UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

ASSESSMENT OF LEVELS OF OCCUPATIONAL EXPOSURE TO MAGNETIC FIELDS AND ULTRAVIOLET RADIATION AMONG WELDERS IN GREATER ACCRA REGION - GHANA.

AKILAKPA SAWYERR

DEPARTMENT OF NUCLEAR SAFETY AND SECURITY

JULY 2015

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BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL RADIATION PROTECTION DEGREE.

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DECLARATION

This thesis is the result of research undertaken by Akilakpa Sawyerr in the Graduate School of Nuclear and Allied Sciences with exception of references to other people's work which has been duly acknowledged and was undertaken in accordance with guidance on supervision of thesis laid down by University of Ghana under the supervision of Dr. J. K. Amoako and Prof. J. J. Fletcher.

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ABSTRACT

Welders make up a large group of workers in Ghana and can be found in various factories and worksites engaged in welding of numerous metals, especially in the sectors of construction, manufacturing, maintenance and repair. The shielded metal arc welding (SMAW) is the most commonly employed welding method in these industries. This welding process can also produce hazardous levels of ultraviolet (UV) radiation and extremely low-frequency (ELF) magnetic fields (MFs) from the welding arc. It is therefore necessary to ensure that the UV radiation and MF exposure of the welders are within the safe exposure levels prescribed by recognized international organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) whose limits have also been adopted by the Radiation Protection Institute (RPI) in Ghana and the American Conference of Governmental Industrial Hygienists (ACGIH). The primary objective of this study was to quantify the level of UV radiation and ELF MFs exposure to welders from the arc of SMAW in factories or worksites in Ghana and compare them to guidelines set by these international bodies. Results from the measured Ultraviolet C (UVC) irradiance levels, E_{UVC} ranged between 0.16 ± 0.08 W/m^2 and 10.46 ± 1.96 W/m^2 with its corresponding permissible exposure duration, $t_{max-uvc}$ per day ranging from 5.74 s to 367.35 s. The measured Ultraviolet-A (UVA) irradiance levels, E_{UVA} ranged between 0.88 ± 0.03 W/m^2 and 23.72 ± 6.66 W/m^2 with its corresponding permissible exposure duration, $t_{max-UVA}$ per day ranging from 421.59 s to 11363.64 s. These results were compared to international guidelines by the ICNIRP and ACGIH and suggested that UV radiation coming from the SMAW process is actually hazardous to the eyes and skin of the welders since the total exposure time of the welders exceeds the permissible exposure durations. The magnetic flux densities ranged from 4.01 ± 0.72 µT to 196.46 ± 4.86 µT and the expected induced current density in the head, J_{head} and trunk, J_{trunk} of the welders ranged from 0.01 to 0.62 mA/m^2 and 0.03 to 1.23 mA/m^2 respectively. Therefore, these results are within the ICNIRP Reference Level and Basic Restriction of 500 µT and 10mA/m^2 respectively. Analysis of the responses from the questionnaire administered to the welders suggested that radiological safety practices among the welders were not adequate and most of them occasionally experienced common symptoms of health effects related to UV radiation and magnetic field exposure.

DEDICATION

This thesis is dedicated to God Almighty, my strong tower and source of refuge and to everyone who contributed towards the completion of this work.

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LIST OF ABBREVIATIONS

ACGIH - American Conference of Governmental Industrial Hygienists

AC - Alternating Current

AD - Alzheimer Disease

AWS - American Welding Society

BCC - Basal Cell Carcinoma

CIE - International Commission on Illumination

EL - Exposure Limit

ELF - Extremely Low-Frequency

EHS - Electromagnetic Hypersensitivity

EM - Electromagnetic

EMF - Electric and Magnetic Fields

EPROM - Electrically Programmable Read-Only Memory

FPC - Finite Population Correction

GAEC - Ghana Atomic Energy Commission

IARC - International Agency for Research on Cancer

ICNIRP - International Commission on Non-Ionizing Radiation Protection

ICRP - International Commission on Radiological Protection

IFA - Institute of Occupational Safety and Health of the German Social Accident Insurance

IR – Infrared

ISO – International Organization for Standardization

MF - Magnetic Fields

MM - Malignant Melanoma

NA – Not Available

NIR - Non-Ionizing Radiation

NP – New Proposal

PPE - Personal Protective Equipment

RF – Radiofrequency

RMS – Root Mean Square

RPI - Radiation Protection Institute

SCC - Squamous Cell Carcinoma

SMAW - Shielded Metal Arc Welding

TLV - Threshold Limit Value

UV - Ultraviolet

UVI - Ultraviolet Index

UVR - Ultraviolet Radiation

WAPAG - Welders and Pipe Fitters Association of Ghana

WHO – World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background

Electromagnetic radiation refers to electromagnetic waves and, especially, the associated electromagnetic energy. Electromagnetic waves are a disturbance which propagates outward from any electric charge which oscillates or is accelerated; far from the charge it consists of vibrating electric and magnetic fields which move at the speed of light and are at right angles to each other and to the direction of motion (Parker, 2003). Non-ionizing radiation (NIR) refers to any type of electromagnetic radiation that does not have sufficient energy to remove electrons from atoms. Instead of producing charged ions when passing through matter, the electromagnetic radiation has sufficient energy only for excitation that is the movement of an electron to a higher energy state. NIR encompass the long wavelength (> 100 nm), low photon energy (<12.4 eV) portion of the electromagnetic spectrum, from 1 Hz to 3 x 10^{15} Hz (Kwan-Hoong, 2009). Except for the narrow visible region, NIR cannot be perceived by any of the human senses unless its intensity is so great that it is felt as heat. The ability of NIR to penetrate the human body, the sites of absorption, and the subsequent health effects are very much frequency dependent (Kwan-Hoong, 2009).

Extremely low-frequency (ELF) magnetic fields (MFs) and Ultraviolet radiations (UV) are part of the NIR. ELF fields designate the electromagnetic fields with frequencies 0 Hz to 3000Hz. Some sources of ELF fields include power plants and substations, induction heaters, power lines and welding machines. ELF fields have an electric and a magnetic component. The electric field is created by attraction and repulsion of electric charges. The magnetic field (MF) is a force created by the movement of charges. The intensity of a magnetic field is usually measured in tesla (T). ELF MFs are particularly strong near induction furnaces and welding machines (Greenfacts, 2009).

This study focuses on magnetic fields and not electric fields because most exposures to electric and magnetic fields arise mainly from the transmission and use of electrical energy at the power frequencies of 50/60 Hz. At this extremely low frequency (ELF), magnetic fields are more challenging to guard against and special materials are required for effective protection against it. Magnetic fields are particularly strong near induction furnaces and welding machines. Some studies have shown an increased risk of various types of cancer and neurodegenerative diseases related to MF exposure (Man and Shahidan, 2008). Electric fields on the other hand are easily shielded with conductive suits and protective clothing (Pretorius et al., 2009). Also in 2002, the International Agency for Research on Cancer (IARC) classified ELF magnetic fields as “possibly carcinogenic to humans” that is Group 2B. This was based on statistical studies indicating children are more likely to develop leukaemia if their exposure to extremely low frequency magnetic fields exceeds 0.3-0.4 μT, which would be relatively strong. As far as ELF electric fields are concerned, the IARC classified them as “unclassifiable as to carcinogenicity in humans” that is Group 3, which suggests that the evidence of carcinogenicity is inadequate in humans and in experimental animals (Greenfacts, 2009). It is for this reason that the focus of this study is on 50 Hz magnetic fields.

UV is part of the electromagnetic spectrum lying between visible light and soft x-rays with frequencies from 750 THz to 300 PHz. The International Commission on Illumination (CIE) has divided the wavelengths between 400 nm and 100 nm into 3 regions:

Table 1.1

Various Regions of UV Radiations. Source: CIE (1999).

Region	Wavelength
UVA (near UV)	315 – 400 nm
UVB (middle UV)	280 – 315 nm
UVC (far UV)	100 – 280 nm

UV radiation is present in normal solar radiation and is produced by arcs and incandescent sources operating at high temperatures. Population exposures result from use of wide range of apparatus in homes, industries, places of entertainment, health clubs and scientific and medical establishments. Typical apparatus emitting ultraviolet radiation includes cosmetic and therapeutic sun lamps, equipment for disinfection, sterilization and analytical instruments (ICNIRP, 2007).

Both the general public and workers can be exposed to ELF MFs and UV radiations from different sources in the environment. The general public can be exposed to ELF MFs of less than 40 µT when passing directly below a high voltage power line. Low voltage power lines cause much lower exposure (0.5-3 µT), and buried cables virtually none. The strength of the electric and magnetic field diminishes rapidly with distance from the line. Workers in the electric power industry can be exposed to high levels of ELF MFs on the job. Extremely low frequency fields often reach or exceed the recommended limits for workers. ELF MFs are also generated by induction and light arc ovens and welding devices, and exposure of workers has to be controlled for such devices (Greenfacts, 2009).

For UV radiation, the general public is usually exposed to it from the solar radiations and devices in homes such as the incandescent and fluorescent lamps.

UV radiation is also used in a wide variety of medical and industrial processes and for cosmetic purposes. These include photocuring of inks and plastics (UVA and UVB), photoresist processes (all UV), solar simulation (all UV), cosmetic tanning (UVA and UVB), fade testing (UVA and UVB), dermatology (all UV), and dentistry (UVA). Even though the principal operating wavelengths for most of these processes are in the UVA, almost always some shorter wavelength (UVB and UVC) radiations are emitted as well. Many industrial applications including welding employ arc sources for heat or light, which also produce UV radiations as an unwanted admixture for which control measures may be necessary (ICNIRP, 2004).

Welding is a metal fabrication process in which metals are joined by the application of heat or pressure which leads to the melting of the metal at the joint and solidifies (Tenkate, 2012). Welding equipment falls into two broad categories; gas welding and electric arc welding. Only arc welding produces hazardous levels of UV radiation (ICNIRRP, 2007).

In Greater-Accra, welding is extensively used in numerous industries. These industries can be categorized into three groups; industries that use welding: (1) for maintenance and repair activity; (2) for fabrication (example manufacturers of classroom metal desks, metal gate, block making machines, metal containers, coal pot etc.), and (3) constructional works (includes companies that build tunnels, subways, structures like bridges and buildings, metal bill board and sign board construction, etc.). These industries employ thousands of welders; therefore, welders make up a large group of workers in Greater-Accra and can be found in small, medium and big-sized industries.

1.2 Statement of the Problem

The Welders and Pipe Fitters Association of Ghana (WAPAG**)** estimates that there about 3000 welders in Ghana across various industries with the number increasing steadily. About 1000 of them are estimated to be in Greater Accra Region alone. The arc welding process is the most widely used (91%) welding process by industries in Ghana. There are a number of the arc welding processes but within the arc welding group, the largest percentage of about seventy-seven percent (77.35%) of the firms use the Shielded Metal Arc Welding (SMAW) only (Adu, 2011). ELF radiations, UV, visible and IR radiation are by-products of the welding process which are emitted by the arc formed between the electrode and the base metal and pose a high risk to welders. However, no comprehensive work of assessing the extent of exposure and potential risks to the welder that could result from the ELF MFs and especially UV radiations emanating from the welding arc, some of whom do not wear Welding Gear or Personal Protective Equipment (PPE). This proposed research will demonstrate the UV and MF exposure conditions to the welders in the Greater-Accra Region and compare them to acceptable guidelines proposed by recognised international and national bodies.

1.3 Objectives of the Research

The primary objective of this study was to quantify the level of UV radiation and ELF Magnetic Fields exposure of welders to the arc of SMAW in factories and worksites in Ghana.

1.3.1 Specific Objectives

- Measurement of the MF exposure and UV levels as a result of the welding process;
- Estimation of the expected induced current densities in the head and trunk due to exposure to ELF MF from the measured magnetic flux densities.
- Estimation of the permissible/maximal exposure duration, t_{max} from the irradiance level of the UVA and UVC radiation.
- Estimation of the effective irradiance of the UV radiation from the arc of the welding process.
- Determining the level of risk to health effects due to the UV radiation and ELF MFs to welders in the industries.
- Comparing the estimated levels of exposure to the limits set by International Commission on Non-Ionizing Radiation Protection (ICNIRP) whose limits have

also been adopted by the Radiation Protection Institute (RPI) in Ghana and international standards.

1.4 Relevance and Justification of the Work

Studies show an increasing concern that several years of exposure to ELF MFs and especially UV radiations may cause or contribute to adverse health effects (Tenkate, 2012). The exposure limit (EL) has therefore been put in place to represent conditions under which it is expected that nearly all workers may be repeatedly exposed without acute adverse effects and, based upon best available evidence, without noticeable risk of delayed effects. There is growing number of industries in the country using welding processes and this has led to an increase in concern of the potential health risks that may exist to the welder. In spite of these concerns, there is very little known about the level of exposure to (Extremely low-frequency magnetic fields (ELF MFs) and especially Ultraviolet (UV) radiations to the welder. This type of study is very relevant to Ghana since there are considerable number of welders, most of whom do not wear Personal Protective Equipment (PPE). This study will demonstrate exposure conditions of ELF MFs and UV radiations to welders in the country and the need for protection. It will also provide the information needed for the assessment of other workers' occupational exposure to occupational health and safety experts, employers and employees. The results may also provide policy makers in Ghana, the needed information to define national policies and monitoring procedures of welders in the country.

1.5 Scope and Limitation

This research will be focused on the assessment of the occupational UVA and UVC exposures along with ELF MF exposures from the Shielded Metal Arc Welding (SMAW) process (since it is the most predominant welding process in Ghana), in worksites and factories in Accra and Tema. The effective exposures will be quantified based on measured data. Greater-Accra Region was selected because it is the most industrial region in Ghana, hence most welding factories can be found in this region. Additionally, it would be easily accessible and affordable. This research focuses on magnetic fields and not electric fields because most exposures to electric and magnetic fields arise mainly from the transmission and use of electrical energy at the power frequencies of 50/60 Hz. Also, the study involves only UVA and UVC exposures because the UV light meter to be used comes only with a UVC and UVA probe. At least, 60 welders in these worksites would be assessed at their highly active hours. Only welders willing to participate will be interviewed to partake in this study.

1.6 Organization of Thesis

This research work has been arranged as follows; in Chapter One, there are introductory notes on UV radiation and ELF MFs. Chapter Two will review the state of scholarly work in this area and theories guiding this thesis. Chapter Three gives detailed explanation of the methods and equipment used in the data collection. In chapter Four, data obtained from the study is analysed and presented. It also discuss the significance of the results obtained and implications in relation to other published works. Chapter Five provides conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Electromagnetic fields are a combination of invisible electric and magnetic fields of force. The electromagnetic environment consists of natural radiation and man-made electromagnetic fields that are produced either intentionally or as by-products of the use of electrical devices and systems. The natural electromagnetic environment originates from terrestrial and extraterrestrial sources such as electrical discharges in the earth's atmosphere and radiation from the sun and space. Mobile phones, power lines, welding arcs and computer screens are examples of equipment that generate electromagnetic fields (Greenfacts, 2009). Occupational exposure to EMF has received in the past years increased attention as a potential risk factor for different long-term health effects, including dementia, Alzheimer disease (AD) and childhood and adult cancer. Forms of electromagnetic energy, ordered in decreasing frequency measured in hertz (Hz), include gamma rays, X-rays, ultraviolet radiation, visible light, infrared radiation, microwaves, radiofrequencies and extremely low frequency fields. Most of the epidemiological research on occupational exposure to non-ionizing electromagnetic fields and long-term effects on health has focused on workers exposed to extremely low frequency electric and magnetic fields (ELF-EMF), with frequencies ranging between 0 and 3000 Hz, and primarily on workers with occupational exposure to power-frequency fields (50 – 60 Hz). Occupations with typical exposures to ELF-EMF include electric power installers and repairers, power plant operators, electricians, electrical and electronic equipment repairers, telephone line technicians, installers and repairers and workers operating electrical equipment such as welders, carpenters or machinists. Exposure levels for these different occupations are usually measured according to the level of the magnetic field created in units of Gauss or Tesla. Even though sources of ELF-EMF produce both electric (measured in volts per meter, V/m) and magnetic fields, research has mostly focused on potential health effects of magnetic field exposure, because some seminal epidemiological studies reported increased cancer risk associated with estimates of magnetic field exposure and because many of the studies examining biological effects of electric fields were essentially negative (Garcia et al, 2008).

Concerns with occupational exposure to electric and magnetic fields (EMF) as a potential cause of cancer were first noted in Wertheimer and Leeper's report on childhood cancer. However, until very recently, all reports of EMF and occupation continued to rely on intuitive notions of which men were likely to be exposed, supplemented at best with a formal judgment by expert panels to assign "definite," "probable," and "possible" EMF exposure (Savitz, 1995). Three recent studies have attempted to overcome some of the deficiencies in earlier work by measuring ELF field exposure at the workplace and by taking duration of work into consideration (Floderus et al. 1993; Theriault et al. 1994; Savitz and Loomis 1995). An elevated cancer risk among exposed individuals was observed, but the type of cancer of which this was true varied from study to study. Floderus et al. (1993) found a significant association with leukaemia; an association was also noted by Theriault et al. (1994), but one that was weak and not significant, and with no link was observed by Savitz and Loomis (1995). For subtypes of leukaemia there was even greater inconsistency, but numbers in the analyses were small. For tumours of nervous tissue, Floderus et al. (1993) found an excess for glioblastoma (astrocytoma III–IV), while both Theriault et al. (1994) and Savitz and Loomis (1995) found only suggestive evidence for an increase in glioma (astrocytoma I–II). If there is truly a link between occupational exposure to magnetic fields and cancer, greater consistency and stronger associations would be expected of these recent studies based on more sophisticated exposure data (ICNIRP, 1998).

Workers may be exposed to ultraviolet radiation (UVR) from the Sun and artificial sources such as specialized lamps and welding arcs. Although indoor workers are normally protected by clothing and eyewear, the same level of protection is not generally available for outdoor workers. Outdoor workers receive significant exposure to solar UVR and are thereby at increased risk of the adverse consequences associated with UVR exposure of the eyes and skin. The magnitude of the risk for the skin depends greatly upon climatological factors and personal sensitivity to UVR, the latter incorporating both the colour of the skin and degree of acclimatization, or adaptation, to UVR. However, this great range of individual susceptibility does not exist for the eye, and people of all racial types are susceptible to cataract and other environmentally related eye diseases. Occupationally exposed workers can be classified into two broad groups; those potentially highly exposed and those receiving low exposure. Highly exposed groups include outdoor workers in the construction industry, recreation workers (e.g. lifeguards), agricultural and horticultural workers, and fishermen. Occupational groups who spend a small proportion of their employment outdoors belong to the low exposure category and include schoolteachers, police officers, delivery-persons and people in the military. Outdoor workers will generally receive similar exposure as the general public as a result of recreational pursuits. When appropriate, outdoor workers should be supplied with protective items such as hats, sunglasses, protective clothing and sunscreens. For the sun-sensitive worker, the difficulties of achieving substantial reduction to solar UVR exposure to comply with the guidelines, may lead these individuals to withdraw from outdoor occupations either partially or completely. Workers in a limited number of occupations are exposed to significant levels of UVR in the indoor workplace. These include welders, staff in television studios and on theatre stages, some scientific and medical workers, and workers in the graphics, paper industry and other industries using photocuring equipment (ICNIRP, 2007). Standards and guidelines for limiting exposure and avoiding known adverse health effects have been drawn up by international and national bodies. These apply in general to characteristic parameters of the radiation field at the point in space where the individual can be or is exposed. They are based on biophysical models and on laboratory and field observations of the biological effects. The standards are limits for field parameters (e.g. to limit current density, and power density) which are designed to protect workers from potentially adverse effects of NIRs and to permit the general use of NIR under safe conditions, though there is no precise boundary between risk and no risk. The earliest recommendations for exposure limits for NIRs were established in the 1950s and 1960s for microwave and Radiofrequency radiations generated by military radars and communication equipment. Recommendations for the protection of the eyes from lasers were established in the 1970s (ICNIRP, 1998). As concern for the increasing applications of all forms of NIRs, the International Non-Ionizing Radiation Committee (INIRC) was set up in 1977. In 1992 the INIRC was renamed the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

The ICNIRP works closely with the World Health Organization (WHO) to assess health effects of NIRs and to develop international guidelines on limits to exposure and protection measures (Kwan-Hoong, 2003).

Guidelines are often presented to take account of two levels of protection:

1. Basic restrictions-based directly on established health effects
2. Reference levels - derived from measurements and/or computed predictions. These provide for practical exposure assessment to determine whether the basic restrictions are likely to be exceeded.

If a reference level is exceeded, it does not necessarily follow that the basic restriction is exceeded. However, in such cases, compliance with the basic restriction must be tested. Guidelines often differentiate between occupational exposure and general public exposure:

1. Occupational/controlled exposures - All exposure to EMF experienced by individuals in the course of performing their work. These limits also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.
2. General population/uncontrolled exposures - Apply when the general public may be exposed or when persons who may not be fully aware of the potential for exposure or cannot exercise control over it are exposed as a consequence of their employment.

Exposure guidelines for UVR have been recommended by the ICNIRP similar to earlier recommendations of the International Radiation Protection Association and the American Conference of Governmental Industrial Hygienist (ACGIH). These guidelines are readily applied to indoor exposures to artificial sources, such as welding arcs and specialized lamps. Although these guidelines for protection (ICNIRP, 2004) apply to exposure to solar UVR and to artificial sources of UVR, the challenge of meeting the guideline is far greater for outdoor workers because of the lack of control over the source. A great reduction in exposure can be achieved by a variety of protective measures. A key element in achieving the goal of reduced UVR exposure is worker awareness (ICNIRP, 2007).

2.2 Relevant Terms

Ultraviolet radiation and Extremely Low Frequency fields are part of the electromagnetic spectrum. The electromagnetic spectrum is shown in Figure 2.1. ELF fields lie between the static fields and radiofrequency (RF) radiations. UV radiation lies between the visible light radiation and the x-rays.

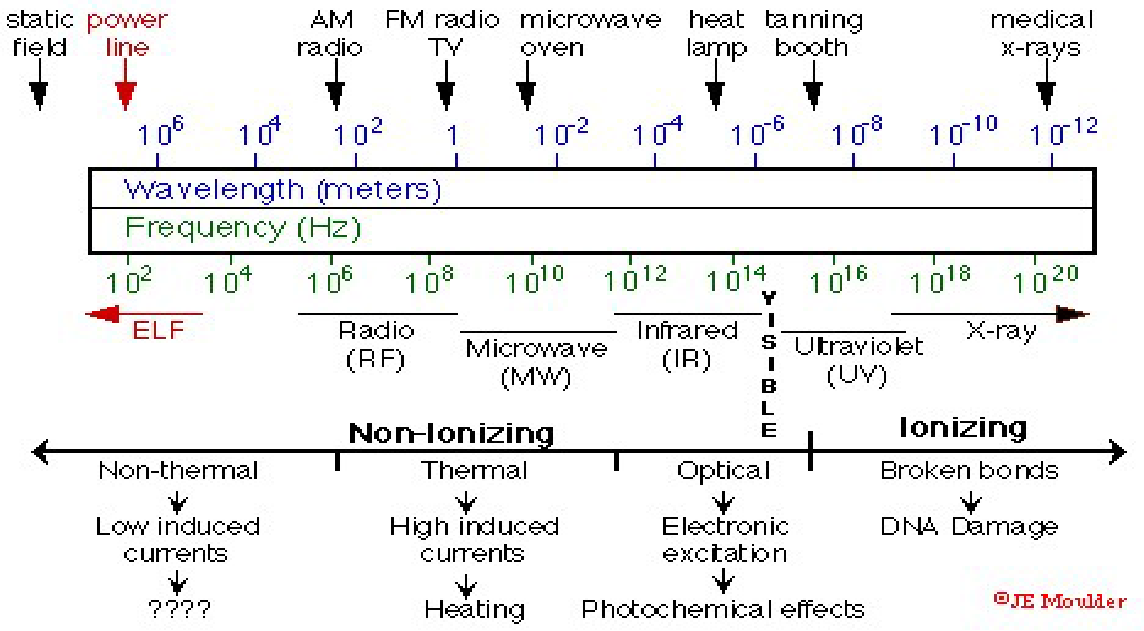

Figure 2.1. Electromagnetic Spectrum.

Source: Kwan-Hoong (2003).

Electromagnetic (EM) waves are generated by oscillating electric charges. The waves consist of oscillating electric and magnetic fields at right angles to each other and to the direction of wave propagation. Thus, electromagnetic waves are transverse waves. The waves radiated from the oscillating charges can be detected at great distances. Furthermore, electromagnetic waves carry energy and momentum and hence can exert pressure on a surface (Serway, 2004). The EM field can be viewed as the combination of an electric field and a magnetic field. Electric and magnetic fields are invisible lines of force associated with the production, transmission, and use of electric power such as those associated with high-voltage transmission lines, secondary power lines, and home wiring and lighting systems. Electric and magnetic fields also arise from the motors and heating coils found in electronic equipment. Because the use of electric power is so widespread, humans are constantly exposed to electric and magnetic fields in the form of radiations (WHO fact sheet N205, 1998).

2.2.1. Quantities and units

2.2.1.1 Basic Concepts of UVR

UV radiation, like visible radiation (light) and infrared radiation, is radiant energy. Together, these forms of radiant energy are referred to as optical radiation. Light and other forms of optical radiation are distinguished from each other by their wavelength (the distance between crests in the wave that carries the energy). In the optical spectrum, wavelengths are normally quantified in terms of nanometres in the UVR and visible spectrum and in terms of micrometres in the infrared spectrum. Light is of shorter wavelengths than infrared and UVR is of shorter wavelengths than light. The Sun and artificial light sources emit radiant energy within the optical spectrum, comprising the ultraviolet, visible and infrared. The measurement of optical radiation is referred to as radiometry. There are a number of radiometric terms that are used provided in appendix (Table A1). The radiant power in watts describes the rate of energy output of an optical source. Two dosimetric quantities quantify human exposure to UVR: irradiance and radiant exposure. The irradiance is the rate of surface exposure in watts per square meter and the radiant exposure is the radiant energy per unit area accumulated over a time interval in joules per square meter. The time integral of the irradiance is strictly termed the radiant exposure, but is sometimes expressed as exposure dose or, even more loosely, as dose. The term dose in photobiology is analogous to the term energy fluence in radiobiology and not to absorbed dose. As yet the problems of estimating the energy absorbed by critical targets in the skin remain unsolved. Although radiometric terminology is widely used in photobiology, the units chosen vary throughout the literature. For example, exposure doses may be quoted in mJ cm^{-2}. Table A2 summarizes the equivalence of these units (Diffey, 2002).

2.2.1.2 Internal EM Fields

An essential element of the research in biological effects of ELF fields is dosimetry, the determination of energy absorbed by an object exposed to the electromagnetic fields composing the ELF field. Since the energy absorbed is directly related to the internal EM fields, dosimetry is also interpreted to mean the determination of internal EM fields' (Osei, 2012). Whereas electric fields are associated with the presence of electric charge, magnetic fields result from the physical movement of electric charge (electric current). Similarly, magnetic fields can exert physical forces on electric charges but only when such charges are in motion. A magnetic field can be represented as a vector and may be specified in two ways: as a magnetic flux density, B or as magnetic field strength, H. B and H are expressed in teslas and amperes per meter, respectively. In a vacuum and in air, B and H are related by the expression:

$$B = \mu_0 H \qquad (2.1)$$

The constant of proportionality, μ_0 in equation 2.1 is termed permeability of free space (or any non-magnetic material) and has the numerical value $4\pi \times 10^{-7}$ expressed in henrys per meter. Thus, in describing a magnetic field for protection purposes, only one of the quantities B or H needs to be specified.

Limits of exposure of the ELF magnetic fields are given in terms of B, H or current density, J, where

$$J = \sigma E \qquad (2.2)$$

Where σ is the electrical conductivity of the medium.

The magnitude of the force acting on an electric charge q moving through with a speed v in a given direction perpendicular to a magnetic flux density, B is given by the expression:

$$F = q\,(v \times B) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(2.3)$$

The direction of the force is determined from the vector product of the charge, velocity and magnetic flux density and is therefore always perpendicular to the direction of the flow of the electric charge. As a result the interaction of a magnetic field with electric charge will result in a change of direction of the flow of the charge but never a change in speed. Magnetic fields therefore do not work but can facilitate the transformation of one form of energy into another. The magnetic flux density is accepted as the most relevant quantity for relating magnetic field effects. The magnetic flux is the product of the area component of the magnetic flux density normal to its surface. The Weber is the unit of magnetic flux, ϕ. A general summary of magnetic field quantities and units are provided in Table A3 (ICNIRP, 2009).

2.2.1.3 Induced Current Density

The current density induced in a circular shaped conductive object, by a uniform magnetic field derived from the Faraday's law of induction, is given by

$$J = \sigma\,.\pi\,.r.\,f\,.B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

Where

- J = the current density (A/m^2);
- σ = the conductivity of the medium taken as 0.2 S/m;
- r = the radius of the object (m);
- f = the frequency of the magnetic field, 50 Hz in this case;
- B = the magnetic flux density (µT).

Current density can be defined as the amount of current flowing through a given cross-sectional area in a given time interval. The exposure limit field for uniform fields (in the frequency range 1 Hz to 1 kHz) is an induced current density in the central nervous system of 10 mA/m^2 and is in accordance with ICNIRP. The standard further notes that the uniform electric (unperturbed) and magnetic fields correspond to the exposure limit value calculations carried out by previous studies for detailed anatomical and reference male and female body models whose dimensions and mass correspond to those of the International Commission on Radiological Protection (ICRP, 2002) which is about 200 mm for the trunk and 100 mm for the head (Pretorius et al., 2009).

2.3 Radiometric Calculations and Occupational Exposure Limits of UVR

Occupational health and safety guidelines, regulations and standards have been developed in several countries and by international organizations to protect workers and the general public from potentially hazardous exposure to UVR. Philosophical differences in the level of protection have led to some difficulties in the development of a consensus for exposure limits, since there are some who argue that UVR exposure offers more health benefit than the risks associated with skin cancer. The variability of the susceptibility to skin cancer by individuals with different skin types poses a challenge in establishing an exposure guideline for all. The two most widely used guidelines are virtually identical. Both the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2004) and the American Conference of Governmental Industrial Hygienists (ACGIH, 2004) guidelines for human exposure are based upon an envelope action spectrum that considers both ocular and skin effects. Although these guidelines were initially based on preventing any acute, detectable changes in corneal and epithelial cells (acute effects), they have also been analysed to show that the risk is extremely small, or undetectable, for delayed effects in both eye and skin for persons exposed below these recommended limits. The limits are considered ceiling values for the eye, but can obviously be exceeded for the skin – at least for most skin phototypes (ICNIRP, 2007).

The fact that the potential for harmful effects is strongly dependent on the wavelength of the UV radiation leads to ranking the various wavelengths relative to 270 nm, which is the wavelength to which the biological systems are most sensitive. The recommended 8-hour radiant exposure threshold limit value (TLV), which is applicable to both the eye and the skin, is 30 J/m^2 for 270 nm radiation. For other wavelengths, whose spectral effectiveness is less than that of 270-nm UV, the TLV is proportionately greater (Table A4) (Cember and Johnson, 2009). For heterochromatic UV radiation, the 30 J/m^2 TLV applies to the effective spectral irradiance, which is defined by (ICNIRP, 2004).

$$E_{eff} = \Sigma E_{\lambda} \times S(\lambda) \times \Delta\lambda \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

Where

E_{eff} = effective irradiance in W m^{-2};

$E\lambda$= spectral irradiance in W m^{-2} nm^{-1};

$S(\lambda)$ = relative spectral effectiveness (unitless);

$\Delta\lambda$ = bandwidth in nanometers of the calculation or measurement intervals.

In practice, the effective spectral irradiance is measured with a radiometer whose response to the different wavelengths is weighted by the relative spectral effectiveness factor, $S(\lambda)$. When the effective irradiance is known, the permissible exposure duration, t_{max}, in seconds, to the spectrally weighted UVR is calculated by:

$$t_{max}\,(s) = (30\ J\ m^{-2}) / E_{eff}\,(W\ m^{-2}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

The permissible exposure duration may also be determined using Table A5, which provides representative exposure durations corresponding to effective irradiances in W m^{-2} (ICNIRP, 2004). Table A6 also lists some permissible exposure duration for given effective irradiance levels of UVC (ACGIH, 2007).

2.4 Occupational Exposure Limits of ELF Fields

Several guidelines have been proposed by international and national agencies which cover the determination of worker exposure to electromagnetic fields, including those at ELF. The scope of these standards provide a general procedure in assessing worker exposure to electric and magnetic fields in a work place to demonstrate compliance with exposure limit and action values. The occupationally exposed population consists of adults who are generally exposed under known conditions and are trained to be aware of the potential risk and to take appropriate precautions. By contrast, the general public comprises individuals of all ages and of varying health status, and may include particularly susceptible groups or individuals. The ICNIRP guidelines deals with the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents, including electromagnetic fields. The basic restrictions of ICNIRP and the reference levels of ICNIRP for Occupational exposure have been summarized in Table A7 and Table A8.

2.5 Exposure Assessment

2.5.1 UV Radiation Exposure Assessment

The measurement or monitoring of UVR from artificial sources or from sunlight may be required for assessment of the worker’s exposure. There are a range of instruments of varying sophistication available and the choice of a particular instrument depends upon the accuracy and/or ease to which measurements are made. National networks to measure the solar UVR have been established and some provide data to the public in the form of the Global Solar UV Index (UVI) on a daily basis.

Measurements are not always required when source information or calculations are sufficient for providing the basis for exposure evaluation. A number of approaches have been developed. For example, UV sources can be grouped into different risk categories (as provided by the manufacturer), such as those developed by the CIE for lamp risk groups where protective measures are keyed to the risk group. An “exempt” category of sources require no further hazard assessment or protective measures, and the protective measures for Risk-Group 1 are only be necessary for prolonged exposures. A number of publications provide typical UV emission characteristics of commercial UVR sources (McKinley et al., 1988). Detailed measurements are then only required when the exposure is at or near exposure limits. If the exposure is clearly very low and well below limits, no action is required. If the source of UVR can be encapsulated so that no exposure occurs outside the encapsulation or shielding, an exposure assessment is also not needed. If the exposures are clearly far above the occupational exposure limits, as in many welding operations, strict protective measures are required. In this case, an exact determination of exposure may not be required for the welder or an associate (helper) when properly protected; however, measurements may be necessary for other unprotected persons further away from the source.

2.5.1.1.1 Measurement Aims

Measurements are most likely to be of value when assessing indoor exposures to UV sources where the characteristics of the sources are generally fixed and work practices are repetitive. On the other hand, the constantly changing position of the sun with time of day and season and changing meteorological conditions limits the usefulness of site-specific measurements for predictive risk assessment in most outdoor occupations. However, they may be used to demonstrate current exposure conditions to workers and the need for protection.

2.5.1.1.2 Measurement of Indoor Workers´ Exposure

If a worker is exposed to potentially hazardous levels of UVR at the workplace, adequate protective measures are necessary. There may be a value in characterizing the exposure level through calculations or measurements. The measurement result is compared with the exposure limit value. When the exposure limit is exceeded, protective measures such as shielding of the source or the use of personal protection have to be applied.

When carrying out such evaluations it is frequently possible to reduce or eliminate some measurements by estimating worst-case exposures. This may be possible from manufacturer’s data or a single emission measurement at the source. If, by choosing the maximum value, the result does not exceed the exposure limit, no further assessment is required. However, care has to be taken when analysing a source for a specific work task. Unlike some workplace exposures, the UV exposure level can vary drastically depending on the behaviour of the worker. For instance in welding, the UV emission can strongly vary with the welding process and materials used.

2.5.1.1.3 Measurement by Consultants Concerning an Accident or a Disease

If an accident has occurred or a disease has developed in an indoor worker, often an expert consultation is needed. The expert has to assess if there is a connection between the workers exposure and the accident or the disease. If measurements are needed, it is frequently not possible to reduce the measurement expenditure by choosing maximum values for unknown parameters. All parameters need to be determined as exactly as possible, even if it may be very difficult.

2.5.1.1.4 Other Measurements

In addition to work-site measurements, laboratory measurements may be made for the purposes of:

i. Determination of the emission and spectrum of a radiation source (for example to determine the Risk Group of the lamp)

ii. Determination of the attenuation effect of a radiation screen, barrier or filter including eye protection

iii. Determination of reflective characteristics of some building materials

2.5.1.2 Measurement Devices

Depending on the quantity that is to be measured and the required accuracy, different measurement techniques and equipment can be used. There are two aspects which are relevant for safety related measurements of UV radiation and they are accounted for in the different measurement devices in different ways: the summation (integration) over the spectral range including some weighting with an action spectrum and the summation (integration) of the exposure time.

2.5.1.2.1 Spectroradiometers

Spectroradiometry is the technique for measuring the spectral irradiance (measurement showing spectral shape and power) that is produced by a source of optical radiation at a given position relative to the source. The three basic features of a spectrometer system are the: (1) input optics, designed to conduct the radiation from the source into the (2) monochromator, which disperses the radiation onto a (3) detector. For accurate measurements of UVR, it is necessary to use a double monochromator. Single monochromators may suffer from stray light problems which result in erroneous measurement. Particularly problematic is the use of diode arrays to measure UVR. Double monochromators are expensive instruments but are the most accurate and precise tools. They are not needed for routine safety surveys and monitoring, but rather in laboratories for lamp risk group determination or for research projects or experts assessments on work place safety.

2.5.1.2.2 Broadband UV Radiometers

For practical hazard evaluations, broad-band integrating UV safety meters with detectors that mimic the ICNIRP UV-hazard action spectra are the most useful instruments. These safety meters basically consist of a photodetector with spectral filters and an electronic readout unit. They are generally calibrated to read directly in effective UV irradiance or in effective radiant exposure. Some even indicate permissible exposure duration t_{max}. To get a detector that truly responds to the required action spectrum such as S (λ) or to only be sensitive to the UVA in an unweighted fashion is very difficult. Often, the detector can only approximate the required action spectrum, in which case the measured effective value can in some cases be seriously erroneous. The detector may be calibrated more accurately for a few representative sources such as xenon arcs, germicidal lamps or tungsten-halogen lamps. Similar instruments originally designed as erythemal biometers that follow the spectral response of the CIE erythemal effectiveness curve also respond mainly to UVB/C radiation with a variable response in the UVA. These can also be calibrated with some degree of accuracy for a few representative sources in terms of ICNIRP effective irradiance. However, UV meters designed to mimic action spectra for germicidal applications or photocuring applications will generally have such strongly different spectral response that they would not be useful for hazard evaluation.

2.5.1.2.2 Personal Dosimeters

In recent years, broadband safety meters have become available and are normally small enough to be used as personal dosimeters, i.e. fixed to a person's clothing or hat and worn during the workday. These personal safety meters either add up the dose continuously or record the time varying irradiance to be read out after the working day. They may even provide audible warning or flashing lights for the worker to avoid exposure. Some are designed specifically for protecting against overexposure to solar UVR mimicking the CIE erythemal effectiveness curve and some may require the input of skin sensitivity. The accuracy and the price vary widely for broadband safety meters, mainly depending on the quality of the spectral responsivity of the detector. Besides electronic instruments, a number of film dosimeters have been developed. These are based on photo-induced changes of chemical or biological materials. The magnitude of the change is related to the effective UVR dose. They accumulate the effect over a certain time and are subsequently analysed in a laboratory. Since the level of exposure is determined with some delay, they cannot be used as a direct warning device against overexposure. These dosimeters may be used for occupational safety assessments where the exposure level is assessed for a specific source and task to decide on the need for protective measures or more accurate assessment. The advantage of these dosimeters when compared to electronic instruments is that they are very light and can be worn without impeding the worker. However, the spectral response only roughly follows erythemal effectiveness curve or the ICNIRP hazard action spectrum. Film dosimeters have been most extensively optimized for solar UVR measurements weighted with the erythemal effectiveness curve. For the measurement of UVR emitted by other sources, the dosimeters would need to be calibrated specifically according to the spectral distribution of the source to be measured and the action spectrum to be used.

2.5.1.3 Procedure for Detailed Indoor Exposure Assessment

For each exposure assessment, a detailed plan should be prepared and should consider the following:

i. The target of the assessment and the basis of the assessment, e.g. the exposure limit values to be applied

ii. Collect available manufacturer’s data on the source, filters and on possible changes made by the user

iii. The initial work task analysis and worst case exposure assessment

iv. Determine whether site measurements are necessary and what uncertainty is allowed on the limits

v. The equipment used and the measurement procedures, or data source if calculations are used

vi. Make photographs or videos of the workplace and, if a more detailed work task analysis is required, the exposure situations and the measurement points

vii. Number of times to repeat any measurements and the exposure assessment

viii. All other necessary details concerning the workplace, the exposed people, the measurement operator, the date and place of the measurement.

2.5.1.3.1 Work Task Analysis

Before initiating calculations of exposures or measurements, one should carry out a detailed work task analysis, i.e. a careful examination of all steps undertaken at work of the person whose exposure is to be determined. Inquire if acute effects such as erythema, photokerato conjunctivitis have occurred. If there are no acute effects reported, this should not be misinterpreted to preclude a potential hazard of exceeding the exposure limits. However, the occurrence of acute effects might indicate special circumstances of increased risk which might not exist during routine operations. An initial worst-case assessment (in terms of exposure duration and distance) may show that further measurements and/or calculations are not required.

For a detailed analysis, all points (distances and positions relative to the source) at which the person remains during the work and the potential body sites of exposure are noted. Then, the duration of exposure at each location is determined. Record the application or non-application of protective measures, such as the use of personal protective equipment. Finally, determine the total exposure duration within a day and even during a year.

2.5.1.3.2 Orientation of the Detector

For the determination of a realistic level of exposure, it is important that the detector is positioned where exposure is expected to occur. The orientation of the detector (the direction of the normal of the detector surface) also should be chosen as realistically as possible.

2.5.1.3.3 Motion of the Worker

Workers often do not remain at one given distance and orientation to the source. Therefore, the time-integrated personal irradiance caused by a fixed radiation source will vary from point to point and will depend on the direction of view of the worker. A practical way of assessing the resulting total radiant exposure of a worker is to determine the effective irradiance at different distances from the source and directions of view, and estimating exposure durations for the respective distances. The local exposure dose is determined by multiplication of the irradiance level and corresponding exposure duration. The total radiant exposure is the sum of all local exposure doses.

Alternatively it may be desirable to attach a personal dosimeter to the worker. Most commercially available dosimeters do not meet all the requirements of spectral response, sensitivity and angular response. Another problem relates to the direction of emission from the source and from reflections if present. A moving worker will always change position in relation to the source and it may be unclear where to fix the dosimeter: on the chest, the back, a shoulder or on several anatomical sites. Thus, current dosimeters should not be relied upon as the sole source of measurement but may provide relevant information.

2.5.1.4 Relevant Properties of Measurement Systems

For the measurement of exposure levels to be compared to the exposure limits, geometrical aspects of the exposure must be considered. The following properties of measurement systems are relevant for obtaining valid data to be compared to exposure limits; field of view, cosine dependence and spectral sensitivity.

2.5.1.4.1 Field of View

The field of view of the detector (the “part” of the world which is seen by the detector) should be 180° for measurements to be used for skin hazard assessment and should be limited to 80° (± 40° from the normal) for measurements to be used for eye hazard assessment. The field of view for eye evaluations does not play a role if the source is smaller than the field of view of the detector. If the source is larger than 80° and the field of view of the instrument is not limited, then the exposure level is overestimated. Due to the difference of the field of view for measurements for skin or eye exposure, for sources which subtend an angle larger than 80° at the distance of evaluation, the exposure level which is compared to the exposure limit will be different (less for the eye than for the skin). Therefore, although the UVR exposure limit is the same, since the exposure level for a given source and exposure distance, might be different, the exposure of the eye might be below the exposure limit while the exposure of the skin might be above the exposure limit.

2.5.1.4.2 Cosine Dependence

The dependence of the sensitivity of the detector on the angle of incidence of the radiation follows a cosine dependence. Thus the detector mimics the directional sensitivity of the human skin, which is assumed to be a plane surface. However, this is relevant only for sources which are extended, i.e. non-point sources. The larger the source is, the more important it is that the detector features a good cosine response even up to larger angles off the normal.

2.5.1.4.3 Spectral Sensitivity

To meet the criterion for a UVB radiometer, the sensor should have a uniform spectral response from 280 to 315 nm (the UVB waveband) with zero response outside this interval. In other words, the electrical output from the sensor should depend only on the total power within the UVB waveband received by the sensor and not on how the power is distributed with respect to wavelength. In practice no such sensor exists with this ideal spectral response (neither does one exist that measure UVA or UVC correctly for that matter). All radiometers that combine a photodetector with an optical filter have a non-uniform spectral sensitivity within their normal spectral band. Consequently it is important that narrowband radiometers are calibrated spectroradiometrically for every type of UV source (where type refers to the spectral power distribution) that it is proposed to measure.

2.5.2 ELF Exposure Assessment

2.5.2.1 External Dosimetry

External dosimetry deals with characterization of static and ELF electric and magnetic fields that define exposure in epidemiological and experimental studies. As with other agents, the timing and duration of exposure are important parameters, but the situation is more complex in the case of ELF fields. The difficulty arises, not from the lack of ability to specify complete and unique characteristics for any given field, but rather from the large number of parameters requiring evaluation, and, more importantly, the inability to identify the critical parameters for biological interactions (IARC, 2002).

Several exposure characteristics, also called metrics that may be of biological significance have been identified (Morgan & Nair, 1992; Valberg, 1995). These include:

i. Intensity (strength) or the corresponding flux density, root mean square, average or peak value of the exposure field; or a function of the field strength such as field-squared;
ii. Duration of exposure at a given intensity;
iii. Time (e.g. daytime versus night-time);
iv. Single versus repeated exposure;
v. Frequency spectrum of the field; single frequency, harmonic content, intermittency, transients;
vi. Spatial field characteristics: orientation, polarization, spatial homogeneity (gradients);
vii. Single field exposure, e.g. ELF magnetic versus combined electric and magnetic field components, and possibly their mutual orientation;
viii. Simultaneous exposure to a static (including geomagnetic field) and ELF field, with a consideration of their mutual orientation;

ix. Exposure to ELF fields in conjunction with other agents, e.g. chemicals.

The overall exposure of a biological system to ELF fields can be a function of the parameters described above (Valberg, 1995).

2.5.2.1.1 Laboratory Exposure Systems

Laboratory exposure systems have the advantage that they can be designed to expose the subjects to fields of specific interest and the fields created are measurable and controllable. Laboratory exposure systems for studying the biological effects of electric and magnetic fields are readily classified as in vivo or in vitro. Most studies of exposure in vivo have been in animals; few have involved humans. In-vitro studies of exposure are conducted on isolated tissues or cultured cells of human or animal origin. One reason for studying the effects of very strong fields is the expectation that internal dose is capable of being biologically scaled. For this reason, many laboratory experiments have been performed at field strengths much higher than those normally measured in residential and occupational settings. This approach is usually used on the assumption that the amplitude of biological effects increases with field strength up to the maxima set in exposure guidelines, and the physical limitations of the exposure system.

2.5.2.1.1.1 In-Vivo Exposure Systems

Many in-vivo studies have used magnetostatic fields. Both iron-core electromagnets and permanent magnets are routinely used in such studies (ICNIRP, 1998).

A magnetic field in an animal-exposure experiment is produced by current flowing through an arrangement of coils. The apparatus can vary from a simple set of two Helmholtz coils (preferably square or rectangular to fit with the geometry of cages), to an arrangement of four coils to more complicated coil systems. The main objectives in designing apparatus for exposure to magnetic fields are firstly, to ensure the maximal uniformity of the field within as much as possible of the volume encompassed by the coils, and secondly, to minimize the stray fields outside the coils, so that sham-exposure apparatus can be placed in the same room. Limiting the stray fields is a challenge, as shielding magnetic fields is much more complex than shielding electric fields. Non-magnetic metal shields only slightly reduce the field strength. Only properly designed multilayer shielding enclosures made of high-permeability materials are effective.

Likely artefacts associated with magnetic-field-exposure systems include heating, vibrations and audible or high-frequency (non-audible to humans) noise. These factors can be minimized (although not entirely eliminated) with careful design and construction, which can be costly. The most economical and reliable way of overcoming these problems is through essentially identical design and construction of the field- and sham-exposure systems except for the current direction in bifilarly wound coils. This solution provides for the same heating of both the control and exposed systems. Vibration and noise are usually not exactly the same but are similar. To limit the vibration and noise, the coil windings should be restricted mechanically in their motion (IARC, 2002).

2.5.2.1.1.2 In-Vitro Exposure Systems

The International Agency for Research on Cancer states that cell and tissue cultures can be exposed to the electric field produced between parallel plates in the same way that animals are exposed. In practice, this procedure is hardly ever used, because the electric fields in the in-vitro preparation produced this way are very weak, even for strong applied fields. For instance, an externally applied field of 10 kV/m at 60 Hz results in only a fraction of a volt per meter in the culture. Furthermore, the field strength is usually not uniform throughout the culture, unless the culture is thin and is placed perpendicular or parallel to the field. A practical solution involves the placement of appropriate electrodes in the cultures. Agar or other media bridges can be used to eliminate the problem of electrode contamination. A comprehensive review of in-vitro exposure systems has recently been published.

In in-vitro studies, special attention is paid to ambient levels of 50 or 60 Hz and to other magnetic fields. Magnetic flux densities from incubators unmodified for bioeffect studies may have background gradients of magnetic fields ranging from a few tenths of a microtesla to approximately one hundred microtesla. Similarly, some other laboratory equipment with an electric motor might expose biological cells to high, but unaccounted for, magnetic flux densities. Specially designed in-vitro systems can avoid these problems. Exposure to magnetic fields that is unaccounted for or is at an incorrect level, as well as the critical influence of temperature and carbon dioxide concentration on some cell preparations, can lead to unreliable findings in laboratory experiments (Misakian et al., 1993).

2.5.2.2 Instrumentation for Assessing Magnetic Fields

Measurements of magnetic fields are used to characterize emissions from sources and exposure of persons or experimental subjects. The mechanisms that define internal doses of ELF magnetic fields and relate them to biological effects are not precisely known with the exception of the well-studied neurostimulatory effects of magnetic fields. Therefore, it is important that investigators recognize the possible absence of a link between selected measured fields and a biological indicator of dose. The instrument best suited to the purpose of the investigation are therefore selected carefully. Investigators evaluate the instrument and its proposed use before starting a study and calibrate it at appropriate intervals thereafter.

2.5.2.2.1 Survey Meters

Magnetic fields can be measured with a survey meter, fixed location monitor or a wearable field meter. The simplest meter measures the voltage induced in a coil of wire. The voltage induced by a given field increases with the addition of turns of wire or of a ferromagnetic core. To prevent interference from electric fields, the magnetic field probe must be shielded. If the meter is used for surveys or personal exposure measurements, frequencies lower than approximately 30 Hz must be filtered out to remove voltages induced in the probe by the motion of the meter in the earth’s magnetic field.

2.5.2.2.2 Personal Exposure Meters for Measuring Magnetic Fields

Wearable meters for measuring magnetic fields have facilitated assessments of the personal exposure of individuals as they go about daily activities at home, school and work. A few instruments can also record electric-field measurements. The available personal exposure meters can integrate field readings in single or multiple data registers over the course of a measurement period. For a single-channel device, the result is a single value representing the integrated exposure over time in μT·h or (kV/m) h. Some meters classify and accumulate exposures into defined intensity ‘bins’. Other personal exposure meters collect samples at fixed intervals and store the measurements in computer memory for subsequent downloading and analysis (IARC, 2002).

2.6 The Welding Processes and Their Sub-divisions

Welding equipment generally falls into two broad categories; gas welding and electric arc welding. Only arc welding produces hazardous levels of UV radiation, the quality and quantity of which depends primarily on the arc current, shielding gas and the metals being welded. For example, aluminium welding produces much more UVR than the arc welding of steel for the same arc current but the official listing of welding processes and their grouping is shown by Figure 2.2; courtesy the American Welding Society (AWS) Master Chart of Welding and Allied Processes. The AWS definition for a welding process is "a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler material." AWS has grouped the processes together according to the "mode of energy transfer" as the primary consideration.

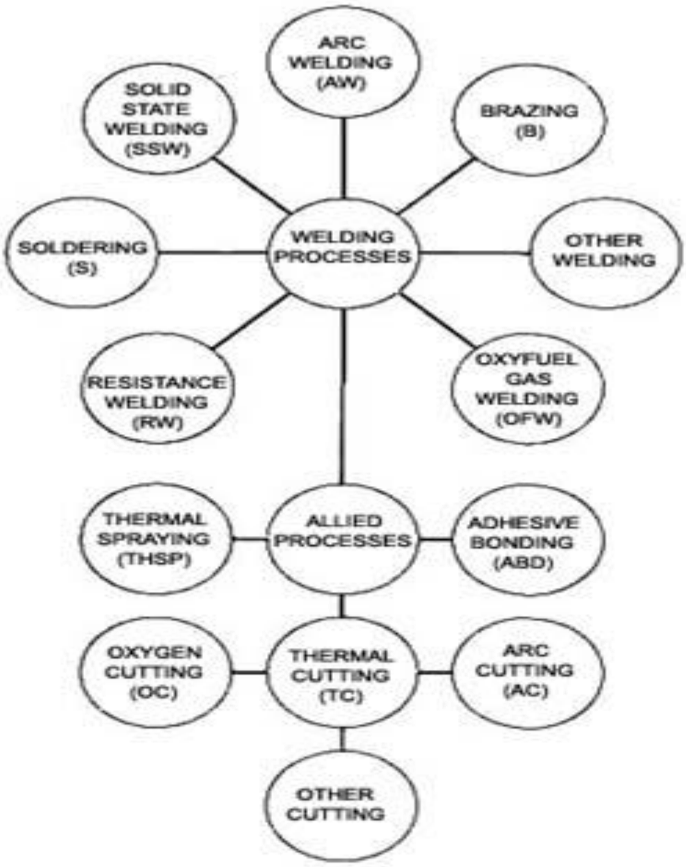

Figure 2.2. AWS master chart of welding and allied processes.

Source: (http://www.arconweld.com/Why-Arcon/Welding-Processes)

Welders are the largest single occupational group exposed to hazardous artificial sources of ELF magnetic fields and especially UV radiations. It has been estimated that there may be half a million welders in the USA alone and over 3000 in Ghana (Adu, 2011).

UVR irradiance levels from welding arcs - and any open-arc processes - are generally very high and the permissible exposure duration before exceeding the ICNIRP guidelines is less than minute. Thus, it is not surprising that most welders at some time or other have experienced welder's flash (photokerato conjunctivitis) and erythema. Studies of worker exposure from welding arcs have shown that the exposure at the outer clothing surface of welders can exceed daily occupational exposure limits to the unprotected eye and skin by several thousand-fold, and in some cases the UV levels on the inner surface of welders' helmets are such that additional eye protection have been advised (Tenkate & Collins, 1997). Even ambient UV levels in the non-welding areas of factories where welding equipment is used can exceed occupational exposure limits within several minutes or hours. Therefore, not only does the welder need to be protected but also helpers (by personal protective equipment) and non-involved staff in the surrounding of the welding workplace (by appropriate shielding of the welding work place). Also care needs to be taken when there are other welding arcs in the vicinity. Welders flash may occur from adjacent arcs when a face shield is temporarily not in place, for instance while inspecting the weld or manipulating the work-piece (ICNIRP, 2007).

2.6.1 The Arc-Welding Processes: Consumable Electrode

In arc welding, the heat required is obtained through electrical energy. Through the use of a consumable or non-consumable electrode (rod or wire), an arc is produced between the tip of the electrode and the parts to be welded, using ac or dc power supplies. The arc welding process is the most widely used (91%) welding process by industries in Ghana. Within the arc welding group, the largest percentage of about seventy-seven percent (77.35%) of the firms uses the shielded metal arc welding (SMAW) only (Adu, 2011).

2.6.1.1 Shielded Metal Arc-Welding Process Overview

Shielded metal arc welding (SMAW) or manual metal arc (MMA) welding is a process that uses covered electrode. The electrodes are in the shape of thin, long sticks; hence, this process is also known as stick welding.

An electric arc is formed when an electric current passes between two electrodes separated by a short distance from each other. In arc welding, using direct-current, one electrode is the welding rod or wire, while the other is the plate to be welded. The electrode and plate are connected to the supply, one to the positive pole and one to the negative pole. The arc is started by momentarily touching the electrode on to the plate and then withdrawing it to about 3 to 4mm from the plate. When the electrode touches the plate, current flows, and as it is withdrawn from the plate the current continues to flow in the form of a 'spark' across the very small gap first formed. This causes the air gap to become ionized or made conducting, and as a result the current is able to flow across the gap, even when it is quite wide, in the form of an arc. The electrode must always be touched on to the plate before the arc can be started, since the smallest air gap will not conduct a current (at the voltages used in welding) unless the air gap is first ionized or made conducting. The thicker the electrode used, the more heat is required to melt it, and thus the more current is required: The welding current may vary from 20 to 600A in manual metal arc welding (Davies, 2004).

When alternating current is used, heat is developed equally at plate and rod, since the electrode and plate are changing polarity at the frequency of the supply. If a bare wire is used as the electrode it is found that the arc is difficult to control, the arc stream wandering hither and thither over the molten pool. The globules are then being exposed to the atmosphere in their travel from the rod to the pool and absorption of oxygen and nitrogen takes place even when a short arc is held. The result is that the weld tends to be porous and brittle. The arc can be rendered easy to control and the absorption of atmospheric gases reduced to a minimum by 'shielding' the arc. This is done by the flux covering the electrode, and as a result gases such as hydrogen and carbon dioxide are released from the covering as it melts and form an envelope around the arc and molten pool, excluding the atmosphere with its harmful effects on the weld metal. Under the heat of the arc chemical compounds in the electrode covering also react to form a slag which is liquid and lighter than the molten metal. It rises to the surface, cools and solidifies, forming a protective covering over the hot metal while cooling and protecting it from atmospheric effects, and also slows down the cooling rate of the weld. Some slags are self-removing while others have to be lightly chipped.

Figure 2.3 shows the essential components of the shielded metal arc welding circuit: Source of energy, welding plant or set, welding lead, electrode holder, electrode, the arc and work (metal to be welded).

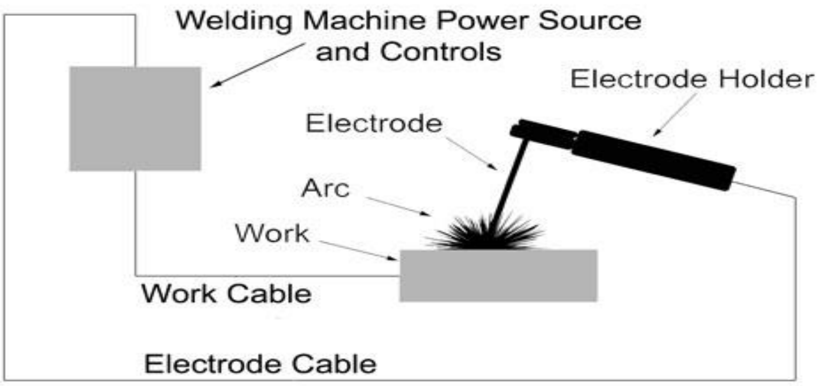

Figure 2.3. The SMAW circuit.

Source: http://www.bikernet.com (2015).

The welding set must be capable of supplying a continuous current, which can be adjusted to suit various sizes of electrode, at an open circuit voltage of between 50V and 100V. There are a number of types available, which vary in their energy requirement, type and amount of current delivered, open circuit voltage, duty cycle, and cooling mechanism (Pritchard, 2001).

2.6.2 The Arc-Welding Processes: Non-Consumable Electrode

Unlike the arc-welding processes that use consumable electrodes described in the previous section, non-consumable-electrode arc-welding processes typically use a tungsten electrode. As one pole of the arc, the electrode generates the heat required for welding; a shielding gas is supplied from an external source (Gourd, 1995).

2.6.3 Filler Metals and Materials for Welding

There are many types of materials used to produce welds. These welding materials are generally categorized under the term filler metals**,** defined as "the metal to be added in making a welded, brazed, or soldered joint." The filler metals are used or consumed and become a part of the finished weld. The definition has been expanded and now includes electrodes normally considered non-consumable such as tungsten and carbon electrodes, fluxes for brazing, submerged arc welding, electroslag welding, etc. Filler metals can be classified into four basic categories. These are: Covered electrodes, Solid (bare) electrode wire or rod, Fabricated (tubular or cored) electrode wire, Fluxes for welding. Included in materials for welding, but a material that cannot be considered a filler metal, would be the gases used in welding. The gases include oxygen and fuel gases for gas welding and cutting and shielding gases for the gas shielded arc welding processes (Adu, 2011).

2.6.4 Welding Gear and Personal Protective Equipment (PPE)

There are varieties of PPE that are important to safety. Some of these PPE are as follows:

1. Gloves; are used to protect the hands from sparks, burns and electric shock.
2. Hats or doo rags; a welding hat or doo rag is worn to absorb sweat and resist sparks from the welding work. Most hats protect the ears as well as the head.
3. Helmets; a welding helmet protects the head and face from sparks and provides protection to the eyes from the flash and intense heat of the flame. It also protects the welder from breathing in the fumes. The cover plate on the outside has to be made of plastic that is polycarbonate because this is the only type of plastic that will protect from UV rays. The helmet has a lens filter that is glass with a filler that protects the light from going through to the eyes.
4. Protective clothing; should be of a design with inside seams which will not be burned by spatter, and which reduces the possibility of snagging on edges of the

work. It should also be reasonably comfortable to wear and not restricting movement too much, and compatible with giving adequate protection. The welder's normal work wear, for example coveralls, trousers, shirts and jackets, should be of material which will not burn or melt easily. Woolen clothing is more fire resistant than cotton.

5. Hand shield; the hand-shield protects one hand as well as the face but gives the least protection to the head.
6. Goggles; goggles can protect the eyes from the heat and light radiated by the work.
7. Dust respirator; if the fume from welding operations cannot be removed from the atmosphere before it reaches the welder, an alternative is to filter it from the air breathed with a dust respirator (Balchin and Castner, 1993).

2.7 Occupational Exposure to Extremely Low Frequency Radiations at Selected Workshops

Exposures to ELF electric fields and magnetic fields generated by arc welding machines have been assessed. Assessments were done on the range of exposures encountered by welders in some workshops (Annor-Nyarko & Essandoh, 2009). ELF fields' measurement was taken with the EMfields professional ELF monitor. It measures Electromagnetic Fields produced near power lines, substations and transformers, building wiring and electrical appliances. It provides digital precision with a wide measurement range, and includes a sounder for an audible indication of field intensity/strength.

Measurement of electric and magnetic fields were taken from 30 different arc welding machines in some selected workshops. Before measurements were taken, the arc welding machine was turned on and other electrical appliances close to it were turned off and taken out from the vicinity. The knob on the side of the instrument was shifted either to the electric or magnetic position before readings were taken. Measurements were taken at places where different types of arc welding machines are used in their operations and also at places where workers were exposed to radiations of extremely low frequency. Values of electric fields and magnetic fields obtained from measurements taken were in the range of 25-561V/m and 28.72 - 34.55 μT respectively. Comparing these values with the reference level set by ICNIRP, it was deduced that the welders of the workshops visited were safe from such extremely low frequency exposures (Annor-Nyarko & Essandoh, 2009).

2.7.1 Measurement of Magnetic Field from Distribution Substation in Ghana

Magnetic field measurements were performed at four distribution substations in Ghana. Measurement of the occupational exposure took place inside the substations (Akomaning-Adofo, 2010).

The maximum flux densities reported for occupationally exposed workers were: 18.98 μT ± 0.15 μT for Volta, 19.77 μT ± 0.12 μT for New Tema, 19.78 μT ± 0.17 μT for Achimota and 19.54 μT ± 0.19 μT for Mallam substations. These values are below the reference level set by International Commission on Non-Ionizing Radiation Protection. However they are above data from similar works done in Europe.

2.7.2 Evaluation and Monitoring of UVR in Shield Metal Arc Welding Processing

No comprehensive work has been done on assessing the ultraviolet radiation in the Shielded Metal Arc Welding process in Ghana. However, studies have been conducted in other parts of the world. In Taiwan, Chiung-yu, Hung-hsin, Cheng-ping, Jeng-yueh and Cheng-hang (2007) established a broad approach to monitoring UVR magnitude from Shielded Metal Arc Welding (SMAW) processing and quantified the effective exposure based on measured data. The irradiances from welding UVR were calculated with biological effective parameter ($S\lambda$) for human exposure assessment. The spectral weighting function for UVR measurement and evaluation followed the American Conference of Governmental Industrial Hygienists (ACGIH) guidelines. Arc welding processing scatters bright light with UVR emission over the full UV spectrum (UVA, UVB, and UVC). The worst case of effective irradiance from a 50 cm distance arc spot with a 200 A electric current and an electrode E6011 (4 mm) is 311.0 µW cm^{-2} and has the maximum allowance time (t_{max}) of 9.6 s. Protective materials like glove and mask, were demonstrated to protect workers from hazardous UVR exposure.

It was recommended that welders should be fitted with appropriate protective materials for protection from UVR emission hazards.

2.8 Review of Studies on Health and Biological Effects of UVR and ELF MF

2.8.1 Biological and Health Effects of UVR

In photobiology, the concept of a biologically effective dose is of critical importance, since not all wavelengths of UVR are equally effective in producing a biological effect. When considering health effects of UVR, the effective exposure rate (i.e., irradiance) E_{eff} (or the exposure summed over time, i.e., the effective radiant exposure H_{eff}) is calculated by spectral weighting as follows: the spectral irradiance E λ at the surface of the exposed biological tissue is mathematically weighted against the action spectrum of the biological response which is a function of the wavelength across the relevant spectrum.

Ultraviolet radiation is absorbed to varying degrees by all constituents of living organisms and so, in the epidermis by nucleic acids (DNA, RNA), proteins, and chromophores dispersed in the cytosol and membranes. Interactions with biomolecules result in absorption of specific UV wavelengths by corresponding molecular structures and result in production of excited state of the biomolecules. The primary product generated by UV absorption is a reactive species in an excited state or free radical. The peak absorption of DNA occurs at around 260 nm with a sharp drop in absorption through the UVB range (several orders of magnitude). No absorption is detected for wavelengths longer than 325 nm. Exposure of the eye to UVR is associated with a variety of disorders, including damage to the eyelids, cornea, lens and retina. The eye, situated behind the eye lids, is deeply buried in a groove on the face. This anatomical feature strongly protects the eye from UVR from most directions. The eye is not well protected from UVR directly incident from the front or the side (ICNIRP, 2007).

2.8.1.1 Sunburn

"Sunburn" is an acute injury following excessive exposure to UVR and is most pronounced for lightly pigmented skin types. Sunburn is actually not caused by heat or caustic chemicals, but is the result of a phototoxic (actinic) effect in the skin. Unlike the other burns, sunburn is not immediate. Skin redness reaches a maximum at about 8 to 12 hours after exposure and fades within a few days. The red appearance of the skin (erythema) results from an increased blood content near the skin's surface.

2.8.1.2 Prickling and burning

Coal tar, pitch and a number of their constituents combined with exposure to sunlight or UVA alone, produce immediate prickling or burning sensations in the exposed skin. Longer exposures increase the intensity of the `pitch smarts' and produce erythema and a wheal and flare reaction which subsides an hour or so after the exposure to leave erythema restricted to the exposed area of skin. The early phase erythema may also fade but develops again, reaching a maximum between 24 and 48 hours. Following the inflammatory reaction, skin darkening (hyper-pigmentation) will develop after a few days.

2.8.1.3 Blistering

Blistering reactions may occur from UVR photosensitization that is most typical of contact with plant psoralens. The reactions are initiated by contact with the sap from a psoralen containing plant and exposure to sunlight. Erythema, possibly painful, distributed in a pattern clearly related to contact with the plant, is first seen about 24 h later. Blisters develop during the next 24 hours which may coalesce to produce a localized pattern of response but subside within days. Pigmentation abnormalities may develop and persist for months. The intensity of erythema and blistering depend on exposure dose and amount of photosensitizer in the skin.

2.8.1.4 Photoaging

Photoaging from occupational exposure has traditionally been particularly observed in fishermen and farmers in sun exposed sites such as the face and the back of the neck and hands. The clinical signs of a photo-aged skin are dryness, deep wrinkles, accentuated skin furrows, sagging, loss of elasticity, mottled pigmentation and the development of tiny but highly visible, superficial blood vessels (telangiectasia). These characteristics reflect profound structural changes in the dermis. It is not yet clear which wavelengths are most responsible for photoaging, but some research studies point to solar UVA and even infrared radiation exposures as contributing factors.

2.8.1.5 Photokerato Conjunctivitis

An unprotected eye exposed to UVR from the sunlight reflected from light sand or snow during one day may accumulate a sufficient dose to cause an adverse effect in the cornea of the eye. As with sunburn of the skin, the symptoms are delayed for several hours. Within six hours such an exposure gives rise to a gradual transition symptoms form a feeling of itchiness, “sand in the eye” sensation, increased tearing, to severe pain and photophobia (light sensitivity). This is caused by an inflammatory reaction in the cornea and conjunctiva known as photokerato conjunctivitis, which leads to a swelling and loss of the superficial cells in the cornea and the conjunctiva. Within 24 to 48 hrs, the pain decreases and the light sensitivity disappears. This condition is popularly referred to as “snow blindness” or “welders flash.”

2.8.1.6 Cataract

Development of cataract, a clouding of the lens that disturbs vision, is part of the natural ageing process. Epidemiological data show an increased risk for cortical cataract with UVB exposure from the sun. Animal experiments have clearly shown that UVR exposures produce cataracts, but experts disagree on the degree of importance played by environmental solar exposure (Sliney, 2002).

2.8.1.7 Skin cancers

The three common forms of skin cancer, listed in ascending order of severity are: basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and malignant melanoma (MM). Around 90% of skin cancer cases are of the non-melanoma variety (BCC and SCC) with BCCs being approximately four to eight times (depending on latitude) as common as SCCs. Exposure to UVR is considered to be a major etiological factor for all three forms of cancer (IARC 1992). For basal cell carcinoma and malignant melanoma, neither the wavelengths involved nor the exposure pattern that results in risk have been established with certainty; whereas for SSC, both UVB and UVA are implicated and the major risk factors seem to be cumulative lifetime exposure to UVR and a poor tanning response. The risk of developing skin cancer varies greatly with skin type, and more than 90% of skin cancers are found in melano-compromised persons. When UVR exposure is unavoidable, protective measures (hats, clothing) is strongly recommended. Therefore, persons who readily sunburn are also more prone to develop skin cancer (ICNIRP, 2007).

2.8.2 Biological and Health Effects of ELF MF

In 2002, the International Agency for Research on Cancer (IARC) classified ELF magnetic fields as “possibly carcinogenic to humans” (Group 2B). This was based on statistical studies indicating children are more likely to develop leukaemia if their exposure to extremely low frequency magnetic fields exceeds 0.3-0.4 μT, which would be relatively strong. Experimental studies on animals did not support these findings. The potential link between extremely low frequency fields and childhood leukaemia has been addressed by a number of epidemiological studies, which have not found any conclusive evidence, and further studies are needed. No new influential study has appeared over the last few years concerning any other type of cancer.

Studies on laboratory animals have shown little evidence that exposure to ELF magnetic fields alone could induce any type of cancer or would affect existing tumours. There is some inconsistent evidence that ELF magnetic fields of about 100 μT may enhance the development of tumours induced by other known carcinogens, but the majority of studies evaluating such combined effects did not find such a link.

A variety of symptoms, often self-reported have been suggested to be caused by ELF field exposure: skin redness, tingling and burning sensations, as well as fatigue, headache, concentration difficulties, nausea, and heart palpitation. The term “electromagnetic hypersensitivity” (EHS) has come into common usage based on the reported experience by the afflicted individuals that electric and/or magnetic ELF fields, or vicinity to activated electrical equipment trigger the symptoms. A relationship between ELF field exposure and those symptoms has not been shown in scientific studies.

It remains unclear if there is a link between extremely-low frequency field exposure and some neurodegenerative diseases such as Alzheimer’s, but some recent data suggests there might be such a link (Greenfacts, 2009).

2.9 Summary of Review

It can be observed in previous studies that significant exposures to ultraviolet radiations may result in severe biological and health effects of the skin and eye. It is therefore essential exposure guidelines for UVR recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) be adhered to and procedures put in place to quantify various UV levels to ensure that they are within these guidelines. Although results so far for the extremely low frequency magnetic fields have been inconclusive on acute health effects, precautionary efforts should be made to lower exposure levels to workers and the public in general. Quantification of the levels of these electromagnetic radiations is therefore very important in ensuring that occupationally exposed workers are within international guidelines which this study seeks to do and also a conscious effort put in place, to constantly lower levels of exposure.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Introduction

This chapter describes the methodology and work plan used in executing the research work and the challenges encountered. The chapter also describes how data was analysed.

3.2 Sampling

The sample size was determined by a sample size calculator software called the Raosoft Sample Size Calculator. A confidence interval of 90% (a confidence level score of 1.645), a margin of error of 0.09, a population size of 600 and a response distribution of 50 % was entered into the calculator and the number required was given as 74, which was rounded to 70. A sample size of 70 was then chosen for the research.

The Raosoft sample size calculation uses the random sampling method and is based on the Normal distribution. The formulas used for the calculation of the sample size is given as:

$$n = r\,(1 - r) / ((E / Z_{\alpha/2})^{2}) \qquad \text{3.1}$$

With the finite population correction (FPC) given as:

$$n_o = (n \times N) / (n + (N - 1)) \qquad \text{3.2}$$

Where n = sample size

N = population size

n_o = true sample size

r = response distribution

E = margin of error

$Z_{\alpha/2}$ = confidence level score of the confidence interval.

A total number of 70 shielded metal arc welders from various welding industries including manufacturing, repair and construction works, all over Greater Accra Region were then selected for this survey based on the scope of work.

3.3 Measurement Instrumentation

A broadband UV radiometer called the UV254SD UVA and UVC Light Meter with Datalogging SD Card with Measurement accuracy ±4% of full-scale reading + 2 digits and serial number of Q612737, manufactured by General Tools & Instruments and designed to measure the irradiance levels of UVA and/or UVC light from many industrial and commercial applications including welding, UV sterilization of food, photochemical matching, erasure of electrically programmable read-only memory (EPROM) chips and curing of inks was used. The UV254SD has the performance and features needed to satisfy the most demanding aspects of these applications. It combines the capabilities of UVA (long waves in the 365 nm band) and UVC (short waves in the 254 nm band) measurement in one instrument. The UV254SD comes with UVA and UVC probes and measures UV light intensity within two automatically switched full-scale ranges: 2 mW/cm^2 and 20 mW/cm^2. Measurement of the intensity of the UV light is done holding either the UVA or UVC probe by its handle, pointing the sensor with its end directly at the light source. The display reads out the intensity of the source’s UVA or UVC light component in units of mW/cm^2. The UV254SD UV spectrum chart is shown in Figure 3.1 and Figure 3.2.

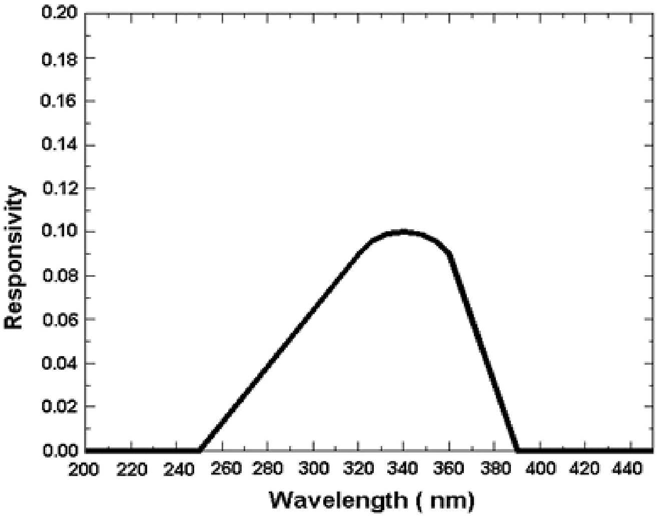

Figure 3.1. UVA sensor spectrum of UV254SD.
Source: General Tools & Instruments (2015).

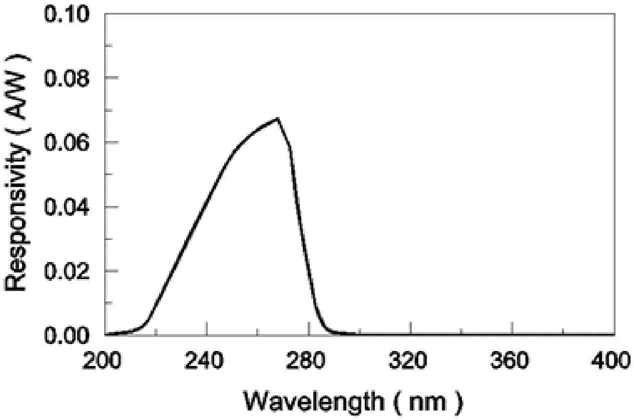

Figure 3.2. UVC sensor spectrum of UV254SD.
Source: General Tools & Instruments (2015).

An AC Milligauss Meter Model UHS2 manufactured by AlphaLab, Inc. was used in measuring the ELF magnetic fields. This meter is designed to read the 3-axis magnitude of the magnetic field in milligauss (RMS equivalent). The meter body is kept stable and always oriented the same way in space as measurements are taken to avoid a temporarily-changing field caused by the Earth’s magnetic field. The AC Milligauss meter is designed to do precise measurements of AC magnetic field in a wide frequency range of 13 Hz to 75 kHz (75,000 Hz). It has a typical error of +/-3% of the reading in the frequency range 45 Hz to 5 kHz. Measurements were taken in close proximity to the welders head or trunk.

A GPS coordinate software which uses the Google maps systems was use to record the geographic coordinates of the measured points. Questionnaires were also administered to the welders to analyse the level of risk to health effects. These analyses were carried out with the Microsoft Excel software.

3.4 Description of Measurement Procedures and Points

Welding worksites and factories that use SMAW were identified all around Greater Accra Region. The welders hailed from a variety of work fields including car maintenance/repair, foundry and construction sites. Permission was then sought in order to get the necessary approval to conduct the research study in the factories. The welders who were willing to participate were then used in this study. Measurements were taken at the working area of the welders. The GPS coordinates of the measurement point and photographs of the workplace were taken. Information on each welding machine such as manufacturer, year of purchase, number of years of usage and current used was noted. There were basically two groups of welding machines that were being used; the locally manufactured ones and the foreign or imported ones. Plates 3.1 and 3.2 shows these types of welding machines. The distance between the welder and the welding arc, the date and time were also recorded. Each measurement was repeated thrice and an average taken. Also, the background radiation was measured when there was no ongoing welding work and subtracted from the averaged value to get the direct radiation from the welding arc to reduce the effects of weather conditions. The sensors of meters were oriented in the same position for both the background and actual direct measurements.

Plate 3.1. Some locally manufactured welding machines.

Source: Field Work (2015).

Plate 3.2. Some imported welding machines.

Source: Field Work (2015).

3.5 Measurement of UVA and UVC radiation

The broadband UV radiometer, UV254SD UVA and UVC Light Meter with Datalogging SD Card with serial number Q612737 were used to measure UVA and UVC radiation emanating from the welding arc. Measurement of the UVA radiation was initially taken with the UVA probe. The seat of the probe was placed in the socket at the top of the

UV254SD and the UVA measurement mode selected. The radiometer was calibrated to give the irradiance level directly and responds with a spectral weighting S (λ) in accordance with Table A4. It was also designed to mimic the directional sensitivity of the human skin, which was assumed to be a plane surface and followed a cosine dependence (cosine response). For the determination of a realistic level of exposure, the probe was held by its handle in close proximity to the welders' head or chest, which is the parts of the body of interest and where significant exposure was expected to occur. The sensor of the probe was pointed at the direction of the light source. The display then read out the irradiance level of the source's UVA light component in units of mW/cm^2, which was converted to $W\ m^{-2}$ for the purposes of this study. For every measurement, multiple sampling times of at least 30 seconds was used. Not less than three sampling times was used for each measurement. Multiple readings were logged in the memory of the radiometer and also recorded on a data sheet for each sampling time. The maximum value measured in 3 selected sampling times, was then chosen and averaged.

After, the UVA probe was replaced with the UVC probe. The same process used in measuring the UVA irradiance level was repeated in measuring that of UVC. The display then read out the irradiance level of the source's UVC light component in units of mW/cm^2 and the maximum value measured in 3 selected sampling times, was then chosen and averaged. A copy of the data sheet is presented in the appendix. Plate 3.1 shows the UV254SD in use.

Plate 3.3. UV254SD UVA and UVC Light Meter in use.

Source: Field Work (2015).

3.6 Measurement of ELF Magnetic Fields

The AC Milligauss Meter Model UHS2 was used to measure ELF MF's emanating from the welding arc. Measurements were made in close proximity to the head and trunk level of the welders since the induced current densities in these parts of the body were to be calculated. The knob of the meter was turned to the 1st position to enable it to read the 3-axis magnitude of the magnetic field in milligauss (RMS equivalent). The milliguass was then converted to the International System (SI) unit of field intensity for magnetic fields, which is the tesla or microtesla (μT) for the purposes of this study.

To avoid false signal caused by the Earth's magnetic field, the body of the meter was kept stable and always oriented the same way until there was a stable reading was observed which was then recorded. For every measurement, multiple sampling times of at least 30 seconds was used. Not less than three sampling times was used for each measurement. Multiple readings were recorded on a data sheet for each sampling time. The maximum value measured in 3 selected sampling times, were then chosen and averaged. The averaged value was then multiplied by a correction factor of 1.01 since it is a 50 Hz signal, as required by the meter. A copy of the data sheet is presented in the appendix. Plate 3.2 shows the AC Milligauss Meter in use.

Plate 3.4. AC Milligauss Meter in use.

Source: Field Work (2015).

3.7 Development and Administration of Questionnaire

Questionnaires were developed and used to elicit information from welders under study at their workplaces. The questionnaire basically sought to enquire about the common complaints they often had and their perception about the exposure to EM radiation. It also included questions on their personal information, information on the work and industry background, information of safety and challenges they go through in the course of their work. Both open-ended and closed-ended questions were included in the questionnaire and each interview took approximately 20 minutes. The open-ended questions were such that respondents were free to use their own words to elaborate on and organize information and give their views on the subject matter, whereas the close-ended questions assisted the respondents in choosing from possible answers given in the questionnaire. A sample of the questionnaire is shown in the appendix.

3.8 Data Analysis

3.8.1 Analysis of Questionnaire

The data was analysed with the Microsoft Excel. The results are described in statistical quantities, graphs and absolute terms in chapter four.

3.8.2 Calculation of Induced Current Densities due to ELF MFs

An approach to calculate the induced current density resulting from the welder exposure to power frequency magnetic fields as described in equation 2.4 was used in this study. The induced current densities in the head and trunk were calculated and compared to the ICNIRP Basic Restriction of 10mA/m^2 to determine whether it was exceeded. The dimensions and mass of the head and trunk corresponds to detailed anatomical and reference male and female body models to those of the International Commission on Radiological Protection (ICRP, 2002), which is about 0.2 m for the trunk and 0.1 m for the head.

3.8.3 Determination of the Permissible Exposure Duration for UVA and UVC radiation

The ICNIRP Guidelines and ACGIH TLV represents conditions under which it is expected that nearly all individuals may be repeatedly exposed without acute adverse effects and, based upon best available evidence, without noticeable risk of delayed effects as discussed in section 2.3. The ICNIRP guidelines or ACGIH TLV for human exposure of the eye and skin to UVR is 30 J m^{-2} is based on 270 nm wavelength which is the wavelength to which the biological systems are most sensitive recommended 8-hour period. When the irradiance level is known, the permissible exposure duration, t_{max}, in seconds, to the spectrally weighted UVR is calculated by Equation 2.6.

The TLV for human exposure of the eye and skin to UVC radiation is 60 J m^{-2} at 253.7nm for a daily 8 hour work shift. The Permissible Exposure Duration can then be calculated for various irradiance levels using Equation 3.3 (ISO/NP 15858, 2007).

$$t_{max\text{-}UVC}\,(s) = (60\ J\ m^{-2}) / E_{UVC}\ (W\ m^{-2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.3$$

Where

$t_{max\text{-}UVC}$ = Permissible Exposure Duration related to the UVC limit in seconds

E_{UVC} = Irradiance level of UVC

For irradiance level related to UVA radiation, the Permissible Exposure Duration can then be expressed using Equation 3.4 (ICNIRP, 2007).

$$t_{max\text{-}UVA}\,(s) = (10000\ J\ m^{-2}) / E_{UVA}\ (W\ m^{-2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.4$$

Where

$t_{max\text{-}UVA}$ = Permissible Exposure Duration related to the UVA limit in seconds

E_{UVA} = Irradiance level of UVA

3.9 Uncertainty Estimation

To calculate the uncertainty of the magnetic field and irradiance level measurements, the various sources of uncertainty in the measurements were identified. The uncertainty from each source was estimated and finally the individual uncertainties were combined to give the overall uncertainty at any point. The standard uncertainty both for the magnetic field, u (B) and irradiance level u (E) was first found by calculating the estimated standard deviation S, which is given by Equation 3.5.

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.5$$

Where

$\bar{x} = \sum_i^n \frac{x_i}{n}$

Because the distribution was a normal one, u (B) and u € were calculated using Equation 3.6

$$u_1 = \frac{S}{\sqrt{n}} \text{ .... } 3.6$$

Where

n = number of measurements, which is equal to 3.

The AC Milligauss Meter and U254SD read to the smallest division or unit of 0.01 and 0.001. Therefore, to estimate the instrument uncertainty, the smallest division is multiplied by interpolation factor of 0.5 as in Equation 3.7.

Instrument uncertainty = interpolation fraction × smallest division …….……….. 3.7

Therefore, the instrument uncertainty for the AC Milligauss Meter is ±0.005 and that of the UV254SD is ±0.0005. This was taken as uniformly distributed uncertainty.

To find the standard uncertainty, $u_2 = \frac{a}{\sqrt{3}}$

Where

a = half width of the error, ±0.005 which is 0.005 for the AC Milligauss Meter and ±0.0005 which is 0.0005 for the UV254SD.

Therefore, the standard uncertainty of the Milliguass meter is

$$u_2 = \frac{0.005}{\sqrt{3}}$$

$$= 2.8868 \times 10^{-3}$$

And the standard uncertainty of the UV254SD is

$$u_2 = \frac{0.0005}{\sqrt{3}}$$

$$= 2.8868 \times 10^{-4}$$

The combined standard uncertainty was then found using the formula in Equation 3.8

Combined standard uncertainty, $u_c = \sqrt{u_1{}^2 + u_2{}^2}$……………………………. 3.8

Hence, the combined standard uncertainty for the magnetic flux density readings imply

$u_c = \sqrt{u_1{}^2 + (2.8868 \times 10^{-3})^2}$ ……………………..…………………. 3.9

And the combined standard uncertainty of the UVA and UVC irradiance level is

$u_c = \sqrt{u_1{}^2 + (2.8868 \times 10^{-4})^2}$ ……………………………………………. 3.10

The expanded uncertainty, U at a 95 % confidence level was found by multiplying the combined standard uncertainty by a coverage factor, k = 2.

Symbolically, U = k × combined standard uncertainty

= 2 × combined standard uncertainty

The magnetic flux density and irradiance levels were written as $\bar{x}$ ± U in the units of µT and W/m^2 respectively. This reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95% (Bell, 2001).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained from the research. The results are presented in sections according to major attributes of this study interest.

4.2 General Information about Welding Measurement Conditions

This section presents the general information about the welders using SMAW under study, such as the location of their factories or workshops; its GPS coordinates, the type of welding machine they use; arc current, the number of years the welding machine has been in use, the year of manufacture and the approximate the distance of the welder from the welding arc as shown in Table B1 in the appendix. There were basically two categories of welding machines, the locally manufactured ones and the imported ones and all of them were alternating current (AC) welding machines. Out of the 70 welders studied, 51 (72.86 %) of them used the locally manufactured welding machines and 19 (27.14 %) of them used the imported arc welding machines. All the locally manufactured welding machines had no current regulators on them and the welders had no idea of the current it was operating on. Some had low, medium and high voltage regulators but a few of the machines were shabby and there was no way of identifying the position of the regulator. However, with the imported arc welding machines, most of them had current regulators and could easily determine the arc current being used. This is desirable since arc current is one primary factor which affects the value and quality of the UV radiation. Table B1 shows the categories and the arc current of the various welding machines and the year of manufacture of the arc welding machines. Most of the imported machines were bought second-hand, therefore the year of manufacture was not available. Information that was not readily available to the researcher or could not be answered by the welders have been shown as N/A, not available or no answer.

Specific codes were given to each welder by the researcher in place of their names to protect their anonymity. These codes corresponded to the part of the Greater Accra Region where their workshops or factories were located. The average distance of welders from the welding arc was measured to be 52.71 cm, although measurements were recorded at various distances ranging from 30 cm to 70 cm as shown in Table B1.

4.3 Assessment of UV Radiation from SMAW

4.3.1 Irradiance Level of UVC

The irradiance level of UVC radiation, E_{UVC} (100 – 280 nm) was measured at the various distances of the welders from the welding arc as shown in Table B3 in the appendix. The E_{UVC} ranged from 0.16 ± 0.08 W/m^2 to 10.46 ± 1.96 W/m^2. The average E_{UVC} was calculated to be 1.89 W/m^2. Figure 4.1 shows the E_{UVC} measured from the shielded arc metal welders. 68.57 % of the measured UVC irradiance was above 1 W/m^2, which as a permissible exposure duration of 1 min as shown in Table A6.

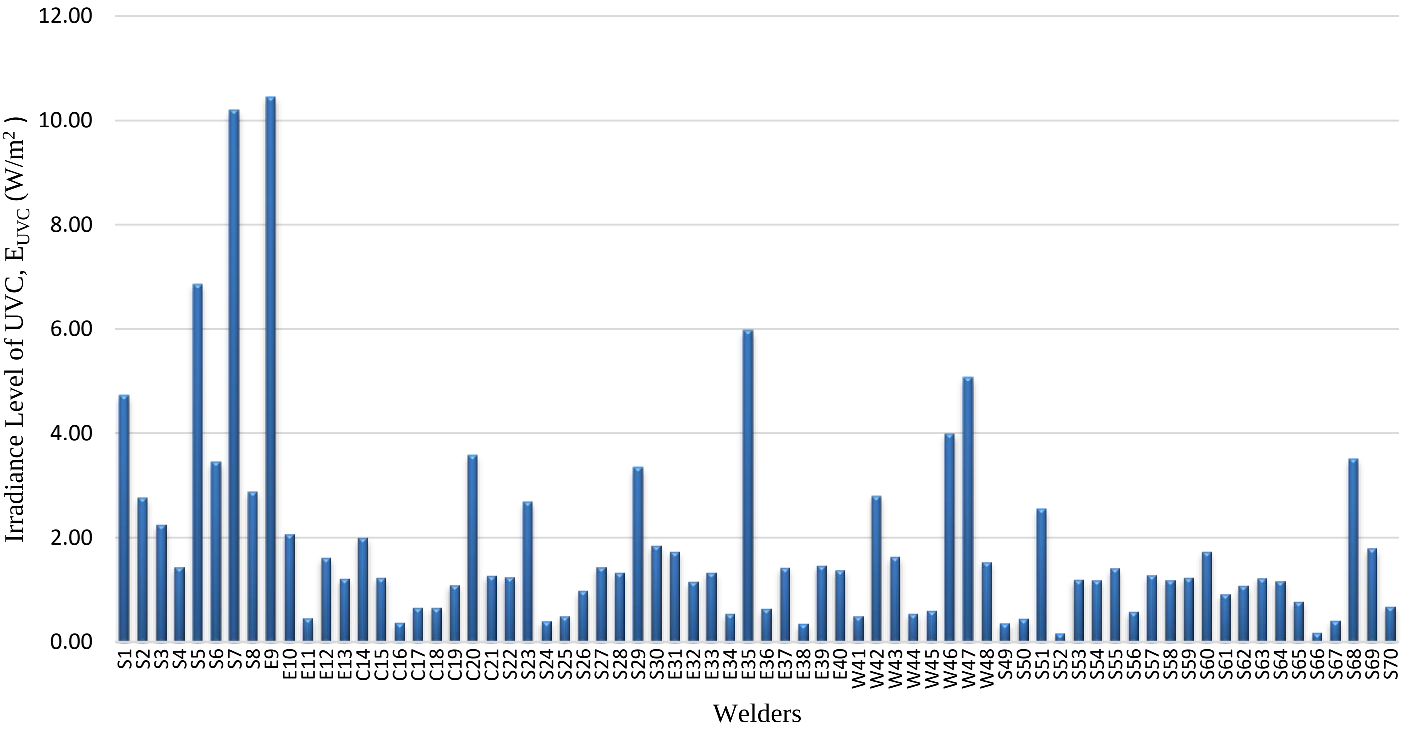

Figure 4.1. Irradiance level of UVC radiation, E_{UVC} of various welders using SMAW.

The E_{UVC} could actually be higher since the welders have the tendency of going closer to the work piece during the strike of the arc and the irradiance level is inversely proportional to the square of the distance. Welder E9 had the worst case of the E_{UVC} of 10.46 ± 1.96 W/m^2 corresponding to the shortest distance measured being 30 cm: measurement was carried out during the repair work of an automobile's exhaust pipe.

4.3.2 Permissible Exposure Duration of UVC

The corresponding Permissible Exposure Duration ($t_{max-UVC}$) per day for the E_{UVC} were calculated. The $t_{max-UVC}$ is intended to provide protection to workers from acute and delayed effects of UVC exposure. Conforming to the irradiance level, the $t_{max-UVC}$ ranged from 5.74 s to 367.35 s. The 5.47 s corresponded to the worst case of UVC exposure of 10.46 ± 1.96 W/m^2, hence, the $t_{max-UVC}$ increases as the irradiance level decrease. Figure 4.2 shows the $t_{max-UVC}$ correlating to the E_{UVC} of the welders using SMAW.

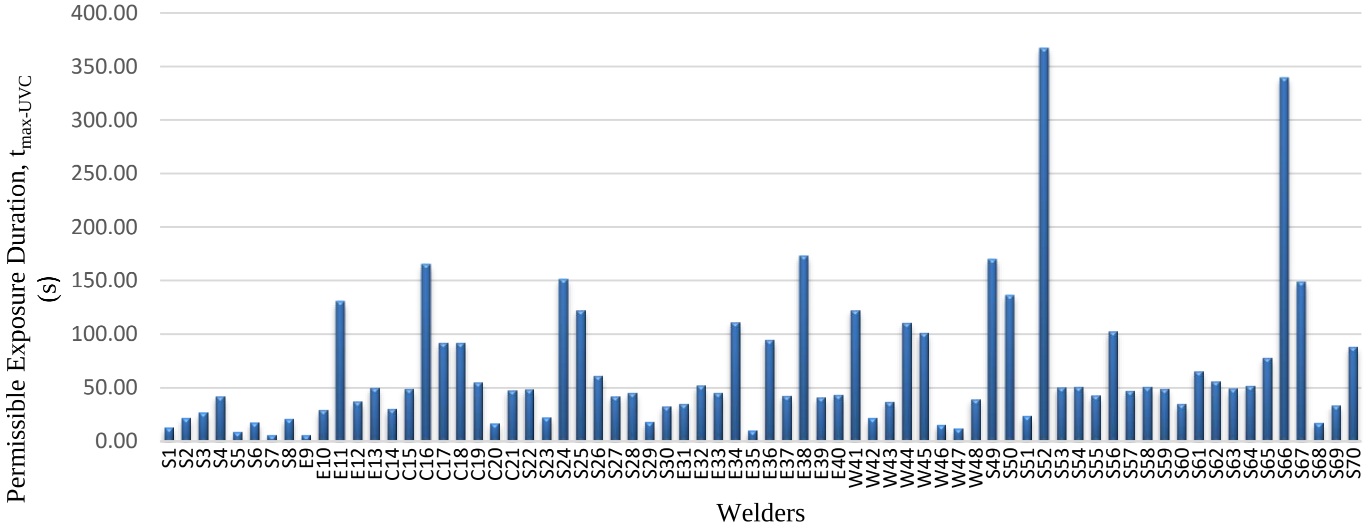

Figure 4.2. Permissible exposure duration, $t_{max\text{-}uvc}$ for corresponding E_{uvc} of welders using SMAW.

The range of $t_{max\text{-}uvc}$ suggests that UVC from SMAW may actually be hazardous to the eyes and skin. The average $t_{max\text{-}uvc}$ was found to be 66.52 s and the welders are likely to exceed this in a day. Therefore, the total exposure time may become sufficient to cause ocular damage such as photokeratitis (inflammation of the cornea) and photokerato conjunctivitis (inflammation of the conjunctiva, the ocular lining) or skin defects such as erythema, if the permissible exposure duration is drastically exceeded in a day, especially if the welder does not wear the appropriate Welding Gear or Personal Protective Equipment (PPE). Appropriate PPE such as masks, gloves and welding goggles have been found to diminish UV radiation levels greatly (Chiung-yu et al., 2007).

4.3.3 Irradiance Level of UVA

The Irradiance level of UVA radiation, E_{UVA} (315 – 400 nm) was measured at the various distances of the welders from the welding arc as shown in Table B2 in the appendix. It was observed that E_{UVA} was generally higher than E_{UVC} for most of the welders surveyed. This could be explained by the fact that UVA has a longer wavelength, hence, it is easily transmitted through air and glass and not easily absorbed unlike UVC. Also, due to the wavelength and the different materials being welded increase in E_{UVA} with a particular welder did not necessarily imply increase in E_{UVC} in that same instance. For example, it is possible for SMAW to produce bulk emissions of UVC compared to UVA when steel is welded (IFA, 2011). Out of the 70 SMAW processes surveyed, 95.71 % of them emitted more UVA than UVC (Figure 4.5). Figure 4.3 shows the E_{UVA} measured from the shielded arc metal welders.

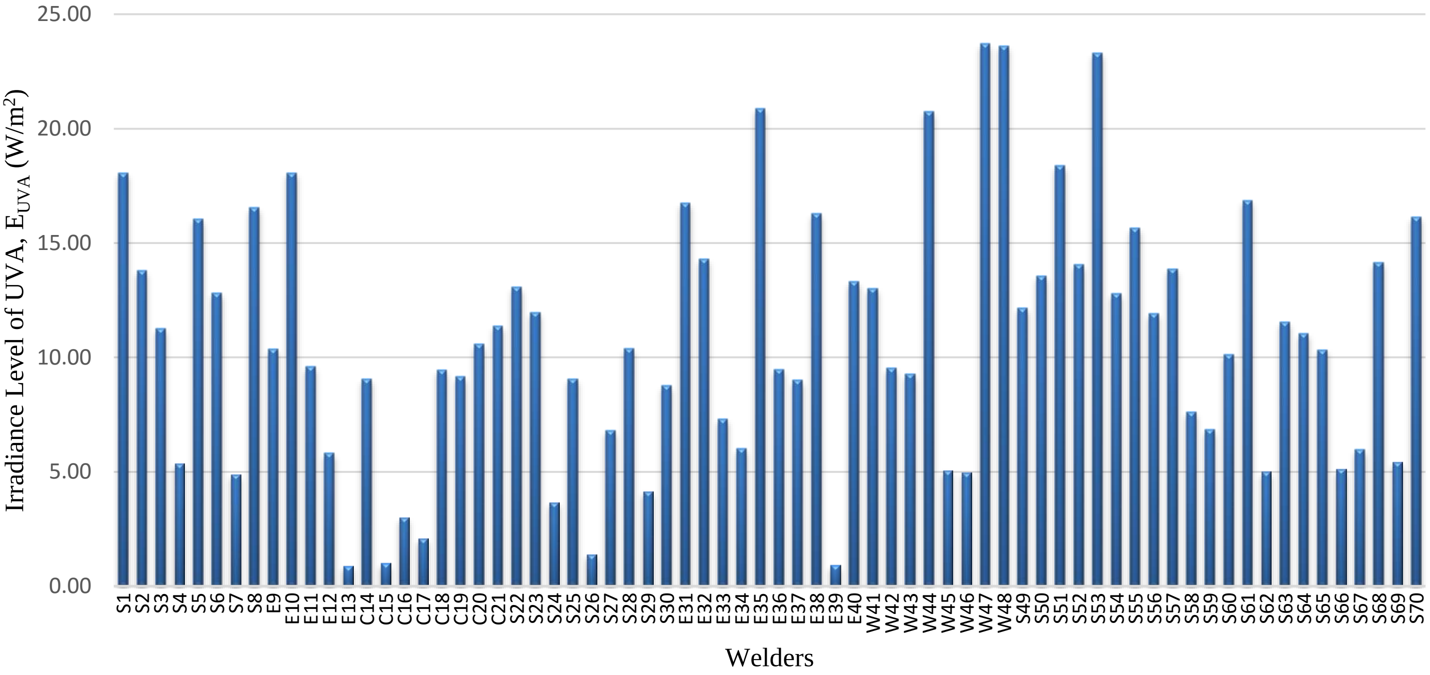

Figure 4.3. Irradiance level of UVA radiation, E_{UVA} of various welders using SMAW.

The E_{UVA} ranged from 0.88 ± 0.03 W/m^2 to 23.72 ± 6.66 W/m^2. The highest reading of 23.72 ± 6.66 W/m^2 was taken for W48, a small scale metal construction welder. Other relatively high values were recorded at S49 and S53 which are other metal construction workshops who weld coal pots and gates respectively at the time of the measurements. The average E_{UVA} was calculated to be 10.78 W/m^2 and 84.29 % of the measured E_{UVA} was above 5 W/m^2, which shows that relatively high UVA was emitted from the SMAW.

4.3.4 Permissible Exposure Duration of UVA

Due to the relatively high E_{UVA}, the permissible exposure duration, $t_{max\text{-}UVA}$ in relation to the UVA was calculated to determine the recommended limits for each welder. This is graphically represented in Figure 4.4.

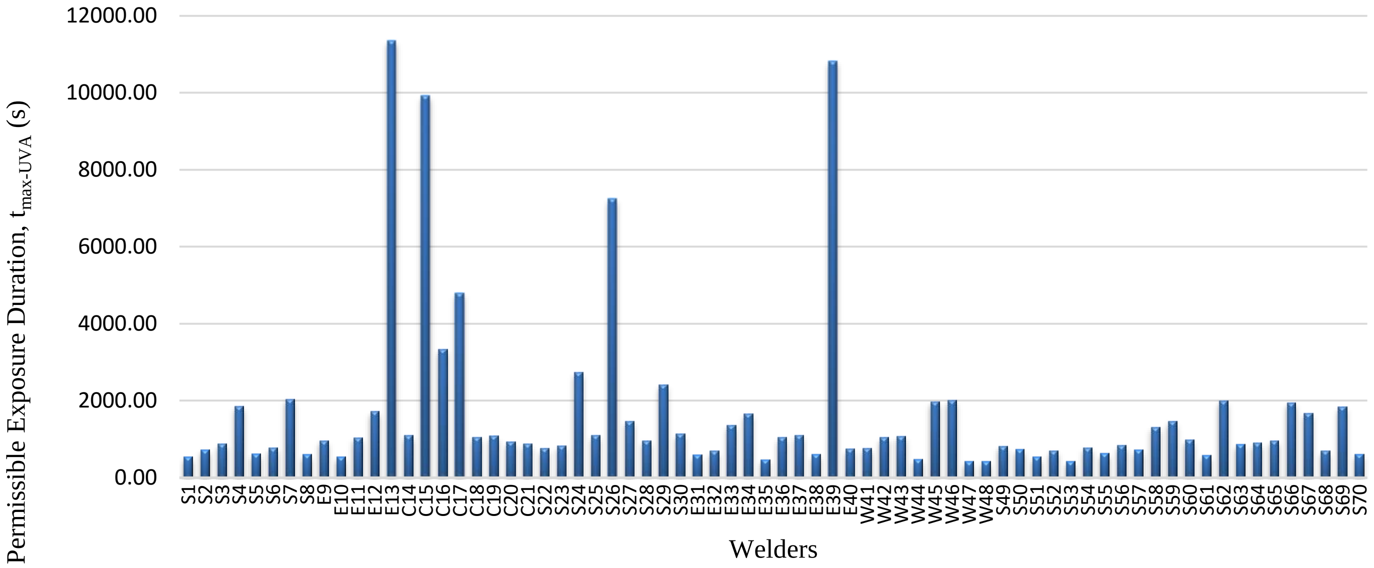

Figure 4.4. Permissible exposure duration, $t_{max\text{-}UVA}$ for corresponding E_{UVA} of welders using SMAW.

The $t_{max\text{-}UVA}$ had a range of 421.59 s to 11363.64 s per day. The highest E_{UVA}, 23.72 ± 6.66 W/m^2 had the least permissible exposure duration of 7.03 min and the lowest E_{UVA}, 0.88 ± 0.03 W/m^2, had the most permissible exposure duration of 189.39 min. The $t_{max\text{-}UVA}$ has a relatively low average of 27.39 min per day but the total exposure time of the welders may be far more than this due to the nature of their work. This means that the UVA measured from the SMAW may be sufficient to cause erythema, blistering, prickling or burning sensations and even cataracts and skin cancers, if the total exposure time frequently exceeds the $t_{max\text{-}UVA}$ in a day and the suitable PPE is not worn.

4.3.5 Analysis of Combined E_{UVA} and E_{UVC}

The combined E_{UVA} and E_{UVC} from each welder using the SMAW process was shown as $E_{eff.}$ This is not reflective of the true E_{eff} in Section 2.3 and Table A5, since UVB was not detected due to the detection limits of the UV254SD radiometer. Hence, it might be underestimated but it does however, give a rough idea of the total UV radiation from the SMAW process. Also, the total permissible exposure duration of the E_{eff} (E_{UVA} + E_{UVC}), t_{max}, was calculated using Equation 2.6. This was done to give an estimate of the permissible exposure duration due to the total UV radiation from the SMAW process and it is presented in Table B3. Figure 4.5 compares the E_{UVA} and E_{UVC} from each measurement whilst Figure 4.6 and 4.7 show the results of the E_{eff} and its corresponding t_{max} respectively.

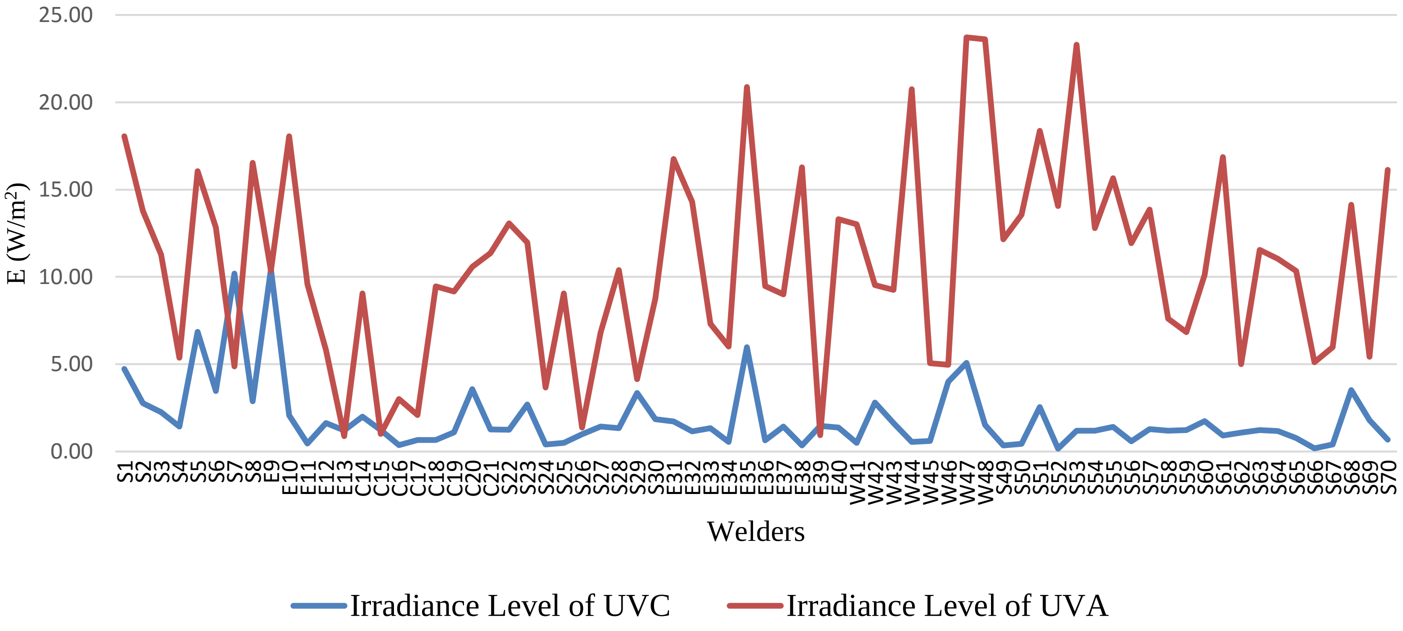

Figure 4.5. Comparing UVA and UVC measurements from the various welders using SMAW.

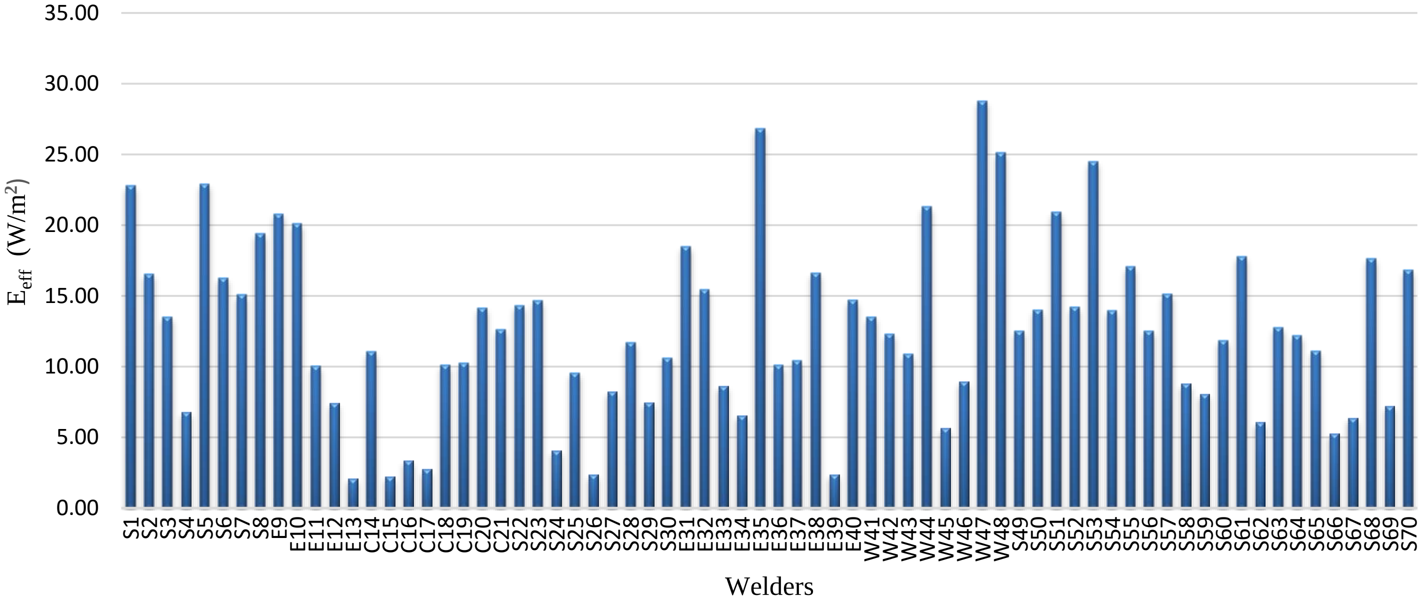

Figure 4.6. E_{eff} (E_{UVA} + E_{UVC}) from the various welders using SMAW.

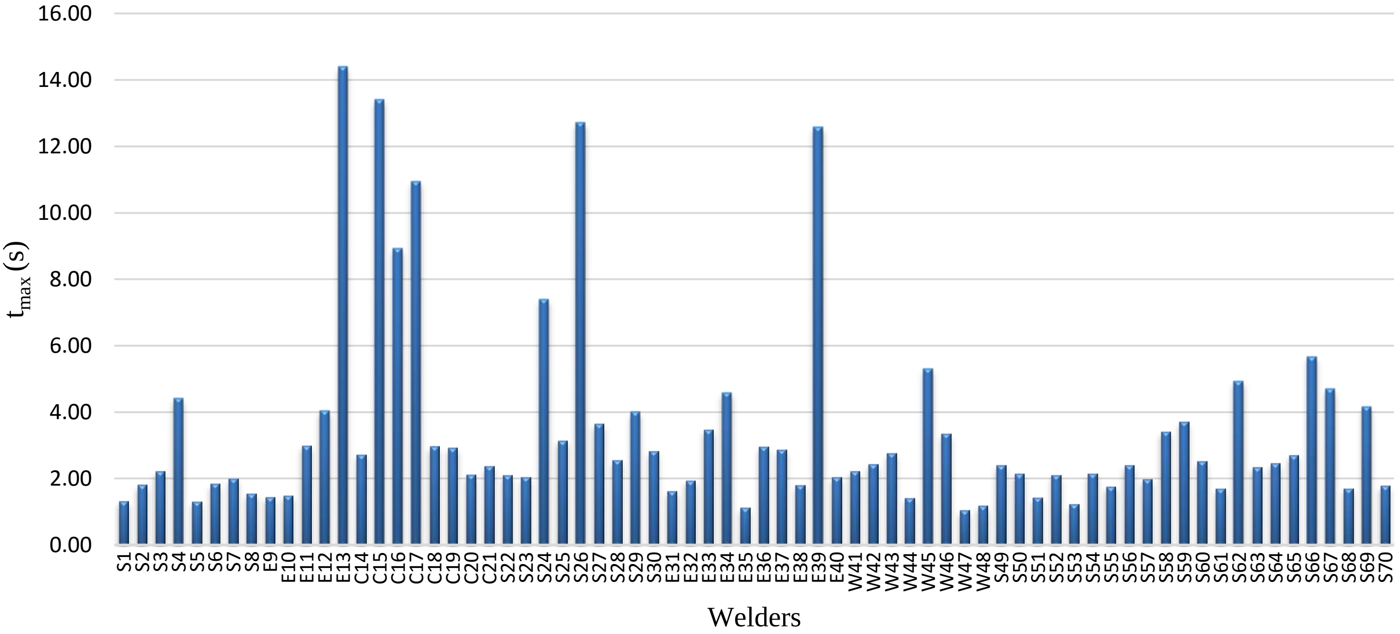

Figure 4.7. Corresponding permissible exposure duration, t_{max}, per day for E_{eff}.

From Figure 4.6, the obtained effective irradiance, E_{eff}, has range of 2.08 W/m^2 to 28.79 W/m^2 with the range of permissible exposure duration, t_{max}, per day of 1.04 s to 14.40 s

(Figure 4.7). This suggests that UV radiation from SMAW is actually hazardous to the eyes and skin. The average E_{eff} is 12.67 W/m^2 and the average t_{max} per day is 3.45 s. Although this might be an underestimation, it still suggests that UV radiation from SMAW may be hazardous to the skin and eyes.

4.4 Assessment of ELF Magnetic Fields from SMAW

4.4.1 Magnetic Flux Densities from SMAW

Figure 4.8 shows the magnetic flux densities, B, of the 50 Hz ELF magnetic fields (MF) measured from the various welders using the SMAW process in the Greater Accra Region. Figure 4.8 illustrates these magnetic flux densities from the various SMAW processes.

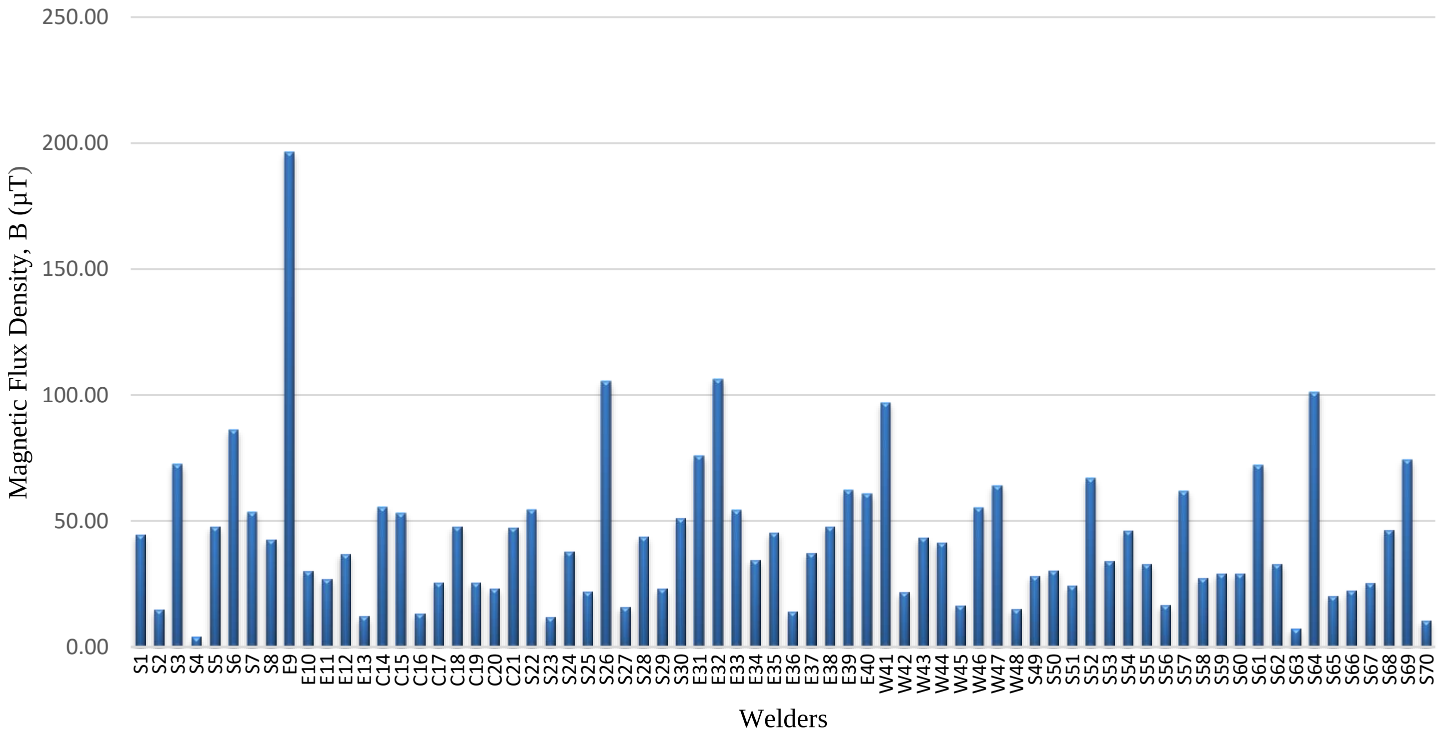

Figure 4.8. Magnetic flux densities from various welders using SMAW.

From Figure 4.8, the magnetic flux densities range from 4.01 ± 0.72 µT to 196.46 ± 4.86 µT. The average magnetic flux density was calculated as 43.68 µT. The maximum magnetic flux density of 196.46 ± 4.86 μT, had one of the least distances between the welder and the welding arc which shows that the magnetic field increases as the distance decrease. All magnetic flux densities did not however, exceed the ICNIRP Reference Level of 500 μT.

4.4.2 Induced Current Density

The heads and trunks was considered in calculating the induced current density, J, resulting from the SMAW welder's exposure to power frequency magnetic fields. Table B4 shows the expected induced current densities in the head, J_{head}, and trunk, J_{trunk} of the welders. Figure 4.9 illustrates these expected induced current densities in the head and trunk of the welders as a result of their exposure to the magnetic flux densities noted in Table B4.

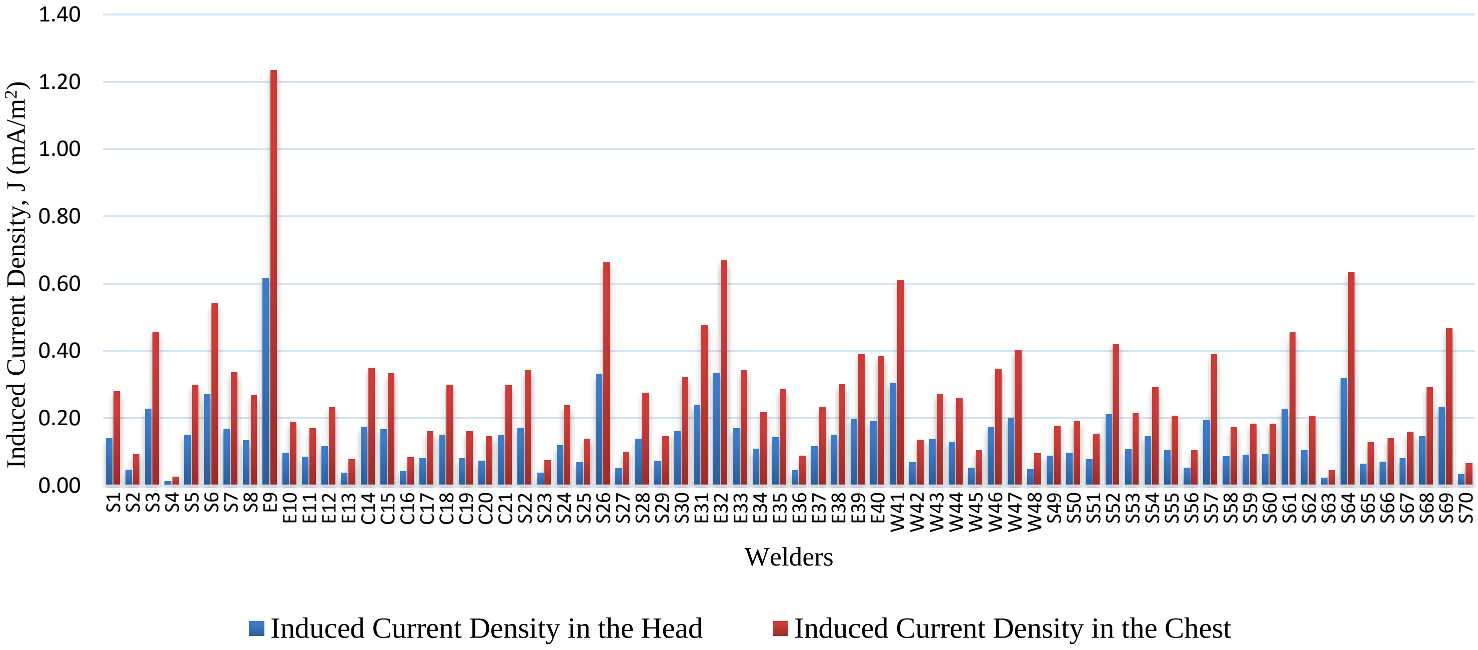

Figure 4.9. Expected induced current density in the head and trunk of a SMAW welder exposed to the magnetic fields.

From Figure 4.9, the expected induced current density, J, of the welder due to the exposure to the magnetic fields from the SMAW process, ranges from 0.01 to 0.62 mA/m^2 for the head and 0.03 to 1.23 mA/m^2 for the trunk. The average expected induced current density in the head and trunk were found to be 0.14 mA/m^2 and 0.27 mA/m^2 respectively. These results show that the induced current densities calculated from the welders are well within the ICNIRP Basic Restriction of 10 mA/m^2.

4.5 Analysis of Questionnaire administered to Welders on some UVR and ELF MF Effects

Table 4.1 shows the results of the closed-ended questions in the questionnaire administered to the 70 welders surveyed using the SMAW process. A copy of the questionnaire is displayed in Appendix C. The results include their demographic information, information on their work background and information about their familiarity with safety.

Table 4.1

Analysis of Information from Welders

Enquiry	**Frequency**	**Percentage (%)**
Age group of welders in years		
16 – 25	14	20.00
26 – 35	36	51.42
36 – 45	16	22.86
46 – 55	3	4.29
56 – 65	1	1.43
Above 66	0	0
Number of years welder has been practicing welding		
Less than 1	1	1.43
1 – 10	38	54.28
11 – 20	27	38.57
21 – 30	3	4.29
31 – 40	1	1.43
Above 40	0	0
Number of years at current factory/workshop		
Less than 1	1	1.43
1 – 10	58	82.86
11 – 20	11	15.71
21 – 30	0	0
31 – 40	0	0
Above 40	0	0

Number of working days in a week		
2	0	0
3	0	0
4	0	0
5	5	7.14
6	64	91.43
7	1	1.43
Number of welding hours in a day		
1 – 2	1	1.43
3 – 4	3	4.29
5 – 6	15	21.43
7 – 8	26	37.14
Above 8	25	35.71
Leave of absence in a year		
Yes	13	18.57
No	57	81.43
Weld without eye protection?		
Frequently	0	0
Sometimes	56	80.00
Never	14	20.00
Type of eye protection		
Welding goggles	50	71.43
Sunglasses	20	28.57
Weld without protective coat?		
Frequently	42	60.00
Sometimes	20	28.57
Never	8	11.43
Attended any safety training/program before?		
Yes	13	18.57
No	57	81.43
Are hospitals/clinics readily available at disposal?		
Yes	21	30.00
No	49	70.00
Has safety had an impact on your health?		
Yes	66	94.29
No	4	5.71

From Table 4.1, it is observed that the age of the welders ranged from 16 to 65 years with most of them being between 26 and 35 (51.42 %). Experience in welding for most of the welders ranged from less than a year to about 40 years and most of them (82.86 %) had spent from 1 to 10 years at the current workshop or factory of survey. Most of the welders work 6 days a week and above 7 hours a day. About 81.43 % of the welders stated they did not take any leave of absence in a year and sometimes only rested on public holidays. Most of the welders (80 %) attested to the fact that they sometimes weld without welding goggles stating that the nature of some works do not permit them to and it is possible that most of these goggles had an inappropriate shade number for the type of welding they performed since most did not take that into consideration when purchasing the gadget. Most of them confirmed that they frequently welded without protective coat, and with some claiming the weather was too hot to put on the coat. This gives a general idea that safety practices among the welders was not adequate. The analysis of the open-ended questions suggested that 87.14 % of them had a fair knowledge about safety although only 18.57 % had attended any safety program or training before. Some stated lack of money as being the reason they could not practice adequate safety standards, indicating that the appropriate goggles was quite expensive and they could not afford it. Figure 4.10 shows some symptoms that were experienced by the welders.

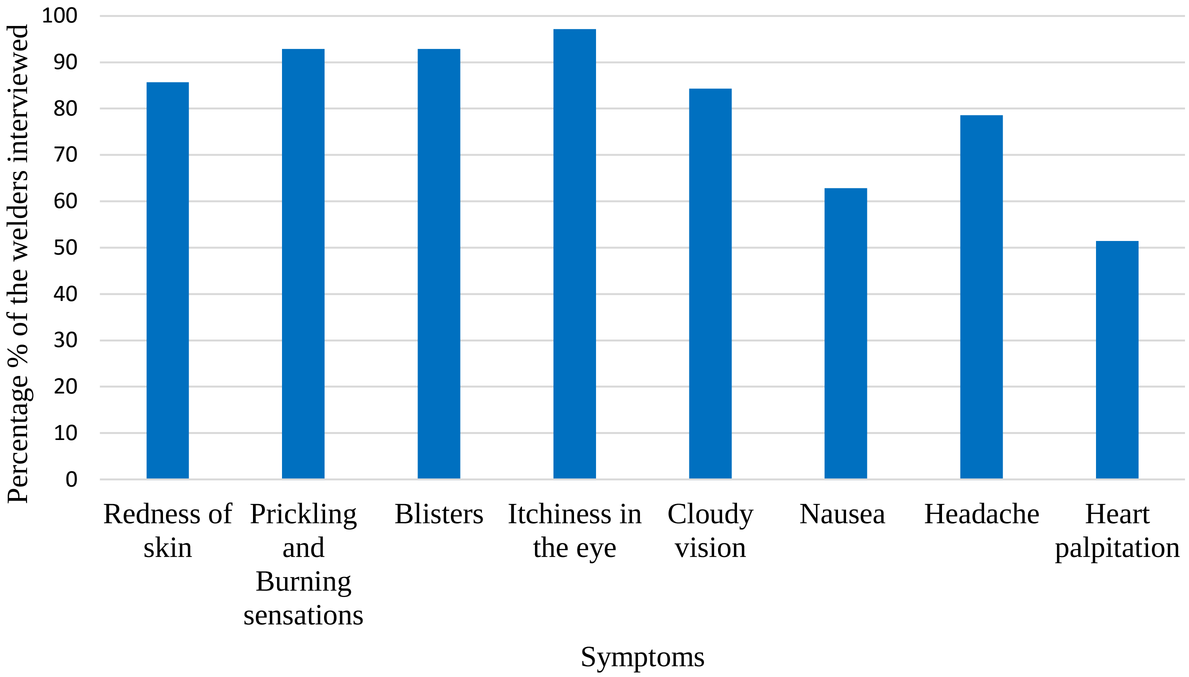

Figure 4.10. The percentages of SMAW welders experiencing common symptoms related to UVR and ELF MF

From Figure 4.10, it is observed that most of the welders experience symptoms related to biological effects of UVA, UVC and ELF MF with itchiness in the eye being the highest reported case (97.14 %). This may be caused by the poor usage of the welding goggles. Inadequate safety precautions and practices on the whole may be the cause of the relatively high symptoms experienced by the welders.

The questionnaire also considered the frequency that these symptoms were experienced by the welders, whether they were experienced occasionally or always during work. Figure 4.11 shows the frequency to which these symptoms were experienced by the welders.

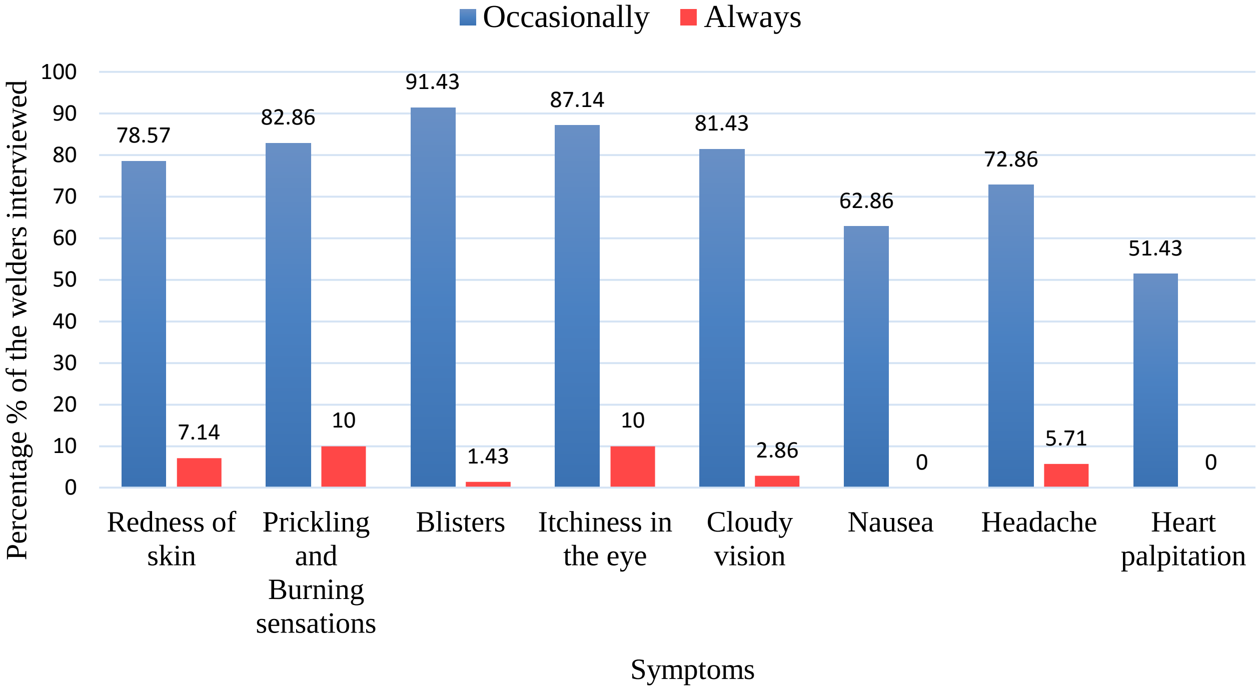

Figure 4.11. The frequency to which symptoms were experienced by the welders.

From Figure 4.11, it is observed that symptoms were mostly experienced occasionally. Although most of these symptoms are experienced occasionally however not only should the immediate signs and symptoms be considered but the long term effects such as skin cancers and cataracts should be taken seriously. Since most of these symptoms are experienced by the welders and may be caused by their exposure to UV radiation and ELF MF, there is a possibility that long term effects associated with these physical agents especially UV radiation may also develop. The welders must therefore take their skin and eye protection very seriously.

4.6 Comparison of Results with Standards

4.6.1 Comparison of the ELF MF Results to International Standards

The guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has the occupational Reference Level for magnetic flux density, B to be 500 μT and the Basic Restriction for induced current density to be 10 mA/m^2 at 50 Hz, as seen in Section 2.4.

The maximum magnetic flux density measured from the SMAW was 196.46 ± 4.86 µT. The maximum induced current densities expected in the head and trunk of the welder are 0.62 mA/m^2 and 1.23 mA/m^2 respectively. These are therefore well within the ICNIRP Reference Level and Basic Restriction.

4.6.2 Comparison of the UV Radiation Results to International Standards

Occupational health and safety guidelines, regulations and standards have been developed in several countries and by international organizations to protect workers and the general public from potentially hazardous exposure to Ultraviolet radiation. The two most widely used guidelines are virtually identical: the ICNIRP and the American Conference of Governmental Industrial Hygienists (ACGIH) guidelines for human exposure of the eyes and skin to UVR is 30 J m^{-2} – effective. The guidelines for UVA and UVC are 10000 J m^{-2} and 60 J m^{-2} respectively. The irradiance level of UVC from the arc of SMAW ranged from 0.16 ± 0.08 W/m^2 to 10.46 ± 1.96 W/m^2 under the conditions of this study. The corresponding permissible exposure duration per day ranged 5.74 s to 367.35 s. The irradiance level of the UVA ranged from 0.88 ± 0.03 W/m^2 to 23.72 ± 6.66 W/m^2 with a permissible exposure duration of 421.59 s to 11363.64 s per day. Since the welders total exposure time may exceed the permissible exposure duration per day, multiplying their total time with the irradiance levels will greatly exceed the recommended guidelines. This suggests that UV radiation from SMAW arc welding may actually be hazardous to the eyes and skin.

4.6.3 Comparison of Results to other Occupationally Exposed Workers

Although the ICNIRP occupational Reference Level and Basic Restriction for ELF magnetic fields is not exceeded, comparing these results to the studies of other occupationally exposed workers in Ghana reveals that the average magnetic flux density from the arc of SMAW is still higher. For instance, the maximum magnetic flux densities for occupationally exposed workers of Electricity Transmission Substations in the Greater Accra Region of Ghana was 19.78 µT ± 0.17 µT (Akomaning-Adofo, 2010). Also, the maximum magnetic flux density for occupationally exposed workers in Television Stations in Accra, Ghana was 9.335 µT (Osei, 2012). Comparing these results to the average magnetic flux density from the arc of SMAW, 43.68 µT suggests that magnetic field exposure to the SMAW welders is relatively high.

Comparing the irradiance levels from SMAW in this research to that conducted by Chiung-yu et al., 2010 in Taiwan suggests that UVR from SMAW arc welding is actually hazardous to the eyes and skin. They had an effective irradiance at 50 cm from the arc of SMAW in the range of 33.1 to 311.0 µW cm^{-2} with a permissible exposure time per day is 9.6 to 90.6 s whist the results of this study suggests the estimated effective irradiance at various distances ranges from 2.08 W/m^2 to 28.79 W/m^2 with a permissible exposure duration of 1.04 s to 14.40 s.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this thesis work was to quantify the level of UV irradiance and ELF Magnetic Fields exposure to welders in factories and worksites, through measurement of the rate of exposures to MF and UV radiations as a result of the Shielded Metal Arc Welding (SMAW) process. Calculation of the expected induced current densities to the head and trunk of the welders due to exposure to ELF MF, calculating the permissible/maximal exposure duration from the irradiance levels of the UV radiation from the arc of SMAW and comparing the estimated levels of exposure to other internationally recommended standards.

The UVC and UVA irradiance levels and ELF magnetic fields emitting from the arc of the SMAW process of welders in the Greater Accra Region, Ghana were then assessed. The measured UVC irradiance levels, E_{UVC} ranged between 0.16 ± 0.08 W/m^2 and 10.46 ± 1.96 W/m^2. The average E_{UVC} was calculated to be 1.89 W/m^2. Its corresponding permissible exposure duration, $t_{max\text{-}uvc}$ per day was 5.74 s to 367.35 s with an average $t_{max\text{-}uvc}$ of 66.52 s.

The measured UVA irradiance levels, E_{UVA} ranged between 0.88 ± 0.03 W/m^2 and 23.72 ± 6.66 W/m^2. The average E_{UVA} was calculated to be 10.78 W/m^2. Its corresponding permissible exposure duration, $t_{max\text{-}UVA}$ per day was measured to be from 421.59 s to 11363.64 s, with an average $t_{max\text{-}UVA}$ of 1643.40 s. An estimated effective irradiance, E_{eff} was calculated by combining the UVA and UVC irradiance levels from each arc of the SMAW and had a range from 2.08 W/m^2 to 28.79 W/m^2 with the corresponding permissible exposure duration, t_{max}, per day ranging from 1.04 s to 14.40 s. These results were compared to international guidelines by the ICNIRP and ACGIH and suggested that UV radiation coming from the SMAW process may have adverse effect on the eyes and skin of the welders.

The extremely low-frequency (ELF) magnetic fields (MFs) measurement results showed that the magnetic flux densities, B from the SMAW process ranged from 4.01 ± 0.72 µT to 196.46 ± 4.86 µT with an average magnetic flux density calculated to be 43.68 µT. These were within the ICNIRP Reference Level of 500 µT although significantly higher than other occupationally exposed workers such as Electricity Transmission Substation (Akomaning-Adofo, 2010) and Television Station workers (Osei, 2012) in the country.

An approach to calculate the expected induced current density, J in the head and trunk resulting from the welders' exposure to power frequency magnetic fields as proposed by ICNIRP was used in this research. The expected induced current density, J_{head} in the head ranged from 0.01 to 0.62 mA/m^2 and that of the trunk, J_{trunk} ranged from 0.03 to 1.23 mA/m^2. Therefore, the expected induced current densities in the head and trunk of the welders are within the ICNIRP Basic Restriction of 10 mA/m^2.

Results from the analysis of the questionnaire administered to the welders suggested that safety practices among the welders was not adequate although most of them had a fair knowledge about safety. Most of the welders are expected to greatly exceed the permissible exposure durations and yet most of them agreed to not wearing eye protection and especially protective coats always. Also, most welders did not use the appropriate welding goggles for the type of welding they performed. The inadequacy of the protective measures may be the reason for the high number of common symptoms related to UV radiation and magnetic field exposure experienced by the welders. There were high percentage reported cases of itchiness in the eye (97.14 %), prickling and burning sensation (92.86 %), blisters (92.86 %), redness of skin (85.71 %), cloudy vision (84.29 %), headache (78.57 %), nausea

(62.86 %) and heart palpitation (51.43 %). Although most of these symptoms were experienced occasionally, not only should the immediate signs and symptoms be considered but the long term effects such as skin cancers and cataracts should be taken seriously. Since most of these symptoms are experienced by the welders and may be caused by their exposure to UV radiation and ELF MF, there is a possibility that long term effects associated to these physical agents especially UV radiation may also develop.

These results have therefore demonstrated UV radiation and magnetic field exposure conditions to the welders and the need for protection.

5.2 Recommendations

On the basis of this research the following recommendations are made:

5.2.1. To Policy Makers

Policy makers should ensure the establishment of relevant regulations to monitor the safe operation of welding activities. This will ensure that welding activities are appropriately analysed and can also serve as a source of income to the Regulatory Authority.

5.2.2 To Big-Sized Welding Industries

Big-sized industries that employ welders in the sectors of automation, maintenance, fabrication, construction and manufacturing should also appoint radiation safety officers to ensure adequate monitoring of radiation protection and safety, ensure that the welders are trained to work safely, ensure that adequate protective equipment, clothing and radiation meters are available and used appropriately and ensure that safety arrangements are updated.

5.2.3 To Welders

1. Welders should be encouraged to as practically as possible reduce their daily exposure time to the welding arc and also take at least one leave of absence in a

year in addition with being fitted with the appropriate protective materials for protection from magnetic field and especially UV radiation emission hazards.

2. The lack of an active welders' organization makes it difficult to communicate to most welders. Welders should ensure the establishment of a recognised welders association or body that will actively deal with the concerns of all welders and be attractive enough to most welders. This association or body should be mandated to regularly organize safety workshops or clinics for the welders.

5.2.4 For Further Studies

In order to resolve the uncertainty about the delayed health effects from arc welding operations, further studies are needed that will include examining senior career welders or retired welders, who are likely to have accumulated greater welding UV radiation and magnetic field exposures.

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APPENDIX A

Table A1: Radiometric terms and units.

Source: Diffey (2002).

TERM	UNIT	SYMBOL
Wavelength	Nm	λ
Radiant energy	J	Q
Radiant flux	W	ϕ
Radiant intensity	$W\ sr^{-1}$	I
Radiance	$W\ m^{-2}\ sr^{-1}$	L
Irradiance	$W\ m^{-2}$	E
Radiant exposure	$J\ m^{-2}$	H

Table A2: Equivalent radiometric quantities.

Source: Diffey (2002).

TO CONVERT FROM	TO	MULTIPLY BY
$J\ cm^{-2}$	$mJ\ cm^{-2}$	10^3
$J\ cm^{-2}$	$J\ m^{-2}$	10^4
$J\ m^{-2}$	$mJ\ cm^{-2}$	10^7
$kJ\ m^{-2}$	$J\ cm^{-2}$	10^7
$kJ\ m^{-2}$	$mJ\ cm^{-2}$	10^{10}

Table A3: Static magnetic field quantities and corresponding SI units.

Source: ICNIRP (2009).

QUANTITY	SYMBOL	UNIT
Current	I	Amperes (A)
Current density	J	Amperes per square meter ($A\ m^{-2}$)
Magnetic field strength	H	Amperes per meter ($A\ m^{-1}$)
Magnetic flux	Φ	Weber (Wb or $T\ m^2$)
Magnetic flux density	B	Tesla (T)
Permeability	μ	Henrys per meter ($H\ m^{-1}$)
Permeability of free space	μ_0	$4\pi \times 10^{-7}\ H\ m^{-1}$

Table A4: UV exposure limits and spectral weighting function

Source: ICNIRP (2004).

λ[a] (nm)	EL[d] (J m^{-2})	EL[d] (mJ cm^{-2})	S(λ)[b]	λ[a] (nm)	EL[d] (J m^{-2})	EL[d] (mJ cm^{-2})	S(λ)[b]
180	2,500	250	0.012	310	2,000	200	0.015
190	1,600	160	0.019	313[c]	5,000	500	0.006
200	1,000	100	0.030	315	1.0×10^4	1.0×10^3	0.003
205	590	59	0.051	316	1.3×10^4	1.3×10^3	0.0024
210	400	40	0.075	317	1.5×10^4	1.5×10^3	0.0020
215	320	32	0.095	318	1.9×10^4	1.9×10^3	0.0016
220	250	25	0.120	319	2.5×10^4	2.5×10^3	0.0012
225	200	20	0.150	320	2.9×10^4	2.9×10^3	0.0010
230	160	16	0.190	322	4.5×10^4	4.5×10^3	0.00067
235	130	13	0.240	323	5.6×10^4	5.6×10^3	0.00054
240	100	10	0.300	325	6.0×10^4	6.0×10^3	0.00050
245	83	8.3	0.360	328	6.8×10^4	6.8×10^3	0.00044
250	70	7	0.430	330	7.3×10^4	7.3×10^3	0.00041
254[c]	60	6	0.500	333	8.1×10^4	8.1×10^3	0.00037
255	58	5.8	0.520	335	8.8×10^4	8.8×10^3	0.00034
260	46	4.6	0.650	340	1.1×10^5	1.1×10^4	0.00028
265	37	3.7	0.810	345	1.3×10^5	1.3×10^4	0.00024
270	30	3.0	1.000	350	1.5×10^5	1.5×10^4	0.00020
275	31	3.1	0.960	355	1.9×10^5	1.9×10^4	0.00016
280[c]	34	3.4	0.880	360	2.3×10^5	2.3×10^4	0.00013
285	39	3.9	0.770	365[c]	2.7×10^5	2.7×10^4	0.00011
290	47	4.7	0.640	370	3.2×10^5	3.2×10^4	0.000093
295	56	5.6	0.540	375	3.9×10^5	3.9×10^4	0.000077
297[c]	65	6.5	0.460	380	4.7×10^5	4.7×10^4	0.000064
300	100	10	0.300	385	5.7×10^5	5.7×10^4	0.000053
303[c]	250	25	0.120	390	6.8×10^5	6.8×10^4	0.000044
305	500	50	0.060	395	8.3×10^5	8.3×10^4	0.000036
308	1,200	120	0.026	400	1.0×10^6	1.0×10^5	0.000030

[a] Wavelengths chosen are representative; other values should be interpolated.

[b] Relative spectral effectiveness.

[C] Emission lines of a mercury discharge spectrum.

[d] EL for a monochromatic source, but also limited by a dose-rate of 10 kW m^{-2} (1 W cm^{-2}) for durations greater than 1 s as well in order to preclude thermal effects.

Table A5: Limiting UV exposure durations based on exposure limits.

Source: ICNIRP (2004).

Duration of exposure per day	Effective irradiance	
	E_{eff} (W m^{-2})	E_{eff} (μW cm^{-2})
8 h	0.001	0.1
4 h	0.002	0.2
2 h	0.004	0.4
1 h	0.008	0.8
30 min	0.017	1.7
15 min	0.033	3.3
10 min	0.05	5
5 min	0.1	10
1 min	0.5	50
30 s	1.0	100
10 s	3.0	300
1 s	30	3,000
0.5 s	60	6,000
0.1 s	300	30,000

Table A6: Limiting UVC exposure durations based on exposure limits

Source: ACGIH (2007).

Duration of exposure per day	Effective irradiance (μW cm^{-2})
24 h	0.07
18 h	0.09
12 h	0.14
10 h	0.17
8 h	0.2
4 h	0.4
2 h	0.8
1 h	1.7
30 min	3.3
15 min	6.7
10 min	10
5 min	20
1 min	100
30 s	200
15 s	400
5 s	1200
1 s	6000

Table A7: Reference levels for occupational exposure to time-varying electric and magnetic fields.

Source: ICNIRP (1998).

Frequency range	E-field strength (Vm^{-1})	H-field strength (Am^{-1})	B-field (μT)	Equivalent plane wave power density $S_{eq}(Wm^{-2})$
1Hz	-	1.63×10^5	2×10^5	-
1-8Hz	20 000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	-
8-25Hz	20 000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	-
0.025-0.82kHz	$500/f$	$20/f$	$25/f$	-
0.82-65kHz	610	24.4	30.7	-
0.065-1MHz	610	$1.6/f$	$2/f$	-
1-10MHz	$610/f$	$1.6/f$	$2/f$	-
10-400MHZ	61	0.16	0.2	10
400-2000MHz	$3 f^{0.5}$	$0.008f^{0.5}$	$0.01f^{0.5}$	$f/40$
2-300GHz	137	0.36	0.45	50

*NOTE:

1. *f* as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
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-min period.
4. For peak values at frequencies up to 100 kHz.
5. For peak values at frequencies exceeding 100 kHz. Between 100 kHz and 10 MHz, peak values for the field.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$ min period (*f* in GHz).
7. No E-field value is provided for frequencies, 1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

Table A8: Basic restriction of current density.

Source: Pretorius et al, (2009).

Basic Restriction	Current Density (mA/m^2) not to be exceeded
Occupational	10

APPENDIX B

Table B1. Welding measurement conditions.

Welder Code	Location of Factory	GPS Coordinates	Category of AC Arc Welding Machine (Name)	Arc Current (A)	Year of manufacture	Duration of Use of Welding Machines (Yr.)	Approximate Distance from Welding Arc (cm)
S1	Nungua	5.6202327, -0.09108479	Locally Manufactured	N/A	2004	11	50
S2	Spintex	5.64264931, -0.1008302	Imported (Powerflex)	150	2012	1	50
S3	Spintex	5.63968191, -0.10047573	Locally Manufactured	N/A	2010	5	40
S4	Teshie Nungua	5.6101516, -0.10248716	Imported (Ruston)	200	N/A	5	50
S5	Teshie Nungua	5.61029776, -0.10248906	Locally Manufactured	N/A	2013	2	50
S6	Teshie Nungua	5.6102996, -0.10211324	Locally Manufactured	N/A	2013	2	50
S7	Teshie Nungua	5.60960348, -0.10510313	Locally Manufactured	N/A	2005	10	50
S8	Teshie Nungua	5.60928812, -0.10606181	Locally Manufactured	N/A	2009	6	50
E9	Amahia	5.76623843, -0.14232161	Locally Manufactured	N/A	2015	1	30
E10	Ashiyie	5.76637157, -0.1428642	Locally Manufactured	N/A	2013	2	40
E11	Amanfrom	5.76411187, -0.14397398	Locally Manufactured	N/A	2005	10	50
E12	Frafraha	5.75831672, -0.14632823	Locally Manufactured	N/A	2014	1	50

E13	Adenta	5.7493876, -0.15038492	Locally Manufactured	N/A	2009	6	40
C14	Adenta	5.56319784, -0.14801156	Locally Manufactured	N/A	2010	5	60
C15	La	5.57037955, -0.15594403	Locally Manufactured	N/A	2007	8	60
C16	La	5.56142153, -0.150771554	Locally Manufactured	N/A	2012	3	50
C17	La	5.559846, -0.1496714	Locally Manufactured	N/A	2007	8	50
C18	Teshie	5.58982146, -0.10015983	Locally Manufactured	N/A	2009	6	40
C19	Teshie	5.60664204, -0.09672055	Locally Manufactured	N/A	2002	13	50
C20	Teshie	5.60658817, -0.09659478	Locally Manufactured	N/A	2010	5	60
C21	Teshie	5.60652714, -0.09662555	Imported	220	2010	5	50
S22	Sakumono	5.61743618,-0.07197659	Locally Manufactured	N/A	2009	6	60
S23	Sakumono	5.61733645, -0.07197207	Locally Manufactured	N/A	2004	11	60
S24	Sakumono	5.61557252, -0.07065762	Imported (WIM AC200)	125	2007	8	50
S25	Sakumono	5.6191548, -0.7115111	Imported (Marquette295)	185	2008	7	60
S26	Sakumono	5.61474149, -0.07072291	Locally Manufactured	N/A	2005	10	50
S27	Sakumono	5.6098864, -0.06970203	Locally Manufactured	N/A	2011	4	50
S28	Sakumono	5.60983895, -0.06976869	Imported (BX6-250)	220	N/A	6	60
S29	Nungua	5.61655343, -0.07895289	Locally Manufactured	N/A	2005	10	50

S30	Teshie Nungua	5.61916929, -0.092445195	Locally Manufactured	N/A	2001	14	50
E31	Haatso	5.66761424, -0.19962544	Locally Manufactured	N/A	2013	2	50
E32	Haatso	5.66740979, -0.19955012	Locally Manufactured	N/A	2014	1	60
E33	Haatso	5.66729856, -0.20030773	Locally Manufactured	N/A	2000	15	50
E34	Haatso	5.66714325, -0.20270097	Locally Manufactured	N/A	2012	3	50
E35	Haatso	5.66721634, -0.20258858	Imported (BX1-400)	320	2010	4	50
E36	Haatso	5.66843963, -0.21306464	Imported (Giant BX1-180b)	70	2010	3	50
E37	Haatso	5.66844791, -0.20328402	Locally Manufactured	N/A	2011	4	60
E38	Haatso	5.66333105, -0.20881834	Locally Manufactured	N/A	2011	4	50
E39	Haatso	5.65971992, -0.20444495	Imported(Powerflex250A)	80	2012	2	50
E40	Haatso	5.65941447, -0.20640498	Imported (Gala74)	300	N/A	5	60
W41	Kaneshie	5.56730464, -0.22964621	Locally Manufactured	N/A	2010	5	60
W42	Kaneshie	5.56697905, -0.23830411	Locally Manufactured	N/A	2001	14	50
W43	Old Fadama	5.55139624, -0.22190762	Locally Manufactured	N/A	2013	3	50
W44	Old Fadama	5.55134763, -0.22185051	Locally Manufactured	N/A	2012	3	50
W45	Old Fadama	5.55126171, -0.22173631	Locally Manufactured	N/A	2006	9	50
W46	Agbogbloshie	5.54747218, -0.21795845	Imported	N/A	2012	3	50

W47	Agbogbloshie	5.54732021, 0.2179953	Locally Manufactured	N/A	2010	5	60
W48	Agbogbloshie	5.54675009, -0.21873168	Locally Manufactured	N/A	2005	10	60
S49	Okpoigonno	5.62605497, -0.10057239	Locally Manufactured	N/A	2003	12	60
S50	Okpoigonno	5.62562525, -0.10778262	Locally Manufactured	N/A	2012	3	60
S51	Okpoigonno	5.62664562, -0.10834435	Locally Manufactured	N/A	2008	7	70
S52	Okpoigonno	5.62571901, -0.1015015	Locally Manufactured	N/A	2009	6	50
S53	Okpoigonno	5.62350302, -0.1809716	Locally Manufactured	N/A	2012	3	50
S54	Okpoigonno	5.623545, -0.10094192	Locally Manufactured	N/A	2013	2	60
S55	Okpoigonno	5.6325506, -0.10091239	Locally Manufactured	N/A	2003	12	60
S56	Tema Comm. 20	5.66032226,-0.06977786	Imported	N/A	N/A	19	60
S57	Tema Comm. 20	5.66000787, -0.069708	Locally Manufactured	N/A	2011	4	50
S58	Tema Comm. 20	5.66137402, -0.06619378	Imported (Edon BX6-8000)	80	N/A	2	50
S59	Tema Comm. 18	5.66141593, -0.0649136	Locally Manufactured	N/A	2011	4	50
S60	Tema Comm. 18	5.64959214, -0.064388593	Imported	185	N/A	15	60
S61	Tema Comm. 18	5.64763815, -0.06609698	Locally Manufactured	N/A	2000	15	50
S62	Tema Comm. 17	5.64246784, -0.0703087	Imported (Powerflex)	100	N/A	1	60
S63	Tema Comm. 17	5.64204762, -0.07165471	Locally Manufactured	N/A	1997	18	50

S64	Tema Comm. 17	5.64204035, -0.07165484	Imported (Edon BX6-900)	185	N/A	1	60
S65	Tema Comm. 17	5.63939871, -0.07619579	Imported (Kemtech BX1-400-1)	200	N/A	3	60
S66	Nungua	5.61246575, -0.07643888	Imported (Mannesmann)	115	N/A	4	50
S67	Lashibi	5.6381033, -0.06223421	Locally Manufactured	N/A	2008	7	60
S68	Lashibi	5.63796088, -0.06191679	Locally Manufactured	N/A	2013	2	40
S69	Lashibi	5.63515497, -0.06372695	Locally Manufactured	N/A	2003	12	50
S70	Lashibi	5.63198579, -0.06538234	Imported (Merex)	120	N/A	9	60

*NOTE: N/A depicts questions that were not answered or available at the time of the survey.

Table B2. UVA irradiance level from the arc of SMAW for various welders and corresponding permissible exposure duration.

Welder Code	BG - E_{UVA}	E_{UVA} (mW cm^{-2})					E_{UVA} (W/m^2)	U (±)	$t_{max\text{-}UVA}$ (s)
		1	2	3	Mean (M)	M - BG			
S1	0.153	1.712	1.855	2.31	1.959	1.806	**18.06**	3.61	**553.71**
S2	0.207	1.479	1.472	1.805	1.585	1.378	**13.78**	2.20	**725.51**
S3	0.174	1.043	1.269	1.593	1.302	1.128	**11.28**	3.19	**886.79**
S4	0.128	0.67	0.543	0.78	0.664	0.536	**5.36**	1.37	**1864.51**
S5	0.076	1.602	1.65	1.792	1.681	1.605	**16.05**	1.14	**622.92**
S6	0.119	1.162	1.27	1.772	1.401	1.282	**12.82**	3.76	**779.83**
S7	0.122	0.617	0.595	0.618	0.610	0.488	**4.88**	0.15	**2049.18**
S8	0.017	1.646	1.611	1.756	1.671	1.654	**16.54**	0.87	**604.59**
E9	0.094	1.109	1.112	1.169	1.130	1.036	**10.36**	0.39	**965.25**
E10	0.215	1.758	1.916	2.39	2.021	1.806	**18.06**	3.80	**553.61**
E11	0.013	0.988	0.952	0.975	0.972	0.959	**9.59**	0.21	**1043.12**
E12	0.149	0.771	0.716	0.702	0.730	0.581	**5.81**	0.42	**1722.16**
E13	0.071	0.158	0.157	0.162	0.159	0.088	**0.88**	0.03	**11363.64**
C14	0.286	1.271	1.192	1.109	1.191	0.905	**9.05**	0.94	**1105.38**
C15	0.171	0.35	0.195	0.27	0.272	0.101	**1.01**	0.90	**9933.77**
C16	0.125	0.395	0.408	0.471	0.425	0.300	**3.00**	0.47	**3337.04**
C17	0.175	0.336	0.355	0.46	0.384	0.209	**2.09**	0.77	**4792.33**
C18	0.116	1.154	1.109	0.921	1.061	0.945	**9.45**	1.43	**1057.83**
C19	0.058	0.844	1.011	1.07	0.975	0.917	**9.17**	1.35	**1090.51**
C20	0.036	1.036	1.041	1.206	1.094	1.058	**10.58**	1.12	**944.88**
C21	0.056	1.106	1.081	1.393	1.193	1.137	**11.37**	2.00	**879.25**

S22	0.35	1.616	1.577	1.779	1.657	1.307	**13.07**	1.24	**764.92**
S23	0.198	1.362	1.306	1.519	1.396	1.198	**11.98**	1.28	**834.96**
S24	0.178	0.554	0.538	0.539	0.544	0.366	**3.66**	0.10	**2734.73**
S25	0.213	1.185	1.063	1.108	1.119	0.906	**9.06**	0.71	**1104.16**
S26	0.071	0.214	0.209	0.204	0.209	0.138	**1.38**	0.06	**7246.38**
S27	0.121	0.784	0.822	0.801	0.802	0.681	**6.81**	0.22	**1467.71**
S28	0.09	1.235	1.017	1.136	1.129	1.039	**10.39**	1.26	**962.16**
S29	0.1	0.49	0.59	0.461	0.514	0.414	**4.14**	0.78	**2417.41**
S30	0.064	0.881	0.947	0.993	0.940	0.876	**8.76**	0.65	**1141.12**
E31	0.09	1.846	1.564	1.886	1.765	1.675	**16.75**	2.03	**596.90**
E32	0.04	1.516	1.329	1.566	1.470	1.430	**14.30**	1.44	**699.14**
E33	0.179	0.847	0.886	0.998	0.910	0.731	**7.31**	0.91	**1367.37**
E34	0.163	0.73	0.726	0.835	0.764	0.601	**6.01**	0.71	**1664.82**
E35	0.08	2.38	1.723	2.4	2.168	2.088	**20.88**	4.45	**479.00**
E36	0.111	1.045	1.071	1.062	1.059	0.948	**9.48**	0.15	**1054.48**
E37	0.111	0.929	1.013	1.092	1.011	0.900	**9.00**	0.94	**1110.70**
E38	0.091	1.73	1.635	1.792	1.719	1.628	**16.28**	0.91	**614.25**
E39	0.064	0.123	0.153	0.193	0.156	0.092	**0.92**	0.41	**10830.32**
E40	0.026	1.231	1.398	1.442	1.357	1.331	**13.31**	1.29	**751.31**
W41	0.101	1.411	1.323	1.474	1.403	1.302	**13.02**	0.88	**768.25**
W42	0.199	1.194	1.081	1.182	1.152	0.953	**9.53**	0.72	**1048.95**
W43	0.103	1.041	1.017	1.03	1.029	0.926	**9.26**	0.14	**1079.53**
W44	0.04	1.875	2.23	2.24	2.115	2.075	**20.75**	2.40	**481.93**
W45	0.08	0.685	0.448	0.625	0.586	0.506	**5.06**	1.42	**1976.28**
W46	0.147	0.638	0.61	0.681	0.643	0.496	**4.96**	0.41	**2016.13**
W47	0.098	2.02	2.27	3.12	2.470	2.372	**23.72**	6.66	**421.59**
W48	0.022	2.49	2.33	2.33	2.383	2.361	**23.61**	1.07	**423.49**

S49	0.055	1.228	1.147	1.436	1.270	1.215	**12.15**	1.72	**822.82**
S50	0.101	1.504	1.284	1.583	1.457	1.356	**13.56**	1.79	**737.46**
S51	0.142	1.869	2.1	1.969	1.979	1.837	**18.37**	1.34	**544.27**
S52	0.07	1.586	1.353	1.491	1.477	1.407	**14.07**	1.35	**710.90**
S53	0.029	2.14	2.23	2.71	2.360	2.331	**23.31**	3.54	**429.00**
S54	0.056	1.337	1.283	1.385	1.335	1.279	**12.79**	0.59	**781.86**
S55	0.052	1.554	1.673	1.628	1.618	1.566	**15.66**	0.69	**638.43**
S56	0.122	1.263	1.364	1.317	1.315	1.193	**11.93**	0.58	**838.46**
S57	0.04	1.331	1.478	1.469	1.426	1.386	**13.86**	0.95	**721.50**
S58	0.131	0.883	0.856	0.937	0.892	0.761	**7.61**	0.48	**1314.06**
S59	0.116	0.717	0.821	0.863	0.800	0.684	**6.84**	0.87	**1461.28**
S60	0.052	1.102	0.927	1.165	1.065	1.013	**10.13**	1.42	**987.49**
S61	0.135	1.895	1.783	1.789	1.822	1.687	**16.87**	0.73	**592.65**
S62	0.128	0.684	0.562	0.637	0.628	0.500	**5.00**	0.71	**2001.33**
S63	0.031	1.052	1.211	1.295	1.186	1.155	**11.55**	1.43	**865.80**
S64	0.113	1.361	1.113	1.176	1.217	1.104	**11.04**	1.49	**906.07**
S65	0.041	1.172	1.024	1.028	1.075	1.034	**10.34**	0.97	**967.43**
S66	0.039	0.578	0.562	0.511	0.550	0.511	**5.11**	0.40	**1955.67**
S67	0.033	0.604	0.628	0.658	0.630	0.597	**5.97**	0.31	**1675.04**
S68	0.052	1.459	1.681	1.258	1.466	1.414	**14.14**	2.44	**707.21**
S69	0.025	0.617	0.557	0.527	0.567	0.542	**5.42**	0.53	**1845.02**
S70	0.32	1.984	1.978	1.84	1.934	1.614	**16.14**	0.94	**619.58**

*NOTE:

1. BG is the background reading

Table B3. Table showing UVC irradiance level and estimated Effective Irradiance from the arc of SMAW for various welders and their corresponding permissible exposure duration.

Welder Code	BG - E_{UVC}	E_{UVC} (mW cm^{-2})				E_{UVC} (W/m^2)	U (±)	$t_{max\text{-}UVC}$ (s)	E_{eff} (E_{UVA} + E_{UVC}) / [W m^{-2}]	t_{max} (s)
		1	2	3	M					
S1	0	0.478	0.571	0.369	0.473	**4.73**	1.17	**12.69**	**22.79**	**1.32**
S2	0	0.279	0.332	0.219	0.277	**2.77**	0.65	**21.69**	**16.55**	**1.81**
S3	0	0.207	0.259	0.209	0.225	**2.25**	0.34	**26.67**	**13.53**	**2.22**
S4	0	0.109	0.175	0.146	0.143	**1.43**	0.38	**41.86**	**6.80**	**4.41**
S5	0	0.724	0.708	0.626	0.686	**6.86**	0.61	**8.75**	**22.91**	**1.31**
S6	0	0.344	0.361	0.332	0.346	**3.46**	0.17	**17.36**	**16.28**	**1.84**
S7	0	1.005	1.035	1.02	1.020	**10.20**	0.17	**5.88**	**15.08**	**1.99**
S8	0	0.208	0.336	0.32	0.288	**2.88**	0.81	**20.83**	**19.42**	**1.54**
E9	0	0.931	1.241	0.965	1.046	**10.46**	1.96	**5.74**	**20.82**	**1.44**
E10	0	0.196	0.213	0.211	0.207	**2.07**	0.11	**29.03**	**20.13**	**1.49**
E11	0	0.04	0.058	0.04	0.046	**0.46**	0.12	**130.43**	**10.05**	**2.99**
E12	0	0.121	0.121	0.244	0.162	**1.62**	0.82	**37.04**	**7.43**	**4.04**
E13	0	0.125	0.133	0.103	0.120	**1.20**	0.18	**49.86**	**2.08**	**14.40**
C14	0	0.199	0.208	0.192	0.200	**2.00**	0.09	**30.05**	**11.04**	**2.72**
C15	0	0.115	0.133	0.121	0.123	**1.23**	0.11	**48.78**	**2.24**	**13.41**
C16	0	0.037	0.05	0.022	0.036	**0.36**	0.16	**165.14**	**3.36**	**8.93**
C17	0	0.057	0.075	0.064	0.065	**0.65**	0.10	**91.84**	**2.74**	**10.95**
C18	0	0.066	0.069	0.061	0.065	**0.65**	0.05	**91.84**	**10.11**	**2.97**
C19	0	0.11	0.104	0.113	0.109	**1.09**	0.05	**55.05**	**10.26**	**2.92**
C20	0	0.345	0.399	0.33	0.358	**3.58**	0.42	**16.76**	**14.16**	**2.12**
C21	0	0.132	0.128	0.12	0.127	**1.27**	0.07	**47.37**	**12.64**	**2.37**

S22	0	0.115	0.101	0.157	0.124	**1.24**	0.34	**48.26**	**14.32**	**2.10**
S23	0	0.293	0.294	0.219	0.269	**2.69**	0.50	**22.33**	**14.66**	**2.05**
S24	0	0.042	0.044	0.033	0.040	**0.40**	0.07	**151.26**	**4.05**	**7.40**
S25	0	0.052	0.055	0.04	0.049	**0.49**	0.09	**122.45**	**9.55**	**3.14**
S26	0	0.096	0.11	0.088	0.098	**0.98**	0.13	**61.22**	**2.36**	**12.71**
S27	0	0.16	0.105	0.163	0.143	**1.43**	0.38	**42.06**	**8.24**	**3.64**
S28	0	0.124	0.146	0.128	0.133	**1.33**	0.14	**45.23**	**11.72**	**2.56**
S29	0	0.285	0.369	0.35	0.335	**3.35**	0.51	**17.93**	**7.48**	**4.01**
S30	0	0.174	0.218	0.162	0.185	**1.85**	0.34	**32.49**	**10.61**	**2.83**
E31	0	0.155	0.185	0.178	0.173	**1.73**	0.18	**34.75**	**18.48**	**1.62**
E32	0	0.106	0.121	0.119	0.115	**1.15**	0.09	**52.02**	**15.46**	**1.94**
E33	0	0.12	0.148	0.13	0.133	**1.33**	0.16	**45.23**	**8.64**	**3.47**
E34	0	0.05	0.05	0.062	0.054	**0.54**	0.08	**111.11**	**6.55**	**4.58**
E35	0	0.589	0.641	0.562	0.597	**5.97**	0.46	**10.04**	**26.85**	**1.12**
E36	0	0.065	0.055	0.07	0.063	**0.63**	0.09	**94.74**	**10.12**	**2.97**
E37	0	0.125	0.14	0.161	0.142	**1.42**	0.21	**42.25**	**10.42**	**2.88**
E38	0	0.033	0.04	0.031	0.035	**0.35**	0.05	**173.08**	**16.63**	**1.80**
E39	0	0.16	0.147	0.131	0.146	**1.46**	0.17	**41.10**	**2.38**	**12.59**
E40	0	0.142	0.15	0.122	0.138	**1.38**	0.17	**43.48**	**14.69**	**2.04**
W41	0	0.044	0.052	0.051	0.049	**0.49**	0.05	**122.45**	**13.51**	**2.22**
W42	0	0.279	0.292	0.267	0.279	**2.79**	0.14	**21.48**	**12.33**	**2.43**
W43	0	0.192	0.193	0.104	0.163	**1.63**	0.59	**36.81**	**10.89**	**2.75**
W44	0	0.043	0.057	0.063	0.054	**0.54**	0.12	**110.43**	**21.29**	**1.41**
W45	0	0.065	0.054	0.059	0.059	**0.59**	0.06	**101.12**	**5.65**	**5.31**
W46	0	0.386	0.401	0.41	0.399	**3.99**	0.14	**15.04**	**8.95**	**3.35**
W47	0	0.522	0.514	0.485	0.507	**5.07**	0.22	**11.83**	**28.79**	**1.04**
W48	0	0.181	0.171	0.106	0.153	**1.53**	0.47	**39.30**	**25.14**	**1.19**
S49	0	0.037	0.038	0.031	0.035	**0.35**	0.04	**169.81**	**12.51**	**2.40**

S50	0	0.045	0.05	0.037	0.044	**0.44**	0.08	**136.36**	**14.00**	**2.14**
S51	0	0.243	0.26	0.263	0.255	**2.55**	0.12	**23.50**	**20.93**	**1.43**
S52	0	0.023	0.016	0.01	0.016	**0.16**	0.08	**367.35**	**14.23**	**2.11**
S53	0	0.118	0.132	0.107	0.119	**1.19**	0.14	**50.42**	**24.50**	**1.22**
S54	0	0.11	0.135	0.11	0.118	**1.18**	0.17	**50.70**	**13.97**	**2.15**
S55	0	0.118	0.143	0.161	0.141	**1.41**	0.25	**42.65**	**17.07**	**1.76**
S56	0	0.047	0.062	0.066	0.058	**0.58**	0.12	**102.86**	**12.51**	**2.40**
S57	0	0.132	0.143	0.107	0.127	**1.27**	0.21	**47.12**	**15.13**	**1.98**
S58	0	0.115	0.106	0.133	0.118	**1.18**	0.16	**50.85**	**8.79**	**3.41**
S59	0	0.129	0.136	0.104	0.123	**1.23**	0.19	**48.78**	**8.07**	**3.72**
S60	0	0.174	0.176	0.169	0.173	**1.73**	0.04	**34.68**	**11.86**	**2.53**
S61	0	0.087	0.091	0.097	0.092	**0.92**	0.06	**65.45**	**17.79**	**1.69**
S62	0	0.092	0.1	0.131	0.108	**1.08**	0.24	**55.73**	**6.07**	**4.94**
S63	0	0.115	0.123	0.129	0.122	**1.22**	0.08	**49.05**	**12.77**	**2.35**
S64	0	0.123	0.122	0.104	0.116	**1.16**	0.12	**51.58**	**12.20**	**2.46**
S65	0	0.085	0.073	0.073	0.077	**0.77**	0.08	**77.92**	**11.11**	**2.70**
S66	0	0.019	0.018	0.016	0.018	**0.18**	0.02	**339.62**	**5.29**	**5.67**
S67	0	0.045	0.046	0.03	0.040	**0.40**	0.10	**148.76**	**6.37**	**4.71**
S68	0	0.364	0.371	0.318	0.351	**3.51**	0.33	**17.09**	**17.65**	**1.70**
S69	0	0.205	0.204	0.129	0.179	**1.79**	0.50	**33.46**	**7.21**	**4.16**
S70	0	0.076	0.068	0.06	0.068	**0.68**	0.09	**88.24**	**16.82**	**1.78**

*NOTE:

1. BG is the background reading

Table B4. Magnetic flux density and expected induced current density in the head and trunk of a SMAW welder.

Welder Code	MAGNETIC FIELD, B (mG)							B / μT	U (±)	Induced current density in the head, J_{head} (mA/m^2)	Induced current density in the trunk, J_{trunk} (mA/m^2)
	BG	B1	B2	B3	Mean B_0	Mean B	B (mean B - BGD)				
S1	1.9	429.03	485.22	419.7	442.75	447.18	445.28	44.53	4.09	0.14	0.28
S2	0.78	169.29	145.35	131.31	147.87	149.35	148.57	14.86	2.22	0.05	0.09
S3	0.27	791.04	490.05	872.09	717.46	724.63	724.36	72.44	23.24	0.23	0.46
S4	0.14	40.36	33.58	46.05	39.86	40.26	40.12	4.01	0.72	0.01	0.03
S5	0.18	482.61	424.91	509.09	472.02	476.74	476.56	47.66	4.97	0.15	0.30
S6	1.7	912.65	800.25	855.53	854.44	862.99	861.29	86.13	6.49	0.27	0.54
S7	1.75	585.99	488.07	527.27	532.03	537.35	535.60	53.56	5.69	0.17	0.34
S8	2.65	316.63	396.23	566.61	423.84	428.08	425.43	42.54	14.75	0.13	0.27
E9	1.15	1930. 16	1977.17	1917.68	1946.28	1965.74	1964.59	196.46	4.86	0.62	1.23
E10	1.11	178.13	346.33	375.46	298.86	301.85	300.74	30.07	12.30	0.09	0.19
E11	1.13	253.13	248.11	305.11	267.65	270.33	269.20	26.92	3.64	0.08	0.17
E12	0.13	328.68	341.28	424.52	364.70	368.34	368.21	36.82	6.01	0.12	0.23
E13	0.77	102.64	127.96	135.04	121.11	122.32	121.55	12.16	1.97	0.04	0.08
C14	1.48	640.91	555.01	460.04	550.51	556.01	554.53	55.45	10.45	0.17	0.35
C15	0.38	639.93	494.13	446.27	526.40	531.66	531.28	53.13	11.65	0.17	0.33
C16	0.61	113.19	133.33	151.54	132.08	133.40	132.79	13.28	2.22	0.04	0.08
C17	0.68	329.71	217.11	214.53	253.10	255.63	254.95	25.50	7.59	0.08	0.16
C18	0.2	424.59	470.61	522.08	472.23	476.95	476.75	47.67	5.63	0.15	0.30

C19	5.64	260.47	290.16	243.17	258.96	261.55	255.91	25.59	2.74	0.08	0.16
C20	2.55	235.24	211.77	255.93	231.76	234.08	231.53	23.15	2.55	0.07	0.15
C21	1.2	382.07	526.79	502.81	469.36	474.05	472.85	47.29	8.96	0.15	0.30
S22	0.13	411.01	627.32	579.44	539.13	544.52	544.39	54.44	13.12	0.17	0.34
S23	0.75	141.33	114.62	97.89	117.20	118.37	117.62	11.76	2.53	0.04	0.07
S24	0.13	333.81	410.76	384.11	376.10	379.86	379.73	37.97	4.51	0.12	0.24
S25	0.6	225.17	216.03	216.79	218.73	220.92	220.32	22.03	0.59	0.07	0.14
S26	0.17	1025	998.44	1108.81	1043.91	1054.35	1054.18	105.42	6.65	0.33	0.66
S27	4.7	143.05	153.16	204.01	162.04	163.66	158.96	15.90	3.77	0.05	0.10
S28	2.73	475.89	423.6	417.11	436.14	440.50	437.77	43.78	3.72	0.14	0.28
S29	0.21	224.34	246.29	216.05	228.68	230.97	230.76	23.08	1.80	0.07	0.15
S30	1.79	499.19	521.53	507.64	507.66	512.74	510.95	51.09	1.30	0.16	0.32
E31	2.77	752.09	778.45	743.32	755.18	762.74	759.97	76.00	2.11	0.24	0.48
E32	0.96	1034.21	1130.01	999.58	1053.64	1064.18	1063.22	106.32	7.80	0.33	0.67
E33	1.99	513.09	579.27	531.18	539.19	544.58	542.59	54.26	3.95	0.17	0.34
E34	0.38	368.11	331.19	328.11	342.09	345.51	345.13	34.51	2.57	0.11	0.22
E35	0.34	425.03	521.67	405.81	450.50	455.00	454.66	45.47	7.17	0.14	0.29
E36	1.98	142.62	128.13	159.66	141.49	142.90	140.92	14.09	1.82	0.04	0.09
E37	0.58	404.8	305.13	400.18	369.46	373.15	372.57	37.26	6.50	0.12	0.23
E38	2.94	515.19	428.08	491.72	475.39	480.14	477.20	47.72	5.20	0.15	0.30
E39	1.64	602.11	689.09	569.27	618.52	624.70	623.06	62.31	7.15	0.20	0.39
E40	0.59	601.82	668.11	543.07	603.74	609.78	609.19	60.92	7.22	0.19	0.38
W41	1.19	1007.17	969.25	908.87	960.57	970.18	968.99	96.90	5.72	0.30	0.61
W42	0.97	230.15	201.23	218.19	215.55	217.71	216.74	21.67	1.68	0.07	0.14

W43	13.15	708.71	326.04	332.21	442.50	446.93	433.78	43.38	25.31	0.14	0.27
W44	11.98	429.08	412.12	460.71	421.99	426.21	414.23	41.42	2.85	0.13	0.26
W45	9.05	179.11	175.91	188.02	171.96	173.68	164.63	16.46	0.72	0.05	0.10
W46	1.33	580.01	586.29	483.11	548.47	553.96	552.63	55.26	6.68	0.17	0.35
W47	1.84	657.71	643.28	611.93	635.80	642.16	640.32	64.03	2.70	0.20	0.40
W48	2.14	151.29	155.91	152.63	151.14	152.65	150.51	15.05	0.27	0.05	0.09
S49	1.01	253.81	248.02	338.11	278.97	281.76	280.75	28.07	5.82	0.09	0.18
S50	3.99	310.01	313.72	299.08	303.61	306.65	302.66	30.27	0.88	0.10	0.19
S51	4.96	201.72	263.16	287.19	245.73	248.19	243.23	24.32	5.09	0.08	0.15
S52	0.97	798.01	594.73	603.21	664.35	670.99	670.02	67.00	13.28	0.21	0.42
S53	1.48	307.17	317.19	397.05	338.99	342.38	340.90	34.09	5.69	0.11	0.21
S54	0.87	475.28	465.01	437.18	458.29	462.87	462.00	46.20	2.28	0.15	0.29
S55	2.3	492.45	244.38	255.96	328.63	331.92	329.62	32.96	16.17	0.10	0.21
S56	0.2	173.17	157.86	164.33	164.92	166.57	166.37	16.64	0.89	0.05	0.10
S57	0.23	663.01	602.31	573.18	612.60	618.73	618.50	61.85	5.29	0.19	0.39
S58	0.25	264.73	283.1	267.11	271.40	274.11	273.86	27.39	1.15	0.09	0.17
S59	1.87	209.01	268.46	398.11	289.99	292.89	291.02	29.10	11.17	0.09	0.18
S60	0.32	300.81	290.61	277.58	289.35	292.24	291.92	29.19	1.34	0.09	0.18
S61	0.29	753.11	713.26	682.01	715.84	723.00	722.71	72.27	4.11	0.23	0.45
S62	2	330.21	336.01	322.11	327.44	330.72	328.72	32.87	0.81	0.10	0.21
S63	1.25	76.01	66.19	82.17	73.54	74.28	73.03	7.30	0.93	0.02	0.05
S64	1.32	1000.02	999.91	1011.01	1002.33	1012.35	1011.03	101.10	0.74	0.32	0.64
S65	13.71	201.01	226.11	254.33	213.44	215.57	201.86	20.19	3.08	0.06	0.13
S66	0.36	225.48	221.13	217.71	221.08	223.29	222.93	22.29	0.45	0.07	0.14

S67	7.72	277.12	273.26	249.81	259.01	261.60	253.88	25.39	1.71	0.08	0.16
S68	0.23	448.11	491.01	442.03	460.15	464.75	464.52	46.45	3.08	0.15	0.29
S69	6.08	669.91	780.63	793.1	741.80	749.22	743.14	74.31	7.83	0.23	0.47
S70	7.08	152.28	109.01	88.76	109.60	110.70	103.62	10.36	3.75	0.03	0.07

*NOTE:

1. Mean B is Mean B_o multiplied by the correction factor of 1.01
2. BG is the background reading

APPENDIX C

Questionnaires administered to welders to assess commonly reported symptoms of health effects of UV radiations and ELF magnetic fields.

GRADUATE SCHOOL OF NUCLEAR AND ALLIED SCIENCES

UNIVERSITY OF GHANA

This questionnaire is designed for the purpose of assessing the levels of ultraviolet radiations and magnetic fields for a project. Responses to questions and statements contained in it shall be used for no other purpose than for the purpose of the study. All persons who take part in the study are assured of their anonymity, and consequently, no one is required to write his or her name on the questionnaire.

1. Location of Company ……………………………………………………………..
2. What is your age, please? 16 – 25 ☐ 26 – 35 ☐ 36 – 45 ☐ 46 – 55 ☐
   56 – 65 ☐ 66 and above ☐
3. How many years have you been welding? ……………………………………………
4. No. of years working at current company ………………………………………………
5. No. of working days a week ……………………………………………………………
6. No. of working hours in a day ………………………………………………………
7. Do you take leave every year? Yes ☐ No ☐
8. How many days of leave do you take per year? ………………………………………..
9. Do you often weld without eye protection (goggles)?

Frequently ☐ Sometimes ☐ Never ☐

10. Where did you purchase the goggles from and on whose advice?

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………………………………………………………………………………………………………

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11. Do you often weld without protective coat?

Frequently ☐ Sometimes ☐ Never ☐

12. Where did you purchase the coat from and on whose advice?

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13. Have you attended any training program/workshop on safety before? Yes ☐ No ☐

14. What is your opinion on safety?

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………………………………………………………………………………………………………

……………………………………………………………………………………………………

15. Which of these symptoms and any other do you experience?

		Occasionally	Always
Redness of skin	☐	☐	☐
Prickling and Burning sensations	☐	☐	☐
Blisters	☐	☐	☐
Itchiness in the eye	☐	☐	☐
Cloudy vision	☐	☐	☐

Nausea	☐	☐	☐
Headache	☐	☐	☐
Heart palpitation	☐	☐	☐
Other(s) 1. …………………………………		☐	☐
2. …………………………………		☐	☐
3. …………………………………		☐	☐

16. Are there hospitals or clinics readily available at your disposal? Yes ☐ No ☐

17. Do you think safety has had an impact on your health? Yes ☐ No ☐

18. Do you have any other comments about the effects of welding on your health?

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