Electromagnetic Radiation and its effects on human beings: Survey and Environmental Recommendations

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ABSTRACT

Wireless mobile communication networks have become essential for human life. A great booming and huge investments are devoted to develop the services without taking into considerations the health effect of electromagnetic radiations of the base stations concerning with these services. Base stations for wireless mobile communication have brought Electromagnetic Field (EMF) sources to the permanent residences of people. A global increase in the level of electromagnetic background has taken place leading to its continuing presence in the environment. Cellular mobile radio communications have developed rapidly in KSA and are one of the most actively growing sectors of the national economy. The highest density of cellular mobile Base Station (BS) occurs in large cities and territories adjourning to them. More BSs are needed in rural and distant territories, as well as for the national digital trunk radio communication network. Many studies were made in this field and they did not prove that there is no effect for the EMF radiated from the mobile base stations. So, in this study we will present a survey for the different researches developed in this field and the recommendation to considerably reduce these effects. In the light of the recommendations a procedure will proposed to reduce the effect of EMF in KSA cities.

Keywords:

Electromagnetic Field Radiation; EMF exposure; Exposure Limit; SAR.

INTRODUCTION

Potential health effects of man-made EMF have been a topic of scientific interest since the late 1800s, and have received particular attention during the last 30 years. EMF can be broadly divided into static and low-frequency electric and magnetic fields, where the common sources include power lines,

household electrical appliances and computers, and high- frequency or radiofrequency fields, for which the main sources are radar, radio and television broadcast facilities, mobile telephones and their base stations, induction heaters and anti-theft devices [1].

The frequency band of microwave radiation is regulated from 300 MHz to 300 GHz. The electromagnetic spectrum are very widely used in different areas of science and technology. These radiation are categorized as non-ionizing. radiation. The radiation in frequency range of 300 MHz to 10 GHz can be easily absorbed in biological tissues and human beings. Due to this property, microwave radiations are extensively used in medicine where heating of the tissues is desired, specifically, in pasteurization of foodstuff, medical diathermy and hyperthermia of cancerous tissues for treatment, etc. While using high power microwave equipments, the safety of the operating personnel is a matter of concern [2].

Unlike ionizing radiation (such as gamma rays given off by radioactive materials, cosmic rays and X-rays) found in the upper part of the electromagnetic spectrum, EMF are much too weak to break the bonds that hold molecules in cells together and, therefore, cannot produce ionization. This is why EMF are called 'non-ionizing radiations' (NIR). Figure 1 shows the relative position of NIR in the wider electromagnetic spectrum [1].

The International Bodies, Governmental and Private Organizations for Limiting Exposure to Electromagnetic fields (up to 300 GHz)

In 1974, the International Radiation Protection Association (IRPA) formed a working group on non-ionizing radiation (NIR), which examined the problems arising in the field of protection against the various types of NIR. At the IRPA Congress in Paris in 1977, this working group became the International Non-Ionizing Radiation Committee (INIRC). In cooperation with the Environmental Health Division of the World Health Organization (WHO), the IRPA/INIRC developed a number of health criteria documents on NIR as part of WHO's Environmental Health Criteria Programme, sponsored by the United Nations Environment Programme (UNEP). Each document includes an overview of the physical characteristics, measurement and instrumentation, sources, and applications of NIR, a thorough review of the literature on biological effects, and an evaluation of the health risks of exposure to NIR. These health criteria have provided the scientific database for the subsequent development of exposure limits and codes of practice relating to NIR [3].

At the Eighth International Congress of the IRPA (Montreal, 18–22 May 1992), a new, independent scientific organization the International Commission on Non-Ionizing Radiation Protection (ICNIRP) was established as a successor to the IRPA/INIRC. The functions of the Commission are to investigate the hazards that may be associated with the different forms of NIR, develop international guidelines on NIR exposure limits, and deal with all aspects of NIR protection [3].

The Federal Communications Commission (FCC) in United States of America (US) regulates interstate and international communications by radio, television, wire, satellite and cable in all 50 states, the District of Columbia and U.S. territories. An independent U.S. government agency overseen by Congress, the commission is the United States' primary authority for communications law, regulation and technological innovation. So it is responsible for consumers, public safety, accessibility, competition and technological and economic opportunity [4].

Several countries all over the world established their governmental bodies to regulate the usage of wire and wireless communications (National Telecommunications Regularity Association) NTRA and get the responsibility to introduce a code for limiting the exposure of human beings to electromagnetic fields.

France, Spain, Belgium, UK, Switzerland, Italy, Russia, Brazil and Egypt regulate the risk of mobile phone base station by their regulatory bodies. And a survey for their efforts will be mention later.

Electromagnetic radiation Effect on Human Health.

The adverse health effects depend on factors such as the type of radiation (ionizing or non-ionizing); the quantity of dose absorbed; the rate at which the dose was absorbed; radio sensitivity of the cells involved; the polarization of the EMF wave; and the distance from the source. The quantity of EMF doses absorbed by the human body is an important factor and is measured in units called the specific absorption rate (SAR) or gray [5], an amount of radiation that releases one joule of energy per kilogram of matter. RF fields below 10 GHz (to 1 MHz) penetrate exposed tissues and produce heating due to energy absorption. The depth of penetration depends on the frequency of the field and is greater for lower frequencies. Absorption of RF fields in tissues is measured as a Specific Absorption Rate (SAR) within a given tissue mass. The unit of SAR is watts per kilogram (W/kg). SAR is the quantity used to measure the "dose" of RF fields between about 1 MHz and 10 GHz [7]. In practice, direct measurements of SAR are only feasible under laboratory conditions. Recommended maximum exposure levels in terms of electric and magnetic field strength as well as power density are therefore given in addition to SAR limits.

Measuring The Biological Impact Of EMF

Both the telecommunications industry and the biomedical engineering research sector have multiplied peer-reviewed scientific studies to determine whether prolonged exposure to electromagnetic waves poses a danger to human health. Biologists concede a wide range of opinion on the subject. While numerous scientific studies report that exposure to EMF has an impact on human tissues and cell development, experts do not agree on how much exposure may lead to health risks for adults or children and some research results seem to contradict previous results [8],[9]. The exposure interval time takes a great effort by the scientists. The effect of long term exposure to base stations and mobile phones on

human profiles is studied in [9]. The results of this study showed that significant decrease in volunteers' Adrenocorticotropic hormone (ACTH), cortisol, thyroid hormones, prolactin for young females, and testosterone levels. The conclusion revealed that high EMR effects on pituitary–adrenal axis. Also a long term interval time during sleeping under the influence of a GSM 1800 electromagnetic far field and biomedical effects was studied in [10].

The impact of high electromagnetic field levels on childhood leukemia (CL) incidence was studied in [11]. And conclude that, Epidemiological studies show a consistent association between ELF-EMF and CL. A 1.4- to 1.7-fold increased risk for exposure levels above 0.3 μT compared to <0.1 μT was found in pooled analyses. Although some bias may persist, it is possible that this is a causal association. Till date, research on RF-EMF and CL is limited and thus no firm conclusions can be drawn. The development of CL is likely to be a "multihit" process in which EMF might play a role. Some hypothesized biological mechanisms are proposed by which EMF could cause CL; however, none of these mechanisms have been consistently confirmed in experimental research. The impact of ELF-EMF exposure on CL incidence is likely to be limited, showing an overall (population attributable risk) PAR% of 1.9% worldwide. However, considering the variability of exposures between countries and regions, a substantial contribution of ELF-EMF to CL incidence cannot be ruled out.

In [12] a survey for 82 students was done. 12 students identified with specific health hazards in a questionnaire of 25 questions with different parameters of the daily usage and identified disease during the period of past one year. The conclusion is shown in table (1).

While the Deoxyribonucleic acid (DNA) and the effects of EMR was studied in several work as mentioned in [8].

After the previous survey about the biomedical hazard due to the exposure to EMR, standard exposure limits was done by WHO and ICNIRP as an International Organizations. The telecommunications and health regularities in different countries use these standards to eliminate EMR effects on human beings.

Standard Exposure Limits

$$SAR = c\Delta T/\Delta t \quad (1)$$

$$SAR = \sigma E^2/\rho \quad (2)$$

where ΔT is the temperature rise (in ◈C) within the time interval Δt (in seconds), and c is the tissue (or phantom material) specific heat capacity in J/Kg◈C, σ is the tissue conductivity (S/m), E is the rms electric field strength induced in the tissue (V/m) and ρ is the mass density (kg/m^3).

Doses of more than 400g SAR can severely damage the human vascular system, which can lead to death within 48 hours. Whole-body doses between 10-40g SAR causes less vascular damage, but they lead to loss of fluids and electrolytes in the intercellular spaces, death occurs within ten days due to imbalance of fluid and electrolytes[5], [13] .

Absorbed doses from 1.5-10g SAR cause destruction of human bone marrows leading to infections and death within 4-5 weeks after exposure. Radio sensitivity of the body has to do with allergy of our body systems on exposure to EMF waves. That is to say two persons of the same body weight can be exposed to the same amount of radiation and yet respond differently in terms of health effects [5], [13].

For mobile base stations, ICNIRP recommends that the general public exposure should be limited to 2 W/kg in any 10g for the head and body, 4 W/kg in any 10g for limbs and in addition 0.08 W/kg for the whole body and all of these subject to an averaging period of 6 minutes [6].

To understand the previous values of SAR we need to know how much the g SAR contains power absorbed in human body by kgm. So we have to know the United States standards, i.e., 1g SAR and IEEE-1528 (IEEE P1528 D1.22003), as well as the European standards, i.e., 10g SAR and EN50361 (CENELEC EN503612001).

Human Exposure to Radio Frequency Sources

Electrical currents exist naturally in the human body and are an essential part of normal bodily functions. All nerves relay their signals by transmitting electric impulses.

Most biochemical reactions, from those associated with digestion to those involved in brain activity, involve electrical processes. The effects of external exposure to EMF on the human body and its cells depend mainly on the EMF frequency and magnitude or strength. The frequency simply describes the number of oscillations or cycles per second [1].

The ITU define the Exposure domain into three domains: Personal Area, Immediate Area, and Wide Area [14]. A survey to the exposure effects in these areas will be introduced.

Human Exposure to household/office appliances/electronic devices (Immediate Area)

Using ICNIRP fact sheet 2010 shown in table (2) and The measurements results shown in table (3) that gotten by [4], it is possible to say that, The most household/office appliances/electronic devices produce high levels of electric and magnetic fields which are actually lower than the standard exposure limits.

Human Exposure to Electromagnetic Radiation from Wireless Devices (Personal Area)

In [6], a comparative study of of Human Exposure to Electromagnetic Radiation from Wireless Devices (DECT, WLAN and Bluetooth, as well as wireless communication devices based on proprietary standards in the frequency range of 30 MHz to 6 GHz in Home and Office Environments had done. Table (3) shows an overview of the tested device classes and the results of the dosimetric and far-field exposure assessments for [6] . Only the maximum values of each device class are shown. The E-field values are indicated for a distance of 20 cm and 1 m. and the results conclude that in the very near future the background exposure in everyday life situations will exceed exposures from base stations and

broadcast stations. This will considerably increase the complexity of epidemiological studies. The dominant source with respect to local and cumulative exposure will, however, remain the cellular phone.

Human Exposure To Electromagnetic Radiation From Mobile Base-Station (Wide Area)

To determine the exposure near the mobile base stations under real life conditions needs to consider several aspects.

The RF field distribution, which depends on several environmental factors, field levels are varying in space and time. Multipath propagation and fading effects lead to scenarios that are often not easy to reproduce leading to large uncertainty budgets [15], [16]. Considerable variations of the field levels in the GSM 900, DCS 1800, UMTS, Broadcasting and FM frequency range were found in restricted areas, e.g. the relation between the maximum field level and the average field level within one cubic meter was found to be typically between 2 and 5, the ratio between the maximum and minimum being much larger.

One approach to describe exposure scenarios is to use laws of field distribution, e.g. Rayleigh, Log Normal, Rice. Within the examined areas it was not possible to find clear relations between field scenarios defined by distance, LOS or NLOS conditions (Line Of Sight, Non Line of Sight) and Indoor versus Outdoor conditions. Preliminary results indicate that the meteorological conditions on the ground like water or snow may have an important impact on the propagation of reflected waves [14].

The hazardous electromagnetic field levels can be quantified analyzing the thermal response of the human body exposed to the HF radiation. Thermally harmful effects can occur if the total power absorbed by the body is large enough to cause protective mechanisms for heat control to break down. This may lead to an uncontrolled rise in the body temperature (hyperthermia). The problem to be considered is by itself twofold: first the rate of power deposition in tissue due to the electromagnetic radiation has to be determined; and then the related temperature distribution within the body has to be calculated [17].

For the mentioned factors above, many studies take the average power spectral density that human beings exposed to as a suitable unit to measure the EMR exposed to human beings from mobile base stations.

Many countries establish its own bodies to regulate and limit the exposure of EMF radiation. In the next sections examples of these countries and their efforts will be introduced.

The EMF uncertainty problem

The EMF uncertainty problem is the lack of scientific certainty. An independent non-profit UK-based organization, writes that, to establish an association between EMF and health effects, the certainty of causal association must be extremely high (95–98%) and that health effects related to smoking, asbestos, thalidomide, lead in petrol, etc., would not have been identified using these criteria [16]. Given the non-

conclusive research of potential risks to human health, which probably will remain inconclusive for decades (in particular, for long-term health effects), a relevant question is: 'How should consumers and policy makers navigate in this environment of uncertainty?'.

The precautionary principle legalizes more research in the field, makes the government more accountable, takes seriously potential future risks and effects, makes it possible to sanction industries/organizations for non-compliance and accommodates the public worry and need for further information. More information about the uncertainty problem exists in [16]. A comparative study in 5 countries (France, UK, Spain, Belgium and Switzerland) was done by Olivier Borraz and Danielle Salomon in Workshop on base stations and wireless networks organized by WHO in 2005. France, UK and Spain adhere the ICNIRP guidelines however Belgium and Switzerland not.

Another comparison study between Australia and New Zealand Government Responses in WHO 16th Seminar in Geneva by David Black MBChB FAFOM MARPS June 2005 and he saw that:

Strict compliance required in Australia

Good practice required in New Zealand

Still some legal challenges in Australia, but less Environment Court Cases in New Zealand now rarely reach Court.

Many countries had taken some actions to eliminate the exposure to EMF depending on the recommendations of international authorities, such as the WHO, the ICNIRP and ITU. Some of them make their own protocol to control the establishment the mobile base stations other was contented with define the exposure limit like in Italy, the government defined three level for radiation Exposure limit less than 60 V/m, Attention level equal to 6 V/m and the Quality goal is 6 V/m [18].

Russia established its own protocol by define the Obligatory maximum permissible levels (MPL) near BS in Russia are contained in the Sanitary-epidemiological norms and regulations SanPiN 2.1.8/2.2.4.1190–03 "Hygienic requirements for installation and operation of terrestrial mobile radio communication equipment". This norm was issued by the Ministry of health of Russia in 2003. For BS operating in UHF range (300–3000 MHz), the norm limits the MPL of equivalent plane wave power density to 10 μW/cm2 under non-occupational exposure conditions. This MPL for public exposure was introduced in 1984 for the first time.

Providing electromagnetic safety for the population around BSs is under state control and has a multi-stage character [19].

1. Before any BS installation is permitted a calculation of the EMF intensity in the surrounding territory is made.

2. On the basis of the calculation results the operator obtains the permission for BS installation

3.After completion of the BS installation EMF intensity measurements are carried out. Measurement results are submitted to the territory authority of the Federal service who issues permission to allow BS operation.

4.Periodic checks are carried out once every 1–3 years.

In Egypt they also made their own protocol for macrocell, microcell and Laser protocol. They define The maximum permissible power density a human being can be safely exposed to must not exceed 0.4 mW/cm^2 (CDMA-GSM 900 MHZ- GSM 1800 MHZ). The endorsed technology of measurement should be identified. They put some conditions restricted to the service providers such as:

1. When the antennas are mounted, the horizontal distance between them and human beings must be not less than 6 meters in the direction of the main beam.

2. The horizontal distance between the centers of two pylons on the same building must not be less than 12 meters.

3. The antennas used must be high-gain antennas and the front gain compared to the back gain must not be less than 20 dB for macrocell. For more details see [20].

As we saw, each country made its own protocol to ensure that the human beings exposure not exceed a certain level of exposure which is 0.45 mW/cm^2, defined by ICNIRP for mobile networks,. Some countries permit more exposure level; such as US and Canada that allow the maximum permissible power density a human being can be safely exposed to is 0.57 mW/cm^2[4].

How can we calculate the safety distance from the source of radiation? The answer will be introduced in the next section.

Safety Distance Calculations For Macrocell

From the infield sites, the maximum power sent from transmission unit to the antenna is 50 Watt (for one directive antenna). Suppose we have four antennas serve four sectors, they may be represented by one Isotropic radiation source with input power equal to 200 Watt which equivalent to 53dBm. Due to cable losses (3dBm) and combiners losses (6dBm).The maximum input power to the antenna = 53-9 = 44 dBm

For the directive antenna that used in mobile base station for macrocell; it has gain between 16 dB and 17 dB (high gain antenna) in the main beam direction and decreases about 20 dB in the back loop direction.

THE Effective Isotropic radiated power (EIRP) from the radiated source is equal to:

$(EIRP) = Max.\ Power + Ant$

$= 44 + 16 = 60$ dBm

EIRP (main) $\cong 60 dBm \cong 1000 Watt$

The power spectral density can be calculated from [4],

$$\text{Standard Isotropic Power Density}(SIPD) = \frac{EIRP}{4\pi D^2} \quad (3)$$

Where D is the distance from the radiation source.

If we consider the safety limit for United States of America which equal to 0.57mW/cm^2 so;

$$D_{main} = \sqrt{\frac{EIRP}{4\pi \times (5.7)}} = 3.74\text{m} \quad (4)$$

For the ICNIRP exposure level which equal to 0.4 mW/Cm^2

$$D_{\text{main}} = \sqrt{\frac{\text{EIRP}}{4\pi \times (4)}} = 4.46\text{m} \quad (5)$$

Considering the directivity of the source (antenna) and human behavior, the safety distance may be considered equal to 6 meter in the direction of the main field.

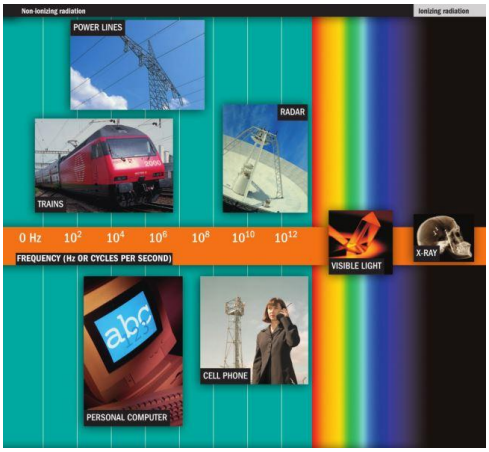

Figure 1. The electromagnetic spectrum [1]

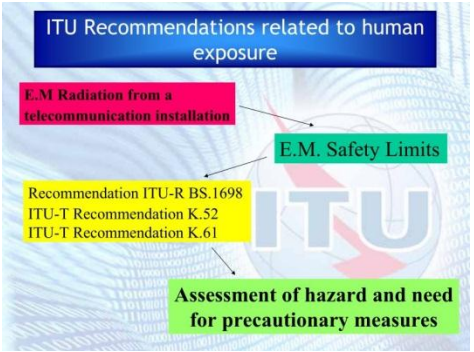

Figure 2. The ITU recommendation to eliminate the EMR effect on human beings. [14]

TABLE 1. QUESTIONNAIRE RESULTS [12]

S. No.	No of years used	No of calls made	No of calls received	Diseases Identified
1	3	3/day	10/day	Ear Problem
2	2	166	176	Fever, Drozziness
3	2	300	--	C, Fever
4	1	--	9678	Ear Problem
5	2	2/day	2/day	Headache, Fever
6	2	400	800	Ear Problem
7	5	15000	20000	Headache, Teeth Problem
8	5	500	1000	Ear Problem
9	4	10000	20000	Headache
10	2	1000	2000	Ear Problem
11	3	15/day	5/day	Headache, Sleeping disturbance
12	2	10/day	7/day	DIP

Table 2. Basic restrictions for human exposure to time-varying electric and magnetic fields [4]

Exposure Characteristic	Frequency Range	Internal Electric Field (Vm-1)
Occupational Exposure		
CNS tissue of the head	1-10 Hz	0.5/f
	10 Hz – 25 Hz	0.05
	25 Hz – 400 Hz	2x10-3f
	400 Hz – 3 KHz	0.8
	3 KHz – 10 MHz	2.7x10-4f
General Public Exposure		
CNS tissue of the head	1-10 Hz	0.1/f
	10 Hz – 25 Hz	0.01
	25 Hz – 400 Hz	4x10-4f
	400 Hz – 3 KHz	0.4
	3 KHz – 10 MHz	1.35 x 10-4f
All tissues of the head and body	1 Hz – 3 kHz	0.4
	3 KHz – 10 MHz	1.35 x 10-4f

f is frequency in Hertz; all values are RMS; in the frequency range above 1000Hz, RF basic restrictions need to be considered additionally

Table 3. Measured EMFs near some household/office Appliances/electronic devices [4]

Appliance	Near the appliance		1m from the appliance	
	Magnetic field (μT)	Electric Field (V/m)	Magnetic field (μT)	Electric Field (V/m)
Computer monitor	1	1500	0.1	300
Water cooler	4	500	0.1	40
Refrigerator	0.4	1000	0.1	150
Laptop charger	6	800	0.04	50
Laptop	0.08	1500	-	80
Photocopy machine	0.8	1500	0.2	350
Hair dryer	70	40	-	-
Electric blanket	33	2000	-	-

Table 4. Worst-case results of the incident E-fields and 1g/10g SAR of the different device classes [6].

Device class	Test frequency range [MHz]	Max. 1g SAR [W/kg]	Max. 10g SAR [W/kg]	Max. E-field [V/m] (20cm)	Max. E-field [V/m] (100cm)	ICNIRP limit [V/m]	ONIR* limit [V/m]
Baby Surveillance	40 – 863	0.115	0.077	8.5	3.2	29	4
DECT**	1880 – 1900	0.087	0.055	11.5	2.9	60	6
WLAN	2400 -2484	1.93	0.81	3.9	1.1	61	6
Bluetooth PC	2402 – 2480	1.31	0.49	3.1	1	61	6
peripherals	27 - 40	<0.005	<0.005	<1.5	<1.5	28	4

*Swiss ordinance for non-ionizing radiation (ONIR) limits for fixed transmitters with ERP of >6W

** Extrapolated maximum for asymmetric transmission mode (fixed part only)

Conclusion, Recommendations and Future Work

There is no a confirmation that the electromagnitic radiation from mobile base station has no effect on human beings and the EMF uncertainty problem is still exist. So, it is required to make some precautions to ensure that the human beings exposured to EMF for a long time period will be safe.

According to the privious calculations and the recommendations of ITU [14] shown in figure 2 its recommended that:

The nearest distance allawable for human beings from the radiation source is 6 meters.
Periodical measurements for power spectral density radiated from mobile base stations for a long term exposure to ensure that it not exceed the ICNIRP defined threshold.
Acoording these measurments, Start to study a certain protocol belong KSA to ensure that the maximum exposure limit for human being from the mobile base station not exceed the ICNIRP defined limit.

An analytical model will be assigned as a future work to represent the power spectral density for power radiated from mobile base station depending on the base station technical specifications and the distance away from the antenna.

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