5.2.1 Objectives of measurement survey

The objectives were to:

- Provide background on the MRI environment and exposure limits adopted for MRI environments.
- Measure the exposure of clinical personnel, to gradient and RF electromagnetic fields, at three MRI units in Bloemfontein, and to compare the results to the reference levels adopted by the Department of Health in South Africa, to ensure that the measured exposures fall well within the limits.

- Prove that the occupational exposure is not only restricted to static magnetic fields in real life by trying to evaluate the gradient and RF fields a health worker is subjected to during his/her daily duties in and around the bore at the MRI unit.

5.2.2 Objectives of stress survey

The objectives were to:

- Supply the reader with background information on stress and stress related problems.
- To carry out a personnel survey to establish the average time a health worker spent in this environment at the MRI units.
- To evaluate the stress levels of health workers arising from factors outside as well as inside the workplace.
- Finally, to draw a possible conclusion regarding the relationship between times spent in the MRI room and the psychological well being of the health worker.

5.3 Conclusions

5.3.1 Conclusion regarding measurements survey

In this study the measurements were separated between low and high frequency levels. Measurements in this round were based on peak or absolute values and no averaging (rms) over a period of time. After the first round measurements concern was raised that the low frequency levels might be above the threshold limits. However, the results from round two and three showed clearly that the gradient and RF exposure one metre and, up against the bore entrance was not a concern, in the low as well as in the high frequency range. During these two rounds measurement were averaged over a six minute period. Noticeable were the higher exposure levels at unit two and three, in the low frequency ranges.

Imaging data performed with the described pulse sequences, with gradient and RF fields and under patient imaging conditions, showed that the gradient and RF field occupational exposure (averaged over a six minute period) limits at the entrance to a 1.5 T MR Imager were not exceeded. Therefore, under these circumstances, no additional RF shielding will be necessary for occupational protection, especially at the 1.5 T units. However, if peak or absolute values over a short period of time (action values – magnetic flux density) were to be considered (Electromagnetic field exposure limitation and the future of MRI, 2005: 973) the occupational exposure limits would have been exceeded in the low frequency (gradient fields) range at a distance 52 cm from the patient landmark position (at the entrance to the bore) (EU Directive 2004/40, 2007: 485).

Occupational exposure and effects due to high static fields in the MRI environment have been well observed and researched. Until recently, (2005) occupational exposure due to the rapidly changing gradient fields and the RF fields in this environment did not get the attention that was expected.

5.3.2 Conclusion regarding stress survey

Unfortunately due to the nature of the questionnaire it was not possible to measure non-ionizing EMF in the MRI environment as a stressor. However, the environmental stressors, like remuneration, organisational function and task characteristics in the MRI environment created high stress levels amongst a large percentage of health workers in this environment.

Health workers in the MRI environment experienced high levels of stress due to stressors in the workplace but had the ability to cope with the stress and did not allow it to interfere with their personal lives and *vice versa*.

The time spent in the MRI environment only had an effect on the psychological well being of the health worker because of the demands and amount of work done. The age and experience of health workers in the MRI environment most probably played a part in their coping strategy.

The type of questions answered in the questionnaire could have lead to the impression that health workers were frustrated with the managerial side of their occupation. They were also often disappointed in the radiography occupation and felt that their abilities and potentials were not used to the full extent.

5.4 Reflection on work done

The research enabled the researcher to broaden her knowledge of EMF and the EMF conditions in the MRI environment, as well as to obtain a relatively good understanding of stress in the workplace.

- Knowledge was gained in the EMF and RF fields at the MRI environment, which would hopefully be of some help to other health workers in this environment.
- Pulse sequence measurements rather than examination measurements should be grouped and compared. The peaks on the graphs would have made more sense in this regard.
- The first round results gave a false positive result; therefore preliminary tests should have been in the form of a mini research project to exclude pitfalls like the six minute averaging period for the measurement results.
- The second round and third round measurements should have been done directly at the entrance of the bore, and at a point 30 cm into the bore for proper comparison with Fermlee & Vetter's (1995) study.
- Due to improper research and publication rights of the owner of the questionnaire a mistake in the dispatch of the questionnaire led to negative feedback from the respondents.
- The personal nature of some of the questions in the questionnaire had a further impact on the response of the respondents.
- The researcher managed to obtain a fair amount of experience and knowledge of work related stress, especially for radiography occupation and this knowledge can hopefully lead to better management and treatment of radiographers in South Africa.

- Although the questionnaire formed a very good basis to establish the stressors in the MRI environment, the nature of the questions were not suitable to establish whether non-ionizing EMF is a stressor.
- Measurement of the occupational exposure in the MRI environment enabled the researcher to prove that the Department of Health's adopted (from ICNIRP) exposure limits were not exceeded in the low as well as the high frequency ranges, when averaged out over the six minute period
- This study formed a basis for further measurements at different MRI sites in South Africa, especially in the wake of the new EU Directive's proposed occupational exposure limits in the gradient field range (100 Hz – 1000 Hz).

5.5 Recommendations

Recommendation on the findings of the research follows:

- Specific pulse sequence measurement and measurements on different manufacturer's MRI units for comparison could be useful to explain the higher exposure levels in the low frequency range at unit two and three.
- Initially only one research study looking into gradient and RF field occupational exposure at the MRI environment could be retrieved, which makes this section of the three fields the least researched. Therefore, more attention should be paid to the occupational exposure to gradient and RF field electromagnetic exposure in the MRI environment.
- Only three MRI units in Bloemfontein were used in the measurements and comparisons. Similar studies should be done on all the 1.5 T MRI units throughout South Africa and special attention should be given to the open magnet MRI units due to their complex pulsed waveforms of the gradient fields (IEEE committee on man and radiation (COMAR) technical information statement exposure of medical personnel to electromagnetic fields from open magnetic resonance imaging systems, 2005: 687)
- Radiography as an occupation can gain a lot by extending the WLQ Questionnaire to all sub-specialties in Radiography.

5.6 The Way forward

In view of the EU Directive's new proposed occupational exposure limits further research on occupational exposure to gradient fields should be done in South Africa. The use of ultra-high magnetic fields (2 T and higher) and ultra-fast pulse sequences in the research should also be considered. The static field limit (2 T) in the EU directive has been removed temporarily due to an outcry from the MRI community but may be brought back.

A specific questionnaire to enable more information on the effects of the EMF environment on the health worker could be useful in the future.

More papers on occupational safety in the MRI environment at radiography seminars in South Africa will also contribute to the radiographers' awareness of EMF exposure in the MRI environment.

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Appendix A: Personnel Survey

Office use

Hospital: [ ]

Instructions:
Mark the appropriate block with a X or write your answer on the line.

Number: [ ][ ]

1. Are you a Radiographer [1]

   or Registered nurse? [2]

2. How long have you been working on a MRI unit in total? ________________Years

3. Are you Male [1] or Female? [2]

4. What is your age? _____________Years

5. Are you working in a [Government] or a [Private] hospital?

6. How many weeks per month do you work at the MRI?

   [1] [2] [3] [4]

7. How often do you have to stay in the MRI room with a patient during an examination?

   ----

8. How long do you take to position a patient?

   --min

9. Have you ever been treated for depression?

   [Yes] [No]

10. Do you find work at the MRI stressful?

    [Yes] [No]

11. Why do you find it stressful?

Patient needs/demands	[ ]	Noise	[ ]
Working in subdued lighting	[ ]	Working on computer	[ ]
Demands of referring doctor	[ ]	Demands of Radiologist	[ ]

General instructions

1.1 Demography

The questionnaire consists of two parts: The first part deals with your experiences in your work environment and the second part with your circumstances. Read the specific instructions and then answer the questions following these instructions on the separate answer sheet.

1.2 Experience of work and life circumstances Questionnaire (WLQ)

The questionnaire contains questions on feelings that you have experienced in your life.

The following should be taken into account as a general guideline when answering the questions:

- Do not ponder over a question too long – read it and indicate the first reaction that comes to mind spontaneously.
- Make sure that you do not skip questions. Some questions may perhaps seem very personal, but remember that your answer will be treated **strictly confidential.**
- There are no right or wrong answers. The best results will be obtained when you indicate your feelings.

2. Specific instructions

2.1 Experience in Work (A)

This part contains questions on feelings that you perhaps experience in your work.

2.2 Circumstances (B)

This part contains questions on the nature of your circumstances in life and work environment.

Indicate below Scale A, or B how frequently a particular feeling occurs by writing down any figure from 1 to 5. Scale A or B is as follows.

1=Virtually never	2=Sometimes	3=Reasonably often	4=Very often	5=Virtually always

Example:

How often in your work do you feel..... restless? 5

Based on this example the deduction can be made that the person feels restless virtually always.

Now answer Experience of work Questions 1 – 40, and Circumstances Questions 1 - 23 on the answer sheet.

WLQ

Experience of work Scale A

	How often in your work do you feel.....	**1 Virtually never**	**2 Sometimes**	**3 Reasonable often**	**4 Very often**	**5 Virtually always**	
1	as if you are coming up against a wall and simply cannot make any progress						
2	afraid, not knowing of what exactly?						
3	uncertain (unsure, doubtful)?						
4	worried?						
5	that your views clash with those of another person?						
6	that you are experiencing conflict?						
7	bored?						
8	irritated (annoyed)?						
9	that you have no confidence in yourself?						
10	that you depend too much on the help of others?						
11	alone?						
12	that you would like to attack another person?						
13	that you merely accept things as they are?						
14	that you are disturbed whenever you work hard at something?						
15	that you are losing control of your temper?						
16	that no-one wants to support you?						
17	that your work situation compares unfavourable with those of others?						
18	Despondent (Cheerless , down)?						
		1	**2**	**3**	**4**	**5**	

	How often in your work do you feel.....	1 Virtually never	2 Sometimes	3 Reasonable often	4 Very often	5 Virtually always	
19	that you have broken some rule or other?						
20	inferior (no self-confidence, unimportant)?						
21	that someone and/or a situation is annoying you terribly?						
22	guilty?						
23	downhearted?						
24	fearful?						
25	that you can do nothing about a situation?						
26	aggressive (want to hurt someone/break something)?						
27	that you are getting sad?						
28	overburdened (too much work/responsibilities)?						
29	angry?						
30	afraid without knowing whether you are of a particular person and/or situation?						
31	not exactly sure how to act?						
32	that you are having trouble concentrating since you are worried about something?						
33	that you have no interest in the activities around you?						
34	that you need assistant constantly?						
35	that you do not wish to participate in anything?						
36	afraid of colleagues and/or supervisors?						
37	that it seems that you will never get out of this mess?						
38	dissatisfied?						
39	that you are tearful (weeping, sorrowful)?						
40	that you have too much responsibilities and too many problems?						
		1	2	3	4	5	

2.2 Circumstances and expectations

This part contains questions on the nature of your circumstances and on your expectations.

2.2.1 Circumstances

Questions are asked about the way you feel about important circumstances within and outside your work.
Indicate below Scale B how often particular circumstances occur by writing down any figure from 1 to 5. Scale B is as follows:

1=Virtually never	2=Sometimes	3=Reasonable often	4= Very often	5= Virtually always

Use this scale to answer each of the questions below.

Example

How often do you feel in your organization that........
there is not sufficient opportunity for social intercourse? 5

Based on this example the deduction can be made that the person feels that there is virtually always insufficient opportunity for social intercourse within the organization.

Note also that questions are asked about circumstances in your everyday life.

How often do you feel that...
there is not enough time for sport and recreation? 2

Based on this example the deduction can be made that the person feels that he/she only sometimes does not have time for sport and recreational activities.

Now answer question 1 – 23 (under scale B) on the answer sheet.

WLQ

Circumstances **SCALE B**

	How often do you feel in your organization.....	**1 Virtually never**	**2 Some times**	**3 Reasonably often**	**4 Very often**	**5 Virtually always**	
1	the organization as a whole does not function satisfactorily (for example owing to poor organization, little confidence in employees and or incorrect leadership styles)?						
2	you are dissatisfied about the nature (content) of your work (for example it is not interesting and challenging or it does not correspond with your aptitudes)?						
3	you encounter one or more of the following: considerable noise, high/low temperatures, odours, gasses, poor lighting, crowding of people and/or any other problems that concern your physical working conditions?						
4	situations in which you find yourself, have a negative effect on the progress and development of your career (for example your weaknesses are over-emphasized and/or you find it difficult to progress to higher posts?						
5	you find it difficult to deal with social matters (such as socializing in a group and/or maintaining good interpersonal relations)?						
6	you are dissatisfied with one or a few of the following: pension, medical and housing aid, bursaries, achievement bonuses, group and/or any other aspects of your remuneration package?						
7	you are dissatisfied with one or more of the following: working clothes, working hours, conditions of employment, communication channels with respect to grievances and complaints, rules regarding transfers, termination of employment and/or any other regulations involving personnel matters?						

	How often in your everyday life do you feel that......	1	2	3	4	5	
8	Family crises (for example death, illness and strife) have an adverse effect on your life?						
9	Financial obligations) for example the payment of a house loan) make life difficult for you?						
10	The phase of life you find yourself currently (for example middle age and /or retirement) makes life difficult for you?						
11	The general situation in the country (for example inflation) makes life exceptionally difficult for you?						
12	Rapidly changing technology poses a problem for you?						
13	Facilities (for example water laid on, electricity) at home are unfavourable?						
14	Social situations with friends and/or relatives are difficult to handle?						
15	Your status among friends and relatives sometimes causes you embarrassment?						
16	Your health does not allow you to do what you would like to do?						
17	Your background (i.e. your past life/where you come from) causes you embarrassment?						
18	Your home life is affected adversely owing to the fact that you have spend much life on activities at work?						
19	Problems with transport make life difficult for you?						
20	There is something wrong with your spiritual life?						
21	Your own views differ from those of other people?						
22	Inadequate provision is made for accommodation (for instance your housing is not suitable)?						
23	There are to few recreational facilities?						

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Expectations

Questions are asked about the extent to which you feel that your expectations with regard to your job are realised.

Indicate according to scale c how often the expectations referred to in the specific questions with regard to your job are actually realised. Scale C is as follows:

1=Virtually never	2=Sometimes	3=Reasonable often	4= Very often	5= Virtually always

Use this scale to answer each of the following questions.

Example

How often do you feel in your organization that....
you are able to talk to your colleagues? 2

Based on this example one can deduce that the respondent only sometimes feel that he/she can talk to his colleagues. Note also that, unlike in the case of the previous questions, a low score (virtually never) represent a negative trend while a high score (virtually always) represent a positive trend.

Now answer Question 1-53 (according to scale C) on the answer sheet.

Answer sheet

Expectations SCALE C

	How often do you feel in your organization that...	1 Virtually never	2 Sometimes	3 Reasonably often	4 Very often	5 Virtually always	
1	You receive recognition for what you do?						
2	Regulations regarding personnel matters (for example concerning working hours, conditions of employment and working clothes) reflect well on the organization?						
3	You can get the work assigned to you done in time?						
4	You are able to perform your tasks without having to be on your feet for long periods, having to lift heavy objects, having to be in a bent or crouching and/or in an uncomfortable position?						
5	You are able to assume full responsibility for all you do?						
6	You can perform your tasks without the nature of your work and your actions endangering other people's safety/lives and/or having a negative effect on the nature/quality of their lives?						
7	Your salary is market –related, in other words it compares well with what persons with similar qualifications and experience earn?						
8	You are able to function independently?						
9	Your necessary job equipment (for example stationary, tools, electronic and laboratory equipment) is always available?						
10	You are exposed to the necessary training courses?						
11	All your good qualities are used?						
		1	2	3	4	5	
12	You are satisfied with your promotion?						
13	Your fringe benefits (for example housing subsidy) ensure your support and security?						

14	You have status 9to feel important)?						
15	You are able to get along with your supervisor?						
16	The personnel regulations (for example regarding working clothes and working hours) satisfy your need?						
17	You can perform your task without endangering your own safety as a result of the nature of your work and the actions required from you?						
18	You are included in decision making that concerns you?						
19	You can perform your task without coming into conflict with other people or staining your relations with other as a result of the nature of your work?						
20	The instructions that you receive are in keeping with previous instructions (in other words that you do not receive contradictory instructions)?						
21	You can trust your supervisors in all circumstances?						
22	Facilities (such as toilets and kitchens) meet your needs?						
23	You have sufficient job equipment to your needs?						
24	Physical working conditions (for example lighting and temperature) are satisfactory?						
25	Your fringe benefit (for example housing subsidy) supplements your salary adequately?						
26	Your abilities and skills are developed and extended?						
27	You have sufficient knowledge and information available to do your work?						
		1	**2**	**3**	**4**	**5**	
28	Your tasks can be performed without demanding your continued and intense concentration?						
29	The true nature of the furniture and decorations in your working area creates a pleasant working environment?						

30	You have good relations with your colleagues?						
31	Your colleagues consider you successful and/or hard-working?						
32	Your salary is adequate to motivate you to work hard at all times?						
33	You are making progress?						
34	Your job equipment (For example computer, stationary and tools) is in working order?						
35	Personal regulations (for example those regarding transfers and working hours) contribute to your satisfaction?						
36	Your input is adequately remunerated?						
37	Your physical working conditions (for example lighting and office space) are adequate for the type of work that you do?						
38	You are happy with the nature of your fringe benefits (for example housing, pension medical aid)?						
39	You are able to perform your duties without time playing too big a role?						
40	The way in which things are organized contributes to your good achievements?						
41	Management believes its employees to be hardworking and/or reliable?						
42	You have enough work to keep busy?						
		1	**2**	**3**	**4**	**5**	
43	The requirement of your job correspond to with what you have to offer?						
44	The social demands made on you are of such a nature that you can easily satisfy them (maintain good relations with others)?						

45	Your good achievements are noticed?						
46	You are able to display initiative?						
47	You are able to be involved in different tasks?						
48	Your post is essential and will be retained?						
49	You find regulations regarding staff matters (for example working hours, working clothes) satisfactory?						
50	You are able to maintain good relations with your supervisor(s)?						
51	Your potential is used to the full?						
52	You are able to talk to your supervisors whenever you want to?						
53	You are able to maintain good social relationship with everybody?						

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