Health Matters

RF Health Safety Limits and Recommendations

■ James C. Lin

The rapid proliferation of cellular mobile telecommunication devices and systems is raising public health concerns about the biological effects and safety of RF radiation exposure. There is also concern about the efficacy of promulgated health safety limits, rules, and recommendations for the RF radiation used by these devices and systems. This article reviews and discusses the U.S. Federal Communications Commission (FCC) notices and rules, International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, and International Committee on Electromagnetic Safety (ICES) standard for safety levels with respect to human exposure to electric, magnetic, and electromagnetic fields (EMFs). The recently revised RF exposure limits are adjusted only for heating with RF radiation. These limits are largely intended to restrict short-term heating by RF radiation that raises tissue temperatures. They are narrow in scope and are not applicable to long-term exposure at low levels. This review discusses the assumptions underlying the standards and the outdated exposure metrics employed, and concludes that the revised guidelines do not adequately protect children, workers, or the public from exposure to RF radiation or people with sensitivity to electromagnetic radiation from wireless devices and systems. Furthermore, the review discusses important animal data that the standards do not appear to take into account. Moreover, for millimeter-wave radiation from 5G mobile communications, there are no adequate human health effects studies in the published literature. The conclusions by scientific organizations, such as the International Agency for Research on Cancer (IARC), that diverge from these standards are also discussed. The review concludes that many of the recommended limits are debatable and require more scientific justification from the standpoint of safety and public health protection.

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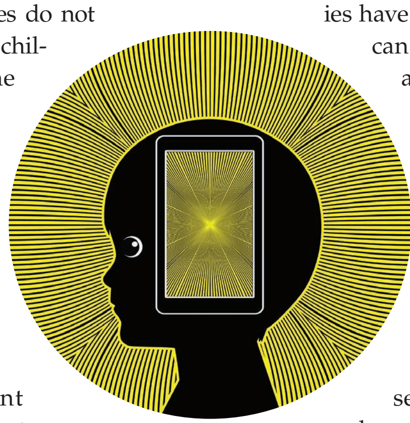

Introduction

The biological effects from exposure to microwave and RF radiation have been a subject of scientific investigation since the mid-20th century [1], [2]. Initial studies have shown that exposure can cause both beneficial and adverse biological effects in humans via heating of tissues inside the body. The heating may or may not be detectable as temperature elevations available from simple temperature sensors. However, the knowledge was influential in setting 100 W/m^2 (10 mW/cm^2) of incident power density in 0.1 h as a safety guideline for human exposure to microwave and RF fields in 1966 [3]. Continued research led to a minor amendment to the limits in 1982 [4]. The efforts took place under the cosponsorship of the U.S. Department of the Navy and what is now known as the *IEEE*. However, the paucity of the then available scientific data was only able to provide the rudimentary basis for a less than rigorous or precise exposure limit. Thus, research interest in biological effects and safe use of microwave and RF radiation continued, biomedical and bioengineering investigations expanded, and scientific knowledge and data steadily improved.

Aside from various observational investigations on biological responses, a salient aspect of the studies provided the approach for a quantitative estimation of the amount of deposited power density or absorbed energy inside the body to reliably induce biological responses by a given incident RF power density. Inauguration of the concept of specific absorption rate (SAR) and its frequency-dependent connection to incident power density formed the basis for the maximum permissible exposure level. It became a compelling rationale for reporting quantitative results from laboratory experiments and observational studies [5]. SAR can be used to relate the RF and microwave radiation to specific responses of the body; it facilitates understanding of biological phenomena and it is independent of mechanisms of interaction. It serves as an index for extrapolation of experimental results from cell-to-cell, cell-to-tissue, tissue-to-animal, animal-to-animal, and animal-to-human exposures. It is also useful in analyzing relationships among various observed biological responses in different experimental models and subjects.

Further advances contributed significantly to the refinement of the abovementioned exposure limit. For example, in its report on biological effects and exposure criteria for microwave and RF radiation [6], the U.S. National Council on Radiation Protection and Measurements (NCRP) recommended the exclusive use of SAR for quantification of RF and microwave distribution and absorption in biological materials or animal bodies under exposure. Also, SAR was used in the 1992 edition of exposure standards developed by the IEEE Standards Association, which was also recognized by the American National Standards Institute (ANSI) [7].

The rapid proliferation of cellular mobile communication devices and systems and public concerns about the biological effects and safety of microwave exposure caused the FCC to implement rules for permissible human exposure to RF and microwave radiation from cell phones and wireless base stations in 1996 [8]. The FCC rules are identical to those recommended by the NCRP (1.6 W/kg over 1 g of tissue mass) and are also essentially the same as ANSI/IEEE-1992 for the relevant frequencies. However, the FCC rules are enforceable by law. For example, at the wireless mobile communication frequencies between 800 and 2,200 MHz, the maximum permissible exposures for the general population are specified by [f (MHz)/1,500] mW/cm^2, as averaged over any 30-min period. For base stations operating at a frequency of 880 MHz, the FCC's RF exposure rules stipulate a maximum permissible level of 0.59 mW/cm^2 (5.9 W/m^2). For base-station antennas transmitting at 1,990 MHz, the FCC limit for the public is 1.27 mW/cm^2 (12.7 W/m^2).

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Subsequently, the newly formed ICNIRP published its recommended guidelines in 1998 [9]. For the most part, it follows the ANSI/IEEE-1992 and FCC-1996 recommendations, except it chose to set SAR values at 2 W/kg averaged over 10 g of tissue mass for local absorption, but without any clearly enunciated biophysical basis or scientific rationale.

In 2001, the name of the ICES was approved by the IEEE Standards Association in place of its prior entities, which developed the ANSI/IEEE-1992 standards [7].

In 2006, ICES published a revised exposure standard, which departs in major ways from the 1992 ANSI/IEEE edition (and its subsequent amendments). Specifically, it adopted ICNIRP's SAR value of 2 W/kg value as averaged over a 10 g of tissue mass for local absorption [10]. This apparently was done as a step toward global standards harmonization, not necessarily to reflect the current state-of-advances in knowledge for health safety protection.

Recently, both the ICNIRP and ICES published revisions of their recommendations for exposure limits [11], [12], [13]. These versions are clearly tied to heating effects associated with measurable tissue temperature changes. They are based primarily on biological data from short-term (6 or 30 min) exposures to RF and microwave radiation and do little to address the troubling question of the recommended limits for long-term, low-level exposures. The scenarios of a persistent lack of confidence in these RF exposure standards are recurring in many parts of the world about wireless and mobile telecommunication devices and installations [14], [15], [16], [17]. This article succinctly examines some of the issues and highlights the more significant aspects applicable to cell phone and wireless mobile telecommunication uses of RF and microwave radiation.

Assessing Recently Revised Limits for Health Safety Protection

A recent article challenged the health safety afforded by the current exposure limits to RF radiation and called for an independent evaluation of the scientific evidence [14]. It shows that the current exposure limits ignore hundreds of scientific studies that document adverse health effects at exposures below the threshold level claimed by these safety limits. It further contends that the scientific evidence invalidates the health assumptions underlying the promulgated RF exposure limits. Specifically, for frequencies below 6 GHz, a SAR value of 4 W/kg, spatially and temporally averaged over the whole-body mass, was assumed as the effective threshold for adverse biological effects in humans. The level was predicated on disruption of operant-conditioned work schedules in a few trained rodents and primates. Also, it assumed that a heat-production rate of 4 W/kg was within the normal range of human thermoregulatory capacity. The ANSI/IEEE C95.1-1992 standards, and thus the FCC rules, ICES limits, and ICNIRP guidelines, are introduced to prevent only adverse thermal effects on the functioning of the human body. So, the SAR of 4 W/kg remains as the basis for the revised ICNIRP and ICES RF exposure limits.

The International Commission on the Biological Effects of Electromagnetic Fields article argued that the exposure limits, based on science from the 1980s, before cellular mobile phones were ubiquitous, do not adequately protect children, people with electromagnetic hypersensitivity, industrial workers, and the public from unsafe exposure to the RF radiation from cell phone and wireless devices and systems. Furthermore, while the revised ICNIRP safety guideline and ICES standard make recommendations to protect against adverse health effects from exposure to RF radiation, in fact, the guidelines and standards are based on controlling whole-body temperatures from increasing above 1 °C or local tissue temperatures to 5 °C for short-term exposures of 6 or 30 min (Table 1).

Contrary to persistent and recent concerns of inadequate health effect studies involving RF radiation with complex novel modulations and pulse sequences, especially about 5G, ICNIRP deleted its 1998 provision of pulse exposure limits from the revised 2020 guidelines. Consequently, there are no longer specific restrictions on pulse modulations of any kind in ICNIRP 2020. Note that time-averaged SAR over a 6-min period is inadequate to account for the unique characteristics of pulse modulations or to capture the effects of pulse-modulated exposures, including the microwave auditory effect that occurs without any measurable temperature rise and at low levels of SAR [18], [19]. It is well known that the outcomes of experimental studies are affected by differences in RF parameters and exposure conditions.

Furthermore, the question of applicability of the recommended limits for safe long-term exposure to low-level RF radiation (in contrast to exposures shorter than 6 or 30 min) remains open. The revised exposure limits do not provide any adjustments for possible effects due to long-term human exposures. There is a perceived lack of appreciation of scientific knowledge on chronic toxicology and carcinogenicity regarding RF exposures below the basic restrictions promulgated through existing exposure guidelines and standards [14], [15], [16], [17], [20].

The IARC, an intergovernmental agency of the World Health Organization, classifies exposure to RF radiation as a possible cancer-causing player in humans [21], [22]. The IARC's role is to conduct and coordinate research into the causes of cancer. It evaluated the accessible scientific investigations and decided that, while its database was imperfect and constrained, especially with respect to results from animal experiments in research laboratories, epidemiological observations in humans exhibited higher risks for the glioma-type of malignant brain cancer and of benign vestibular schwannoma of the vestibulocochlear nerve among heavy or long-term subscribers of cell or mobile phones are satisfactorily robust to underwrite a classification of RF radiation from cellular mobile phones as a carcinogenic actor for humans.

Significantly, the results from animal experiments that the IARC was lacking were later provided by the U.S. National Toxicology Program (NTP) report of two types of cancers in laboratory rats that were exposed, lifelong, to 2G and 3G cell phone RF radiation frequencies below 6 GHz [23], [24]. The study was the largest health effect

TABLE 1. Current guidelines or standards based on thermal effect for "safe" human exposure to RF radiation.

Frequency Range	Tissue Type	$\triangle T$	Average Mass	Average Time	Health Effect Level	Factor*	Public Level	Factor*	Worker Level**
100 kHz–6 GHz	Local head-torso	2 °C	10 g	6 min	20 W/kg	10	2 W/kg	2	10 W/kg
	Local limbs	2 °C	10 g	6 min	40 W/kg	10	4 W/kg	2	20 W/kg
>6 GHz–300 GHz (5G)	Local head-torso	5 °C	4 cm^2	6 min	200 W/cm^2	10	20 W/cm^2	2	100 W/cm^2
30 GHz–300 GHz (5G)	Local limbs	5 °C	2 cm^2	6 min	400 W/cm^2	10	40 W/cm^2	2	200 W/cm^2
100 kHz–300 GHz	Body core	1 °C	WBA	30 min	4 W/kg	50	0.08 W/kg	10	0.4 W/kg

Compiled from [11] and [12]. WBA, whole-body average.
*Safety or reduction factor; **controlled or occupational exposure.

animal investigation performed by researchers at the NTP, arguably, the largest animal health study conducted of cell phone RF radiation. The findings included statistically significant and clear evidence that RF exposure caused the development of a rare form of malignant tumor (schwannoma) in the heart of male rats whose RF-induced body temperature increase did not exceed 1 °C at the highest SAR (6 W/kg). There was also a hint of some schwannoma risk among female rats. The NTP study also noted damage to the heart (cardiomyopathy) in both RF-exposed male and female rats compared to concurrent controls. In addition, based on statistical significance, the outcome of pathological examinations showed signs of RF-dependent carcinogenic activity in the brain of male rats, namely gliomas. However, the effects on females were deemed as presenting only equivocal evidence for malignant gliomas when compared to control rats.

In that same year, the Cesare Maltoni Cancer Research Center of the Ramazzini Institute in Bologna, Italy, reported the conclusions from its large laboratory study of cancer risks in rats exposed to 3G RF radiation. The research involved whole-body exposure of the same strain of rats as used by the NTP, either lifelong or prenatal until death, under far-field exposure conditions [25]. During the 19-h day for roughly two-year exposures, the calculated whole-body SARs were .001, .03, and 0.1 W/kg. A statistically significant elevation in the incidence of schwannomas in male rat hearts was noted for the 0.1-W/kg RF exposure. It is important to observe that the NTP and Ramazzini RF exposure investigations produced comparable outcomes for heart schwannomas and brain gliomas. Thus, two well-conducted large RF animal exposure investigations involving life-long exposures of the same strain of rats revealed consistent carcinogenicity outcomes.

The positions taken in the recent revisions of the health safety limits appear to view these animal studies as not applicable. The revisions ignored the independent variable for the experiments: the RF exposure. While the standards reference the animal studies, they opted to object with putative "chance differences" from experimental treatments or complications of thermally induced body-core temperature rises of up to 1 °C in rats at the highest RF exposure levels. In doing so, the standards overlook the error of proposing a 1 °C body-core temperature rise as a cause for cancer. Unfortunately, vague expressions, such as *substantial limitations*, do not specify why the standards' authors felt that "conclusions being drawn concerning RF EMFs and carcinogenesis" were not possible in formulating the recommended RF limits.

Regarding epidemiological studies of cell phone RF radiation and carcinogenicity, the revised recommendations argue that, while much research has been conducted, results on gliomas, meningiomas, parotid gland tumors, and vestibular schwannomas (acoustic neuromas) have not provided sufficient evidence of an increased cancer risk. Also, the revision states that, while there are reports of greater odds ratios, methodological differences and weaknesses—including recall and selection bias—thwarted the epidemiological results from being taken into consideration for the recommended exposure limits. Based on the published discussion accompanying the standards, it is hard not to suspect a tendency toward scepticism of positive results, along with an equal tendency toward less critical acceptance of negative findings.

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Table 1 shows that for frequencies between 6 GHz and 300 GHz, including millimeter-waves deployed for 5G wireless mobile communications, the permissible local tissue temperature rise in the head, limbs, and torso of humans is 5 °C. This level of temperature rise could induce the tissue temperature to increase from a nominal value of 37 °C to a hyperthermic 42 °C. A hyperthermic tissue temperature of 42 °C is cytotoxic, with the potential for exponential cell death. Furthermore, it serves as the medical foundation for treatment of malignant tumors with hyperthermia therapy for cancer [26], [27], [28]. The recently revised exposure limits provide a reduction factor of 10 for ordinary people at 20–40 W/m^2 or a safety factor of 2 in RF workplaces at 100–200 W/m^2. Under these scenarios, the efficacy of these limits is marginal, and they may be irrelevant from the standpoint of health safety protection considering the measurement's uncertain and physiological variability.

Discussion and Conclusion

The newly revised RF exposure limits are devised largely for restricting short-term heating of RF radiation to raise tissue temperatures. These limits also exhibit a strong conviction that there is nothing but heat to worry about with RF radiation.

The IARC classified RF radiation from cell/mobile phones as a possible carcinogen in humans on the strength of the then-available epidemiological reports but with access to only partial data from experimental animals [21], [22]. The classification of RF radiation as possibly carcinogenic to humans ranks third in the IARC categories of carcinogenic risk. The highest category is reserved for agents that are "carcinogenic." It is followed by "probably carcinogenic," "possibly carcinogenic," "not classifiable" as to its carcinogenicity, and finally, "probably not carcinogenic to humans."

The animal data the IARC sought were delivered by the NTP [25] and the Ramazzini Institute [26], which logically and scientifically supplement the IARC's earlier evaluation of human epidemiological studies that support the IARC's classification of RF radiation as a possible carcinogen. The latest animal data should help to upgrade the classification to the "probably carcinogenic" category, if not elevate it to a higher level. Nonetheless, the revisions evaded them by declaring that the findings do not provide credible evidence of adverse effects induced by chronic RF exposures.

Another perplexing issue pertains to the establishment of exposure limits based on scientific evidence rather than other assumptions. The problem arises from the harmonization of the IEEE's SAR limit value of 1.6 W/kg (over 1-g mass) to the ICNRIP's 2.0 W/kg (over 10-g mass) for short-term (<6 min) exposures below 6 GHz. The adoption of SAR as a dosimetry quantity and establishment of the value 1.6 W/kg over a 1-g mass have been examined with great scientific care and deliberation since the 1980s and were reaffirmed through several renditions of IEEE standards in the early 2000s. As mentioned above, the choice by the ICNIRP in 1998 to set the SAR at 2.0 W/kg was not accompanied by any enunciated biophysical basis or scientific rationale. Indeed, global harmonization of RF exposure limits for the public would be a worthy objective. However, it should not be approached on a basis of harmonization for harmonization's sake [29]. The process ought to aim toward improvement beyond the current state-of-affairs, through better precision in SAR specification and less uncertainty in exposure assessment.

It is interesting to note that in December 2019, the FCC reaffirmed its RF exposure limits [30]. The action was taken despite appeals from some to loosen the existing limits, and others to tighten them. Among campaigners embracing weaker limits were proposals from consultants for the wireless industry, CTIA–The Wireless Association, Mobile Manufacturers Forum, and the Telecommunications Industry Association. The same appeals also argued that the evidence for health effects suggests that 5G is akin to any other installed cell or mobile technology and systems. Claims were presented for lessening cell phone RF limits to SARs of 2.0 W/kg, averaged over 10 g of tissue instead of the FCC's limit of 1.6 W/kg over 1 g. Thus, the waxing question—if it is not for science—is the process in changing SAR limits from 1.6 to 2.0 W/kg an action on behest of others.

Aside from the numerical 25% increase of SAR from 1.6–2.0 W/kg, the expansion of averaging tissue mass from 1 to 10 g materially reduces 10-fold the precision of SAR determinations. Thus, harmonization could have a combined impact of raising the permissible IEEE exposure limit by a factor of 1,250%, with less safety protection. Of course, there is also the biological issue of vast differences in quantity and variety of cells in 1- or 10-g mass of living tissues.

Furthermore, research on correlation of SAR and induced tissue temperature elevation revealed a close dependence on size of averaging tissue mass and exposure duration [31]. The study investigated the influence of SAR and averaging mass on the correlation between RF energy and induced tissue temperature elevation for exposures involving anatomically realistic models of the human body. It found that SAR provides a better correlation with temperature for short exposures. The best correlation with temperature increase occurs for exposure durations between 1 and 2 min for SAR for most frequencies investigated (700 to 2,700 MHz). In this case, a mass of 1 g was found to be optimal for correlation of temperature elevation with SAR. For longer exposures, the correlation is reduced, and it favors larger averaging mass. At steady-state exposures (~30 min), correlation of temperature elevation with SAR is maximum for a mass of 9 g (~10 g) for the frequencies investigated. Thus, in a science-based exposure limit, the appropriate averaging mass for frequencies below 6 GHz should not be the same for short-term and longer exposure durations, even for heating-related exposure limits.

In conclusion, the revised RF exposure limits make allowances only to worry about heat with RF radiation. These limits are devised for restricting short-term heating by RF radiation and aim to prevent increased tissue temperatures. Thus, they are not applicable to long-term exposure at low levels. Instead of advances in science, they are predicated on assumptions using outdated exposure metrics, thus their ability to protect children, workers, and the public from exposure to the RF radiation or people with sensitivity to electromagnetic radiation from wireless devices and systems. Furthermore, the limits are based on outdated information and circumvent important animal data. These issues are even more relevant in the case of millimeter-wave radiation from 5G mobile communications for which there are no adequate health effects studies in the published literature. Finally, the guidelines do not adequately address conclusions from scientific organizations, such as the IARC. Thus, many of the recommended limits are questionable from the standpoint of scientific justification for the safety and public health protection.

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