The Effects of Radio Frequency Radiation on Biological Environment Due to Cellular Communications

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***Abstract*— This paper deals with the recent concerning matter of study about the adverse effects of wireless radiation on biological environment. Both circumstantial and epidemiological study show that radio frequency radiation (RFR) exposure from cellular base station and other antenna array to the living organism caused different types of health hazards like headaches, skin rashes, sleep disturbances, depression, memory changes, increased risk of cancer, tremors, and other neurophysiological effects where most of the service provider of cellular communication system show protected radiation. This paper presents the review work on the biological effects of cellular communication system considering the radiated power density, exposure duration, specific absorption rate(SAR) which are the determining factors to evaluate the public health hazards. While most of the studies in this area are still contradictory and not well recognized but this study recommends that the continuity of these potential studies like long-term exposure to RFR and cumulative effects may forecast the long-term environmental effects. This will also warrant caution to the service provider of cellular infrastructure and also to the manufacturer and user of cell phones especially in developing countries for unplanned cellular development.**

***Keywords*— Cellular Infrastructure; Radio Frequency Radiation (RFR); Biological Effects; Specific Absorption Rate (SAR); Duration of Exposure to RFR.**

I. INTRODUCTION

Millions of people use cellular phones every day and it is increasing day-by-day. In 2013[1], cell phone subscribers numbered in USA 326.4 million, Japan 134 million, Germany 113 million, UK 78 million, Italy 92 million, Canada 28 million, Spain 53 million, South Korea 54 million and Mexico 101 million whereas this scenario is also same in developing countries like Bangladesh 113.78 million on December 2013 as per Bangladesh Telecommunication Regulatory Commission, BTRC statistics. The investment firm Bank of America Merril-Lynch estimated that the worldwide penetration of mobile phone customers is twice that of landline customers today. In some developing countries like Bangladesh where landline systems have never been fully developed around the urban areas, cell phones are the only means of communication and developed fully without concerning the radiation pollution and safety guideline. Cellular technology, especially the new 3G, 4G, and broadband services that allow wireless communications for real-time voice communication, text messaging, photos, Internet connections, music and video downloads, and TV viewing, is the fastest growing segment of many economies that are in otherwise sharp decline due to the global economic downturn.

However, cellular communication become universal around the present world but the infrastructure (the roof top antenna, base station tower antenna and other antenna array) of it may cause biological effects due to the non-ionizing radiation. A lot of studies have been adopted to identify the health issues due to the RFR since 1978. Most of these cellular infrastructure service providers are categorically excluded from regulation by the U.S. Federal Communications Commission (FCC) or oversight by government agencies because they operate below a certain power density threshold. However, power density is not the only factor determining biological effects from radiofrequency radiation (RFR) but other factors also found in research like specific absorption rate (SAR) and duration of exposure. Based on thermal effect some specified organizations sitting up some allowed level of exposure and infrastructure guideline [2-4]. These include standards by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) used throughout Europe, Canada, and elsewhere (ICNIRP 1998). The standards currently adopted by the U.S. FCC, which uses a two-tiered system of recommendations put out by the National Council on Radiation Protection (NCRP) and the International Electricians and Electronics Engineers (IEEE). The objectives of this paper is to study about the cellular infrastructure i.e. base station antenna, nature of RFR,

mobile station etc. for defining the factors such as power density, specific absorption rate(SAR), duration of exposure and investigate the health risk issues and desired guideline for a radiation pollution free environment.

II. Determining Factors

A. Cellular Infrastructure

To develop a cellular communication system, cellular service providers are moving to deploy heterogeneous networks in an attempt to keep up with the surging demand for data services. They are transitioning their infrastructure from voice-driven and data-driven macro base stations to small cell, distributed antenna, and MIMO architectures with smaller coverage areas and low power transmit architectures. As the volume of these types of cells increases, solutions are necessary to constrain the hardware, deployment and operating (power consumption) costs of these units. However our study concern is about the base station power transmit architecture because the power density of radio frequency radiation(RFR) is responsible for biological impacts on living organism near the base station. Basically four types of cellular architectures are found such as macrocell(cell radius 1-30 km), microcell(cell radius 200-2000 m), picocell(cell radius < 300m) and femtocell(cell radius < 50m)[2]. Their transmission power that is related to RFR intensity proportionally rated with respect to cell radius so femtocell is recognized for low power. The intensity of RFR is generally measured and noted in scientific literature in watts per square meter; milliwatts per square centimetre, or microwatts per square centimetre. All are energy relationships that exist in space. However, biological effects depend on how much of the energy is absorbed in the body of a living organism, not just what exists in space which define new and most important determining factor as discussed in the next section .

B. Specific Absorption Rate (SAR)

This factor that used to describe the absorption of RFR in the body is specific absorption rate (SAR), which is the rate of energy that is actually absorbed by a unit of tissue of living organism. Specific absorption rates (SARs) are generally expressed in watts per kilogram of tissue. The SAR measurements are averaged either over the whole body, or over a small volume of tissue, typically between 1 and 10 g of tissue. The SAR is used to quantify energy absorption to fields typically between 100 kHz and 10 GHz and encompasses RFR from devices such as cellular phones up through diagnostic MRI (magnetic resonance imaging).

Absorption of RFR depends on many factors including the transmission frequency and the power density, one's distance from the radiating source, and one's orientation toward the radiation of the system. Other factors include the size, shape, mineral and water content of an organism. Children absorb energy differently than adults because of differences in their anatomies and tissue composition. Children are not just ''little adults''. For this reason, and because their bodies are still developing, children may be more susceptible to damage from cell phone radiation. For instance, radiation from a cell phone penetrates deeper into the head of children [5-6] and certain tissues of a child's head, e.g., the bone marrow and the eye, absorb significantly more energy than those in an adult head [7]. The same can be presumed for proximity to towers, even though exposure will be lower from towers under most circumstances than from cell phones. This is because of the distance from the source. The transmitter is placed directly against the head during cell phone use whereas proximity to a cell tower will be an ambient exposure at a distance.

Depend on these criteria the measurement of SAR around the body area is a matter of concern. Recent studies of whole body plane wave exposure of both adult and children phantoms demonstrated that when children and small persons are exposed to levels which are in compliance with reference levels, exceeding the basic restrictions cannot be excluded [8]. However, while SARs may be a more precise model, at least in theory, there were only a handful of animal studies that were used to determine the threshold values of SAR for the setting of human exposure guidelines [9-10]. The factor SAR is more reliable and determinant other than power intensities but the factual measuring technique is most important for human body. Further study on this factor is more needed as recommended this study. Another factor that is the duration of exposure to RFR as discussed in next section.

C. Duration of Exposure to Radio Frequency Radiation (RFR)

The duration of exposure to radio frequency radiation means how many minutes, hours per day or how many days per week, month of cumulative exposure on people around the cellular infrastructure. There are a large amount of research have been conducted with important gaps such as most of them done for short term exposure i.e. several minutes to hours. Little is known about the effects of long-term exposure such as would be experienced by people living near telecommunications installations, especially with exposures spanning months or years. The important questions then are: What are the effects of long-term exposure? Does long-term exposure produce different effects from short-term exposure? Do effects accumulate over time?

There is some evidence of cumulative effects. A study [11] reported that DNA damage in cells after 24 h exposure to low-intensity RFR. DNA damage can lead to gene mutation that accumulates over time. Mice exposed to low-intensity RFR became less reproductive [12]. After five generations of exposure the mice were not able to produce offspring. This shows that the effects of RFR can pass from one generation to another. The permeability of the blood–brain barrier in rats is increasing when the energy deposited in the body exceeded 1.5 J/kg (joule per kilogram) — a measurement of the total cumulative amount of energy deposited [13]. This suggests that a short-term, high-intensity exposure can produce the same effect as a long-term, low-intensity exposure, and is another indication that RFR effects can accumulate over time. In addition, there two animal test experiments have conducted as "behavior disruption experiment" which defines the SAR standard in present. In first experiment [10] the rats are trained on an auditory task after learning that task rats were then irradiated with 1280 MHz or 5620 MHz RFR during performance. Disruption of behavior (i.e., the rats could not perform very well) was observed within 30–60 min of

exposure at a SAR of 3.75 W/kg for 1280 MHz, and 4.9 W/kg for 5620 MHz. Another same experiment [9] on monkeys done as Monkeys were exposed to RFR at 225, 1300, and 5800 MHz. Disruption of performance was observed at 8.1 mW/cm^2 (SAR 3.2 W/kg) for 225 MHz; at 57 mW/cm^2 (SAR 7.4 W/kg) for 1300 MHz; and at 140 mW/cm^2 (SAR 4.3 W/kg) for 5800 MHz. The disruption occurred when body temperature was increased by 18ºC.

Since most of the studies on short-term exposure to RFR, so they are not valid for safety guideline. So this study encouraged to consider long-term RFR studies to set guidelines and for further study on long term exposure studies.

III. RADIO FREQUENCY RADIATION AND HUMAN HEALTH

Basically human health hazards are caused due to the biological effects of exposure to RFR on living organism i.e. tissue, molecular, blood-brain barrier, DNA, nervous system, psychological part etc. Many biological effects have been documented at very low intensities comparable to what the population experiences within 200 to 500 ft (60–150 m) of a cell tower, including effects that occurred in studies of cell cultures and animals after exposures to low-intensity RFR. Effects reported include: genetic, growth, and reproductive; increases in permeability of the blood–brain barrier; behavioral; molecular, cellular, and metabolic; and increases in cancer risk. The experimental and epidemiological studies on radio frequency radiation RFR and human health risk can be listed up in a table as shown in Table I.

TABLE I

STUDIED DETERMINING FACTORS AND REPORTED EFFECTS

Ref.	Exposure duration	SAR (W/Kg)	Power density (µW/cm2)	Reported biological effects/health hazards due to exposure to RFR
[11]	2-21 h	0.0024		DNA damage in human
[12]	For several generation		0.168	Decrease in reproductive function
[13]	2-960 min	0.004		Increase in the permeability of blood brain barrier
[14]	24-48 h	0.037		Genetic changes in human white blood cells
[15]		0.024		Immune activities human white blood cells
[16]	14 days, 5-20 min/day		26	DNA damage in human glial cells
[17]	24-48 h	0.015		Protein damage
[18]	10 days, 2 h/day	0.018		Increase in serum testosterone
[19]	20 min	0.026		A gene related cancer
[20]	45 min	0.06		Improved cognitive system
[21]	20 min	0.0021		Increased stress protein in human epithelial amnion cells
[22]	20 min	0.0021		Increased stress protein in human epithelial amnion cells
[23]	8 h		20	A transient increase in blood cristisol
[24]	30 min	0.055		Increase in calcium efflux in brain cells
[25]	30 min	0.005		Increase in calcium efflux in brain cells
[26]	2 h/week, 55 weeks	0.0006		Reduced memory function
[27]	24 h	0.0004		Increased proliferation rate in human astrocytoma cancer cells
[28]	6 min/day, 5 days		10	Reproductive capacity of fly decreased with exposure
[29]	1-21 min/day, 5 days		10	Reproductive capacity of fly linearly decreased with increased exposure
[30]	30 min	0.0054		Human lymphocyte chromatin affected similar to stress response
[31]	24 h	0.05		Genes in human fibrolasts

The reporting effects of low intensity radio frequency radiation RFR on living organism mainly to find out the human hazards like DNA damage (leading to tumors, cancer, gene problem etc.), increase the permeability of blood brain barrier (selectively permeable which pass the necessary compounds and protect the brain from toxic or other harmful compounds), protein damage(skin problem), human cell damage, increase calcium efflux in human brain cells (leading to memory and mental problems such as sleep disorder, headache, short-term memory loss) and other problems like decrease in reproductive system, neuropsychological problem. Here, all the reported effects based on either SAR or power density along with the duration of exposure. However, this paper suggests to do further research considering all the factors at a time and cumulative (long-term) exposure to RFR. Recent research focuses on the long-term exposure to RFR and cancer risk of human as discussed in the next section.

A. Cell phones and Cancer

There are three main reasons why people are concerned that cellular communication might have the potential to cause certain types of cancer or other health problems:

- Cell phones emit radiofrequency radiation in a form of non-ionizing radiation that can be absorbed by tissues nearest to the cell phone.
- Tremendous increase in cell phone users in the world as discussed in section I.
- Over generation, the numbers of cell phone calls per day, the length of each call, and the amount of time people use cell phones have increased. Cell phone technology has also undergone substantial changes.

According to National Cancer Institute, two types of study have followed. In one type of study, called a case-control study, cell phone use is compared between people with these types of tumors and people without them. In another type of study, called a cohort study, a large group of people is followed over time and the rate of these tumors in people who did and didn't use cell phones is compared. Cancer incidence data can also be analyzed over time to see if the rates of cancer changed in large populations during the time that cell phone use increased dramatically. The results of

these studies have generally not provided clear evidence of a relationship between cell phone use and cancer, but there have been some statistically significant findings in certain subgroups of people. However, considering the above matters of concern lots of recent studies have done where most of them did not give the consistent result for causing cancer due to RFR and recommend for further study as summarized:

- The researchers considered this finding inconclusive because they felt that the amount of use reported by some respondents was unlikely and because the participants who reported lower levels of use appeared to have a slightly reduced risk of brain cancer compared with people who did not use cell phones regularly [32-34]. Another recent study from the group found no relationship between brain tumor locations and regions of the brain that were exposed to the highest level of radiofrequency energy from cell phones [35].
- An early case-control study in the United States was unable to demonstrate a relationship between cell phone use and glioma or meningioma [36].
- A cohort study in Denmark linked billing information from more than 358,000 cell phone subscribers with brain tumor incidence data from the Danish Cancer Registry. The analyses found no association between cell phone use and the incidence of glioma, meningioma, or acoustic neuroma, even among people who had been cell phone subscribers for 13 or more years [37–39].
- The researchers did find that the use of cell phones for more than 5 years was associated with an increased risk of acoustic neuroma, and that the risk of acoustic neuroma increased with increasing duration of cell phone use [40].

A limited number of studies have shown some evidence of statistical association of cell phone use and brain tumor risks, but most studies have found no association. This paper commends for further study in this topic cell phones and cancer for long-term biological effects of exposure to RFR with cellular engineers and medial specialist. This work suggests for further study on the cumulative effects of long-term exposure to RFR and cancer risk.

B. Safety Guideline and Recommendations

Due to the wide-spread use of cell phone, and fueled by numerous (frequently conflicting) media reports about the biological and possible adverse health effects of the radio-frequencies emitted by cell phones, there has been public concern about the safety of this relatively young technology, particularly with respect to cancer and potential effects. So there are some world recognized organization for sitting up some guideline and recommendation with respect to the determining factors i.e. power density (W/cm^2), specific absorption rate (SAR).

The U.S. FCC has issued guidelines for both power density and SARs. For power density, the U.S. guidelines are between 0.2–1.0 mW/cm^2. For cell phones, SAR levels require hand-held devices to be at or below 1.6 W/kg measured over 1.0 g of tissue. For whole body exposures, the limit is 0.08 W/kg. In most European countries, the SAR limit for hand-held devices is 2.0 W/kg averaged over 10 g of tissue. Whole body exposure limits are 0.08 W/kg. At 100–200 ft (30–60 m) from a cell phone base station, a person can be exposed to a power density of 0.001 mW/cm^2 (i.e.1.0 mW/cm^2). The SAR at such a distance can be 0.001 W/kg (i.e., 1.0 mW/kg). The U.S. guidelines for SARs are between 0.08–0.40 W/kg. The researchers [41] purposes to define low-intensity exposure to RFR of power density of 0.001 mW/cm^2 or a SAR of 0.001 W/kg. Guideline should update with respect to the recent studies. Basically the developed countries around the world concerned about the RFR safety guideline and have a restriction on the cellular service provider but in the developing countries like Bangladesh general people are not alarmed about the guideline and practically no restriction on the cellular service provider. So it is very necessary to be concerned about this anew but important matter.

IV. DISCUSSION

Frequent biological effects do occur after short-term exposures to low-intensity RFR but potential hazardous health effects from such exposures on humans are still not well established, despite increasing evidence as discussed throughout this paper. Unfortunately, not enough is known about biological effects from long-term exposures, especially as the cumulative effects of long-term exposure can be quite different from those of short-term exposure. It is the long-term, low-intensity exposures that are most common today and increasing significantly from various wireless products and services. Primarily, the adverse effect of RFR on human health reported as “microwave sickness syndrome” also known as “radio frequency sickness”.

Firstly identified in 1950 by Soviet medical researchers, symptoms included headache, fatigue, ocular dysfunction, dizziness, and sleep disorders. In Soviet medicine, clinical manifestations include dermographism, tumors, blood changes, reproductive and cardiovascular abnormalities, depression, irritability, and memory impairment, among others. The Soviet researchers noted that the syndrome is reversible in early stages but is considered lethal over time [42]. The symptoms that Lilienfield found included four that fit the Soviet description for dermographism- neczema, psoriasis, allergic, and inflammatory reactions. Also found were neurological problems with diseases of peripheral nerves and ganglia in males; reproductive problems in females during pregnancy, childbearing, and the period immediately after delivery (puerperium); tumor increases (malignant in females, benign in males); hematological alterations; an effects on mood and well-being including irritability, depression, loss of appetite, concentration, and eye problems. This description of symptoms in the early literature is nearly identical to the Santini, Abdel-Rassoul, and Narvarro studies cited earlier, as well as the current (though still

anecdotal) reports in communities where broadcast facilities have switched from analog to digital signals at power intensities that are remarkably similar.

Cent percentages of the researches on this topic as cited in this paper have done in developed countries like America, Europe. So there is a public concern on this matter and their Government has guideline to the cellular infrastructure provider and cell phone manufacturing company. The scenario is relatively different in developing countries like Bangladesh. The telecommunication regulatory commission of these countries should have a guideline for setting up cellular infrastructure i.e. base station antenna and RFR coverage on population.

The increasing popularity of wireless technologies makes understanding actual environmental exposures more critical with each passing day. This also includes any potential effects on wildlife. There is a new environmental concept taking form that of ''air as habitat'' [43] for species such as birds, bats, and insects, in the same way that water is considered habitat for marine life. Until now, air has been considered something ''used'' but not necessarily ''lived in'' or critical to the survival of species. However, when air is considered habitat, RFR is among the potential pollutants with an ability to adversely affect other species. It is a new area of inquiry deserving of recent research and funding.

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