Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/060302

Evaluation of Occupational Exposure to Extremely Low Frequency Magnetic Fields in Shield Metal Arc Welding Processing in Accra, Ghana

A. Sawyerr [1], Joseph K. Amoako [2], John J. Fletcher [3], E. Sosu [4], M. Portuphy [5] and J. Kalognia [1]*

[1] Institute of Scientific and Technology Information (INSTI) – Council for Scientific and Industrial Research (CSIR), Ghana.
[2] Radiation Protection Institute, Ghana Atomic Energy Commission, Ghana.
[3] University for Development Studies, Navrongo, Ghana.
[4] Radiological and Medical Sciences Research Institute, Ghana Atomic Energy Commission, Ghana.
[5] Office of Research, Innovation and Development, University of Ghana.

Received: 1 Jun .2021, Revised: 13 Jul .2021, Accepted: 11 Aug. 2021.
Published online: 1 Sep. 2021.

Abstract: The shielded metal arc welding (SMAW) is the most commonly employed welding method in Ghana. This welding process can also produce some levels extremely low-frequency (ELF) magnetic fields (MFs) from the welding arc. The primary objective of this study was to quantify the level of 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. 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. 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 10 mA/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 ELF MF exposure.

Keywords: Non-ionizing radiation, extremely low-frequency, magnetic fields, induced current density.

1 Introduction

Extremely low-frequency (ELF) magnetic fields (MFs) are part of the Non-ionizing radiation (NIR). ELF fields designate the electromagnetic fields with frequencies 0 *Hz* to 3000 *Hz*. 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 [1,2].

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 [3]. Electric fields on the other hand are easily shielded with conductive suits and protective clothing [4]. 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

*Corresponding author e-mail: asawyerr001@st.ug.edu.gh

"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 [1,5]. It is for this reason that this study focused on 50 *Hz* magnetic fields.

Both workers and general public can be exposed to ELF MFs 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 are found to cause much lower exposure (0.5-3 μT), but buried cables virtually none. The electric and magnetic fields strength weakens rapidly with distance from power lines. Extremely low frequency fields often reach or exceed the recommended limits for workers including welders. ELF MFs are also generated by induction and light arc ovens and welding devices, and it is advised that exposure of workers who use such devices is controlled [1].

In the Greater-Accra region, Ghana, 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. 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 [6].

ELF radiations, Ultraviolet radiation, visible and infrared 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 [7]. 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 affected individuals that electric and/or magnetic ELF fields, or closeness to activated electrical equipment trigger the symptoms. A relationship between ELF field exposure and those symptoms has not yet been demonstrated in scientific studies. It remains uncertain if there is a relation between extremely-low frequency field exposure and some neurodegenerative diseases such as Alzheimer's, but some current data suggests there might be such a relation [1, 8].

However, no comprehensive work of assessing the extent of exposure and potential risks to the welder that could result from the ELF MFs emanating from the welding arc, some of whom do not wear Welding Gear or Personal Protective Equipment (PPE). This proposed research will demonstrate the ELF MF exposure conditions to the welders in the Greater-Accra Region and compare them to acceptable guidelines proposed by recognized international and national agencies. One such agency is the International Commission on Non-Ionising Radiation Protection (ICNIRP) which 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. The ICNIRP Guidelines [9] are summarised in Table 1.

Table 1: Summary of the ICNIRP Exposure Guidelines [9].

Reference Level (Occupational)	Basic Restrictions (Occupational)
Magnetic Field (μT)	Current Density (mA/m^2) not to be exceeded
500	10

An important 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 understood to mean the determination of internal EM fields' [10]. 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 [8, 11]. A magnetic field can be signified as a vector and can 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:

$$B = \mu_0 H \qquad (1)$$

The constant of proportionality, μ_0 in equation (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

$$J = \sigma E \quad (2)$$

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:

$$F = q\,(v \times B) \quad (3)$$

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 [11].

1.1 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

$$J = \sigma\, .\pi\, .r.\ f\, .B \quad (4)$$

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 [12] which is about 200 mm for the trunk and 100 mm for the head [5].

2 Experimental Section

2.1 Study Population

At least, 70 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.

2.2 Measurement Instrumentation

An AC Milligauss Meter Model UHS2 (manufactured by AlphaLab, Inc., 3005 S 300 W, South Salt Lake, UT 84115, USA) 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*. The meter was well calibrated before use for quality assurance purposes. Measurements were taken in close proximity to the welders head or trunk.

2.3 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 distance between the welder and the welding arc, the date and time were recorded. 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.

2.4 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 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 three 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.

2.5 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 health 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.

2.6 Uncertainty Estimation

To calculate the uncertainty of the magnetic field 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 for the magnetic field, u(B) was first found by calculating the combined standard uncertainty, u_c in (5) [13].

$$u_c = \sqrt{u_1{}^2 + u_2{}^2} \qquad (5)$$

Where, u_1 = instrument uncertainty

u_2 = standard uncertainty

Because the distribution was a normal one, *u(B)* was calculated using (6)

$$u_1 = \frac{S}{\sqrt{n}} \qquad (6)$$

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

The AC Milligauss Meter read to the smallest division or unit of 0.01. Therefore, to estimate the instrument uncertainty, the smallest division is multiplied by interpolation factor of 0.5 as in (7).

$$u_2 = \text{interpolation fraction} \times \text{smallest division} \qquad (7)$$

Therefore, the instrument uncertainty for the AC Milligauss Meter is ±0.005. This was taken as uniformly distributed uncertainty.

To find the standard uncertainty (8) is used,

$$u_2 = \frac{a}{\sqrt{3}} \qquad (8)$$

Where,

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

Therefore, the standard uncertainty for the AC Milligauss Meter is

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

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

The combined standard uncertainty, u_c was then found using the formula in (9)

$$u_c = \sqrt{u_1{}^2 + u_2{}^2} \qquad (9)$$

The expanded uncertainty, U at a 95 % confidence level was found by multiplying the combined standard uncertainty by a coverage factor, k = 2 [13].

Symbolically, $U = k \times u_c$

$$= 2 \times u_c$$

Therefore, the magnetic flux densities were written as $\bar{x} \pm$ U in the units of μT. This reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95% [7].

3 Results and Discussion

3.1 Information about Welding Measurement Conditions

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. 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*.

3.2 Assessment of ELF MFs from SMAW

3.2.1 Magnetic Flux Densities from SMAW

Figure 1 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.

From Figure 1, 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.

The average magnetic flux density was consistent with that of Man *et al.*, 2008 which was found to be close to 40 μT [2].

3.3 Induced Current Density

The heads, J_{head} and trunks, J_{trunk} was considered in calculating the induced current density, J, resulting from the SMAW welder's exposure to power frequency magnetic fields. J_{head} and J_{trunk} were calculated using equation (4). Figure 2 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.

From Figure 2, the expected J_{head} and J_{trunk} 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 and 0.03 to 1.23 mA/m^2 respectively. The average expected J_{head} and J_{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.

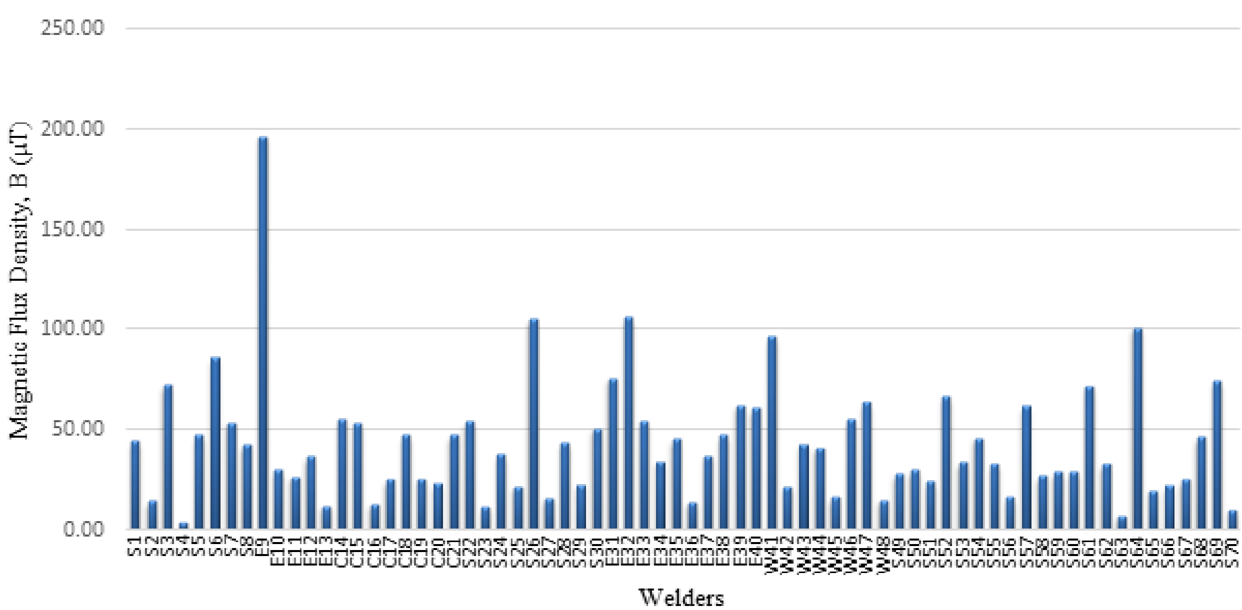

Fig. 1: Magnetic flux densities from various welders using SMAW.

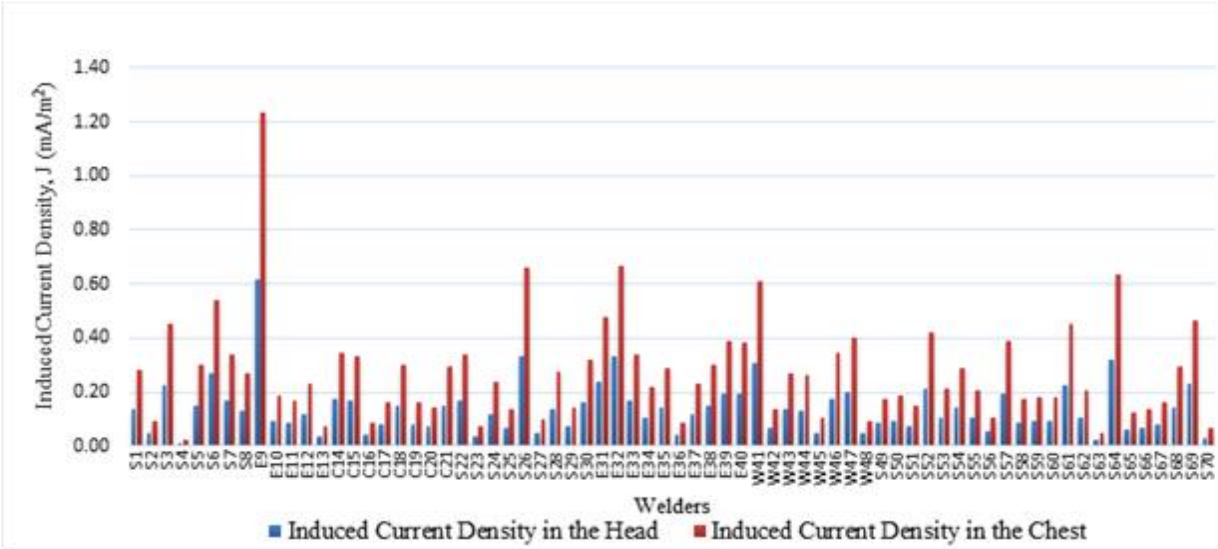

Fig. 2: Expected induced current density in the head and trunk of a SMAW welder exposed to the magnetic fields.

3.4 Analysis of Health Effects

Although, the magnetic flux densities did not exceed the ICNIRP Reference Level, it was observed that most of the welders experienced symptoms related to biological effects of ELF MF with itchiness in the eye being the highest reported case (97.14 %) followed by prickling and burning sensations (92.86%) from the analysis of the questionnaire. These may be due to inadequate safety practices among the welders since most confirmed to 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. It was determined that most of the used 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 and if corrected can reduce the occurrence these health effects.

4 Conclusions

The ELF MFs measurements showed that the magnetic flux densities, B from the SMAW processes 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. 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. Although, the magnetic flux densities did not exceed the ICNIRP Reference Level, from the analysis of the questionnaire it was observed that most of the welders experienced symptoms related to biological effects of ELF MF. These effects are likely to reduce if the welders improve their safety practices.

Acknowledgements

The authors would like to thank Catherine Adjei, Gladstone Sawyerr, Regina Sawyerr, Toyin Sawyerr, Ayodele Sawyerr, Mr. Ojumiri Sawyerr and Theo Sowah for their keen interest and encouragement.

References

[1] Greenfacts. Electromagnetic Fields Update, 2009.
[2] WHO. Electromagnetic Fields and Public Health: Extremely Low Frequency Fields. Fact sheet N205, 1998.
[3] A.K. Man and R. Shahidan, Variations in Occupational Exposure to Magnetic Fields among Welders in Malaysia. Radiation Protection Dosimetry., **128 (4)**, 444-8, 2008.
[4] P.H. Pretorius, P. Luhlanga and P.T. Bhulose, Magnetic Field Exposure of Live Line Workers on High Power Transfer 765 kV and 400 kV Power Lines. Proceedings of the 16th International Symposium on High Voltage Engineering, Johannesburg, South Africa., 2009.
[5] J.E. Moulder. Power-frequency fields and cancer, Crit Rev Biomed Eng,, **26**, 1-116, 1998.

[6] E. Adu and A. Danquah. Welding Practices in Selected Metal Welding Industries in Ghana. IJSER, **7(6)**, 462-73, 2016.

[7] A. Sawyerr, J.J. Fletcher, J. Amoako and E. Sosu. Assessment of Levels of Occupational Exposure to UV-A and UV-C Radiation among Shielded Metal Arc Welders in Accra, Ghana. Atom Indonesia., **4(2)**, 115-24, 2020.

[8] A.M. Garcia, A. Sisternas and S.P. Hoyos, Occupational Exposure to Extremely Low Frequency Electric and Magnetic Fields and Alzheimer Disease: A Meta- Analysis. Int. J. Epidemiol., **37**, 329-40 (2008).

[9] ICNIRP. Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300GHz), Health phys., 1998.

[10] S. Osei. Assessment of Levels of Occupational Exposure to Electromagnetic Fields to Workers in Television Stations in Accra-Ghana, MPhil thesis, University of Ghana, Legon, Ghana., 2012.

[11] ICNIRP. Guidelines of Exposure to Static Magnetic Fields; Health phys., 2009.

[12] ICRP. Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values, Annals of the ICRP, Publication., **89**, 2003.

[13] A, Possolo. Simple Guide for Evaluating and Expressing the Uncertainty of NIST Measurement Results. NIST Technical Note 1900, National Insstitute of Standards and Technoloogy, Gaithersburg, MD., 2015.