University "Politehnica" of Bucharest

Doctoral School of Electrical Engineering

DOCTORAL THESIS SUMMARY

Electromagnetic Ambient and Interference Phenomena in Medical Environment

PhD student: **Husssain Kazem Leaibi Alnamir**

PhD supervisor: **Prof. Univ. Dr. Eng. Mihaela Morega**

Bucharest, 2020

Contents

ABSTRACT

Electromagnetic field emissions are considered today a significant pollution factor for the clinical environment; dangerous electromagnetic emissions might exist around various electrical or electronic equipments and might cause the failure of medical devices or harm the human body.

In this study, the theoretical information has been obtained through careful documentation and synthesis from many articles and websites. It provides historical landmarks and information regarding the standards and regulations of EMC. Also, this study is presenting the limits of exposure accepted for the human body at low frequency levels. The measurements address low frequency magnetic field indoors, in various clinical intervention rooms and operational spaces in hospitals, where the medical staff carries out the current work in day-to-day activities. RMS values of the magnetic flux densities are determined in several organized measurements sessions, by a magnetic field meter of general use, which was successfully verified in a comparison test against a certified precision device. The assessment of human exposure in such environments could be used for classifying various groups of medical personnel and / or working environments and / or working conditions with regard to typical low frequency magnetic field stress in health care units.

Some electromagnetic compatibility elements are studied in hospital environment, and a survey is presented, aiming to recognize the perception of the hospitals high-qualified personnel regarding the electromagnetic interference problems in clinical environment. We have studied the distribution of the magnetic flux densities in a variety of areas inside hospitals for the purpose of estimating the level of exposure to low frequency magnetic field of health care operative personnel.

INTRODUCTION

Due to the diversification of anthropogenic magnetic field sources, numerous studies have led to field monitoring and, at the same time, to diminishing the disturbing effects that are produced by it. Electrical systems were noted as the main sources of low frequency magnetic field. The field generated by them can lead to disturbing effects on both people and equipment.

By using one commercial equipment made by the company (EXTECH), for magnetic field surveillance, in the thesis, we studied the spatial distribution of low frequency magnetic field in numerous areas in hospitals and problems of the electromagnetic interference in the hospital environments.

We also presented specific methods for measuring and analysing the magnetic field to each studied area, among which a method of representing the spatial distribution of magnetic field using a small number of measurements, for different areas in hospitals environment, and we made a survey for the determination of the knowledge of hospital personnel regarding the electromagnetic interference problems.

Research questions addressed by a genuine survey study (in Iraq)

1. What kind of electro-magnetic compatibility issue, which results from intentional emitters, could be identified in the hospital environments of the modern days, and what is the risk associated with their use?

2. Is Hospitals personnel familiarized with electromagnetic interference problems?

3. Are there worries regarding hospitals workers constantly exposed to MF higher than regulatory limits?

ORGANIZATION OF THE WORK

The doctoral thesis entitled “Electromagnetic Ambient And Interference Phenomena In Medical Environment ”is structured in five chapters, being preceded by an introduction. The entire research study is presented over 123 pages, using 77 figures, 25 tables, 141 bibliographic references.

In Chapter 1, “normative framework for limiting human exposure to electromagnetic field (international standards and guidelines); particular references for the clinical environment,” We have presented the purpose and importance of measuring the magnetic field generated by electrical systems. We also presented some regulations adopted at national and international level on exposure of both general public and occupational to the magnetic fields .

Chapter 2, entitled “methods and instrumentation for low frequency magnetic field measurements “presents some principles and measurement criteria, the use of special equipment, the choice of measuring areas and the application of specific methods for each area, depending on the existing sources and the complexity of the studied space.

Chapter 3, “a study of the problems of the low frequency electro-magnetic interference in the hospital environments”, will present a study that is concerned with impact of the electro-magnetic radiations from the electric devices in the hospitals (i.e. the medical equipment, appliances and mains). The analyzed data have been taken from a number of the Iraqi hospitals. This study included 2 parts: (a) A survey that has been focused upon evaluating the understanding and perception of hospital staff about the problem of electro-magnetic interference (EMI), (b) the data that is related to a campaign of the measurements that aim at identifying the magnetic field levels in several hospitals.

Chapter 4, “study of low frequency electromagnetic field near the magnetic resonance imaging area”, presents the results of measuring magnetic field in several areas near a magnetic resonance imaging unit. For this purpose, we performed measurements and characterized an magnetic field study strategy near the MRI scanners, this study reached spot measurements in various points using EMF TESTER EXTECH with frequency between 30 - 300 Hz. For every room we identified the spatial variability related to MF at 3 distinctive distance values (0.3 m, 1m and 2m) from the floor. The magnetic field results were determined throughout in the case when MRI has been ON and outside the program in a case where MRI was OFF, while the research area is divided right in four sections: A waiting room (WR), Hall area, Control room (CR), Technical room (TR).

In Chapter 5, entitled “assessment of magnetic field density produced in operating rooms”, we presented the estimation of the magnetic field density in the operating room for medical personnel standing, near the patient and in the anesthesiologist position. In the following stage, the magnetic field density strength was measured in various orientations, at 0.1, 0.5, and 1m distance from the device, with a single device functioning, while all other systems were disconnected.

1. CHAPTER 1: NORMATIVE FRAMEWORK FOR LIMITING HUMAN EXPOSURE TO ELECTROMAGNETIC FIELD (INTERNATIONAL STANDARDS AND GUIDELINES); PARTICULAR REFERENCES FOR THE CLINICAL ENVIRONMENT

1.1. Why focusing on EMFs?

EMFs can be produced by all sorts of equipment and systems are existing majorly in all the things surrounding us, particularly because of utilizing manufactured electric current. EMFs might affect employees in various activity areas. Also, the exposure properties were significantly distinctive compared to that of public: workers might be exposed to higher levels compared to the public; they are typically closer to high power sources, while the EMF modulation is more difficult. There are various health effects were investigated based on the distance and strength of sources [Feychting M 2005]. In addition, the symptoms related to acute consequences were well-defined in numerous studies. With regard to radio frequency range, severe burns might occur, whereas in very-low frequency range, the created currents have the ability of affecting the nervous system's function, while the exposed individuals might be experiencing metallic taste feeling, nausea and vertigo, as documented by various publications.

1.1.1. Electric and Magnetic Fields

1.1.1.1. Electric Fields

In order to produce electrical energy, the electricity flow (voltage) involves a pressure which generates an electric field and the electricity quantity (i.e. the current) creates a magnetic field. While a piece of equipment is energised, the voltage is constant. The electrical field is directly proportionate with the voltage, which has been indicated by the fact that higher voltage generates higher electrical field. If the device is not powered, but the power point is connected, the EF is still present, as power cord continues to be energized. Numerous elements of the environment shield the electric field, such as objects, buildings, human skin or trees, which makes the electric fields around buried electrical cables insignificant. The electric field's strength is decreased with the increase of distance from source. For measuring the strength of the electric field, volts per metres (V/m) or kilo-volts (1000 V) per metres (kV/m) are the commonly used units.

1.1.1.2. Magnetic Fields

Moving current produces a magnetic field, directly proportionate with the electric current, as the magnetic field increase at higher currents. A device does not generate a magnetic field while completely powered down. Similarly to electric fields, the MF losses strength in the case of an increase of distance from the source. However, the elements of an environment do not provide shielding against magnetic fields, as in the electric field cases. In order to describe magnetic fields, the common practice is to use their flux density measured in Tesla (T) or older unit of Gauss (G)

» 1 Tesla (T) = 1000 milliT (mT) = 1000000 microT (µT)

» 1µT = 10mG

» 1Gauss (G) = 1000 milliG (mG)

1.2. Exposure to very low-frequency fields

Since each one of the electrical equipment is considered as ELF source that is related to EMF, there were many sources with difficulty in considering all of them. Therefore, the direction is originated only on our knowledge with exposure evaluation regarding industrial high-direct exposure ELF sources. Generally, the work environment is very large domain with low-frequency field (LF) EMFs of which very low frequency (ELF: 30Hz -- 300Hz) field sources were representatives of high importance [WHO 2007].

1.3. Guidelines and Exposure Limits to EMF

At international level, there are two guidelines which include regulations on exposure limits to magnetic and electric fields. These guidelines issued by ICNIRP in 2010[ICNIRP 2010] and by International Committee on Electro-magnetic Safety, IEEE in USA in 2002[Standard C95.6].

1.3.1. ICNIRP Guidelines

In November 2010, ICNIRP reported its final version related to the guidelines to protect the health of individuals exposed to the ELF-EMF; this document represents an extended revision of the previous version of the same guidelines for low frequency EF, MF and EMFs, of 1998. Coinciding with ICNIRP 2010 limits which are permitted for the human exposures to the magnetic fields at a (50Hz – 60Hz) power frequency for the occupational exposures are 1mT and for the general exposure 0.20mT.

1.3.2. IEEE standard

The aim of this standard is limiting the levels of exposure against the dangerous impacts from the exposures to the ELF-EMF from 0Hz to 3kHz. The standard has been based upon the analyses which have been related to verified biological impacts in the human beings from magnetic and electric field exposures. The allowed exposures for 50Hz are in the following way:

- MF: 75800μT (arms and legs), 904μT (head and torso);
- Electric field: 5kV/m - 10kV/m.

It is indicated that limits of IEEE for the magnetic field was higher compared to the recommendations of ICNIRP 1998 document for general public exposures, while it was very close to reference for the work environment exposure. The ICNIRP 2010 document brings a closer harmonization of the provisions with IEEE.

2. CHAPTER 2: METHODS AND INSTRUMENTATION FOR LOW FREQUENCY MAGNETIC FIELD MEASUREMENTS

2.1. METHODS AND TOOLS FOR EXPOSURE ASSESSMENT

2.1.1. Methods

This section gives a brief of the measurement principles of commonly used magnetic field sensors that can be considered for magnetic field measurements in the required field strength range. Every method has its own characteristic strengths and drawbacks that should be carefully evaluated for the specific application.

2.1.1.1. Induction coils

Because of their extremely high linearity and virtually unlimited dynamic range, induction coils are widely used to sense magnetic fields. The operating principle of a sensor with an induction coil is shown in (Fig.2.8), if a wire loop is put into time varying magnetic flux density B(t) normal to the loop plane, a voltage U(t) is induced at the terminals of the loop. The induced voltage is dependent on the mechanical construction of a loop (number of turns N and surface area A) in addition to the magnitude of the density of magnetic flux and can be computed according to equation.

$$U(t) = \frac{-d\Phi}{dt} = -N \,.\, A \,.\, \frac{d\,|\,B(t)\,|}{dt}$$

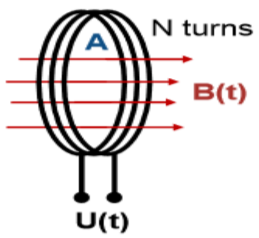

Figure 2.8. The operating principle of an induction coil

As the induced voltage is proportionate with the time derivative of the density of the magnetic flux, an integrator circuit is required to get the correct time representation of measured magnetic flux density B (t). Furthermore, the sensitivity of coil, i.e. the output voltage for a given flux density, decreases linearly with the frequency of B (t). In order to measure static fields with the induction coil method it would be necessary to mechanically move the measurement coil during the measurement which is not practical for most applications. A major advantage of the induction coil method is its scalability. The very same approach can be used for the measurement of geomagnetic phenomena occurring at sub-Hz frequencies as well as magnetic fields at several GHz. The coil may be easily optimized for a specific frequency range through the variation of the area and the number of coil turns. However, covering a wide frequency range of several decades with a single coil while maintaining a high dynamic range and accuracy is very challenging [Zahner Marco 2017].

2.1.1.2. Hall Effect based sensors

Edwin Hall discovered the Hall Effect in 1879. It relies on the fact that moving electrical charges are deflected due to the Lorentz force in the case where an MF has been applied perpendicular to the direction of the current. Hall Effect sensors consist of a rectangular conductor with a contact on each edge. If a bias current (I_{bias}) flows between two opposite contacts and an external magnetic flux density B is applied to Hall element, Lorentz force leads to an accumulation of charges at the other two contacts. This produces a measurable voltage U_{Hall} that is proportionate with the strength of the density of the magnetic flux B and the intensity of a bias current. Hall sensors can sense DC magnetic field including the polarity. The bandwidth of commercial Hall sensors is typically in the range of 100 kHz.

Among the advantages of these sensors are their robustness, small size, and the lack of moving parts. However, the Hall Effect is relatively weak and strong magnetic fields are necessary to produce a useable hall voltage. The sensitivity of Hall sensors is relatively low compared to other sensor technologies [Zahner Marco 2017, D. P. Pappas 2016]. In addition, Hall sensors typically exhibit a relatively large DC offset and are prone to temperature drift. Typical applications of Hall sensors include magnetic switches for motor commutation, displacement sensors and rotary encoders.

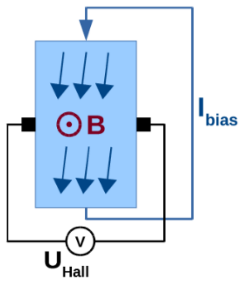

Figure 2.9. Hall-effect sensor—conceptual diagram

2.1.1.3. Magnetoresistive (MR) sensors

Magnetoresistive sensors rely on the magnetoresistance effect. Magnetoresistance was first discovered by William Thomson in 1856 can be observed as an intrinsic property of certain materials and can be greatly enhanced by means of special arrangements of specific material combinations. As the name implies, magnetoresistance describes the material's property to change its own electric conductivity in the case of being subjected to an external magnetic field. By arranging magnetoresistive elements in a resistor bridge it is possible to create a sensor that outputs a magnetic field dependent voltage. MR sensors therefore provide a true time domain representation of the magnetic field and are also able to measure static magnetic fields. There are several different physical phenomena that can lead to magnetoresistance. The vast majority of commercially available magnetoresistive sensors today rely on one of the three following effects:

- Giant magneto-resistance (GMR)
- Anisotropic magneto-resistance (AMR),
- Tunneling magneto-resistance (TMR)

AMR and GMR sensors are only able to detect the absolute value of field strength. To determine the orientation of the field it is necessary to actively bias the sensors. TMR based sensors are bipolar and do not require any magnetic bias. Compared to Hall sensors, MR sensors feature a higher sensitivity and a much lower power consumption thanks to the possibility to build sensors with high bridge resistances requiring only a few µA bias current. Because of these properties magnetoresistive sensors are also used in the electronic compass built in modern smartphones and tablets.

2.1.1.4. Flux Gate

Flux gate magnetometers consist of a coil wrapped around a core of very high permeability. During operation, the core is magnetized by an actively applied AC current strong enough to drive it into saturation. The flux in the core is sensed with a second (sense) coil. If an external MF has been applied to the core, it will saturate more easily in the direction of external field. This imbalance is detected with the sense coil which translates it to an output signal proportionate with the magnetic field. It is possible to scale fluxgate sensors to very small scales. Texas Instruments achieved to integrate a complete fluxgate sensor solution into a 4x4 mm integrated circuit package [Zahner Marco 2017, T. Instruments 2015] which is commercially available. As the sensitivity of a fluxgate sensor is proportional to the volume of the magnetic core, integrated solutions exhibit a relatively high noise floor, which is however still in the range level of the most sensitive magnetoresistive sensors. The power consumption of fluxgate sensors is relatively low (tens of mW) but still more than 1 magnitude order higher than magnetoresistive sensors.

2.3.2.5. Superconducting Quantum Interference Device (SQUID)

SQUID magnetometers can achieve extremely high sensitivities and have been utilized in a many different applications in which very weak magnetic field variations have to be measured. Typical applications of SQUID devices are medical diagnosis systems and geological mineral exploration instruments. A SQUID device includes a superconducting ring that is interrupted in 1 or 2 places by a thin insulating layer referred to as Josephson junction. This measurement method exploits the fact that the magnetic flux through a conductor ring can only assume discrete values corresponding to an integer multiple of the flux quantum φ0 ($2.07 \cdot 10^{-15}$ Tm^2). If a flux different from N·φ0 is applied to the ring, compensatory currents flow in the superconducting ring in order to round the magnetic flux to the next allowed level. Consequently, a steadily increasing magnetic fields leads to an oscillatory compensation current through the ring. The Josephson junctions translate the current through the ring into a proportional voltage which can be measured. To measure flux densities larger than one flux quantum it is necessary to keep track of the number of current oscillations or to use a feedback loop with active compensation. For a more exhaustive explanation of this measurement principle [Zahner Marco 2017, R. Fagaly 2006].

SQUID magnetometers feature by far the highest sensitivity and among the presented magnetic field measurement methods and can also provide a very high dynamic range. However, the use of a superconductor requires the sensing element to be kept at cryogenic temperatures. Even though portable SQUID magnetometers are commercially available [Zahner Marco 2017], the necessity to include a liquid nitrogen supply is a major limitation of this approach.

Table 2.3, summarizes the strengths and limitations of the presented measurement approaches. In the context of ELF-MF exposure assessment, small size and low power consumption of the measuring instrument represent the top priorities to achieve both good portability and a long battery life time necessary for personal measurements over one to several days.

Table 2.3. Strength and limitations of the presented ELF magnetic field measurement methods [41]

Method	Sensitivity & Noise	DC Sensitive	Dynamic Range	Band width	Size	Power	Offset & Drift
Induction coil	+	**No**[1]	++	++	+	+	++
Hall effect	-	**Yes**	**o**	+	++	+	-
SQUID	++	**Yes**[2]	++	**o**	-	--	++
Magnetoresistive	+	**Yes**	+	++[3]	++	++	**o**
Flux Gate	+	**Yes**	+	+	++[4]	+	+
Notes	[1]DC sensitivity can be achieved by rotating coil magnetometers [2]DC Offset calibration required at every power-up [3]Limited by RC time constant of sensor bridge resistance and load capacitance [4]Assuming integrated circuit implementation						

2.2. Personal Exposure Meter for ELF Magnetic Fields

2.2.1. Single Axis Electromagnetic Field Meter (model Extech 480823)

Extech 480823 EMF/ELF [EXTECH Instruments] meter is utilized in order to measure the levels of the EMF radiations from the electrical appliances, fans, power lines, and wiring.

An Extech 480823 overview has been depicted in Fig.2.19.

Figure 2.19. Extech 480823: Single axis EMF/ELF Meter .

b. Specifications

The technical specifications of the Extech 480823 single axis EMF/ELF Meter have been listed in Table 2.5.

Table2.5. The technical specifications of the Extech 480823

Display	0.5" (13mm) 3-1/2 digit (1999 count) LCD with low battery and overload indication
Measurement rate	Approx. 0.4 seconds
Maximum ranges and resolution	19.99μTesla (0.01) and 199.9mGauss (0.1) NOTE: 1 μTesla = 10 milli-Gauss
Accuracy	± (4% of Reading + 3 digits) @ 50/60Hz
Frequency bandwidth	30 to 300Hz (single axis measurements only)
Over-range indication	"1___" is displayed
Operating Temperature/Humidity	Temperature: 32 to 122°F (0 to 50°C) RH: 90% max. (0 to 35°C); 80% max. (35 to 50°C)
Power source	9V Battery
Power consumption	Approx. 3mA DC
Dimensions	5.2 x 2.8 x 1" (131 x 70 x 25mm)
Weight	0.36 lbs. (165g)

2.3. CALIBRATION OF MAGNETIC FIELD METER

In this section we present a test executed for the verification of the Extech 480823 single axis EMF/ELF Meter, which is used for the measurement campaign in this study. In an attempt to find the levels of measurements uncertainty and to validate the use of the Extech field-meter, a comparative measurement study was performed, with other two precision field meters from Narda STS Solutions (EFA-300 type). One of the EFA-300 devices was recently undergone a calibration procedure performed by its producer and it is taken as the reference for the comparison presented here. The testing program was performed in the Laboratory for Electromagnetic Compatibility at the Faculty of Power Engineering, University "Politehnica" of Bucharest. The magnetic field under measurement was produced inside a large conductive frame, positioned on a table (Fig.2.20). The tested field meters were successively placed in the same position, at the center of the current fed frame, where they are supposed to measure the same magnetic field (Fig. 2.21); the indications were finally compared.

The comparative test is illustrated by the directional measurements of magnetic flux density (r.m.s. values) on a direction, which is normal to the table surface. Table 2.6, shows the magnetic flux density values that have been measured with the three meters and the percent errors for the Extech and the second Narda devices. The same results of the comparative measurements and percent errors are shown in Figures 2.22 and 2.23 too, relative to the measurements performed with the calibrated Narda field-meter.

As the results show, the average relative error of EXTECH meter is (5.36%), with a maximum of 6.68%. So, one could consider that the uncertainties of the Extech meter are satisfactorily and the device is able to perform environmental magnetic field measurements for the assessment of general exposure levels, in various conditions.

Figure 2.20. Calibrated coil for generating a controlled magnetic field

Figure 2.21. The positioning of the calibrated EFA-300 (left) and Extech (right) field-meters for the comparative measurements

Table 2.6. The results of the comparative measurements session – magnetic field density [uT]

Measurement number	EFA300 field analyzer (Narda) - calibrated, reference -	EFA300 field analyzer (Narda) - for comparative tests -		EMF/ELF meter EXTECH - for comparative tests -	
	Measured B (reference)	Measured B	Error	Measured B	Error
-	[uT]	[uT]	[%]	[uT]	[%]
1	1.09	1.10	0.92	1.15	5.50
2	2.57	2.58	0.39	2.69	4.67
3	3.70	3.73	0.81	3.89	5.14
4	5.14	5.14	0.00	5.40	5.06
5	6.36	6.37	0.16	6.67	4.87
6	7.19	7.23	0.56	7.60	5.70
7	8.68	8.69	0.12	9.26	6.68
8	10.51	10.52	0.10	11.09	5.52
9	11.44	11.45	0.09	12.04	5.24
10	12.51	12.59	0.64	13.27	6.08
11	16.35	16.35	0.00	17.19	5.14
12	17.45	17.46	0.06	18.32	4.99
13	18.64	18.70	0.32	19.59	5.10

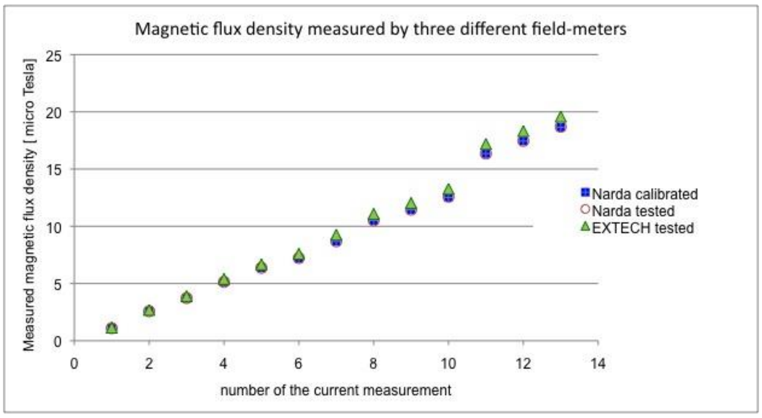

Figure 2.22. Magnetic field density measured in a comparative study by three field-meters

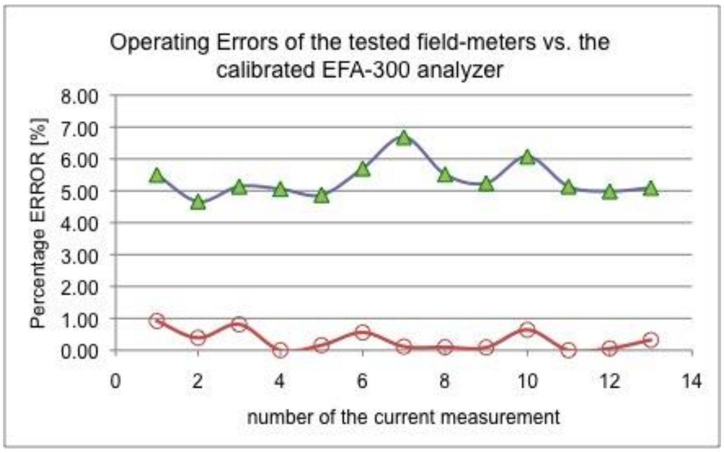

Figure 2.23. Measurement errors for the tested devices (Extech and Narda) comparative to a calibrated field-meter

3. CHAPTER 3: STUDY OF LOW FREQUENCY ELECTRO-MAGNETIC INTERFERENCE PROBLEMS IN HOSPITAL ENVIRONMENTS

3.1. CASE STUDY

The main issue is that, in spite of the regulations and researches regarding the electromagnetic compatibility, until now there is a basic absence of understanding amongst the medical employees concerning the electro-magnetic compatibility problems which have the ability to influence details diagnostics which have been essential to the health conditions of the patients. Taking into consideration the professional interest of the author of this thesis for the impact of the electromagnetic field environment on persons (medical personnel and patients) and on medical equipment, a study on the perception of this subject in the clinical environment in Iraq was performed and presented further. Those guidelines are not usually complied with in Iraqi hospitals, leading to a basic bad understanding of this issue in medical community. Because of that, the significant aim of this research study is showing current data and results, emphasizing the needs to produce a regulation frame in Iraq, for the purpose of controlling the levels of the electro-magnetic emissions of devices that operate in the sensitive places of hospitals.

3.1.1. Problem Identification

The present study has been based upon a survey, which has been targeted on numerous objectives:

- identifying the perception and knowledge of the medical staff, in relation to issues of the EMI while utilizing the electrical medical equipment;
- finding whether or not any earlier studies on the electro-magnetic compatibility have been conducted in Iraqi hospitals included in that study;
- seeing whether any measurements of protection have been implemented for the purpose of avoiding the issues that are related to the EMIs.

For the aims above, a research has been carried out in 47 Iraqi hospitals. The survey of the present study started by asking the hospital workers (i.e. the doctors, bio-medical engineers, and medical physics team), about issues related to the EMI; the survey questions were as follows:

- Were there any earlier researches on the electro-magnetic compatibility performed in the hospital?
- Do you know any kind of details regarding the electromagnetic field emissions of devices?
- Are you aware of the problems of the electro-magnetic compatibility?
- Were there any kind of problems or failings in medical devices due to the electro-magnetic disturbance?
- Are there any details known on levels of the electro-magnetic sensibility of devices?
- Have been taken place any kind of damages or failures in medical equipment without identification of the reason?

Figures 3.5 – 3.10, illustrate via charts the important survey results.

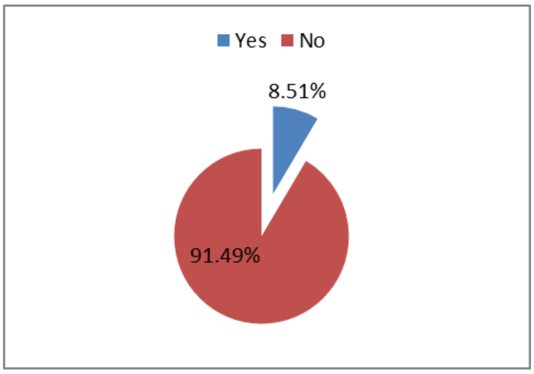

Figure 3.5. Former researches of EMC in hospitals

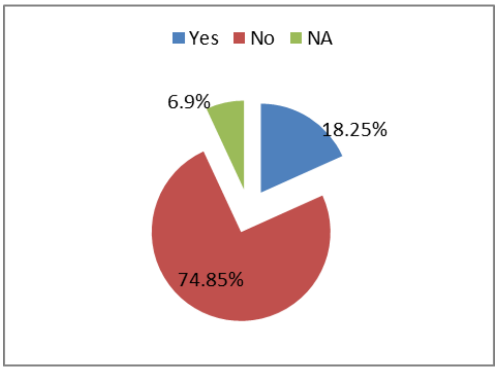

Figure 3.6. The knowledge of workers regarding the problems of EMC

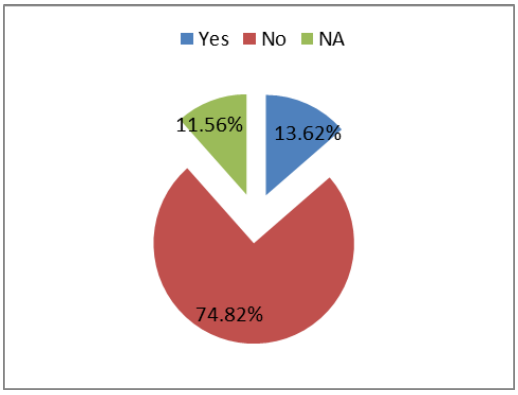

Figure 3.7. The knowledge of workers regarding MF emissions of medical devices

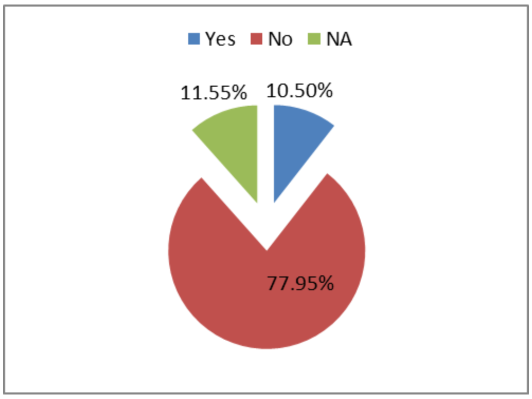

Figure 3.8. The knowledge of workers regarding the levels of the devices' EM sensibility

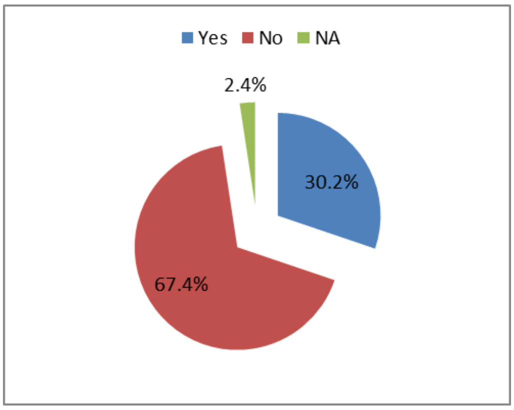

Figure 3.9. Recorded damage values in the medical devices due to EMI

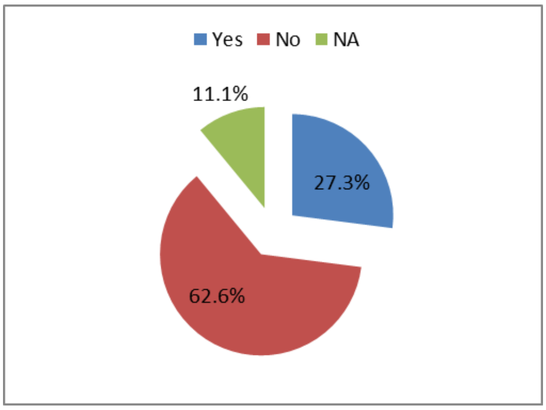

Figure 3.10. Recorded damage values in the medical devices with no specification of reasons.

In general, there has been an absence of understanding of this issue in every one of the hospitals, not only are most majority of workers unaware of the interference problems but a large number of the healthcare facilities have damages of the devices due to the EMIs or other unknown causes. In many hospitals, safety and security measurements were not actually taken. Which is why, it is most definitely a problem that has to be thought about due to the fact that there are lives at risk in the case where assessments are not carried out and adequate precautions actions are not taken.

3.1.2. Experimental Study

3.1.2.1. Materials

For this study, the EXTECH 480823 single axis MF meter has been used, the features of this device are presented in (section 2.2.1).

3.1.2.2. Methods

The magnetic field density has been measured in three representative Iraqi hospitals. Hospitals A, B and C have been chosen as a form of abbreviation, and they sufficiently depict other hospitals' propensity. The chosen rooms have been visited and several measures have been made on real work-places. Data have been expressed as resulting value. The magnetic flux density on every one of the 3 axes x, y & z (r.m.s. values) was generally measured for each observation point, and the resultant magnitude was calculated $B = \sqrt{B_x^2 + B_y^2 + B_z^2}$.

The departments of the hospital have been selected based upon services that have been supplied in every department, and according to medical devices that are operational within them. Table 3.5, includes departments and the number of the rooms were the measurements were performed, in each hospital. All electric devices and monitors were switched on throughout measuring. The magnetic flux density has been evaluated with the use of measuring instrument (EXTECH480823). This device of measurement has been placed in each square metre at a 100cm height from floor; the testing protocol was performed to measure the low frequency magnetic flux density, according to standard IEC of 2013 [IEC2013]. The specific measuring instrument placement as well as the numbers of the measurements are dependent upon every room's situation, attempting at the identification of most dangerous configurations of exposure (i.e. the worst cases).

Table 3.5.Numerous departments in which magnetic flux density has been measured

Hospital identifier	Departments	Number of the rooms	Number of the measurements
Hospital A	Hospitalization	14	149
	CCU	6	74
	ICU	10	127
	Emergency	12	98
Hospital B	Surgical room	5	121
	Emergency	16	151
	ICU	8	48
	NICU	4	32
Hospital C	Consulting Room	20	120
	Dentistry	5	34
	Obstetrics and Gynecology	11	184
	Clinical Lab	3	86
	Emergency	8	67
	ICU	10	60

3.2. Results

Results which have been acquired in the 3 hospitals pointed out above are shown further. They have been compared to magnetic field levels which have been suggested by the IEC60601-1-2 standard [IEC 60601:2007]. This typical standard specifies that electrical medical devices have to be supporting a 37.8mG magnetic field at industrial frequency.

1. Hospital A

Table 3.6, lists the maximum, minimum and also the average values of the low frequency magnetic flux density that have been evaluated in a number of Hospital A departments, while Fig.3.12, illustrates those values compared to the magnetic field level suggested by the IEC60601-1-2 standard. Results have shown that, in the CCU and also in emergency, the value of immunity has been exceeded.

Table 3.6. Low frequency magnetic flux density that has been measured in numerous Hospital A departments

Departments	MF (mG)		
	Max.	Avg.	Min
Hospitalization	4.99	4.10	1.1
CCU	45.8	7.30	1.9
ICU	13.60	2.6	0.9
Emergency	61.3	4.30	0.89

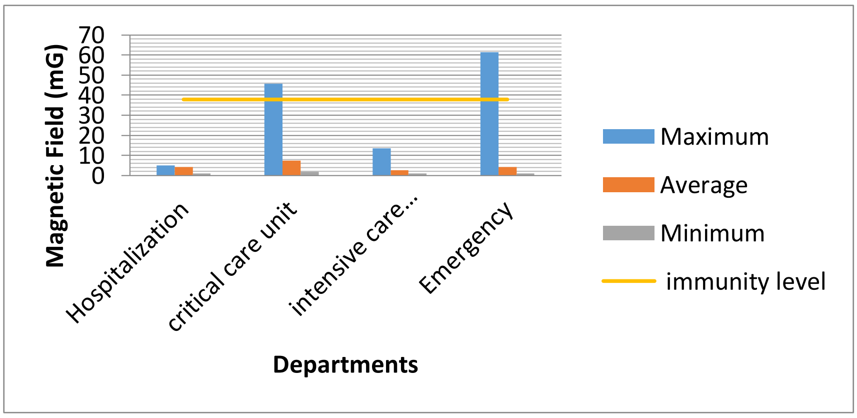

Figure 3.12. Low frequency magnetic flux density; levels are measured at Hospital A and a comparison is made with the immunity level suggested by the IEC60601-1-2 standard

2. Hospital B

Table 3.7, shows the maximum, minimum and also the average values of low frequency magnetic flux density that were evaluated in a number of Hospital B departments; Fig.3.13, presents these values compared to MF level that has been suggested by IEC60601-1-2 standard. Results have indicated that the magnetic field level which has been suggested by IEC standard has been exceeded in surgical rooms, ICU, and NICU sections in that hospital.

Table 3.7. Low frequency magnetic flux density that has been measured in numerous Hospital B departments

Departments	MF (mG)		
	Max	AVG.	Min
Surgery rooms	41.50	3.90	2.10
Emergency	22.30	5.20	0.99
ICU	57.90	2.80	1.30
NICU	39.40	6.30	1.80

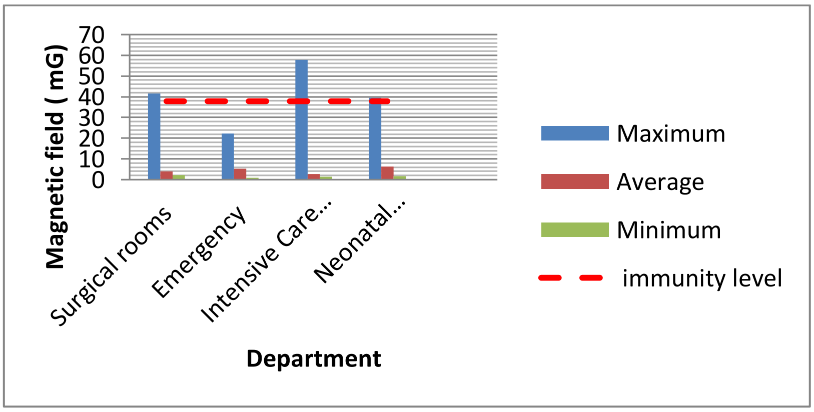

Figure 3.13. Low frequency magnetic flux density; levels are measured at Hospital B and a comparison is made with the immunity level suggested by IEC60601-1-2 standard.

3. Hospital C

Table 3.8, presents the values of the low frequency magnetic flux density that have been measured in numerous Hospital C departments. In the representation shown in Fig.3.14, these values are compared with the corresponding magnetic field level suggested by IEC60601-1-2 standard. Results have indicated that there is no location where standard has been surpassed, even though there have been fluctuations in levels between rooms.

Table 3.8. Low frequency magnetic flux density that have been measured in numerous departments of hospital C

Departments	MF (mG)		
	Max	Avg.	Min
Consulting Rooms	15.4	2.70	0.89
Gynecology and Obstetrics	03.9	01.9	0.76
Clinical Lab	26.7	11.3	01.9
Emergency	02.96	01.60	0.62
ICU	04.60	03.12	01.57

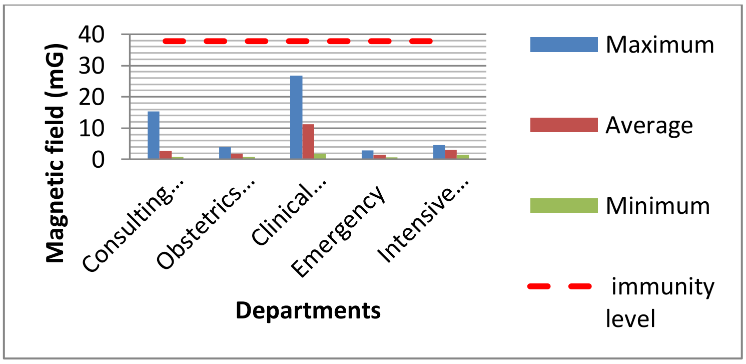

Figure 3.14. Low frequency magnetic flux density; levels are measured at Hospital C and a comparison is made with the immunity level suggested by IEC60601-1-2 standard.

4. *CHAPTER 4:* STUDY OF LOW FREQUENCY ELECTROMAGNETIC FIELD NEAR A MAGNETIC RESONANCE IMAGING AREA

4.1. LOW-FREQUENCY MF MEASUREMENT NEAR MRI AREA

In order to analyze the MF in such an area, initially, it is necessary to identify the sources, then using the spot measurements method; we perform measurements for the determination of the low frequency magnetic field density near MRI area.

4.1.1. Method And Instrumentation

4.1.1.1. Instrumentation

For this study, the EXTECH 480823 single axis MF meter has been used, the features of this device are presented in (section 2.2.1).

4.1.1.2. Low frequency MF measurement locations

In Fig.4.1 & Fig.4.2 we offered a map related to first and 2nd MRI scanner location respectively, with the MF sources and also the measurement points, in which the study examined the spatial variability regarding low-frequency MF, while the research area is divided right in four sections:

1. A waiting room (WR), in which clients were projected to be called by the medical personnel for the pre-interventional inspection and instruction, prior to getting into the MRI scanner.

2. Hall area, a portion dividing the Reception room from MRI and Control room.

3. Control room (CR), in which individuals were checked out by the medical personnel before entering MRI scanner.

4. Technical room (TR), specifying most of equipment that make MRI scanning functionality possible.

Green points represent the place of the measurement area in the waiting room, Control Room, Hall, and Technical Area.

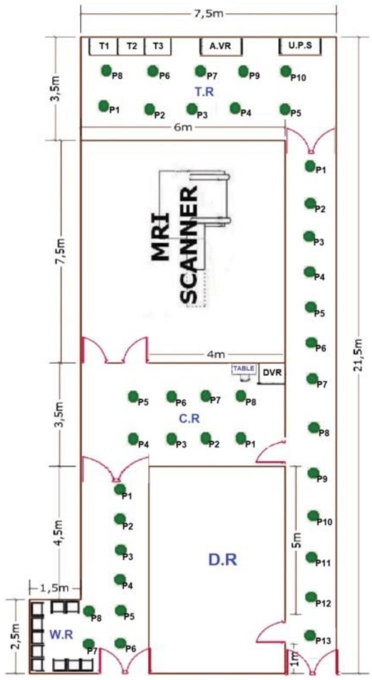

Figure 4.1. Map of first area of MRI scanner as well as sources of the MF as well as points of measurement.

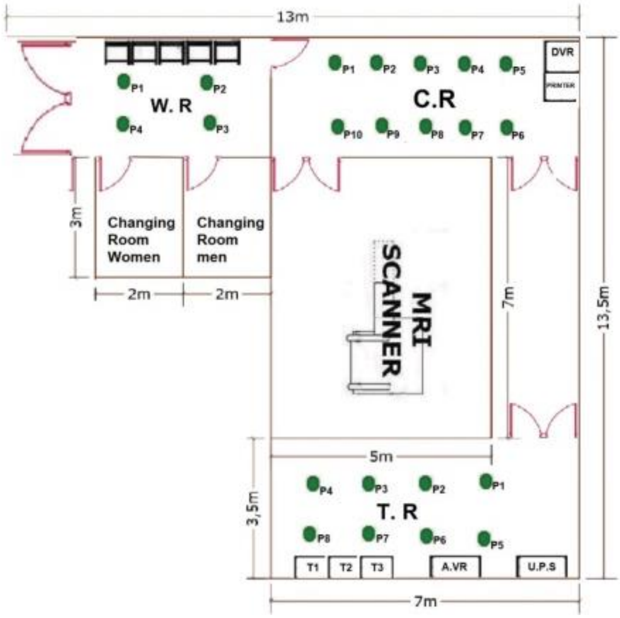

Figure 4.2. Map of second area of MRI scanner with MF sources as well as points of measurement.

4.1.1.3. Magnetic field sources

The MF sources in researched area were: the 150 kVA UPS and Automatic Voltage Regulators shown in Fig.4.3, the DVR from Control Space, the conditioner air Cool System (CS) that is residing in the Technical Area and control room.

Figure 4.3. The 150 kVA UPS and Automatic Voltage Regulators located in Technical Room.

4.1.1.4. Spot measurements method

As an electromagnetic field study strategy near MRI scanner, this study reached spot measurements in various points using EMF TESTER EXTECH with frequency sensitivity range between 30 -300 Hz. For every room we identified the spatial variability related to MF at 3 distinctive distance values (0.3 m, 1m and 2m) from the floor as seen in Fig.4.4, the magnetic field results were determined throughout in the case when MRI has been ON and outside program in a case where MRI was OFF. MF density is measured in two representative sites near MRI scanner. In addition, the sites A and B have been selected for brevity, and they were suitably depictive regarding the other site's propensity, while the selected rooms have been visited and many measurement values are carried out on actual work-places. The data have been represented as a resulting value. Furthermore, the magnetic flux density values on spatial x, y & z axes, in r.m.s. form were measured and the resultant B-field value is calculated. The protocol of the testing has been carried out based on the standard IEC of 2013[IEC 2013].

Figure 4.4. The MF measurements at 3 distances (0.3-meter, 1 m and 2 m) from floor.

4.2. RESULTS

The outcomes gotten in spot measurements techniques were graphically represented in both cases: throughout work program, in a case when the scanner of the MRI was ON and out of program in a case where MRI was OFF.

4.2.1. The first site

4.2.1.1. Control Room

Fig.4.5, and Fig.4.6; are showing the results related to MF in the control room, by comparison, the results acquired as the MRI was on with the ones as the MRI was off. With regard to such room, the study indicated that the functionality of the MRI scanner has impact on the background MF, since the results were specified for being high in the case when the MRI scanner was ON in comparison to when the results acquired throughout OFF program.

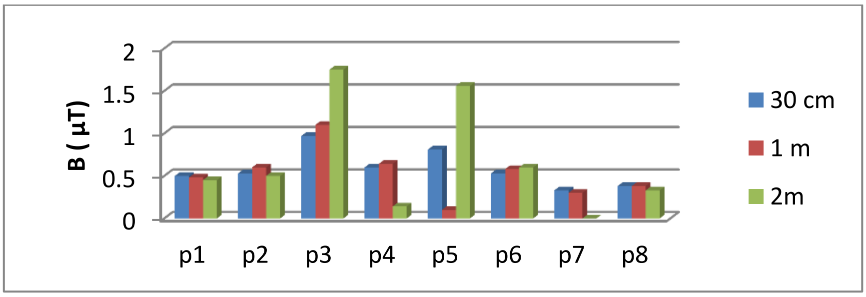

Figure 4.5. Spatial variability related to MF in Control Room in the case when MRI scanner was ON.

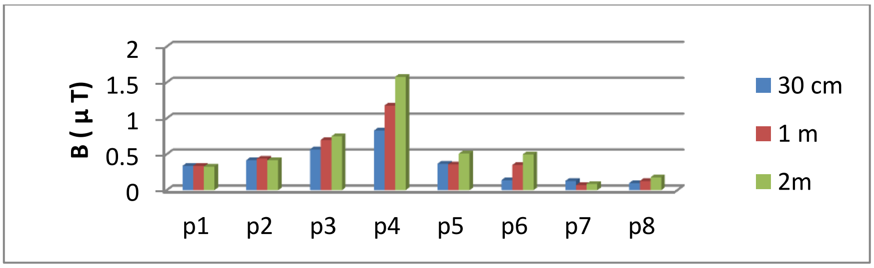

Figure 4.6. Spatial variability related to MF in Control Room in the case when MRI scanner was OFF.

4.2.1.2. Waiting Room

In comparable approach to Control Room, in Waiting Area, the spatial variability related to MF is examined, as shown in the Fig.4.7, and Fig.4.8, with regard to such area, one might note that the MF variations were impacted via MRI scanner operation.

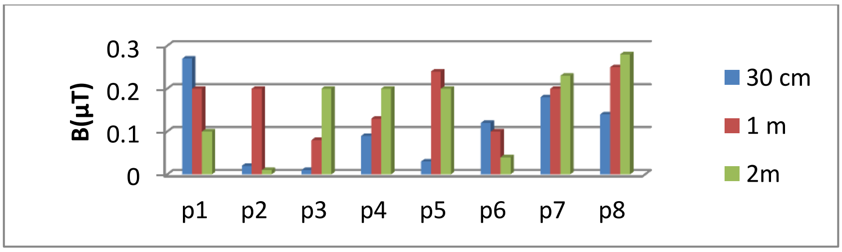

Figure 4.7. The magnetic field's spatial variability in Waiting Room in the case where the MRI was ON.

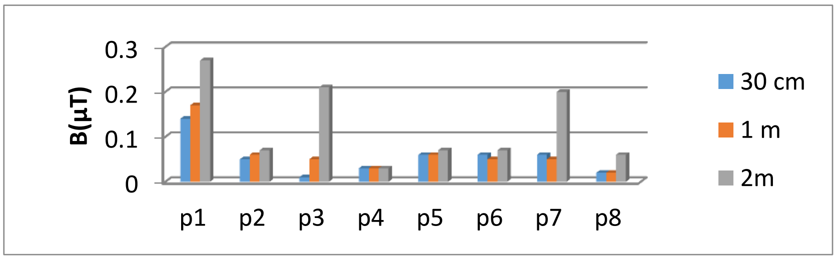

Figure4.8. Spatial variability related to MF in Waiting Room in the case when MRI scanner was OFF.

4.2.1.3. Hall Area

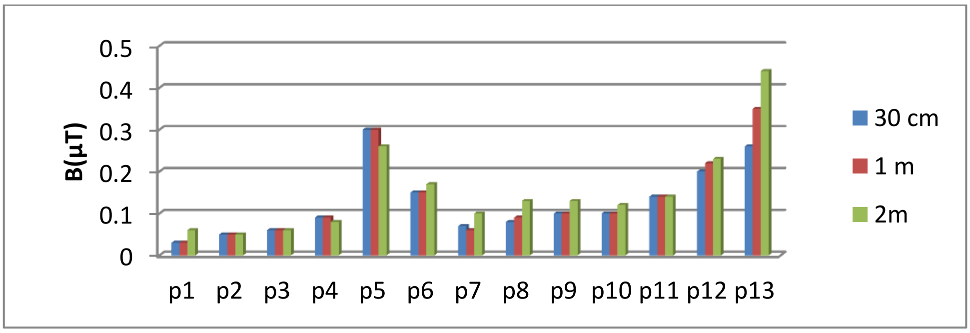

Figure 4.9. Spatial variability related to MF in Hall area in the case when MRI scanner was ON.

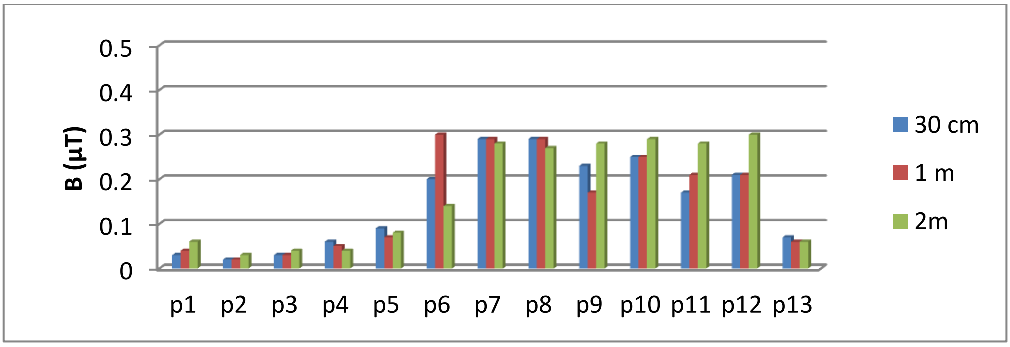

Figure 4.10. Spatial variability related to MF in Hall area in the case when MRI scanner was OFF.

In Fig.4.9, and Fig.4.10, we recognize the spatial variability related to MF from Hall area. With regard to such area, the study indicated that the MRI scanner does not impact the current MF; the higher values were specified at the time, in the case when MRI scanner was OFF in comparison to values that have been acquired throughout ON program.

4.2.1.4. Technical Room

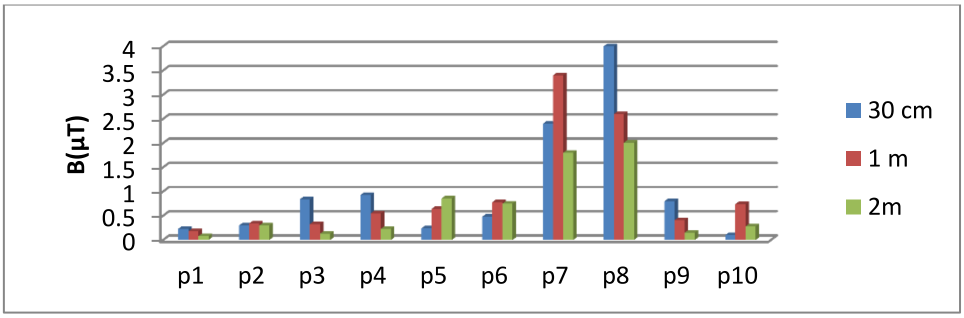

Figure 4.11. Spatial variability related to MF in Technical Room in the case when MRI scanner was ON.

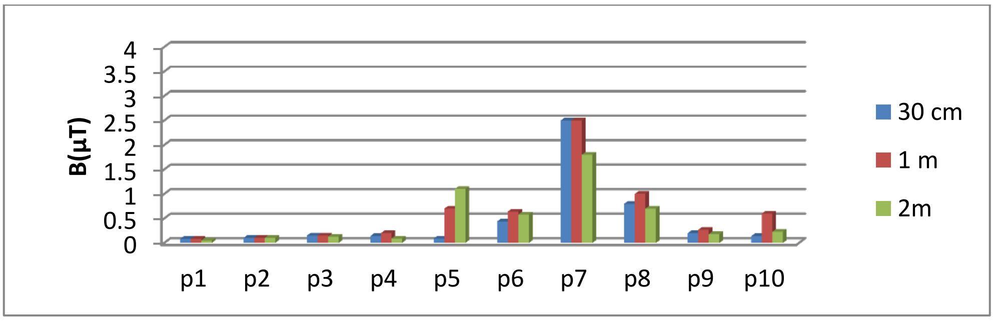

Figure 4.12. Spatial variability related to MF in Technical Room in the case when MRI scanner was OFF.

For the last area in the first site, the acquired values from the Technical room are shown in Fig.4.11, and Fig.4.12, like in CR, the study indicated that the MF variations were impacted via operation related to MRI scanner. Since the results were recognized to be high in the case when MRI scanner was ON in comparison to the results acquired throughout OFF program.

In Table 4.2, this study presents average, minimum and maximum values related to MF in all the rooms near the MRI scanner location in 2 conditions: in the case when MRI device was ON/ OFF. Then, measurements have been made at 0.3 meters, 1m, particularly 2m high from floor, as seen in Fig. 4.4.

Table 4.2. Average, minimal and maximal values of magnetic flux density in all the sectors that are close to the area of MRI scanner[µT].

		Control Room			Waiting Room			Hall area			Technical Room		
		B_{max}	B_{min}	$B_{Aver.}$	B_{max}	B_{min}	$B_{Aver.}$	B_{max}	B_{min}	$B_{Aver.}$	B_{max}	B_{min}	$B_{Aver.}$
MRI On	0.3m	0.97	0.33	0.58	0.32	0.01	0.11	0.29	0.02	0.17	4.00	0.10	1.03
	1m	1.1	0.1	0.52	0.38	0.08	0.19	0.30	0.02	0.18	3.40	0.18	0.99
	2m	1.75	0.14	0.66	0.59	0.01	0.21	0.30	0.03	0.19	2.01	0.99	0.65
MRI Off	0.3m	0.83	0.1	0.36	0.14	0.01	0.05	0.35	0.03	0.17	2.50	0.08	0.46
	1m	1.18	0.07	0.44	0.17	0.02	0.06	0.35	0.03	0.19	2.50	0.08	0.62
	2m	1.58	0.09	0.54	0.27	0.03	0.12	0.44	0.05	0.22	1.80	0.05	0.49

4.2.2. The second site

4.2.2.1. Control Room

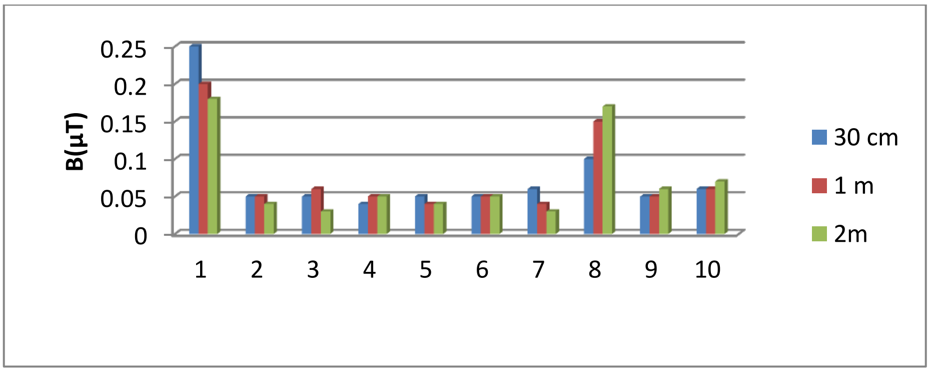

Figure 4.13. Spatial variability related to MF in Control Room in the case when MRI scanner was ON.

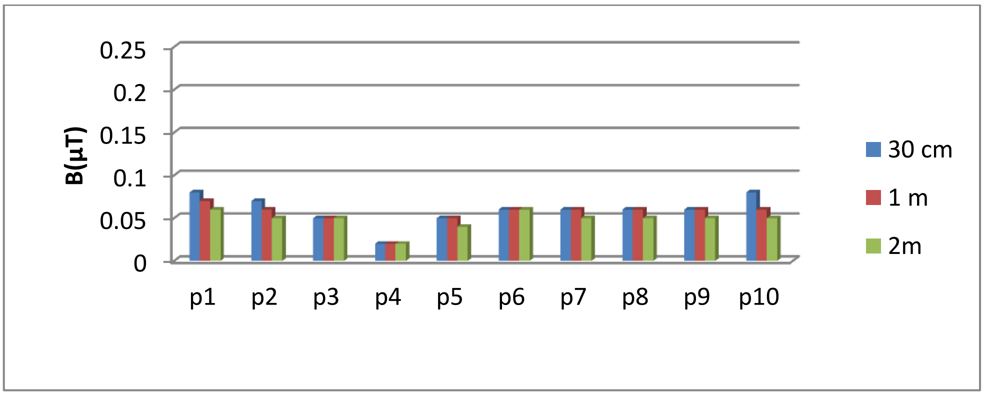

Figure 4.14. Spatial variability related to MF in Control Room in the case when MRI scanner was OFF.

Fig.4.13, and Fig.4.14; are showing the results related to MF in Control Room, by comparison, the values acquired in the case when MRI was ON with those in the case when MRI was OFF.

With regard to such room, the study indicated that the MF is impacted via the working regarding MRI scanner, since the greater value is specified when the MRI scanner was ON in comparison to results which have been obtained when MRI scanner was OFF.

4.2.2.2. Waiting Room

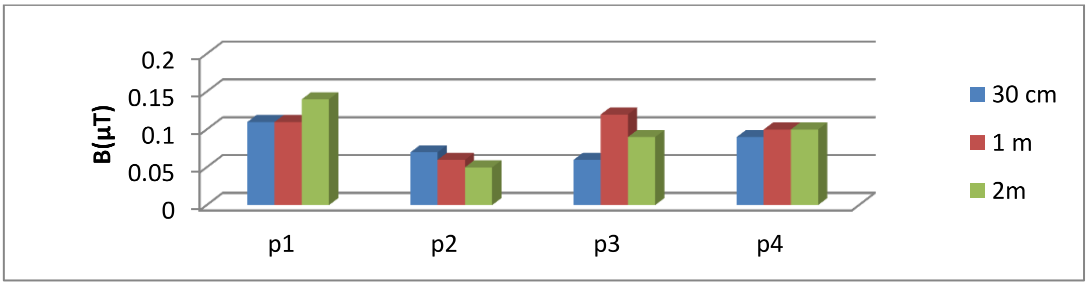

Figure 4.15. Spatial variability related to MF in Waiting Room in the case when MRI scanner was ON.

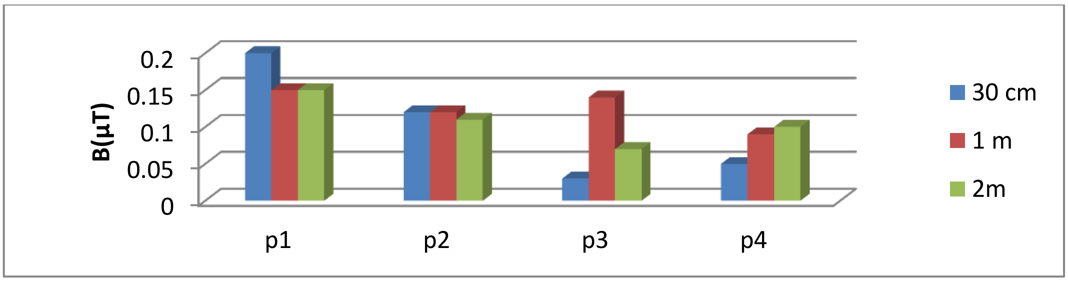

Figure 4.16. Spatial variability related to MF in Waiting Room in the case when MRI scanner was OFF.

By applying an identical strategy as in CR, in Waiting Room, spatial variability which is related to MF is examined, as shown in Fig.4.15, and Fig.4.16; the study indicated that MRI scanner performance doesn't impact the current MF.

4.2.2.3. Technical Room

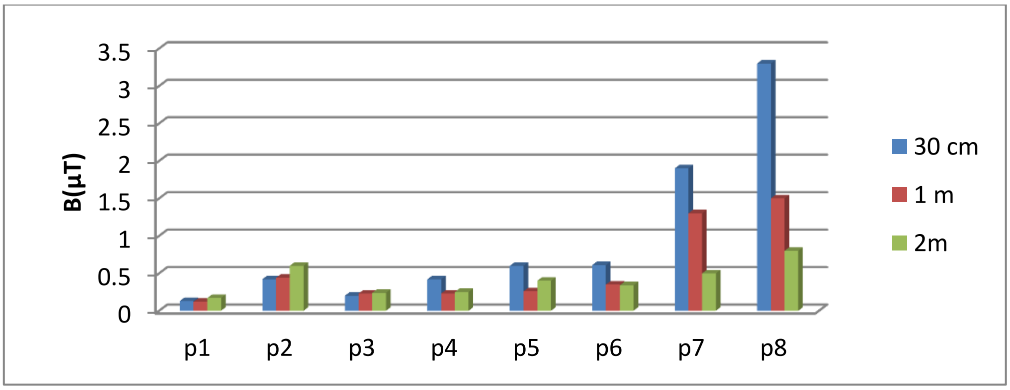

Figure 4.17. Spatial variability related to MF in Technical Room in the case when MRI scanner was ON.

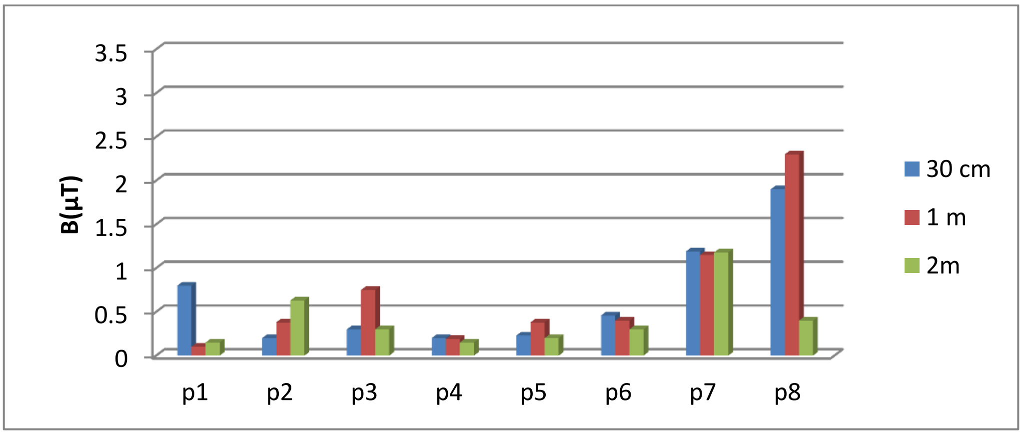

Figure 4.18. Spatial variability related to MF in Technical Room in the case when MRI scanner was OFF.

Fig.4.17, and Fig.4.18; are showing the values regarding MF in Technical Room, also, by comparing the values acquired in the case when MRI was ON with those when MRI was OFF.

In such area, this study indicated that the MF variation was impacted due to the MRI scanner operation.

Table 4.3; presents average, minimum and maximum values regarding MF in all of the sectors that are close to the area of the scanner in 2 conditions: in the case when MRI scanner was ON then OFF and the measures are made at 0.3meters, 1m and 2m high from the floor.

Table 4.3. Average, minimal and maximal values of the magnetic flux density in all the sectors, which are near the area of the MRI scanner[µT].

		Control Room			Waiting Room			Technical Room		
		B_{max}	B_{min}	$B_{Aver.}$	B_{max}	B_{min}	$B_{Aver.}$	B_{max}	B_{min}	$B_{Aver.}$
MRI On	0.3m	0.25	0.04	0.07	0.20	0.03	0.20	3.30	0.20	0.94
	1m	0.20	0.04	0.07	0.15	0.09	0.25	1.50	0.20	0.55
	2m	0.18	0.03	0.07	0.15	0.07	0.21	0.80	0.24	0.41
MRI Off	0.3m	0.08	0.02	0.05	0.11	0.06	0.08	1.90	0.20	0.66
	1m	0.07	0.02	0.05	0.11	0.06	0.09	2.30	0.10	0.70
	2m	0.06	0.02	0.04	0.14	0.05	0.09	1.18	0.15	0.41

Fig.4.19, and Fig.4.20, present the values of the minimum, maximum and average values for MF in 2 sites in the case where the MRI scanner was ON or OFF.

In the first site, it was identified that in the Control Room there were 2 points which are located close to the DVR feeding column (1.75 & 1.58) µT, and in TR there were the MRI scanner's control panels, the maximal values have been recognized near the panel of the gradients, 4µT.

In second site, maximum values (3.30 µT) in control room are identified. Also, we recognized that the maximum, minimum and average values regarding MF have been high in the technical room in 2 sites. It is important to be mentioned that in the majority of conditions, the measured MF was below the limit, which is allowed through the guidelines of ICNIRP.

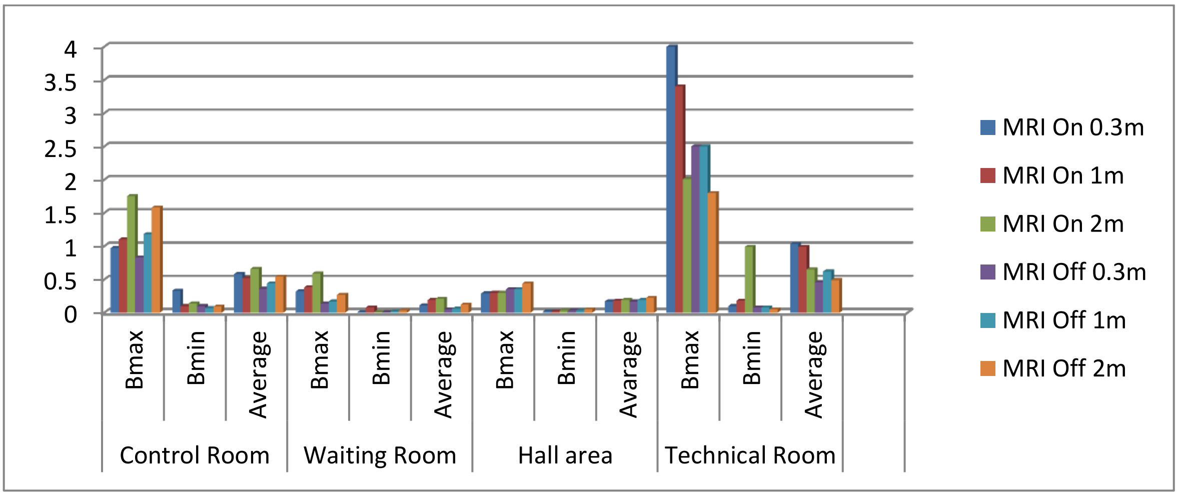

Figure 4.19. Average, minimum and maximum values of magnetic flux density (in μT) in all the sectors near the MRI scanner area, at the first site (the MRI unit was turned ON / OFF).

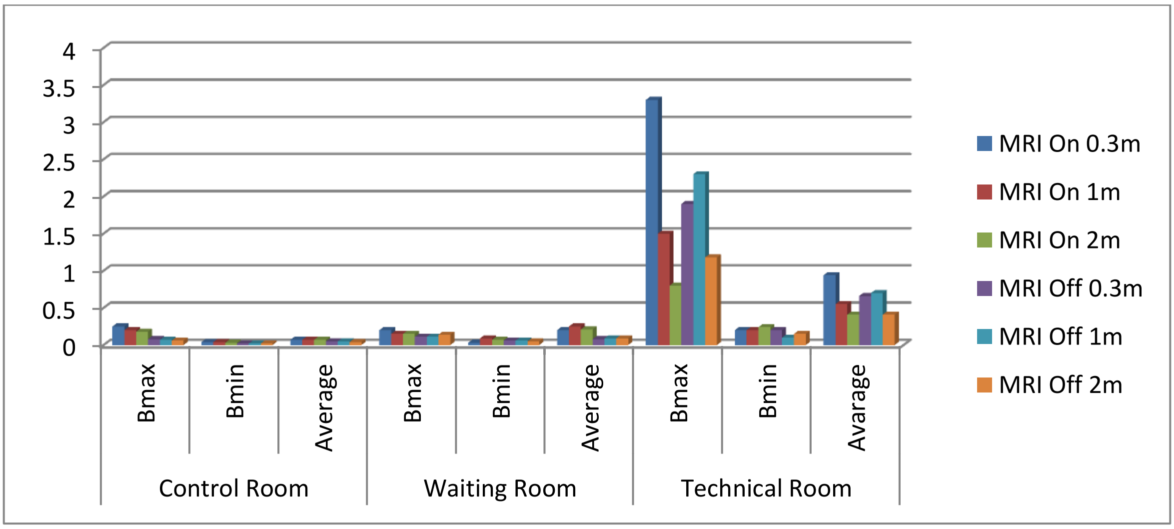

Figure 4.20. Average, minimum and maximum values of magnetic flux density (in μT) in all the sectors near the MRI scanner area, at the second site (the MRI unit was turned ON / OFF).

5. *CHAPTER 5:* ASSESSMENT OF MAGNETIC FIELD DENSITY PRODUCED IN OPERATING ROOMS

5.1. MEASUREMENTS PROGRAM

5.1.1. Materials

For this study, the EXTECH 480823 single axis MF meter has been used, the features of this device are presented in (section 2.2.1).

5.1.2. Methods

The EXTECH 480823 single-axis MF meter is used for measuring the MF magnetic flux in different sections of the operating room, while all devices are operating. The measurements were performed during one day in twelve operating rooms, starting from the first surgery until the end of the last surgical procedure and covering the time between procedures as well. In addition, the survey covered various positions, at a standing position regarding operating room staff also in nearest position to a patient, and position of the anesthesiologist. Data were collected at 120 cm above the floor for all the analyzed cases and expressed as resulting values. The magnetic flux density is measured on x, y, z spatial axes and resulting values are analyzed afterwards. Secondly, the MF flux density is measured in a variety of the directions at 0.1m, 0.5m, and 1m distance from the device. The measurements are performed while only one device is operating, while all the other devices are switched off. The protocol of the testing has been carried out for measuring the density of low frequency magnetic flux, based on standard IEC of 2013[IEC 2013].

5.2. RESULTS

Table 5.5, presents results of the measurements of magnetic field density, located closest to the patient, in position of the medical staff and in the anesthesiologist's position, while the equipment is functioning. The values are expressed in (mG) and they indicate the average values.

Table 5.5. Magnetic field densities (average mG)

			Magnetic field densities (average mG)		
	Operating rooms	nr. of measurements	located closest to the patient	in position of the medical staff	in the anesthesiologist's position
1	laparotomy surgery	**87**	**1.25**	**1.1**	**1.94**
2	General surgery	**98**	**0.9**	**0.58**	**1.78**
3	Knee arthroscopy surgery	**79**	**0.79**	**0.45**	**2.01**
4	Tracheostomy surgery	**88**	**0.3**	**0.22**	**2.01**
5	Prostate biopsy surgery	**96**	**1.45**	**1.3**	**1.75**
6	plastic surgery	**104**	**1.6**	**1.38**	**2.32**
7	Gastrostomy surgery	**96**	**0.75**	**0.8**	**4.71**
8	Parotid surgery	**80**	**0.67**	**0.5**	**3.87**
9	Shoulder arthroscopy surgery	**96**	**1.23**	**5.4**	**2.05**
10	Orthopedic surgery	**72**	**0.84**	**0.67**	**1.95**
11	Artery repair surgery	**67**	**0.59**	**0.81**	**3.1**
12	Endoscopy surgery	**74**	**1.15**	**4.92**	**2**

The maximum exposure levels to magnetic field were recorded in shoulder arthroscopy operating room 9 (5.4 mG) and in the endoscopy operating room 12 (4.92 mG), for standing position of the medical staff.

The local sources of the magnetic field in operating rooms comprise all of the electronic and electric equipment: vital indices monitors (electro-cardio graphic, pulse-oximetry), ventilators and lab devices, devices of emergency interventions, communication devices, refrigerators, systems of air conditioning and cleaning, facilities of water heating and purification and of course, the electric mains.

The MF measurements have been carried out within Shoulder arthroscopy surgery, Gastrostomy surgery and plastic surgery operating rooms in locations that have been identified by the colored spots on blueprints in the Fig.5.2, Fig.5.3, and Fig.5.4, at a 1.20m height above floor; the operating rooms have been operational at a full load.
Fig.5.2, Fig.5.3, Fig.5.4, illustrates the measured point distribution on the floor; the red colored spots represent the measurements at the standing position of the medical staff, the blue colored spots at the nearest distance to patient, the green colored spots at the rest area of the operating room.

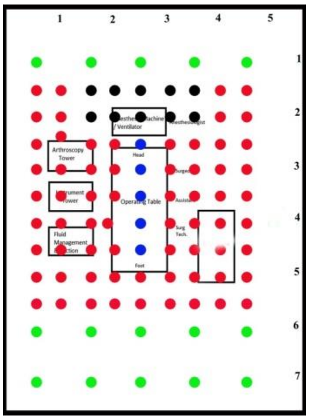

Figure 5.2. Shoulder arthroscopy surgery blueprint under the assessment; colored spots represent the locations in which measurements have been carried out

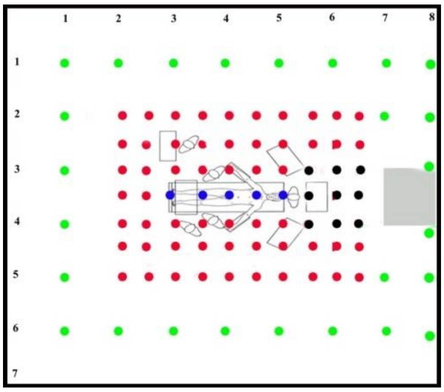

Figure 5.3. Gastrostomy surgery blueprint under the assessment; colored spots represent the locations in which measurements have been carried out

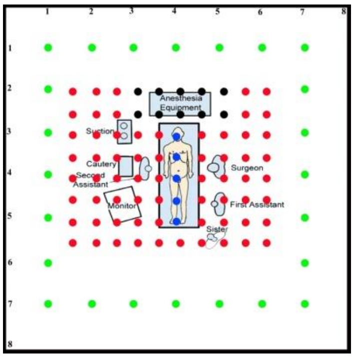

Figure 5.4. Plastic surgery blueprint under the assessment; colored spots represent the locations in which measurements have been carried out

Magnetic field distribution in Shoulder arthroscopy surgery, Gastrostomy surgery, and plastic surgery operating rooms are illustrated in the Fig.5.5, Fig.5.6, and Fig.5.7.

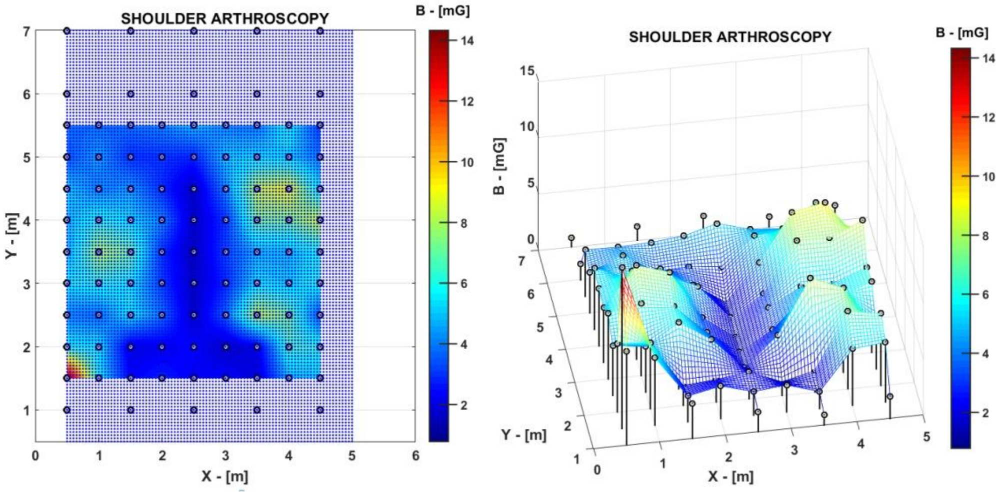

Figure 5.5. Shoulder arthroscopy – colored maps of the distribution of magnetic flux density

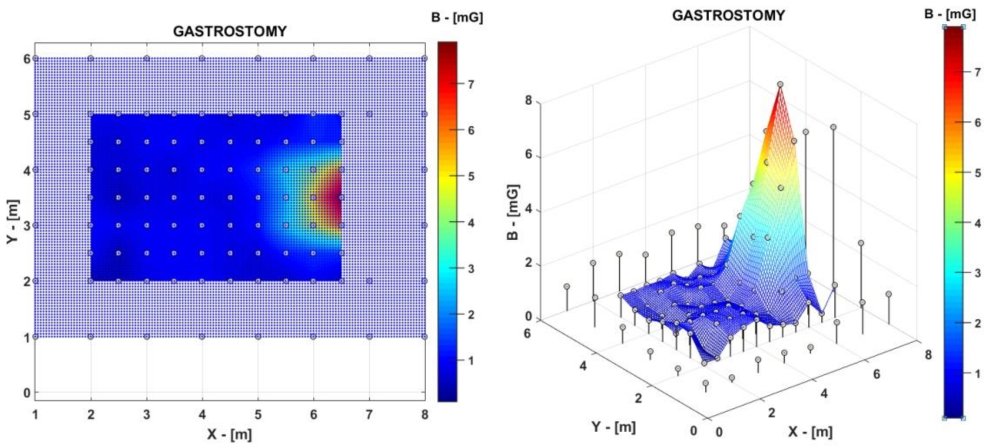

Figure 5.6. Gastrostomy surgery – colored maps of the distribution of magnetic flux density

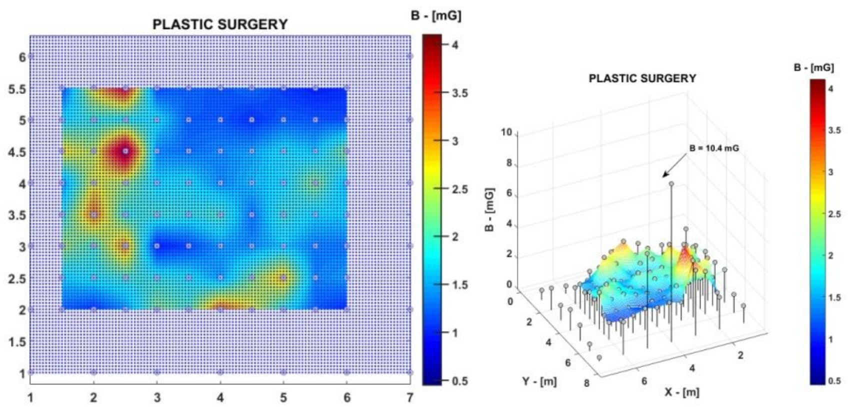

Figure 5.7. Plastic surgery – colored maps of the distribution of magnetic flux density

Table 5.6, shows the average MF density at different distances from each active system. The measurements were performed while one device is running and all the other devices are switched off.

Table 5.6 . Magnetic field density [mG] levels from the device.

	Average of magnetic flux density (mG)		
Equipment	0.1 m	0.5m	1 m
Operating theatre light	3.47	0.72	0.33
Suction Pump	3.2	0.62	0.28
Anesthesia trolley	6.4	1	0.48
Ventilator	1.99	0.72	0.29
Anesthesia monitor	11.32	2.41	0.98
Fluoroscopy	1.89	0.75	0.22
Sterilizer	1.97	0.91	0.36
High-voltage power supply	52.06	14.32	6.01
Oximeter pulse	1.31	0.62	0.37
Laparoscope	18.37	1.59	0.49
Defibrillator	0.89	0.26	0.2
Negatoscope	41.25	12.31	0.96

The maximum values of magnetic flux density have been registered for the area surrounding the High-voltage power supply at 10 cm distance, out of all the devices in an operating room. The value for the power supply was 52.06 mG (approximately), followed by anesthesia LCD monitor (11.32 mG) and by laparoscope (18.37 mG).
Fig.5. 8 - Fig.5.19, represent the magnetic field distribution from devices.

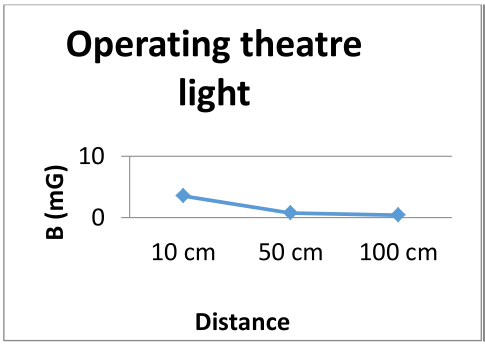

Figure 5.8. Distribution of MF from operating theatre light

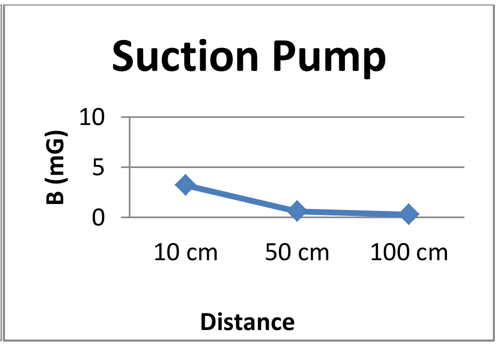

Figure 5.9. Distribution of MF from Suction pump

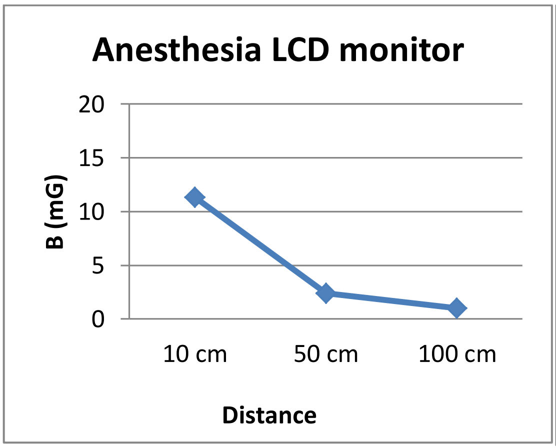

Figure 5.10. Distribution of the MF from Anesthesia monitor

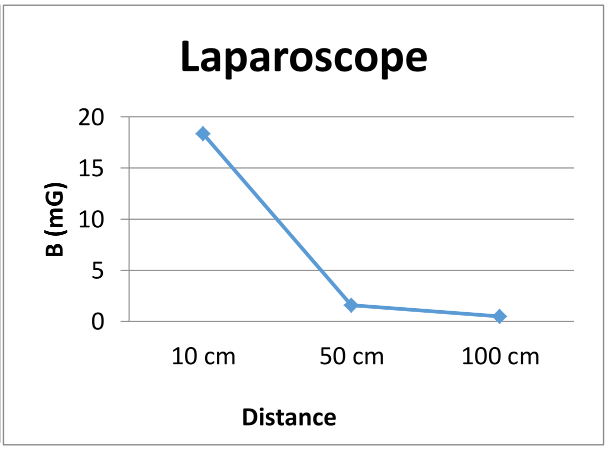

Figure 5.11. Distribution of MF from Laparoscope

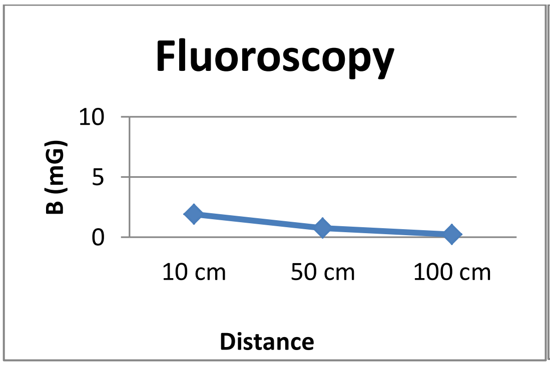

Figure5.12. Distribution of MF from Fluroscopy

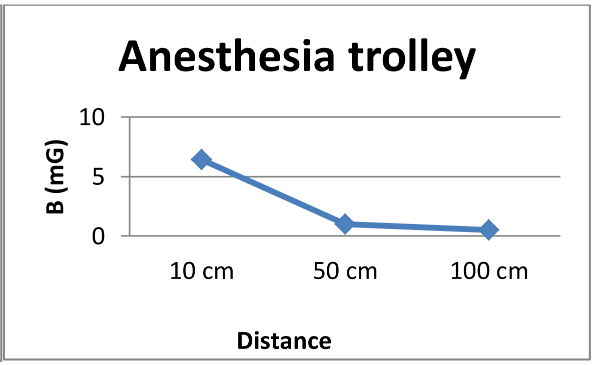

Figure 5.13. Distribution of MF from Anesthesia trolley

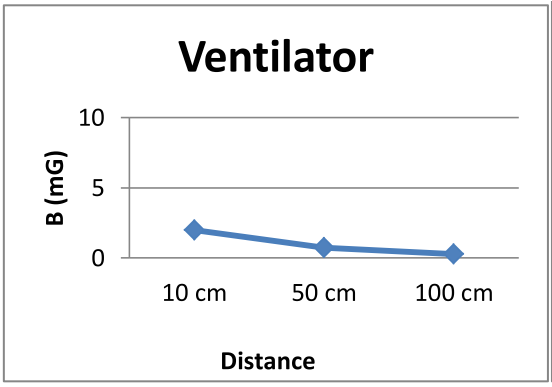

Figure 5.14. Distribution of MF from Ventilator

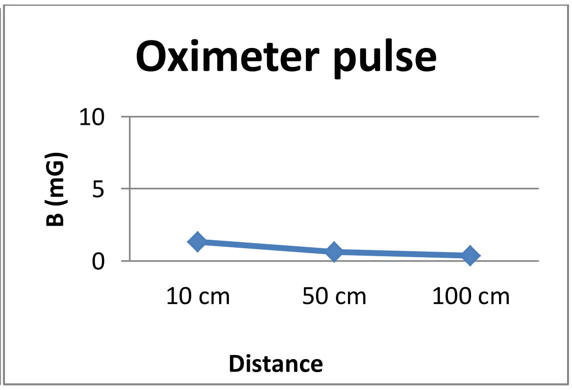

Figure 5.15. Distribution of MF from Oximeter pulse

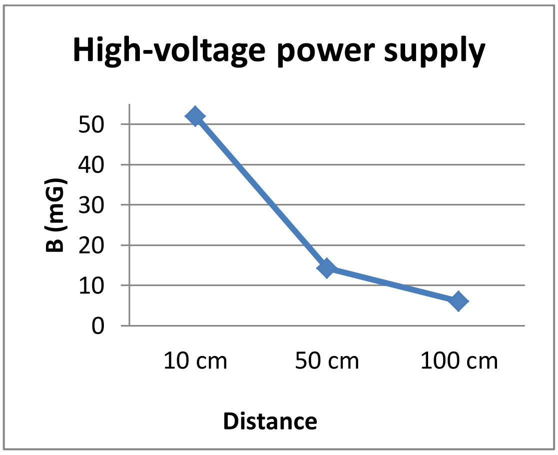

Figure 5.16. Distribution of MF from High-voltage power supply

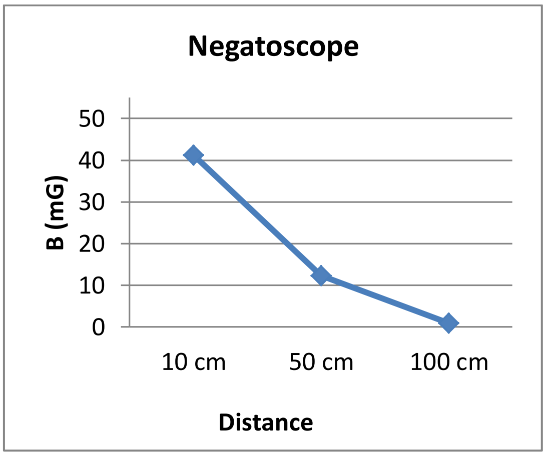

Figure 5.17. Distribution of MF from Negatoscope

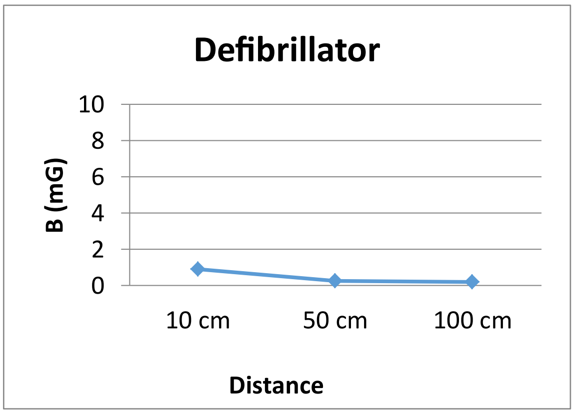

Figure 5.18. Distribution of MF from Defibrillator

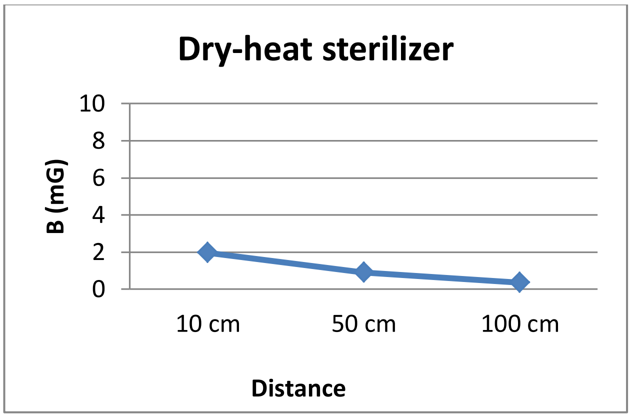

Figure 5.19. Distribution of MF from Sterilizer

6. GENERAL CONCLUSIONS

1. Thorough safety systems were established at international level, and used in a lot of nations. They were flexible, conservative, and on the basis of solid science, thus providing suitable safety versus all the recognized health impacts of the EMF. Within the response to worries of public, and assuming many uncertainties presenting in a few fields of the scientific knowledge, considerations regarding precautionary measures might be warranted in many conditions. A major requirement is that such measures were used such that never weakening the dependability regarding international standards, and thus the trust in health authorities and also in the science.

2. MFs may be characterized based on several parameters, for example, magnitude, frequency, polarization. Characterization of one or several of those parameters and the way they might be related to the human exposure can be serving as potential aims of a measurement program.

3. The different measurement methods which were explained can be utilized based on the selected requirements of exposure evaluation that have been undertaken. The cost of the assessment of the exposure in terms of money and time can as well have a considerable impact on the selection of a measurement method.

4. The procedure will describe the step-by-step technique that should be followed, utilizing the possible methods indicated, to accomplish the measurement goals. The protocol can explicitly indicate such factors as instrument requirements, (e.g., passband, probe size, magnitude range), location of measurements, and duration of measurements.

5. Sketches of locations and areas where measurements will be made are often very useful. Electrical diagrams of buildings may be helpful in identifying sources of fields in office and similar buildings, although excessive reliance on such documentation must be avoided because of unrecorded changes in the building electrical system. While many sources of magnetic fields are visible, e.g., overhead lighting or electrical devices, others are not, e.g., electrical appliances in adjacent rooms or on upper or lower floors. During pilot studies, decisions may be made regarding spacing between measurements, measurement locations, sample size, formats of data sheets, questionnaires for job/task classification, etc.

6. With advancements of the technological growth, work place has viewed the environmental exposure proliferations. The opportunity of the negative health impacts connected with exposure to low frequency MFs remains partially not known. As study into any kind of possible hazard continues, it is essential measuring the true exposure to MFs in the work place.

6. It is very important that the goals of a measurement program to be clearly specified at the beginning. A clear definition of goals is needed for determination of instrumentation and calibration requirements, e.g., instrumentation passband, dynamic range, frequency calibration points.

7. The combination regarding electrical devices in hospital environments might be posing the risks of EMC problems. The devices of ME providing essential functions to patients; thus, the issues of EMC might have dangerous consequences.

8. EMC is an issue not just for manufacturers of the medical devices, yet, also for those installing or using medical equipment. The presence regarding standards has actually motivated great EMC design methods, however shouldn't be relied upon to avoid EMI problems as a result of the nature of EM environment of hospitals.

9. A lot can be done by promoting understanding of EMI problems as well as its underlying mechanisms of coupling. Lots of potential issues may be solved by making sure sufficient

separation of sources and also victims of the interference: e.g. through placing the medical equipment which known to produce high level of magnetic field such as diathermy and also electro surgery in a various part of a building to sensitive equipment like EEG and others.

10. With regard to the presented study, just introductory study regarding EMC in hospital environment was done, while not much medical instruments are estimated in limited sections of hospitals. Differences in immunity between the devices of ME related to the same model weren't examined. With regard to other environments, there are other emitters might be identified such as diathermy and MRI, while the spurious emissions as well as their impacts on electrical devices weren't specified, for having well-reasoned views on such subject, a more in-depth and thorough study will be needed.

12. The present research has been a useful example of estimating the exposure level to the ELF MFs around the MRI scanner which are quite difficultly portrayed, partially due to the fact that the certain characteristics of tasks that are performed by persons who work in those environments need a set of the changes in their work throughout a working day. The analyses of complex information on MF frequency spectrum has shown that the 50Hz frequency has been dominating in studied spaces.

13. This work is providing the results of low-frequency MF in rooms near MRI scanner taking into account the spatial variability regarding EMF, also this study specified that the low-frequency EMF was impacted via MRI in Control area as well as the Technical Area. Therefore, the maximal results related to areas have been recognized in Technical Area, particularly (4.00 µT) in the first site and (3.30µT) in the second site.

14. every magnetic field value researched has been well less than 1mT reference level that has been advised by the ICNIRP [2,3], for the protection of the staff from the acute effects of the exposure in a 50Hz field. None-the-less, the implemented method can have a limited level of the accuracy in the case of the determination of the weaker fields' frequency components, and inappropriate for the detection of these transient, complex or high frequency magnetic signals that can be presented at the analyzed media level. Studying those undetected signals as well as their compliance level with ICNIRP regulations is not within this work's scope.

15. Standard assessment rules and methods for measuring exposure levels were developed. It is still a challenge to compare results from different studies that adopted various assessment strategies.

16. According to the results obtained, the occupational exposure of the medical staff in operating rooms is below standard levels permitted. Therefore, the risks of such exposure are not substantial regarding to non-ionizing radiation overexposure.

17. The analysis showed that magnetic field intensity in operating rooms is influenced by various factors, which include: number of monitors and devices, type of procedure performed, placement relative to main power input lines, distance of personnel (including the anesthesiologists) from the source, as well as operating room illumination.

18. Operational settings are required to focus on ensuring magnetic safety of the involved staff. One proposal indicates that personnel should maintain a safe distance from the high-voltage supplies. Additionally, for the purpose of reducing the EF and MF density in the operating rooms, the power supplies for the electrical system should be placed outside of the operating rooms. Another precaution can be taken by all personnel in terms of reducing quantity, maintaining distance and shielding.

7. ORIGINAL CONTRIBUTIONS OF THE AUTHOR

The original contributions of the doctoral thesis can be summarized in three main directions:

1. Survey on the perception of high-qualified health care personnel in Iraqi Hospitals, regarding electromagnetic compatibility and electromagnetic Interference problems.

2. Study on the methods and instrumentation for low frequency magnetic field measurements.

3. Low frequency magnetic field measurements over a period of three years in several areas of medical environment - case studies in Iraqi hospitals.

The original data (results of the survey and results of the measurements campaigns) adequately processed and discussed are already published in several scientific papers in journals and at electrical engineering conferences.

Detailed contributions are shown further.

1. Regarding the **survey,** we performed the following operations:

1.1. We performed the survey in 47 Hospitals in Iraq.

1.2. We started our survey by asking the hospital high qualified staff (biomedical engineers, doctors and medical physics team), about the electromagnetic interference problems related to the equipment currently used and to local practices - awareness on EMC and EMI phenomena inside medical environment, preventive measures, observed issues, correction attitudes.

1.3. The survey results were processed and presented in statistical form and adequate conclusions were drawn.

2. Regarding the **study of the methods and instrumentation for low frequency magnetic field measurements,** the thesis includes original contributions like:

2.1. Study of the literature in the field of instrumentation and methods of supervision in order to characterize certain areas and sources in terms of exposure to magnetic field.

2.2. We presented a test executed for the verification of the accuracy of the Extech 480823 single axis EMF/ELF Meter, which is used for the measurement campaign in this study. In an attempt to find the levels of measurements uncertainty and to validate the use of the Extech field-meter, **a comparative measurement study was performed,** with other two precision field meters from Narda STS Solutions (EFA-300 type). The testing program was performed in the Laboratory for Electromagnetic Compatibility at the Faculty of Power Engineering, University "Politehnica" of Bucharest.

3. Regarding the **measurements program,** which is entirely original, the following case studies were analyzed and the shown operations were performed:

3.1. We identified sensitive locations in hospitals, with regard to higher levels of magnetic field, environments that could raise risk concern for medical personnel; six hospitals in Baghdad were assessed.

3.2. We measured the low frequency magnetic flux density in several departments in 3 hospitals; the departments of each hospital have been selected based upon services that have been supplied in every department, and according to medical devices that are operational within them.

- ✓ Hospital A - measurements were performed in 4 departments: Hospitalization (149 measurements in 14 rooms), Critical Care Unit (74 measurements in 6 rooms), Intensive Care Unit (127 measurements in 10 rooms, Emergency (98 measurements in 12 rooms);
- ✓ Hospital B - measurements were performed in 4 departments: Surgical rooms (121 measurements in 5 rooms), Emergency (151measurements in 16 rooms), Intensive Care Unit (48 measurements in 8 rooms), Neonatal Intensive Care Unit (32 measurements in 4 rooms);
- ✓ Hospital C - measurements were performed in 4 departments: Consulting Rooms (120 measurements in 20 rooms), Dentistry (120 measurements in 20 rooms), Obstetrics and Gynecology (184 measurements in 11 rooms), Clinical Laboratory (86 measurements in 3 rooms), Emergency (67 measurements in 8 rooms), Intensive Care Unit (60 measurements in 10 rooms).

For all areas presented, we studied and represented the maximum, minimum and also the average values of the low frequency magnetic flux density and compared the results with magnetic field levels suggested by the IEC60601-1-2:2014 standard. This typical standard specifies that electrical medical devices have to be supporting a 37.8mG magnetic field at industrial frequency, and I looked for reduction methods that can be locally applied to those areas.

3.3. We measured the low frequency magnetic flux density in two hospitals near a magnetic resonance imaging area (MRI) (the sites called for brevity A and B); the research area is divided right in four sections in each site: A waiting room (WR), Hall area, Control room (CR), Technical room (TR). For all mentioned areas, the measurements protocol included:

Measurements were performed at 3 distinct heights from the floor (0.3m, 1m, 2m) and in two conditions, i.e. the MRI equipment was operational (ON) and non-operational (OFF); the spatial distribution of the low frequency magnetic flux density was determined in each case and compared to ICNIRP 2010 recommendations for occupational reference level of 1mT. A statistical analysis of all data is also included for a general view and comparison.

3.4. Since the operation room is an area where the magnetic field is particularly high, due to many power interventional devices; a measurements campaign was performed in such rooms too, in one hospital. The measurements were performed in different sections of twelve operating rooms, at a standing positions characteristic for the interventional staff, also in nearest position to a patient, and in the position of the anesthesiologist, while all devices are operating. Secondly, the magnetic flux density was measured at different distances from the critical devices. The measurements are performed while only one device is operating and all the other devices are switched off. The protocol of the testing has been carried out for measuring the density of the low frequency magnetic flux, based on the standard IEC 61786-1:2013. Graphical representation of all data is also included for a general view and comparison.

REFERENCES

[1] *Repacholi M, "Concern that* 'EMF' magnetic fields from power lines cause cancer." Sci Total Environ (2012), doi:10.1016/j.scitotenv.2012.03.030, page 3.

[2] *ICNIRP Guidelines*, "Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz to 100 Khz)," Health Physics, Vol. 99, No. 6, 2010, pp. 825-827.

[3] *Standard C95.6* – "Safety Levels with Respect to Human Exposure to Electromagnetic Fields", 0–3 kHz. issued by the IEEE International Committee on Electromagnetic Safety.

[4] The "International Electrotechnical Commission" http://www.iec.ch/).

[5] *Ahlbom A, Cardis E, Green A, Linet M, Savitz D, Swerdlow A*.2001. "Review of the epidemiologic literature on EMF and Health. Environ Health Perspect" 109:911–933.

[6] *Feychting M*. "Non-cancer EMF effects related to children". Bioelectromagnetics 2005;(Suppl 7):S69–74.

[7] *European Parliament and Council (2013) "Directives 2013/35EU* of the European Parliament and of Council of 26 Jun. 2013 on minimal safety and health requirements regarding exposures of the workers to risks that arise from the physical agents (EMFs) (20-th individual Directive in the meaning of Article 16(1) of Directive 89/391EEC) and repealing Directive 2004/40EC". Off J Eur Union L 179, 1–21.

[8] *WHO*, "Extremely Low Frequency Fields: Radiation and Environmental Health," World Health Organization, Geneva, 2007.

[9] *IEEE Std C95.6*™, "IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 - 3 kHz," 2002.

[10] *M. Zahner*, "*Analysis, Methods, and Tools for Electromagnetic Field Exposure Assessment and Control"*: ETH Zurich, 2017.

[11] *A. Ahlbom, U. Bergqvist, J. Bernhardt, J. Cesarini, M*. Grandolfo, M. Hietanen, et al., "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," Health physics, vol. 74, pp. 494-521, 1998.

[12] *IEEE* "Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 100 kHz", IEEE Standard C95.3.1-2010, 2010;

[13] *J. L. Gould*, "Magnetic field sensitivity in animals," Annual Review of Physiology, vol. 46, pp. 585-598, 1984.

[14] *L. Kheifets, A. Ahlbom, C. Crespi, G. Draper, J. Hagihara, R. Lowenthal, et al.*, "Pooled analysis of recent studies on magnetic fields and childhood leukaemia," British journal of cancer, vol. 103, p. 1128, 2010.

[15] *J. Grellier, P. Ravazzani, and E. Cardis*, "Potential health impacts of residential exposures to extremely low frequency magnetic fields in Europe," Environment international, vol. 62, pp. 55-63, 2014.

[16] *M. Soffritti, E. Tibaldi, M. Padovani, D. G. Hoel, L. Giuliani, L. Bua, et al.*, "Synergism between sinusoidal-50 Hz magnetic field and formaldehyde in triggering carcinogenic effects in male Sprague–Dawley rats," American journal of industrial medicine, vol. 59, pp. 509-521, 2016.

[17] *Q. Ma, C. Chen, P. Deng, G. Zhu, M. Lin, L. Zhang, et al.*, "Extremely low-frequency electromagnetic fields promote in vitro neuronal differentiation and neurite outgrowth of embryonic neural stem cells via up-regulating TRPC1," PloS one, vol. 11, p. e0150923, 2016.

[18] *M. A. Martínez, A. Úbeda, J. Moreno, and M. Á. Trillo,* "Power frequency magnetic fields affect the p38 MAPK-mediated regulation of NB69 cell proliferation implication of free radicals," International journal of molecular sciences, vol. 17, p. 510, 2016.

[19] *C. N. Giachello, N. S. Scrutton, A. R. Jones, and R. A. Baines,* "Magnetic fields modulate blue-light-dependent regulation of neuronal firing by cryptochrome," Journal of Neuroscience, vol. 36, pp. 10742-10749, 2016.

[20] *I. Liorni, M. Parazzini, B. Struchen, S. Fiocchi, M. Röösli, and P. Ravazzani,* "Children's personal exposure measurements to extremely low frequency magnetic fields in Italy," International journal of environmental research and public health, vol. 13, p. 549, 2016.

[21] *ITU-R*, "Nomenclature of the frequency and wavelength bands used in telecommunications," Recommendation V.431-8, 2015.

[22] *ICNIRP*, "Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (up to 300 GHz)", Health Physics 74, 4, pp. 494–522, 1998: http://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf

[23] *IEEE,* "Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz", IEEE Standard C95.6-2002; on line at: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=1046043

[24] *EU Document, Document 2010/C83/02, "*Charter of Fundamental Rights of the European Union, Official Journal of the EU", Vol. 53, 30 March 2010, pp. 389–403; http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:08 3:0389:0403:EN:PDF

[25] *European Parliament*, "Directive 2004/40/EC of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (electromagnetic fields)", (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) Official Journal of the European Communities.

[26] *ICNIRP*, "Exposure to Static and Low Frequency Electromagnetic Fields, Biological Effects and Health Consequences (0–100 kHz)" – Review of the Scientific Evidence, Munich meeting 2003; http://www.icnirp.org/en/publications/article/static-andlow-frequency-review-2003.html

[27] *M. Morega, I.M. Băran, A.M. Morega*, "Evaluation of Environmental Low Frequency Magnetic Fields in Occupational Exposure", Proc. 8th Int. Conf. and Exposition on Electrical and Power Engineering (EPE-2014), Iaşi, Romania, October 2014, pp. 522–527.

[28] *Executive Decision* no. 1136 of 30.08.2006 "on minimum requirements of security and health, regarding workers' exposure to risks generated by electromagnetic fields", Romanian Official Monitor, part I, no. 769/2006.

[29] *Executive Decision no*. 520 of 20.07.2016 "on minimum requirements of security and health, regarding workers' exposure to risks generated by electromagnetic fields", Romanian Official Monitor, part I, no. 576 from 28.07.2016 (transposition of Directive 2013/35/EU).

[30] *G. Alecu, A. Voina , W. Kappel, C. Mateescu,* "Safety and health legislative requirements regarding workers exposure to risks generated by electromagnetic fields", Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., 53, 2, pp. 7–12, 2008.

[31] *M. Morega, V.C. Calotă,* "From Directive 2013/35/EU to National Legislation. Transposition, Implementation and Assessment Work", Proc. Int. Conf. on Applied and Theoretical Electricity (ICATE-2016), Craiova, Romania, October 2016.

[32] *EC Documents, D-G for Employment,* Social Affairs and Inclusion Unit B3, "Non-binding guide to good practice for implementing Directive 2013/35/EU Electromagnetic Fields, Vol. 1: Practical Guide, Vol. 2: Case Studies", Vol. 3: Guide for SMEs, 2015; on-line at: http://ec.europa.eu/ social/main.jsp?catId=738&langId =en&pubId=7845

[33] *E. CENELEC*, "50499: 2008-12," “Procedure for the assessment of the exposure of workers to electromagnetic fields”. Classificazione CEI, pp. 106-23.

[34] *E. CENELEC*, "50413: 2008," “Basic Standard on Measurement and Calculation Procedures for Human Exposure to Electric, Magnetic and Electromagnetic Fields (0 Hz–300 GHz)”, 2008.

[35] *I. E. Commission*, “Electric and Magnetic Field Levels Generated by AC Power Systems: Measurement Procedures with Regard to Public Exposure”: IEC, 2009.

[36] *I. Standard*, “61786. Measurement of low frequency magnetic and electric fields with regard to exposure of human beings. Special requirements for instruments and guidance for measurements,” August 1998, 1998.

[37] *Council Recommendation of 12 July 1999* “on the limitation of exposure of the general public to electromagnetic fields” (0 Hz to 300 GHz) (1999/519/EC), Official Journal of the European Communities no. L 199/59.

[38] *E. Commission*, “Non-binding guide to good practice for implementing Directive 2013/35/EU Electromagnetic Fields-Volume 2- Case Studies,” ed: Publications Office of the European Union Luxembourg, 2015.

[39] *E. Commission*, “Non-binding guide to good practice for implementing Directive 2013/35/EU Electromagnetic Fields- Guide for SMEs,” ed: Publications Office of the European Union Luxembourg, 2015.

[40] *E. Commission*, “Non-binding guide to good practice for implementing Directive 2013/35/EU Electromagnetic Fields-Volume 1-Practical guide,” ed: Publications Office of the European Union Luxembourg, 2015.

[41] *Zahner Marco “*Analysis, Methods, and Tools for Electromagnetic Field Exposure Assessment and Contro” *, Doctoral Thesis,2017.*

[42] *D. P. Pappas.* "High Sensitivity Magnetic Field Sensor Technology overview," Jun, 2016.

[43] *T. Instruments,* "DRV425 Fluxgate Magnetic-Field Sensor," SBOS729 datasheet, Oct, 2015.

[44] *R. Fagaly,* "Superconducting quantum interference device instruments and applications," Review of scientific instruments, vol. 77, p. 101101, 2006.

[45] *https://www.narda-sts.com/en/wideband-emf/elt-400.*

[46] *IEC*, “Measurement of DC magnetic fields, AC magnetic and electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part. 1. Requirements for measuring instruments”, IEC Standard EN61786-1, 2013, http://www.en-standard.eu

[47] *IEEE*, “Guide for the Measurement of Quasi-Static Magnetic and Electric Fields”, IEEE Standard 1460–1996 (reaffirmed in 2002), on line at: http://ieeexplore.ieee. org/xpl/articleDetails.jsp?arnumber=582155

[48] *ICNIRP*, “Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (up to 300 GHz)”, Health Physics 74, 4, pp. 494–522, 1998: http://www.icnirp.org/ cms/upload/publications/ICNIRPemfgdl.pdf

[49] *Lunca Eduard, David Valeriu*, “Wideband Three-axis Magnetic Field Sensor”, Proceedings of the 10th International Conference and Exposition on Electrical and Power Engineering, Oct. 18-19 2018, Iasi, Romania, pp. 693-696, ISBN:978-1-5386-5062-2, ISSN: 2471-6855

[50] *EN 62233:2008*. “Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure” (IEC 62233:2005, modified)

[51] *EXTECH Instruments, “Electromagnetic Field Meter,* Model 480823, User manual 480823-en-GB_V2.3”

[52] *Ken K Karipidis,* "Measurement of Residential Power Frequency Magnetic Fields," Technical Report 134, March 2002, ISSN 0157-1400.

[53] *Mariappan, P.M., et al.,* "Effects of electromagnetic interference on the functional usage of medical equipment by 2G/3G/4G cellular phones": A review. Journal of Advanced Research, 2016. 7(5): p. 727-738.

[54] *Gerke, D.,* "Electromagnetic compatibility in medical equipment: a guide for designers and installers". 2018: Routledge.

[55] *Ishida, K., et al.,* "Evaluation of Electromagnetic Fields in a Hospital for Safe Use of Electronic Medical Equipment". Journal of medical systems, 2016. 40(3): p. 46.

[56] *Sardana, S.R., I. Kabir, and S.K. Arya,* "A Way To Assess Functional Status And Improve Equipment Utilization In A Tertiary Care Institute". Indian Journal Of Applied Research, 2018. 7(11).

[57] *Al-Shaikh, B. and S.G. Stacey,* "Essentials of Equipment in Anaesthesia, Critical Care, and Peri-Operative Medicine" E-Book. 2017: Elsevier Health Sciences.

[58] *Food Drug Admin.,* "Electromagnetic Compatibility Standard for Medical Devices": U.S. Dept. Health, Education, Welfare, PublicHealth Service, , Bur. Medical Devices, 1979: FDA MDS-201-0004

[59] *IEC,* "International Standard IEC 601-1-2," Int. Electrotech. Commission,1993.

[60] *IEC,* "International Standard IEC 1000-4-3," Int. Electrotech. Commission,1995.

[61] *Lapinsky, S.E. and A.C. Easty,* Electromagnetic interference in critical care. Journal of critical care, 2006. 21(3): p. 267-270.

[62] *Morrissey, J.J., M. Swicord, and Q. Balzano,* Characterization of electromagnetic interference of medical devices in the hospital due to cell phones. Health physics, 2002. 82(1): p. 45-51.

[63] *Tan, K.-S., I. Hinberg, and J. Wadhwani*. "Electromagnetic interference in medical devices": Health Canada's past and current perspectives and activities. in Electromagnetic Compatibility, 2001. EMC. 2001 IEEE International Symposium on. 2001. IEEE.

[64] *Ott, H.W.,* "Electromagnetic compatibility engineering". 2011: John Wiley & Sons.

[65] *Mengxia, Z., et al.,* "Radiation Interference Suppression Technology on Medical Electronic Equipment Based on Near Field Diagnosis". Journal of Nanjing Normal University (Engineering and Technology Edition), 2016(2): p. 5.

[66] *Urden, L.D., K.M. Stacy, and M.E. Lough,* "Critical Care Nursing-E-Book: Diagnosis and Management". 2017: Elsevier Health Sciences.

[67] *J. Tikkanen,* "Wireless electromagnetic interference (emi) in healthcare facilities," Blackberry White Paper, 2009.

[68] *Witters D.M. and P. S. Ruggera,* "Electromagnetic Compatibility (EMC) of Powered Wheelchairs and Scooters", Proceedings of the RESNA '94 (Rehabilitation Society of North America) Annual Conference Tuning in to the 21st Century Through Assistive Technology (July 1994) page 359- 60.

[69] *Ruggera P. S. and E. R O'Bryan,* "Studies of Apnea Monitor Radio frequency Electromagnetic Interference", Proceedings of the 13th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Vol. 13, No. 4, (1991), pages 1641-1643.

[70] *Casamento J., P. Ruggera, D. Witters, H. Bassen,* "Applying Standardized Electromagnetic Compatibility Testing Methods for Evaluating Radio Frequency Interference Of Ventilators" (in draft)

[71] *Silberberg J. L.,* "Performance Degradation of Electronic Medical Devices Due to Electromagnetic Interference", Compliance Engineering (Fall 1993) pages 25-39.

[72] *Public Hearing, 103 U.S. Congress, Information, Justice,*Transportation, and Agriculture Subcommittee, Rep. G. Condit (CA) Chairman, "Do Cellular and other Wireless Devices Interfere with Sensitive Medical Equipment?", Rayburn House Office Building (October 5, 1994).

[73] *Antila S.,* "Where Shoplifting Bolsters Profits, New York Times, Money section", (December 12,1994) page 13.

[74] *Baskim R.,* Haywire, "segment on CBS television show Eye-to- Eye with Connie Cheung", (December 1, 1994.

[75] *'Banana Skins'*, UK EMC Journal, vol. 15, p. 8, February 1998.

[76] *Jeffrey L Silberberg*, "Performance degradation of electronic medical devices due to electromagnetic interference", Compliance Engineering vol. 10 p. 25 1993.

[77] *Medical Devices Agency*, "Electromagnetic Compatibility of Medical Devices with Mobile Communications", MDA DB 9702, 1997.

[78] *Christopher Marshman*, "EMC Management and Planning in the Hospital Environment to minimise Hazards' IPEM Conference on 'Practical Methods for Mitigation of EMI and EMF Hazards within Hospitals" 28th January 2003.

[79] *EN55011 1998 (+ Amendment A2:2002)* – "Industrial, scientific and medical (ISM) radio frequency equipment - Radio disturbance - Characteristics - Limits and methods of measurement".

[80] *Christopher Marshman*, "EMC Management and Planning in the Hospital Environment to minimise Hazards" IPEM Conference on 'Practical Methods for Mitigation of EMI and EMF Hazards within Hospitals' 28th January 2003.

[81] *Cătălin Luca, Alexandru Sălceanu,* "Study upon electromagnetic interferences inside an intensive care unit", Proceedings of the 2012 International Conference and Exposition on Electrical and Power Engineering – EPE", 25-27 Oct. 2012, DOI:10.1109/ICEPE.2012.6463878.

[82] *European Parliament and Council of the European Union*, "Directive 2014/30/EU," Brussels, 2014.

[83] *Federal Communications Commission.* "Quick labelling guide". Accessed December 1, 2016.

[84] *International Electrotechnical Commission (IEC).* Who we are. Accessed December 5, 2016. [Online]. Available: http://www.iec.ch/about/profile/

[85] *Developing international standards*. Accessed December 5, 2016. [Online]. Available: http://www.iec.ch/about/activities/standards.htm

[86] *IEC 60601:2014(E) Medical electrical equipment — Part 1-2*: "General requirements for basic safety and essential performance — Collateral Standard: Electromagnetic disturbances – Requirements and tests," International Electrotechnical Commission, Geneva, Switzerland, International Standard, February 2014.

[87] *IEC 60601:2007(E) Medical electrical equipment — Part 1-2:* "General requirements for basic safety and essential performance — Collateral Standard: Electromagnetic disturbances – Requirements and tests," International Electrotechnical Commission, Geneva, Switzerland, International Standard, March 2007.

[88] *IEC 60601:2004(E) Medical electrical equipment — Part 1-2:* "General requirements for basic safety and essential performance — Collateral Standard: Electromagnetic disturbances – Requirements and tests," International Electrotechnical Commission, Geneva, Switzerland, International Standard, November 2001.

[89] *IEC 60601:1993(E) Medical electrical equipment — Part 1-2:* "General requirements for basic safety and essential performance — Collateral Standard: Electromagnetic disturbances –

Requirements and tests," International Electrotechnical Commission, Geneva, Switzerland, International Standard, April 1993.

[90] *Alnamir, H.* "Occupational Exposure to Power Frequency Magnetic Fields in Intensive Care Unit Rooms", in 2018 Proceedings of the International Conference on Applied and Theoretical Electricity (ICATE), Craiova, Romania, October 2018

[91] *IEC, "Measurement of DC magnetic fields, AC magnetic and electric fields from 1 Hz to 100 kHz* with regard to exposure of human beings – Part. 1. Requirements for measuring instruments", IEC Standard EN61786-1, 2013; http://www.en-standard.eu.

[92] *ICNIRP* "statement on diagnostic devices using non-ionizing radiation: existing regulations and potential health risks", published in Health Phys. 112(3):305–321; 2017.

[93] *ICNIRP*. "Guidelines on limits of exposure to static magnetic fields". Health Physics (2009) 96(4):504–14. doi:10.1097/01.hp.0000343164.27920.4a.

[94] *IEEE. C95.1-2005* "IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz". Piscataway, NJ, USA: IEEE/Institute of Electrical and Electronics Engineers Incorporated (2006).

[95] *R. Stam and S. Yamaguchi-Sekino,* "Occupational exposure to electromagnetic fields from medical sources," Industrial Health, vol. 56(2), pp. 96-105, November 2017.

[96] *Chadwick P.* "Assessment of electromagnetic fields around magnetic resonance imaging (MRI) equipment". UK Health and Safety Executive 2007;RR570. Accessed 21 December 2011. Available from: http://www.hse.gov.uk/research/ rrpdf/rr570.pdf.

[97] *M. A. Fuentes et. al.,* "Analysis and Measurements of Magnetic Field Exposures for Healthcare Workers in Selected MR Environments," IEEE Transactions on Biomedical Engineering, vol. 55, no. 4, April 2008.

[98] *Stehling SMK,* Turner R. "Echo-planar imaging theory, techniqueand application". New York: Springer, 1998. p. 662.

[99] *Crozier S, Liu F. "*Numerical evaluation of the fields caused by bodymotion in or near high-field MRI scanners". Prog Biophys Mol Biol2005;87:267–278.

[100] *I. Pavel, V. David and A. C. Podaru, "A Survey of the Magnetic Field in a MRI Area," 2018 International Conference and Exposition on Electrical And Power Engineering (EPE), Iasi, 2018, pp. 0572-0577, doi: 10.1109/ICEPE.2018.8559645.*

[101] *Gobba F. et al., "*Occupational and environmental exposure to extremely low frequencymagnetic fields: a personal monitoring study in a large group of workers in Italy", Journal of Exposure Science and Environmental Epidemiology, 2011, pp 634-645.

[102] *E. Hanada,* "The electromagnetic environment of hospitals: How it is affected by the strength of electromagnetic fields generated both inside and outside the hospital," Ann Ist Super Sanita 2007; 43:208–17.

[103] *Ionel Pavel, David Valeriu , ("*Cercetări privind supravegherea câmpurilor magnetice generate de sistemele de alimentare cu energie electrică*") http://www.doctorat.tuiasi.ro*

[104] *M. Morega, I.M. Baran, A.M. Morega, K.L. Hussain Alnamir,* "On the assesement of human exposure to low frequency magnetic field at the workplace," Vol. 63, 2, pp. 162-171, Bucharest, 2018, ISSN: 0035-4066.

[105] *Hotărâre nr. 520/2016,* "Cerinţele minime de securitate şi sănătate referitoare la expunerea lucrătorilor la riscuri generale de câmpuri electromagnetice", Monitorul Oficial, 2016, nr. 576.

[106] *David V., Nica I., Salceanu A., Breniuc L.,* (2009), "Monitoring of environmental low frequency magnetic fields", Environmental Engineering and Management Journal, vol. 8, 2009, pp. 1253 -1261, ISSN: 1582-9596, eISSN: 1843-3707

[107] McRobbie DW. "Occupational exposure in MRI". Br J Radiol. 2012;85(1012):293–312. doi:10.1259/bjr/30146162.

[108] *I. Magne et. al.,* "Exposure of children to extremely low frequency magnetic fields in France: Results of the EXPERS study," Journal of Exposure Science and Environmental Epidemiology, vol 27, pp. 505512, 2017.

[109] *I. Eliyahua, et. al*, "24-h personal monitoring of exposure to Power Frequency Magnetic Fields in adolescents˟Results of a National Survey," Environmental Research 158, pp. 295-300, June 2017.

[110] *Dewey M, Schink T, Dewey CF*. "Claustrophobia during magnetic resonance imaging": cohort study in over 55,000 patients. J Magn Reson Imag 2007;26:1322–7.

[111] *Norris DG*. "High field human imaging". J Magn Reson Imag 2003;18:519–29.

[112] *Medicines and Healthcare Products Regulatory Agency*. "Safety guidelines for magnetic resonance imaging equipment in clinical use". MHRA DB2007. London, UK: Medicines and Healthcare Products Regulatory Agency; 2007.

[113] *Kanal E, Borgstede JP, Barkovich AJ, Bell C, Borgstede JP, Bradley WG, et al*. "American College of Radiology white paper on MR safety". AJR Am J Roentgenol 2001;178:1335– 47.

[114] *Ciorap Radu, Ciorap Mariana, David Valeriu, Andriţoi Doru, Corciovă Călin*, "Analysis of brain activity in the case of magnetic field exposure", Environmental Engineering and Management Journal, vol. 12/6, 2013, pp. 1223 -1230, ISSN: 1582-9596, eISSN: 1843-3707

[115] *David Valeriu, Sălceanu Alexandru, Ciorap Radu,* "Acquisition and Analysis of Biomedical Signals in Case of People Exposed to Electromagnetic Fields", In: Pervasive and Mobile Sensing and Computing for Healthcare, Smart Sensors, Measurement and Instrumentation book series, SSMI, vol. 2, pp. 269-295, Springer-Verlag, Berlin, Heidelberg 2013

[116] *M. Cucu, M. Vlad, C. L. Popescu and M. O. Popescu*, "Determination of electromagnetic risk area in electrical equipments," 2013 8TH INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING (ATEE), Bucharest, 2013, pp. 1-4, doi: 10.1109/ATEE.2013.6563450.

[117] *M. Feychting,* "Non-cancer EMF effects related to children," Bioelectromagnetics 2005;(Suppl 7):S69–74.

[118] *A. Ahlbom,* "Neurodegenerative diseases, suicide and depressive symptoms in relation to EMF," Bioelectromagnetics 22, 2001; (Suppl 5): S132–S143.

[119] *Hanada E, Takano K, Antoku Y, Matsumura K, Watanabe Y, Nose Y.* "A practical procedure to prevent electromagnetic interference with electronic medical equipment". J Med Syst. 2002 Feb;26(1):61-5. doi: 10.1023/a:1013094904976. PMID: 11777312.

[120] *Ahlbom A., Day N. et al.,* "A pooled analysis of magnetic fields and childhood leukemia", British Jurnal of Cancer, vol. 83, no. 5, 16 June 2000, pp. 692-698.

[121] *Nica Ionuţ, David Valeriu, Pavel Ionel, Sălceanu Andrei*, "Automatic long term Survey of Magnetic Fields in Residential Areas. Instrumentation and Measurements", Environmental Engineering and Management Journal, Vol.15/12, 2016, pp. 2631-2640, ISSN: 1582-9596,

eISSN: 1843-3707

[122] *Kamiya K, Ozasa K, Akiba S, Niwa O, Kodama K, Takamura N, Zaharieva EK, Kimura Y, Wakeford R:* "Long-term effects of radiation exposure on health". Lancet 386, 469–478 (2015)

[123] *Hareuveny R, Kavet R, Shachar A, Margaliot M, Kheifets L*: "Occupational exposures to radiofrequency fields: Results of an Israeli national survey". J Radiol Prot 35, 429 (2015)

[124] *Pavel Ionel, David Valeriu, Donose Costel*, "A Measurement System for the Automatic Survey of the Low Frequency Magnetic Field", Proceedings of the 10th International Conference and Exposition on Electrical and Power Engineering, Oct. 18-19 2018, Iasi, Romania, pp. 568-571, ISBN:978-1-5386-5062-2, ISSN: 2471-6855

[125] *Akdag MZ, Dasdag S, Aksen F, Isik B, Yilmaz F*: "Effect of ELF magnetic fields on lipid peroxidation, sperm count", p53, and trace elements. Med Sci Monit 12, BR366–BR371 (2006)

[126] *Mostafa RM, El Hefnawi A, Moustafa K, Ali F, Moustafa Y, Kamal S, Hefnawi MH*: "Effect of 50 Hz, 10 mTesla magnetic field on sex hormones level in male rats". J Med Sci Res 1, 31–36 (2007)

[127] *Amara S, Abdelmelek H, Salem MB, Abidi R, Sakly M*: "Effects of static magnetic field exposure on hematological and biochemical parameters in rats". Braz Arch Biol Technol 49, 889–895 (2006)

[128] *Havas M*: "When theory and observation collide: Can non-ionizing radiation cause cancer?" Environ Pollut 221, 501–555 (2017)

[129] *Hardell L*, Sage C: "Biological effects from electromagnetic field exposure and public exposure standards".BiomedPharmacother62, 104–109 (2008)

[130] *Selmaoui B, Lambrozo J, Touitou Y*: "Endocrine functions in young men exposed for one night to a 50-Hz magnetic field. A circadian study of pituitary, thyroid and adrenocortical hormones". LifeSci61, 473–486 (1997)

[131] *Lacy-Hulbert A, Metcalfe JC, Hesketh R*: "Biological responses to electromagnetic fields". FASEB J 12, 395–420 (1998).

[132] *SelmaouiB,LambrozoJ,TouitouY*: "Endocrine functions in young men exposed for one night to a 50-Hz magnetic field".LifeSci61, 473–486 (1997).

[133] *Matavulj M, Rajkovic V, Uscebrka G, Lukac T, Stevanovic D, LazeticB:"*Studies on the possible endocrinological effects of 50Hz electromagnetic field". Cent Eur J Occup Environ Med 6, 183–188 (2000).

[134] *ForgacsZ, Thur´oczyG, PaksyK, SzaboLD*:" Effect of sinusoidal 50 Hz magnetic field on the testosterone production of mouse primary Leydig cell culture". Bioelectromagnetics 19, 429–431 (1998).

[135] *Stam R, Yamaguchi-Sekino S*: Occupational exposure to electromagnetic fields from medical sources. Ind Health 56, 96–105 (2017).

[136] *Hallett M.* (2007), "Transcranial magnetic stimulation: a primer". Neuron 55, 187–99.

[137] *Kikuchi M, Amemiya Y, Egawa S, Onoyama Y, Kato H, Kanai H, Saito Y, Tsukiyama I, Hiraoka M, Mizushina S, Yamashita T, Ikeda T, Kozuka Y, Sugiura K* (1993) "Guide for the protection of occupationally-exposed personnel in hyperthermia treatment from the potential hazards to health". Int J Hyperthermia 9, 613–24.

[138] *Tzima E, Martin CJ* (1994) "An evaluation of safe practices to restrict exposure to electric and magnetic fields from therapeutic and surgical diathermy equipment". Physiol Meas 15, 201–16.

[139] *Wilén J*. (2010), "Exposure assessment of electromagnetic fields near electrosurgical units". Bioelectromagnetics 31, 513–8.

[140] *E.K. Svenska,* " Computers and office machines: Measuring methods for electric and magnetic near fields," 2nd ed. Stockholm, Sweden, 1995, Report No. SS 436-14–90.

[141] *Vila J, Bowman JD, Richardson L, Kincl L, Conover DL, McLean D, Mann S, Vecchia P, van Tongeren M, Cardis E*: "A source-based measurement database for occupational"