

Non-Ionizing EMF Hazard in the 21th Century

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Abstract— With the fast advancement in technologies and the heavy reliance on wireless devices, we are exposed to ever increasing electromagnetic field (EMF) radiation from home to office to public places. The two most widely referenced standards for non-ionizing EMF radiation protection – IEEE C95.1 and ICNIRP – were last updated in 2005 and 1998 respectively. A comparison of the two standards with the Russian standard shows that the Russian maximum permissible exposure (MPE) is 41 and 5.8 times lower in terms of electric field strength at 1MHz respectively. Despite numerous tests showing potential hazards to humans from radiation levels below the MPE levels stated in ICNIRP guidelines and C95.1, ICNIRP and IEEE continue to ignore calls by scientists to review their MPE levels.

This paper addresses the current and future trends in communication and wireless technologies and their impact on the EMF radiation level that the general public will be exposed to. Studies on biological effects due to EMF radiation carried out over the last 20+ years will also be discussed. Based on the effects of these studies from radiation levels well below the MPE in C95.1 and ICNIRP guidelines, this paper recommends a review of the current safety levels.

Keywords—*Non-ionizing Electromagnetic Field, Radio Frequency, Radiation Hazard, Biological Effects.*

I. INTRODUCTION

Between 1953 and 1976, staff in the US embassy in Moscow was exposed to microwave radiations [1] between 2.5GHz and 4.0GHz. The maximum exposure level was 150mW/m², which is below the acceptable exposure standards set by IEEE C95.1 and the guidelines set by the International Committee on Non-Ionizing Radiation Protection (ICNIRP), but higher than the Soviet's maximum exposure standard.

In 1976, a study sponsored by the US Department of State, was conducted by Dr Lilienfeld of Johns Hopkins School of Hygiene and Public Health to investigate possible health effects on the staff of the US embassy in Moscow and their families. The results were published in 1978 [2] and in the summary, it states that “with very few exceptions, an exhaustive comparison of the health status of the State and Non-State Department employees who had served in Moscow with those who had served in other Eastern European posts during the same period of time revealed no differences in health status as indicated by their mortality experience and a variety of morbidity measures”. It then concluded that there is

no evidence of adverse health effects from the exposure of microwave radiation at Moscow embassy.

However, the findings were rebutted by John R. Goldsmith, who pointed out that there was significant increase in deaths from leukemia, brain tumors and breast cancer from both employees and dependents in Moscow and other Eastern European embassies [3]. Lilienfeld's report uses employees in other embassies as the control group with the assumption that only Moscow embassy was irradiated with microwave. However, the review of epidemiological studies for ICNIRP [4] states that it was unclear whether employees in other US embassies in Eastern Europe were exposed.

This incident brings out two interesting points; why is the Russian standard for non-ionizing radiation hazard way below the level given by C95.1 and ICNIRP? Are there effects on human from radiations levels that are below C95.1/ICNIRP maximum permissible exposure (MPE) levels?

II. RADIATION HAZARD STANDARDS

Today, the most widely accepted non-ionizing radiation hazard standards covering from 100 kHz to 300GHz are IEEE C95.1 [5] and ICNIRP Guidelines [6].

These two standards are quite similar especially between 30MHz and 100GHz for general public exposure. Below 30MHz, C95.1's MPE level goes up to 614V/m from 100kHz to 1.34MHz while the highest ICNIRP MPE level is 87V/m between 3kHz and 1MHz.

The Russian radiation hazard standard is given by SanPin 2.2.4/2.1.8.055-96 [7]. A comparison of the MPE for general public for the 3 standards is given in Table 1.

TABLE I. MPE COMPARISON

Sanpin	30kHz to 300kHz	300kHz to 3MHz	3MHz to 30MHz	30MHz to 300MHz	300MHz to 300GHz
	25V/m	15V/m	10V/m	3V/m	0.1W/m ²
ICNIRP	3kHz to 1MHz	1MHz to 10MHz	10MHz to 400MHz	400MHz to 2GHz	2GHz to 300GHz
	87V/m	87 to 28 V/m	28V/m	28 to 61 V/m	10W/m ²
C95.1	100kHz to 1.34MHz	1.34MHz to 30MHz	30MHz to 400MHz	400MHz to 2GHz	2GHz to 100GHz
	614 V/m	614 to 27.5 V/m	27.5V/m	2 to 10 W/m ²	10W/m ²

From table 1, at around 1MHz, the MPE under C95.1 is about 41 times higher while that of ICNIRP is 5.8 times higher in terms of E field strength when compared with the Russian standard. Between 2GHz and 100GHz, both the MPE of C95.1 and ICNIRP are 100 times higher in terms of power density.

The key considerations [8] in setting the various MPE level in SanPin 2.2.4/2.1.8.055-96 are that the Russian National Committee on Non-Ionizing Radiation Protection (RNCNIRP) assumes that there could be long term health consequences if people have to compensate for RF exposures that produces biological but not pathological effects. Hence, the limits are set in order not to cause any possible biological consequence among the population during the RF exposure period or long after the exposure is over. Whereas, ICNIRP sets their limits based on the lowest RF exposure that causes any established adverse health effect plus a safety factor. For C95.1, the MPEs are set primarily to protect against adverse heating to human body.

In terms of exposure duration, the MPE levels in ICNIRP and C95.1 are set by averaging over 6 minutes exposure time for frequency between 100kHz and 10GHz. For Sanpin 2.2.4, the MPE for workplace is tied to exposure duration but for general public, it did not specify the exposure duration. Comparing with workplace MPE, it is likely that the public exposure level is tied to exposure duration of 8 hours or longer.

III. ELECTROMAGNETIC FIELD IN THE 21TH CENTURY

With the fast advancement in telecommunication and wireless technologies, we are seeing an explosion of devices radiating Electromagnetic Fields (EMFs) and a large number of workers and general public are being exposed to RF-EMF radiation in their work place, public areas and residences. And the increase in exposure will only get worst over the years due to newer technologies and devices that are being pushed out. Below is a summary of some of these new technologies that are either already here or are expected to grow in leaps and bounds in the coming years.

A. Wireless Power Transfer

Today's wireless power transfer (WPT) is mostly limited to charging hand phones. But that scenario could change soon with the arrival of more and more electric vehicles (EV). Wireless charging in commercial parking lots will eventually take over wired charging as it is much more convenient. Wireless charging along the road is also being tested in UK [9] and in Korea [10] in order to extend the distance EV can cover. Charging at high current, the induced magnetic field in the close vicinity will be high and may pose radiation hazard.

WPT do not limit itself to near field magnetic coupling. Between 1978 and 1986, the US department of Energy and NASA jointly investigated the feasibility of getting solar energy from space under the Space Base Solar Power (SBSP) program [11]. The objective is to beam GW's of clean solar energy from huge solar panels placed in geostationary orbit. The DC power collected from the solar panels are converted to microwave frequency (either 2.4GHz or 5.8GHz) and beam back to earth using huge antenna array. On earth, microwave energy is captured by rectenna array and converts back to DC.

The progress of SBSP program is slow due to the extremely high cost in implementing it. Other nations such as Japan, China and India have carried out their own research to look for breakthrough to lower the cost.

While the SBSP program may take many more years to come, smaller scale microwave power transfer research were being carried out. [12] & [13] give various studies on microwave wireless power transfer applications including wireless power supply for electric vehicles. [14] discusses the delivery of energy wirelessly from stations called power beacons (PBs) to mobile devices by microwave radiation. This provides mobiles practically infinite battery lives and eliminates the need of power cords and chargers.

B. WiFi

Released in 1997, IEEE 802.11 sets the stage for the rapid growth of WiFi connected devices. The frequency spectrum used by WiFi has expanded over the years from 2.4GHz to 5GHz and to 60GHz under IEEE 802.11ad released in 2012. Demands for faster data streaming have pushed WiFi bandwidth from the original 22 MHz to 160MHz under IEEE 802.11ac to 2,160MHz when operated at 60GHz. Output power level from WiFi routers have also increased from a few hundred milli-watts up to 1 watt to support higher data rate. Started off with limited access mainly to residential area, today, WiFi is available almost everywhere from office to city wide to public buses and airplanes.

WiFi is now the biggest concern in terms of EMF safety. Children and adults spent hours playing computer games connected wirelessly through WiFi. To improve data rate, some place their router close to the computer and expose themselves to strong emissions from the WiFi router. Today, there are numerous studies [15] carried out that show adverse effects on rodents from WiFi radiation. Many of these were carried out with exposure levels way below the ICNIRP/C95.1 MPE level of 10W/m².

C. Internet of Things

Internet of Things (IoT) devices are widely projected to grow to several tens of billion units by 2020. It will cover everywhere from residence to office to busy streets and even nature parks. To support the growth of IoT, IEEE 802.11ah was released in 2016 to enhance machine-to-machine (M2M) communication. With such a wide coverage, we can be expected to be exposed to EMF radiation everywhere we go and 24/7.

D. mm Wave

mm wave covers from 30GHz to 300GHz. Today, many airport scanners are using low power mm wave for body scanning. To meet the high demand for data rate, wireless engineers are looking at new technologies which will likely to include mm wave [15]. Transmitting at 60GHz, it can support data rate up to 6Gb/s. Augmented by small cell technology, it offers low interference and increased security.

mm wave anti-collision radar operating at 77GHz has been used in many advanced vehicles for years. With the

development of autonomous vehicles, mm wave usage is expected to increase to enhance connectivity. [16] introduces the concept of V2X, where X can be another vehicle, internet, road system, sensors as well as pedestrian. mm wave is chosen for its high data rate and mm wave base stations are expected to be installed along the roads side due to the short range constrain.

Due to its high data rate and wide bandwidth capabilities, mm wave are also being researched to transmit high quality video to VR headsets as well as other high definition video applications.

At mm wave, penetration into human body is limited to a few mm of the skin tissue. There were limited studies on the effect of low level mm wave on biological tissues, but some of these suggested mm wave may alter structural and functional properties of membranes, among others. [17]

E. Wearable electronics and conductive textile

Wearable electronics achieved mainstream popularity with the release of Bluetooth headset in 2002. This was followed by Google Glass and Apple watch. Today, many of us have wearable electronics to help us monitor our health conditions and track exercise progresses. Moving ahead, we can expect wearable computer to emerge to allow one to work on the move, wearable antennas to increase connectivity and even conductive textile to connect all the wearables for communication and power. Without proper regulation on the amount of current and radiation allowable, we are going to let the EMF near our body to make changes to our genes and our cells. Special attention should be paid to pregnant women and young children.

F. DC Power Transmission

In later 1880s and early 1890s, the war of current was “fought” between DC based Edison Electric Light Company and AC based Westinghouse Electric Company. Westinghouse eventually won the fight due to its ability to step up the AC voltage using transformer, thus reducing power loss over long transmission line and hence reducing the cost of electricity. Today, with the advancement of solar panels and other renewable energy products as well as the development of high voltage DC (HVDC) converters, high voltage long distance DC transmission is slowly coming back.

Magnetic field associated with 50/60Hz power frequencies has been classified by International Agency for Research on Cancer (IARC) as “possibly carcinogenic to humans” [18]. ICNIRP reported that up to 2% of the annual number of childhood leukemia cases are attributable to magnetic fields in EU [19]. With high voltage DC, it will also produce strong magnetic field in close vicinity. Today, ICNIRP’s MPE below 1Hz is $4 \times 10^4 \mu\text{T}$. Is it safe?

IV. EM-BIO EFFECT STUDIES

The possible biological effects of EMF have been investigated by numerous investigators since the 1950s or even before, and now a massive literature exists on the subject. The

IEEE ICES database [20] alone currently lists 4,408 studies of varying relevance covering the range 300 kHz to 300 GHz, going back to the late 1950s.

Several publications evaluated a large number of EM-Bio effect studies and provided concise summaries. In this article, we extracted findings from 2 of these reports. The first one is the BioInitiative 2012 report [21] and its recent updates. BioInitiative was formed by an international group of 29 experts. The BioInitiative 2012 report was written by 14 scientists, public health and public policy experts to document scientific evidence on health impacts from EMR below current public exposure limits. The second one is the EUREOPAEM EMF guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses [22]. This document was prepared by the European Academy for Environment Medicine (EUROPAEM) working group.

A. Genotoxic effects of EMF and RF

Genotoxic effects of EMF dealing with DNA damage, mutations, chromatin structure, and DNA repair have recently been reviewed by Henry Lai in the Bioinitiative Report (2012) and by the IARC Working Group in the assessment of RF carcinogenicity (2013). In general, about half of the available studies found genotoxicity (positive reports) although other studies did not. Of note, a similar ratio of positive and negative RF studies was reported for other biological endpoints. The evident reason for this eventual inconsistency is strong dependence of the EMF effects on a number of physical and biological parameters, which significantly varied between studies. These dependencies were established for both Extremely Low Frequency (ELF) and Radio Frequency (RF) effects.

A 2017 update to the BioInitiative 2012 report [23] compiled 76 RFR Comet Assay Studies done between 1995 and 2016. Out of the 76 studies, 49 (64%) showed positive effect while 27 (36%) reported no significant effect.

B. Cancer causing effects of EMF and RF

Based on two pooled analyses of magnetic fields and childhood leukemia conducted in 2000, which clearly demonstrated an increase of leukemia risk with increasing average exposure to ELF Magnetic Field (MF), the IARC classified ELF MF in 2002 as a Group 2B (possible) carcinogen. The current ICNIRP limit for ELF MF is 1000mG at 50Hz. However, studies have shown that the increased risk for childhood leukemia starts at a few mG, almost 1000 times below the safety level. The BioInitiative 2012 report calls for a review of ELF public exposure limits.

In a recent review on childhood leukemia and ELF MF, it was concluded that there is sufficient evidence from epidemiological studies of an increased risk for childhood leukemia from exposure to power-frequency MF that cannot be attributed to chance, bias, or confounding. Therefore, according to the rules of IARC, such exposures ought to be classified as a Group 1(definitive) carcinogen [22].

For brain tumour, IARC initiated an Interphone study in 13 countries around the world in 2000, with the objective to determine whether mobile phone use increases the risk of tumour. Based on the Interphone study outcome as well as other published epidemiological studies, IARC classified RFR as Group 2B carcinogen in 2011. In 2014 and 2015, two studies showed significant decreased survival rates in patients with glioblastoma and the use of wireless phones, and latency periods of >25 years respectively[22].

C. Neurological effects of EMF

Neurological and behavioral effects were among the earliest topics of research on potential adverse effects of ELF as well as RF EMFs. Concerning epidemiological evidence, more than a decade before the seminal publication of Wertheimer and Leeper, Haynal and Regli reported in 1965 an approximately four-fold higher prevalence of a history of electrical engineering jobs in patients with amyotrophic lateral sclerosis (ALS) than in control subjects. Research has shown that EMFs (RF and ELF) have deleterious effects on brain neurons and brain functioning [22].

In the 2017 update of the BioInitiative Report, it compiled a total of 325 studies related to neurological effects from RFR captured from 2007 to 2017, among these, 235 (72%) showed effects while 90 (28%) showed no effects[24]. One paper by MJ Abramson et al. conducted a cross-sectional epidemiological study to examine cognitive function in secondary school students in Melbourne, Australia. A total of 144 boys and 173 girls from 20 schools were recruited for the study. It concluded that mobile phone use was associated with faster and less accurate responding to higher level cognitive tasks.

A recent review by Pall ML [25], concluded that the mechanism of action of microwave EMFs, the role of the voltage-gated calcium channel (VGCC) activation in the brain, the impact of non-thermal EMFs on the brain, extensive epidemiological studies performed over the past 50 years, and 5 criteria testing for causality, all collectively show that various non-thermal microwave EMF exposures produce diverse neuropsychiatric effects.

D. Effects of EMF on infertility and reproduction

Both ICNIRP and C95.1 classified testis as one of the most sensitive tissue to EMF. In the BioInitiative Report on Electromagnetic Field Exposure Effects (ELF-EMF and RFR) on Fertility and Reproduction, it concluded that, though causal evidence of one or more mechanism(s) are not yet fully refined, it is generally accepted that oxidative stress and free radical action may be responsible for the recorded genotoxic effects of EMFs which may lead to impairments in fertility and reproduction. Free radical action and/or hydrolytic enzymes like DNAase induced by exposure to EMFs may constitute the biochemical actions leading to adverse changes in hormones essential in males and female reproduction, DNA damage, which in turn causes damage to sperm motility, viability, and sperm morphology.

There are also some studies of adverse birth outcomes in EMF-exposed women. A case-control study and a population-based prospective cohort study from California showed an association between miscarriages and the maximum value measured by a 24-h body-worn magnetic field dosimeter [22].

E. Electromagnetic hypersensitivity (EHS)

Electromagnetic hypersensitivity (EHS) is a phenomenon characterized by the appearance of symptoms after exposure of people to electromagnetic fields. EHS is characterized as a syndrome with a broad spectrum of non-specific multiple organ symptoms including both acute and chronic inflammatory processes located mainly in the skin and nervous systems, as well as in respiratory, cardiovascular systems, and musculoskeletal system. The symptoms may be associated with a single source of EMF or be derived from a combination of many sources.

In 2001, 63 persons who attributed health problems to environmental exposure were counseled in an interdisciplinary environmental medicine pilot project in Basel. With respect to 25 persons with EHS, the expert team attested to the fact that in one third of them, at least one symptom was plausibly related to electrosmog, although the EMF exposure level was within the Swiss Limits [22]. EUROPAEM recommended classifying EHS as part of Chronic Multisystem Illnesses, but still recognizing that the underlying cause remains the environment, where EMF is one of the possible causes.

V. CONCLUSION

With the fast advancement in telecommunication and wireless technologies and the heavy reliance on AC and DC power supplies, we will be constantly and increasingly exposed to EMF everywhere we go, including where we sleep. Based on the findings from numerous EM-Bio effect studies, it is evident that non-thermal and low radiation level (below MPE levels specified in C95.1 and ICNIRP guidelines) EMF could have significant effects on human body. It should be mentioned here that very specific exposure conditions may trigger biological response in one individual, but not in others. And some may take longer time than others for the symptoms to appear. Any health safety standard must protect not just those who are healthy but include those in poor health, the young and the pregnant women.

WHO's decision to classify mobile phone radiation as possibly carcinogenic came more than 20 years after mobile phones were introduced. Should we wait another 20 years for severe biological effects to show up and then regret that we did not do something earlier? We hope IEEE and ICNIRP can seriously consider potential effects from long term exposure of EMF radiation and review their MPE levels as soon as possible. If the committees still think that the results are inconclusive, then they may want to define a set of objective specific testing protocols so scientists and researchers can work on it to produce clear and definitive results.

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