

Journal Pre-proof

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PII: S0013-9351(23)00161-5

DOI: <https://doi.org/10.1016/j.envres.2023.115369>

Reference: YENRS 115369

To appear in: *Environmental Research*

Received Date: 8 August 2022

Revised Date: 27 December 2022

Accepted Date: 24 January 2023

Please cite this article as: Lin, J.C., Incongruities in recently revised radiofrequency exposure guidelines and standards, *Environmental Research* (2023), doi: <https://doi.org/10.1016/j.envres.2023.115369>.

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INCONGRUITIES IN RECENTLY REVISED RADIOFREQUENCY EXPOSURE GUIDELINES AND STANDARDS

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ABSTRACT

The currently promulgated RF exposure guidelines and standards cover the entire range of RF radiation and apply predominantly to restrict RF-induced short-term heating and in guarding against raising tissue temperatures, including the 5G frequencies. There are substantial abnormalities in these putative health safety protection guidelines and standards. Some of the safety limits are irrelevant, debatable, and absent of scientific justification from the standpoint of safety and public health protection. Also, the cellular mobile 5G technology is hailed as a speedier and more secure wireless communication technology than its predecessor systems. The key supporting architecture uses millimeter-wave (mm-wave) and antenna array technology to achieve better directivity, lower latency, and elevated data transmission rates. For radiation protection, it is not obvious whether the health effects of 5G mm-wave radiations would be analogous or not to radiations from previous generations (which was classified as possibly carcinogenic in humans by IARC). The interaction of mm-waves with the structure and function of pertinent cellular elements and cutaneous neuroreceptors in the skin are of special concern. The current scientific database is inadequate at mm wavelengths to render a trustworthy appraisal or to reach a judgment with confidence.

INTRODUCTION

Without a question cellphones and wireless mobile communication technology have embellished human lives. They have proven their place in modern life beyond any dispute even to the point of helping to safeguard our personal safety and security. According to surveys, the vast majority of adults in the United States, roughly 97%, own a cellphone, including 100% of those between the ages of 18 to 29 and 94% of the population residing in rural areas (Pew, 2021). It is estimated that there are 15-billion cellphone users, worldwide (Statista, 2022). So, cellphones have rendered direct benefits to multiple arenas of human endeavor. The new 5G technology rolled out about

two years ago is hailed as a speedier and more secure technology than its predecessor mobile communication systems. It uses previously assigned 3G, 4G, or newly opened frequencies. Its key supporting architecture uses millimeter-wave (mm-waves at 24-GHz to 60-GHz) and antenna array technology to achieve better directivity, lower latency, and elevated data transmission rates. A major security and sensitivity concern is that it may be subject to snooping. While the system architecture, technology, and regulatory issues are important topics they are not health and safety protection matters.

Recently, the International Commission on Nonionizing Radiation Protection (ICNIRP, 2020) and Institute of Electrical and Electronic Engineers (IEEE) International Committee on Electromagnetic Safety (IEEE-ICES, 2019) have published revised safety guidelines and standards for protection against adverse health effects in humans resulting from exposure to radiofrequency (RF) radiation in the frequency range from 100 kHz to 300 GHz. These putative health safety guidelines and standards apply predominantly to restrict short-term heating of RF radiation and in guarding against raising tissue temperatures. Moreover, for radiation protection, it is not obvious whether the health effects of higher 5G frequencies would be analogous or not to the earlier generation counter parts.

This paper provides a brief historical perspective on the development of exposure limits, succinct assessments of efficacies and flaws of recently published revisions, and discusses significant health safety issues as applied to cellphone and wireless mobile telecommunication uses of RF and microwave radiation including 5G mm-waves.

A BRIEF HISTORY OF EXPOSURE LIMIT DEVELOPMENT

The biological effects from exposure to microwave and RF radiation have been a subject of scientific investigation since the mid-20th century (Michaelson and Lin, 1987; Schwan, 1957). 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 utilizing 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 hour as a safety guideline for human exposure to microwave and RF fields in 1966 (Schwan, 1992). Renewed research led to some minor amendments to the document in 1982 (ANSI, 1982). The efforts took place under the co-sponsorship of U.S. Department of Navy and what is now known as the IEEE. However, the paucity of 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 the scientific knowledge and database steadily improved.

NCRP

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 (NCRP, 1982). 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.

ANSI/IEEE

Further advances contributed significantly to the refinement of above-mentioned exposure limit. For example, in its report on biological effects and exposure criteria for microwave and RF radiation (NCRP, 1986), the U.S. National Council on Radiation Protection and Measurements (NCRP) recommended the exclusive use of SAR for quantifying 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) (ANSI/IEEE, 1992).

FCC

The rapid proliferation of cellular mobile communication devices and systems and public concerns about the biological effects and safety of microwave exposure caused the U.S. Federal Communications Commission (FCC) to implement rules for permissible human exposure to RF and microwave radiation from cellphones and wireless base stations in 1996. The FCC (1996) 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 2200 MHz, the maximum permissible exposures for the general population are specified by $(f \text{ (MHz)}/1500) \text{ mW/cm}^2$, 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 1990 MHz, the FCC limit for the public is 1.27 mW/cm^2 (12.7 W/m^2).

ICNIRP

Subsequently, the newly formed International Commission on Non-Ionizing Radiation Protection (ICNIRP) published its recommended guidelines in 1998 [ICNIRP, 1998]. In most parts, it is like the ANSI/IEEE-1992 and FCC-1996, except it chose to set the SAR values at 2.0 W/kg averaged over 10 g of tissue mass, but without any clearly enunciated biophysical basis or scientific rationale.

IEEE-ICES

In 2001, the name of International Committee on Electromagnetic Safety (ICES) was approved by the IEEE Standards Association in place of its prior entities, which developed the ANSI/IEEE-1992 standards.

In 2006, IEEE-ICES published a revised exposure standard, which depart in major ways from the 1992 ANSI/IEEE edition (and its subsequent amendments). Specifically, it adopted ICNIRP's SAR value of 2.0 W/kg value as averaged over a 10-g tissue mass for local absorption (IEEE-ICES, 2006). It was apparently done as a step towards global standards harmonization – not necessarily to reflect the current state-of-advances in knowledge for health safety protection.

As mentioned, recently, both ICES and ICNIRP have published revisions of their recommendations for exposure limits (IEEE-ICES, 2019; ICNIRP, 2020). The revised limits 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 placate the troubling questions on recommended limits for long-term, low-level exposures. The scenarios of a persistently expressed lack of confidence in these RF exposure guidelines are recurring in many parts of the world involving wireless and mobile telecommunication devices and installations (ICBE-EMF, 2022; Elkind, 2022; Investigate Europe, 2019; Koeppe, 2022).

5G WIRELESS MOBILE COMMUNICATION TECHNOLOGY

The earlier generations of cellular mobile technology associated with 2G, 3G, or 4G operations are well known. Details of the embedded technology are commonly available in the open literature [Lin et al., 2008; NTP/NIEHS, 2018]. 5G is a mobile telecommunication technology that is multilayered in spectral coverage with varying performance and operational scope. It includes multiple bands of RF and microwave frequencies, which may be approximately separated into two bands: the < 6 GHz frequencies and 24-GHz to 60-GHz range that spread into the mm-wave region. The spectral coverage is typically further divided into high-, mid-, and low-band 5G. Low-band 5G begins at about 400 MHz and uses previously assigned 2G, 3G, 4G, or newly opened frequencies, which may coincide with existing 4G. Most 5G rollouts started with mid-band, which comprises the common frequencies between 3 and 4 GHz. Nonetheless, the primary 5G technological advances are tied to the high band 5G, which pledges performance bandwidth as high as 20 GHz with multiple input, multiple output architectures. It employs 64-256 antenna arrays for short distances and offers performances of up to 10-fold better than 4G systems.

From the perspective of spectral allotment, 5G encompasses an enormously wide domain of frequencies from 3 to 60 GHz and beyond, in a massive step over 3G and 4G. Even with current technological advances, the requirements and functional challenges can differ enormously from the low to high bands. The promised execution bandwidth of 20 GHz clearly is not viable or even supportable at low band. By design default or spectrum requirement, the bandwidth performance can only be achieved by leapfrogging to the high band 5G. The higher 5G bands, where the wider mm-wave spectrum is available are operable primarily at shorter distances. The vast deployment would lead to large numbers of microcells on existing or newly installed cellphone poles. The scenario would be massive and potentially intrusive for the urban surroundings where mm-wave antenna arrays are mostly deployed.

MM-WAVES IN BIOLOGICAL SYSTEMS

Interaction of mm-waves with the cutaneous and subcutaneous cells and tissues such as neuroreceptors in nerve-rich skin cells are biological effects of special concern. Indeed, skin is the largest surface organ that protects nearly the entire human body. The human skin is heterogeneous. It consists of several major layers of stratum corneum, epidermis, dermis, and the deeper subcutaneous hypodermis. It is approximately 2-3 mm in thickness and has a total mass of roughly 3 kg (Kumar et al., 2020; Widmaier et al., 2019). It encompasses nearly the whole-body shell with about 1.85 m². The thickness of skin is differentiated by its location on the body and depends on the specific part of the body. The skin thickness on the back can be greater than 2.0 mm, and on the eyelids, it may be less than 0.35 mm. Furthermore, the skin is an essential sensory tissue endowed with peripheral receptors or nerve endings that are sensitive to pain, temperature, and tactile sensations. Structurally, it is the largest anatomic organ of the human body. Its numerous essential tissue components function to hold microbes out, keep body fluids in, and avoid dehydration.

The coefficient of power reflection and transmission of the skin for mm-wavelengths decreases from 60 to 20% and increases from 50 to 65% as frequency increases, respectively (Fig. 1). The penetration depth through which the power deposition falls off exponentially as e^{-2} . For a plane mm-wave, it decreases from 1.2 to 0.4 mm in human skin tissue (Fig. 2), while the absorbed energy increases with increasing frequency. However, at higher frequencies the energy absorption in the deeper regions inside the skin may become lower due to the diminished penetration depth at these mm-wave frequencies (Lin, 2011).

Biological Effects of MM-Waves

The interaction of mm-wave radiation with biological systems and its physiological effects and medical applications have been subjects of scientific investigation for nearly half a century. A comprehensive review of research on biological effects of mm-waves from earlier studies (most notably in the former Soviet Union) showed that at incident power densities of roughly 100 W/m², mm-waves may impact enzyme activity, genetic status, function of excitable membranes, cell growth and

proliferation, peripheral receptors, and other biological systems (Pakhomov, et al., 1998).

However, a common concern of those investigations has been the paucity of details or clarity in reported experimental protocols, inadequate in-situ dosimetry, absence of sham-exposure, temperature controls, rigor in statistical analysis, and overall lack of reported study details (Alekseev and Ziskin, 2019; Leszczynski, 2020; Simkó and Mattsson, 2019).

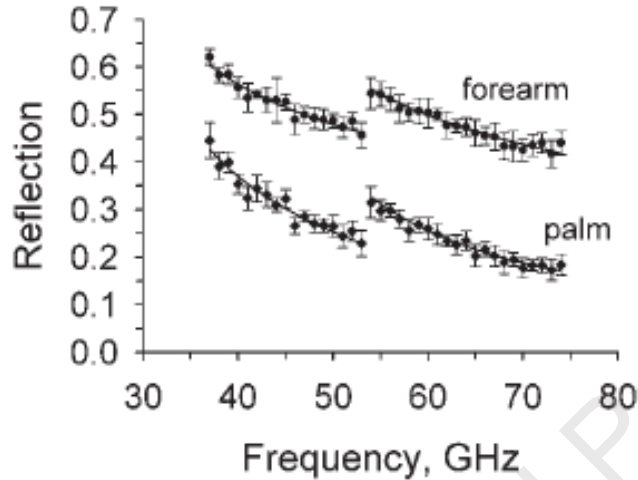


Fig. 1 Coefficient of power reflection in the palm and forearm as a function of mm-wave frequency for 3-layered skin model with stratum corneum, epidermis, and dermis. Error bars are standard deviations (Alekseev and Ziskin, 2007).

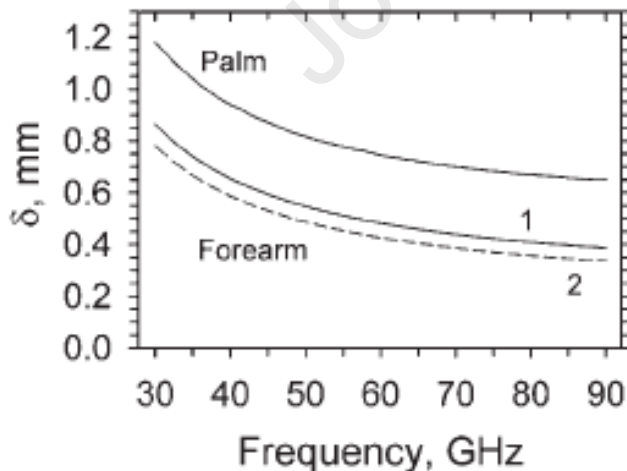


Fig. 2 Depth of penetration (δ) of plane mm-wave field for human palm and forearm skin. Graphs 1 and 2 are for the forearm by employing different dielectric permittivity values (Alekseev et al., 2008).

Review of Published Papers

A recent review provided an updated summary of published results from Russian investigations since 1997, which also included some relevant reports from elsewhere (Alekseev and Ziskin, 2019). The paper concentrated on experimental observations of mm-wave influences at cellular and subcellular levels, which include gene expression and cellular proliferation. It also contained effects on immunological responses and excitable tissues, and effects on the eyes and skin. The conclusion was that the accumulated information indicated that incident mm-wave power densities below 100 W/m² do not induce any damaging consequences on eyes however, exposures to mm-waves at higher levels may result in deleterious effects that are functions of frequency and duration of exposure. Similarly, investigations have not demonstrated any genotoxic consequences in skin cells or alterations in gene expression for low-power density mm-wave exposures without substantial temperature elevations. Nevertheless, results on the proliferations of different cell types have been controversial.

Additionally, while reviews of recent experiments failed to demonstrate a temperature-related changes in evoked electrical activity or structure of excitable cells, the rate of mm-wave energy absorption was noted to play an important role in measured electrical behavior of neural cells (Alekseev and Ziskin, 2019; Leszczynski, 2020; Simkó and Mattsson, 2019). There have been reports of mm-wave exposures inducing systemic effects on humans and animals that include hypoalgesia and endogenous opioids and influence on the immunological and nervous systems response at 100 W/m². It was suggested that systemic responses may be activated by stimulation of peripheral receptors or free nerve endings in the skin which is then relayed to modulate functions of the central nervous system.

Lately, some reviews targeted primarily English language papers as sources. One paper reviewed 45 in vivo investigations performed using laboratory animals and other biological subjects, and 53 in vitro experiments involving primary cells and cultured cell lines (Simko and Mattsson, 2019). The review included papers published as of the end of 2018 utilizing 6-100 GHz as the RF source frequency. Also, since fewer experiments were reported for frequencies below 30 GHz or above 90 GHz, the assessment largely consisted of investigations performed using mm-wave frequencies between 30 and 65 GHz. The industry-funded review mentioned that apart from the wide-ranging frequencies, the investigations were mixed, both in endpoints and subjects studied. Responses were detectable both in vitro and in vivo for numerous biological endpoints investigated. As high as 70% of positive reactions were detected at levels without any temperature rise. Incident mm-wave power densities, up to 200 W/m², didn't appear to produce a larger reaction. For instance, in 53 in vitro investigations concerning primary cells (n = 24) or cell lines (n = 29), approximately 70% of the primary cell investigations and 40% of the cell line studies indicated outcomes that were linked to mm-wave irradiation. Nevertheless, the protocol used to manage cell or culture

medium temperature during mm-wave irradiation was unclear in many of the investigations.

A tally of the scientific reports on potential effects of mm-waves on cutaneous and subcutaneous cells scored 99 experimental investigations (Leszczynski, 2020). The overview noted that many of them were concentrated on temperature-induced heat stress and pathological physiology connected to exposure to high incident mm-wave powers.

A more recent review article examined 107 (one human, 15 in vivo, and 91 in vitro) experimental studies that evaluated various physiological responses to mm-wave exposures, such as gene expression, genotoxicity, membrane function, cell signaling, cell proliferation, and other properties (Karipidis et al., 2021). The review claimed that the current reports of laboratory investigations do not offer any corroborated evidence that nonthermal level mm-waves are linked to biological responses applicable to the safety and health of humans. It hinted that many of the papers reporting biological effects came from the same but limited number of research laboratories and the findings need to be externally replicated. It asserted that many of the investigations applied inadequate methodologies for exposure evaluation and management thus, the likelihood of measurement artifacts cannot be dismissed. It further stated that many of the reported responses may be associated with tissue heating from unmeasured or unspecified absorption of mm-wave radiation, so the assertion of a low-level mm-wave effect is debatable in many of the reported investigations.

It is noteworthy that to date, there was not a single reported epidemiological investigation studying 5G mm-wave exposure and its possible safety and health implications.

In summary, while there are roughly 100 reported experimental studies of various sorts, assessment of the health and safety are inconsistent in the correlation between biological effects and mm-wave exposure. The numbers and types of reported experimental studies are disparate, modest, and very limited, given the extremely wide mm-wave frequency spectrum. The jury on biological effect or health impact is still out on 5G mm-wave radiation. Furthermore, there is a serious scarcity of ongoing research support for organized experimental studies – a crucial consideration that is needed to help resolve current ambiguities. To help improve the ecosystem, any new laboratory research should provide experimental designs with statistical validity that are supported by methods, procedures, and protocols amenable to independent replication and must include quantitative exposure determination, dosimetry, and temperature sensing and monitoring.

REVISION OF HEALTH SAFETY GUIDELINES AND STANDARDS

Recently, the commonly circulated RF safety and health protection guidelines have published revisions of their prior editions. The revised guidelines (ICNIRP, 2020)

and standards (IEEE-ICES, 2019) ~~appear to accommodate business-related purposes.~~ They are strongly linked to acute thermal effects related to measurable tissue temperature rises. A waxing question persists on these guidelines and standards for safe long-term exposure to low-level RF radiation (in contrast to exposures shorter than 6 to 30 min). There is a general sense about lack of appreciation of scientific knowledge regarding long-term human exposure below the basic restrictions promulgated through these exposure guidelines and standards (Council of Europe, 2011; Elkind, 2022; Falcioni et al., 2018; FCC, 2019; Investigate Europe, 2019; Koeppel, 2022; NTP/NIEHS, 2018; Wyde et al., 2018).

ICNIRP is a private sector group, with self-appointed membership. It is recognized as a non-governmental organization by the World Health Organization's (WHO) EMF Project, which reportedly has close links with industries (Council of Europe, 2011). The German Federal Office for Radiation Protection (BfS) contributes as much as 80% to ICNIRP's annual operating budget (Microwave News, 2020). IEEE-ICES is a large committee open to anyone with a material interest. Its leadership ranks and committee meetings are populated principally by industry representatives (IEEE-ICES, 2016; 2018).

It is noteworthy that there are media accounts suggesting reasons to suspect ~~that sponsors of cellphone or the~~ organized campaign to devalue the science of RF radiation health and safety research that are unfavorable to the sponsors such as the cellphone industry. Some have speculated that the cellphone companies often frustrate and refute any suggestion that its product might be harmful to human health (Elkind, 2022). Furthermore, research results showed that studies exclusively funded by industry were less likely to report statistically significant results: the odds ratio for reporting at least one significant finding was 0.11, compared to 1.00 for studies funded by public agencies or charities (Huss et al., 2007).

Furthermore, the U.S. Court of Appeals in Washington D.C., ruled in August 2021 that the Federal Communications Commission (FCC) had to reconsider the studies to ascertain if its 1996 regulations should be revised and to address the issue of what level of RF radiation from cellphones should be deemed as safe (Koeppel, 2022). The FCC is the sole U.S. governmental agency empowered by law to determine the permissible RF exposure levels from wireless systems for persons of all ages.

ASSESSING RECENTLY REVISED LIMITS FOR HEALTH SAFETY PROTECTION

Strong Convictions on RF Heating

The recently published ICNIRP safety guidelines and ICES standards make recommendations to purportedly protect against adverse health effects in humans resulting from exposure to RF radiation in the frequency range from 100 kHz to 300 GHz. 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 (IEEE-ICES, 2019; ICNIRP, 2020). The revised safety

guidelines and standards demonstrate, without any doubt, that the groups' strong convictions on nothing but heat to worry about with RF radiation.

The promulgated ~~the~~ safety protection recommendations disregarded the independent exposure agent of RF radiation in the experimental rat study of the National Toxicology Program (NTP), which is an integral part of the U.S. National Institute of Environmental Health Science (NIEHS). They seem to take the ludicrous stance of a whole-body temperature rise of 1°C causes cancer. Thus, the putative safety or reduction factors of 50 proposed for the general public, or 10 for RF workers (Table 1) would be marginal for their stated purpose, and practically, meaningless from the standpoint of safety protection.

Deficiency in Restriction for Pulse Modulations

Contrary to persistent and recent concerns of inadequate health effect studies involving RF radiation with complex novel modulations and pulse sequences, curiously, ICNIRP opted to delete its 1998 provision of pulse exposure limits from the revised 2020 guidelines. Thus, there are no longer specific restrictions on pulse modulations of any kind or form in ICNIRP 2020. Note that time-averaged exposure limit and basic restriction over a 6-min period is woefully inadequate to account for the unique characteristics of pulse modulations or to capture the effects of pulse-modulated exposures. It is well-known that the outcomes of experimental studies are affected by differences in RF parameters and exposure conditions.

Take for example 20- μ s wide pulses, the average incident power density thresholds are about 14 kW/m² in the near field of 1250 to 3000 MHz sources for microwave auditory effect in human subjects with normal hearing under controlled laboratory conditions (Lin, 2021b). Specifically, the 14 kW/m² per pulse power density would produce a 0 dB sound pressure level that is just audible by humans. Generating a sound pressure at 60 dB, the hearing level for typical dialogue, takes 1000-fold greater power density. Producing a tissue injuring quantity of sound pressure at 120 dB would call for another 1000-fold increase in needed peak power density, or 14 GW/m² per pulse. The high-power microwave pulse-produced sound wave can originate in the brain and then resonate within the human head. Yet the resultant calculated temperature increase would be approximately 1 °C, which is assumed "safe" by the revised protection guidelines and standards.

Hyperthermic 42 °C for MM-Waves

It can be seen from Table 1 that for mm-waves (30 GHz to 300 GHz), the allowable local tissue temperature increase in the head, limbs, and torso of humans is 5 °C. This level of temperature increase would cause the tissue temperature to rise from a nominal value of 37 °C to a hyperthermic 42 °C. A tissue temperature of 42 °C is understood to be cytotoxic, with exponential cell-killing capabilities. It serves as the foundation for clinical treatment of malignant cancer in hyperthermia therapy for cancer

(Watmough and Ross, 1986; Lin, 1999; NIH/NCI, 2021). The recent safety protection guidelines and standards provide a “reduction factor” of 10 for the public’s safety or a “safety factor” of 2 in RF workplaces. In this case, the efficacy of these guidelines and standards is minimal, and they are irrelevant from the standpoint of radiation protection.

Table 1. Summary of Current Guidelines or Standards Based on Short-term Thermal Effect for “Putative Safe” Human Exposure to RF Radiation (IEEE-ICES, 2019; ICNIRP, 2020).

Frequency Range	Tissue Type	ΔT	Average Mass	Average Time	Health Effect Level	Factor ^b	Public Level	Factor ^b	Worker Level ^c
100 kHz – 300 GHz	Body Core	1 °C	WBA ^d	30 min	4 W/kg	50	0.08 W/kg	10	0.4 W/kg
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 ^a	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 ^a	Local Limbs	5 °C	2 cm ²	6 min	400 W/cm ²	10	40 W/cm ²	2	200 W/cm ²

5G mm-wave^a, Safety or Reduction Factor^b, Controlled or Occupational Exposure^c, Whole-body Ave – WBA^d

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 ill-defined. The revised exposure limits do not provide any adjustments for possible effects due to long-term human exposures. There is perceived lack of appreciation of scientific knowledge for chronic toxicology and carcinogenicity regarding RF exposures below the promulgated basic restrictions (Elkind, 2022; ICBE-EMF, 2022; Investigate Europe, 2019; Koepfel, 2022; Nyberg et al., 2022).

IARC CLASSIFICATION OF RF RADIATION AS POSSIBLY CARCINOGENIC TO HUMANS

The International Agency for Research on Cancer (IARC) – an intergovernmental agency of the World Health Organization – classified exposure to RF radiation as a possible cancer-causing agent in humans (Baan et al., 2011; IARC, 2013). IARC’s role

is to conduct and coordinate research into the causes of cancer. It evaluated the accessible scientific investigations and decided that, while the database was imperfect and constrained with regards to results from laboratory animal experiments, epidemiological investigations on humans suggest elevated risks for gliomas and acoustic neuromas (vestibular schwannomas) among heavy or long-term users of mobile phones are sufficiently strong to support the classification. The classification of RF radiation as possibly carcinogenic to humans is third on the IARC categories of carcinogenic risks. The highest category is reserved for agents that are carcinogenic. It is followed by probably carcinogenic, possibly carcinogenic, and not classifiable as to its carcinogenicity; and lastly, probably not carcinogenic to humans.

Clear Evidence of Cancer in Exposed Rats

Significantly, the results from animal experiments that 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 cellphone RF radiation frequencies below 6 GHz (Wyde et al., 2018; NTP/NIEHS, 2018). The project was the largest health effect animal study ever undertaken by NTP in its history, including chemical agents. The results showed that, among other findings, there was statistically significant and clear evidence that exposure to RF radiation had caused the development of malignant schwannoma (a rare form of tumor) in the heart of male rats whose RF-induced body temperature elevation did not exceed 1 °C. Furthermore, there was indication of the same schwannoma risk among female rats. The NTP study also noted that there were unusual patterns of damage to heart tissue (cardiomyopathy) in both RF-exposed male and female rats when compared with concurrent controls. In addition, based on statistical significance, the outcome of pathological examinations showed signs of indication for RF-dependent carcinogenic activity in the brain of male rats, particularly glioma. Nonetheless, the outcomes for females were regarded as offering only equivocal evidence for malignant gliomas when compared with control rats.

Moreover, shortly after the U.S. Government's NTP report, the private sector Ramazzini Institute's Cesare Maltoni Cancer Research Center in Bologna, Italy, published results from its extensive research on cancer risks in rats exposed to 1800-MHz 3G RF radiation. The investigation involved whole-body exposure of the same strain of male and female rats, either lifelong or prenatal until death, under far-field or plane-wave equivalent exposure conditions (Falcioni et al., 2018). During the 19-h-day exposures for approximately two years, the study estimated that the whole-body SARs were 0.001, 0.03, and 0.1 W/kg. A statistically significant rise in the incidents of schwannomas in the heart of male rats was found for the 0.1 W/kg RF exposure. It is important to note that the two mutually complementary and independent NTP and Ramazzini RF exposure studies presented similar conclusions in heart schwannomas and brain gliomas. Thus, two well-conducted RF animal exposure investigations using the same strain of rats demonstrated consistent carcinogenicity findings.

While acknowledging that both recent animal studies employed large number of animals, good-laboratory practices, and similarly prolonged exposures of animals for their entire lives, the recent revisions of safety protection guidelines and standards decided to nitpick with objections of alleged “chance differences” between experimental treatment conditions and measured animal body-core temperature increases of up to 1 °C. Oddly, in choosing to do so, it neglected the incongruity of suggesting a 1 °C body core temperature elevation as carcinogenic. Furthermore, it totally ignored the RF exposure (the independent variable for the experiments) or preferred to evade them through pretenses such as the evidence or findings do not provide credible indication of adverse effects caused by chronic RF exposures. Those same groups proceeded to use ambiguous phrases such as “substantial limitations” to assert their reasons in barring any “conclusions being drawn concerning RF EMFs and carcinogenesis,” to justify their RF safety protection guidelines and standards.

Carcinogenicity from Human Epidemiology

Moreover, it opined that although many epidemiological studies of cell-phone RF radiation and carcinogenicity have been performed, research results on brain tumors, acoustic neuroma, meningioma, and parotid gland tumors have not provided sufficient indication of a heightened cancer risk. The recently revised safety guidelines and standards also noted that while higher odds ratios were reported, variations and shortcomings including selection or recall bias impede these epidemiological results from being considered for the recommended exposure standards and guidelines. The penchant to disparage and reject positive results, and keenness for or enthusiasm to accept negative findings, all together, are palpable and concerning.

In fact, more recent systematic reviews, and meta-analyses of the case-control research on cellphone use have reported a statistically significant increase in brain tumor risk associated with 1,000 or more hours of cellphone use, or about 17 min per day over 10 years (Myung et al., 2009; Choi et al., 2020). Nonetheless, it is noted that a new report found that cellphone use by women in the U.K., for 20 min per week—a much lower exposure—did not show a statistical increase in overall brain tumor incidence or by tumor subtype during the 10 years between 2001 and 2011 (Schuz et al., 2022).

DISCUSSION

The currently promulgated RF exposure guidelines and standards pertain predominantly for restricting short-term heating of RF radiation to increase tissue temperatures. There are substantial abnormalities in these guidelines. Furthermore, apart from the guideline’s anomalies, the current scientific database on health effects at mm wavelengths is inadequate to render a trustworthy appraisal or to reach a judgment with confidence. Some of the safety guidelines are irrelevant, debatable, and absent of scientific justification from the standpoint of safety and public health protection.

IARC Classification

IARC classified RF radiation from cellphones as a possible carcinogen in humans according to the strength of then available epidemiological reports but partial data from experimental animals (Baan et al., 2011; IARC, 2013). The sought-after animal data were presented later by NTP (2018) and Ramazzini Institute (Falcioni et al., 2018), which logically and scientifically supplement IARC's earlier decision. Nonetheless, the revisions evaded them by declaring the findings do not provide credible evidence of adverse effects induced by chronic RF exposures. The latest animal data should help to upgrade the classification to the probably carcinogenic category, if not elevated to a higher level.

SAR Harmonization or Hegemony

Another perplexing issue pertains to the establishment of exposure limits based on scientific evidence rather than flawed assumptions. A problem arises from the harmonization of IEEE's SAR limit value of 1.6 W/kg (over 1-g mass) to ICNIRP'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 were examined with great scientific care and deliberations since the 1980's and were reaffirmed through several editions of IEEE standards in the early 2000's. As mentioned above the choice by ICNIRP in 1998 to set the SAR at 2.0 W/kg was not accompanied by any clearly stated 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 unconvincingly on a basis of harmonization for harmonization's sake – apparently preferred by some (MMF, 2006). The process ought to aim toward improvement beyond the current state-of-affairs, through better precision in SAR computations and less uncertainty in exposure assessment.

It is interesting to note that in December 2019, FCC reaffirmed its RF exposure limits (FCC, 2019). The action was commenced despite appeals from some to loosen the existing limits, and others to tighten them. Among campaigners to embrace weaker limits are proposals from consultants for the wireless industry, CTIA – The Wireless Association, Mobile Manufacturers Forum (MMF), and Telecommunications Industry Association. The same appeals also argued that the evidence for health effects suggests 5G is akin to any other installed cell or mobile technology and systems. Claims were made for lessening cellphone RF limits to SARs of 2.0 W/kg, averaged over 10 g of tissue instead of FCC's limit of 1.6 W/kg over 1 g. Thus, the vexing question – if it is not for science – is the process in changing SARs from 1.6 to 2.0 W/kg an act of harmonization by the willing or a case of hegemony by the shrewd?

Aside from the numerical 25% increase of SAR from 1.6 to 2.0 W/kg, the expansion of averaging tissue mass from 1 g to 10 g materially reduces by 10-fold the precision of SAR determinations. Thus, the harmonization maneuver could have a combined impact of raising the permissible IEEE exposure limit by 1250 % – with considerable less safety protection! Of course, there also stands the biological issue of vast differences in type and quantity of living cells in 1-g or 10-g mass of body 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 or averaging time interval (Cavagnaro and Lin, 2019). 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 2700 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 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.

RF Safety and Public Health Protection

Full recognition of a public health risk takes time, and it is taking even longer these days given the fast pace of technological developments and rapidity at which they are launched into the commercial realm. The paradigms of “An ounce of prevention is far better than a pound of cure” appear to have vanished with little trace (Lin, 2016). Its mere mention under the current environment easily arouses robust rejoinders, with momentous opposition from those who may have profited from the massive marketing efforts. But given the growing ubiquity, is the premise of an “ounce of prevention” for RF radiation from cellphones and related wireless communication systems so far out of the question?

The question of how there can be such dissimilar assessments and inferences of the same scientific studies has persisted for some time. Less than strict enforcement of policies in research conduct or full disclosure of financial conflicts can lead to failures in guiding and informing the development of transparent and consistent evaluations of scientific evidence for safety protection. Humans are not necessarily coherent or as reasonable as imagined. To be fair, scientists are not invulnerable to conflicts of interest and can be driven by egocentric motives. Indeed, science has never been devoid of politics – like it or not. Biases can impair rational thinking and lead to flawed decisions. “Groupthink can keep humans from being sensible and prevent us from reaching obvious conclusions” (Lin, 2021a). Regrettably, groupthink or the herd mindset is as rife today as ever. “Has science become partisan? And the corollary, if science becomes partisan, is it science or politics, or would it be political science? Perhaps, science got wrapped up in politics and politics is intervening with science – a matter of guilelessly being politically correct of the willing” (Lin, 2020). When decisions are made via compromised judgment or not reached by prudently weighing the scientific information they could lead to poor conclusions through biases.

CONCLUSION

The rapid proliferation of cellular mobile telecommunication devices and systems is raising public health concerns about the biological effects and safety of radiofrequency (RF) radiation exposure. There is also concern about the efficacy of promulgated health safety limits, rules, and recommendations for RF radiation used by these devices and systems. The recently revised RF exposure limits adjust only for heating with RF radiation. These limits are devised largely for restricting short-term heating by RF radiation to raise tissue temperatures. They disregarded decisions by scientific organizations such as IARC. Furthermore, the limits are based on obsolete information, circumvent important animal data, and even more so in the case of mm-wave radiation from 5G mobile communications for which there is a paucity of health effects studies in the published literature. They are flawed and are not applicable to long-term exposure at low levels. Instead of advances in science, they are predicated on misguided assumptions with outdated exposure metrics that do not adequately protect children, workers, and the public from exposure to the RF radiation or people with sensitivity to electromagnetic radiation from wireless devices and systems. Thus, many of the recommended limits are debatable and absent of scientific justification from the standpoint of safety and public health protection.

Cellphones and wireless mobile communication technologies have enriched human lives. It is difficult to imagine contemporary lives without them. The deployment of 5G mobile technology is well underway with it heralded mm-wave performances. It is not evident whether the health effects of 5G mm-wave radiations would be analogous or not to previous generations of cellphone and wireless communication technologies. Without dispute, cellphones have provided direct benefits to multiple arenas of human endeavor that includes helping to safeguard our personal security and safety. Nonetheless, for the judgment on the health and safety of billions of users who are subjected to repeated, unnecessary levels of RF radiation perhaps over their lifetimes, the verdict is still out. It is significant to note that current cellphones have SARs ranging from 0.2 and 0.5 W/kg (EMF Academy, 2022). Clearly, cellphones are operating at a fraction of the 2.0-W/kg SAR acceptable to ICNIRP and IEEE-ICES. It is conceivable that forthcoming developments could enable cellphone functions including data and video operations at much lower exposure levels. The practice of ALARA — as low as reasonably achievable — should be followed for RF health and safety when confronted with such divergent assessments of wireless RF radiation.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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